Distribution Category:
Energy Conservation-
Transportation (UC-96)

ANL/CNSV-13

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ENVIRONMENTAL ASSESSMENT OF
THE U.S. DEPARTMENT OF ENERGY
ELECTRIC AND HYBRID VEHICLE PROGRAM

by

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November 1980

Work sponsored by

U.S. DEPARTMENT OF ENERGY
Assistant Secretary for Conservation and Solar Energy
Office of Transportation Programs

PREFACE

This document is an environmental assessment (EA) of the U.S. Department of Energy (DOE) electric and hybrid vehicle (EHV) program. The document has been prepared in accordance with the National Environmental Policy Act (NEPA) of 1969 (10 CFR, Part 1021), as amended (42 U.S.C. Section 4321 et. seq.) and the implementing regulations of the Council on Environmental Quality (40 CFR, Parts 1500-1508).

The EA focuses on the long-term (1985-2000) impacts of the EHV program, which has been designed to accelerate the development of EHVs and to demonstrate their commercial feasibility as required by the Electric and Hybrid Vehicle Research, Development and Demonstration Act of 1976 (P.L. 94-413), as amended (P.L. 95-238). The DOE EHV program alternatives examined in this EA are represented by five market penetration scenarios. These scenarios are based on three different levels of DOE investment, as well as on plausible assumptions regarding technological breakthroughs in EHV components, EHV activity in the private sector, liquid fuels prices and availability, advances in other transportation technologies, influences of other EHV-related governmental programs, and basic societal driving forces. The scenarios are designed to encompass the full range of EHV commercialization possibilities up to 2000. The EA analyzes the impacts of these alternative EHV market penetration scenarios on a broad range of environmental subsystems.

SUMMARY

This environmental assessment (EA) focuses on the long-term (1985-2000) impacts of the U.S. Department of Energy (DOE) electric and hybrid vehicle (EHV) program. This program has been designed to accelerate the development of EHVs and to demonstrate their commercial feasibility as required by the Electric and Hybrid Vehicle Research, Development and Demonstration Act of 1976 (P.L. 94-413), as amended (P.L. 95-238). The overall goal of the program is the commercialization of: (1) electric vehicles (EVs) acceptable to broad segments of the personal and commercial vehicle markets, (2) hybrid vehicles (HVs) with range capabilities comparable to those of conventional vehicles (CVs), and (3) advanced EHVs completely competitive with CVs with respect to both cost and performance. Five major EHV projects have been established by DOE: market demonstration, vehicle evaluation and improvement, electric vehicle commercialization, hybrid vehicle commercialization, and advanced vehicle development.

ALTERNATIVES

The DOE EHV program alternatives requiring examination for their environmental impacts are represented by the five market penetration scenarios developed for this EA. These scenarios are based on three different levels of DOE investment. While the relationship between DOE funding and the degree of future EHV market penetration is not known precisely, the higher the level of DOE funding, the more likely it is that technological advances will occur and that EHV penetration will be assisted. The scenarios are also based on plausible assumptions regarding technological breakthroughs in EHV components, EHV activity in the private sector, liquid fuels prices and availability, advances in other transportation technologies, influences from other EHV-related governmental programs, and basic societal driving forces. The scenarios are thought to encompass the full range of EHV market penetration possibilities up to 2000.

The five scenarios are designated LOW I, LOW II, MEDIUM, HIGH I, and HIGH II. The LOW scenarios assume that the DOE EHV program concludes in 1986 with the completion of the current demonstration and represent the no-action alternative normally discussed in environmental assessments. Liquid fuels availability remains high. The lead-acid (Pb/acid) battery is assumed to dominate through 2000, but the nickel-zinc (Ni/Zn) battery begins significant penetration after 1990. The market for EHVs in the LOW scenarios is basically commercial fleets, where a limited range of 50-75 mi is acceptable for some vehicles. Pb/acid HVs generally penetrate truck markets but are used for longer-range missions. By 2000, three million EVs are in use in LOW I and LOW II; in LOW II, an additional two million HVs are in operation.

The MEDIUM scenario assumes continued federal EHV program activity at levels higher than the LOW scenarios and extended into 1997. Liquid fuels remain available but costs are relatively high. Pb/acid EVs dominate the market early, but the higher-performance Ni/Zn EV experiences successful commercialization beginning in the 1980s and dominates by 1990. The 50- to 150-mi range of the Ni/Zn vehicles opens new markets; although these are still predominantly commercial, greater penetration in the personal-use market

occurs. With strong federal commercialization efforts, such as the inclusion of EVs in corporate average fuel economy (CAFE) standards beyond 1986, this scenario assumes eight million EVs in use by 2000. No HVs are included in this scenario.

The HIGH scenarios assume that federal support is very high in all areas of EHV development, including battery system research and development, raw material supply, and EHV infrastructure subsidies. It is several times higher than the support in the MEDIUM scenario and extends through 1998. State, local, and private programs complement this effort. The HIGH scenarios assume a sense of national emergency, with rising prices, significantly lower availability, and sporadic but significant shortages of liquid fuels. In HIGH I, Ni/Zn EVs predominate, but lithium-metal sulfide (Li/S) EVs with ranges up to 220 mi are fully commercialized in the 1990s. Although Ni/Zn EVs also predominate in HIGH II, unlimited-range Ni/Zn HVs penetrate heavily by 2000. Because of improvements in range, EHVs are able to enter nearly all vehicle markets and approximately half of the EHVs are personal-use vehicles by 2000. HIGH I has 24 million EVs in operation in 2000; HIGH II has 15.9 million EVs and 8.1 million HVs.

MAJOR FINDINGS OF THE EA

This EA analyzes the impacts of alternative EHV market penetration scenarios on a broad range of environmental subsystems. Comparisons are made with the projected impacts of a baseline scenario (BASE), which assumes no EHV penetration by 2000. Generally, the emphasis is on the impacts occurring under the HIGH scenarios. While the probability of achieving these scenarios is low, they are certainly possible outcomes of the DOE EHV program and do identify worst-case impacts. In addition, the impacts associated with these scenarios in 2000 reflect the potential impacts associated with the more probable MEDIUM scenario a few years beyond 2000.

Resources

Materials

Ten major materials are evaluated for potential materials supply and demand imbalances resulting from EHV penetration. Four of these (nickel, cobalt, zinc, and lithium) are found to present possible constraints on the MEDIUM and HIGH scenarios. Over 50% of current U.S. nickel supplies are imported. With large increases in nickel demand and the small number of firms producing nickel, significant price increases are possible. Similarly, cartel activities may affect the supply and cost of cobalt, which is required for the nickel batteries. Nearly all of the U.S. cobalt supply is imported, much of it from Zaire. Potential solutions to these problems include development of deep-sea mining techniques, improved recovery technologies for domestic mining, slower penetration of EHVs to build up stocks of recyclable nickel and cobalt, and substitution of other materials for cobalt. Some of these solutions will require further impact assessment.

While 50% of zinc supplies are imported, domestic zinc reserves could meet projected demand under each of the scenarios. However, zinc refining capacity has been reduced by 50% since 1972 due to obsolescence and environmental constraints (e.g., sulfur oxide [SO_x] emission limits). The refining capacity of this industry may need to be expanded significantly. The lithium industry, which is currently quite small, would have significant "gearing-up" problems to meet the projected 1285% increase in demand of the HIGH I scenario in 2000.

Raw materials for aluminum production are usually imported and subject to cartel action. Nevertheless, EHV aluminum requirements are minor relative to total U.S. demand for aluminum and would not alter the total supply and demand situation significantly. Lead, copper, boron, iron, and steel supplies are expected to be adequate for EHV development.

These conclusions generally reflect EHV materials rquirements whether or not substantial recycling of battery materials occurs. Obviously, worst-case impacts occur without recycling. Many technological barriers to a high level of recycling remain, and improvements are necessary in recycling technologies for all major battery materials except lead.

Energy

Although EHVs save petroleum, they do require more total energy for production and operation as measured from the mine mouth or wellhead. Estimated petroleum requirements (including petroleum-related external subsidies) for production and operation of EHVs in 2000 are 22-36% of the petroleum requirements for the production of an equivalent number of CVs and their operation over equivalent miles. But, EHVs require 11-23% more total energy for production and operation in 2000 than would be required by an equivalent number of CVs. However, if the measurement of total energy used includes resources left in the ground that are unavailable today given current extractive technology and economics, EHVs require less total energy than CVs.

Ecosystems

The ecosystem impacts of EHVs are very difficult to evaluate on either a national or regional scale, because ecosystem analysis is usually site specific. While site-specific analysis is not included in this EA, several areas of potential for adverse impact on local ecosystems are identified and discussed: (1) increased and diverse quantities of metals and metal cations introduced into the environment during all phases of EHV production, operation, reuse, and disposal; (2) increased erosion and sedimentation from mining EHV materials and fuels; (3) increased nitrate residues from EHV-related mining operations; (4) higher local SO_x emissions from EHV manufacture and operation; (5) increased thermal pollution from power plants; and (6) more solid wastes from EHV operation and production.

Physical Environment

Air Quality

Market penetration of EHVs results in overall reductions in ambient levels of four air pollutants for which national ambient air quality standards

(NAAQS) have been promulgated: hydrocarbons (HC), particulates, nitrogen oxides (NO_x), and carbon monoxide (CO). The production and operation of EHVs result in increased SO_x, for which there is also a NAAQS. This increase is largely the result of greater electricity generation for EHV operation. In terms of national totals, the largest increment in SO_x generation occurs in HIGH I in 2000, at which time the increase in SO_x represents 2.6% of the 1975 national SO_x emissions. Although this increment appears small, it would add to the national trend of increasing SO_x emissions. A larger percentage increase in SO_x emissions may occur in some urbanized areas and may be significant.

EHV market success may lead to a slight increase in carbon dioxide (CO_2) emissions. Although CO_2 emissions may affect global temperatures, the increase associated with EHVs (3% in HIGH II over the CO_2 generated by an equivalent number of CVs) is considered insignificant compared to the CO_2 generated by worldwide fossil-fuel combustion. EHV production also leads to increased generation of heavy metals, lead sulfide, gas fluorides, and copper sulfide. These increases may be significant at local levels.

Two additional air quality concerns require further examination: (1) the impact of accidents and battery charging on air quality on a microscale and (2) the emissions associated with full accessory load operation (air conditioners and heaters) in EHVs. The technologies that would be used to operate these accessories are not specified in this analysis.

Water Quality, Solid Waste, and Land Use

Water pollutant loadings and solid waste from vehicle production and operation will increase with EHV market penetration. However, the increases may be significant only at the local level. High incremental pollutant loadings can be expected in specific geographical areas, especially near EHV materials-and-fuels extraction and processing, and heavy manufacturing centers. If not properly handled, these loadings could adversely impact communities and the environment. Similarly, land requirements for solid waste disposal, mining, and manufacturing stemming from EHV market penetration could be important, but only at the local level.

Noise

The impact of EHVs on urban traffic noise by 2000 will be beneficial though minor. EVs are quieter than CVs and should continue to be quieter, despite anticipated reductions in the noise levels of CVs. However, EVs do generate some noise, primarily tire noise. HVs also will emit tire noise and will periodically emit powertrain-related noises. Even in 2000, however, EHVs will still represent a small percentage of the vehicles on the road and will be substituted for vehicles that are already relatively quiet compared to more dominant noise sources. Additional empirical data are required to verify or revise these conclusions.

Occupational Health and Safety

EHV market penetration will result in increases over the BASE scenario in the number and severity of occupationally related health injuries and illnesses in 2000. While the increases nationally will be very small, some individual economic sectors could incur major increases. For example, the battery industry is expected to have a 26.5% increase in total recordable cases in the HIGH I scenario in 2000.

Historical incidence rates are used to generate these expected increases. However, manufacturing EHVs involves considerable development and modification of production processes, particularly in the battery sector. As processes change, occupational hazards will change, and potentially significant risks are likely. The types of hazards that might result from new EHV technologies and appropriate preventative measures require further study.

Public Health and Safety

Public Health

The public health impacts resulting from EHV market penetration vary depending on the particular pollutant. Because increasing use of EHVs leads to reductions in NO_x, HC, CO, and particulate emissions, public health impacts at the national level are positive for these pollutants. However, because SO_x emissions are expected to increase with EHV development, public exposure to SO_x will increase on a national, regional, and local scale. The national increase in risk of exposure to SO_x under worst-case conditions is no greater than 3% of the risk of exposure to 1975 SO_x emissions levels. However, there is a national trend of increasing SO_x emissions. The increase in the potential for adverse public health impact from SO_x exposure in individual urbanized areas may be higher and may be significant.

The public health impact of increased water pollutants, solid waste, various air pollutants (including those whose EHV-related national public health impacts are beneficial), and trace elements generated as a result of EHV development does not appear to be of concern on the national level but may be of concern on a site-specific level and should be examined further. Also of potentially significant concern but requiring further study are the potential health impacts of exposure from advanced battery use to certain toxic substances not covered in this analysis (i.e., possible minor ingredients in EHV batteries) and the health risks associated with accidents and battery charging.

Public Safety

Public safety concerns associated with EHVs do exist and include those related to nonoperating safety, crash avoidance, and crash energy management, and operating safety concerns, such as electrolyte spillage and toxic gas release. Performance standards addressing some of the safety questions have been issued by DOE for the current EHV demonstration. Additional safety standards must be promulgated as directed by the EHV Act as commercialization progresses and as understanding of each concern improves. Standards set for the current demonstration are assumed to apply to all EHVs commercialized in 1985 and beyond. While further evaluation of many of the safety concerns is still required, all public safety concerns are expected to be mitigated by standards promulgated by appropriate regulatory agencies as EHV commercialization proceeds.

Social

There may be some beneficial as well as adverse impacts on mobility, urban structure, and lifestyle resulting from EHV commercialization. In particular, the limitations in range of EVs and the time required for recharging EHVs limit mobility. However, in times of liquid fuel shortages, EHVs will enhance mobility. The relative importance of these impacts is difficult to evaluate but certainly is lower than that of impacts resulting from the introduction of large numbers of limited-performance EVs. Finally, social impacts associated with significant employment changes in local areas will occur and may be substantial. These impacts will result, in part, from growth in population and in-migration and may include the particular social problems often associated with boom-town development.

Institutional

EHVs are expected to have little or no impact on many elements of the transportation infrastructure needed to support EHV penetration (e.g., roadway infrastructure, highway use, safety regulations and existing financial and insurance institutions). However, EHVs affect some aspects of that infrastructure. For example, while EHV production and distribution can be absorbed by present CV manufacturers, the rapid conversion required in the HIGH scenarios of auto production lines of the major CV manufacturers may present problems.

While the impact of EHVs on electric utilities is small nationally, EHV electricity consumption may be large enough in a very few urbanized areas for it to be included in utility planning. Further, some electrical distribution facilities used in recharging EHVs may have to be upgraded.

Especially in the HIGH scenarios, the government may have to continue encouraging the development of an EHV servicing network and give attention to the potential impacts of EHV service facilities on CV service facilities. Finally, EHV penetration also will require that fire fighters receive special instruction, since EHV fires require different fire-fighting techniques.

Economic

Cost of Travel

EHVs of different battery types vary considerably in their initial and life cycle costs. However, EHVs of any battery type in all vehicle categories are projected to be more expensive than the CVs they replace, both in initial and life cycle costs. EHVs are projected to be 33-143% higher in initial cost than CVs and up to 146% higher in life cycle costs. The smallest life cycle cost differentials occur in the passenger car categories; the differentials widen in the light truck and bus categories. Such differences in cost could adversely affect EHV commercialization. As battery technology develops and if reductions in material input requirements or prices occur, the cost situation for EHVs may improve.

Employment

While total national employment is not affected by EHV market penetration, significant changes may occur in five industries -- mining, nonferrous metals processing, electric utilities, batteries, and crude oil production. Employment is expected to decline in crude oil production and increase in the other four industries. Significant local employment changes also may occur with EHV penetration.

Factor Prices and Balance of Trade

EHV market success could affect major EHV materials prices, depending on the scenario and the dominant battery technology. Under certain scenarios, materials import requirements could more than offset imported oil dollars saved by EHV penetration. The LOW scenarios generally result in positive trade balances because lead, which is the main battery material, is available domestically. In the MEDIUM and HIGH scenarios in 2000, the balance of trade could swing either way, depending on oil and materials price assumptions. If a negative balance of trade occurs, it will be due basically to nickel and cobalt import requirements for Ni/Zn EHVs. The greatest negative trade balances occur in the HIGH II scenario; the worst of these is $25 billion (constant 1979$), even assuming substantial battery materials recycling. Solutions to these potentially negative impacts are the same as those discussed in the materials section in this summary, i.e., deep-sea mining, improved recovery technologies, material substitution, and slower EHV market penetration.

Private and Public Sector Capital

The major impact of EHVs in terms of public sector capital is on the federal motor vehicle fuel tax. EHVs are not subject to this tax. Without an equivalent tax imposed on EHVs, the federal government could lose up to $704 million out of the $15 billion in revenue projected for 2000 (constant 1979$). However, one of a number of alternative EHV taxes will certainly be imposed, and the public sector should not lose revenue. In addition to this impact, some local governments will face substantial expenditures associated with increasing use of EHVs, such as a need for increased municipal services arising from EHV-related employment changes.

A significant aspect of the "gearing-up" problems projected for certain industries as a result of EHV development is capital requirements. For example, battery industry capital needs in 2000 increase 25% in HIGH I and 11% in HIGH II over the BASE scenario. Problems also could arise in some of the scenarios in the zinc, lead, lithium, nickel, and cobalt industries, especially if domestic mining were greatly expanded or if ocean nodule deposits were developed. Although total capital investment in the motor vehicle sector is not expected to change radically, construction of production lines or conversion of lines from CVs to EHVs may create difficulties.

CONCLUSIONS AND RECOMMENDATIONS

Significant impacts to the human environment will occur both at national and local levels from increasing use of EHVs. While some impacts will be beneficial, some adverse impacts will occur in resource, ecosystem, physical environment, health, safety, and socioeconomic subsystems. The following actions could help mitigate some of these adverse impacts:

1. Resources and Economic Concerns. Development of deep-sea mining, improved mine recovery technologies, material substitution, lower material input requirements, and new recycling technologies.
2. Physical Environment, Public Health, and Ecosystem Concerns. For specific pollutants in certain local areas, development of stricter air and water quality standards for industrial processes.
3. Occupational Health and Safety Concerns. Preventative measures, such as protective equipment and design controls.
4. Public Safety Concerns. Promulgation of additional vehicle safety standards by DOE and DOT.
5. Institutional Concerns. Government measures to defray manufacturing risk and inclusion of EHV electricity consumption in local utility planning.

It is not certain, however, that all such mitigating measures can be in place by 2000. Since the effects of not being able to mitigate some of these concerns appear quite substantial, significant impacts to the human environment may occur. The potential for significant impacts, coupled with the fact that an environmental impact statement (EIS) is normally required for DOE programs that result in the construction and operation of full-scale energy system projects,* leads to the recommendation that an EIS be developed for the DOE EHV program. Other site-specific National Environmental Policy Act documents related to EHV development (e.g., for new battery manufacturing plants) also may have to be prepared, but these may not be the responsibility of DOE. Finally, it is recommended that the DOE EHV program EIS take the following into consideration:

1. New developments in the zinc-chlorine (Zn/Cl) battery that make that battery appear more promising as an alternative near-term battery.
2. Further characterization, if possible, of advanced EHVs.

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*U.S. Dept. of Energy compliance with the National Environmental Policy Act, Federal Register, 45(62), March 28, 1980.

3. The potential impacts beyond 2000, because the greatest market penetration should occur after 2000. (There may be significantly more EHVs than the 24 million postulated for the HIGH scenarios in this EA.)
4. The potential worldwide demand for EHVs, which could dramatically affect EHV materials supply and prices.
5. Greater dependence on coal- rather than nuclear-generated electricity than was projected for this EA, and
6. Any new information pertaining to any of the areas identified in this EA as requiring further study.

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FIGURES

1 PURPOSE OR NEED FOR PROPOSED ACTION

The U.S. Congress approved the Electric and Hybrid Vehicle Research, Development, and Demonstration Act of 1976 (P.L. 94-413) on September 17, 1976. Congress believed that accelerated commercialization of these vehicles could contribute to reduced petroleum consumption and greater independence from foreign oil.

The Act, as amended on February 25, 1978 (P.L. 95-238), provides for accelerating the development of electric and hybrid vehicles (EHVs) and demonstrating their commercial feasibility through government-sponsored research and development (R&D), demonstrations, and financial incentives. The U.S. Department of Energy (DOE) is responsible for undertaking these activities and has established the Electric and Hybrid Vehicles Division in the Office of Transportation Programs under the Assistant Secretary for Conservation and Solar Energy.

This environmental assessment (EA) focuses on the long-term impacts (1985-2000) of the DOE EHV program. These impacts are assessed for a number of EHV market penetration scenarios.

Two EAs have been prepared previously for the DOE EHV program. The first EA (March, 1979) is directed at the short-term consequences of the DOE EHV demonstration program that is currently underway.[1] The second EA (May, 1980) considers the probable impacts of including EHVs in corporate average fuel economy (CAFE) standards during an evaluation period ending January 1, 1987.[2] Neither assessment found significant impact on the human environment.

1.1 DOE PROGRAM OVERVIEW

The goal of the DOE EHV program is to assure the availability and broad acceptance of vehicles that depend primarily on electricity for propulsion in order to minimize dependence on imported oil while maintaining flexibility in the transportation sector. In general, the government's role is to provide support until industry is able to achieve the above goal on its own. The overall strategy is a balance between "market pull" to build demand for EHVs and "technology push" to provide new products of proven desirability.

To achieve the overall goal, five projects have been established by DOE: market demonstration (MD), vehicle evaluation and improvement (VEI), electric vehicle commercialization (EVC), hybrid vehicle commercialization (HVC), and advanced vehicle development (AVD).[3] These projects are described briefly in Secs. 1.1.1-1.1.5.

1.1.1. Market Demonstration

The Act requires that DOE, within the next six years, place up to 10,000 EHVs in uses involving private fleet operators, market and service operators, individuals, state and local government fleets, and federal agency fleet. Over 60 site operators have been selected, and the total number of vehicles involved by the end of FY80 will be about 1200. In addition, DOE will offer loan guarantees to qualified small businesses to expand production of EHVs.

The MD project includes identifying, developing, testing, and proving markets; collecting and analyzing data on energy, economics, vehicle design, safety, and use; and determining infrastructure requirements. It will generate much of the information needed to understand the environmental impacts of large-scale penetration of EHVs into a variety of markets. It will aid in determining the suitability of EHVs for particular operations and will provide practical experience data to manufacturers to encourage vehicle improvements.

Because the infrastructure for maintenance, parts supply, warranty processing, and training is not available throughout the country and because better information flow and DOE supervision are required, the demonstrations are being implemented through local operators. The operators own the demonstration vehicles and are responsible for purchase, maintenance, and control. To encourage participation, to offset some of the risk, and to acquire data, DOE shares costs with the operators.

1.1.2 Vehicle Evaluation and Improvement

The purpose of this project is to optimize off-tne-shelf technology and to aid rapid commercialization of improved vehicles through: (1) evaluating the need for technology improvements, (2) setting minimum performance standards that vehicles must meet or surpass to participate in the MD, (3) testing and evaluating available vehicles to determine performance and safety, (4) providing engineering support for vehicles in the MD, and (5) supporting product improvement engineering efforts.

Revised performance standards have been promulgated recently that show what many EHVs can achieve. Improvements are evident in both range and performance over EHVs tested in the first state-of-the-art (SOA) assessment in 1977.[4]

The first hardware development under the VEI project was the 2x4 program, which provided assistance to small businesses for product improvements. In this program, four manufacturers each developed two vehicles incorporating improved, off-the-shelf technology. The vehicles were delivered in 1979, and test data indicate that they surpass the performance standards in most cases. The most recent SOA report was published in 1979.[5]

1.1.3 Electric Vehicle Commercialization

The purpose of the EVC project is to induce the development and large-scale commercial production of electric vehicles (EVs) and related components and subsystems (including batteries) by the mid-1980s. The vehicle-related objectives, to be achieved by the end of 1986, are to: (1) develop an electric passenger car with the attributes necessary to insure broad market acceptance, (2) initiate limited production of these electric cars, and (3) establish the production capacity necessary to produce at least 100,000 of these electric cars annually. These objectives are to be achieved through the sharing of costs and risks in a business relationship between the government and selected manufacturers.

The EVC project also provides for R&D related to EV components and subsystems (including batteries) and stimulation of their commercial production. Since 1976 DOE has been sponsoring research, development, test, and evaluation efforts related to EV components and subsystems, including motors, controllers, transmissions, propulsion subsystems, charger/charge indicators, and environmental controls. Battery development and commercialization activities are focused on lead-acid (Pb/acid), nickel-zinc (Ni/Zn), nickel-iron (Ni/Fe), and zinc-chlorine (Zn/Cl) batteries.

Finally, DOE provides technical and commercialization assistance of a nonfinancial nature to vehicle, subsystem, component, and battery manufacturers. This support includes commercialization studies, field test vehicle development, field testing, brokering of coordination with the utility industry, market development assistance, and activities to supplement the incentives efforts underway in the DOE MD project.

1.1.4 Hybrid Vehicle Commercialization

The purpose of the HVC effort is to induce mass production by 1988 of cost-competitive hybrid vehicles (HVs) with a range comparable to conventional vehicles (CVs). The DOE HVC effort is similar to the EVC effort but displaced by about two years. The nature of HV technology means that major government involvement in HV development must be preceded by a detailed assessment to determine the potential of HVs to save petroleum. This study is now complete, and the results indicate that HVs can replace a significant amount of the petroleum used by CVs.[6]

To convert this theoretical potential into demonstrable results, DOE initiated an HV development program in 1978. Four separate contractors were selected for the design study, and one was selected to continue work on the detailed design, development, fabrication, and test of an experimental HV. Development of a near-term HV is in the final design stage. It couples the ETV-1 EV technology with a fuel-injected, 80-peak-hp gasoline engine. (The ETV-1 is the first DOE electric test vehicle, which was unveiled in June, 1979.) Test vehicles will be delivered in 1982.

1.1.5 Advanced Vehicle Development

The purpose of this project is to develop and demonstrate by the early 1990s a general-purpose EV or HV system that would not use petroleum and that would be completely competitive with CVs. More specifically, DOE has defined an "advanced vehicle" to be: (1) an EV or HV that does not use petroleum for its operation; (2) an EV or HV that uses nonpetroleum electricity-based systems, including fuel cells; or (3) an EV or HV with two or more power, fuel, or energy storage devices.

A number of advanced technologies supported by DOE and in various stages of development have the potential to enhance greatly the capabilities or reduce the costs of EVs or HVs. In addition to the relatively short range per charge, a further limitation to be overcome for full competitiveness in the marketplace is the 8- to 16-hr (depending on the charge voltage) recharge time required by current EVs. Some of the technologies that may provide improved performance are primary metal/air batteries, fuel cells, high temperature batteries (e.g., lithium-metal sulfide [Li/S] batteries), inductive coupling to electrified roadways, and flywheels. Some of the advantages of flywheels are being defined through testing of the ETV-2, which is the second DOE electric test vehicle of very advanced design. Other approaches to extending the range of EHVs are rapid battery recharge and rapid battery exchange.

1.2 PROGRAM MANAGEMENT

Program management responsibility for the EHV program has been assigned to the Electric and Hybrid Vehicles Division in the DOE Office of Transportation Programs. Management policy is to decentralize program implementation as much as possible. Management of specifically assigned tasks is being undertaken by the DOE Office of Advanced Conservation Technologies, by DOE laboratories (Argonne National Laboratory and Lawrence Livermore Laboratory), by DOE operations offices, by laboratories of the National Aeronautics and Space Administration (Jet Propulsion Laboratory and Lewis Research Center), and by federally contracted research centers (The Aerospace Corporation).

2 ALTERNATIVES

Section 2 presents alternative DOE EHV program funding levels and the EHV market penetration scenarios* and technology options associated with each. In particular, three levels of DOE investment are considered, from which five market penetration scenarios are developed. The EHV vehicle types and numbers in the market segments of each scenario are given. The EHV technology mix required for these scenarios to occur as described also is specified. The battery options selected as most probable include advanced Pb/acid, Ni/Fe, Ni/Zn, and Li/S systems. The technical details supporting this approach are in Apps. A and B.

This EA of a complex vehicle program considers an almost infinite set of advances in and combinations of EHV technology components. This degree of complexity is in contrast to many EAs that deal with one or more aspects of an individual facility, a piece of equipment, or a demonstration project. In addition, the vehicles will be driven by the general public on all types of roads and are, therefore, very different from specially constructed facilities operated only by trained personnel. Hence, the various DOE EHV program alternatives have been defined in terms of market penetration scenarios, each with their individual mix of vehicles, uses, and technological advances. This approach requires projections for many variables, including private sector EHV activity, liquid fuels prices and availability, advances in other transportation technologies, and the many driving forces in society, as well as the DOE EHV program funding levels and technological breakthroughs in EHV components themselves. Each market penetration scenario combines a plausible set of projections for these variables and, based on the projections, delineates the types and numbers of EHVs that would be in operation under a specific DOE EHV program alternative.

2.1 FUNDING LEVELS

It is impossible to isolate the impact that the DOE EHV program is having on the development and commercialization of EHVs. However, the impact is undoubtedly great and is in proportion to the level of funding the program receives which, in turn, determines the amount of R&D, demonstrations, grants, and incentives the program can generate. Although the rate of technological advance is related to R&D funds, a random component is always present that makes defining the market impact of an R&D dollar difficult. Similar problems arise when attempting to measure the market penetration impact of funds spent on demonstrations, grants, and incentives. Therefore, only broad estimates of the relationships between DOE EHV program funding and future EHV markets can be made, but such estimates are necessary to link the level of DOE effort and the resulting environmental impacts.

The three levels of DOE investment that are considered are illustrated in Fig. 2.1. The figure also shows two current DOE budget levels to 1986. Table 2.1 summarizes the most probable federal activities at each investment level.

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*The term scenario means an internally consistent description of a potential future.

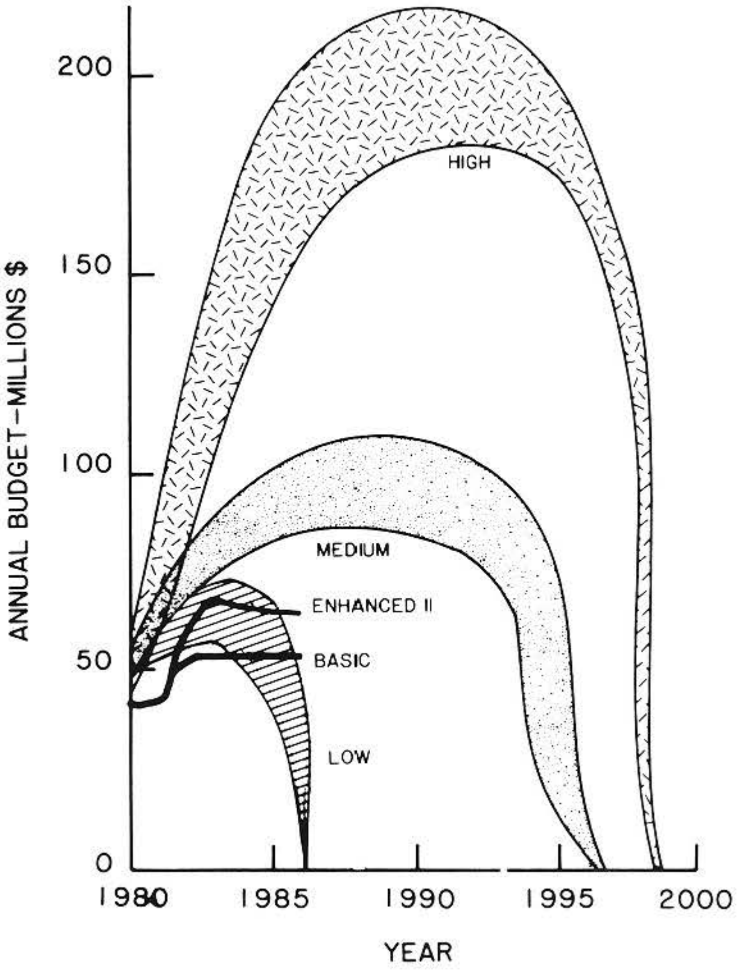

Fig. 2.1. Three Ranges of Funding Levels for DOE EHV Program and Two DOE Budget Levels to 1986

The low funding level allows completion of the current demonstration and little else. Medium funding is more than twice as high as low. High funding is about three times greater than the medium level. Few program choices exist at the low level. Under medium and high, the program takes on similar tasks, but medium assumes a slowly increasing level of effort over the next several years, which then remains at fairly constant levels until 1995. High assumes a significant increase in the level of effort in the near term and maintains that level through 1995. The high alternative is basically an all-out federal EHV effort, where all DOE program elements are pursued vigorously. (Other federal, state, local, and private programs are expected to complement the federal effort.) DOE incentives to manufacturers and EHV owners are significant, as are improvements in vehicle performance as a result of R&D effort. The result of all these efforts is that most of the above program elements are exercised successfully. In contrast, the medium level requires decisions on which program elements to emphasize, and several combinations of successes and failures are possible. In general, however, medium is an extension of the current program with both higher and longer funding levels than the low option.

Table 2.1. DOE EHV Program Alternatives

Program Element	Low	Medium	High
Demonstration	Conducted as currently mandated; only 10,000 vehicles purchased; basically a market demonstration.	Extended for one more buy of 10,000 EHVs in 1987-1989 to demonstrate state of the art.	Extended for one more buy of 15,000 EHVs in 1987 and augmented in 1983-1988 to include engineering demonstrations (about 200 EHVs per year).
Battery R&D	Concluded in 1986 with little success because of lack of good technology.	Both nickel batteries demonstrated in vehicles in 1983; same for Li/S batteries in 1987; other batteries dropped from program in 1981.	Both nickel batteries demonstrated in vehicles in 1981; same for Li/S batteries in 1984; other batteries dropped from program in 1981.
Component R&D	Program funding tapers to zero by 1985.	Few major breakthroughs but components designed for EHVs by 1984.	Major breakthroughs in most areas, with each designed for EHV application by 1982.
Incentive loan and grant program	Only as in current demonstration.	Loans continue to 1990 when large domestic firms start mass production; subsidies to buyers begin in 1985.	Loans at high level to 1988 and continuing for small firms at low level to 2000; subsidized operating costs begin in 1985.
Other federal programs	Negative effect on EHVs because CVs are made environmentally acceptable and liquid fuels are available.	Air quality program and basic research assist EHV penetration and technology; EHVs remain in CAFE after 1986.	Same as medium level plus strong EHV incentives and CV disincentives (CV-free zones become common, intercity transport improves, and high gasoline taxes begin in 1982); government fleets become mostly EHVs; EHVs remain in CAFE after 1986.

2.2 MARKET SCENARIOS

The three funding levels suggest a corresponding set of probable market penetration scenarios. LOW I, MEDIUM, and HIGH I are EV-only scenarios, while LOW II and HIGH II have both EVs and HVs. A BASE (CV-only) scenario is used throughout the assessment for comparative purposes, even though the current momentum in the EHV program makes such a scenario unrealistic. Market projections are made for 1985, 1990, and 2000.

Figure 2.2 and Table 2.2 show the total number of EHVs in use in the United States for each scenario. Table 2.2 also summarizes vehicle sales by type, scenario, and year. The EHVs are assumed to substitute for CVs on a one-for-one basis. Section A.2 (Sec. A.2 of Appendix A) presents the mathematical relationships used to derive the growth curves and the rationale for the market penetrations, and Sec. A.3 discusses the vehicle manufacturers for each scenario.

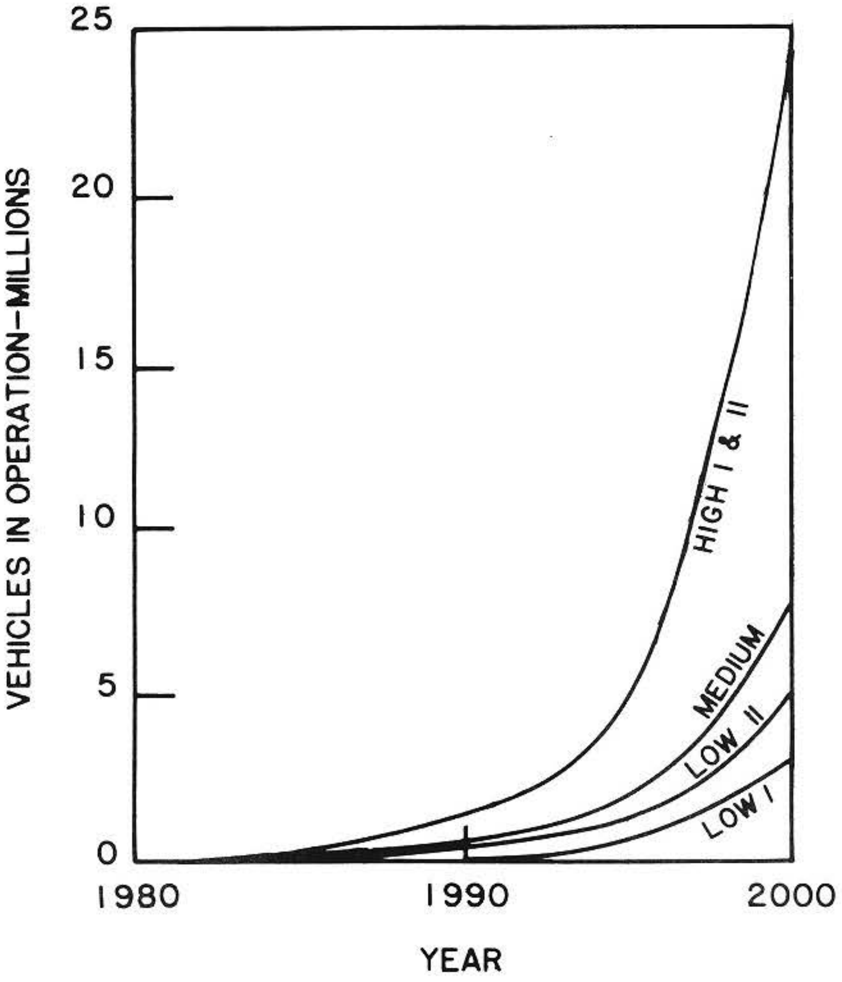

Fig. 2.2. EHV Market Scenarios, 1980-2000

Table 2.2. On-the-Road EV and HV Totals and Vehicle Sales by Vehicle Type, Scenario, and Year (thousands of vehicles)[a]

Vehicle Type	Scenario														
	LOW I			LOW II			MEDIUM			HIGH I			HIGH II		
	1985	1990	2000	1985	1990	2000	1985	1990	2000	1985	1990	2000	1985	1990	2000
EV Trucks															
Total	34	131	2,000	34	131	2,000	55	245	4,750	116	525	13,000	116	472	8,780
Sales	10	43	641	10	43	641	21	92	1,720	40	232	4,520	40	183	3,105
HV Trucks															
Total	0	0	0	13	64	1,370	0	0	0	0	0	0	0	62	5,300
Sales	0	0	0	5	28	525	0	0	0	0	0	0	0	33	2,040
EV Buses[b]															
Total	0	10	60	0	10	60	0	40	190	2	80	250	2	72	121
Sales	0	3	20	0	3	20	0	15	49	1	31	60	1	26	43
EV Autos															
Total	20	70	940	20	70	940	30	125	3,060	50	350	10,800	50	298	6,990
Sales	6	23	300	6	23	300	11	47	1,130	29	159	3,760	29	140	2,310
HV Autos															
Total	0	0	0	7	32	626	0	0	0	0	0	0	0	52	2,820
Sales	0	0	0	3	14	236	0	0	0	0	0	0	0	29	1,080
Total HV	0	0	0	20	96	2,000	0	0	0	0	0	0	0	114	8,110
Sales HV	0	0	0	7	41	761	0	0	0	0	0	0	0	62	3,120
Total EV	54	211	3,000	54	211	3,000	85	410	8,000	168	955	24,000	168	840	15,900
Sales EV	16	69	961	16	69	961	32	154	2,900	70	420	8,340	70	349	5,460
Total EHV	54	211	3,000	74	307	5,000	85	410	8,000	168	955	24,000	168	955	24,000
Sales EHV	16	69	961	23	110	1,722	32	154	2,900	70	420	8,340	70	411	8,580
EHVs (%)[c]	0.04	0.13	1.7	0.05	0.20	2.8	0.06	0.26	4.5	0.11	0.61	13.7	0.11	0.61	13.7

[a] Numbers may not add due to rounding.

[b] No HV buses characterized or assessed.

[c] Percentage of total small highway vehicles.

The LOW scenarios are relatively probable from a technological point of view. The other scenarios depend on significant technological advances in battery technology that are relatively unlikely, even with strong federal support. For example, the HIGH I scenario requires early and successful commercialization of Ni/Zn batteries and mid-term commercialization of the Li/S battery. Given these prerequisites, the probability of HIGH I is less than one in five.

2.2.1 Reference Scenario

The LOW and MIDDLE scenarios are variations on the mid-reference scenario used by DOE.[7] This reference scenario is mildly optimistic in terms of basic societal driving forces: population size and distribution, national economics, national prevailing attitudes, and technological advances. The standard of living continues to increase, but there are no major changes in the quality of life. Migration to suburbia and the sunbelt continues as do increases in per capita gross national product (GNP). It is the most probable scenario of the set chosen by DOE for planning purposes. Figure 2.3 presents U.S. population and GNP growth through 2000 for this scenario.

Because of postulated liquid fuel shortages, the HIGH scenarios contain an element of urgency that is not in keeping with the status quo nature of the reference scenario. Nonetheless, the important parameters of population and propensity for travel do not vary for these scenarios before 2000.

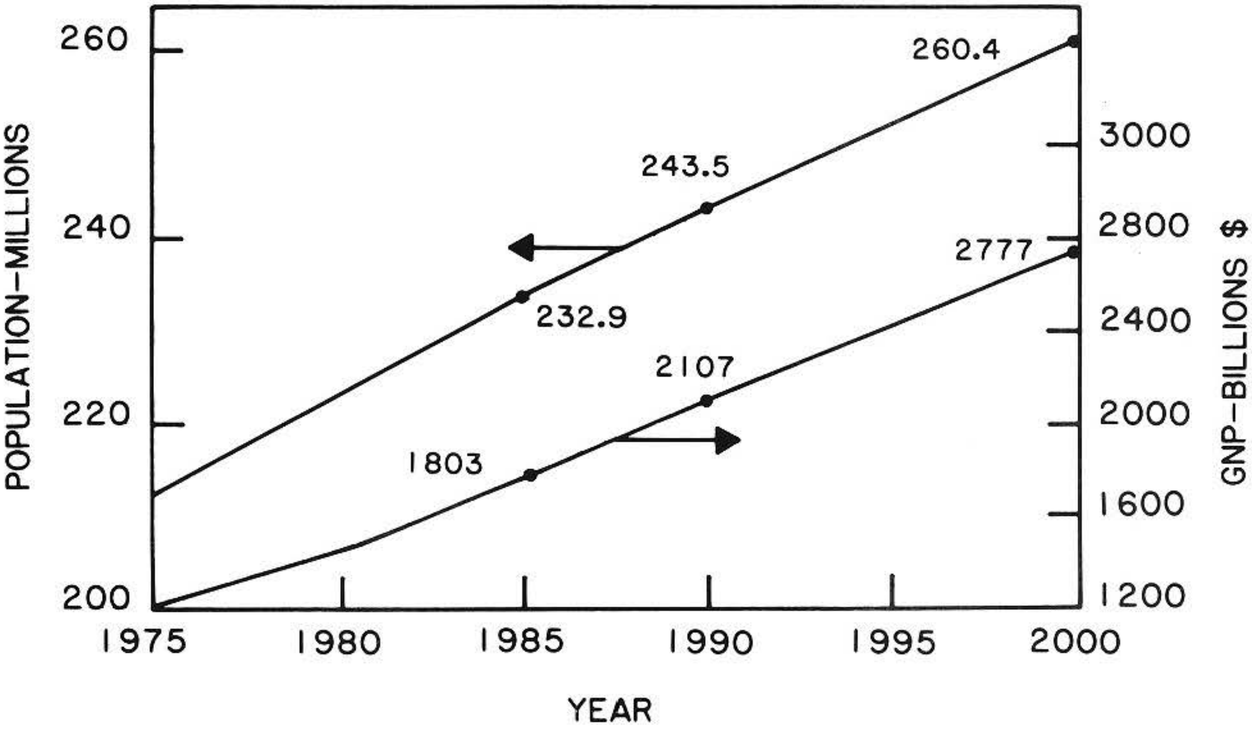

Fig. 2.3. U.S. Population and GNP, Reference Scenario, 1975-2000 (Source: Ref. 7)

2.2.2 LOW Scenarios

The LOW scenarios represent a phaseout of all government EHV-related programs by the 1986 conclusion of the current demonstration. Few battery technology advances are foreseen. The Pb/acid battery dominates the vehicle population through the end of the century, though the Ni/Zn battery begins significant penetration after 1990. Availability of liquid fuels, including alcohol and broad-cut petroleum fuels, remains high, and Stirling and/or gas turbine engines are commercialized in the 1990s. The few Otto-cycle engines that remain in transportation use are quite efficient. Little shift away from automobile travel is foreseen. CVs, including the advanced heat engines, become environmentally acceptable, and the federal air quality program has little or no EHV emphasis. In the private sector, a few domestic EHV mass production lines are in operation in the 1990s. Table A.1 summarizes the projections for the major variables of the LOW scenarios.

In environmental assessments, a no-action alternative is normally discussed. In this case, because the EA analysis starts in 1985 and the current EHV legislation ends in 1986, and because the LOW scenarios represent a phaseout of all government EHV-related activity by 1986, the LOW scenarios represent the no-action alternative.

Study of the individual vehicle types characterized for this assessment shows that the three million EVs in 2000 in LOW I and LOW II can be achieved through penetration of markets for which a 50- to 75-mi range is satisfactory. Highest penetrations are postulated for commercial trucks operating in fleets. Because the 50- to 75-mi range is acceptable for these market segments, the established Pb/acid battery is tough competition for other battery types. In LOW II, the two million additional HVs do not compete with the EVs because they are used for longer-range missions.

2.2.3 MEDIUM Scenario

The MEDIUM scenario is based on government EHV activity increasing over the next several years and then remaining at fairly constant levels to 1995. Battery technology advances occur. The Ni/Zn battery takes over domination of the market from the Pb/acid battery by 1990, and the Li/S battery is successfully commercialized. Liquid fuel remains available, but costs are relatively high. The Stirling and/or gas turbine engines penetrate some markets, but the Otto-cycle CVs using petroleum-based fuels still hold 50% of the market. As in the LOW scenarios, little shift is seen from automobile travel to other modes. Federal air quality regulations encourage but do not mandate EV utilization. For example, CV-free zones in several urban areas* are established, government fleets include many EVs, and control technology limits CV performance somewhat. Private sector EHV activity is moderate. Table A.2 outlines the projections made for the major variables of the MEDIUM scenario.

Government intervention probably will be required in the 1980s to stimulate EV sales sufficiently to obtain an EV population of eight million by

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*The phrase "urban area" as used in this EA is a general term. The phrase "urbanized area" is used whenever the Bureau of Census definition (i.e., a developed area within a Standard Metropolitan Statistical Area [SMSA]) is appropriate.

2000 under this scenario. A government decision to include EVs in CAFE calculations is an example of such assistance. The fact that EVs have recently been included in CAFE calculations through 1986 by passage of P.L. 96-185 moves EHV development closer to this scenario.

The 50- to 150-mi range of the Ni/Zn vehicle opens new markets. Although these markets are still predominantly commercial, greater penetration in the personal-use market occurs. Personal light-light truck and private automobile owners in particular will shift to EV systems promising higher performance than the Pb/acid systems. Finally, Li/S batteries, with their potential for lower life cycle costs, will begin to capture some of the market dominated by the Ni/Zn battery.

2.2.4 HIGH Scenarios

Four basic elements distinguish the HIGH EHV scenarios from the MEDIUM scenario: (1) longer range (for HIGH I, Li/S batteries used in EVs are fully commercialized in the 1990s; for HIGH II, Ni/Zn batteries used in HVs penetrate heavily in the last decade of the century); (2) rising prices, significantly lower availability, and sporadic but significant shortages of liquid fuels; (3) slow progress in the alternative heat engines program, and (4) local and federal EHV incentives (including tax credits to owners) concurrent with CV disincentives, such as the enforcement of high air quality standards. The Otto engine continues to dominate the CV market. Private sector EHV activity is high, with mass production beginning in the 1980s. Concomitant with the high rate of EHV substitution are increased use of mass transit, greater freight centralization, and improved distribution in all urban and suburban areas. Also, intercity bus and rail systems experience patronage increases, while per capita air travel drops significantly. Telecommunications is implemented with federal assistance.

In essence, the HIGH scenarios assume a large measure of national urgency. The level of government EHV support is very high through 1995 in all areas (battery system R&D, raw material supply, production development, and EHV infrastructure subsidies). The government takes strong measures to defray manufacturer and consumer risk and/or economic burden, and imposes CV disincentives. Table A.3 summarizes the projections for the major variables of the HIGH scenarios.

Under the impact of government pressure and in the course of international events, purchasers of all vehicle types attempt to use EHVs if at all possible economically and if such vehicles fulfill prospective needs. In the mid-1980s, Pb/acid batteries give way to Ni/Zn batteries in EVs. In the 1990s, Li/S batteries in EVs penetrate in HIGH I and Ni/Zn batteries in HVs in HIGH II. These systems significantly penetrate nearly all markets. EHV automobile market penetration begins in earnest about 1990; approximately 50% of the 24 million EHVs in use in 2000 are personal use vehicles.

2.2.5 Regional Variation

The market penetration of EVs will vary among the different areas of the United States because of variable climatic, topological, and trip-making characteristics. EV sales in each of 158 urbanized areas were modified from the national per capita mean based on temperature extremes, average trip length, average trip speed, average annual miles per vehicle, terrain, and price of gasoline relative to electricity.

The method used in making the modifications employs 1990 projections of these variables and is explained in Sec. A.5. It generates a regional variation indicator that is: (1) 1.0 for urbanized areas with average characteristics, (2) greater than 1.0 for urbanized areas with characteristics amenable to EVs (Miami scored highest at 1.239 because it is flat, has moderate temperatures, and requires relatively little freeway driving), and (3) less than 1.0 for urbanized areas having characteristics that conflict with EV performance (Colorado Springs scored lowest at 0.748). New York-New Jersey scored 1.128, while Chicago and Los Angeles scored 1.058 and 0.782, respectively. This indicator is used to distribute EVs to the various urbanized areas to allow analysis of local impacts.

2.3 VEHICLE TECHNOLOGY

The details on future characteristics of batteries, the methods used to characterize the EHVs and CVs, and the detailed characterizations of the vehicles are presented in App. B. These characterizations include information on vehicle weight, range, and performance, and on vehicle materials requirements. Also in App. B are descriptions of the processes associated with vehicle production (including battery manufacture) and with the fuels production necessary for vehicle operation. These descriptions include data on the energy required to produce the vehicles and on associated emissions to the physical environment.

Forty-eight electric, six hybrid, and seven conventional autos, buses, and light trucks of the future are characterized. The EVs incorporate either Pb/acid, Ni/Fe, Ni/Zn, or Li/S batteries. Each EV is designed to meet at 80% depth of discharge (DOD) the acceleration requirements of the Society of Automotive Engineers J227A Schedule D driving cycle, which includes a 0-45 mph acceleration in 28 s. In other words, the peak specific power of each EV battery at 80% DOD is sufficient to accomplish that acceleration. At less DOD, the EVs do even better. This capability means that each EV would be similar in performance to future CVs except for range. The range for an individual EV varies by battery type, and the ranges of different battery types improve over the course of the assessment timeframe. For example, a typical Pb/acid battery light truck in 1985 has a range of 50 mi, while the same vehicle has a range of 73 mi in 2000. In the same year, the same type of truck, but with a Li/S battery, has a range of 220 mi.

HVs are expected to incorporate either Pb/acid or Ni/Zn batteries. The characterized HVs are all parallel configured as shown in Fig. 2.4. Although less is known about future HVs than EVs because HV technology is less mature, it is possible to project a likely HV operation profile. For the first 47 mi (1985) or 69 mi (2000), the vehicle operates exclusively off batteries charged with electricity from the utility, except when rapid vehicle acceleration or hill-climbing requires the heat engine to provide additional power, which should be relatively infrequently. At about 47 mi (1985) or 69 mi (2000), the battery discharge reaches 80%, and the heat engine operates to extend the

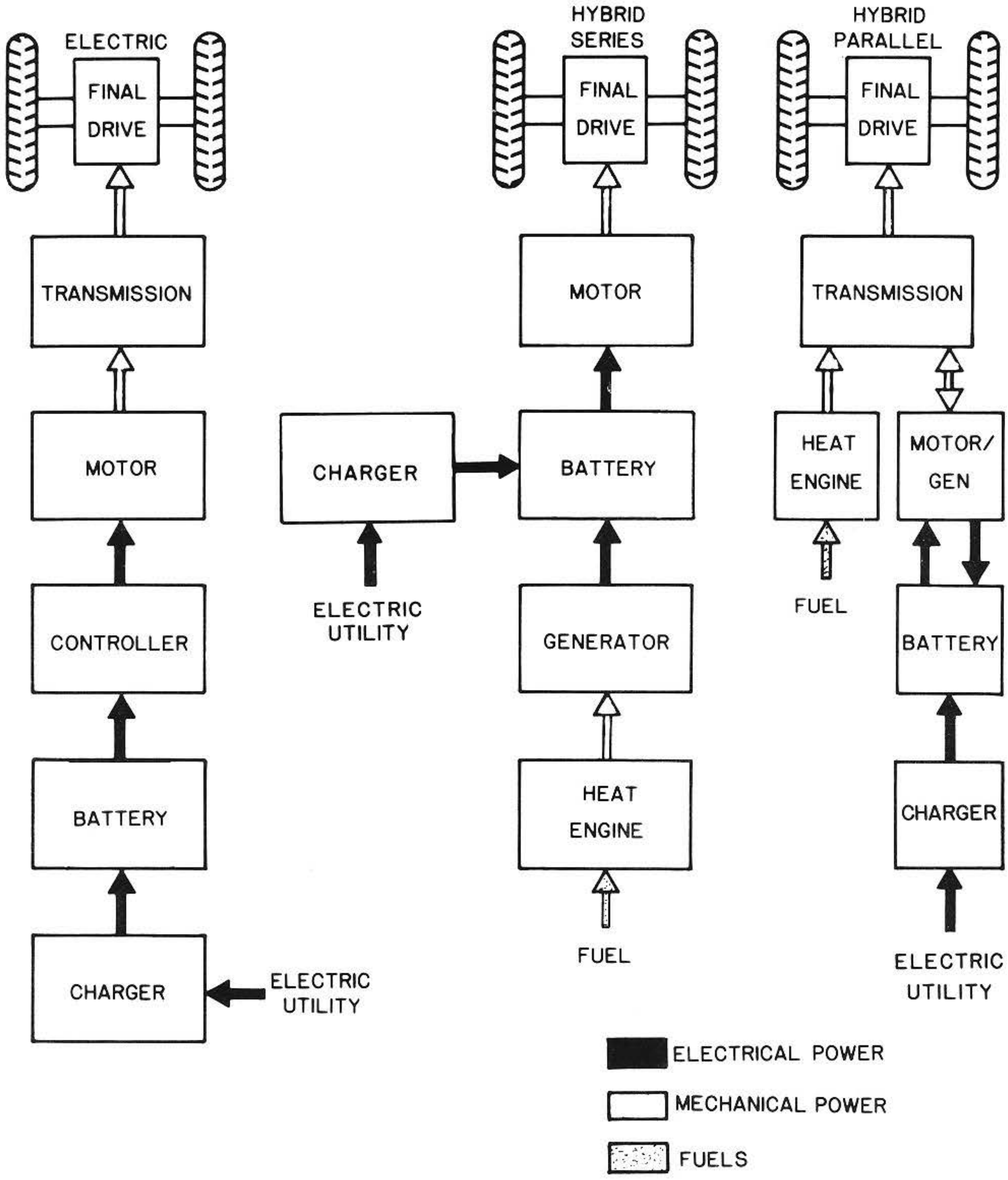

Fig. 2.4. Comparative EV and HV Schematics

vehicle's range. At this point, the battery assists the engine when peak power is required, and the heat engine maintains the battery at 80% DOD. The selected driving cycle for the HVs is a combination of 70% urban and 30% highway for automobiles and a delivery schedule for trucks. The HV performs exactly like a CV but should be plugged in when not in use.

The EHVs are approximately the same size as the CVs they are expected to replace, but their gross vehicle weight (GVW)* is greater. A shift to lighter-weight materials is projected for both EHVs and CVs. In fact, lightweight materials are expected to be used to the same degree in EHV and CV bodies.

The EHVs use sealed batteries and regenerative braking but not flywheels. The EHV battery chargers are on board. While DC motors and silicon-controlled rectifiers are dominant until about 1990, AC motors and power transistors are expected to dominate the market after 1990. All EHVs have an auxiliary battery for auxiliary electric systems operation. Since a number of alternatives are possible, the technologies used for heating and air-conditioning accessories are not specified (see Sec. B.1).

Several types of batteries other than the four characterized for this analysis were considered and rejected based on a variety of criteria (see Sec. B.1). However, since the time of the battery characterizations, Zn/Cl battery developments have occurred that have resulted in its reevaluation as a near-term candidate. Although excluded from this EA, EHVs powered by Zn/Cl batteries will be included in future EHV environmental analyses. Similarly, advanced vehicles other than the Li/S EV may be included in later studies.

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*Gross vehicle weight is the weight of the vehicle plus payload.

3 ENVIRONMENTAL IMPACTS

Section 3 defines the scope of the assessment and summarizes the expected environmental impacts for each of the five EHV market penetration scenarios. This summary is based on the analyses and detailed results presented in Apps. C-G.

3.1 SCOPE

This EA analyzes the environmental impacts expected to result from three different DOE EHV program funding levels and the five associated market penetration scenarios. Thus, the EA provides DOE, other federal agencies, and the general public with an overview of the impacts of different degrees of EHV market success. The EA also serves as the basis for deciding whether an environmental impact statement (EIS) is required for the DOE EHV program.

Figure 3.1 illustrates the scope of the assessment. It begins with the technologies and the scenarios that define the EHV system and concludes with environmental impact analyses for a broad range of subsystems where costs and benefits to the human environment may occur as a result of EHV commercialization.

In the discussion that follows, the emphasis is usually on the HIGH scenario impacts. Although the probability is low that either of these two HIGH scenarios will happen, they are nonetheless possible outcomes of the DOE EHV program and do identify worst-case impacts. In addition, the impacts associated with the HIGH I and II scenarios in 2000 do reflect the impacts most likely to be associated with the more probable MEDIUM scenario a few years beyond 2000.

3.2 MATERIALS IMPACTS

The analysis of natural resources focuses on 10 major materials (lead, nickel, cobalt, lithium, copper, boron, zinc, aluminum, iron, and steel) and energy. Although a more complete list of EHV materials appears in App. B, adverse environmental consequences, such as material supply and demand imbalances, are more likely to occur with these 10 materials. Energy impacts are discussed in Sec. 3.3.

The methods and details of the materials analysis are presented in Sec. C.1. Section C.1.1 gives the methodology for determining the direct materials requirements of the EHV scenarios. Tables C.2-C.10 list the amounts of the 10 major materials that EHVs require by scenario and by assessment year. These data assume battery replacement during the life of the vehicle and improved metals recycling techniques. Recycling is assumed to occur at a 95% rate for battery materials and at a 90% rate for motor/controller/charger materials. The results presented in most of the summary tables in Sec. 3.2 are based on these assumptions. Since many technological barriers to this level of recycling remain for many of the materials analyzed, Tables C.2-C.10 also give materials requirements without recycling.

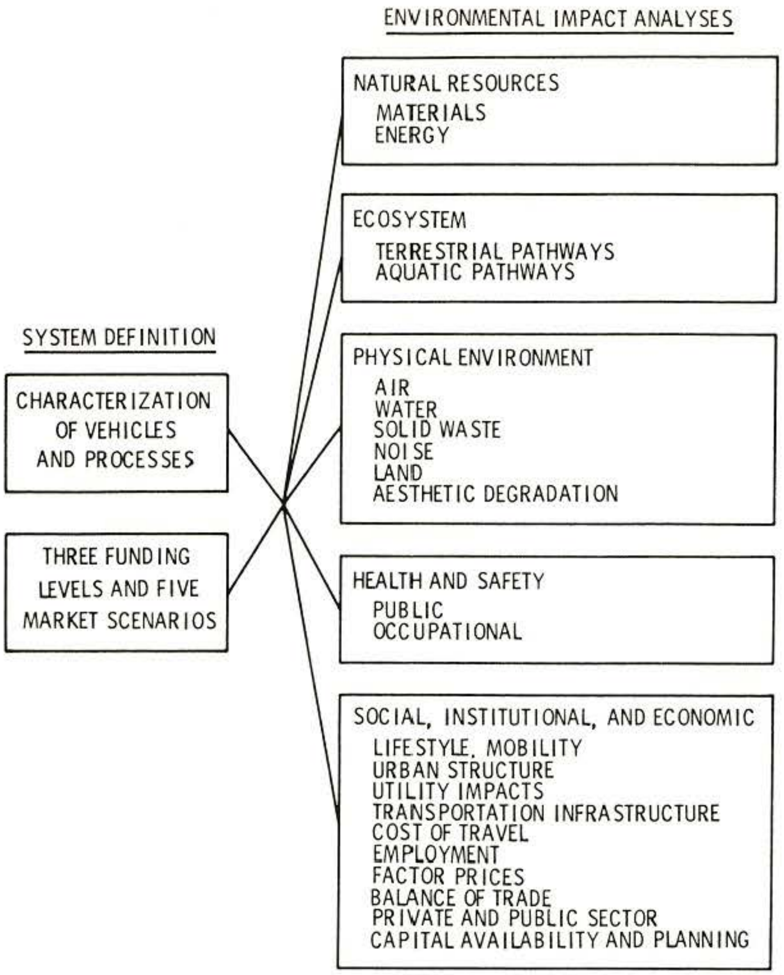

Fig. 3.1. Scope of the Assessment

Section C.1.3 considers indirect materials requirements, such as the additional amounts of materials required for the machines to produce the EHVs. However, in no case are these additional amounts large enough to change the results of the direct materials requirements analysis. Therefore, the following discussion considers direct materials demand only. Although the discussion does not explicitly state the materials requirements for CVs, these requirements are already incorporated in the U.S. Bureau of Mines (BOM) materials estimates with which the EHV requirements are compared.

In the following analysis, direct materials requirements are contrasted with major materials import percentages where appropriate. The materials import percentages of 1976 were used, because they were the latest available at the time of the analysis (see Table 3.1). The high import levels of cobalt, nickel, and zinc cause several environmental consequences in the HIGH scenarios, even with recycling. These problems and the other supply problems noted in Secs. 3.2.1-3.2.9 could be compounded by materials requirements for EHV development in other countries. The EA does not address world EHV development.

Table 3.1. 1976 Major Materials Import Percentages

Material[a]	Percentage Imported[b]
Lead	15
Zinc	50
Nickel	50[c]
Copper	13
Cobalt	100

[a] The other five major materials are not presented because their balance-of-trade impact is considered insignificant.

[b] Most of these import percentages are obtained from the U.S. Bureau of Mines series "Mineral Commodity Profiles." Where calculations are needed to obtain these figures, the percentages are calculated as a percentage of total supply.

[c] This is a very conservative estimate of nickel imports.

Sources: Refs. 8-13.

3.2.1 Lead (Pb)

Batteries used to start current CVs contain about 24 lb of lead. In 1977, transportation was the major end use of lead, accounting for 71% of total U.S. demand, which was 1.5 million short tons. Automobile batteries accounted for 52% of total lead demand. Bureau of Mines projections for transportation demand in 2000 are 1.2-2.6 million short tons, with 1.7 million short tons as the most probable estimate.[8] These estimates are based on projected growth in GNP and other factors not related to EHVs.

Lead resources are scattered widely throughout the world. The United States has the largest reserves and has been the leading producer for several years, accounting for 16% of total world mine production in 1976.* In recent years, lead reclaimed from old scrap (chiefly discarded batteries) has averaged about 40% of total lead consumption, slightly more than was recovered by refiners of domestic ores. Domestic mine production has met over 65% of total U.S. primary demand for lead, the remainder coming from imported materials and sales of stockpile excesses. Total domestic production, including both primary and secondary metal, was over 75% of total industrial demand.[8] U.S. reserves of lead are situated primarily in the Mississippi

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*Reserves are economically recoverable materials, i.e., materials available at current prices. Resources are either undiscovered (hypothetical) or identified materials that are either economic or subeconomic at current prices.

Valley, especially in the Viburnum Trend, which is a westward extension of the old Missouri lead belt. Total U.S. reserves are estimated at 28.4 million short tons, with 20.6 million short tons located in Missouri.

The BOM estimate for U.S. lead demand in 2000 is 2.3 million short tons, and the EHV lead requirements for each scenario are listed in Table 3.2. Current domestic measured and indicated (highly probable) reserves are nearly adequate to meet the probable lead demands based on the scenarios. Estimated U.S. reserves combined with efficient functioning of the lead recycling system are sufficient to achieve estimated yearly and cumulative demand. Recycling meets a significant fraction of total demand, and the vehicles themselves become a "rolling reserve" of lead for future batteries. This aspect of recycling is important for all of the metals considered.

3.2.2 Nickel (Ni)

Fifty percent of the 1976 U.S. nickel supply was imported, mainly from Canada, New Caledonia, and the Dominican Republic. While U.S. nickel reserves are small, the country does possess large amounts of nickel resources that could be exploited if technological and environmental problems are solved. Ocean nodules off our Hawaiian waters offer a potential source of nickel, provided the necessary processing and mining technologies can be developed and legal problems regarding mining rights and controls can be resolved. Recycling of secondary nickel is expected to occur when its availability increases through EHV usage. However, no process now exists for recycling nickel into battery-grade, powdered nickel, which presently comprises roughly 50% of the nickel in certain Ni/Zn batteries. The remainder of the nickel in the batteries is actually a lower-grade nickel of the type currently used in the production of stainless steel.

Table 3.2. EHV Lead Requirements and Percentage of U.S. Demand, 2000

Scenario	EHV Lead Requirements (thousands of short tons with 95% recycling)	Percentage of U.S. Bureau of Mines U.S. Demand Estimate[a]
LOW I	292	13
LOW II	568	24
MEDIUM	173	7
HIGH I	346	15
HIGH II	346	15

[a] EHV requirements are not included in BOM estimate.

Source: Ref. 8.

U.S. nickel mining operations have produced 13,200-15,600 short tons of nickel per year over the last 10 years. From 1966 to 1976, the United States produced 1.5-2.0% of the world's nickel supplies. Estimated 1976 U.S. nickel reserves were 200,000 short tons.

The BOM estimate for U.S. nickel demand in 2000 is 560,000 short tons, and the EHV nickel requirements for each scenario are listed in Table 3.3. The large percentages in the last column occur because significant amounts of nickel are required for Ni/Zn and Ni/Fe vehicles. A large bus with a Ni/Zn battery uses 2550 lb of battery-grade nickel.

If U.S. reserves do not increase, significant dependence on foreign supplies in the MEDIUM and HIGH scenarios will occur. Significant price increases are possible with such large increases in demand, especially since such a relatively small number of firms export our primary nickel supply.

Several solutions to this apparent constraint on EHV market penetration are immediately evident. First, most of the nickel requirements come from medium-light and heavy-light trucks and from small and large buses using Ni/Zn batteries. (These vehicles make up 66% of the nickel requirements in 2000 in the MEDIUM and HIGH scenarios.) If Ni/Zn battery use were limited to certain vehicles, current import rates could be maintained. The second solution is to increase domestic nickel supplies by passing legislation to encourage the development of offshore nodules and by developing mining technologies that would make known nickel deposits in the Duluth gabbro of northeastern Minnesota and deposits in Oregon, California, and Washington more commercially feasible. Table 3.4 shows that under the HIGH II scenario in 2000 (the scenario with the greatest EHV nickel requirements), if only ocean mining projects were used to meet EHV-related nickel demand, 25 such projects would be needed. It is estimated that five to six American-owned projects and five to six foreign-owned projects will be in operation by 2000. It should be noted, however, that significant extra processing costs would be required to refine the nickel oxide from the offshore nodules into battery-grade, powdered nickel.

Table 3.3. EHV Nickel Requirements and Percentage of U.S. Demand, 2000

Scenario	EHV Nickel Requirements (thousands of short tons with 95% recycling)	Percentage of U.S. Bureau of Mines U.S. Demand Estimate[a]	Percentage of Recent Domestic Production
LOW I	30	5	215
LOW II	30	5	215
MEDIUM	334	60	2390
HIGH I	918	164	6560
HIGH II	1170	210	8360

[a] EHV requirements are not included in BOM estimate.

Source: Ref. 11.

Table 3.4. Material Output for an Ocean Mining Project and Number of Projects Needed to Meet HIGH II Demand in 2000

Material	Percentage of Nodule	Output per Operation (short tons)	BOM Demand Estimate[a] (short tons)	HIGH II 2000 EHV Estimate (short tons)	Number of Mining Operations to Meet EHV Demand
Nickel	1.0	46,500	560,000	1,170,000	25
Copper	1.0	46,500	5,100,000	723,000	16
Cobalt	0.35	5,115	20,200	63,300	12

[a] EHV requirements are not included in BOM estimate.

A longer-term solution will occur naturally as gradual commercialization of nickel battery vehicles builds up a stock of recyclable nickel. However, for the first seven or eight years of nickel recycling, recycled nickel will not be able to be refined economically into battery-grade nickel. Recycled nickel will go mainly to the stainless steel industry, and nickel for batteries will have to come from other sources. After this initial period, it is expected that a substantial amount of nickel will be refined to battery-grade material if recycling processes are developed as anticipated. Further analysis of nickel recycling processes and their impact on the availability of battery-grade nickel powder is necessary.

3.2.3 Cobalt (Co)

The Ni/Fe and Ni/Zn batteries both require cobalt. Mining of cobalt in the United States ceased at the end of 1971, and all production since that time has been from relatively minor amounts of secondary material derived from recycled alloys. Since domestic reserves of cobalt are so low, the basic problems are excessive dependence (98%) on foreign sources and concentration of higher-grade deposits in so few areas of the world. From 1972 to 1975, an average of about 75% of U.S. imports originated from a Zaire government-owned company, which produces cobalt as a by-product of copper. In 1975 Zaire's share of total world cobalt mine production was 53%.

This degree of dependence is expected to continue for many years. However, if cobalt prices were to increase or if new technology were to lower production costs, some U.S. identified resources may become economic. Although U.S. identified resources are second only to Canada, all of them are presently uneconomic. According to the U.S. Geological Survey, Minnesota possesses the largest identified resources in the United States, i.e., approximately one billion pounds of cobalt as sulfide in the Ely area. However, if U.S. cobalt mining resumes, the Blackbird district of Lehmi County, Idaho, would be the most likely area because of its relatively high-grade ore (0.6%).

(It has recently been announced that mining of cobalt in the Blackbird district of Idaho will be resumed in 1982.) Nonetheless, the best short-term prospect for abundant supplies may be the development of cobalt-bearing manganese nodules on the Pacific Ocean floor.

The BOM estimate for U.S. cobalt demand in 2000 is 20,200 short tons. The EHV cobalt requirements for each scenario are listed in Table 3.5.

The cobalt cartel, which apparently exists, could significantly affect the supply and cost of cobalt. Solutions similar to those suggested for nickel hold true for cobalt. For example, domestic supplies could be increased if recovery technologies were improved. In addition, Table 3.4 shows that under the HIGH II scenario in 2000, 12 ocean mining projects would be needed to meet EHV excess cobalt demand. That number may be in operation by that time.

Cadmium (a heavy metal with its own set of environmental consequences) is one of the materials under study as a substitute for cobalt in nickel batteries. A subsequent programmatic EA must address any substitute for cobalt.

3.2.4 Lithium (Li)

Lithium is needed for Ni/Fe and Li/S batteries. Since U.S. lithium reserves have been more than adequate to meet demand, there has been little effort to assess resources. Further, since there are relatively few producers, production data are withheld by BOM to avoid disclosing confidential company information.

Some maintain that lithium reserves and resources are sufficient to meet estimated EHV demand. Others suggest that a serious shortage will occur in 2000 because of EHV and fusion power developments. BOM estimates U.S. lithium reserves in 1976 at 410,000 short tons and world reserves at 2.2

Table 3.5. EHV Cobalt Requirements and Percentage of U.S. Demand, 2000

Scenario	EHV Cobalt Requirements (thousands of short tons with 95% recycling)	Percentage of U.S. Bureau of Mines U.S. Demand Estimate[a]
LOW I	1.8	9
LOW II	1.8	9
MEDIUM	18.0	89
HIGH I	49.5	245
HIGH II	63.3	314

[a] EHV requirements are not included in BOM estimate.

Source: Ref. 13.

million short tons.[14] The accuracy of these figures is open to debate.[15] They are conservative in that they represent known reserves only. Other figures for lithium are much greater but include both known reserves and unknown resource estimates.[15]

If lithium demand were to increase at present growth rates of approximately 5% per year, the total cumulative demand without lithium batteries would be 13,400 short tons in 2000. The HIGH I scenario (the only scenario with significant Li/S battery use) requires 172,000 short tons in 2000. Such a dramatic increase in production would pose serious "gearing up" problems for this small industry. Increased exploration, mining, refining, construction, and operating costs preclude the industry from meeting this projected 1285% increase in demand. Further, the industry is leery of government incentives, much less directives. In the past, the industry was told to "gear up" for the nuclear industry, only to be glutted with overcapacity when demand failed to materialize.

3.2.5 Copper (Cu)

Copper and copper compounds are relatively expensive materials and are required for Ni/Fe, Ni/Zn, and Li/S batteries and for the motors, controllers, and chargers in all EHVs. The United States is the leading producer of copper, with 1976 mine production of 2.2 million short tons of metal plus recycling of old scrap. Copper supplies entering domestic consumption from 1965 to 1976 (excluding stock changes) were 64% from domestic mines, 23% from old scrap, and 13% from net imports. Imports in recent years have been largely from Canada, Chile, and Peru.[12] The principal copper-producing states in 1976 were Arizona (63% of U.S. production), Utah (14%), New Mexico (11%), Montana (7%), Nevada (4%), and Michigan (3%). United States 1977 reserves are estimated at 93 million short tons, with 320 million short tons additional estimated uneconomical and undiscovered resources. World resources are estimated at 2.5 billion short tons. None of these estimates includes potential deep-sea nodule copper deposits located off the Hawaiian coast.

The BOM estimate of U.S. copper demand in 2000 is 5.1 million short tons. The EHV copper requirements for each scenario are listed in Table 3.6. The U.S. is largely self-sufficient with respect to copper and can be expected to remain so, even under the HIGH scenarios. A significant percentage of U.S. supply is met currently with secondary recovery of scrap, and the level of scrap recovery is expected to increase as the absolute amount of scrap increases and the price of copper continues to increase.

Ocean mining is suggested as a remedy for copper shortfalls that may occur in the very long term. Twelve ocean mining projects may be in operation by 2000, and significant amounts of copper could be produced from the nodules. Sixteen such projects would be required to meet the copper demands of the HIGH II scenario (see Table 3.4).

3.2.6 Boron (B)

Boron is a component of the Li/S battery. Domestic production of boron minerals, primarily sodium borates, is centered in southern California.

Table 3.6. EHV Copper Requirements and Percentage of U.S. Demand, 2000

Scenario	EHV Copper Requirements (thousands of short tons with 95% recycling)	Percentage of U.S. Bureau of Mines U.S. Demand Estimate[a]
LOW I	49	1
LOW II	101	2
MEDIUM	152	3
HIGH I	542	11
HIGH II	723	14

[a]EHV requirements are not included in BOM estimate.

Source: Ref. 12.

Domestic mine production was one million short tons in 1976. This met the domestic demand for boron of 105,000 short tons. Large domestic reserves of borates occur in California; 1977 estimated U.S. reserves are 20 million short tons.

A relatively small increase in boron demand in 2000 is expected due to the Li/S battery. Domestic and world reserves are adequate for hundreds of years.

3.2.7 Zinc (Zn)

Zinc is a significant component only in the Ni/Zn battery. While the United States is a major consumer of zinc (using about 20% of the total world supply in 1977), it produces only 8% of the primary zinc supply. Over the past 12 yr, imports of metal, ore, and compounds provided 48%; secondary zinc, 5%; net government releases, 5%; industry stocks, 11%; and U.S. mines, 31% of total U.S. supply.

Zinc deposits occur throughout much of the United States. They are found from Maine south through the Appalachian Mountains and up the Mississippi Valley into the Rocky Mountain states. Measured and indicated reserves are estimated at 24 million short tons. Reserves containing only zinc account for about one-third of domestic reserves; extraction of the remaining two-thirds depends to some degree on the recovery of one or more coproducts or by-products. For example, nearly 37% of U.S. zinc reserves occurs as a small percentage of the total contained metal in southeastern Missouri lead deposits. Inferred reserves (hypothetical, economic resources in known districts) and some identified, subeconomic resources total 25 million short tons.[9] Thus, total U.S. reserves plus uneconomic resources of zinc total 49 million short tons. Secondary sources should become increasingly important as improved recycling technology, potentially more favorable tax and freight rates for recycled materials, and greater public involvement in the recycling movement result in increased scrap zinc recovery. Automobiles would provide most of the scrap.[9]

The BOM estimate for U.S. zinc demand in 2000 is 2.2 million short tons, and the EHV requirements are listed in Table 3.7. These demands could be met with existing U.S. reserves. However, U.S. zinc refining capacity has been reduced 50% since 1972 due to obsolescence and environment constraints (e.g., limits on SO_x emissions). Smelting capacity may need to be expanded significantly, and incentives may be necessary. Also, new recycling technologies are required to achieve 95% recycling.

3.2.8 Aluminum (Al)

Aluminum is a significant component of the Li/S battery and the motor, controller, and charger. In addition, future vehicle bodies are expected to contain significant amounts of the material. Aluminum is the most abundant structural metallic element in the earth's crust. Principal deposits of bauxite, the main ore of aluminum, are located in less-developed countries far from the main aluminum-producing and -consuming centers of North America, Europe, and Japan. Known world reserves of bauxite are adequate to meet cumulative world demand beyond 2000. Domestic reserves of bauxite are equivalent to only two or three years' consumption at present rates and are more difficult to process than foreign bauxite. In addition, most of these reserves are dedicated for use in two alumina plants in Arkansas and can not be used efficiently in other existing alumina plants. Low-grade domestic bauxite resources also are inadequate to meet long-term demand. The United States has 10 million short tons of domestic bauxite reserves and 40 million short tons of other presently subeconomic, hypothetical, and speculative resources. About 90% of the domestic supply of aluminum raw materials is imported.

Both the short- and long-range strategic positions of the U.S. with respect to aluminum leave this country vulnerable to political and economic actions by other countries. The International Bauxite Association (IBA) was organized in 1974 by most of the leading bauxite-exporting countries in order

Table 3.7. EHV Zinc Requirements and Percentage of U.S. Demand, 2000

Scenario	EHV Zinc Requirements (thousands of short tons with 95% recycling)	Percentage of U.S. Bureau of Mines U.S. Demand Estimate[a]
LOW I	25	1
LOW II	25	1
MEDIUM	253	11
HIGH I	681	31
HIGH II	897	41

[a] EHV requirements are not included in BOM estimate.

Source: Ref. 9.

to increase their control over bauxite operations and to increase revenues from bauxite production.[16] This association is a cartel much like the Oil Producing and Exporting Countries (OPEC) cartel. However, several supply factors have prevented IBA from dominating the aluminum industry. First, given present technology and industry practices, about 15% (720,000 short tons) of the aluminum in industrial and consumer products is expected to be recovered as old scrap over the next several decades. (For example, in 1977 the aluminum industry purchased about six billion used aluminum cans weighing about 135 short tons and representing 28% of the old aluminum scrap recycled that year.)[16] Second, although bauxite is presently the main source of aluminum both domestically and abroad, other aluminum resources (kaolin clays, anorthosite, and alumite) are expected to be significant in the future. Although the United States has large alternate aluminum resources that could supply our domestic requirements indefinitely, projected costs would be too high based on the present state of research and development on technologies to exploit these resources. Moreover, from four to seven years would be required to select a process and to design, build, and test industrial-scale facilities to produce alumina from such materials.

The United States should continue to be heavily dependent on foreign sources of bauxite, with or without EHV market penetration, unless there is a technological breakthrough. However, BOM is optimistic about such a breakthrough and, if recycling of old scrap continues to increase, our domestic dependence on bauxite imports could decline significantly.

The BOM estimate for U.S. aluminum demand in 2000 is 20 million short tons. EHV requirements are calculated without recycling, because recycling would not alter domestic supply and demand relationships substantially (see Table 3.8).

Table 3.8. EHV Aluminum Requirements and Percentage of U.S. Demand, 2000

Scenario	EHV Aluminum Requirements (thousands of short tons without recycling)	Percentage of U.S. Bureau of Mines U.S. Demand Estimate[a]
LOW I	122	1
LOW II	272	1
MEDIUM	376	2
HIGH I	1110	6
HIGH II	1690	8

[a] EHV requirements are not included in BOM estimate.

Source: Ref. 16.

The large amounts of electrical energy needed for primary aluminum production may slow EHV commercialization. For example, the continued availability of relatively inexpensive electric power for aluminum production in the Pacific Northwest is uncertain. Based on projected supply and demand for electric power in the region, the Bonneville Power Administration announced in 1976 that it will not renew its power contracts with the aluminum industry after present contracts expire in 1984-1988. Continued operation of aluminum plants in this area after this period will be contingent on allocation of available power among industrial, commercial, and residential users and on development of additional local energy sources.[16] If the domestic aluminum industry is forced to reduce production as a result of reduced energy availability, the expected probable demand could not be met. One result could be a slowdown in the commercialization of at least the Li/S EVs.

3.2.9 Iron (Fe) and Steel

Substantial amounts of iron and steel are used in Ni/Fe and Li/S batteries, and in the motors, controllers, chargers and vehicle bodies of all EHVs. Although the United States is the world's fourth largest producer of iron ore, it is also a major importer. Imports have been supplying about 33% of the iron ore required by the U.S. steel industry, whereas they supplied less than 5% in 1953. The decline in U.S. iron ore production has occurred because most U.S. ores are relatively low grade and comparatively costly to produce. And, the increasing availability of low-cost, high-grade foreign ore has become a way to combat growing competition from the reconstructed steel industries of Europe and Japan. However, production of high-grade taconite pellets started in the 1950s, and a $2 billion investment between 1973 and 1980 has increased their production. By 1980 imports are anticipated to have decreased to about 25% of U.S. ore requirements, and this import percentage should continue to 2000.

Identified world iron ore resources total more than 215 billion short tons of iron. World reserves are adequate to supply projected demand well into the 22nd century. U.S. reserves are four billion short tons of iron and are more than adequate to meet expected demand.[17]

EHVs are not expected to change existing supply and demand relationships for iron ore or iron and steel production. In all five scenarios, EHV demand is only a small percentage of U.S. demand.

3.3 ENERGY COMPARISON

Energy losses and subsidies are associated with the extraction, production, delivery, and consumption of different forms of energy. In this analysis, energy resources and subsidies embodied in the production and operation of EHVs are compared with those of CVs. In particular, energy consumption is assessed in order to compare the level of petroleum use in the production and operation of CVs with the level of petroleum use that would result from introduction of EHVs.

The detailed energy analysis is presented in Sec. C.2. Two analytical approaches are used. The first sets the boundary for energy analysis at the mine mouth or wellhead. Under this recovered resource approach, EHVs require more energy, both by scenario and on a per-mile basis. As shown in Table 3.9, the greatest increase in 2000 over CV energy requirements for production and operation is 23% (LOW II). On a per-mile basis (see Table 3.10), the greatest increase is 36% (HIGH I). Both EHV operation and production energy requirements are greater than those for CVs. However, EHVs require less petroleum than CVs. When estimated petroleum requirements for both vehicle production and operation (including some external subsidies) are calculated, EHVs require 22-36% of the petroleum required by CVs in 2000 (see Table 3.11).

Table 3.9. EHV and CV Operation and Production Energy, Recovered Resource Approach (trillions of Btu)[a]

	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
1990					
EHV Operation	15	27	32	84	87
EHV Production	7	11	21	58	53
Total EHV	21[b]	38	53	141	139
CV Operation[c]	14	23	30	76	77
CV Production[d]	5	8	15	38	35
Total CV	19	31	45	114	112
% EHV of CV	114	125	119	124	124
2000					
EHV Operation	231	509	707	2294	2458
EHV Production	95	177	332	1050	1011
Total EHV	325	686	1039	3345	3469
CV Operation[c]	219	424	694	2207	2185
CV Production[d]	73	135	228	650	693
Total CV	292	559	922	2857	2878
% EHV of CV	111	123	113	117	121

[a] Includes external subsidies.

[b] Columns do not always sum because of rounding.

[c] Same CV vehicle miles traveled (VMT) as EHV VMT for each scenario and year.

[d] Same number of CVs produced as EHVs.

Table 3.10. EHV and CV Operation and Production Energy, Recovered Resource Approach (thousands of Btu per mile)[a,b]

	Vehicles Produced in 1985 and Operating in 1990				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
EHV	10.5	11.2	12.3	12.9	12.6
CV	8.7	8.7	9.9	10.0	9.4
% EHV of CV	121	129	124	129	134

	Vehicles Produced in 1995 and Operating in 2000				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
EHV	9.8	10.9	9.3	10.9	9.7
CV	8.4	8.3	8.3	8.0	8.0
% EHV of CV	117	131	112	136	121

[a] Includes external subsidies.

[b] Production energy for CVs adjusted to account for the fact that fewer CVs are required to travel the annual EHV VMT.

The second approach sets the boundary for energy analysis at the in situ resource level, which includes unrecovered resources either left in the ground, damaged, lost, or otherwise degraded, and generally unavailable given current extractive technology and economics. Under this second approach, EHVs require more energy for production than CVs but substantially less for operation. In fact, when both production and operation in situ energy requirements are totaled, EHVs require less energy, both by scenario (see Table 3.12) and on a per-mile basis (see Table 3.13). At worst, EHVs require 78% of the in situ energy required by CVs, both by scenario and on a per-mile basis (LOW II). As before, EHVs require less petroleum than CVs.

The Btu values of the different energy resources used in the production and operation of vehicles are summed, even though they are not readily interchangeable. They are summed in this analysis to provide a perspective on the relative energy requirements of EHVs and CVs.

Table 3.11. EHV and CV Operation and Production Petroleum Requirements, Recovered Resource Approach (trillions of Btu)[a]

	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
1990					
EHV Operation	2	7	5	15	18
EHV Production	2	3	6	15	14
Total EHV	4	10	11	30	32
CV Operation[b]	14	23	30	76	77
CV Production[c]	1	2	4	10	9
Total CV	15	25	34	86	86
% EHV of CV	28.2	38.3	32.7	34.8	37.2
2000					
EHV Operation	29	116	100	366	588
EHV Production	23	44	82	259	250
Total EHV	53[d]	160	182	625	837
CV Operation[b]	219	424	694	2207	2185
CV Production[c]	18	33	56	161	171
Total CV	237	458	750	2367	2357
% EHV of CV	22.2	35.0	24.3	26.4	35.5

[a] Includes external subsidies.

[b] Same CV VMT as EHV VMT for each scenario and year.

[c] Same number of CVs produced as EHVs.

[d] Columns do not always sum because of rounding.

Several items involving energy expenditure are not included in this analysis. In particular, where the energies necessary at certain points in the EHV and CV energy trajectories are the same or nearly the same, they are generally excluded from the overall comparison. For example, the energy necessary for highway construction and maintenance, and the energy used in vehicle disposal are not included.

Also excluded is the energy needed to service EHVs and CVs. EVs should be more reliable and easier to maintain and, therefore, should require less downtime than CVs. Overall, less energy should be consumed in servicing EVs. HVs, because of their dual power sources, should be more complex to maintain and should require more energy for servicing. Second, the energy consumed by heaters and air conditioners is not included. As shown in App.

Table 3.12. EHV and CV Operation and Production Energy, In Situ Resource Approach (trillions of Btu)[a]

	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
1990					
EHV Operation	22	44	48	126	135
EHV Production	12	20	38	103	94
Total EHV	34	64	86	228[b]	228
CV Operation[c]	38	63	83	213	215
CV Production[d]	9	14	27	67	63
Total CV	47	78	110	280	277
% EHV of CV	71.6	81.8	78.0	81.5	82.2
2000					
EHV Operation	322	794	1005	3335	3887
EHV Production	165	308	577	1826	1757
Total EHV	487	1102	1582	5161	5644
CV Operation[c]	614	1189	1943	6182	6122
CV Production[d]	127	234	397	1131	1205
Total CV	740	1423	2340	7313	7327
% EHV of CV	65.7	77.4	67.6	70.6	77.0

[a] Includes external subsidies.

[b] Columns do not always sum because of rounding.

[c] Same CV VMT as EHV VMT for each scenario and year.

[d] Same number of CVs produced as EHVs.

B, these accessories could be operated by batteries (which would affect vehicle range), by liquid fuel (heaters), or by other technologies of varying energy requirements. While these two energy items are not included, they do not appear to affect the general conclusions of the analysis.

3.4 ECOSYSTEM IMPACTS

The national and regional ecosystem impacts of EHVs are very difficult to evaluate. In general, ecosystem analysis is site specific because of local variations in soils, climate, topography, and biotic and abiotic factors. However, the results of the air quality, water quality, and solid waste analyses indicate some general areas of concern with respect to EHV impacts on ecosystems:

Table 3.13. EHV and CV Operation and Production Energy, In Situ Resource Approach (thousands of Btu per mile)[a,b]

	Vehicles Produced in 1985 and Operating in 1990				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
EHV	16.0	18.3	18.9	20.0	20.0
CV	23.6	23.6	26.6	26.9	25.2
% EHV of CV	67.8	77.5	71.1	74.3	79.4

	Vehicles Produced in 1995 and Operating in 2000				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
EHV	14.1	17.3	13.6	16.2	15.5
CV	22.7	22.3	22.6	21.6	21.8
% EHV of CV	62.1	77.6	60.2	75.0	71.1

[a] Includes external subsidies.

[b] Production energy for CVs adjusted to account for the fact that fewer CVs are required to travel the annual EHV VMT.

1. Potential introduction of increased and diverse quantities of metals and metal cations into the environment during all phases of EHV production, operation, materials recycling, and vehicle disposal.
2. Erosion and sedimentation resulting from mining of all EHV materials and fuels.
3. Nitrate residues from the mining operations required to produce and operate EHVs.
4. Air pollution, particularly sulfur oxide (SO_x) formation, from EHV manufacture and operation.
5. Thermal pollution from power plants.
6. Solid wastes from EHV operation and production.

Other incremental pollutant problems were identified during the air, water, and solid waste assessments, and some of these will affect local ecosystems. However, they were considered insignificant nationally or regionally, or their broad impacts were too poorly understood to warrant discussion.

No overall assessment of EHV versus CV impacts on ecosystems can be made. Also, it is impossible to conclude that any of the EHV scenarios will have a greater or lesser impact on ecosystems than any of the other scenarios. There are no generally accepted thresholds of significance for ecosystem effects that could be used to make such an assessment. The EA does give detailed outlines of the general areas where ecosystem impacts might occur. Water, air, and terrestrial pathways are discussed separately; however, of the three pathways, the most significant ecosystem impacts result from materials transported through water. The details of the analysis are presented in Sec. D.1.

There are many ecosystem impacts associated with the mining and processing of the materials and fuels required for vehicle production and operation. Since EHVs require greater quantities of materials in their production, increased quantities of metals and metal cations (with their potential for adverse health impacts) will be introduced into the environment, particularly through water pathways.

More mining is required for EHVs than for an equivalent number of CVs; therefore, more erosion and sedimentation can be expected, both of which are serious water quality problems. With respect to EHV fuels extraction, much of that mining will occur in regions where limited availability of water already poses problems. However, the magnitude and significance of the problems for all these impact areas must be determined on a site-specific basis.

Nitrate residues from mining operations disrupt the equilibrium of local ecosystems. Concentrations up to 760 times normal background have been observed in mine waters. As with other ecosystem impacts, these problems are site specific and must be addressed at that level.

The EHV scenarios show significantly higher local production of SO_x. Since SO_x contributes to the formation of acid rain (approximately 60%),[18] increased injury to vegetation can be expected, which affects animals indirectly through their habitat. Impacts on the aquatic environment are severe and can result in fish kills. Any linking of these types of problems to EHV operation must be done on a site-by-site basis.

The impacts of thermal pollution from power plants also will be localized and can be devastating to aquatic environments. Moreover, many pollutants are transmitted by cooling water discharges, stack gases, and water vapor from cooling towers. Existing water effluent standards promulgated by the U.S. Environmental Protection Agency (EPA) and regulations of state agencies responsible for issuing power plant construction and operation permits should mitigate many of these potentially negative impacts. On the positive side, EHVs will be replacing CVs, whose exhaust heat contributes to the formation of heat islands that affect local weather conditions. The contribution of CV operation to such heat island formation will decrease, though perhaps only slightly, with EHV market penetration.

The EHV scenarios result in greater quantities of solid waste than would be produced by an equivalent number of CVs. Solid waste may contaminate groundwater as it decomposes. In addition, it produces decomposition gases (e.g., methane and carbon dioxide [CO_2]) and odors. Landfill processes cause erosion and sedimentation. The ecosystem impacts, however, can be minimal assuming the regulations for hazardous waste disposal resulting from the Resource Conservation and Recovery Act (RCRA, P.L. 94-580) are enforced and existing control technology is properly applied to other wastes generated by EHVs.

3.5 PHYSICAL ENVIRONMENT IMPACTS

3.5.1 Air Quality

3.5.1.1 Summary

The air quality impacts of the five EHV scenarios result from production of vehicles, operation of vehicles, and production of fuels for vehicle operation. The method and details of the analysis are presented in Sec. D.2. In general, the analysis is based on: (1) projections of nuclear power generation made prior to the Three Mile Island incident, (2) off-peak charging of virtually all EHVs, and (3) application of 1975 new source performance standards (NSPS) to the power plants needed to generate electricity for EHV operation. Decreased availability of nuclear power; greater charging of EHVs during peak hours, which would mean more use of peak-load fossil-fuel power plants; and application of 1979 NSPS for power plants would modify the results presented below. Further, stricter standards for other industrial processes are expected to be promulgated within five years. These standards also would modify the following results to some extent.

Based on the assumptions stated above, the following air quality impacts are anticipated. More emissions to the air result from the production of EHVs than from an equivalent number of CVs. For vehicle operation, loadings of four of the five principal pollutants for which national ambient air quality standards have been promulgated generally decrease with increased EHV operation, while SO_x loadings increase. Depending on the scenario, CO_2 generation in 2000 from vehicle operation increases or decreases with market penetration of EHVs. Fuels production for EHV operation increases SO_x and particulate loadings but decreases nitrogen oxide (NO_x), hydrocarbon (HC), and carbon monoxide (CO) burdens. When all phases of production and operation are combined, EHV market penetration leads to substantial increases in SO_x, some reduction in particulates, and substantial decreases in NO_x, HC, and CO.

National increases in air pollutants from the production of EHVs (materials mining and processing and battery and vehicle manufacturing) are represented in Table 3.14 for the five principal pollutants. These increases vary by pollutant and scenario, and range from 150% to 960% compared to levels associated with the production of an equivalent number of CVs. Table 3.15 relates national EHV emissions from fuels production to CV emissions for these same pollutants. Particulate emissions increase by a factor of 12 and SO_x emissions by a factor of five in 2000 with penetration of EHVs. Other air pollutants generated in vehicle and fuels production are shown in Sec. D.2. Increases in four of these other air pollutants are discussed in Sec. 3.7.1.

Table 3.14. Ratio of EHV to CV Vehicle Production Air Emissions by Pollutant[a,b]

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
1990					
CO	6.0	4.5	2.5	1.8	3.6
HC	1.5	1.5	1.4	1.5	1.5
SO_x	9.2	9.1	4.7	5.0	5.3
NO_x	3.2	2.8	1.6	1.8	1.9
Particulates	2.0	2.0	1.6	1.7	1.7
2000					
CO	5.0	5.2	2.2	2.0	1.8
HC	1.6	1.5	1.5	1.5	1.5
SO_x	9.6	9.1	5.0	4.3	4.4
NO_x	2.8	2.8	1.8	1.6	1.6
Particulates	1.9	1.6	1.7	1.7	1.7

[a] Air emissions for CVs are based on the same number of CVs produced as EHVs for each scenario and year.

[b] See Tables D.1–D.10 for actual pollutant burdens.

Table 3.16 relates national EHV and CV emissions to the air for the same VMT. The EHV scenarios generate more SO_x nationally as a result of vehicle operation because of the amount of electricity provided by coal, oil, and natural gas power plants. The amount varies by scenario and year, but fossil fuels generally provide 70% in 1990 and 60% in 2000. The remainder is nuclear except for approximately 1% from other sources. Appendix F provides details of the utility fuel projections. In addition, as shown in Sec. D.2, variations occur among urbanized areas and regions depending on the types and amounts of fuels used to generate electricity in these areas and depending on whether 1975 or 1979 NSPS apply. Urbanized areas that use primarily nuclear power to fuel EHVs may, in fact, experience a reduction in SO_x emissions with EHV penetration. This implies that power plant emissions occur in the same general location as vehicle operation, which is not always the case.

Tables 3.17 and 3.18 present the total loadings of SO_x, HC, NO_x, CO, and particulates for EHVs and CVs for each scenario in both 1990 and 2000. Emissions from vehicle and fuels production and vehicle operation are summed. For CVs, emissions from vehicle operation are much greater than those from vehicle or fuels production. For EHVs, vehicle operation also generates the greatest proportion of SO_x, NO_x, and CO. However, vehicle production generates the greatest proportion of HC emissions associated with the EHV scenarios. All three factors (vehicle operation, vehicle production, and fuels production) contribute substantially to the particulate load of the EHV scenarios.

Table 3.15. Ratio of EHV to CV Fuels Production and Transport Air Emissions by Pollutant[a,b]

Pollutant	Scenario LOW I	LOW II	MEDIUM	HIGH I	HIGH II
1990					
CO	0.3	0.4	0.3	0.3	0.4
HC	0.4	0.5	0.4	0.4	0.5
SO_x	4.3	4.5	4.3	4.4	4.4
NO_x	0.8	0.9	0.8	0.8	0.8
Particulates	12.1	12.6	12.3	12.4	12.3
2000					
CO	0.3	0.4	0.3	0.3	0.4
HC	0.4	0.5	0.4	0.4	0.5
SO_x	5.1	5.2	4.8	4.6	4.6
NO_x	0.8	1.0	0.8	0.8	0.9
Particulates	12.6	12.7	11.9	11.8	11.6

[a] Air emissions for CVs are based on CV fuel requirements to operate the same VMT as EHVs for each scenario and year.

[b] See Tables D.46-D.56 for actual weights of pollutants.

As noted above, the SO_x increase associated with the EHV scenarios will be substantial, i.e., over eight times greater in each scenario in both 1990 and 2000. To put this increase in perspective, SO_x generation associated with EHVs in 2000 represents 0.3-2.6% (depending on the scenario) of 1975 national SO_x emissions (see Table 3.19). In comparison, the SO_x emissions associated with a similar number of CVs would be 0.03-0.3% of 1975 national SO_x emissions. If lower projections of the availability of nuclear power for EHV charging are used, these national SO_x results would increase. Application of 1979 NSPS for power plants to power plants used in generating electricity for EHVs would decrease the SO_x results presented.

3.5.1.2 Discussion

It is very difficult to assess the significance of these results, partly because of the sparseness of definitive research concerning the effects of the pollutants and partly because of the tradeoffs that are implicit in any assessment of significance. What follows is a brief description of the significance of the results for each of the pollutants as well as several overall conclusions. Health effects are presented in more detail in Sec. 3.7 and App. E.

Across the nation, there is a trend of increasing SO_x and NO_x emissions that is largely the result of current national energy policy. Power plants

Table 3.16. Ratio of EHV to CV Vehicle Operation Air Emissions by Pollutant[a,b]

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
1990					
CO	c	c	c	c	c
CO_2	1.1	1.2	1.1	1.3	1.2
HC	c	0.1	c	c	c
SO_x	15.8	15.4	11.0	10.5	10.5
NO_x	0.6	0.8	0.6	0.7	0.7
Particulates	0.4	0.5	0.4	0.4	0.5
2000					
CO	c	0.1	c	c	0.1
CO_2	0.9	1.1	0.9	0.9	1.0
HC	c	0.1	c	c	c
SO_x	13.2	11.4	12.0	10.5	10.6
NO_x	0.8	0.7	0.5	0.5	0.6
Particulates	0.3	0.5	0.3	0.3	0.5

[a] Air emissions for CVs are based on the same CV VMT as EHV VMT for each scenario and year.

[b] See Tables D.17 and D.18 for actual pollutant burdens.

[c] Less than 0.1.

fueled with natural gas are going to be fueled with oil, and power plants burning oil are going to shift to coal. Even though oil- and coal-fired plants coming on line after June, 1979, will pollute less than existing plants, increased use of oil and coal will still result in more SO_x and NO_x emissions. From 1975 to 2000, SO_x emissions will increase for the nation as a whole by 12% and NO_x emissions by 61%.[18] Current high levels of SO_x and NO_x will continue in the northeast and north central areas of the country through the year 2000, and there will be some increase in SO_x and NO_x emissions in the West and East.

Research results with regard to SO_x are mixed. Some of the literature indicates that pure SO_x in large concentrations may not affect an individual's health.[19] However, other research shows that high ambient SO_x can be associated with increased mortality and morbidity.[20] Neither of the above conclusions negates the finding that SO_x in combination with other elements in the atmosphere may affect human health. Finally, SO_x combines

Table 3.17. Total Air Emissions from Vehicle Production, Fuels Production and Transport, and Vehicle Operation by EHV Scenario and for Equivalent CVs, 1990 (thousands of tons)[a]

	EHV Scenario				
Pollutant	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
CO	0.2	2.6	0.4	1.1	10.5
HC	0.5	1.4	1.2	3.0	3.8
SO_x	5.4	9.2	11.5	30.2	30.3
NO_x	3.2	6.1	6.8	18.0	19.0
Particulates	1.2	2.1	2.6	6.9	7.0

	Equivalent CVs				
Pollutant	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
CO	51.4	75.2	108.5	247.8	244.1
HC	5.0	7.2	10.4	24.8	24.5
SO_x	0.5	0.8	1.3	3.5	3.5
NO_x	4.9	7.3	10.7	26.3	25.8
Particulates	1.3	2.0	3.0	7.6	7.4

[a] Equivalent CVs indicates the same number of CVs produced as EHVs and the same CV VMT as EHV VMT for each scenario and year.

with precipitation to create acid rain. The Energy Security Act (P.L. 96-294) recently established a program and task force to study acid precipitation.

Most areas in the country are in attainment of the current NO_x national ambient standards. Correlation of health effects with exposure to NO_x is relatively inconclusive.

Of even greater concern in the atmosphere are the oxidants created by photochemical reactions of NO_x, HC, and sunlight. The current literature indicates that it is more beneficial to reduce HC than NO_x in trying to reduce the total level of oxidants in the atmosphere. That is, a 5% decrease in HC does more to decrease oxidant levels than a 5% decrease in NO_x. Polycyclic aromatic HC may be carcinogenic and are more dangerous when emitted at ground level than when emitted at higher elevations, because there is more potential for exposure to higher concentrations at ground level. When emitted from the power plant stack, these compounds are dispersed, resulting in lower concentrations at ground level.

Table 3.18. Total Air Emissions from Vehicle Production, Fuels Production and Transport, and Vehicle Operation by EHV Scenario and for Equivalent CVs, 2000 (thousands of tons)[a]

	EHV Scenario				
Pollutant	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
CO	2.7	138.6	8.5	28.6	600.7
HC	6.5	25.3	19.8	58.2	93.8
SO_x	74.9	149.3	225.8	744.4	728.7
NO_x	37.0	89.3	113.6	377.4	411.3
Particulates	16.8	34.4	49.5	155.2	172.6

	Equivalent CVs				
Pollutant	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
CO	601.8	1048.0	1825.0	5833.0	5387.0
HC	62.4	109.8	190.7	607.5	568.3
SO_x	7.3	15.9	24.3	87.4	87.0
NO_x	47.7	128.4	226.8	723.3	666.1
Particulates	21.4	38.3	67.3	213.1	198.9

[a] Equivalent CVs indicates the same number of CVs produced as EHVs and the same CV VMT as EHV VMT for each scenario and year.

Coarser particulates are not as dangerous to human health as the finer particulates, since the former can be filtered out to a greater degree by lungs, nostrils, etc.[21] Conventional automobiles emit higher percentages of fine particulates than power plants. Although power plants emit a whole spectrum of particulates, a large proportion (90.0-99.9%) is captured by control equipment.[22,23]

Carbon monoxide is a problem mainly in very localized areas and can be fatal at high concentrations. Over long periods of time at levels of CO approaching the one-hour standard (35 parts per million [ppm]), human motor skills and perceptions can be altered and cardiovascular problems can be aggravated. Even without market penetration of EHVs, the CO burden is expected to decrease because of improved CV emisison controls.

Carbon dioxide is treated in this EA as a benigh residual of energy-producing processes. However, its concentration in the air is increasing and, according to global climatic simulation models, an increase in mean global temperature could result. Carbon dioxide is being studied further under provisions of the Energy Security Act.

Table 3.19. Total EHV and CV Sulfur Oxide Emissions in 2000 as a Percentage of 1975 National Sulfur Oxide Emissions[a,b]

Scenario	EHV (%)	CV (%)
LOW I	0.26	0.03
LOW II	0.52	0.06
MEDIUM	0.79	0.09
HIGH I	2.61	0.31
HIGH II	2.56	0.31

[a] Same number of CVs and EHVs produced and same VMT.

[b] 1975 national SO_x emissions were 57 billion lb.

3.5.1.3 Conclusions

Assuming the distribution of fuel types for electricity generation that has been used in this assessment, the following conclusions can be drawn:

1. As far as HC and particulates are concerned, market penetration of EHVs is advantageous. Polycyclic aromatic HC emitted from power plant stacks may be less dangerous than those emitted at ground level from CVs. In terms of ozone, the EHVs may be more advantageous because lower levels of HC are emitted. Finally, power plants with particulate control technology may emit fewer of the fine particulates that are more dangerous to human health.

2. Carbon monoxide emissions will continue to decrease, irrespective of EHV market penetration. Many areas expect to be in compliance with CO air quality standards in the 1980s. Nevertheless, many rapidly developing areas of the country have set more stringent emission reduction goals for mobile sources than would otherwise be required to attain national air pollutant standards by the end of 1987. These stringent goals have been set to permit continued industrial, commercial, and population growth. In such areas, EHVs should contribute to achieving these goals.

3. Nitrogen oxide emissions from vehicles will decrease with EHV market penetration. Although most areas of the country are in attainment of the current NO_x standard, there is an indication that total NO_x emissions will increase over the next 20 yr. The rate of increase will be reduced by EHV market penetration.

4. While the effects of increased SO_x emissions are not certain, one can conclude that SO_x in combination with other elements in the atmosphere can be dangerous and that national SO_x emissions are increasing. Therefore, increases in SO_x emissions as a result of EHV market penetration may be significant, even though the increase may be a small percentage of the total emissions in the nation or a federal region. At the urbanized area level, increases over the BASE scenario for a specific area also may be significant. In some urbanized areas, such increases may occur within the context of a decline in total SO_x levels, depending on the stringency of controls imposed on power plants and other SO_x sources in specific air quality control regions (AQCRs).

5. While CO_2 emissions may decrease in the EV-only scenarios, the introduction of HVs will lead to a slight increase in CO_2 emissions. However, the increase is not significant when compared to total worldwide CO_2 loading attributable to fossil fuel combustion.

6. The urbanized areas that would benefit most from EHV and especially EV market penetration are those projected to have a high percentage of electricity generated by nuclear power plants. This is because the emissions from the CVs that would have been used are being replaced by air pollutant emissions from the nuclear power plants that provide electricity for the EHVs.

In reviewing the above conclusions, several items must be kept in mind. First, the potential for ozone generation by EHV motors has not been quantified. However, this appears to be a near-term concern, because AC motors that generate little or no ozone are expected to dominate the EHV market about 1990. Second, emissions from EHV accessories (air conditioners and heaters) have not been included. As stated in Sec. B.2.1.3, the technologies that would be used to operate these accessories are not specified in this analysis. The emission factors used for CVs do not include an adjustment for full accessory load. Differences between EHVs and CVs in emissions associated with full accessory load operation will exist and will depend on the technologies actually used by the EHVs. This item requires further study. Third, estimates of air quality impact at the microscale from battery charging and accidents have not been included in this analysis. Since sealed batteries have been assumed, emissions from battery charging should not occur. However, in the event that sealed batteries are not used, particularly in the early years, study of potential emissions from battery charging should continue. Additional study is also required of the impacts from accidents.

3.5.2 Water Quality

Water pollutant loadings from vehicle manufacture, vehicle operation, and fuels production for operation will increase with EHV market penetration. Table 3.20 shows that EHVs and CVs generate similar loads of total dissolved

Table 3.20. Total Water Pollutant Loadings from Vehicle Production, Fuels Production and Transport, and Vehicle Operation by EHV Scenario and for Equivalent CVs, 2000 (tons)[a]

Pollutant	EHV Scenario					Equivalent CVs				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
TDS	111,354	251,376	343,354	1,154,000	1,245,000	122,620	238,890	387,455	1,235,000	1,227,000
TSS[b]	1,022	2,004	31,346	10,709	10,643	114	219	357	1,069	1,115
BOD_5[c]	530	1,037	1,726	5,383	5,495	348	568	1,093	3,110	2,917
COD[c]	11,214	22,076	34,167	113,468	109,830	273	529	863	2,751	2,728
Sulfate/sulfite/ sulfide	14,901	28,988	45,222	148,835	144,033	d	d	d	2	2
Nitrate	312	599	903	3,047	2,940	-[e]	-	-	-	-
Aluminum	168	327	508	1,675	1,621	-	-	-	-	-
Iron[f]	1,037	2,029	3,147	10,311	9,995	-	-	-	-	-
Lead[g]	1	1	1	3	3	d	d	1	2	2
Zinc	29	58	91	310	300	d	d	1	2	2
Nickel[f]	420	805	1,260	4,237	4,078	-	-	-	-	-
Manganese[f,g]	27	53	82	268	260	-	-	-	-	-
Chromium/chromate	8	16	24	74	72	d	1	1	4	4
Chlorine/chloride	402	785	1,214	3,912	3,795	-	-	-	-	-
Fluoride[h]	127	244	377	1,157	1,123	-	-	-	-	-
Ammonia	98	193	295	941	924	11	21	34	110	109
Oil and grease	22	40	33	95	90	6	11	13	54	57
Organics	251	610	772	2,475	2,887	451	875	1,425	4,546	4,510
Phosphorus/ phosphates	174	342	531	1,684	1,634	-	-	-	-	-
Boron	988	1,917	2,941	9,007	8,762	-	-	-	-	-

[a] Equivalent CVs indicates the same number of CVs produced as EHVs and the same CV VMT as EHV VMT for each scenario and year.

[b] Total suspended solids.

[c] Biological oxygen demand. Some overlap exists between BOD and chemical oxygen demand (COD).

[d] A measurable amount generated but less than one ton.

[e] A hyphen indicates no appreciable amount generated.

[f] Totals for these substances may be underestimated in that some may have been grouped in previous work with heavy metals.

[g] Totals for these substances may be underestimated in that some have been grouped in previous work with nonferrous metals.

[h] Totals for this substance may be underestimated in that it may have been grouped in previous work with acids.

solids (TDS) in all scenarios. Otherwise, except for organics, the EHV scenarios generate higher pollutant loadings. (All loadings are calculated assuming application of best available technology [BAT] regulations to be effective in 1983 and thus may represent a worst case for 2000.)

While EHVs generate greater loadings, water quality impacts resulting from EHVs are expected to be a very small fraction of national water pollutant generation. The largest ratio of an EHV pollutant to national background levels (for those pollutants that could be measured) is less than 0.3%. In many cases, the percentage is much lower. However, high incremental pollutant levels can be expected in specific geographical areas, especially in the vicinity of materials and fuels extraction, processing, and heavy manufacturing.

The analysis of water pollutants generated in each phase of production and operation is presented in Sec. D.3. Water pollutants increase in each phase as a result of EHV market penetration.

3.5.3 Solid Waste

The solid waste impacts associated with vehicle production, vehicle operation, fuels production, and vehicle disposal were analyzed for the five EHV scenarios. The full analysis is presented in Sec. D.4 and assumes that the potential for environmental pollution due to solid wastes would be minimal by the year 2000 because of RCRA, which requires strict standards for hazardous waste disposal and demands cradle-to-grave control of these wastes through manifests and reporting. In other words, all hazardous wastes will be monitored during the production phase, during transport, and at the point of disposal. Therefore, the primary impact of solid wastes will be the land area disturbed and consumed by their disposal.

Table 3.21 summarizes the results of the analysis. It gives the total land areas required for solid waste disposal for EHVs and CVs by scenario in the year 2000. It does not, however, represent all of the solid wastes from the vehicles. For instance, the solid wastes generated by body parts and disposal of body hulks are not calculated, since it is assumed that they are virtually the same for EHVs and for CVs. Also, since waste oil is not usually disposed of in landfills, the totals do not include the reduction in waste oil realized by EHVs.

The following conclusions can be drawn from Table 3.21 and the analysis in Sec. D.4.

1. For solid wastes generated during vehicle production, the greatest impact in terms of land area required for solid waste disposal (i.e., 7944 additional acres over those that would have been required to produce an equivalent number of CVs in 2000) occurs in HIGH I. The next highest difference is 832 acres and occurs in the MEDIUM scenario. The remaining scenarios show considerably less additional acreage. Most of the extra acreage required is due to tailings from the milling of lead and, in the case of the MEDIUM and HIGH I scenarios, to the large amounts of waste rock generated by lithium extraction.

Table 3.21. Land Required for Solid Waste Disposal from Vehicle Production, Vehicle Operation, and Fuels Production by EHV Scenario and for Equivalent CVs, 2000 (acres)[a,b]

Source		Scenario				
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
Vehicle production						
Waste rock	- EHV	39.4	74.0	685.3	7,353.7	63.9
	- CV	2.1	3.9	6.6	18.6	19.8
Tailings	- EHV	195.1	367.2	142.5	330.5	302.9
	- CV	10.1	19.0	31.6	91.9	97.9
Slag	- EHV	1.2	1.8	26.9	248.4	18.7
	- CV	c	0.1	0.2	0.6	0.6
Lead processing	- EHV	6.8	12.7	4.1	8.2	7.3
	- CV	-[d]	-	-	-	-
Plastics	- EHV	0.4	0.7	1.1	3.2	3.5
	- CV	0.2	0.5	0.74	2.2	2.4
KOH	- EHV	c	c	1.0	2.5	3.0
	- CV	-	-	-	-	-
KCl	- EHV	-	-	10.0	110.7	-
	- CV	-	-	-	-	-
Total	- EHV	243.0[e]	456.6	871.8	8,057.2	399.3
	- CV	12.5	23.4	39.1	113.2	120.7
Vehicle operation						
Engine parts	- EHV	-	c	-	-	c
	- CV	c	c	b	0.2	0.2
Power plant	- EHV	27.7	54.4	110.5	280.4	270.7
	- CV	-	-	-	-	-
Fuels production	- EHV	818.0	1,587.0	2,444.6	7,567.7	7,343.1
	- CV	0.1	0.2	0.3	1.0	1.0
Total EHV acreage		1,088.7	2,097.9	3,426.0	15,905.2	8,013.3
Total CV acreage		12.6	23.6	39.5	114.5	121.9
Difference		1,076.1	2,074.3	3,386.5	15,790.8	7,891.3
EHV to CV ratio		86.3	88.8	86.8	138.9	65.7

[a] Equivalent CVs indicates the same number of CVs produced as EHVs and the same CV VMT as EHV VMT for each scenario and year.

[b] Acres are to a depth of six feet except for power plant residues, which are to a depth of 42 ft.

[c] Less than 0.1.

[d] A hyphen indicates no appreciable amount generated.

[e] Columns do not always sum because of rounding.

2. During vehicle operation, the volume of solid wastes generated by EHVs (and expressed as the acreage required for disposal) will be much greater than that generated by operating an equivalent number of CVs. This is because power plant residues have a significantly greater volume than the solid wastes generated by replacing CV engine parts. However, EHV market penetration will mean decreases in the amount of waste oil.

3. If EHVs achieve market success, substantial increases in land for waste disposal from fuels production and transport will be required. Most of this increase can be attributed to the large amounts of overburden removed during uranium extraction and, to a lesser extent, to residues generated by coal beneficiation. As an example, over 7000 additional acres are required in the HIGH scenarios for disposal of solid wastes from fuels production.

4. The volume of solid wastes generated by vehicle disposal remains about the same among the five scenarios. In the MEDIUM and HIGH scenarios, there is a slight reduction in waste oil.

5. In all five scenarios, the sum of land areas required by EHVs for solid waste disposal in vehicle production, vehicle operation, and fuels production is much higher than for an equivalent number of CVs. The HIGH I scenario produces the greatest increase in solid wastes; nearly 16,000 additional acres of land are required for disposal. When this figure is compared to national municipal waste disposal requirements, the result appears to be quite significant. However, over 80% of the HIGH I scenario solid wastes consists of waste rock and overburden which, if properly reclaimed, (i.e., back filled) could produce minimal environmental hazards. Further, when the total potential acreage requirements for disposal of mining, industrial, utility, municipal, and agricultural solid wastes are considered, the increases generated by the HIGH I scenario and certainly by the other scenarios are probably insignificant.

6. While the volume of solid waste generated under the EHV scenarios is probably small relative to national solid waste volumes, the EHV volumes can produce substantial impact on communities and ecosystems, especially if the solid waste is concentrated in a few specific regions and if the wastes are improperly handled.

3.5.4 Noise

Current EVs are considerably quieter than CVs, although future improvements in CV noise levels in response to regulation should narrow the difference. (Drive-by and stationary transportation noise level standards have been promulgated by EPA.) EVs do not have an engine, radiator fan, air intake, or exhaust, which are the four major sources of CV noise. EV autos have been measured at 10 dBA* less drive-by noise during acceleration than similarly sized CVs or, in other words, half as loud.[24] Some current EVs do emit a penetrating whine, which results from chopper control of large electric currents. Utilization of power transistors, which are expected to be included in all EVs by 2000, will eliminate this whine. Much of the noise that EVs emit is tire noise, which is virtually equal to the tire noise of corresponding CVs. If tire noise regulations were to be in force, both types of vehicles would be controlled similarly.

Although based on very limited data, past research does provide a convenient capsule of existing and potential noise levels of current and future CV and EV autos (see Table 3.22).[24] In spite of potential improvements to CVs, Table 3.22 shows they will still be noisier than EVs.

The estimated composite vehicle noise levels are applied to the HIGH I scenario to provide a rough estimate of the greater potential of EVs to reduce urban traffic noise. Although the noise levels in Table 3.22 are for autos, they are assumed to be appropriate for light trucks and small buses. The noise levels are not appropriate for large buses, but these buses represent a very small percentage of the total vehicles and VMT in the five scenarios.

By applying the composite dBA of a typical CV to total VMT by CVs in the HIGH I scenario and the composite dBA of a typical EV to total VMT by EVs, a composite dBA for an average auto, light truck, or small bus for the HIGH I scenario in 2000 can be determined. Table 3.23 shows that EVs will make a beneficial but quite small (less than 1 dBA) difference in overall noise levels, even at the 14% penetration level of HIGH I in 2000. A three-dBA increase or decrease in noise is required before there is a noticeable change to the human ear under typical outdoor (nonlaboratory) conditions.

The noise reduction impact of EVs may be greater in some central business districts (CBDs) because of the significant penetration of EVs in the light truck market in the HIGH I scenario (13 million of 43 million light trucks). If EV light trucks are used in significant numbers for delivery in CBDs and if they constitute a significant proportion of the vehicles on the road at any given time, the noise reduction from an all-CV light delivery truck fleet would be somewhat larger than shown in Table 3.23. Similarly, significant noise reductions could occur in mall areas where buses are the predominant transportation mode and where EV buses would replace large diesel CV buses.

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*dB is the abbreviation for decibel, a measure of noise level. Measurements in terms of human hearing response are described as A-weighted and are expressed in dBA.

Table 3.22. Noise Levels of Current and Future CV and EV Autos (dBA)

Vehicle	Urban Cruise[a]	Urban Acceleration[b]	Composite[c]
Conventional car			
Current	60	72	65
Future	58	68	62
Electric car	58	61	59

[a] 27 mph.

[b] Not maximum acceleration but typical of urban requirements.

[c] Median pass-by noise at 50 ft (based on 17% acceleration and 83% cruise).

Source: Ref. 24.

Table 3.23. Impacts of EVs on Average Light Truck, Auto, and Small Bus Noise Levels, HIGH I, 2000

Scenario	No Changes in Noise Level from Existing CVs	Three-dBA Reduction in Noise Level from Existing CVs
HIGH I		
CV VMT (trillion)	1.96	1.96
CV dBA	65	62
EV VMT	0.30	0.30
EV dBA (trillion)	59	59
Composite dBA[a]	64.5	61.7
BASE (all CVs)		
CV VMT (trillion)	2.26	2.26
CV dBA	65	62
CV dBA (BASE) minus Composite (HIGH I)	0.5	0.3

[a] The composite dBA was derived using energy equivalents of sound pressure.

Even less noise data exist for HVs than for EVs. The noise levels of HVs are higher than EVs, because HVs will periodically emit engine, exhaust, air intake, and fan noise, as well as noise from the motor and controller during acceleration. Therefore, noise reduction through HV usage will not be as great as that achieved through EVs.

The use of any vehicle that is quieter than another will help in reducing urban traffic noise. However, EHVs are being substituted for vehicles that are relatively quiet compared to the noisier medium and heavy trucks, buses, and motorcycles. Urban traffic noise is presently dominated by these latter vehicles, and improvements in them will result in significant traffic noise reductions. Therefore, the impact of EHVs on urban traffic noise, even under the HIGH scenarios, will be small through the year 2000. This analysis is based on very limited data; for the estimates to be verified or revised, additional empirical data are required. The current EHV demonstration should provide more information.

The public safety implications associated with relatively quiet EV operation are discussed in Sec. 3.7.2.2.

3.5.5 Land Use

As shown in Sec. 3.5.3, EHV introduction will result in an increase in land area requirements for solid waste disposal associated with vehicle production and operation. Depending on the scenario, EHVs will require 66-139 times as much acreage as CVs.

Although other land requirements that might be generated by the EHV scenarios have not been quantified in this EA, they can be characterized. For example, if additional power plant capacity were needed, additional land for power plants would be required. However, the utility impact analysis (see Sec. 3.9.1) estimates that only four of the 158 urbanized areas projected to have EHV penetration might require additional capacity, even in the HIGH scenarios. Further, it is possible that the EHV scenarios could contribute to the need for additional facilities for fuels production that would entail the use of additional land. Nonetheless, the portion of such land requirements attributable to EHVs would be very small relative to overall national requirements for fuels production facilities.

Similarly, additional facilities and land may be required for mining and materials refining activities related to vehicle and, in particular, battery production. For some industries (e.g., zinc and lithium), the expansion requirements under some of the scenarios beyond what is expected in the BASE scenario are not small. What this degree of expansion would mean in terms of actual acreage is difficult to evaluate.

EHV impacts on urban structure and transportation infrastructure are minimal, and additional land should not be required (see Secs. 3.8 and 3.9). For example, EHV market penetration is defined in the scenarios as a one-for-one substitution for CVs; therefore, additional land for roadways and parking facilities beyond that required for the BASE scenario should not be necessary. However, there may be some additional land requirements for new vehicle and battery production facilities.

Overall, the introduction of EHVs may lead to a large increase in land requirements compared to what would be required for the CVs being replaced. The increment should be small relative to national requirements. However, national land requirements for all waste disposal from all sources and for all land used in mining, manufacturing, and electricity generation can not be readily quantified. Depending on the concentration of activities, additional land use needs at the local level could be substantial.

3.5.6 Aesthetic Degradation

Manufacture, operation, and disposal of EHVs are not expected to cause significant aesthetic degradation on a national scale. Although some additional land will be taken out of current use and disrupted, the acreage should be small. Whether the disruption is considered aesthetically degrading will be a site-specific issue. Reasonable controls can be used to alleviate some of the adverse impact. Additional highways or parking facilities, which are usually considered less than pleasing to the eye, will not be required beyond those projected for the BASE scenario.

3.6 OCCUPATIONAL HEALTH AND SAFETY IMPACTS

Development of an EHV industry in the United States will result in shifts in the number and severity of occupationally related health injuries and illnesses. These shifts will reflect changes in the number of workers employed by different sectors of the economy. The injuries and illnesses themselves will be related to EHV technologies (e.g., exposure to toxic substances and to trauma-causing situations). Section E.1 presents the methodology and the detailed analysis.

The number of total recordable cases (TRC) of work-related injuries, conditions, or disorders, and person days lost (PDL) due to occupational illness and injury are projected for the BASE scenario and for each EHV scenario. These projections are made only for the 22 economic sectors listed in Table 3.24. These are the industries that will be impacted most in terms of employment by EHV development. (See App. G for employment projections of a number of these industries.) Looking at the effects of EHV market penetration on the 22 economic sectors both individually and collectively provides insight into the occupational health and safety impacts of EHV development.

The changes in TRC and PDL for all 22 sectors by scenario and assessment year are listed in Tables 3.25 and 3.26. The trend exhibited by TRC is that, for the BASE and for each EHV scenario, the number of impacts increases by approximately 20% from 1975 to 1985, increases again by less than 1% from 1985 to 1990, and decreases 3-5% from 1990 to 2000. The PDL projections follow roughly the same trend, although a slight decrease occurs from 1985 to 1990 under each scenario. In 1985 and 1990, the EHV scenarios show very slight decreases in the number of TRC and PDL relative to the BASE scenario, but by 2000 all the EHV scenarios have greater TRC and PDL than the BASE. The greatest increase in 2000 in the number of TRC and PDL between the EHV and the BASE scenarios occurs between BASE and HIGH I (15,100 TRC; 114,000 PDL). The variance, however, represents only a 1.4% increase in TRC and a 1.3% change in PDL.

Table 3.24. Economic Sectors Assessed for Occupational Health and Safety Impacts

Mining	Metal working machinery
Petroleum and gas production	Transformers
Petroleum refining	Electric motors
Tires and tube production	Electric wiring
Rubber products except tires	Batteries
Plastic products	Railroad equipment
Iron and steel	Mechanical measuring devices
Nonferrous metals	Railroads
Structural metal products	Trucking
Engines and turbines	Other transport
Mine construction and material handling	Electric utilities

An indication of the severity of the EHV-induced perturbations is provided by examining the relative changes between TRC and PDL. An increase in the number of PDL per case indicates a more severe impact on the economy. Table 3.27 provides a comparison between the number of PDL per case of accident or injury for each assessment year by scenario. Although a slight decrease in the ratio of PDL to TRC occurs with time, the variation in this ratio between scenarios is negligible. Thus, employment changes between high- and low-risk occupations as a result of EHV development do not cause significant changes in impact on the economy.

Table 3.25. Increases in Total Recordable Cases from 1975 to 1985, 1990, and 2000, by Scenario[a]

	Increase in Total Recordable Cases from 1975[b]		
Scenario	1985	1990	2000
BASE (all CVs)	177,400	184,700	131,600
LOW I	175,900	181,700	134,600
LOW II	177,400	181,300	137,800
MEDIUM	177,400	184,000	136,400
HIGH I	177,200	183,900	146,700
HIGH II	177,200	181,300	143,600

[a] For the 22 economic sectors from Table 3.24.

[b] 1975 TRC were 938,580.

Table 3.26. Increases in Person Days Lost from 1975 to 1985, 1990, and 2000, by Scenario[a]

Scenario	Increase in Person Days Lost from 1975[b]		
	1985	1990	2000
BASE (all CVs)	1,345,600	1,309,000	865,800
LOW I	1,333,200	1,285,400	889,700
LOW II	1,345,600	1,282,000	919,600
MEDIUM	1,345,600	1,303,400	903,300
HIGH I	1,344,600	1,302,800	980,200
HIGH II	1,344,500	1,283,400	963,200

[a] For the 22 economic sectors from Table 3.24.

[b] 1975 PDL were 7,987,700.

The effect of EHV development on the occupational health and safety impacts of several individual economic sectors is much greater than the effect on the entire economy. Table 3.28 lists the changes in TRC between the BASE and HIGH scenarios for the six most impacted sectors. Two of these (electric utilities and batteries) exhibit large percentage and total TRC increases by 2000 under both HIGH scenarios. The increases are less under HIGH II than HIGH I because greater HV development means less additional electricity and battery demand. Petroleum and gas production is the only sector for which the percentage and number of TRC declines significantly under the HIGH scenarios. Three other sectors (mining, nonferrous metals, and structural metal products) all show increases of more than 1000 TRC from the

Table 3.27. Number of Person Days Lost per Recordable Case for Each Assessment Year by Scenario[a,b]

Scenario	Year		
	1985	1990	2000
BASE (all CVs)	8.363	8.276	8.273
LOW I	8.364	8.278	8.272
LOW II	8.363	8.278	8.275
MEDIUM	8.365	8.276	8.271
HIGH I	8.364	8.276	8.263
HIGH II	8.364	8.278	8.271

[a] For the 22 economic sectors from Table 3.24.

[b] 1975 PDL per recordable case were 8.510.

Table 3.28. Changes in Total Recordable Cases between the BASE and HIGH Scenarios for the Six Most Impacted Sectors, 2000

	Total Recordable Cases			Change (%)	
Sector	BASE	HIGH I	HIGH II	BASE to HIGH I	BASE to HIGH II
Petroleum and gas production	8,910	7,830	8,010	-12.1	-10.1
Nonferrous metals	41,400	42,700	43,100	3.1	4.1
Structural metal products	105,260	106,590	106,270	1.2	0.9
Batteries	16,170	20,460	18,040	26.5	11.6
Electric utilities	42,640	46,480	45,920	9.0	7.6
Mining	34,500	35,700	35,700	3.4	3.4

BASE to both the HIGH I and HIGH II scenarios in 2000. None of the other 16 sectors shows an increase greater than 4% or 1000 cases. These six sectors account for approximately 24% of the TRC attributable to the 22 sectors analyzed. No major changes in TRC or percentage change in TRC from the BASE scenario are projected for any of the 22 sectors under the LOW I, LOW II, or MEDIUM scenarios. Results of TRC and PDL projections for all economic sectors for each scenario and assessment year are found in Table E.1.

Market penetration of EHVs involves development and modification of production processes to meet the material, structural, and component requirements of EHVs. As production techniques change, occupational hazards, such as the potential for physical trauma and exposure to toxic substances, will vary. In particular, development of new types of batteries (Ni/Fe, Ni/Zn, and Li/S) may increase worker exposure to toxic and carcinogenic materials during production. Large-scale recycling or disposal of spent fuel cells may increase the risk of exposure to burns, explosions, and toxic materials resulting from structural failure or electrolyte spillage. Although it appears that protective equipment and design controls can minimize health risks related to battery production and disposal of EHV-related products, potentially significant risks are likely.

Quantitative estimates of the health and safety impacts of these EHV-related changes are not possible at this time. However, the potential impacts can be anticipated and are listed in Table 3.29. The battery sector is where most of the changes are likely to occur. Further study is necessary to analyze the types of accidents and toxic exposures resulting from new EHV technologies and to determine which preventative measures can be used to lower occupational health risks.

Table 3.29 Major Unquantifiable EHV Occupational Health and Safety Issues

Process	Issue
Battery use	Exposure to toxic and carcinogenic elements and compounds used in electrodes (e.g., Pb, SO_x, arsenic (As, Ni, Zn, and electrolytes).
Battery production	Exposure to toxic gases released during fires or industrial accidents (e.g., nickel carbonyl and SO_x).
Battery disposal/recycling	Exposure to burns from electrolytes, toxic gases, and elements (e.g., Ni, Zn, Pb, and As).
Vehicle structure production	Exposure to toxic vapors from petrochemical processes (e.g., methacrylic vapors).

3.7 PUBLIC HEALTH AND SAFETY IMPACTS

3.7.1 Public Health Concerns

The details of the public health impacts of the EHV scenarios are presented in Sec. E.2. The relative exposure risks of air emissions from EHV production, operation, and fuels production are projected on a national level. These risks are compared to the risks associated with similar numbers of CVs and to 1975 levels of emissions from selected U.S. sources. The potential for public health impact from air emissions during EHV operation is also examined by scenario on an urbanized-area level and compared to the potential for impact from CV operation emissions and to projected emissions from all other emission sources. The potential for public health risk from water effluents and solid wastes from vehicle production, vehicle operation, and fuels production is examined on a qualitative basis.

On a national level, the risk of exposure to NO_x, HC, CO, and particulates decreases with EHV market penetration. Sulfur oxides are the only one of the five principal regulated pollutants for which risks from EHVs exceed the risks from CVs. This can be attributed to the use of additional fossil fuels for electricity generation. However, the greatest increases in exposure to SO_x in the scenarios represent no more than 3% of the risk of exposure to 1975 national SO_x emission levels. Risk of exposure to heavy metals, lead sulfide (PbS), gas fluorides, and copper sulfide (CuS) also is greater with EHVs.

At the urbanized-area level, the potential for public health impact of air emissions from EHV operation and electricity generation is a function primarily of the type of fuel used for electricity generation. Urbanized areas like Dallas, Cincinnati, and Buffalo, which rely on oil and coal for electricity generation for EHVs, experience greater potential for impact from power plant emissions than urbanized areas like Milwaukee and Little Rock, which rely on nuclear power.

For all 10 urbanized areas assessed for potential public health impact, operation of EHVs reduces the potential for adverse health impacts from NO_x, HC, particulates, and CO from the potential that is generated by operating an equivalent number of CVs the same VMT. For those urbanized areas that rely to a major degree on fossil fuels to generate electricity, EHV operation increases the potential for adverse health impacts from SO_x over the BASE scenario. These increases generally are small but are potentially significant in some urbanized areas under some scenarios. However, as implied from Sec. 3.5.1.3, the increases in potential for public health impact from SO_x due to EHVs in some urbanized areas may occur in the context of a decline in potential for public health impact from SO_x from all sources. Where electricity is generated almost entirely by nuclear power plants, that urbanized area's potential for adverse health impacts from SO_x is reduced by operation of EHVs.

The HIGH I scenario in 2000 results in the greatest changes in any urbanized area's overall potential for adverse impacts from pollutants from all sources (power plants, vehicles, etc.) from EHV operation. Of the 10 urbanized areas examined, the maximum increase over the BASE scenario (6.5%) in potential for impact from SO_x is in Buffalo. The greatest reductions in potential for impact are in San Diego (12.4% from NO_x; 5.0% from HC; 7.3% from particulates; and 20.8% from CO). In the MEDIUM and LOW scenarios the changes in potential are substantially smaller.

The solid waste and water quality impacts of the EHV scenarios do not appear to be a major public health concern on a national level but may be of concern locally. Promulgation of proposed disposal regulations on both the local and federal levels may have major effects on the solid waste and water quality impacts.

On a national scale, the potential health impacts of respirable particulate emissions from EHV fossil fuel combustion need to be addressed. Also requiring study is the potential for exposure to toxic substances from advanced battery manufacture, use, and disposal, an area that is not covered in this analysis. (Some of these substances are listed as possible additional ingredients in EHV batteries in Table B.15.) Although the adverse health impacts of EHV-related mining and manufacturing appear to be minimal on a national level, the site-specific effects of such emissions are of potential significance and are not examined in this EA. A similar statement can be made regarding EHV operation and emissions of trace elements from electric generating stations. Finally, studies of public health impacts resulting from accidents and battery charging (e.g., the emission of arsine and stibine during Pb/acid battery charging) should be continued.

3.7.2 Public Safety Concerns

Numerous reports identify and discuss the public safety concerns of EHVs: (1) nonoperating safety, (2) crash avoidance, (3) crash energy management, and (4) other operating safety concerns.[1,25-30] Obviously, some overlap exists between these four areas. Safety concerns that are the same for EHVs and CVs, such as hazards associated with tire changing and cargo loading and unloading, are not treated in this assessment.

The U.S. Dept. of Energy has issued performance standards for the demonstration program of the EHV Act (P.L. 94-413). Additional safety standards must be promulgated as directed by the Act as commercialization progresses and as the understanding of each concern improves. All relevant standards set for the P.L. 94-413 demonstration are assumed to apply to EHVs commercialized in 1985 and beyond. All future EHVs are assumed to meet Federal Motor Vehicle Safety Standards (FMVSS).

3.7.2.1 Nonoperating Safety

Nonoperating safety pertains to hazards presented by vehicle features that are touched and/or manipulated during vehicle-related activities other than normal over-the-road operation.

Electric Shock

The current EHV propulsion battery voltage is approximately 100 V dc; therefore, a potential lethal hazard exists for anyone (including drivers and maintenance personnel) who might work with the battery pack. Similarly, on-board chargers present potential shock hazards. However, both of these shock hazards are being minimized through use of electrical interlocks and fuses as stipulated in the P.L. 94-413 demonstration. Interlocks incorporating known technology disconnect the charging power if the battery compartment is opened and disconnect the batteries in a collision.[25]

While electric shock accidents are possible, they are not likely. Should experience demonstrate that additional standards are needed, appropriate standards could be developed.

Fire

There is also danger of fire from a short circuit between the propulsion batteries and other vehicle components as a result of a collision. This danger is mitigated by the current P.L. 94-413 standard.[31] Further standards could be developed if the P.L. 94-413 demonstration indicates a need.

Burns

Protection against burns needs to be provided for persons who might handle the Li/S battery pack. This battery is a high-temperature battery (750-840°F), but the insulation jacket that has been developed for the battery should provide adequate protection. When design standards are established for burn protection, the Li/S EV is expected to meet those standards.

Hydrogen Gas Explosion

Hydrogen gas is generated during Pb/acid, Ni/Fe, and Ni/Zn battery charging. The potential for an explosion is reduced by requiring positive ventilation to preclude buildup of concentrated pockets of hydrogen and by installing flame arrestors to limit propagation if an explosion were to occur.[25,32] Sealed batteries and recombination methods are projected to be available by 1985 and will significantly reduce this problem. Hydrogen also is generated during charging from regenerative braking. However, ram air created by the forward motion of the vehicle is considered adequate to ventilate the battery tunnel.

3.7.2.2 Crash Avoidance

Crash avoidance addresses those vehicle performance characteristics or features that enhance the probability that crash situations can be avoided altogether or neutralized by evasive maneuvers. U.S. Dept. of Energy demonstration performance standards require that EHVs meet FMVSS for crash avoidance.[25,33]

Driver Error

Without driver training for EHV operation and reaction to mechanical failures, driver errors are a concern. HVs will require very clear instructions because of the two propulsion systems. EV power characteristics vary with depth of discharge, and drivers must understand the power variations between full charge and 80% discharge.

Since drivers in commercial fleets should be able to learn from other drivers in the fleet, they may have an easier time than members of the general public acclimating themselves to EHVs. Clear instructions concerning operation, charge, and maintenance, and vehicle control and display designs should ameliorate this concern.

Handling and Braking Performance

Battery mass and weight can adversely affect handling and braking performance. Simulations have indicated that current EHV designs perform well within associated performance envelopes for handling and braking established by the DOT National Highway Traffic Safety Administration (NHTSA) for an advanced vehicle safety program.[25] The handling and braking performance of future EHVs must be consistent with FMVSS.

With high levels of regenerative braking, glazing of brake linings and high rates of wear in transmissions could be problems.[26] Since future EHVs will use regenerative braking, further evaluation will be necessary. If standards are needed, future EHVs are expected to meet them.

Powertrain Safety Performance

Powertrain safety performance pertains to adequate operator control and capacity. The safety implications of adequate control generally are the same for EVHs and CVs since, in both cases, the vehicle must respond completely and exclusively to driver inputs. The possibility that environmental electrical noise, electromagnetic interference, and strong radio frequency signals could initiate sudden or uncommanded vehicle responses in EHVs is under study.[25] As commercialization progresses, design adjustments will be made to preclude EHVs from operating in an unresponsive manner.

Capacity refers to the vehicle speed and acceleration provided by the powertrain. The safety implications of adequate speed and acceleration relate to the ability to execute passing, merging, and evasive maneuvers safely. Existing EVs have demonstrated inadequate speed, acceleration, and hill-climbing capabilities compared to their CV counterparts. In addition, performance in all these areas gradually degrades as batteries discharge. The P.L. 94-413 demonstration performance standards cover acceleration, gradeability,* and speed.[34] However, to meet these standards, the EV power-to-weight ratio may be below 0.01 hp/lb.[35] CVs currently have ratios of 0.03 hp/lb with many models at 0.05 hp/lb.

Future EVs will have maximum speed, acceleration, and hill-climbing capabilities comparable to those of future CVs. Maximum speed will be maintained for an adequate time period (i.e., to 80% discharge). Thus, EVs are expected to meet or exceed the powertrain performance standards necessary to overcome any associated safety problems. Because HVs utilize the heat engine for high acceleration or hill climbing, their powertrain performance should be comparable to that of CVs.

EHV Noise

In general, EVs have lower noise levels than CVs, particularly during acceleration (see Sec. 3.5.4). Concern has been expressed that EVs may offer little indication of their approach to pedestrians who depend on vehicle noise as a warning (e.g., the blind). This would appear to be particularly true at low speeds and during acceleration. Additional noise data, including data for HVs, are required to determine the need for minimum noise standards. If a minimum noise standard is instituted, future EHVs are expected to meet it.

3.7.2.3 Crash Energy Management

Structural Crashworthiness and Occupant Protection

A safety concern in this area is the need to accommodate a 1000-lb battery pack and still provide occupant protection. In collisions of the same magnitude, it is possible that EHVs could be more injurious than comparable CVs because of the tradeoff between structural strength and battery weight.[28] However, EHVs will be designed to prevent the battery pack from intruding into the occupant compartment. The P.L. 94-413 demonstration performance standards call for EHVs to meet FMVSS for occupant protection,[33] with all battery materials remaining outside the passenger compartment.[36]

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*There are two measures of gradeability: (1) "gradeability at speed" or the grade that can be traversed up at a given speed and (2) "gradeability limit" or the grade at which a vehicle can start and climb for a specific time period.

Lighter cars experience much greater velocity changes in collisions with heavier vehicles and provide less stopping space and protection for their occupants. The smallness of current electric cars has been pointed to as a safety problem. However, the CVs for which EHVs are projected to be substituted are of the same size. The EHVs, which are heavier than comparably sized CVs, could be safer in terms of crashworthiness because of that extra weight.

Vehicle Aggressivity

A potential problem in developing EHVs as crashworthy vehicles is that the structural designs may cause the EHV to be aggressive in collisions. This means that one vehicle, because of its extensive structure, mass distribution, and/or geometry, imparts force levels in excess of those that can be supported by other vehicles. This element of aggressivity also can increase hazards to pedestrians. Although specific standards have not been established to limit EHV aggressivity, such standards could be developed if demonstration and/or further analysis shows this problem to be of concern.

3.7.2.4 Other Operating Safety Concerns

These concerns generally arise during vehicle operation or in accident or failure situations.

Spillage of Battery Electrolyte and Metal Fires

Electrolyte spillage and metal fires could occur during replacement of a dry battery, as a result of battery failure during operation (short circuit or overheating), or in an accident. Sulfuric acid spills from Pb/acid batteries could lead to burns. Similar problems exist for the Ni/Fe and Ni/Zn batteries with respect to their caustic electrolyte. Although little electrolyte spillage is anticipated from the Li/S battery, occasional metal fires could occur in an accident that might release toxic substances like sulfur and SO_2. Since the Li/S battery operates in a vacuum at about 800°F, hot materials could be released during an accident.

Future EHVs will have sealed batteries; therefore, no liquids or gases should be released during battery replacement. However, standards regarding flammable materials, overheat protection, short-circuit protection, and electrolyte containment could still be required for battery failure situations. The P.L. 94-413 performance standards generally address this issue by requiring that all battery materials remain outside the passenger compartment.[36] Experience gained in crash tests and in the ongoing demonstration program may reveal the need for additional standards to mitigate potential safety problems. Additional testing of simulated vehicle accidents with Li/S EVs are required to assure safe containment of the hot battery materials. Standards may be required to mitigate this problem as commercialization proceeds.

Toxic Gas Release from On-Board Charger

Although toxic gas can be released from on-board chargers during fire or battery system failure, the possible rates of release are unknown. Proposed solutions include use of nonflammable, nontoxic materials and minimizing overheating through design standards. EHVs are expected to meet any standards addressing this issue.

Explosion and Fire from HV Energy System Combinations

The potential exists for explosion and fire from certain combinations of energy systems (e.g., gasoline and electrolyte) in HVs in accident or failure situations. The solution is to develop effective designs that isolate these energy sources. HVs are expected to meet any associated standard prior to commercialization.

Electromagnetic Radiation

EVs emit electromagnetic radiation during operation. This emission may interfere with the operation of certain electronic medical aids like cardiac pacemakers. Methods to keep this hazard to a safe level have been ascertained, but no standards have been established.[26] If electromagnetic radiation is found to be a health-related problem, mitigating standards could be promulgated.

3.7.3 Risk of Accident

There is very little on-the-road experience with EHVs to use for accident risk analysis. The University of Michigan, in its work for the opportunity and risk assessment (OPRA) study, relied on traditional CV accident analysis to derive EV accident, injury, and fatality rates in urban areas.[28,30] In the OPRA study, demonstration EVs were assumed to be like minicompact CVs. This approach could be extended to other EHV vehicle types. However, the approach does assume that there are no differences in accident rates between EHVs and comparably sized CVs driven in the same location. This assumption is consistent with the expectation that future EHVs will meet FMVSS, that EHVs will be similar in performance to the CVs they are projected to replace, and that EHVs will meet any standards set for the specific public safety concerns discussed above.

Since EHV market penetration does not lead to changes in total number of vehicles or in total VMT, the assumption of similar accident rates means there will be no difference in the accident totals based on the number of EHVs. Although EVs are driven fewer miles per year than the CVs they replace, the VMT not driven by the EVs are assumed to be made up by CVs. (HVs are assumed to be driven the same annual mileage.) In summary, where accident totals are based on rates per VMT or rates per number of vehicles, the degree of market penetration of EHVs makes no difference.

The total number of accidents will be the same, even when the assumption is made that EVs will be driven primarily in urban areas. This is because the additional mileage that the EV would have been driven if it were a CV will still be driven, but by a CV. If those extra miles are driven in urban areas, an urban rate applies; if driven in rural areas, a rural rate applies. In the end, an EV, with a CV making up the additional mileage, generates the same accident totals as a CV.

Injury and fatality rates can be assumed to be the same for EHVs and CVs. (The OPRA study makes this assumption for EVs and CVs.[30]) Again, assuming similar performance and structural integrity, there should be no difference. However, different types of injuries may result. Chemical burns resulting from electrolyte spillage and fire would be associated with EVs, and injuries resulting from gas tank explosion and fire would be associated with CVs. All these types of injuries would be associated with HVs.

The OPRA study estimates that 3.5-9% of accidents involving EV autos might result in chemical burns: 53% would be first degree burns or less, 19% would be second degree, and 28% would be third degree. However, these estimates are not based on experience and could be too high. The greater structural integrity of the vehicles and batteries along with careful positioning of the batteries could lower the probability of a spill reaching the occupants of the vehicle. Because of the great uncertainty associated with estimating the number and degree of chemical burns and because of assumptions that future EHVs will meet the standards set to lessen this concern, no estimates are offered.

The lower noise level of EVs during acceleration and low-speed operation may prove hazardous to pedestrians who depend on vehicle noise as a warning. Whether this is significant and what the impact of minimum noise standards would be can not be ascertained. The P.L. 94-413 demonstration should provide data to help answer these questions.

3.8 SOCIAL IMPACTS

The social impacts of EHVs are difficult to estimate. One concern that has been expressed is that increased utilization of EHVs might cause or require lifestyle, mobility, or urban structure changes. For example, because EVs have been characterized as vehicles of limited range and performance, changes in trip-making behavior have been predicted. However, with reasonable advances in battery technology, future EHVs are expected to perform as well as CVs. Further, even though EVs are limited as to range, the range is nonetheless substantial. Finally, EVs are predominantly commercial vehicles, particularly in the LOW and MEDIUM scenarios, and lifestyle and mobility are thought to be impacted more by the use of EVs as personal autos and trucks than as commercial vehicles. HVs, of course, are not limited in range and perform like CVs.

While the above paragraph seems to argue against EHVs having major impacts on lifestyle, mobility, and urban structure, their market success will have some effect, particularly on mobility. Mobility is measured by a number of characteristics, including the number of transportation options available for a personal trip and the cost, comfort, convenience, safety, reliability, and speed of the trip.[37] Although the range of electric autos is expected to be sufficient for 95-98% of the trips made in urban areas, there are some trips that will not be possible unless battery exchange stations or quick recharge facilities are available. Thus, the mobility of the owner or operator of an EV may be somewhat reduced. On the other hand, if there are substantial liquid fuel shortages, the owner or operator of an EV might be able to make trips that a CV owner or operator could not.

With respect to the cost aspects of mobility, the overall costs of owning and operating EHVs will be higher than those of the CVs they replace (see Sec. 3.10.1). Thus, it could be argued that EHVs will, to some degree, result in reduced mobility. However, as long as freedom of choice in the purchase decision remains, the purchaser might trade off other attributes against cost, and mobility would be maintained. Nevertheless, the higher overall costs of EHVs may mean that lower-income groups would remain tied to lower-cost CVs, even in times of high liquid fuel prices and low liquid fuel availability, which would restrict their mobility. Personal electric autos are expected to penetrate higher-income markets.

With respect to other measurements of mobility, EHVs may not be as convenient as the CVs they replace. Fuel needs require more planning. However, at least in times of fuel shortages, the fuel (electricity) generally should be more readily available. EVs may be more reliable than the CVs they replace but HVs may not be. EHVs should be as comfortable as CVs, and they will be safe once they are commercialized. Although EVs do not sustain maximum speed as long as CVs, they will be able to maintain it for an adequate time period (i.e., to 80% discharge).

In summary, there may be some impacts from EHV penetration on mobility, on urban structure as it is affected by changes in mobility, and on lifestyle. Although some positive impacts are anticipated along with the negative, the degree to which all of these impacts are significant is unknown. What is known is that the use of large numbers of limited performance EVs would result in more severe social impacts than those anticipated with the use of EVs having the performance capabilities assumed in this assessment.

Apart from the social impacts that are associated with mobility changes, EHV penetration may lead to other social impacts. Particularly in the HIGH I and HIGH II scenarios, the potential exists for other types of social impacts in specific local areas, i.e., those impacts resulting from significant employment changes (see Sec. 3.10.2). Further, EHV penetration may be associated with some changes in lifestyle, mobility, and urban structure necessitated by liquid fuel shortages or high costs. For example, the HIGH I and HIGH II scenarios include increased use of mass transit in all urban and suburban areas. However, the increased penetration of EHVs does not itself cause these changes.

3.9 INSTITUTIONAL IMPACTS

The institutional impacts analyzed here are those related to the transportation infrastructure needed to support EHV penetration. Several reports that examine infrastructure factors affecting EHV commercialization are used in the following discussion.[30,38,39]

3.9.1 Electricity Supply and Fuel Delivery

Adequate availability of electricity for battery charging is essential to EHV commercialization. Appendix F presents the analysis of the fuel types used to generate electricity for 158 urbanized areas for the LOW I, MEDIUM, and HIGH I scenarios in 1990 and 2000. Regional and national summaries are presented for all five EHV scenarios for 1990 and 2000, along with summaries for 10 selected urbanized areas for all five scenarios for 1985, 1990, and 2000. In each scenario, approximately 80% of the required charging energy is generated by coal or nuclear power plants, with the balance generated by power plants fueled with oil or natural gas.

The impact of any of the five EHV scenarios on electric utilities is minimal, even in the year 2000. For example, total EHV electrical consumption in HIGH I and HIGH II represents only about 3% of projected U.S. electricity demand in 2000. However, for four of the 158 urbanized areas, and particularly the New York-New Jersey area, additional electricity consumption as a result of EHV penetration under HIGH I and HIGH II represents a sizable fraction of the electricity demand in the year 2000 and would have to be included in the utility planning process.

These conclusions are based on the assumption that all truck and auto EHVs are charged off peak. Buses are charged twice a day but only once during peak hours. However, this is less than 1% of all the electricity used by EHVs in all scenarios. Utility time-of-day pricing encourages off-peak charging. This type of pricing structure occurs relatively infrequently in the LOW scenarios but is a nationwide phenomenon in the HIGH scenarios.

The availability of a recharging infrastructure is essential to EHV commercialization. In fact, the lack of a recharging infrastructure for EHVs other than at fleet facilities is considered by some to be a barrier to EHV commercialization.[38,39] For example, 60% of the households in the 24 largest urban areas of the United States are not in single-family houses with a garage or carport that would make it possible to use the household's individual electricity supply to charge the battery.[39] It has been suggested that EHV commercialization could be encouraged by establishing central recharging facilities, such as electric hookups at public parking garages or lots or at multiunit housing.

In this analysis, the scenarios assume penetration only where recharging facilities could be readily available. This is true for all EHV markets. For the personal auto market, for example, EHV owners are assumed to be higher-income households with two or more vehicles in single-family housing with off-street parking where the EHVs could be charged. In other words, lack of public charging facilities does not affect the penetration totals of the scenarios.

Although the availability of battery exchange stations or recharging facilities at service stations is not required for these scenarios, these facilities would act as range extenders. Recharging at service stations for range extension would often occur at the expense of the off-peak charging assumption. Fueling facilities in public places and in multiunit housing garages may be required to achieve higher penetration totals in the years beyond 2000. Studies to investigate facility requirements, costs and impacts of commercial recharging facilities, and battery exchange are underway.

The local distribution system of an electric utility could be adversely affected by the recharging of an EHV commercial fleet. Such effects would be most pronounced near the EHV charging facility and might require the utility to install additional distribution lines and line transformers and possibly to upgrade the substation. A quick recharge capability would cause the most severe effects. However, these effects could be mitigated through the use of direct load management by the utility. Further, some older houses might require the installation of larger electrical capacity to allow for the charging of EHVs during operation of other high-load applicances. Fleet facilities with recharge centers might also require increased electrical capacity.

3.9.2 Vehicle Manufacture

Past experience with automotive innovations indicates that EHV manufacturing and distribution can be absorbed by the present CV industry. However, it is expected that small entrepreneurial firms generally will be the main source of personal and commercial EHVs during the early stages of market development. The major auto manufacturers are poorly suited to limited production and, to reduce risk, prefer to innovate through a process of gradual change in product performance and design.[38] Therefore, because EHVs represent a major departure from CVs and because initial auto market demand is expected to be too small to support production lines of a minimum of 100,000 units per year, the major vehicle manufacturers will most likely enter the auto market with mass production at later stages of EHV development. In fact, these major manufacturers, General Motors Corporation in particular, may move into mass production of electric autos earlier than projected in the scenarios (i.e., in the next five to seven years).

Historically, commercial vehicle manufacturing and passenger auto production have been organized differently.[38] Commercial products are more likely to be built to meet particular customer needs. Each of the major vehicle manufacturers has subsidiary operations that produce CVs for commercial applications. Commercial EHVs could be manufactured along with their equivalent CVs through the use of similar mass-produced components (bodies and frames) and serially added electric drive components. Thus, commercial EHVs could be produced by the major manufacturers at lower volumes than would normally be required for an EHV auto of totally new design. Since the commercial segment of the major vehicle manufacturers is more likely to respond rapidly to customer demands for new types of vehicles like EHVs, EHVs are assumed to penetrate the commercial market first. In fact, commercial vehicles are assumed to be the predominant vehicles in the LOW and MEDIUM scenarios.

While little change is expected in the light truck body and chassis assembly lines, the HIGH scenarios call for rapid conversion of the conventional auto production lines of the three largest domestic auto manufacturers. Seven large-scale production lines, each capable of producing 400,000 electric autos, would have to be in place to produce the 3,000,000 electric autos the HIGH I scenario requires of the major manufacturers by 2000.[40] Decisions to proceed with these production lines would have to be made by 1995 with prior production experience with only one EV production line. Decision-making requirements and the minimal level of experience would be similar in HIGH II. Further, these industry decisions probably would have to be made in an era of severe gasoline shortages and a climate of intense business difficulty.

Although sufficient capital should be available for the production of EHVs, an uncertain business climate in the HIGH scenarios may dampen investments of this type. Section 3.10.5 describes additional impacts of EHVs on the capital investment requirements of the motor vehicle and battery industries.

Financing depends on the creditworthiness of the borrower. Federal loan guarantees are available under the P.L. 94-413 demonstration program for current EHV producers to increase production capacity. Under the MEDIUM and HIGH scenarios, these guarantees are projected to continue beyond the demonstration. Particularly under the HIGH scenarios, the government would have to take additional strong measures to defray manufacturing risk.

3.9.3 Vehicle Servicing

Because of their simpler propulsion systems (fewer moving parts), EVs should be more reliable and easier to maintain and therefore require less downtime for repairs than CVs, at least past the initial stages of EV development.[38] Because of their two power sources, HVs should be more complex to maintain. Both require scheduled periodic maintenance as well as unscheduled and accident repairs. Equipment to provide these services and personnel trained in servicing EHVs will be required. (Facilities for battery exchange and battery charging are discussed in Sec. 3.9.1.)

Since much of the initial development of EHVs is expected to be in commercial fleets, the lack of public vehicle servicing facilities is not as serious as it would be if initial commercialization were largely in private autos. Fleet operators normally provide some of their own support systems and could provide relatively easily for the additional special requirements associated with EHVs, including routine service and maintenance.[41] Major repairs may be performed by some fleet EHV operators. However, even for fleet operators, the lack of diagnostic and test equipment for identification of failure causes, adequate parts supply, and local facilities for warranty processing must be overcome in order to enhance commercialization.

There will be nonfleet commercial and personal electric and hybrid truck and auto operators, who will not have their own vehicle servicing facilities, parts supply, warranty processing facilities, or trained service personnel. The institutions that will service these nonfleet EHVs are uncertain. Existing vehicle repair and maintenance facilities could be adapted to include EHVs. At a minimum, the major common components could be repaired and maintained by the same facilities. Major manufacturers of subsystem components could issue warranties for EHV subsystems and service these subsystems through their existing distribution networks and service centers. Major retail stores could market EHVs manufactured by others and service them at their auto service centers. Facilities designed to service only EHVs also are possible. EHV sales centers, which could include CV dealerships, might provide servicing. In the P.L. 94-413 demonstration, nonfleet EHV users are expected to return to the sales center for servicing.

Personnel trained in servicing EHVs are required. Mechanics who service CVs will require new skills to service systems unique to EHVs.

With nearly four million EHV light personal trucks and over 10 million EHV autos in 2000 under the HIGH scenarios, it is expected that the government will have to encourage the development of a servicing network. To achieve the LOW and MEDIUM scenarios, government activity beyond that occurring in the demonstration program is not anticipated.

The impact on existing CV servicing facilities is not clear. As stated above, some existing vehicle repair and maintenance facilities may be adapted to include EHVs. The existing CV service network may be changing, even without penetration of EHVs; there appears to be a trend toward reduced repair and maintenance services provided by major oil companies. Particularly under the HIGH scenarios, some attention by the government to any adverse impacts resulting from EHV penetration on CV repair and maintenance facilities and on their personnel will be required.

3.9.4 Roadway Construction, Operation and Maintenance

The existing roadway infrastructure is available to EHVs. However, current limited-access highways and minimum speed laws have been considered by some to be a barrier to EHV acceptance.[38,39] In particular, EVs have been characterized as having slower acceleration than CVs, which would affect their merging capabilities on freeways, and as having maximum speeds (especially at 80% discharge) too low to meet minimum speed laws. This is not true of the vehicles expected to be available in 1985 and beyond; they will be comparable in performance to future CVs and will meet the acceleration and minimum speed requirements of limited-access roadways. Thus, increased use of EHVs should not require changes in highway design, speed laws, traffic signal timing, or intersection capacity.

3.9.5 Financing

Existing financial institutions should support the sale of EHVs.[38] Normal loan relationships should apply. The major criterion that banks are expected to use in making loans to EHV dealers and purchasers will be the creditworthiness of the borrower. However, some near-term problems could emerge. For example, consumers may withhold loan payments if manufacturers default on written or implied warranties. Or, if a consumer expects but does not find EHV performance to be similar to CV performance and if the seller referred the consumer to the lender (a common practice), the consumer legally may withhold payment.[38] However, EHVs are expected to be similar in performance to CVs by 1985.

Another problem is that near-term EHV manufacturers are likely to be small, entrepreneurial firms with limited finances. They may not be able to meet valid warranty obligations.[38] However, this problem should be reduced as EHV commercialization leads to growth in these firms. It will be much reduced by the time the major domestic vehicle manufacturers are dominant in the EHV market.

3.9.6 Insurance

It is expected that existing insurance and legal institutions will not impede the sale and use of EHVs. Large fleet operators may self-insure. Insurance carriers for other EHVs will be concerned with safety, damageability, and ease of repairs.[38] In the initial stages of EHV development, insurance rates may be high until accident statistics can provide a reliable basis for rate adjustments. Since accident rates and performance are expected to be similar for future EHVs and CVs (see Sec. 3.7.3), insurance rates based on these factors should be similar after the initial EHV development stages. However, because EHVs are expected to cost more than the CVs they replace, the part of vehicle insurance based on the market value of the vehicle (comprehensive and collision coverage) will remain higher for EHVs.

Initially, lack of repair parts and trained service personnel may result in higher costs to insurers, which could translate into higher rates. In certain situations, insurers must provide substitute vehicles; therefore, delays in securing scarce parts and service are costly.[30]

The potential also exists in the early stages of EHV development for excessive product liability claims and, thus, for expensive product liability insurance. EHV owners, drivers, and manufacturers can be sued and held liable in vehicle accidents resulting in personal injuries that are caused by EHV design defects or manufacturing negligence.[38] (In the P.L. 94-913 demonstration program, the federal government also can be sued for design defects.) However, if the EHV driver or owner is held liable, they are able to make a claim against the manufacturer. Thus, a design defect or a series of manufacturing errors could result in many millions of dollars of exposure for a manufacturer. If major corporations like General Motors or General Electric Company were the manufacturers, this potential liability probably would not be a serious problem. However, many of the current EHV manufacturers are small entrepreneurial firms and can not absorb the costs of adequate liability insurance or excessive claims.

One solution that has been suggested has been government insurance similar to the Price-Anderson Act, which provides coverage for utilities operating nuclear power plants.[38] The manufacturer is required to provide some insurance privately, and the government insures against liabilities over a certain amount. This, of course, distributes some of the cost of EHVs to all of society. Whether or not this solution is adopted, the larger firms that will come to dominate as EHV manufacturers are less vulnerable in this respect. Nonetheless, product liability will be an impediment in the early years to achieving the degrees of market penetration assumed for each of the scenarios.

3.9.7 Taxes

A number of transportation taxes and fees will be affected by EHV commercialization. The gasoline tax is one major source of federal, state, and sometimes local revenues for road construction, repairs, and maintenance. Since EVs do not use gas and HVs use less gas than CVs, replacement taxes will be required (see Sec. 3.10.5).

Sales taxes and vehicle property taxes will be higher for EHVs than for the CVs they replace, because EHVs will have higher purchase prices. Vehicle registration fees are calculated differently from state to state; they can be imposed on specific classes of vehicles or they can be proportional to vehicle weight or price. Because EHVs are heavier and cost more than the CVs they replace, these latter forms of registration would impose higher fees on EHVs. However, as currently structured, these higher fees would not affect life cycle costs significantly. No projection is made in this assessment as to how the sales tax, property tax, and registration fees might be changed as a result of EHV commercialization.

EHV owners may benefit from tax credits or other government incentives. No incentives to buyers are included in the LOW scenarios, but DOE incentives begin in 1985 in the MEDIUM and HIGH scenarios.

3.9.8 Regulation and Enforcement

A number of highway use, safety, and insurance regulations have been established based on CV performance characteristics. These should not be affected by EHV commercialization. For example, mandatory liability insurance coverage, licensing of vehicles and vehicle drivers, and FMVSS should not be affected because EHVs will be similar in performance to CVs.

Enforcement of highway use and other regulations generally will be the same. Vehicle inspection related to emission control (air or noise) will continue for CVs and probably HVs. EVs may have to undergo these tests if they use gasoline-powered accessories.

3.9.9 Other Transportation Infrastructure

There are a number of other potential impacts on transportation institutions related to EHV commercialization. First, fires in EHVs resulting from malfunctions or accidents require different fire-fighting techniques than CV fires. Fire fighters must be informed that EHVs are operating, especially in the LOW scenarios and in the early years of the other scenarios when relatively few EHVs are on the road. Special instruction and preparation for fire fighters will be required.

Second, driver training will be affected. Although EHVs penetrate significantly in commercial fleets where operators can learn from each other, they also penetrate in the personal use markets. Instructions on operating EHVs will have to be clear, since operation will be somewhat different than CV operation (see Sec. 3.7.2.2).

Third, regional planners, particularly those concerned with transportation and air quality, will have to incorporate EHVs and their air and noise emissions in their planning. For example, planners will have to decide whether to allow EHVs in CV-free zones (zones often established to reduce air and noise emissions). The MEDIUM scenario in 1990 projects that several CBDs will have CV-free zones; under the HIGH scenarios, most major CBDs and some other local areas with severe air quality problems will be free of CVs. Finally, EHV priority parking schemes may affect CV parking.

3.10 ECONOMIC IMPACTS

3.10.1 Cost of Travel

Estimating initial EHV costs is extremely difficult. For example, significant problems exist in characterizing nonexistent production processes. This is the current situation for Ni/Zn, Ni/Fe, and Li/S EHVs. Changes in the characterization of the batteries could significantly change the vehicle cost estimates. Another problem is forecasting the price of materials. However, ranking EHVs in terms of cost relative to one another and cost comparisons with equivalent CVs are less likely to change than the costs themselves. Consequently, ranking and cost comparisons are emphasized in this analysis. Even this approach has its limitations, because it does not give weight to the differences in range expected among the EHVs or the differences between EHVs and CVs in total lifetime VMT.

Initial costs are calculated for the timeframe 1985-2000 by the value-added and the fixed mark-up methods. When EHVs are ranked in cost by battery type, the results using these two methods are similar to those of four other recent EHV cost studies. These two methods and the assumptions necessary to calculate life cycle costs are presented in Sec. G.1. The life cycle costs method is a minor modification of a method discussed in Ref. 42.

3.10.1.1 Initial Vehicle Cost

Initial Cost of EHVs

Considering all EHV and CV vehicle classes and using both the value-added and fixed mark-up method, Pb/acid EVs have lower initial costs than any other EHV in the scenarios (see Tables 3.30 and 3.31). Using the value-added approach only, Li/S EVs are next lowest, while the Ni/Zn EHVs are the most expensive passenger cars and among the most expensive trucks and buses.

The fixed mark-up approach could not be applied to Li/S EVs, because their battery production process is expected to be quite different from the others. However, the Ni/Zn and Ni/Fe battery production processes are somewhat similar to the better known Pb/acid production process and should have similar costs. Thus, the Ni/Zn and Ni/Fe EHVs were assigned the Pb/acid battery mark-up. Using this method, vehicle costs are about the same within each truck and bus category, regardless of battery type. In the passenger car category, Pb/acid and Ni/Fe EVs are approximately equal in cost and are the least expensive of the EHVs; Ni/Zn passenger EVs are the most expensive of the EHVs.

Pb/acid EHVs probably have the lowest initial cost, because the batteries are constructed with relatively inexpensive materials and the battery production process is known. Ranking Li/S EVs second results from their relatively inexpensive battery material base. This analysis assumes the best-case usage of lithium metal in Li/S batteries. If expected technology breakthroughs do not occur, the cost of these vehicles will be substantially greater. Further, the Li/S battery production process is not yet known. When the process is known, vehicle cost estimates could be significantly different.

Table 3.30. Initial Costs of EHVs and CVs Using Value-Added and Fixed Mark-Up Methods

Vehicle Type	EV or HV and Type of Battery	Cost (constant 1979$) Initial Cost Using Value-Added Method	Initial Cost Using Fixed Mark-Up Method	Initial Cost of Equivalent CV Using Value-Added Method	Increase from CV Cost to EHV Value-Added Cost (%)	Increase from CV Cost to EHV Fixed Mark-Up Cost (%)
4P1	Pb/Acid EV	4,090	4,090	3,000	36	36
4P3	Ni/Fe EV	4,760	4,160	3,000	59	38
4P5	Ni/Zn EV	7,630	5,990	3,170	110	87
4P7	Li/S EV	4,560	a	3,220	42	-
4P10	Pb/Acid HV	5,140	5,080	3,550	45	43
4P11	Ni/Zn HV	5,640	5,030	3,550	59	42
5P1	Pb/Acid EV	4,980	4,980	3,630	37	37
5P3	Ni/Fe EV	6,840	5,290	3,630	88	46
5P5	Ni/Zn EV	9,240	7,240	3,800	143	91
5P7	Li/S EV	5,920	a	3,840	54	-
5P10	Pb/Acid EV	5,880	5,880	4,340	35	35
5P11	Ni/Zn HV	6,450	5,810	4,340	49	34
LT1	Pb/Acid EV	6,180	6,180	3,830	61	61
LT2	Ni/Fe EV	7,520	6,420	3,830	97	68
LT3	Ni/Zn EV	7,330	6,100	3,830	92	59
LT5	Li/S EV	6,780	a	3,830	77	-
MT1	Pb/Acid EV	9,110	9,110	6,350	44	44
MT2	Ni/Fe EV	10,660	9,740	6,350	68	53
MT3	Ni/Zn EV	10,790	9,670	6,350	70	52
MT5	Li/S EV	9,920	a	6,350	56	-
MT7	Pb/Acid EV	8,940	9,040	6,350	41	43
MT8	Ni/Zn HV	11,820	9,930	6,350	86	56
HT1	Pb/Acid EV	12,240	12,240	8,400	46	46
HT2	Ni/Fe EV	14,940	13,390	8,400	78	59
HT3	Ni/Zn EV	14,650	13,060	8,400	74	55
HT5	Li/S EV	13,750	a	8,400	64	-
SB1	Pb/Acid EV	15,960	15,960	11,130	43	43
SB2	Ni/Fe EV	18,560	17,020	11,130	67	53
SB3	Ni/Zn EV	18,790	16,950	11,130	69	52
SB5	Li/S EV	17,890	a	11,130	61	-
LB1	Pb/Acid EV	35,980	35,980	27,070	33	33
LB2	Ni/Fe EV	42,910	37,450	27,070	58	38
LB3	Ni/Zn EV	43,460	37,660	27,070	61	39
LB5	Li/S EV	42,310	a	27,070	56	-

[a] Fixed mark-up not applicable to Li/S vehicles.

Table 3.31. Ranking of EHVs Based on Initial Costs

Vehicle Type	Method	Lowest Cost ——→ Highest Cost			
		1	2	3	4
Four-passenger car	Value-added	Pb/Acid EV	Li/S EV Ni/Fe EV	Pb/Acid HV Ni/Zn HV	Ni/Zn EV
	Fixed mark-up	Pb/Acid EV Ni/Fe EV	Pb/Acid HV Ni/Zn HV	Ni/Zn EV	
Five-passenger car	Value-added	Pb/Acid EV	Pb/Acid HV Li/S EV	Ni/Zn HV Ni/Zn EV	Ni/Zn EV
	Fixed mark-up	Pb/Acid EV Ni/Fe EV	Pb/Acid HV Ni/Zn HV	Ni/Zn EV	
Light truck	Value-added	Pb/Acid EV	Li/S EV	Ni/Zn EV Ni/Fe EV	
	Fixed mark-up	[a]			
Medium truck	Value-added	Pb/Acid EV Pb/Acid HV	Li/S EV	Ni/Zn EV Ni/Fe EV	Ni/Zn HV
	Fixed mark-up	[a]			
Heavy truck	Value-added	Pb/Acid EV	Li/S EV	Ni/Zn EV Ni/Fe EV	
	Fixed mark-up	[a]			
Small bus	Value-added	Pb/Acid EV	Li/S EV Ni/Zn EV Ni/Fe EV		
	Fixed mark-up	[a]			
Large bus	Value-added	Pb/Acid EV	Li/S EV Ni/Zn EV Ni/Fe EV		
	Fixed mark-up	[a]			

[a] Pb/acid, Ni/Fe, and Ni/Zn vehicles are very similar in cost.

Generally, Ni/Zn EHVs are the most costly because of the relatively large quantities of high-priced materials needed for their battery packs. However, technology changes have occurred recently that could reduce the required quantities of these expensive materials from the quantities assumed in this analysis. Further, the fixed mark-up method does lessen the impact of the higher materials costs of these vehicles.

Comparison of Initial Costs of EHVs and CVs

Using the value-added method, EHV initial costs are 36-143% higher than those of equivalent CVs (see Table 3.30). As expected, the fixed mark-up method narrows this difference slightly (36-91%). These initial cost differences and the lower range of the EHVs may hinder EHV market penetration.

Several factors could alter the initial cost differences. First, new technologies usually have high initial costs. While mass production has been assumed, initial costs should be lowered significantly as experience is gained in producing EHVs. Second, if technology breakthroughs are achieved, material input requirements could be lowered. Third, higher materials prices and potential materials shortages could occur as EHVs achieve greater penetration (see Sec. 3.2). This study does not project increased materials prices.

3.10.1.2 Life Cycle Vehicle Costs

All life cycle costs are calculated using the value-added initial cost method to provide a basis for comparison. (Li/S EVs could not be analyzed using the fixed mark-up method.)

Life Cycle Cost of EHVs

Table 3.32 presents the life cycle costs for EHVs and equivalent CVs, and Table 3.33 shows the EHV life cycle cost rankings. For passenger cars, the order from least expensive to most expensive is: Pb/acid and Ni/Fe EVs, Li/S EVs, Pb/acid HVs, Ni/Zn HVs, and Ni/Zn EVs. This order is usually the same for trucks and buses, except that Ni/Zn EVs and Ni/Zn HVs are reversed. For all vehicles, Pb/acid and Ni/Fe EVs generally have lower life cycle costs.

The low life cycle costs of Ni/Fe EVs can be attributed to their long-lasting battery packs. Their long life more than offsets their relatively high material costs. Therefore, capital and replacement costs for Ni/Fe EVs are significantly lower than for other EHVs. The lower materials input costs for the battery packs of Pb/acid and Li/S vehicles affect their life cycle costs, since those capital and replacement costs are relatively lower. Ni/Zn EHV life cycle costs are heavily influenced by the relatively high cost of the Ni/Zn battery pack.

If significant penetration of EHVs occurs, there will be increases in the prices of component materials. Thus, it is possible that the value of a battery will appreciate significantly during its life. Certain EHVs, Ni/Fe and Ni/Zn EHVs in particular, could come to be viewed as investments in precious metals. This cost advantage of EHVs is not usually recognized and has not been explicitly included in this analysis.

Comparison of Life Cycle Costs of EHVs and CVs

Table 3.32 shows EHV life cycle costs are always higher (up to 146%) than the costs of equivalent CVs. This can be attributed to the higher

Table 3.32. Life Cycle Costs of EHVs and CVs

Vehicle Type	EV or HV and Type of Battery	Cost (constant 1979$) Initial Cost	Operating Cost	Capital Cost	Total Life Cycle Cost	Equivalent CV Life Cycle Cost	Increase from CV Cost to EHV Cost (%)
4P1	Pb/Acid EV	4,090	9,940	2,050	16,080	15,040	7
4P3	Ni/Fe EV	4,760	8,250	2,510	15,520	15,040	3
4P5	Ni/Zn EV	7,630	16,250	3,490	27,370	15,160	80
4P7	Li/S EV	4,560	10,580	2,240	17,380	15,200	14
4P10	Pb/Acid HV	5,140	13,080	2,580	20,800	17,660	18
4P11	Ni/Zn HV	5,640	15,140	2,710	23,490	17,660	33
5P1	Pb/Acid EV	4,980	10,980	2,480	18,440	17,490	5
5P3	Ni/Fe EV	6,840	8,830	3,600	19,270	17,490	10
5P5	Ni/Zn EV	9,240	18,760	4,230	32,230	17,610	83
5P7	Li/S EV	5,920	12,500	2,870	21,290	17,640	21
5P10	Pb/Acid HV	5,880	14,350	2,960	23,190	20,380	14
5P11	Ni/Zn HV	6,450	17,430	3,100	26,980	20,380	32
LT1	Pb/Acid EV	6,180	12,390	3,050	21,620	17,930	21
LT2	Ni/Fe EV	7,520	9,490	3,970	20,980	17,930	17
LT3	Ni/Zn EV	7,330	14,840	3,460	25,620	17,930	43
LT5	Li/S EV	6,780	13,450	3,270	23,500	17,930	31
MT1	Pb/Acid EV	9,110	15,700	4,520	29,330	22,360	31
MT2	Ni/Fe EV	10,660	11,720	5,620	28,000	22,360	25
MT3	NI/Zn EV	10,790	19,140	5,130	35,060	22,360	57
MT5	Li/S EV	9,920	17,740	4,780	32,440	22,360	45
MT7	Pb/Acid HV	8,940	17,120	4,460	30,520	22,360	36
MT8	Ni/Zn HV	11,820	21,880	5,630	39,320	22,360	76
HT1	Pb/Acid EV	12,240	19,360	6,050	37,650	25,290	49
HT2	Ni/Fe EV	14,940	13,780	7,880	36,590	25,290	45
HT3	Ni/Zn EV	14,650	25,220	6,930	46,800	25,290	85
HT5	Li/S EV	13,750	22,440	6,600	42,790	25,290	69
SB1	Pb/Acid EV	15,960	21,200	7,940	45,100	29,810	51
SB2	Ni/Fe EV	18,560	14,570	9,790	42,920	29,810	44
SB3	Ni/Zn EV	18,790	27,030	8,960	54,800	29,810	84
SB5	Li/S EV	17,890	25,020	8,660	51,570	29,810	73
LB1	Pb/Acid	35,980	43,240	17,870	97,090	49,510	96
LB2	Ni/Fe EV	42,910	28,000	22,630	93,540	49,510	89
LB3	Ni/Zn EV	43,460	57,660	20,660	121,780	49,510	146
LB5	Li/S EV	42,310	55,140	20,330	117,780	49,510	138

Table 3.33. Rankings of EHVs Based on Life Cycle Costs (1 = least cost)

Vehicle Type	Lowest Cost → 1	2	3	4	5	Highest Cost 6
Four-passenger car	Pb/Acid EV Ni/Fe EV	Li/S EV	Pb/Acid HV	Ni/Zn HV	Ni/Zn EV	
Five-passenger car	Pb/Acid EV Ni/Fe EV	Li/S EV	Pb/Acid HV	Ni/Zn HV	Ni/Zn EV	
Light truck	Pb/Acid EV Ni/Fe EV	Li/S EV	Ni/Zn EV			
Medium truck	Ni/Fe EV	Pb/Acid EV	Pb/Acid HV	Li/S EV	Ni/Zn EV	Ni/Zn HV
Heavy truck	Ni/Fe EV	Pb/Acid EV	Li/S EV	Ni/Zn EV		
Small bus	Ni/Fe EV	Pb/Acid EV	Li/S EV	Ni/Zn EV		
Large bus	Ni/Fe EV	Pb/Acid EV	Li/S EV	Ni/Zn EV		

initial, capital (financing), and battery replacement costs of the EHVs. However, Pb/acid and Ni/Fe EV passenger car life cycle costs are only 3-10% higher than the costs of equivalent CVs. Pb/acid HV cars are 14-18% higher than CVs. This is probably due to relatively low materials costs and greater experience in making Pb/acid batteries. The lower Ni/Fe EV battery replacement and capital costs make that vehicle nearly competitive with the equivalent CV. Ni/Zn EHV life cycle costs are significantly higher because of higher battery materials, replacement, and capital costs. As EHVs get larger (trucks and buses), the difference in life cycle costs between an EV or HV and the equivalent CV increases as a result of greater capital costs, insurance, road taxes, and title registration and license fees of EHVs. For example, a Pb/acid light truck has 21% higher life cycle costs than the equivalent CV, but the difference is 96% for large buses.

3.10.1.3 Summary

This analysis shows that the Pb/acid EV has lower initial costs using both the value-added and fixed mark-up methods and lower life cycle costs than other EHVs, with Li/S EVs second using only the value-added method. Ni/Zn EHVs have the largest initial cost using both methods. No other definitive statements can be made about EHV initial costs. Pb/acid and Ni/Fe EHVs have the lowest life cycle costs; Ni/Zn EHVs have the highest. While some of the cost differences among EHVs are substantial, the value to the consumer of some of the higher cost EHVs is that they have greater range.

EHV initial costs (using both methods) and life cycle costs are always higher than those of the equivalent CVs. The life cycle cost difference widens as EHVs become larger. This could affect EHV commercialization, for commercial vehicles make up at least half of the EHV totals in all scenarios.

3.10.2 Employment

Ninety national employment sectors are examined for each scenario. Table 3.34 lists the 11 industries that are most likely to be impacted by EHV market penetration and that are examined in detail in this analysis. Section G.2 presents the analysis method and the likely national employment changes for these industries. Materials requirement changes as a result of EHV market success are a major factor in employment changes associated with EHVs. The employment results discussed in this subsection are based on EHV direct materials requirements without recycling.

Significant national changes in industrial employment do not occur until the late 1990s; even then, only 5 of the 11 industries have EHV-induced employment changes of greater than 10,000 workers and only in the HIGH scenarios. Four industries (mining, nonferrous metals processing, electric utilities, and batteries) show increased employment. Crude oil production shows decreased employment. These results are similar to those found by other researchers.[24] Table 3.35 summarizes the results.

Total national employment is not affected to any measureable degree by EHV market penetration. Table 3.36 shows that operatives (semiskilled workers) would be in most demand as a result of predicted employment changes. Managers, professionals (engineers), and sales personnel would not be significantly impacted.

Since most U.S. lead mining occurs in Iron County, Missouri, this community was selected as a case study area for several of the analyses for this EA, including employment. Lead mining employment in 2000 increases from 1480 in the BASE scenario to 2672 in the HIGH I scenario. Table 3.37 summarizes basic employment projections, and Table 3.38 shows employment, population, and in-migrant changes by scenario. Significant changes due to EHVs also occur in population and in-migration figures. For example, the BASE

Table 3.34. Industries for Which Employment Impacts Were Examined in Detail

Motor vehicle	Petroleum refining
Batteries	Crude oil production
Plastics	Electric utilities
Rubber	Iron and steel
Mining	Engine electrical equipment
Nonferrous processing	

Table 3.35. Industries with Changes in Employment Greater than 10,000 from BASE Scenario, 2000

Industry	Scenario	BASE Scenario Employment	Employment Change from BASE Scenario	Change as Percentage of BASE Scenario Employment
Mining	HIGH I	345,000	12,000	3
	HIGH II	345,000	12,000	3
Nonferrous processing	LOW II	414,000	10,000	2
	HIGH I	414,000	13,000	3
	HIGH II	414,000	17,000	4
Crude oil production	HIGH I	99,000	-12,000	-12
	HIGH II	99,000	-10,000	-10
Electric utilities	HIGH I	553,000	28,000	5
	HIGH II	553,000	21,000	4
Batteries	MEDIUM	147,000	11,000	7
	HIGH I	147,000	39,000	27
	HIGH II	147,000	17,000	12

Table 3.36. Skill Change Requirements Greater than 4000 per Skill Category from BASE Scenario, 2000

Industry	Scenario	Skill Category	Employment Change from BASE Scenario
Mining	HIGH I and II	Operatives[a]	4,771
Nonferrous processing	LOW II	Operatives	4,711
	HIGH I	Operatives	6,124
	HIGH II	Operatives	8,009
Crude oil production	HIGH I	Operatives	-4,302
Electric utilities	HIGH I	Clerical	5,634
		Crafts	13,014
	HIGH II	Clerical	4,225
		Crafts	9,761
Batteries	HIGH I	Managerial	9,036
		Sales	8,280
		Clerical	6,150
		Crafts	6,154
		Operatives	7,773

[a] Operatives include semiskilled metalworking, packing, inspecting, and transport workers.

Table 3.37. Lead Mining and Refining Employment Projections, Iron County, Missouri

	Basic Employment[a]				Change from BASE Scenario		
Scenario	1978	1985	1990	2000	1985	1990	2000
BASE (all CVs)	779	1083	1184	1480	-	-	-
LOW I	779	1083	1231	1815	0	47	335
LOW II	779	1083	1215	2127	0	31	647
MEDIUM	779	1083	1200	1828	0	16	348
HIGH I	779	1098	1231	2672	15	47	1192
HIGH II	779	1098	1223	2189	15	39	709

[a] Basic employment is employment that creates goods to be exported from a given locality. Secondary employment services basic workers and their families (e.g., teachers, bank tellers, and police officers).

scenario shows 543 new persons in 2000, whereas the HIGH I scenario shows 2719 new persons. In-migrants show similar increases (from 286 to 1431). Table 3.39 summarizes the Iron County skills requirements changes for the HIGH I scenario. Crafts, operatives (semiskilled workers), and professionals would be in most demand. Sales, managers, and clerical workers do not significantly increase. Under any of the scenarios, Iron County employment would be significantly changed. This example illustrates that EHV market penetration can impact employment in local areas.

3.10.3 Factor Prices

Factor prices are the prices an industry must pay for its labor and materials. This section discusses the effects that EHV market penetration will have on certain factor prices.

The HIGH scenarios significantly impact national employment only in the petroleum and battery industries as shown in Sec. 3.10.2. Some 23,000 of the additional battery workers required under HIGH I are in skill areas not effectively unionized. Thus, EHV market penetration should not impact battery industry wages significantly. Decreased petroleum industry employment should not result in wage reductions, because the industry is effectively unionized. In summary, EHV penetration will not impact national wages significantly.

EHV penetration could significantly impact Iron County, Missouri. As presented in Table 3.37, EHV-related increases in employment range from 335 to 1192. HIGH I requires 1192 additional lead workers, with 836 (70%) of them being craft or semiskilled workers. Wages should increase because these skills areas are highly unionized. The size of the wage increases would depend on many factors, including union leadership and corporate financial status. Therefore, EHVs can impact local area factor prices.

Table 3.38. Employment and Population Changes in Iron County as a Result of Increases in Lead Mining from EHV Production

	Change in Basic Employment[a]			Secondary Employment[a]			Total Change in Employment			In-Migrants			Population Change		
Scenario	1985	1990	2000	1985	1990	2000	1985	1990	2000	1985	1990	2000	1985	1990	2000
BASE (all CVs)	304	101	296	185	62	181	489	163	477	310	95	286	589	200	543
LOW I	304	148	584	185	90	356	489	238	940	310	152	574	589	289	1091
LOW II	304	132	912	185	81	557	489	213	1469	310	136	902	589	259	1714
MEDIUM	304	117	638	185	72	390	489	189	1028	310	121	628	589	230	1194
HIGH I	319	133	1441	195	81	880	514	214	2321	325	137	1431	618	260	2719
HIGH II	319	125	966	195	76	590	514	201	1556	325	129	956	618	245	1816

[a] Basic employment is employment that creates goods to be exported from a given locality. Secondary employment services basic workers and their families (e.g., teachers, bank tellers, and police officers).

Table 3.39. Increases in Employment by Skill Category between BASE and HIGH I Scenarios, Iron County, 2000[a]

Skill Category	Increase in Employment
Total	1145
Professional (engineers)	119
Managers	39
Sales	1
Clerical	64
Crafts	412
Operatives (semiskilled)	424
Service	21
Laborers	65

[a]Basic employment only.

Table 3.40 shows oil price projections of the DOE Energy Information Administration (EIA).[43] The figures appear somewhat low when compared with current prices. Of the alternatives, scenario B is most likely. Domestic EHV market penetration should not affect world oil prices before 2000, especially since oil prices are set largely independently of market forces.

Table 3.41 shows the price ranges used in the analysis of major EHV materials prices. The assumptions and details of these projections are given

Table 3.40. Oil Price Projections for EIA Scenarios and Comparison with Early 1979 Saudi Arabian Crude Prices

EIA Oil Scenario	Supply Assumption	Demand Assumption	Projected Oil Price (constant 1979$/bbl)			Early 1979 Saudi Arabian Crude Oil Price (constant 1979$/bbl)
			1985	1990	2000	
A	High	High	34.50	42.81	67.65	21.71
B	Low	High	42.86	38.05	63.65	21.71
C	Mid	Mid	26.78	30.98	43.28	21.71
D	High	Low	20.82	21.34	27.48	21.71
E	Low	Low	18.53	16.32	20.99	21.71

[a]Source: Ref. 43.

Table 3.41. Material Price Range Projections[a]

Year	Material (constant 1979$/lb)				
	Lead	Zinc	Nickel[b]	Copper	Cobalt
1979	0.50[c]	0.36[c]	3.80	0.96[c]	25.00
1985	0.51[d]	0.39[d]	3.40-4.78	1.38-1.94	25.00-40.97
1990	0.51[d]	0.39[d]	3.40-6.35	1.38-2.58	25.00-82.50
2000	0.51[d]	0.39[d]	3.40-11.22	1.38-4.55	25.00-140.83

[a] See Table G.5 for detailed projections.

[b] Battery-grade, powdered nickel.

[c] Spot prices.

[d] No range projected.

in Sec. G.3. It is these price escalations that cause the balance-of-trade problems discussed in Sec. 3.10.4 and that could strongly affect the projections of initial costs of vehicles presented in Sec. 3.10.1.

3.10.4 Balance of Trade

Imported finished cars have averaged 23% of all U.S. car sales over the past few years. EHV scenarios project that up to 28% of EHV cars and light trucks will be imported, depending on the scenario and year. Since most of these will substitute for CVs, the impact on balance of trade should be very small.

Materials import requirements could, under certain scenarios, offset imported oil dollars saved by EHV commercialization. This negative impact on balance of trade could occur even with recycling and is basically the result of the nickel and cobalt import requirements of Ni/Zn EHVs. Tables 3.42-3.46 present the results of the balance-of-trade analysis, which assumes battery and motor/controller/charger materials recycling. The results with no recycling are given in Sec. G.4. The LOW scenarios result in positive impacts (i.e., net savings when materials imported dollars are subtracted from dollars of imported oil saved by EHV commercialization) for nearly all oil and materials scenario computations for all assessment years, because lead, which is domestically available, is the main battery metal. LOW II savings in 2000 could be as large as $4.28 billion (constant 1979$). These results also are generally true with no recycling.

In 1985 the balance of trade in the MEDIUM and HIGH scenarios is generally positive, while the balance is basically negative by 1990, even with recycling. By 2000, depending on oil and materials price assumptions, the balance of trade with recycling could swing either way for these scenarios. Where negative balances occur, they are largest in HIGH II. This scenario

Table 3.42. EHV Impacts on Balance of Trade, LOW I (millions of constant 1979$)[a]

EIA Oil Scenario[c]	Materials Price Scenario[b] Best Case	Strong/Weak Case	Half Case	Worst Case
1985				
A	20.21	19.65	19.93	19.65
B	25.68	25.12	25.40	25.12
C	15.16	14.60	14.88	14.60
D	11.27	10.70	10.98	10.70
E	9.77	9.21	9.49	9.21
1990				
A	87.27	71.32	79.29	71.32
B	75.82	59.87	67.84	59.87
C	58.82	42.87	50.84	42.87
D	35.64	19.69	27.66	19.69
E	23.56	7.62	15.58	7.62
2000				
A	2,595.00	2,595.00	2,244.00	1,893.00
B	2,426.00	2,426.00	2,075.00	1,724.00
C	1,564.00	1,564.00	1,213.00	862.40
D	896.00	896.00	544.90	194.10
E	621.40	621.40	270.40	-80.46

[a] Dollars of net oil saved (oil saved minus the oil used in generating required electricity to fuel EHVs) minus dollars of materials imported (assuming recycle).

[b] See Sec. G.3 for an explanation of materials pricing scenarios.

[c] Ref. 37.

uses the greatest amount of imported major battery materials. With no recycling, the balance of trade for all five scenarios is generally negative in 1990 and 2000, except for some extreme price assumptions.

Solutions to these potentially negative impacts are the same as those presented for materials (see Sec. 3.2), because battery materials are the problem. In short, the commonly held notion that EHVs will have a positive impact on balance of trade seems in doubt if the market penetration rate is high. It is quite possible that there would be no change or that further deficits would occur.

Table 3.43. EHV Impacts on Balance of Trade, LOW II (millions of constant 1979$)[a]

EIA Oil Scenario[c]	Materials Price Scenario[b]			
	Best Case	Strong/Weak Case	Half Case	Worst Case
1985				
A	26.45	25.73	26.09	25.73
B	33.64	32.92	33.28	32.92
C	19.81	19.10	19.45	19.10
D	14.69	13.97	14.33	13.97
E	12.72	12.00	12.36	12.00
1990				
A	126.20	108.70	117.40	108.70
B	110.00	92.49	101.20	92.49
C	85.87	68.40	77.13	68.40
D	53.03	35.56	44.28	35.56
E	35.92	18.46	27.18	18.46
2000				
A	4,278.00	4,278.00	3,905.00	3,533.00
B	4,005.00	4,005.00	3,633.00	3,260.00
C	2,619.00	2,619.00	2,246.00	1,874.00
D	1,543.00	1,543.00	1,171.00	798.30
E	1,101.00	1,101.00	728.80	356.50

[a] Dollars of net oil saved (oil saved minus the oil used in generating required electricity to fuel EHVs) minus dollars of materials imported (assuming recycle).

[b] See Sec. G.3 for an explanation of materials pricing scenarios.

[c] Ref. 37.

3.10.5 Private and Public Sector Capital

Empirical estimates are made of the impact of EHV commercialization on federal motor fuel revenue loss, local government expenditures (Iron County, Missouri), and capital requirements of selected industries. The method for this analysis is presented in Sec. G.5.

3.10.5.1 Federal Motor Fuel Tax Loss

A maximum loss of $704 million per year (about 5%) in federal motor fuel tax revenues will occur in 2000 under the HIGH I scenario. Table 3.47 presents the summary for each scenario and year. Most analysts agree it is

Table 3.44. EHV Impacts on Balance of Trade, MEDIUM (millions of constant 1979$)[a]

EIA Oil Scenario[c]	Materials Price Scenario[b]			
	Best Case	Strong/Weak Case	Half Case	Worst Case
1985				
A	17.25	8.43	12.84	8.43
B	26.07	17.24	21.66	17.24
C	9.11	0.28	4.70	0.28
D	2.83	-6.00	-1.59	-6.00
E	0.41	-8.42	-4.01	-8.42
1990				
A	107.90	-73.69	17.01	-73.69
B	81.46	-100.10	-9.43	-100.10
C	42.18	-139.40	-48.71	-139.40
D	-11.37	-193.00	-102.30	-193.00
E	39.26	-220.90	-130.20	-220.90
2000				
A	4,796.00	4,796.00	1,340.00	-2,115.00
B	4,381.00	4,381.00	925.20	-2,530.00
C	2,270.00	2,270.00	-1,186.00	-4,641.00
D	632.00	632.00	-2,824.00	-6,279.00
E	40.62	-40.62	-3,496.00	-6,951.00

[a] Dollars of net oil saved (oil saved minus the oil used in generating required electricity to fuel EHVs) minus dollars of materials imported (assuming recycle).

[b] See Sec. G.3 for an explanation of materials pricing scenarios.

[c] Ref. 37.

unlikely that EVs will escape an equivalent federal tax.[39] Alternative EHV taxing proposals to make up this loss include: (1) Btu-based tax for HVs on all liquid motor vehicle fuels, (2) increased annual registration fees for EHVs, (3) periodic odometer readings, (4) electric flow recharge metering, (5) tax on traction batteries, and (6) road surface checkpoint metering.

3.10.5.2 Local Government Impacts

The Iron County, Missouri, case study shows significant impacts on local government expenditures as a result of EHV market penetration (see Table 3.48). The largest impacts would be in solid waste disposal and fire protection. These impacts result largely from increased home construction for nes lead mining and processing workers and their families. Welfare expenditures decrease in all but the HIGH I scenario, reflecting increased

Table 3.45. EHV Impacts on Balance of Trade, HIGH I (millions of constant 1979$)[a]

EIA Oil Scenario[c]	Materials Price Scenario[b]			
	Best Case	Strong/Weak Case	Half Case	Worst Case
1985				
A	50.31	40.25	45.28	40.25
B	68.35	58.29	63.32	58.29
C	33.64	23.59	28.61	23.59
D	20.78	10.72	15.75	10.72
E	15.84	5.78	10.81	5.78
1990				
A	61.75	-477.30	-208.00	-477.30
B	11.79	-527.20	-258.00	-527.20
C	-62.41	-601.40	-332.20	-601.40
D	-163.60	-702.60	-433.40	-702.60
E	-216.30	-755.30	-486.10	-755.30
2000				
A	18,060.00	18,060.00	8,508.00	-1,039.00
B	16,630.00	16,630.00	7,079.00	-2,468.00
C	9,351.00	9,351.00	-197.80	-9,745.00
D	3,707.00	3,707.00	-5,842.00	-15,390.00
E	1,389.00	1,389.00	-8,160.00	-17,710.00

[a] Dollars of net oil saved (oil saved minus the oil used in generating required electricity to fuel EHVs) minus dollars of materials imported (assuming recycle).

[b] See Sec. G.3 for an explanation of materials pricing scenarios.

[c] Ref. 37.

employment among native Iron County residents due to EHV market penetration. Increases in library expenditures result from the high percentage of skilled and semiskilled workers among the in-migrants. The largest absolute increase over the BASE scenario occurs in the educational expenditures category, reflecting increased family in-migration.

3.10.5.3 Industrial Capital Investment Impacts

Table 3.49 shows the capital investment requirements in 2000 for 8 of the 90 industries analyzed. The requirements of electric utilities are not significantly changed under any scenario. On the other hand, battery industry capital formation would increase 25% in 2000 under HIGH I. Since no additional capital investment is needed in the battery industry in 1990, this

Table 3.46. EHV Impacts on Balance of Trade, HIGH II (millions of constant 1979$)[a]

EIA Oil Scenario[c]	Materials Price Scenario[b]			
	Best Case	Strong/Weak Case	Half Case	Worst Case
1985				
A	49.71	39.40	44.55	39.40
B	67.75	57.45	62.60	57.45
C	33.04	22.74	27.89	22.74
D	20.18	9.88	15.03	9.88
E	15.24	4.93	10.08	4.93
1990				
A	17.20	-568.20	-275.80	-568.20
B	-31.62	-617.00	-324.60	-617.00
C	-104.10	-689.50	-397.10	-689.50
D	-203.00	-788.40	-496.00	-788.40
E	-254.50	-839.90	-547.50	-839.90
2000				
A	15,220.00	15,220.00	3,018.00	-9,185.00
B	13,860.00	13,860.00	1,657.00	-10,550.00
C	6,928.00	6,928.00	-5,278.00	-17,480.00
D	1,550.00	1,550.00	-10,660.00	-22,860.00
E	-659.60	-659.60	-12,870.00	-25,070.00

[a] Dollars of net oil saved (oil saved minus the oil used in generating required electricity to fuel EHVs) minus dollars of materials imported (assuming recycle).

[b] See Sec. G.3 for an explanation of materials pricing scenarios.

[c] Ref. 37.

could create significant gearing-up problems. Petroleum refining capital investment is not significantly reduced under any scenario.

Motor vehicle sector capital investment is not changed significantly under any scenario, but problems may develop under the MEDIUM and HIGH scenarios. Although total capital investment does not change, construction or conversion of production lines from CVs to EHVs could cause significant transition problems. The initial decision for conversion must occur a minimum of three years before full-scale production. Decisions to proceed with the seven 400,000-per-year-capacity auto assembly lines required before 2000 for HIGH I would have to be made in 1995 or before. These decisions would have to be made based on the production experience of only one production line. Additional decisions would then have to be made to commit capital in 1996 and 1997 for seven more auto lines to be opened in 2000.[40] Numerous

Table 3.47. Federal Gasoline and Diesel Fuel Taxes Lost Due to EHV Market Penetration in 2000

Scenario and Year	Barrels of Oil Saved (millions)[b]	Revenue Losses Due to EHVs (millions of constant 1979$)	Revenue Loss over BASE Scenario[a] (%)
1985			
LOW I	0.65	1.29	0
LOW II	0.86	1.69	0
MEDIUM	1.05	2.08	0
HIGH I	2.16	4.25	0
HIGH II	2.16	4.25	0
1990			
LOW I	2.41	4.74	0
LOW II	3.41	6.71	0
MEDIUM	5.56	10.95	0
HIGH I	10.50	20.68	0
HIGH II	10.29	20.26	0
2000			
LOW I	42.30	83.34	1
LOW II	68.08	134.12	1
MEDIUM	103.66	204.21	1
HIGH I	357.28	703.84	5
HIGH II	340.47	670.73	5

[a] Actual and estimated federal motor fuel taxes (millions of constant 1979$):

1975	$ 4,927.28
1976	5,287.07
1977	5,430.24
1985	7,268.06
1990	9,188.91
2000	14,825.83

[b] Does not account for oil used in electricity generation which is not subject to these taxes.

additional investment decisions would have to be made in ensuing years, very likely in a climate of intense business difficulty because of the disruptive liquid fuel shortages of the HIGH scenarios.

Total capital investment in the nonferrous processing sector does not change significantly due to EHV commercialization. This sector is aggregated in the input/output model used for analysis so that the tremendous increases in battery materials processing are lost in the gross capital figures. However, significant gearing-up problems could arise in certain battery materials industries. For example, 50% of U.S. zinc smelting capacity has

Table 3.48. Projected Expenditures of Public Funds for Services and Facilities in Iron County, Missouri, 2000

Services and Facilities	Scenario (constant 1979$)						Percentage Change from BASE to:				
	BASE	LOW I	LOW II	MEDIUM	HIGH I	HIGH II	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
Social welfare	3,600	2,600	3,100	2,600	4,100	3,200	-28	-12	-27	15	-9
Hospital	124,200	236,400	289,000	240,300	380,900	299,400	90	133	93	207	141
Police	40,600	69,100	84,500	70,300	111,400	87,600	70	108	73	174	116
Fire	4,000	21,500	26,200	21,800	34,600	27,200	435	555	444	763	578
Sewage	79,300	127,700	156,100	129,800	131,100	161,700	61	97	64	65	104
Solid waste	1,800	18,200	22,200	18,500	29,300	23,000	928	1,156	945	1,556	1,202
Recreation	56,200	99,300	121,400	100,900	160,000	125,800	77	116	80	185	124
Libraries	12,400	25,300	30,900	25,700	40,700	32,000	103	148	106	227	157
General government	29,000	45,500	55,600	46,200	73,300	57,600	57	92	59	153	98
Water treatment	72,000	84,500	96,200	85,400	116,500	98,500	17	34	19	62	37
Education	945,700	1,234,400	1,501,700	1,254,800	1,967,800	1,555,700	31	59	33	108	64
Total	1,368,900	1,964,300	2,387,100	1,996,300	3,049,800	2,471,700	43	74	46	123	81

Table 3.49. Capital Investment Requirements in Selected Industries

		Capital Expenditures (millions of constant 1979$)				Percentage Change from BASE to:	
Industry	Scenario	1977	1985	1990	2000	1990	2000
Tires and tubes	BASE	409	1,284	1,679	1,615	-	-
	LOW I	409	1,284	1,677	1,615	0	0
	LOW II	409	1,284	1,677	1,616	0	0
	MEDIUM	409	1,284	1,679	1,616	0	0
	HIGH I	409	1,284	1,679	1,616	0	0
	HIGH II	409	1,284	1,677	1,616	0	0
Nonferrous processing	BASE	2,397	6,652	8,586	6,419	-	-
	LOW I	2,397	6,650	8,579	6,460	0	1
	LOW II	2,397	6,652	8,578	6,602	0	3
	MEDIUM	2,397	6,652	8,590	6,470	0	1
	HIGH I	2,397	6,654	8,588	6,645	0	4
	HIGH II	2,397	6,654	8,583	6,739	0	5
Electric utilities	BASE	16,659	32,208	44,586	66,053	-	-
	LOW I	16,659	32,207	42,993	66,931	-4	1
	LOW II	16,659	32,217	43,003	67,450	-4	2
	MEDIUM	16,659	32,228	44,191	67,354	-1	2
	HIGH I	16,659	32,242	44,269	71,198	-1	8
	HIGH II	16,659	32,223	43,094	70,349	-3	7
Motor vehicles	BASE	3,940	5,340	6,367	5,544	-	-
	LOW I	3,940	5,340	6,364	5,546	0	0
	LOW II	3,940	5,340	6,364	5,546	0	0
	MEDIUM	3,940	5,340	6,366	5,546	0	0
	HIGH I	3,940	5,340	6,364	5,548	0	0
	HIGH II	3,940	5,340	6,364	5,548	0	0
Batteries	BASE	352	1,049	1,367	937	-	-
	LOW I	352	1,049	1,376	944	1	1
	LOW II	352	1,049	1,367	964	0	3
	MEDIUM	352	1,051	1,369	1,005	0	7
	HIGH I	352	1,051	1,374	1,172	1	25
	HIGH II	352	1,051	1,373	1,038	0	11
Vehicle engines and electrical equipment	BASE	638	1,883	2,135	1,545	-	-
	LOW I	638	1,883	2,132	1,547	0	0
	LOW II	638	1,885	2,132	1,550	0	0
	MEDIUM	638	1,885	2,134	1,547	0	0
	HIGH I	638	1,883	2,132	1,556	0	1
	HIGH II	638	1,883	2,132	1,556	0	1
Petroleum refining	BASE	1,776	2,870	3,158	2,683	-	-
	LOW I	1,776	2,870	3,153	2,678	0	0
	LOW II	1,776	2,870	3,154	2,667	0	-1
	MEDIUM	1,776	2,870	3,156	2,658	0	-1
	HIGH I	1,776	2,870	3,153	2,573	0	-4
	HIGH II	1,776	2,870	3,151	2,598	0	-3
Crude oil production	BASE	2,205	3,265	4,038	4,700	-	-
	LOW I	2,205	3,265	4,038	4,701	0	0
	LOW II	2,205	3,265	4,038	4,689	0	0
	MEDIUM	2,205	3,265	4,038	4,669	0	-1
	HIGH I	2,205	3,265	4,038	4,579	0	-3
	HIGH II	2,205	3,265	4,038	4,595	0	-2

been closed down in the last eight years because of obsolescence and environmental constraints. Therefore, zinc smelting capacity may need to be expanded significantly in some of the scenarios. Lead smelting capacity also will have to be increased, but a number of factors may impede this expansion, including a lack of skilled labor, environmental restrictions, and shortages of investment funds at moderate cost in a capital-intensive industry.

Cobalt capital investment impacts also are lost because of aggregation in the model. If marine or domestic mining occurs, mining and refining capital investment could be substantial. Ocean-mining environmental constraints in California and Hawaii (the two most likely land-based refining locations) could preclude cobalt capital investment.

Nickel investment is similarly lost through aggregation, but severe capital investment impacts could occur under the MEDIUM and HIGH scenarios. Battery-grade nickel is presently made by the carbonyl process by International Nickel Company (INCO) in Clydach, Wales, and Sudbury, Ontario, Canada (Copper Cliff). Table 3.50 shows estimates of additional industry capital requirements and lead times with various levels of additional EHV nickel demand. Table 3.51 shows that new battery decomposers would be required for all scenarios after 1985. (A battery decomposer takes approximately two years to construct and is a unit in which nickel carbonyl gas is decomposed to obtain battery-grade powder.) New carbonyl refineries would be required for all scenarios in 2000. Ni/Zn EHVs in the MEDIUM and HIGH scenarios would mean a new carbonyl refinery in 1990. These plants take from three to four years to construct. The HIGH scenarios require new mines in 1990 and the MEDIUM scenario a new mine in 2000. New mines take 10 yr to construct. There is now no nickel recycling process to produce battery-grade nickel, but research is being conducted.

Lithium capital investment impacts also are lost through aggregation. The HIGH I scenario shows a 1285% increase in demand for lithium in 2000 over the demand that would occur with continuation of present growth rates. For

Table 3.50. Nickel Industry Capital Process Requirements at Various Levels of Increased EHV Demand[a]

Additional Nickel Demand (Thousands of short tons)	New Battery Decomposers	New Carbonyl Refineries	New Mines
1	No	No	No
5	Yes	No	No
25	Yes	Yes	No
50	Yes	Yes	Yes

[a] Approximate lead times required to complete a capital investment project are: (1) 2 yr for a battery decomposer, (2) 3-4 yr for a carbonyl refinery, and (3) 10 yr for a new mine.

Table 3.51. EHV Nickel Demand without Recycling and Capital Requirements

Scenario	Year	Required Nickel (short tons)	New Battery Decomposers	New Carbonyl Refineries	New Mines
LOW I	1985	58	No	No	No
	1990	1,530	Yes	No	No
	2000	48,056	Yes	Yes	No
LOW II	1985	58	No	No	No
	1990	1,530	Yes	No	No
	2000	48,056	Yes	Yes	No
MEDIUM	1985	2,616	Yes	No	No
	1990	23,545	Yes	Yes	No
	2000	508,856	Yes	Yes	Yes
HIGH I	1985	2,809	Yes	No	No
	1990	64,471	Yes	Yes	Yes
	2000	1,331,073	Yes	Yes	Yes
HIGH II	1985	2,809	Yes	No	No
	1990	69,423	Yes	Yes	Yes
	2000	1,718,675	Yes	Yes	Yes

a small industry, such major increases in capital investment would be impossible to achieve.

The above results reflect capital investment requirements without recycling of battery materials. The impacts on capital investment requirements with 95% battery material recycling are difficult to assess but are probably similar to those discussed above, although less investment in mining would be required.

3.11 RELATIONSHIP BETWEEN NATIONAL AND LOCAL SHORT- AND LONG-TERM IMPACTS

This EA addresses the long-term (1985-2000) impacts of alternative EHV market penetration scenarios on a broad range of environmental subsystems. Impacts occurring under the HIGH scenarios in 2000 represent worst-case impacts. Potential impacts beyond 2000, when there may be significantly more EHVs than the 24 million postulated for the HIGH scenarios, are not addressed. Short-term consequences of the DOE EHV demonstration program currently underway and those resulting from the inclusion of EVs in CAFE calculations are addressed in two earlier EAs.[1,2]

On a national scale, EHV market success could result in substantial supply and demand imbalances for nickel, cobalt, zinc, and lithium. In addition, it could lead to significant gearing-up and transition problems for the nickel, cobalt, zinc, lithium, lead, battery, and motor vehicle industries. Major EHV materials prices could increase substantially. Expenditures for imported EHV materials could be considerably greater than the dollars saved from reduced oil imports. EHV market penetration also could lead to small increases in SO_x generation, thereby adding to the national trend of increasing SO_x emissions. This will increase public health exposure to SO_x. Substantial increases in cost of travel for persons owning and operating EHVs could occur that are over and above the increases that could occur for CV owners and operators. Significant decreases in the amount of federal motor vehicle fuel tax collected could occur unless compensating taxes are levied. Total national employment should not be affected by use of EHVs, but important changes in several economic sectors could occur. For example, employment in U.S. crude oil production could decline substantially. While a very small increase in work-related injuries and illnesses over the BASE scenario might occur, some individual economic sectors (principally the battery industry) could incur major increases.

On a local scale (including individual sites, urban areas, and specific geographical regions), EHV market penetration could have substantial impact. Increases in SO_x greater than those at the national level could occur in specific urban areas. Major increases in water pollutant levels could occur, especially in areas where EHV materials and fuels are extracted and processed and where EHVs are manufactured. In some areas, high incremental solid waste volumes and substantial land use needs for solid waste disposal and other EHV-related mining and manufacturing requirements are projected. The potential for adverse impacts on local ecosystems is increased. The potential also exists for adverse impacts on public health resulting from human exposure to various air pollutants, water pollutants, and solid waste in specific areas. Increased demand for electricity resulting from use of EHVs may result in utilities in a few select geographical areas having to expand their generating capacity. Also, significant local employment changes are possible, which could cause substantial impacts on area wages and local government expenditures, and changes in the local social setting. Some examples of these changes are growth in population, in-migration, and social problems associated with "boom towns."

On the positive side, EHVs result in substantial petroleum savings. In addition, their market penetration could lead to reductions in NO_x, CO, HC, and particulates, both nationally and locally, which will reduce public health exposure to these pollutants. Beneficial though minor impacts on urban traffic noise may also occur.

There are some environmental subsystems in which EHVs have virtually no impact either on a national or local level. For example, while further evaluation of many public safety concerns is still needed, all public safety concerns are expected to be mitigated by standards promulgated by appropriate regulatory agencies as EHV development proceeds. Further, EHVs are expected to have little or no impact on many elements of the transportation infrastructure (e.g., roadway infrastructure, highway use, safety regulations, and existing financial and insurance institutions). There are also some subsystems in which the impacts are quite mixed. In particular, EHV impacts on mobility, urban structure, and lifestyle (which are very difficult to evaluate) may be both beneficial and adverse.

3.12 IRREVERSIBLE AND IRRETRIEVABLE COMMITMENT OF RESOURCES

Resources (metals, fuels, and land) will be committed to the production and operation of EHVs, partly to offset the irretrievable commitment to CVs of crude oil, a scarce domestic resource. Commitment of most metals to EHV manufacture should not be viewed as irretrievable, because metals recycling is likely to be technologically feasible if not always economically attractive. However, recycling technologies need further study. The only truly irrevocable resource commitments associated with market penetration of EHVs through 2000 involve fuels (coal, oil, natural gas, and uranium) and land. EHVs use considerably less petroleum than CVs. While use of coal is an inescapable and irreversible commitment, it is consistent with current national policy to substitute coal for petroleum. Use of uranium in light water reactors, which generate up to 40% of the electricity required by EHVs in 2000, also represents an irretrievable commitment. Natural gas consumption by EHVs is small. Additional land is required for EHV-related waste disposal, mining, and manufacturing. Although some of this land may be reclaimed eventually, development may be restricted by its prior use.

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ACKNOWLEDGMENTS

Many individuals contributed to the preparation of this document. The authors would like to thank those who provided assistance in the analysis performed for this assessment, those who have reviewed and helped refine this report, and those who have helped write, edit, type, and publish the final document. Many of these individuals are listed in Appendix I. In particular, we would like to thank the project sponsor, Dr. Daniel P. Maxfield, of DOE's Office of Transportation Programs whose guidance, support, and substantive contributions have been essential in all phases of the preparation of this assessment.

APPENDIX A*

MARKET PENETRATION SCENARIOS

This appendix presents the EHV market details for each of the five scenarios described in Sec. 2. Figure A.1 illustrates the process used to develop these details.

A.1 SCENARIO VARIABLES

Tables A.1-A.3 summarize the variables that drive each scenario.

A.2 VEHICLE PENETRATION RATES

A.2.1 Market Penetration Curves

Figure A.2 shows the EHV growth curves for the five scenarios through market saturation, which is expected to occur about 2020. The curves are calculated using the Mansfield-Blackman model, which is often used to forecast technological substitution in the transportation sector.[A.1] The model is:

$$\ln \frac{M_t}{L - M_t} = b(t - t_o) \qquad (A.1)$$

where:

M_t = market share at any year t other than t_o,

t_o = year of 50% penetration of the final market,

L = final market share at market saturation, and

b = constant governing the rate of substitution.

Model calibration data are given in Table A.4.

A.2.2 Plausibility of the HIGH Scenarios

A scenario, by definition, must be internally consistent and plausible. The HIGH scenarios have sufficient EHVs on the road in 2000 to cause impacts of reasonable magnitude. They are consistent, because they are based on strong governmental incentives for EHVs and disincentives for CVs and on substantial liquid fuel shortfalls. Plausibility, however, has to be considered from several perspectives. Of primary interest is whether the scenarios are physically possible. For example, one factor to be considered is whether there can be enough raw materials available at reasonable

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*The appendices supplement Secs. 2 and 3. Therefore, the appropriate parts of those sections should be read along with each appendix.

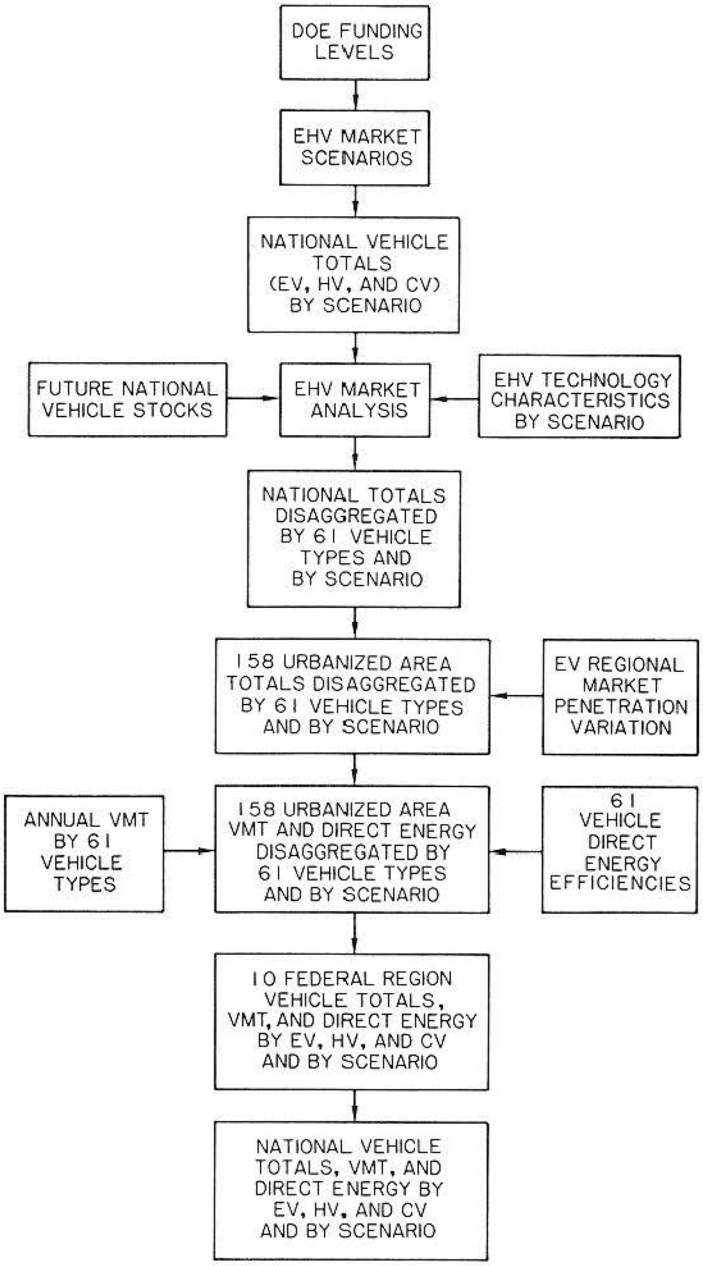

Fig. A.1. Flow of the Process Used to Develop the EHV Market Scenarios

prices to make the batteries required and whether there can be sufficient production facilities for the materials. As demonstrated in Sec. 3.2 and App. C, the availability of raw materials places real constraints on accomplishing not only the HIGH scenarios but even the MEDIUM scenario.

Vehicle production requirements also are a factor. The maximum market for EHVs in 2020 probably will be over 200 million vehicles. The HIGH scenarios state that half of these will be EHVs, many of which will be very high performance EHVs. They also state that the EHV fleet will increase by

Table A.1. LOW I and LOW II Scenario Variables

Event	1985	1990	2000
DOE EHV program	Demonstration in last phase; R&D program funding low; no successful new battery system developed.	None; Pb/acid remains the main battery; EV range remains approximately 50-60 mi.	None; Ni/Zn batteries beginning to capture new EV sales, but Pb/acid remains the HV battery because of cost considerations.
Federal air quality program	No impact on EHV commercialization.	Mildly encouraging for EHV commercialization.	CVs (including very clean and advanced Stirling and gas turbine [Brayton] engines) become environmentally acceptable; no EHV emphasis.
Federal alternative fuels and alternative engine programs	R&D results in demonstration of broad-cut petroleum and alcohol fuels; petroleum still relatively cheap and abundant; expenditures high in both programs.	Alcohols and broad-cut petroleum fuels make significant penetration in several transportation markets, while gasoline and diesel fuel continue to serve remainder; Stirling and/or Brayton engines 30% of new vehicle market; expenditures high.	Sufficient liquid fuels to meet all transport needs; expenditures remain high; the few Otto cycle engines that remain in transportation use are small, clean, and quite efficient.
Private sector EHV activity	Several small domestic firms and a few foreign manufacturers making a wide variety of vehicles.	Large domestic firms enter market; mass production about to begin.	Foreign and many small domestic firms for special EHV applications; a few domestic mass production lines in operation.
Utility time-of-day pricing	Scattered, although legislation to encourage such a scheme passed in 1979.	Scattered.	Scattered.

Table A.2. MEDIUM Scenario Variables

Event	1985	1990	2000
DOE EHV program	Demonstration extended for one more buy; R&D results in demonstration and initial sales of both Ni batteries; large incentives to small firms; incentives to buyers begin.	Ni/Zn and Pb/acid batteries share market; Li/S battery begins market penetration; incentive programs increase.	Li/S battery gains substantial share of vehicle market, DOE program ends in 1997.
Federal air quality program	Mildly encouraging for EV commercialization.	Three eastern and Los Angeles CBDs have CV-free zones; all government fleets begin to use EHVs.	Several CV-free zones; all government fleets have many EVs; control technology limits CV performance somewhat.
Federal alternative fuels and alternative engine programs	Environmental problems slow both programs but expenditures remain high; petroleum still relatively cheap and abundant.	Demonstrations of fuels and engines successful; penetration starts; petroleum prices rise; EVs remain in CAFE calculations.	Otto cycle on petroleum-based fuels has 50% of CV market; liquid fuel costs relatively high; expenditures in both programs remain high.
Private sector EHV activity	Several small firms and a few manufacturers making a wide variety of vehicles; General Motors about to make serial vehicles.	Mass production begins; large domestic firms dominate; small firms carve out special vehicle markets.	Large domestic firms dominate EV market; small firms dominate in special markets.
Utility time-of-day pricing	Scattered but growing.	At most northeast and midwest utilities.	In most urban areas; encourages EV automobile market.

Table A.3. HIGH I and HIGH II Scenario Variables

Event	1985	1990	2000
DOE EHV program	Demonstration extended for one more buy; R&D results in initial applications of Ni/Zn and demonstration of Li/S batteries; incentives to small firms are large and also available to users directly for operating costs.	Ni/Zn vehicles dominate new vehicle market; R&D results in competitive vehicle in many markets; Li/S vehicles begin their EV penetration; R&D expenditures remain high.	Due to downgrading of CVs, EHV competitive in most markets; for EVs Li/S and Ni/Zn batteries share market, Ni/Zn dominates for HVs, but Pb/acid still holds a few applications; DOE program ends in 1998.
Federal air quality program	States write EHVs into state implementation plans (SIPs); quite encouraging.	Most major CBDs and several other air quality hot spots are CV-free zones with EHVs allowed; EHVs also given preferential parking authority; most new government vehicles are EHVs.	Government fleets essentially all EHVs, air quality quite high.
Federal alternative fuels and alternative engine programs	Environmental problems slow both programs; expenditures remain high; many predict a petroleum crisis as prices continue a strong rise; gas tax increased significantly to discourage use.	Only alcohols are being demonstrated; new heat engine R&D advances below 1980 expectations; alternative fuel expenditures remain high but heat engine R&D tapering off; EHVs remain in CAFE calculations.	Both programs face many technical and environmental barriers, progress is slow; Otto engine dominates CV market burning very scarce petroleum-based fuels and alcohols; expenditures moderate.
Private sector EHV activity	R&D strong and all major manufacturers producing serial vehicles; many small firms and foreign manufacturers make a wide variety of vehicles.	Large domestic manufacturers two years into mass production and dominate new EHV sales; foreign manufacturers gain large share also; small firms focus solely on specialized vehicles.	Mass-produced vehicles totally dominate EHV market; for the last decade, every production line nearing economic maturity converted to EHV production.
Utility time-of-day pricing	At most northeast and midwest utilities.	In all urban areas, EHVs thereby encouraged; EHV owners also get discounts subsidized by government.	Nationwide.

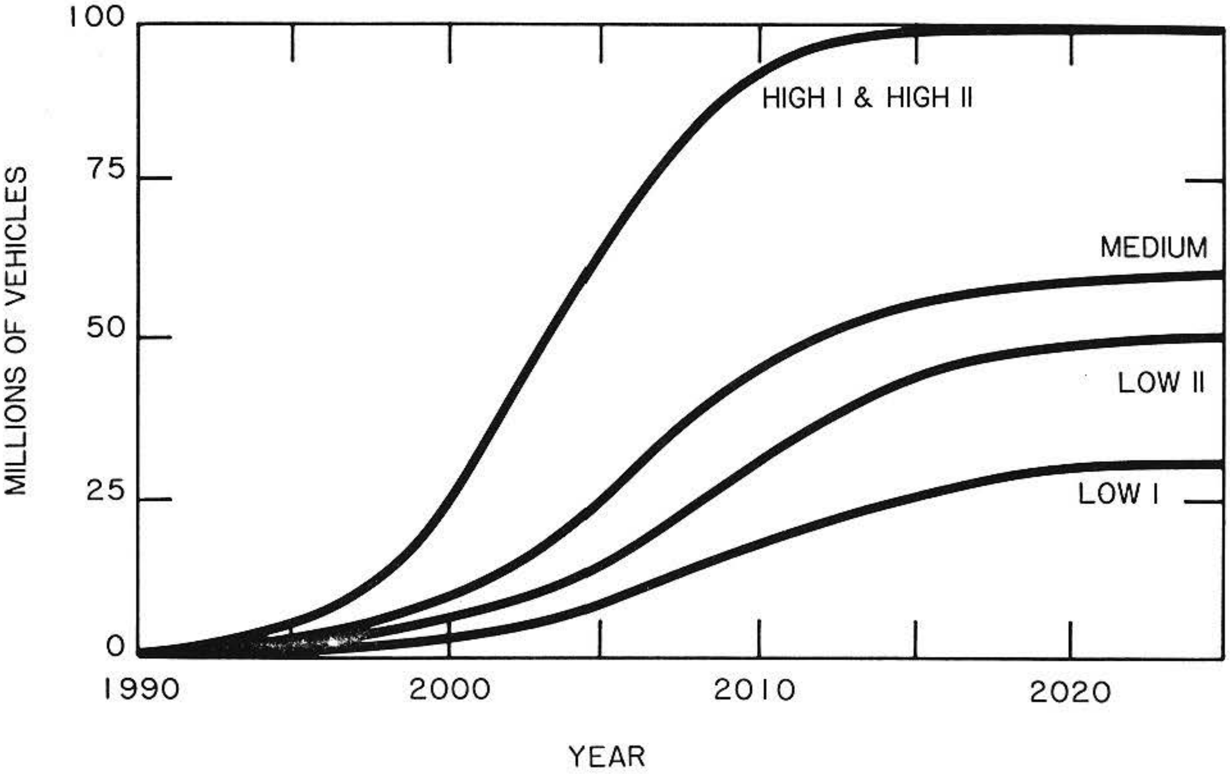

Fig. A.2. EHV Market Penetration, 1990-2025

Table A.4. Model Calibration Data

Scenario	Vehicle Type	10^6 L	10^6 M_t	b	t_o	t
LOW I	Electric	30	3.0	0.275	2008.0	2000
LOW II	Electric	30	3.0	0.275	2008.0	2000
	Hybrid	20	2.0	0.314	2007.0	2000
MEDIUM	Electric	60	8.0	0.312	2006.0	2000
HIGH I	Electric	100	24.0	0.349	2003.3	2000
HIGH II	Hybrid	50	6.545	0.421	2004.5	2000
	Electric	a	a	a	a	a

[a] The number of electrics in HIGH II is the number of electrics in HIGH I minus the number of hybrids in HIGH II.

nearly 20 million between 1995 and 2000 and that eight million will be produced in 2000, when total production of conventional vehicles for which EHVs could be substituted will be about 16.7 million vehicles. In approximately 2003, almost every small truck and school and transit bus produced will be an EHV. Figures A.3 and A.4 show two recent technological substitutions in the transportation sector.[A.2] In both these examples, market saturation occurs more rapidly and is more complete than that predicted for the HIGH scenarios. In 2000 under the HIGH scenarios, EHVs account for approximately 50% of the vehicles sold in the market comprising conventional vehicles for which EHVs could be substituted. Very strong economic incentives are assumed necessary for substitution to occur at the rates shown in Figs. A.3 and A.4. An analysis of the U.S. production lines required to produce the domestic portion of these vehicles does indicate that sufficient numbers of CV lines would be available, assuming the 10-20 yr economic life of present production facilities.

Technological advances are yet another factor. Major advances in both the Ni/Zn and Li/S battery systems are postulated in the HIGH scenarios. Solely from a technological viewpoint, the probability of achieving these scenarios is less than 20%.

A.2.3 Types of EHVs under Each Scenario

Table A.5 presents the forecast of both on-the-road totals and sales of conventional vehicle for which EHVs could be substituted. The totals exclude medium and heavy trucks and intercity buses. (Table 2.2 presents EHV totals and sales by scenario.) For EVs, the markets penetrated are based on the range requirements of each market and the availability and suitability of the characterized EVs. HV market penetration is not constrained by range requirements. The details for each market and vehicle type are given in subsequent tables in this appendix. Table A.6 presents the distribution of battery types by vehicle type and scenario.

Sales in a given year are calculated by:

$$S_t = c\ V_t - V_{t-10} + S_{t-10} + G_t \qquad (A.2)$$

where:

S_t = sales in year t,

V_t = total vehicles at the beginning of t,

G_t = increase in EVs or HVs at t due to their substituting for CVs ($M_{t+1} - M_t$ from Eq. A.1), and

c = constant related to the rate of growth.

Implicit in Eq. A.2 is an average 10-yr life cycle for future EHVs. Although term S_{t-10} appears to account for this, a correction must be made because the distribution of EHVs with age in any year is skewed toward newer vehicles. Since a disproportionate number of newer vehicles are being replaced due to accidents, an adjustment is accomplished by the term $c(V_t - V_{t-10})$. The constant c is found by applying the actual survival rates to several age distributions: it is 0.030 for calculating 1990 EHV sales and 0.043 for 2000 EHV sales.

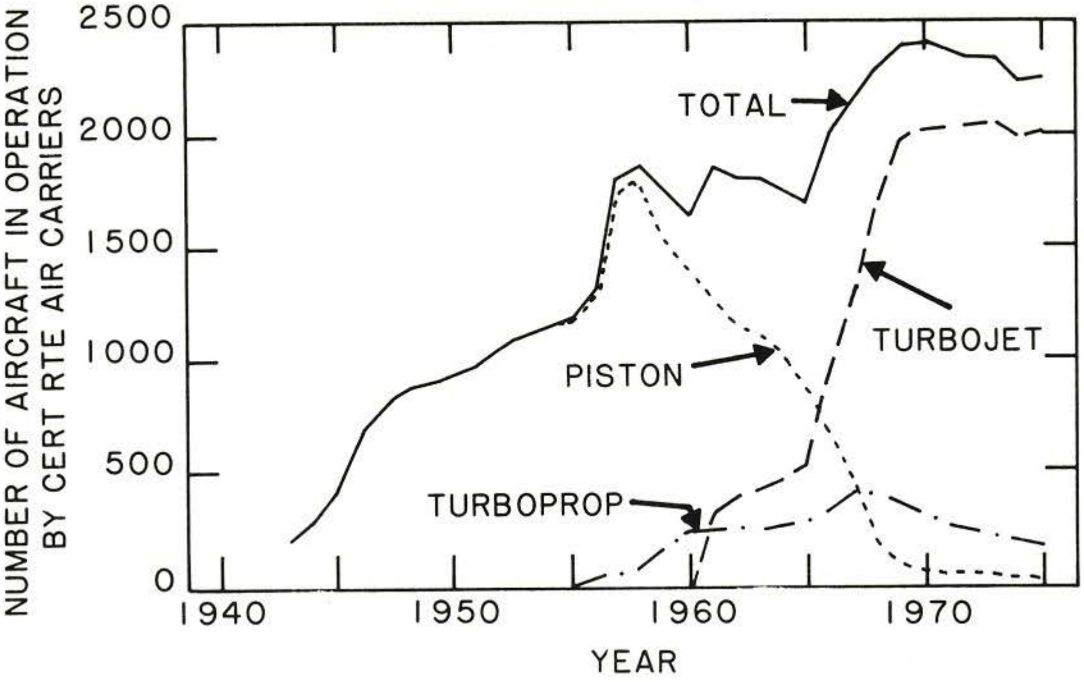

Fig. A.3. Substitution of Jet Commercial Planes for Piston Planes (Source: Ref. A.2)

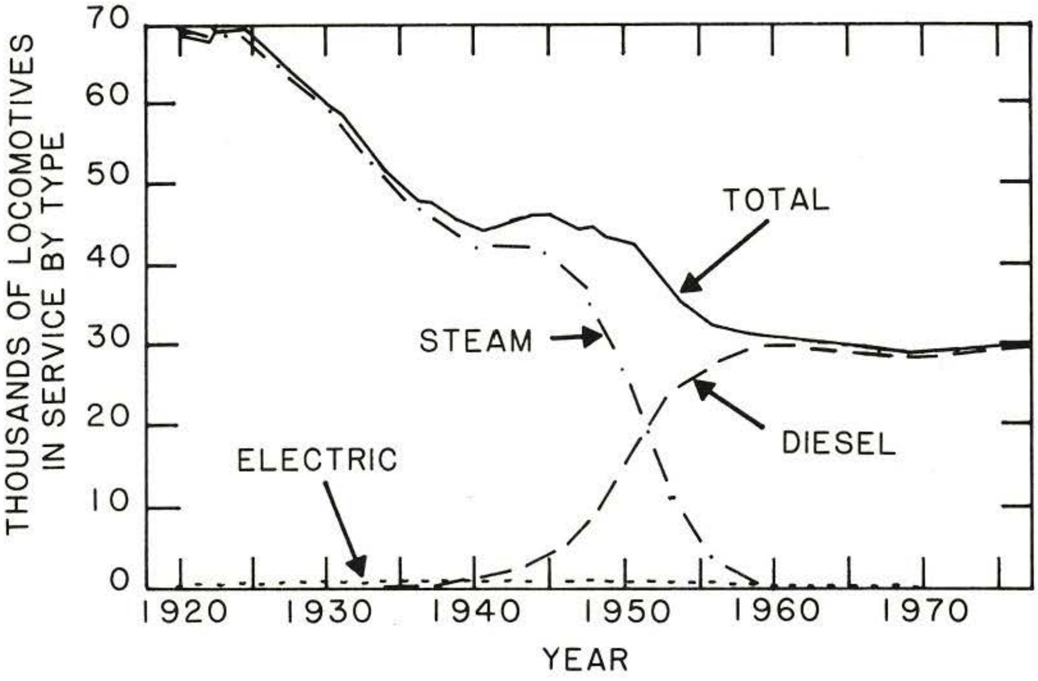

Fig. A.4. Substitution of Diesel Railroad Locomotives for Steam Locomotives (Source: Ref. A.2)

Table A.5. CVs for Which EHVs Could Be Substituted by Type, 1975-2000 (10^3)

				2000	
Vehicle Type	1975	1985	1990	LOW I and II, MEDIUM	HIGH I and II[a]
Truck totals					
Personal[b]	10,300	20,800	22,600	26,900	26,500
Nonpersonal[b]	9,000	12,700	14,600	16,300	16,300
Total	19,300	33,500	37,200	43,200	42,800
Truck sales	2,100	3,700	4,300	4,500	4,460
Bus totals					
Small[c]	33	69	80	86	95
Large[d]	384	400	440	490	505
Total	417	469	520	576	600
Bus sales	38	43	47	54	60
Auto totals					
Small[e]	30,500	45,400	47,900	53,400	54,500
Large[f]	64,700	68,100	71,800	80,200	77,000
Total	95,200	113,500	119,700	133,600	131,500
Auto sales	8,640	11,600	12,200	13,300	12,200
Total vehicles	114,900[g]	147,500	157,400	177,400	174,900
Total sales	10,778	15,300	16,500	17,900	16,700

[a] By 2000, the HIGH scenarios show a shift to public transportation (both urban and intercity), which accounts for the differences in vehicles and sales from the LOW and MEDIUM scenarios.

[b] All weights to 10,000 lb.

[c] School and transit.

[d] School and transit but excluding intercity.

[e] Four-passenger or less.

[f] Five-passenger or more.

[g] Columns do not always sum because of rounding.

Source: Ref. A.3.

Table A.6. Distribution of Battery Types by Vehicle and Scenario (%)[a]

Scenario	Vehicle Type	Pb/Acid			Ni/Fe			Ni/Zn			Li/S		
		1985	1990	2000	1985	1990	2000	1985	1990	2000	1985	1990	2000
LOW I	Truck												
	Small	95	89	82	b	b	b	4	10	17			
	Medium	95	89	82	b	1	1	4	10	17			
	Large	c	90	85	c	b	1	c	10	14			
	Bus												
	Small	c	97	90	c	c	c	c	3	10		NA[d]	
	Large	c	c	92	c	c	1	c	c	7			
	Auto												
	Small	98	90	80	b	2	2	1	8	12			
	Large	98	90	80	b	2	2	1	8	12			
MEDIUM	Truck												
	Small	80	30	15	2	1	b	18	64	74	NA[d]	5	10
	Medium	80	30	15	2	1	b	18	64	74	NA	5	10
	Large	c	40	20	a	b	c	c	58	70	NA	2	10
	Bus												
	Small	c	50	30	c	b	c	c	48	60	NA	1	10
	Large	c	40	20	c	1	1	c	59	67	NA	c	12
	Auto												
	Small	75	30	10	2	b	b	23	67	69	NA	2	20
	Large	75	30	10	2	b	b	23	67	69	NA	2	20
HIGH I	Truck												
	Small	75	29	14				25	61	53	c	10	33
	Medium	75	29	15				25	61	53	c	10	32
	Large	77	39	15				23	51	53	c	10	32
	Bus												
	Small	40	20	9		NA[d]		60	70	66	c	10	25
	Large	c	20	7				c	70	73	c	10	20
	Auto												
	Small	70	15	10				30	70	55	c	15	35
	Large	70	15	10				30	70	55	c	15	35

[a] The HVs of LOW II use Pb/acid batteries, and the HVs of HIGH II use Ni/Zn batteries. There are no Li/S EVs in HIGH II.

[b] Less than 1%.

[c] Less than 100 EVs of this type.

[d] Battery not available.

For any particular vehicle battery combination, Eq. A.2 can be written with every element having a subscript i that designates the particular combination. For example, for a Pb/acid four-passenger car, S_{t_i} designates sales of that vehicle and $\sum_i S_{t_i} = S_t$. Eq. A.2 would hold if the particular i were following the same growth pattern as the sum of all the EHVs in the scenario. However, this is seldom the case. In later years, this Pb/acid four-passenger car may have no sales because a better, advanced battery car is on the market. This advanced car would have not only its own growth by substituting for CVs but would replace any similar Pb/acid cars being retired. This accounting process is evident in the subsequent tables in this appendix and is described further at the end of Sec. A.2.3.1.

Table A.7. Conventional Trucks for Which EHVs Could Be Substituted by Use, Annual Miles, and GVW, 1975-2000

GVW[a] (lb)	Miles per year (10^3)	Personal Use (10^3) 1975	1985	1990	2000	Nonpersonal Use (10^3) 1975	1985	1990	2000
Light 0-4,500	0-6	320	1,590	2,170	3,310	180	640	910	1,300
	6-10	250	1,270	1,730	2,630	170	610	870	1,250
	10-15	130	630	850	1,300	130	460	650	940
	15-20	130	660	900	1,370	240	840	1,220	1,730
Medium 4,501- 7,500	0-6	3,160	5,540	5,640	6,190	1,800	2,220	2,370	2,440
	6-10	2,520	4,450	4,490	4,940	1,730	2,130	2,270	2,340
	10-15	1,246	2,200	2,220	2,440	1,300	1,600	1,710	1,760
	15-20	1,310	2,310	2,340	2,570	2,370	2,930	3,140	3,240
Heavy 7,501- 10,000	0-6	470	800	860	830	270	320	360	330
	6-10	380	640	690	660	260	300	350	310
	10-15	190	330	340	320	190	230	260	230
	15-20	200	330	310	340	360	420	490	430
Total		10,300[b]	20,800	22,600	26,900	9,000	12,700	14,600	16,300

[a] Gross vehicle weight of conventional truck.

[b] Columns do not always sum because of rounding.

Source: Ref. A.3.

A.2.3.1 EV Light Truck Markets

This section presents the details of how the EV light truck markets are defined. For the 18 EV light trucks characterized in App. B and numbered LT1 (light light truck 1) through HT6 (heavy light truck 6), the method is as follows. Table A.7 gives the future size of truck markets in which EHVs could be substituted by annual miles, GVW, and use. Table A.8 gives EV truck substitution by use, GVW, and characterization number. This latter table is derived by analysis of the required annual mileage shown in Table A.7 and the light EV trucks available as characterized in App. B in each year of each scenario. Fleet owners with some vehicles with easy vehicle missions (i.e., less than 6000 mi/yr) can accept limited-range EV light trucks for a portion of their fleet. However, EVs can never substitute for the trucks in Table A.7 with the highest annual mileage, even in the later years of HIGH I.

Table A.9 gives EV truck totals and sales by scenario and characterization number. Of the 43 million trucks for which EHVs could have been substituted, two million in LOW I and 13 million in HIGH I are EVs. In LOW I all two million are in nonpersonal use (wholesale, utility, manufacturing, government, etc.); in HIGH I, 72% are in nonpersonal use. In LOW I all of these vehicles can be accommodated in tasks that require less than 10,000 mi/yr (40 mi/workday for a 250-workday year). All of these trucks could be Pb/acid vehicles, if no other battery were developed. The later years of the higher scenarios do show penetration by longer-range trucks into personal-use markets with higher daily and annual mileage requirements.

Table A.8. EV Truck Totals by Use and by Scenario[a]

GVW[b] (lb)	Truck No.[c]	LOW I (10^3)						MEDIUM (10^3)						HIGH I (10^3)					
		Personal			Nonpersonal			Personal			Nonpersonal			Personal			Nonpersonal		
		1985	1990	2000	1985	1990	2000	1985	1990	2000	1985	1990	2000	1985	1990	2000	1985	1990	2000
Light 0–4,500	LT1	0[d]	0	0	14.3	45.6	651	0	0	7.5	17.6	22.8	230	0	0.4	0.2	34.5	47.7	600
	LT2	0	0	0	0.1	0.5	7.9	0	0	0	0.4	0.8	15.3	NA[e]	NA	NA	NA	NA	NA
	LT3	0	0	0	0.6	1.0	15.9	0	0	0	4.0	38.0	460	0	3.3	2.0	11.5	39.8	30.0
	LT4	0	0	0	0	4.2	119	0	0	22.5	0	10.6	675	0	3.5	366	0	55.7	1800
	LT5	NA	NA	NA	NA	NA	NA	NA	0	2.0	NA	3.8	153	0	0.8	181	0	12.7	150
	LT6	NA	NA	NA	NA	NA	NA	NA	0	0	NA	0	0	NA	0	647	0	3.2	420
Medium 4,501–7,500	MT1	0	0	0	18.1	66.9	951	0	0	15.0	26.4	44.7	419	0	0.8	0.3	50.3	90.6	1140
	MT2	0	0	0	0.1	0.8	11.6	0	0	0	0.6	1.5	27.9	NA	NA	NA	NA	NA	NA
	MT3	0	0	0	0.8	1.5	23.2	0	0	0	6.0	74.5	838	0	6.6	3.0	16.7	75.5	56.8
	MT4	0	0	0	0	6.1	174	0	0	45.0	0	20.9	1230	0	7.0	720	0	106	3410
	MT5	NA	NA	NA	NA	NA	NA	NA	0	5.0	NA	7.5	279	0	1.6	356	0	24.2	284
	MT6	NA	NA	NA	NA	NA	NA	NA	0	0	NA	0	0	NA	0	1080	0	6.0	795
Heavy 7,501–10,000	HT1	0	0	0	0	2.7	39.1	0	0	0.8	0	8.0	65.2	0	0.2	0	2.3	15.6	144
	HT2	0	0	0	0	0	0.5	0	0	0	0	0.1	0	NA	NA	NA	NA	NA	NA
	HT3	0	0	0	0	0.3	4.6	0	0	0	0	9.0	97.8	0	0.3	0.1	0.7	7.8	21.6
	HT4	0	0	0	0	0	1.8	0	0	2.2	0	2.6	130	0	0.5	74.9	0	11.7	418
	HT5	NA	NA	NA	NA	NA	NA	NA	0	0	NA	0.4	32.6	0	0	50.0	0	3.1	36.0
	HT6	NA	NA	NA	NA	NA	NA	NA	0	0	NA	0	0	NA	0	123	0	0.8	101

[a] LOW II has the same number and type of EV trucks as LOW I. HIGH II has the same number and type of EV trucks as HIGH I, except that there are no Li/S EV trucks (LT5, LT6, MT5, MT6, HT5, and HT6) in HIGH II.

[b] Gross vehicle weight of comparable conventional truck.

[c] See App. B for characteristics of each truck type.

[d] A zero means less than 100 vehicles.

[e] Not available.

Table A.9. EV Truck Totals and Sales by Scenario[a]

GVW[b] (lb)	Truck No.[c]	LOW I (10^3)						MEDIUM (10^3)						HIGH I (10^3)					
		Totals			Sales			Totals			Sales			Totals			Sales		
		1985	1990	2000	1985	1990	2000	1985	1990	2000	1985	1990	2000	1985	1990	2000	1985	1990	2000
Light 0–4,500	LT1	14.3	45.6	651	4.3	18.0	207	17.6	22.8	238	1.5	2.8	95.6	34.5	48.1	600	3.2	12.2	235
	LT2	0.1	0.5	7.9	0.05	0.23	2.0	0.4	0.8	15.3	0.16	0.38	5.1	NA[d]	NA	NA	NA	NA	NA
	LT3	0.6	1.0	15.9	0.11	0.44	5.5	4.0	38.0	460	7.3	10.7	159	11.5	43.1	32.0	6.4	4.5	0
	LT4	0[e]	4.2	119	0	1.1	47.0	0	10.6	698	0	7.1	233	0	59.2	2170	0	36.3	661
	LT5	NA	NA	NA	NA	NA	NA	NA	3.8	155	NA	0.88	62.7	0	13.5	331	0	12.8	121
	LT6	NA	NA	NA	NA	NA	NA	NA	0	0	NA	0	0	NA	3.2	1070	NA	4.7	335
Medium 4,501–7,500	MT1	18.1	66.9	951	5.4	18.6	279	26.4	44.7	434	4.4	10.0	163	50.3	91.4	1140	19.2	32.5	325
	MT2	0.1	0.8	11.6	0.06	0.41	3.6	0.6	1.5	27.9	0.16	0.44	11.3	NA	NA	NA	NA	NA	NA
	MT3	0.8	1.5	23.2	0.13	0.52	8.83	6.0	74.5	838	7.3	28.4	314	16.7	81.2	59.8	8.9	5.2	0
	MT4	0	6.1	174	0	2.3	72.5	0	20.9	1270	0	16.7	485	0	113	4130	0	74.3	1680
	MT5	NA	NA	NA	NA	NA	NA	NA	7.5	284	NA	5.7	101	0	25.8	640	0	18.4	201
	MT6	NA	NA	NA	NA	NA	NA	NA	0	0	NA	0	0	NA	6.0	1870	NA	8.2	642
Heavy 7,501–10,000	HT1	0	2.7	39.1	0	1.2	11.8	0	8.0	66.0	0	3.6	20.0	2.3	15.8	144	1.9	5.3	40.5
	HT2	0	0	0.5	0	0	0.12	0	0.1	0	0	0.04	0	NA	NA	NA	NA	NA	NA
	HT3	0	0.3	4.6	0	0.13	1.7	0	9.0	97.8	0	3.8	25.6	0.7	8.1	21.7	0.38	4.3	1.5
	HT4	0	0	1.8	0	0	0.61	0	2.6	132	0	1.1	34.8	0	12.2	493	0	8.7	162
	HT5	NA	NA	NA	NA	NA	NA	NA	0.4	32.6	NA	0.22	9.4	0	3.1	86.0	0	4.2	26.0
	HT6	NA	NA	NA	NA	NA	NA	NA	0	0	NA	0	0	NA	0.8	224	NA	0.6	88.0
Total		34	131[f]	2000	10	43	641	55	245	4750	21	92	1721	116	525	13,000	40	232	4525

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[a] LOW II has the same number and type of EV trucks as LOW I. HIGH II has the same number and type of EV trucks as HIGH I, except that there are no Li/S EV trucks (LT5, LT6, MT5, MT6, HT5, and HT6) in HIGH II.

[b] Gross vehicle weight of comparable conventional truck.

[c] See App. B for characteristics of each truck type.

[d] Not available.

[e] A zero means less than 100 vehicles.

[f] Columns do not always sum because of rounding.

Because of the relative compatability of EV characteristics with nonpersonal-use truck requirements, EV truck penetrations are large when compared to bus and automobile penetrations. While trucks are about 15% of the total vehicle market, they are always more than 50% of the EV market in the assessment years of all scenarios.

Figure A.5 shows the changes in market penetrations of four types of EV trucks for particular scenarios. Using these curves, all the subscripted i terms required to calculate S_{t_i} can be estimated (see Sec. A.2.3).

A.2.3.2 EV Bus and EV Automobile Markets

These markets are developed by methods similar to those discussed in Sec. A.2.3.1. Bus totals and sales are given in Tables A.10 and A.11. Since

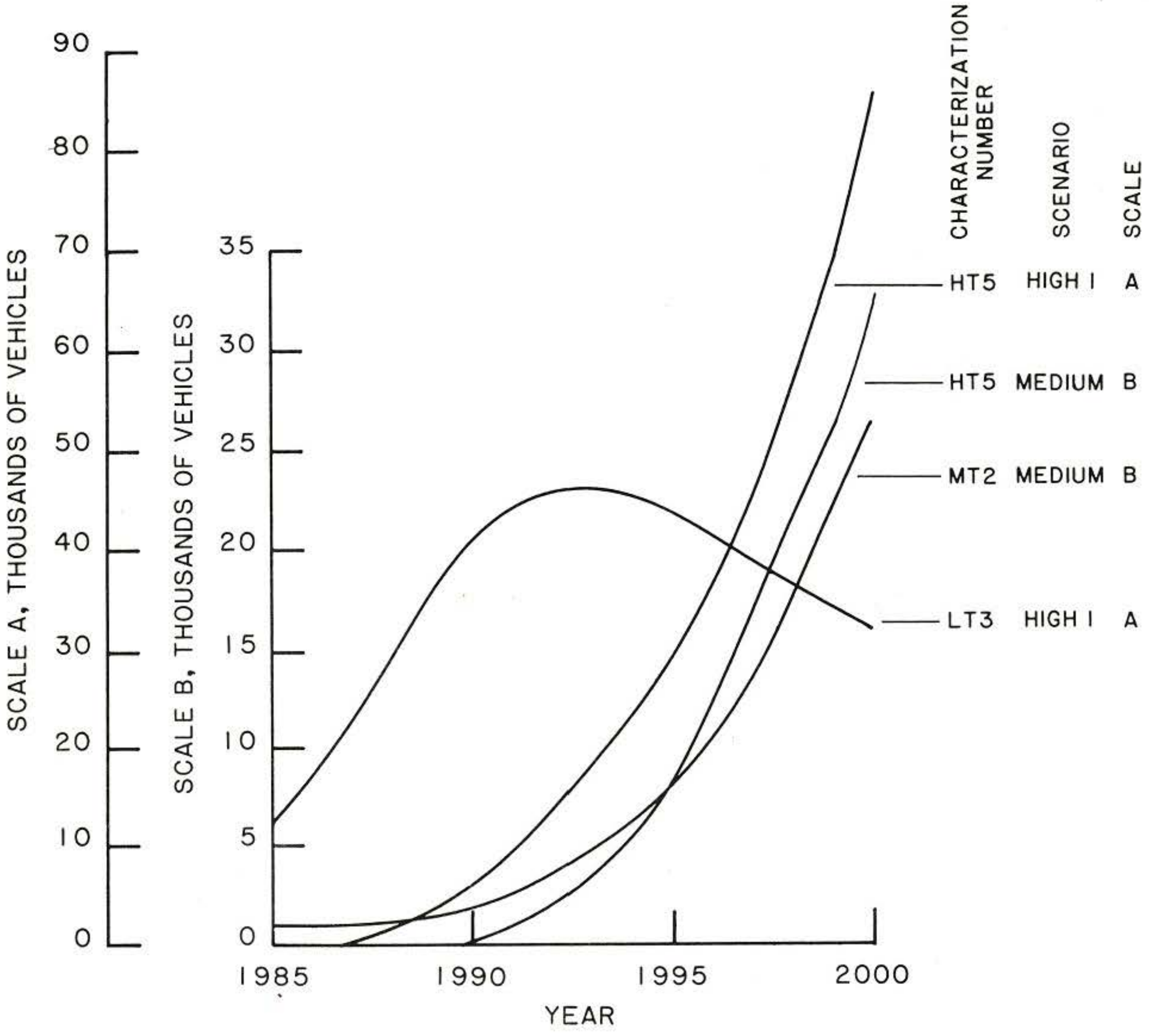

Fig. A.5. Sample EV Truck Totals Used to Calculate Sales the federal government controls the purchase of school and transit buses, these markets are penetration rapidly under MEDIUM and HIGH I. Because of the various ranges required of buses (a large portion can be recharged at midday), this market saturates at about 60%. This percentage is almost achieved as early as 2000 in HIGH I. HIGH II has a lower penatration rate because no HV buses were characterized.

Table A.12 presents EV automobile totals and sales. Recent trends in automobile purchases have been toward less seating capacity per vehicle. By 1985 it is expected that 40% of automobiles will have four or fewer seats. EVs penetrate this market more easily than the larger-car market, because larger cars tend to be the primary vehicle of a household. This factor plus EV range limitations, even under HIGH I, will slow EV penetrations in the large-car market. Thus, the EV automobile market is expected to split about fifty-fifty in terms of the characterized vehicles. The four-passenger vehicle is typical of future small cars and the five-passenger vehicle of larger cars. Two-passenger and six-or-more-passenger cars will become (or remain) specialty items. It is not, however, until the later years of the higher scenarios that more than a few percent of the automobile fleet are EVs. By then the penetration will be by Ni/Zn and Li/S vehicles having longer ranges.

Table A.10. Conventional Buses for Which EHVs Could Be Substituted by Type and Size, 1975-2000 (10^3)

Bus Type	1975	1985	1990	2000
School				
Small	30.9	47.8	53.3	60.1
Large	335	350	391	441
Transit				
Small	1.8	21.2	26.5	26.0
Large	49.0	49.5	49.5	49.5
Total[a]				
Small	32.7	69.0	79.8	86.1
Large	384	400	440	490
Total	417[b]	469	520	576

[a] Excludes intercity and other commercial buses.

[b] Columns do not always sum because of rounding.

Source: Ref. A.3.

Table A.11. EV Bus Totals and Sales by Scenario[a]

Typical GVW[b] (lb)	Bus No.[c]	LOW I (10^3)						MEDIUM (10^3)						HIGH I (10^3)					
		Totals			Sales			Totals			Sales			Totals			Sales		
		1985	1990	2000	1985	1990	2000	1985	1990	2000	1985	1990	2000	1985	1990	2000	1985	1990	2000
Small 10,000	SB1	0[d]	9.3	18.0	0	2.86	5.18	0	15.0	12.0	0	4.02	0	0.8	8.0	4.5	0.39	2.58	0
	SB2	0	0	0	0	0	0	0	0.24	0	0	0.01	0	NA[e]	NA	NA	NA	NA	NA
	SB3	0	0.3	0.6	0	0.14	0.17	0	10.9	9.6	0	4.64	0	1.2	16.8	4.0	0.61	4.59	0
	SB4	0	0	1.4	0	0	0.32	0	3.6	14.4	0	2.16	3.39	0	11.2	29.0	0	5.24	4.40
	SB5	NA	NA	NA	NA	NA	NA	NA	0.3	4.0	NA	0.16	0.95	0	3.2	3.2	0	1.93	0.09
	SB6	NA	NA	NA	NA	NA	NA	NA	0	0	NA	0	0	NA	0.8	9.3	NA	0.67	1.85
Large 26,000	LB1	0	0	36.8	0	0	12.9	0	4.0	30.0	0	1.53	8.49	0	8.0	40.8	0	2.24	0.85
	LB2	0	0	0.4	0	0	0.14	0	0.1	1.5	0	0.03	0.38	NA	NA	NA	NA	NA	NA
	LB3	0	0	0.8	0	0	0.23	0	4.4	39.0	0	1.69	10.6	0	16.8	5.2	0	5.59	0
	LB4	0	0	2.0	0	0	0.60	0	1.5	61.5	0	0.75	19.6	0	11.2	37.3	0	5.67	11.8
	LB5	NA	NA	NA	NA	NA	NA	NA	0	15.0	NA	0	4.7	0	3.2	29.2	0	2.00	3.08
	LB6	NA	NA	NA	NA	NA	NA	NA	0	3.0	NA	0	0.48	NA	0.8	87.5	NA	0.50	37.5
Total Small		0	10.0[f]	20.0	0	3.00	5.67	0	30.0	40.0	0	11.0	4.34	2.0	40.0	50.0	1.00	15.0	6.34
Total Large		0	0	40.0	0	0	13.9	0	10.0	150.0	0	4.00	44.3	0	40.0	200.0	0	16.0	53.2
Total		0	10.0	60.0	0	3.00	19.6	0	40.0	190.0	0	15.0	48.6	2.0	80.0	250.0	1.00	31.0	59.5

[a] LOW II has the same number and type of EV buses as LOW I. HIGH II has the same number and type of EV buses as HIGH I, except that there are no Li/S EV buses (SB5, SB6, LB5, and LB6) in HIGH II.

[b] Gross vehicle weight of typical comparable conventional bus.

[c] See App. B for characteristics of each bus type.

[d] A zero means less than 100 vehicles.

[e] Not available.

[f] Columns do not always sum because of rounding.

Table A.12. EV Automobile Totals and Sales by Scenario (10^3)[a]

Auto Size and No.[b]		LOW I						MEDIUM						HIGH I					
		Totals			Sales			Totals			Sales			Totals			Sales		
		1985	1990	2000	1985	1990	2000	1985	1990	2000	1985	1990	2000	1985	1990	2000	1985	1990	2000
Small	4P1	10.8	31.5	376	2.81	9.50	124	12.8	18.9	1.50	1.70	1.30	0[c]	19.6	26.2	53.8	8.50	1.89	1.65
	4P2	NA[d]	NA	NA	NA	NA	NA	NA	NA	151	NA	NA	73.7	NA	NA	484	NA	NA	192
	4P3	0.10	0.63	0.94	0.04	0.18	0	0.34	0.50	0	0.15	0.12	0	NA	NA	NA	NA	NA	NA
	4P4	NA	NA	8.46	NA	NA	2.97	NA	NA	12.2	NA	NA	3.69	NA	NA	NA	NA	NA	NA
	4P5	0.12	2.80	84.6	0.05	1.81	22.4	3.91	42.3	138	3.39	20.1	0	8.4	123	538	5.50	67.9	0
	4P6	NA	NA	NA	NA	NA	NA	NA	NA	921	NA	NA	366	NA	NA	2420	NA	NA	961
	4P7	NA	NA	NA	NA	NA	NA	NA	1.26	306	NA	2.07	121	0	26.2	53.8	0	9.62	1.65
	4P8	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	753	NA	NA	299
	4P9	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1080	NA	NA	427
Large	5P1	8.82	31.5	376	3.00	9.50	124	9.75	18.6	1.50	2.02	1.36	0	15.4	26.2	53.8	11.0	1.89	1.65
	5P2	NA	NA	NA	NA	NA	NA	NA	NA	151	NA	NA	73.7	NA	NA	484	NA	NA	192
	5P3	0.08	0.63	0.94	0.04	0.18	0	0.26	0.50	0	0.17	0.12	0	NA	NA	NA	NA	NA	NA
	5P4	NA	NA	8.46	NA	NA	2.97	NA	NA	12.2	NA	NA	3.69	NA	NA	NA	NA	NA	NA
	5P5	0.10	2.80	84.6	0.07	1.81	22.4	2.99	41.7	138	3.55	19.8	0	6.6	123	538	6.02	67.9	0
	5P6	NA	NA	NA	NA	NA	NA	NA	NA	921	NA	NA	366	NA	NA	2420	NA	NA	961
	5P7	NA	NA	NA	NA	NA	NA	NA	1.24	306	NA	2.03	121	0	26.2	53.8	0	9.62	1.65
	5P8	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	753	NA	NA	299
	5P9	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1080	NA	NA	427
Total Small		11.0[e]	35.0	470	2.90	11.5	150	17.0	63.0	1530	5.25	23.7	564	28.0	175	5380	14.0	79.5	1880
Total Large		9.00	35.0	470	3.10	11.5	150	13.0	62.0	1530	5.75	23.3	564	22.0	175	5380	15.0	79.5	1880
Total		20.0	70.0	940	6.00	23.0	300	30.0	125.0	3060	11.0	47.0	1130	50.0	350	10,800	29.0	159.0	3760

[a] LOW II has the same number and type of EV autos as LOW I. HIGH II has the same number and type of EV autos as HIGH I, except that there are no Li/S EV autos (4P7, 4P8, 4P9, 5P7, 5P8, and 5P9) in HIGH II.

[b] See App. B for characteristics of each bus type.

[c] A zero means less than 100 vehicles.

[d] Not available.

[e] Columns do not always sum because of rounding.

A.2.3.3 HV Markets

Only HV medium-light trucks and cars are characterized for the assessment because of limited information about HVs. Market constraints are far less severe because no range limitations exist. Methods similar to those already described are used to determine these markets. Table A.13 presents a summary of the HV sales and totals by vehicle type and by scenario.

A.3 TYPES OF EHV MANUFACTURERS

Three types of EHV manufacturers have been identified: foreign, large domestic (Ford, GM, and possibly Chrysler and American Motors), and small domestic. Vehicles from foreign and large domestic manufacturers will be mass produced (except in the early years) and those from small domestic firms will be serially produced. Small firms will be pushed into specialty markets as soon as the larger firms enter the market with mass-produced vehicles. This should happen when EV or HV sales reach several hundred thousand per year. Also, a large, EHV-only manufacturer may arise in the MEDIUM and HIGH scenarios.

The contribution of foreign manufacturers to EHV stocks will not be insignificant. About 10% of small trucks (less than 4500 lb GVW) currently are foreigh made and are either distributed there by the manufacturer (e.g., Datsun) or are captive imports distributed by domestic firms (e.g., Chevy Luv). About 15% of today's automobile market is imported. The vehicles are mostly small cars and are either sold directly or as captive imports. In 1980 the CAFE numbers can no longer include captive imports and a change in this market can be expected. For this assessment, it is assumed that domestic manufacturers will gain and hold 60% of the small truck market by 1985, but foreign-made car sales will continue to be approximately 15% of U.S. auto sales.

Table A.13. HV Totals by Scenario (10^3)[a]

Vehicle No.	LOW II						HIGH II					
	Totals			Sales			Totals			Sales		
	1985	1990	2000	1985	1990	2000	1985	1990	2000	1985	1990	2000
MT7	12.6	63.7	1370	4.7	27.5	525	-	-	-	-	-	-
MT8	-	-	-	-	-	-	0	61.6	5297	0	33.1	2040
4P10	4.1	15.9	313	1.35	6.85	118	-	-	-	-	-	-
4P11	-	-	-	-	-	-	0	26.2	1408	0	14.4	542
5P10	3.3	15.9	313	1.35	6.85	118	-	-	-	-	-	-
5P11	-	-	-	-	-	-	0	26.2	1408	0	14.4	542
Total	20.0	95.6	2000	7.4	41.3	761	0	114	8110	0	61.9	3120

[a] Only medium-light trucks and four- and five-passenger autos are characterized.

The distribution of EHV sales by type of manufacturer and scenario is presented in Table A.14. The small domestic firms are the only producers in the early years; by 1985 in the HIGH scenarios and by 1990 in the LOW and MEDIUM scenarios, the large domestic firms begin to dominate the market. HIGH I, for example, is possible because of the large number of imports in 1990 (28%), but U.S. manufacturers gain 87% of the market by 2000.

In the middle and later years, the large domestic manufacturers avoid EHV markets with insufficient vehicle demand to sustain mass production. Insufficient vehicle demand can occur when there is either strong foreign and small firm competition or small numbers of vehicles. Foreign manufacturers do well in the EHV light truck market, selling about as many of these trucks as small automobiles in most years. Small domestic firms looking for gaps in foreign and large domestic manufacturer EHV lines find the small auto (commuter car) and the light truck to be their mainstays. This can be attributed to the large markets, to similarities between the two vehicle types, and to the relative simplicity of the vehicles.

Exports by domestic manufacturers are considered to be insignificant and are not included in the sales totals or scenarios.

A.4 EHV ANNUAL VEHICLE MILES TRAVELED

Projections of national annual VMT for buses, trucks, and autos are based on Ref. A.3 and serve as the basis for the distribution of VMT by vehicle type. The projections used are only for vehicles that can be substituted by EHVs. In other words, annual VMT for medium and heavy trucks and intercity buses are not included in the basis for EHV projections.

Table A.15 gives the VMT for sample EHVs and CVs by scenario and year. It shows that EVs and HVs substitute in each scenario on a one-for-one basis for CVs. Therefore, a penetration of shorter-range EVs with lower annual VMT causes average CV VMT to increase slightly. (This increase often appears in the third or fourth significant figure of average CV VMT.) HV VMT equals CV VMT per vehicle in scenarios with HVs. A 50-mile range EV, if used to its maximum each day, could generate 18,250 mi/yr. Half of this number is more reasonable and is the limiting value used to define markets. A 9000-mile year for a commercial truck is only 36 mi per 250-workday year. The average 1985 transit bus mission of 28,000 mi/yr is more difficult but does not, on the average, tax a 100-mi/day, 300-day/yr transit bus. Such a bus averages 93.3 mi/day. Some midday charging of batteries can be expected.

A.5 REGIONAL VARIATION

This section outlines the methods used: (1) to derive the variations in market penetration of EVs in different areas of the United States and (2) to develop the number of EVs, HVs, and CVs for each area.

Table A.14. EHV Auto and Truck Market Share and Sales by Type of Manufacturer and Vehicle and by Scenario (10^3)

U.S. Sales by Manufacturer	LOW I			LOW II			MEDIUM			HIGH I			HIGH II		
	1985	1990	2000	1985	1990	2000	1985	1990	2000	1985	1990	2000	1985	1990	2000
Foreign firms[a]															
% of all EHVs[b]	c	20	22	4	23	20	c	20	19	20	28	13	20	28	13
Light trucks[d]	c	9.3	115	c	9.3	115	c	15.4	293	4.3	50.8	517	4.3	38.3	342
Medium trucks[d]				c	6.1	93.3		0	0	0	0	0	0	6.7	233
Small autos	c	4.0	92.1	1.0	9.1	127	c	12.4	250	9.5	59.0	560	9.5	62.6	505
Total sales	c	13.2	207	1.0	24.4	335	c	27.8	543	13.8	109	1077	13.8	107	1080
Domestic small firms[e]															
% of all EHVs[b]	100	30	18	96	25	19	100	25	15	30	15	5	30	14	4
Light trucks[d]	4.4	7.0	46.5	4.4	7.0	46.5	9.0	6.5	112	2.6	20.5	175	2.6	15.5	116
Medium trucks[d]	5.6	4.0	35.1	10.3	7.9	76.5	11.9	11.1	73.0	7.1	13.2	67.0	7.1	13.2	90
Small autos[f]	2.9	5.4	57.9	3.3	6.6	141	5.3	11.6	164	3.0	10.0	122	3.0	10.6	109
Large autos[f]	3.1	3.5	30.0	4.5	5.5	53.6	5.7	5.5	80.0	8.0	15.0	50.0	8.0	15.9	45
Total sales	16.0	19.8	169	22.4	26.9	317	32.0	34.7	429	20.7	58.7	414	20.7	55.2	360
Domestic large firms															
% of all EHVs[b]	c	50	60	c	52	61	c	55	66	50	57	82	50	58	83
Light trucks[d]	c	2.9	100	c	2.9	100	c	0	150	2.7	0	660	2.7	0	438
Medium trucks[d]	c	17.8	329	c	35.2	719	c	50.1	1001	21.0	125.4	2781	21.0	125	3720
Heavy trucks[d]	c	1.3	14.2	c	1.3	14.2	c	8.7	89.8	2.3	23.1	318	2.3	18.3	204
Small autos[f]	c	2.5	0	c	3.1	0	c	0	150	1.5	10.5	1200	1.5	11.1	1080
Large autos[f]	c	8.5	120	c	13.4	214	c	17.4	484	7.0	64.5	1832	7.0	68.3	1650
Total sales[b]	c	33.0	565	c	55.9	1050	c	76.0	1880	34.5	223	6791	34.5	222	7090

[a] Includes direct and captive imports.

[b] Except buses, which are assumed to be produced by current bus manufacturers.

[c] Less than 1000 vehicle sales.

[d] Light: less than 4,500 lb GVW; medium: 4,500-7,500 lb GVW; and high: 7,500-10,000 lb GVW.

[e] U.S. firms that produce vehicles serially.

[f] Small: four or fewer passengers
Large: five or more passengers.

Table A.15. Distribution of Average Annual VMT of Sample Vehicle Types by Scenario and Year (10^3)

Vehicle			Scenario														
Vehicle No. and Battery Type		EV HV CV	LOW I			LOW II			MEDIUM			HIGH I			HIGH II		
			1985	1990	2000	1985	1990	2000	1985	1990	2000	1985	1990	2000	1985	1990	2000
MT1	Pb/Acid	EV	8.00	8.00	9.15	8.00	8.00	9.15	8.00	8.03	9.64	8.00	8.10	9.98	8.00	8.10	9.98
MT4	Ni/Zn	EV	NA[a]	9.27	11.50	NA	9.27	11.50	NA	9.21	12.89	NA	10.10	13.04	NA	10.10	13.04
MT5	Li/S	EV	NA	NA	NA	NA	NA	NA	NA	9.21	12.89	NA	10.10	13.04	NA	NA	NA
MT7	Pb/Acid	HV	NA	NA	NA	11.89	12.50	13.82	NA	NA	NA	NA	NA	NA	NA	NA	NA
MT8	Ni/Zn	HV	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	12.51	13.97
MT9	None	CV	11.89	12.50	13.82	11.89	12.50	13.82	11.89	12.49	13.89	11.89	12.51	13.97	11.89	12.51	13.97
LB1	Pb/Acid	EV	NA	NA	7.70	NA	NA	7.70	NA	6.95	7.07	0	7.30	8.00	0	7.30	9.16
LB5	Li/S	EV	NA	NA	NA	NA	NA	NA	NA	NA	10.74	NA	8.82	10.44	NA	NA	NA
LB6	Li/S	EV	NA	NA	NA	NA	NA	NA	NA	NA	10.75	NA	8.82	11.50	NA	NA	NA
LB7	None	CV	9.56	9.48	10.81	9.56	9.48	10.81	9.56	9.64	11.25	9.57	9.72	11.66	9.57	9.70	11.51
4P1	Pb/Acid	EV	8.75	9.25	10.47	8.75	9.25	10.47	8.75	9.25	11.17	8.75	9.25	11.25	8.75	9.25	11.51
4P5	Ni/Zn	EV	9.90	10.00	12.00	10.03	10.91	12.67	9.90	10.00	12.10	10.03	10.50	12.55	10.03	10.50	11.60
4P9	Li/S	EV	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	12.69	NA	NA	NA
4P10	Pb/Acid	HV	NA	NA	NA	10.03	10.91	12.67	NA	NA	NA	NA	NA	NA	NA	NA	NA
4P11	Ni/Zn	HV	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	10.92	12.67
4P12	None	CV	10.03	10.91	12.69	10.03	10.91	12.67	10.03	10.91	12.69	10.03	10.92	12.69	10.03	10.92	12.67

[a] Not available.

A.5.1 EV Regional Market Model

A market share indicator for each of 158 urbanized areas (UAs) is developed. (The 158 UAs are those with 1990 populations forecasted to be over 150,000.) The indicator shows the variation in EV penetration rate from the typical UA rate and is based on the characteristics of the particular UA. This section summarizes the development of the indicator. For a detailed discussion, see Ref. A.4. HVs are not considered to have this type of variation.

The variables that influence EV regional variation and that are included in this analysis are differences in temperature, average trip length, average trip speed, terrain, average annual vehicle miles, and the relative price of electricity and gasoline.* Since no EV market data exist to calibrate a model, engineering judgment is applied to existing UA projections. Table A.16 lists the name and definition of each variable used in the analysis (S, L, H, M, D, T_1, and T_2) and the corresponding data source. Figure A.6 presents these data by variable as frequency distributions.

The indicator is given by:

$$V = 1/6[a(S) + b(L) + c(H) + d(M) + e(D) + f(T_1,T_2)] \qquad (A.3)$$

where:

V = indicator for the UA variation (averages 1.0 over all the UAs), and

a, b, c, d, e and f = functions.

Functions a, b, c, d, and e are linear functions that operate on the variables. Each function has a mean value of 1.0 over all UAs and varies with the standard deviation of its argument as shown in Table A.17. The function f also operates on its variables and has a mean of 1.0, but it is a discontinuous function as shown in Fig. A.7. Function f reduces EV penetration for UAs at either temperature extreme. For none of the 158 UAs did T_1 and T_2 both fall outside the moderate temperature range. Thus, only one f value is assigned to each UA, either the moderate value 1.19 or a value determined by one temperature extreme.

The effect of market penetration variation with each of these variables was discussed with EHV R&D engineers. Climate and hills are considered to have the greatest effect because of adverse impacts on EV performance and because temperature extremes require passenger compartment heating or air conditioning. (See Sec. B.2.1.3 for a discussion of the latter problem.) EV range limitations are considered to be the next most detrimental to EV acceptance. Variables L and M address this. Average trip speed and relative energy cost (S and D) are considered to be the third and fourth most important.

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*EV regional variations also will be affected by certain factors not directly related to UA population, such as per capita auto ownership and variations in transit bus operation. Such factors are considered when distributing vehicles to UAs as described in Sec. A.5.2.

Table A.16. Definitions of Variables

Parameter	Definition	Reference
S	Average UA 1990 trip speed.	A.5
L	Average UA 1990 trip length.	A.5
H	Number of 100-ft contour lines along a 10-mile radius from the UA center through the hilliest of the surrounding area with roads.	A.6
M	UA 1990 annual per capita VMT.	A.5
D	Difference in price of gasoline at the pump and residential electricity (per equivalent barrel); only for the 10 federal regions; electricity price always higher; D always positive.	A.7
T_1	Normal July maximum temperature.	A.8
T_2	Normal January minimum temperature.	A.8

Sources: Refs. A.5-A.8.

The major assumptions imbedded in this method are:

1. EV populations in 1985 and 2000 will have the same distribution over the United States as in 1990.
2. Penetrations of different types of EVs will be affected by the variables to the same degree.
3. The assumed effect of each variable on market penetration is reasonable, and the effect of each variable sums to give the total effect.
4. All EVs will be in the 158 UAs.

Evaluating these assumptions is difficult, because no data on EV penetrations exist. With respect to the fourth assumption, it is obvious that not all EVs will penetrate in the 158 UAs. Some penetration will occur in smaller UAs and rural areas. The assumption is made simply for computational expediency. However, it is not expected that the impacts shown in the air quality and utility analyses that utilize these regional variations will be affected by this assumption.

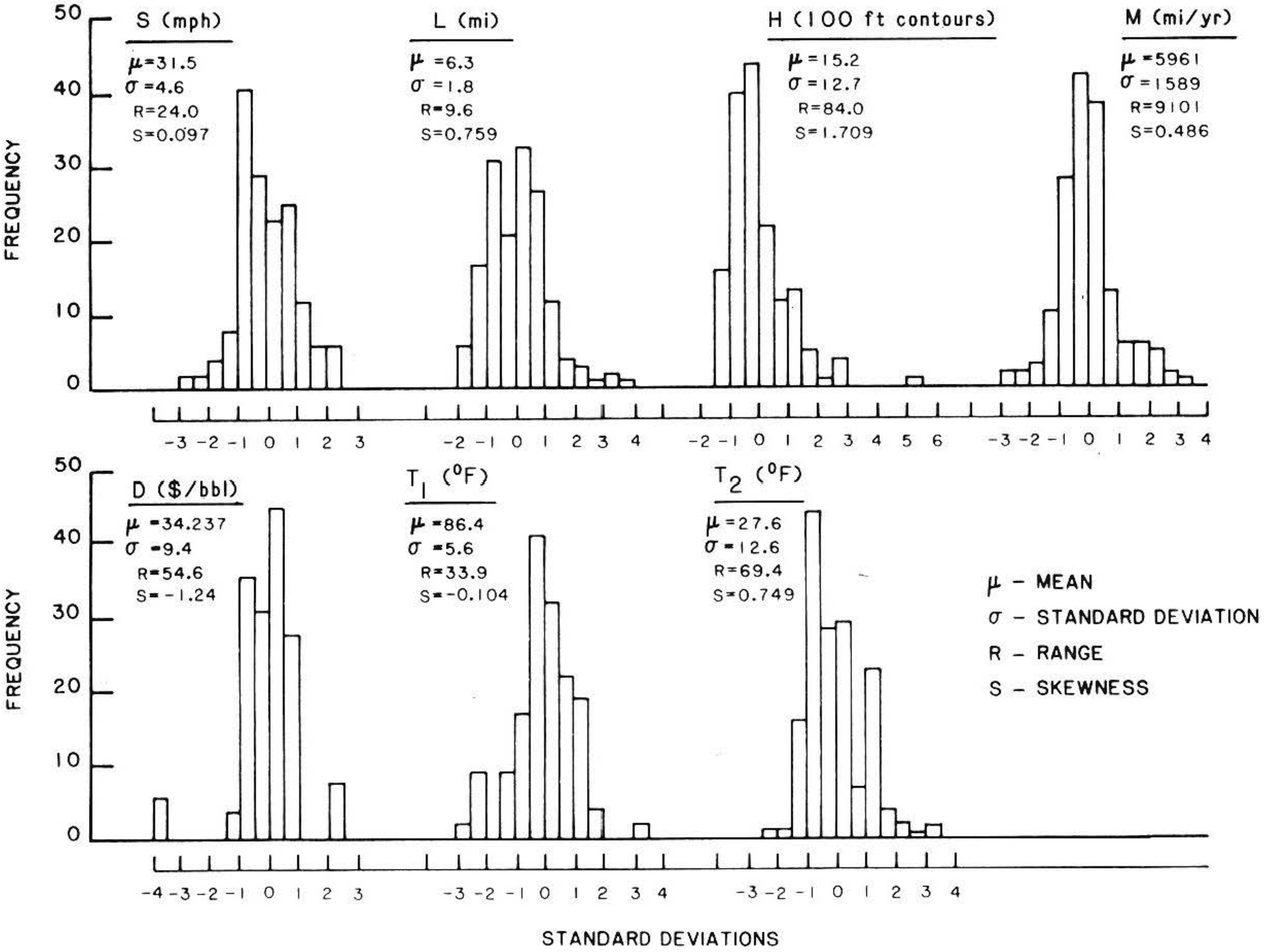

Fig. A.6. Frequency Distributions of the Variables

Table A.17. Description of Functions a through e

Function	Two Coordinates of Each Linear Function: Three Standard Deviations above the Mean of the Argument	Three Standard Deviations below the Mean of the Argument
a(S)	0.2	1.8
b(L)	0.4	1.6
c(H)	-0.2	2.2
d(M)	0.4	1.6
e(D)	0.4	1.6

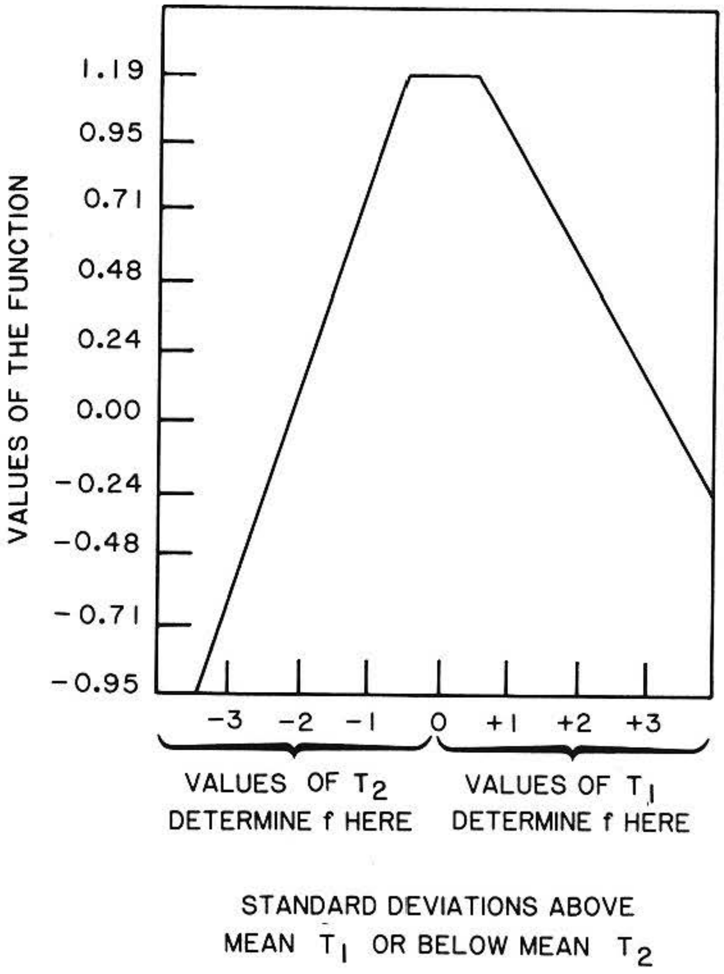

Fig. A.7. Function f

Table A.18 lists the values of the functions a through f and V for each of the 158 UAs. Also listed in this table for each UA is a column showing the share each UA would have of all the EVs in each scenario. The column sums to 1.0. Table A.19 classifies the UAs by the 10 federal regions and the values of V, and Fig. A.8 is a map showing these 10 federal regions.

A.5.2 Distribution of EVs, HVs, and CVs to the 158 UAs by Scenario

Each of the 18 types of electric autos is distributed to the 158 UAs as follows:

$$\mathrm{EVAUTO}_{mijk} = V_m\ \mathrm{NEVAUTO}_{ijk}\left(\frac{\mathrm{AUTO}_m}{\sum\limits_m \mathrm{AUTO}_m}\right) \tag{A.4}$$

where:

m = UA number (158 possible values),

i = year (1985, 1990, or 2000),

j = scenario (five possible values),

k = type of automobile (e.g., 4P3, 18 possible values),

EVAUTO_{mijk} = the number of that type of EV automobile,

V_m = EV market penetration indicator that varies with UA characteristics (see Table A.18),

$\mathrm{NEVAUTO}_{ijk}$ = national total of that type of EV automobile (see Table A.12), and

AUTO_m = number of automobiles in 1970 from Table 1-17 of Ref. A.9. Thus, the ratio

$$\frac{\mathrm{AUTO}_m}{\sum\limits_m \mathrm{AUTO}_m}$$

takes into account variation in per capita auto ownership. UAs not listed in the referenced table are assumed to have the national per capita ownership rates.

Each of the 18 types of electric trucks and 12 types of electric school buses are distributed to each UA_m on a per capita basis but depending on V_m:

$$\mathrm{EVTRUCK}_{mijk} = V_m\ \mathrm{NEVTRUCK}_{ijk}\left(\frac{\mathrm{POPULATION}_m}{\sum\limits_m \mathrm{POPULATION}_m}\right) \tag{A.5}$$

and

The number of conventional automobiles in UA_m, year i, and scenario j is as follows:

$$CVAUTO_{mij} = NAUTO_{ij} \left(\frac{AUTO_m}{\Sigma AUTO_m} \right) - \sum_k EVAUTO_{mijk} - \sum_k HVAUTO_{mijk}. \qquad (A.10)$$

The number of CV transit buses is determined as follows:

$$CVTRNBUS_{mij} = NTRNBUS_{ij} \left(\frac{TRNBUS_m}{\Sigma TRNBUS_m} \right) - \sum_k EVTRNBUS_{mijk}. \qquad (A.11)$$

The number of each other CV (truck and school buses) is determined as follows:

$$CVVEH_{mij} = NVEH_{ij} \left(\frac{POPULATION_m}{\sum_m POPULATION_m} \right) - \sum_k EVVEH_{mijk} - \sum_k HVVEH_{mijk}. \qquad (A.12)$$

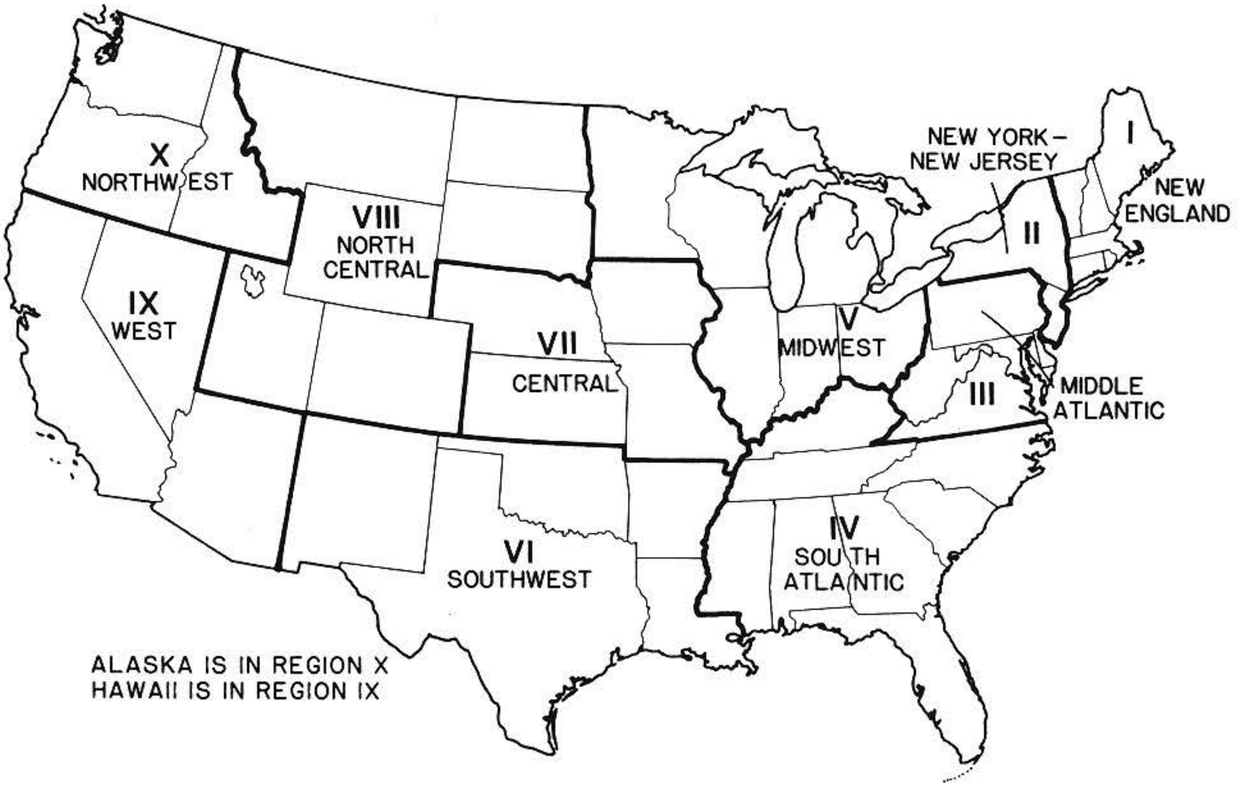

Fig. A.8. U.S. Federal Regions

Table A.18. Values of the Functions and V, and the Share of Total EVs by UA

UA NO.	FED. REGION	UA NAME	FUNCTIONS a	b	c	d	e	f	V	SHARE
1	2	NY-NJ	1.5559	0.9333	1.2600	1.2721	0.5559	1.1886	1.1276	0.1594
2	9	LOS ANGLES	0.9113	0.7289	-0.0325	0.9476	0.9495	1.1886	0.7823	0.0608
3	5	CHICAGO	0.9699	0.8993	1.3061	1.1343	1.0148	0.9462	1.0584	0.0608
4	3	PHILA-TREN	1.0285	0.9560	1.1024	0.9728	0.8383	1.1886	1.0144	0.0365
5	9	SAN FRAN	1.1457	1.1037	0.4038	0.9185	0.9495	1.1886	0.9525	0.0330
6	5	DETROIT	0.4426	0.8538	1.3545	0.9228	1.0148	1.0703	0.9432	0.0317
7	1	BOSTON	0.9699	0.8765	1.0393	0.9748	0.8653	1.1886	0.9858	0.0191
8	3	WASH-MD-VA	0.8528	0.6380	1.0393	0.9015	0.8383	1.1886	0.9093	0.0235
9	5	CLEVELAND	0.9113	0.8652	1.2284	0.9357	1.0148	1.1324	1.0147	0.0177
10	7	ST LOUIS	0.8528	0.7857	1.1024	1.0511	0.9270	1.1886	0.9346	0.0163
11	3	PITTSBURGH	1.2629	0.5013	0.2512	1.1305	0.8383	1.1606	0.8576	0.0111
12	3	BALTIMORE	1.2043	0.8652	0.8817	0.8370	0.8383	1.1886	0.9692	0.0138
13	5	MINN-ST P	1.1457	0.9788	1.2915	0.9277	1.0148	0.1674	0.9210	0.0133
14	6	HOUSTON	0.9113	0.9901	1.3061	0.8122	0.9506	0.8342	0.9303	0.0144
15	10	SEATTLE	1.2629	0.5813	0.8502	0.9277	1.7179	1.1886	1.0831	0.0111
16	4	ATLANTA	1.2629	0.6721	0.7871	0.6685	1.1269	1.1886	0.9510	0.0147
17	4	MIAMI	1.3801	1.1718	1.4806	1.0345	1.1269	1.1886	1.2338	0.0140
18	5	CINCNATI	0.9699	0.8425	1.0078	0.9535	1.0148	1.1886	0.9962	0.0104
19	9	SAN DIEGO	0.5598	0.8379	0.4719	0.9721	0.9495	1.1886	0.8333	0.0109
20	5	MILWAUKEE	1.1457	0.2973	1.3230	1.1965	1.0148	0.6302	0.9346	0.0086
21	7	KANSAS CTY	0.5012	0.8538	0.8186	1.0834	0.9270	1.0760	0.8775	0.0089
22	2	BUFFALO	1.2629	0.9901	1.2600	1.2960	0.5559	0.9800	1.0575	0.0078
23	8	DENVER	0.9113	0.9560	1.2284	1.0778	1.2421	0.9010	1.0528	0.0104
24	9	PHOENIX	0.7356	0.9674	1.1654	1.0002	0.9495	-0.0030	0.8020	0.0077
25	6	NEW ORLEAN	0.7356	0.3882	1.4176	1.4271	0.9506	1.0939	1.0022	0.0095
26	6	DALLAS	0.9113	0.9788	1.1024	0.4315	0.9506	0.7043	0.8465	0.0101
27	10	PORTLAND O	0.7942	1.2173	0.3458	1.1476	1.7179	1.1886	1.0605	0.0086
28	4	SAN JAUN	1.7903	0.3428	0.7241	1.4390	1.1269	1.1886	1.1019	0.0102
29	1	PRVDNCE RI	0.7942	0.9106	1.0708	1.0633	0.8653	1.1493	0.9756	0.0063
30	5	COLUMBUS	0.9699	0.8538	1.1969	0.9473	1.0148	1.1380	1.0202	0.0072
31	5	INDIANPLIS	0.9113	1.1150	1.3230	1.0321	1.0148	1.0985	1.0825	0.0075
32	4	LOUISVILLE	1.1457	0.8425	1.2284	0.8659	1.1269	1.1886	1.0665	0.0068
33	3	NRFLK-PORT	1.0871	1.1378	1.4806	0.8999	0.8383	1.1886	1.1054	0.0062
34	4	MEMPHIS	1.4337	1.0355	1.3061	1.0232	1.1269	1.0022	1.1688	0.0074
35	5	DAYTON	1.1457	0.9220	1.3230	0.8518	1.0148	1.1380	1.0659	0.0064
36	9	SACRAMENTO	0.6770	0.8379	1.4491	0.9092	0.9495	0.9029	0.9626	0.0056
37	4	FT LAUDRDL	0.6770	0.8765	1.4806	1.0039	1.1269	1.1626	1.0546	0.0066
38	6	SAN ANTNIO	1.1457	1.0583	1.1339	1.0009	0.9506	0.7043	0.9989	0.0072
39	2	ROCHESTER	1.2043	1.1264	0.9447	1.2496	0.5559	0.6922	0.9622	0.0051
40	6	OKLA CITY	1.1457	0.8084	1.2915	0.6486	0.9506	0.9259	0.9618	0.0048
41	4	ST PTRSBRG	1.4973	1.0242	1.4806	0.9009	1.1269	1.1886	1.2031	0.0065
42	5	AKRON	0.9699	0.7857	1.0708	0.9637	1.0148	1.1380	0.9905	0.0045
43	4	BIRMINGHAM	1.0285	0.6040	1.0393	1.0866	1.1269	1.0863	0.9953	0.0055
44	1	SPRGFLD MA	0.8528	1.0015	1.0393	1.1476	0.8653	0.8954	0.9670	0.0042
45	4	JCKSNVL FL	0.5012	0.8993	1.4176	0.9307	1.1269	1.1244	1.0000	0.0047
46	1	HARTFORD	1.0285	0.8765	0.9447	0.8113	0.8653	0.8954	0.9036	0.0037
47	2	ALBANY	0.7356	0.9447	0.8817	1.2080	0.5559	0.6922	0.8364	0.0032
48	4	TAMPA	1.2629	1.0469	1.3545	0.9023	1.1269	1.1626	1.1427	0.0050
49	8	SLT LK CTY	0.8528	0.8311	0.4719	0.9929	1.2421	1.0303	0.9036	0.0033
50	5	TOLEDO	1.0871	0.9788	1.2915	1.0145	1.0148	1.0703	1.0762	0.0042
51	7	OMAHA	1.0871	1.1378	0.9447	1.1069	0.9270	0.6866	0.9317	0.0040
52	4	ORLANDO	1.2043	0.6948	1.2915	0.9665	1.1269	1.1626	1.0744	0.0054
53	3	RICHMOND	1.0871	0.9901	1.1654	0.9265	0.8383	1.1886	1.0327	0.0040
54	5	YNGSTOWN	1.0871	0.8034	1.1969	0.9576	1.0148	1.1324	1.0329	0.0032
55	4	NASHVILLE	1.1457	1.0242	0.6926	0.6586	1.1269	1.1092	0.9595	0.0037
56	9	HONOLULU	1.6731	1.0696	0.5930	1.1379	0.9495	1.1886	1.1023	0.0039
57	6	FT WORTH	0.8528	0.9788	1.2284	0.3890	0.9506	0.7043	0.8506	0.0054
58	2	SYRACUSE	1.0285	1.0128	1.0393	1.2476	0.5559	0.6922	0.9294	0.0028
59	3	SCRANTON	1.3801	0.9674	0.5034	0.9537	0.8383	0.8333	0.9127	0.0025

Table A.18. (Cont'd)

UA NO.	FED. REGION	UA NAME	FUNCTIONS						V	SHARE
			a	b	c	d	e	f		
60	3	WILMNGTON	0.9113	1.1491	0.8817	1.0546	0.8383	1.1886	1.0039	0.0038
61	3	ALLENTOWN	1.2043	0.9560	0.7871	0.8617	0.8383	0.8333	0.9135	0.0026
62	6	TULSA	0.7356	1.1150	1.1969	1.0547	0.9506	0.9259	0.9964	0.0031
63	5	GRND RAPDS	0.7942	1.1264	1.1339	1.0866	1.0148	1.0703	1.0377	0.0031
64	9	TUCSON	1.2043	1.0355	1.1024	0.8413	0.9495	-0.0060	0.8545	0.0029
65	4	W PALM BCH	1.0285	0.9333	1.4806	1.1675	1.1269	1.1626	1.1499	0.0048
66	5	FLINT	0.8528	0.8879	1.2284	0.9287	1.0148	1.0703	0.9972	0.0034
67	3	NPORT	1.0285	0.7970	1.4806	0.9461	0.8383	1.1886	1.0465	0.0031
68	10	TACOMA	1.2043	0.7175	0.9763	0.9132	1.7179	1.1886	1.1196	0.0029
69	6	ELPASO	0.9699	1.1832	0.5034	0.9108	0.9506	0.7731	0.8818	0.0023
70	7	WICHITA	1.3301	1.1378	1.3861	1.0478	0.9270	1.1832	1.1770	0.0027
71	6	ALBUQUERQE	1.2629	1.0696	0.7871	1.0420	0.9506	0.9564	1.0114	0.0036
72	4	CHARLOTTE	0.6770	0.7857	1.1024	0.5476	1.1269	1.1886	0.9047	0.0030
73	1	WORCESTER	0.7356	0.9674	0.8502	0.9675	0.8653	0.8954	0.8802	0.0013
74	4	GREENVILLE	0.6184	1.3876	0.6610	0.8715	1.1269	1.1092	0.9624	0.0027
75	5	SO BEND	1.2629	1.3081	1.2600	1.0548	1.0148	0.9462	1.1411	0.0026
76	9	FRESNO	0.3840	1.0469	1.4176	1.1254	0.9495	1.1886	1.0187	0.0023
77	6	BATON ROUG	0.7942	0.7857	1.3230	1.0491	0.9506	1.0939	0.9994	0.0026
78	7	DAVENPORT	1.0871	1.1832	1.0393	1.0781	0.9270	0.6245	0.9099	0.0023
79	4	MOBILE	1.1457	0.8879	1.2600	0.9737	1.1269	1.0863	1.0801	0.0028
80	1	LAWRENC MA	0.7942	0.9560	0.7556	1.0216	0.8653	0.8954	0.8313	0.0019
81	5	CANTON	1.0871	1.0355	0.6926	0.8822	1.0148	1.1330	0.9751	0.0019
82	6	AUSTIN	0.9699	0.6948	0.8817	1.0686	0.9506	0.8342	0.9800	0.0022
83	6	SHREVEPORT	0.6770	1.0015	1.3230	1.0810	0.9506	1.0939	1.0212	0.0026
84	4	COLUMBA SC	0.5012	1.3763	1.1654	1.0173	1.1269	1.1092	1.0494	0.0026
85	5	PEORIA	1.0871	1.0242	1.0078	0.9974	1.0148	0.8728	1.0007	0.0020
86	7	DES MOINES	1.1457	1.1718	1.1339	0.7868	0.9270	0.6245	0.9650	0.0021
87	6	LTL ROCK	0.4426	1.2740	1.1969	0.5084	0.9506	0.9259	0.8831	0.0023
88	3	HARRISBURG	1.2043	0.9560	0.2512	0.7208	0.8383	1.1886	0.8599	0.0017
89	4	CHATTANOGA	1.2043	0.9447	0.3773	0.6431	1.1269	1.0022	0.8831	0.0018
90	4	CHARLTN SC	0.5012	1.3763	1.4006	1.0400	1.1269	0.9717	1.0828	0.0024
91	9	LAS VEGAS	0.8528	1.0696	0.4719	1.0857	0.9495	1.0195	0.9082	0.0026
92	10	SPOKANE	0.9113	0.7062	0.3458	0.7187	1.7179	1.0939	0.9155	0.0014
93	5	LANSING	0.7356	0.8311	1.2284	0.8742	1.0148	1.0703	0.9591	0.0020
94	5	ROCKFORD	1.3215	1.1605	1.3230	1.2028	1.0148	0.8728	1.1492	0.0025
95	5	FT WAYNE	1.1457	1.3195	1.2600	1.1754	1.0148	1.0703	1.1643	0.0021
96	8	COLO SPRNG	1.0285	1.1832	-1.1673	1.3028	1.2421	0.9010	0.7484	0.0020
97	5	MADISON	0.9699	1.1491	0.9132	0.9571	1.0148	0.8728	0.9795	0.0019
98	1	LOWELL MA	0.9699	1.2173	0.9763	1.1242	0.8653	1.1886	1.0569	0.0015
99	1	FALL RV MA	0.7942	1.0242	1.1654	1.1039	0.8653	1.1886	1.0244	0.0015
100	4	JACKSON	0.4426	0.7289	1.2284	1.0346	1.1269	0.9182	0.9133	0.0021
101	6	CORPUS CHR	1.2043	1.3195	1.3545	1.0757	0.9506	0.8342	1.1231	0.0018
102	4	BILOXI	0.6770	0.7630	1.2915	1.1529	1.1269	0.9182	0.9382	0.0023
103	4	PENSACOLA	0.9113	0.9560	1.2600	0.8731	1.1269	1.0863	1.0356	0.0017
104	2	UTICA-ROME	1.1457	0.9788	0.8502	1.2670	0.5559	0.6922	0.9150	0.0012
105	3	ERIE	1.2629	1.1491	1.0393	1.1445	0.8383	0.9800	1.0690	0.0015
106	2	BINGHMPTON	1.1457	0.9788	0.4088	1.2379	0.5559	0.6922	0.8366	0.0011
107	4	COLMBUS GA	1.4337	1.0242	1.0703	1.0251	1.1269	1.1886	1.1457	0.0020
108	4	KNOXVILLE	1.0871	1.1832	0.4404	0.5779	1.1269	1.1092	0.9203	0.0015
109	9	BAKERSFLD	0.3840	1.1378	0.6610	1.1696	0.9495	1.1886	0.9151	0.0013
110	5	ANN ARBOR	1.0285	1.2173	1.1339	0.9524	1.0148	1.0703	1.0695	0.0016
111	1	BROCKTN MA	1.0285	1.0128	1.2284	1.0224	0.8653	1.1886	1.0577	0.0015
112	3	READING PA	1.4337	1.0923	0.6295	1.1783	0.8383	1.1886	1.0610	0.0013
113	4	FAYTTVL NC	0.6770	1.2286	1.0393	0.9417	1.1269	1.1886	1.0337	0.0017
114	9	STOCKTON	0.8528	1.1378	1.1654	0.9076	0.9495	0.9029	0.9360	0.0014
115	3	HNTNGTN WV	1.0285	1.1037	-0.0955	1.1668	0.8383	1.1886	0.8717	0.0013
116	1	WATERBY CT	1.0871	0.9106	0.6295	1.1728	0.8653	0.8954	0.9263	0.0012
117	4	SAVANNAH	1.3215	0.8652	1.4806	0.9916	1.1269	1.1886	1.1624	0.0018
118	4	LEXINGTON	1.1457	1.0583	1.0393	1.1514	1.1269	1.1886	1.1184	0.0018
119	4	RALEIGH	0.6770	1.2286	0.8502	0.5532	1.1269	1.1886	0.9374	0.0016

Table A.18. (Cont'd)

UA NO.	FED. REGION	UA NAME	FUNCTIONS							SHARE
			a	b	c	d	e	f	V	
120	3	ROANOKE	1.0285	1.2173	-0.0010	1.0394	0.8383	1.1886	0.8852	0.0011
121	4	GRNSBORO	0.7356	1.1491	1.0393	0.5919	1.1269	1.1886	0.9719	0.0016
122	3	CHRLSTN WV	1.3801	0.8879	-0.0955	1.0383	0.8383	1.1886	0.8729	0.0013
123	4	WIN-SALEM	0.5598	1.2059	0.8186	0.7065	1.1269	1.1886	0.9344	0.0015
124	8	OGDEN	0.3840	0.8879	0.9132	1.1332	1.2421	1.0303	0.9319	0.0014
125	4	HUNTSVL AL	1.1457	0.9220	0.4719	1.2530	1.1269	1.0863	1.0010	0.0018
126	5	EVANSVL IN	1.3215	1.1491	0.9447	1.0070	1.0148	1.0985	1.0393	0.0012
127	10	EUGENE OR	0.9699	1.2513	0.4719	1.1874	1.7179	1.1886	1.1312	0.0016
128	4	AUGUSTA GA	1.2629	0.9560	1.1969	0.6297	1.1269	1.1886	1.0602	0.0015
129	9	SANTA BARB	0.6770	1.0355	0.6610	0.9472	0.9495	1.1886	0.9098	0.0013
130	5	KALAMAZOO	0.8528	1.0128	1.1339	0.8961	1.0148	1.0703	0.9968	0.0012
131	7	LINCOLN	0.6770	1.0128	1.1024	1.1165	0.9270	0.6866	0.9204	0.0011
132	7	TOPEKA	1.1457	1.2513	1.0078	1.1126	0.9270	1.1832	1.1046	0.0012
133	6	LUBOCK TX	1.1457	1.3081	1.3861	1.0087	0.9506	0.7043	1.0839	0.0014
134	4	MONTGOMERY	1.0871	1.1491	1.2234	1.1525	1.1269	1.0863	1.1384	0.0019
135	5	SAGINAW MI	0.7942	1.0696	1.3545	1.0121	1.0148	0.9462	1.0319	0.0012
136	3	LANCSTR PA	1.1457	1.0355	0.9763	0.7244	0.8383	1.1886	0.9848	0.0011
137	2	ATLNTC CTY	1.3801	1.0015	1.3545	1.0564	0.5559	1.1886	1.0395	0.0013
138	1	NEW BRT CT	1.0285	0.9106	0.8502	1.0161	0.8653	0.8954	0.9277	0.0010
139	5	DULUTH MN	1.2043	1.1264	1.1024	1.0193	1.0148	-0.0470	0.9034	0.0003
140	7	CDR RAPIDS	0.9699	1.2854	1.0078	1.1608	0.9270	0.6245	0.9959	0.0014
141	4	PONCE PR	1.6145	1.2400	0.0306	1.4415	1.1269	1.1886	1.1070	0.0014
142	3	YORK PA	1.2043	1.0696	0.8502	1.3463	0.8383	1.1886	1.0830	0.0010
143	4	MACON GA	1.1457	0.8765	0.8502	1.0873	1.1269	1.1886	1.0459	0.0013
144	5	SPRNGFD IL	1.0285	1.1264	1.2600	0.7253	1.0148	0.8728	1.0046	0.0010
145	9	SANTA ROSA	1.1457	1.1037	0.4719	1.5345	0.9495	1.1886	1.0657	0.0040
146	5	GRN BAY	1.1457	0.4904	1.1654	1.2372	1.0148	0.5173	0.9285	0.0026
147	5	APPLTON WI	1.0871	1.2400	1.2915	1.0857	1.0148	0.5173	1.0394	0.0012
148	5	RACINE WI	0.8528	1.1378	1.2600	1.0356	1.0148	0.6302	0.9885	0.0011
149	7	SPRNGFD MO	0.6770	1.0310	1.0078	1.1481	0.9270	1.1886	1.0049	0.0010
150	6	AMARILLO	0.8528	1.3763	1.2915	0.9959	0.9506	0.9259	1.0655	0.0011
151	1	PORTLND ME	0.9113	1.0015	1.0078	1.0783	0.8653	0.6471	0.9185	0.0010
152	9	MODESTO CA	1.0285	1.1491	1.4176	1.1788	0.9495	1.1886	1.1520	0.0013
153	7	WATRLOO IA	1.0871	1.2286	1.1969	0.9400	0.9270	0.6245	1.0007	0.0011
154	6	BEAUMNT TX	1.0285	1.2627	1.4806	0.9695	0.9506	0.8342	1.0877	0.0014
155	4	DURHAM NC	0.6184	1.2740	1.0708	0.6536	1.1269	1.1886	0.9887	0.0010
156	10	SALEM OR	1.0285	1.1491	0.4719	1.1101	1.7179	1.1886	1.1110	0.0011
157	6	GALVESTON	0.9699	0.9901	1.4806	1.5045	0.9506	0.8342	1.1217	0.0013
158	6	TEX CTY TX	0.9699	0.9901	1.4806	0.4347	0.9506	0.8342	0.9434	0.0010
TOTAL			158.00	157.99	158.00	158.00	157.76	158.00	157.96	1.00

$$EVSCHBUS_{mijk} = V_m \; NEVSCHBUS_{ijk} \left(\frac{POPULATION_m}{\sum_m POPULATION_m} \right) . \tag{A.6}$$

Population is from Ref. A.5.

Each of the 12 types of electric transit buses is distributed as follows:

$$EVTRNBUS_{mijk} = V_m \; NEVTRNBUS_{ijk} \left(\frac{TRNBUS_m}{\sum_m TRNBUS_m} \right) \tag{A.7}$$

Table A.19. Number of Urbanized Areas by Values of Variation and Federal Region

Federal Region[a]	Range of Variation 0.7 to 0.8	0.8 to 0.9	0.9 to 1.0	1.0 to 1.1	1.1 to 1.2	1.2 to 1.3	Row Total[b]
I	0	2	7	3	0	0	12
II	0	2	3	2	3	0	8
III	0	5	5	7	2	0	19
IV	0	1	12	13	8	2	36
V	0	0	13	14	2	0	29
VI	0	4	7	6	2	0	19
VII	0	1	6	2	2	0	11
VIII	1	0	2	1	0	0	4
IX	1	3	6	2	2	0	14
X	0	0	1	2	3	0	6
Total	2	18	62	52	22	2	158

[a] See Fig. A.8.

[b] Number of UAs in each federal region.

or on the basis of the 1990 number of expected transit buses of the size (small, large) in the UA.[A.5.]

For each of the four types of hybrid automobiles, the distribution is as follows:

$$\mathrm{HVAUTO}_{mijk} = \mathrm{NHVAUTO}_{ijk} \left(\frac{\mathrm{AUTO}_m}{\sum\limits_m \mathrm{AUTO}_m} \right) . \tag{A.8}$$

For each of the two HV trucks, the distribution is as follows:

$$\mathrm{HVTRUCK}_{mijk} = \mathrm{NHVTRUCK}_{ijk} \left(\frac{\mathrm{POPULATION}_m}{\sum\limits_m \mathrm{POPULATION}_m} \right) . \tag{A.9}$$

A.6 URBAN, REGIONAL, AND NATIONAL VMT AND ENERGY TOTALS

Tables A.20-A.29 summarize the results of distributing the national EHV totals to the 158 UAs. UA totals are then summed by federal region. These tables also present summaries of total VMT and direct energy use by EVs, HVs, and substitutable CVs by year and by scenario. VMT is the product of the appropriate national average VMT for a particular vehicle from data similar to Table A.15 and the number of that vehicle projected for the UA. UA totals are summed by federal region and then again to get U.S. totals. Direct energy use is the product of VMT and the proper energy intensity (see Sec. B.2.2).

Table A.20 is the U.S. summary and presents total vehicles, total annual VMT, and total direct energy use by scenario and assessment year; by truck, bus, and auto; and by electric, hybrid, and conventional vehicle. The CV totals are for substitutable CVs, not the total fleet. Tables A.21-A.24 present the same information at a slightly higher level of aggregation, i.e., for selected federal regions. Tables A.25-29 present the same information for the UAs of New York-New Jersey; Los Angeles; Washington, D.C.; Miami (which has the largest value of V); and Waterloo, Iowa.

Several trends can be identified. CV gasoline and diesel fuel usage declines in every scenario between 1985 and 1990, even though the CV fleet grows. This is because the less-efficient, pre-1985 vehicles are being retired. The growth in CV fuel use between 1990 and 2000 is significant in the LOW scenarios but slight in the HIGH scenarios, where EHVs substitute for about 300 billion VMT in 2000. The slight increase in CV fuel consumption in the HIGH I scenario is due to increased VMT per vehicle. Actually, the total number of vehicles drops slightly.

Miami is a revealing case study (see Table A.28). Since it is an excellent place for EVs, penetration takes place rapidly in HIGH I. Between 1990 and 2000, total vehicle population increases by 11%. EVs increase by 2,526%, while CVs decline 7%. Gallons of petroleum fuels consumed by CVs do not change, since the increase in VMT is offset by improved fuel economy. This is in contrast to HIGH II, where the distribution of HVs does not depend on the regional variation indicator. In this case, Miami does not fare as well, and more gasoline is consumed by CVs in HIGH II than in HIGH I.

Table A.20. U.S. Total Vehicles, VMT, and Direct Energy[a]

TOTAL VEHICLES(THOUSANDS)

TRUCKS

ELECTRICS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
	1985	33.81	33.81	54.70	115.38	115.33
YEAR	1990	128.90	128.90	243.88	521.45	469.44
	2000	1983.77	1983.77	4718.11	12927.11	8730.65

HYBRIDS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
	1985	0.00	12.60	0.00	0.00	0.00
YEAR	1990	0.00	63.70	0.00	0.00	61.60
	2000	0.00	1372.93	0.00	0.00	5296.45

CONVENTIONALS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
	1985	33415.24	33402.21	33394.32	33333.71	33333.71
YEAR	1990	37010.75	36951.77	36095.35	36617.83	36617.54
	2000	40969.67	39636.67	38473.23	29995.04	29972.59

BUSES

ELECTRICS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
	1985	0.00	0.00	0.00	1.99	1.99
YEAR	1990	9.54	9.54	39.80	79.55	71.60
	2000	59.68	59.68	189.01	243.70	120.16

HYBRIDS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
	1985	0.00	0.00	0.00	0.00	0.00
YEAR	1990	0.00	0.00	0.00	0.00	0.00
	2000	0.00	0.00	0.00	0.00	0.00

CONVENTIONALS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
	1985	468.97	468.97	468.97	466.98	466.98
YEAR	1990	510.02	505.42	480.19	440.40	440.35
	2000	516.28	476.33	386.95	351.26	350.60

CARS

ELECTRICS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
	1985	19.74	19.74	29.63	49.31	49.31
YEAR	1990	68.89	68.89	123.27	345.89	294.25
	2000	926.89	926.89	3017.01	10597.04	6887.24

HYBRIDS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
	1985	0.00	7.40	0.00	0.00	0.00
YEAR	1990	0.00	31.80	0.00	0.00	52.40
	2000	0.00	625.96	0.00	0.00	2816.23

CONVENTIONALS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
	1985	113472.00	113465.00	113462.31	113442.94	113442.94
YEAR	1990	119622.75	119590.88	119568.75	119346.88	119345.81
	2000	132664.63	132038.75	130573.69	120839.31	120838.06

Table A.20 (Cont'd)

TOTAL ANNUAL VMT(MILLIONS)

TRUCKS

ELECTRICS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	270.52	270.52	437.56	922.96	922.96
	1990	1044.14	1044.14	2011.81	4698.52	4145.64
	2000	18891.57	18891.57	53823.76	165414.06	107777.06

HYBRIDS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	0.00	149.81	0.00	0.00	0.00
	1990	0.00	796.23	0.00	0.00	770.60
	2000	0.00	18974.55	0.00	0.00	73991.81

CONVENTIONALS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	397303.69	397149.44	397055.31	396333.19	396333.19
	1990	462631.38	461893.81	460819.63	458036.31	458082.69
	2000	566198.44	547776.50	534391.38	419028.56	418715.75

BUSES

ELECTRICS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	0.00	0.00	0.00	12.57	12.57
	1990	69.97	69.97	281.33	626.64	560.31
	2000	465.53	465.53	1693.45	2566.18	1235.20

HYBRIDS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	0.00	0.00	0.00	0.00	0.00
	1990	0.00	0.00	0.00	0.00	0.00
	2000	0.00	0.00	0.00	0.00	0.00

CONVENTIONALS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	4482.90	4482.90	4482.90	4470.40	4470.40
	1990	4837.50	4793.89	4630.00	4284.79	4272.94
	2000	5580.89	5149.61	4353.29	4095.94	4035.74

CARS

ELECTRICS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	173.00	173.03	267.11	450.34	450.34
	1990	641.33	646.36	1204.14	3567.93	3025.35
	2000	9959.20	10927.56	36202.86	131899.13	79415.50

HYBRIDS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	0.00	74.22	0.00	0.00	0.00
	1990	0.00	346.91	0.00	0.00	572.18
	2000	0.00	7943.49	0.00	0.00	35682.00

CONVENTIONALS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	1138149.00	1138080.00	1138050.00	1137853.00	1137853.00
	1990	1305077.00	1304731.00	1304491.00	1303262.00	1303251.00
	2000	1683482.00	1672905.00	1656968.00	1534084.00	1531003.00

Table A.20. (Cont'd)

TOTAL ANNUAL KWH AT THE POWER PLANT(MILLIONS)

TRUCKS

ELECTRICS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
	1985	246.22	246.22	394.23	832.43	832.43
YEAR	1990	819.11	819.11	1529.90	3723.83	3294.65
	2000	13261.55	13261.55	37669.99	123653.00	80380.31

HYBRIDS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
	1985	0.00	149.08	0.00	0.00	0.00
YEAR	1990	0.00	662.30	0.00	0.00	582.95
	2000	0.00	14120.77	0.00	0.00	50086.70

BUSES

ELECTRICS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
	1985	0.00	0.00	0.00	19.97	19.97
YEAR	1990	98.83	98.88	533.45	1530.83	1365.46
	2000	1235.57	1235.57	4810.77	7717.96	3319.12

HYBRIDS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
	1985	0.00	0.00	0.00	0.00	0.00
YEAR	1990	0.00	0.00	0.00	0.00	0.00
	2000	0.00	0.00	0.00	0.00	0.00

CARS

ELECTRICS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
	1985	75.72	75.68	117.23	198.42	198.42
YEAR	1990	239.78	239.48	452.82	1336.15	1144.69
	2000	3396.57	3659.15	12354.73	46169.29	27531.50

HYBRIDS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
	1985	0.00	37.15	0.00	0.00	0.00
YEAR	1990	0.00	146.35	0.00	0.00	193.09
	2000	0.00	2998.02	0.00	0.00	10773.80

TOTAL ANNUAL GALLONS(MILLIONS)

TRUCKS

HYBRIDS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
	1985	0.00	2.32	0.00	0.00	0.00
YEAR	1990	0.00	10.91	0.00	0.00	9.94
	2000	0.00	244.77	0.00	0.00	902.72

Table A.20 (Cont'd)

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      CONVENTIONALS               SCENARIO
                       LOW I       LOW II      MEDIUM      HIGH I      HIGH II
              1985   23840.73    23831.97    23826.33    23784.85    23784.85
     YEAR     1990   24750.82    24712.51    24652.95    24509.18    24508.97
              2000   28578.15    27664.18    26962.39    21138.45    21122.77

***BUSES***

      HYBRIDS                     SCENARIO
                       LOW I       LOW II      MEDIUM      HIGH I      HIGH II
              1985       0.00        0.00        0.00        0.00        0.00
     YEAR     1990       0.00        0.00        0.00        0.00        0.00
              2000       0.00        0.00        0.00        0.00        0.00

      CONVENTIONALS               SCENARIO
                       LOW I       LOW II      MEDIUM      HIGH I      HIGH II
              1985     710.64      710.64      710.64      709.56      709.56
     YEAR     1990     762.12      757.76      739.57      688.16      686.26
              2000     882.70      820.39      691.00      647.54      638.01

***CARS***

      HYBRIDS                     SCENARIO
                       LOW I       LOW II      MEDIUM      HIGH I      HIGH II
              1985       0.00        1.28        0.00        0.00        0.00
     YEAR     1990       0.00        5.24        0.00        0.00       11.01
              2000       0.00      114.39        0.00        0.00      654.74

      CONVENTIONALS               SCENARIO
                       LOW I       LOW II      MEDIUM      HIGH I      HIGH II
              1985   62328.18    62324.54    62323.04    62312.61    62312.61
     YEAR     1990   61341.47    61325.42    61314.27    61258.71    61258.37
              2000   75298.75    74831.06    74131.56    68530.31    68393.38
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[a] CVs include only those vehicles for which EHVs could substitute.

Table A.21. Total Vehicles, VMT, and Direct Energy for Federal Region I[a]

TOTAL VEHICLES(THOUSANDS)

ELECTRICS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	2.19	2.19	3.45	6.88	6.88
	1990	8.51	8.51	16.75	38.62	34.12
	2000	122.46	122.46	322.96	960.57	636.71

HYBRIDS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	0.00	0.84	0.00	0.00	0.00
	1990	0.00	4.01	0.00	0.00	4.70
	2000	0.00	84.23	0.00	0.00	340.18

CONVENTIONALS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	5799.91	5799.07	5798.64	5795.23	5795.23
	1990	6193.75	6189.74	6185.50	6163.67	6163.52
	2000	6866.29	6782.11	6676.10	5947.99	5937.64

TOTAL ANNUAL VMT(MILLIONS)

ELECTRICS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	18.07	18.07	28.75	56.97	56.97
	1990	71.74	71.93	143.18	361.00	314.19
	2000	1202.10	1238.16	3730.94	12129.04	7641.16

HYBRIDS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	0.00	9.42	0.00	0.00	0.00
	1990	0.00	48.24	0.00	0.00	55.66
	2000	0.00	1137.22	0.00	0.00	4613.32

CONVENTIONALS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	60901.82	60892.35	60887.47	60848.56	60848.56
	1990	70135.31	70087.69	70026.38	69850.63	69848.38
	2000	89132.94	87901.69	86735.00	77172.88	76940.94

TOTAL ANNUAL KWH AT THE POWER PLANT(MILLIONS)

ELECTRICS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	13.40	13.40	21.31	44.02	44.02
	1990	48.36	48.34	104.95	273.09	240.68
	2000	747.48	757.26	2277.14	7352.38	4617.03

HYBRIDS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	0.00	7.98	0.00	0.00	0.00
	1990	0.00	34.72	0.00	0.00	33.00
	2000	0.00	735.68	0.00	0.00	2614.78

TOTAL ANNUAL GALLONS(MILLIONS)

HYBRIDS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	0.00	0.15	0.00	0.00	0.00
	1990	0.00	0.68	0.00	0.00	0.86
	2000	0.00	15.12	0.00	0.00	64.61

CONVENTIONALS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	3446.25	3445.73	3445.44	3443.22	3443.22
	1990	3451.25	3448.76	3445.07	3434.80	3434.63
	2000	4156.95	4096.29	4036.54	3574.94	3563.70

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[a] CVs include only those vehicles for which EHVs could substitute.

Table A.22. Total Vehicles, VMT, and Direct Energy for Federal Region III[a]

TOTAL VEHICLES(THOUSANDS)

ELECTRICS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	6.10	6.10	9.61	19.01	19.01
	1990	23.58	23.58	46.31	107.82	95.14
	2000	339.46	339.46	902.52	2701.42	1788.53

HYBRIDS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	0.00	2.34	0.00	0.00	0.00
	1990	0.00	11.18	0.00	0.00	13.28
	2000	0.00	234.27	0.00	0.00	949.44

CONVENTIONALS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	16946.00	16943.66	16942.50	16933.13	16933.13
	1990	18078.47	18067.35	18055.76	17994.39	17993.95
	2000	20042.83	19808.52	19507.59	17440.69	17408.25

TOTAL ANNUAL VMT(MILLIONS)

ELECTRICS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	50.47	50.47	80.22	157.97	157.97
	1990	199.52	200.08	397.62	1011.39	879.34
	2000	3342.18	3450.18	10437.90	34084.70	21425.02

HYBRIDS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	0.00	26.24	0.00	0.00	0.00
	1990	0.00	134.03	0.00	0.00	156.63
	2000	0.00	3157.04	0.00	0.00	12846.81

CONVENTIONALS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	177318.63	177292.19	177278.75	177172.31	177172.31
	1990	204132.94	204000.44	203834.56	203347.56	203341.19
	2000	259727.69	256283.88	252981.94	225892.06	225177.00

TOTAL ANNUAL KWH AT THE POWER PLANT(MILLIONS)

ELECTRICS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	36.82	36.81	58.51	120.26	120.26
	1990	131.96	131.93	287.76	757.15	666.99
	2000	2052.89	2082.17	6288.82	20319.30	12726.32

HYBRIDS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	0.00	21.93	0.00	0.00	0.00
	1990	0.00	95.29	0.00	0.00	91.19
	2000	0.00	2017.67	0.00	0.00	7172.52

TOTAL ANNUAL GALLONS(MILLIONS)

HYBRIDS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	0.00	0.42	0.00	0.00	0.00
	1990	0.00	1.89	0.00	0.00	2.43
	2000	0.00	42.08	0.00	0.00	181.72

CONVENTIONALS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	10014.75	10013.28	10012.50	10006.46	10006.46
	1990	10016.77	10009.91	9999.91	9971.39	9970.88
	2000	12081.30	11912.04	11743.50	10439.30	10404.66

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[a] CVs include only those vehicles for which EHVs could substitute.

Table A.23. Total Vehicles, VMT, and Direct Energy for Federal Region V[a]

TOTAL VEHICLES(THOUSANDS)

ELECTRICS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	11.39	11.39	17.93	35.42	35.42
	1990	44.00	44.00	86.33	201.35	177.59
	2000	632.76	632.76	1686.14	5056.76	3348.05

HYBRIDS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	0.00	4.18	0.00	0.00	0.00
	1990	0.00	19.96	0.00	0.00	23.80
	2000	0.00	417.82	0.00	0.00	1695.39

CONVENTIONALS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	30712.26	30703.06	30705.71	30688.26	30638.26
	1990	32753.13	32733.18	32710.80	32596.02	32596.23
	2000	36287.21	35869.34	35282.91	31422.93	31438.20

TOTAL ANNUAL VMT(MILLIONS)

ELECTRICS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	94.32	94.33	149.88	294.60	294.60
	1990	372.66	373.73	742.25	1891.02	1643.59
	2000	6234.69	6440.64	19510.22	63803.79	40085.15

HYBRIDS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	0.00	46.82	0.00	0.00	0.00
	1990	0.00	233.96	0.00	0.00	280.47
	2000	0.00	5627.13	0.00	0.00	22922.75

CONVENTIONALS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	321012.31	320964.94	320937.94	320740.00	320740.00
	1990	369503.13	369267.50	368950.94	368026.13	368025.75
	2000	469965.00	463813.13	457272.06	406668.81	406359.75

TOTAL ANNUAL KWH AT THE POWER PLANT(MILLIONS)

ELECTRICS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	68.45	68.45	108.77	223.29	223.29
	1990	245.30	245.23	534.12	1405.31	1237.73
	2000	3810.24	3866.10	11683.88	37803.80	23669.74

HYBRIDS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	0.00	38.95	0.00	0.00	0.00
	1990	0.00	169.18	0.00	0.00	162.28
	2000	0.00	3581.48	0.00	0.00	12732.46

TOTAL ANNUAL GALLONS(MILLIONS)

HYBRIDS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	0.00	0.75	0.00	0.00	0.00
	1990	0.00	3.37	0.00	0.00	4.37
	2000	0.00	75.07	0.00	0.00	325.31

CONVENTIONALS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	18116.02	18113.45	18111.88	18100.61	18100.61
	1990	18111.70	18099.46	18080.48	18026.54	18026.25
	2000	21837.54	21535.57	21202.86	18769.27	18755.07

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[a] CVs include only those vehicles for which EHVs could substitute.

Table A.24. Total Vehicles, VMT, and Direct Energy for Federal Region X[a]

TOTAL VEHICLES(THOUSANDS)

ELECTRICS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	1.46	1.46	2.30	4.58	4.58
	1990	5.88	5.88	11.80	26.82	23.66
	2000	81.55	81.55	217.56	652.95	432.20

HYBRIDS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	0.00	0.50	0.00	0.00	0.00
	1990	0.00	2.40	0.00	0.00	2.87
	2000	0.00	50.17	0.00	0.00	203.84

CONVENTIONALS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	3752.82	3752.32	3751.98	3749.70	3749.70
	1990	4000.68	3998.18	3994.78	3979.79	3980.02
	2000	4427.37	4376.94	4297.19	3802.08	3818.01

TOTAL ANNUAL VMT(MILLIONS)

ELECTRICS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	12.13	12.13	19.27	38.08	38.08
	1990	49.63	49.77	100.47	250.80	218.08
	2000	803.64	830.79	2516.66	8232.71	5170.38

HYBRIDS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	0.00	5.63	0.00	0.00	0.00
	1990	0.00	28.68	0.00	0.00	33.82
	2000	0.00	675.25	0.00	0.00	2753.84

CONVENTIONALS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	39179.23	39173.60	39169.77	39144.08	39144.08
	1990	45089.45	45060.14	45014.82	44890.86	44893.17
	2000	57303.26	56560.53	55652.79	49159.18	49308.37

TOTAL ANNUAL KWH AT THE POWER PLANT(MILLIONS)

ELECTRICS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	8.75	8.75	13.90	28.95	28.95
	1990	33.77	33.77	75.02	188.93	166.48
	2000	489.79	497.15	1499.04	4845.66	3036.44

HYBRIDS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	0.00	4.66	0.00	0.00	0.00
	1990	0.00	20.21	0.00	0.00	19.44
	2000	0.00	427.82	0.00	0.00	1521.05

TOTAL ANNUAL GALLONS(MILLIONS)

HYBRIDS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	0.00	0.09	0.00	0.00	0.00
	1990	0.00	0.41	0.00	0.00	0.53
	2000	0.00	9.02	0.00	0.00	39.22

CONVENTIONALS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	2209.52	2209.21	2208.99	2207.51	2207.51
	1990	2207.88	2206.31	2203.46	2196.20	2196.30
	2000	2659.93	2623.40	2577.41	2265.57	2273.01

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[a] CVs include only those vehicles for which EHVs could substitute.

Table A.25. Total Vehicles, VMT, and Direct Energy for New York-New Jersey[a]

TOTAL VEHICLES(THOUSANDS)

ELECTRICS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
	1985	7.86	7.86	12.43	24.88	24.88
YEAR	1990	30.54	30.54	60.21	138.58	122.61
	2000	442.79	442.79	1159.96	3424.27	2271.25

HYBRIDS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
	1985	0.00	2.58	0.00	0.00	0.00
YEAR	1990	0.00	12.45	0.00	0.00	14.39
	2000	0.00	261.98	0.00	0.00	1054.16

CONVENTIONALS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
	1985	17091.36	17088.77	17086.79	17074.34	17074.34
YEAR	1990	18269.43	18257.05	18239.77	18161.53	18163.33
	2000	20194.66	19932.84	19510.68	16984.23	17114.17

TOTAL ANNUAL VMT(MILLIONS)

ELECTRICS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
	1985	64.77	64.78	103.20	205.46	205.46
YEAR	1990	256.69	257.31	512.97	1290.74	1124.48
	2000	4333.66	4453.62	13376.97	43264.03	27304.96

HYBRIDS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
	1985	0.00	29.23	0.00	0.00	0.00
YEAR	1990	0.00	150.19	0.00	0.00	170.98
	2000	0.00	3543.88	0.00	0.00	14329.70

CONVENTIONALS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
	1985	180181.44	180152.00	180129.38	179987.56	179987.56
YEAR	1990	207533.19	207385.69	207145.19	206467.31	206486.63
	2000	262638.13	258826.88	253937.50	220600.56	222077.00

TOTAL ANNUAL KWH AT THE POWER PLANT(MILLIONS)

ELECTRICS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
	1985	48.82	48.82	77.69	160.82	160.82
YEAR	1990	175.00	174.96	382.26	1002.95	884.42
	2000	2743.13	2775.66	8341.51	26783.21	16821.96

HYBRIDS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
	1985	0.00	25.10	0.00	0.00	0.00
YEAR	1990	0.00	109.51	0.00	0.00	103.35
	2000	0.00	2321.49	0.00	0.00	8249.46

TOTAL ANNUAL GALLONS(MILLIONS)

HYBRIDS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
	1985	0.00	0.47	0.00	0.00	0.00
YEAR	1990	0.00	2.11	0.00	0.00	2.60
	2000	0.00	47.01	0.00	0.00	198.61

CONVENTIONALS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
	1985	10228.00	10226.37	10225.06	10216.97	10216.97
YEAR	1990	10255.31	10247.61	10233.11	10193.23	10194.13
	2000	12293.93	12105.32	11852.90	10238.86	10312.72

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[a] CVs include only those vehicles for which EHVs could substitute.

Table A.26. Total Vehicles, VMT, and Direct Energy for Los Angeles[a]

TOTAL VEHICLES(THOUSANDS)

ELECTRICS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	3.52	3.52	5.53	10.82	10.82
	1990	13.59	13.59	26.54	62.30	54.82
	2000	193.55	193.55	522.25	1586.92	1049.09

HYBRIDS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	0.00	1.67	0.00	0.00	0.00
	1990	0.00	7.91	0.00	0.00	9.66
	2000	0.00	164.99	0.00	0.00	673.79

CONVENTIONALS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	13185.57	13183.91	13183.57	13178.27	13178.27
	1990	14043.02	14035.08	14030.10	13994.43	13992.35
	2000	15612.40	15447.47	15301.93	14023.05	13873.12

TOTAL ANNUAL VMT(MILLIONS)

ELECTRICS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	29.30	29.30	46.45	90.47	90.47
	1990	115.76	116.13	229.76	589.06	511.03
	2000	1917.73	1989.12	6060.64	19998.56	12522.94

HYBRIDS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	0.00	18.55	0.00	0.00	0.00
	1990	0.00	94.18	0.00	0.00	113.14
	2000	0.00	2214.33	0.00	0.00	9072.43

CONVENTIONALS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	137069.81	137051.31	137047.31	136987.88	136987.88
	1990	157735.31	157641.94	157562.75	157320.88	157296.00
	2000	201685.25	199234.94	197820.44	181182.81	178959.13

TOTAL ANNUAL KWH AT THE POWER PLANT(MILLIONS)

ELECTRICS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	20.64	20.64	32.75	66.85	66.85
	1990	74.30	74.28	159.98	417.45	367.22
	2000	1134.18	1153.54	3494.84	11417.85	7141.33

HYBRIDS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	0.00	15.05	0.00	0.00	0.00
	1990	0.00	65.12	0.00	0.00	63.29
	2000	0.00	1376.98	0.00	0.00	4897.16

TOTAL ANNUAL GALLONS(MILLIONS)

HYBRIDS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	0.00	0.30	0.00	0.00	0.00
	1990	0.00	1.34	0.00	0.00	1.80
	2000	0.00	29.67	0.00	0.00	131.09

CONVENTIONALS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	7702.05	7701.04	7700.80	7697.43	7697.43
	1990	7686.78	7681.94	7677.22	7663.18	7661.75
	2000	9323.69	9204.41	9133.58	8336.41	8228.80

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[a] CVs include only those vehicles for which EHVs could substitute.

Table A.27. Total Vehicles, VMT, and Direct Energy for Washington, D.C.[a]

TOTAL VEHICLES(THOUSANDS)

ELECTRICS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	1.24	1.24	1.95	3.87	3.87
	1990	4.79	4.79	9.42	21.90	19.33
	2000	69.07	69.07	183.36	548.08	362.94

HYBRIDS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	0.00	0.50	0.00	0.00	0.00
	1990	0.00	2.42	0.00	0.00	2.86
	2000	0.00	50.64	0.00	0.00	205.07

CONVENTIONALS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	3627.81	3627.30	3627.10	3625.18	3625.18
	1990	3871.20	3868.79	3866.58	3854.13	3853.87
	2000	4295.78	4245.14	4187.55	3765.60	3747.07

TOTAL ANNUAL VMT(MILLIONS)

ELECTRICS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	10.25	10.25	16.30	32.13	32.13
	1990	40.54	40.65	80.82	205.33	178.55
	2000	679.58	701.23	2120.10	6916.38	4349.24

HYBRIDS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	0.00	5.67	0.00	0.00	0.00
	1990	0.00	28.97	0.00	0.00	33.78
	2000	0.00	682.62	0.00	0.00	2776.07

CONVENTIONALS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	37936.06	37980.37	37977.99	37956.29	37956.29
	1990	43735.58	43707.02	43674.29	43578.16	43574.88
	2000	55688.05	54944.42	54329.39	48803.60	48495.71

TOTAL ANNUAL KWH AT THE POWER PLANT(MILLIONS)

ELECTRICS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	7.50	7.50	11.93	24.53	24.53
	1990	26.89	26.89	58.65	154.22	135.86
	2000	418.62	424.49	1281.53	4138.16	2592.63

HYBRIDS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	0.00	4.75	0.00	0.00	0.00
	1990	0.00	20.65	0.00	0.00	19.74
	2000	0.00	437.33	0.00	0.00	1554.61

TOTAL ANNUAL GALLONS(MILLIONS)

HYBRIDS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	0.00	0.09	0.00	0.00	0.00
	1990	0.00	0.41	0.00	0.00	0.52
	2000	0.00	9.09	0.00	0.00	39.19

CONVENTIONALS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
YEAR	1985	2146.34	2146.03	2145.89	2144.66	2144.66
	1990	2147.43	2145.95	2143.99	2133.33	2138.12
	2000	2592.00	2555.43	2523.95	2257.72	2242.67

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[a] CVs include only those vehicles for which EHVs could substitute.

Table A.28. Total Vehicles, VMT, and Direct Energy for Miami[a]

TOTAL VEHICLES(THOUSANDS)

ELECTRICS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
	1985	0.73	0.73	1.16	2.29	2.29
YEAR	1990	2.81	2.81	5.47	12.82	11.31
	2000	40.83	40.83	108.34	323.86	214.47

HYBRIDS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
	1985	0.00	0.22	0.00	0.00	0.00
YEAR	1990	0.00	1.05	0.00	0.00	1.24
	2000	0.00	22.01	0.00	0.00	89.13

CONVENTIONALS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
	1985	1568.71	1568.49	1568.29	1567.16	1567.16
YEAR	1990	1673.59	1672.55	1670.92	1663.59	1663.83
	2000	1847.18	1825.20	1782.31	1542.05	1563.08

TOTAL ANNUAL VMT(MILLIONS)

ELECTRICS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
	1985	6.07	6.07	9.64	18.98	18.98
YEAR	1990	23.75	23.82	47.10	120.32	104.62
	2000	401.73	414.45	1252.88	4037.60	2570.77

HYBRIDS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
	1985	0.00	2.46	0.00	0.00	0.00
YEAR	1990	0.00	12.60	0.00	0.00	14.67
	2000	0.00	296.84	0.00	0.00	1206.78

CONVENTIONALS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
	1985	16431.62	16429.14	16426.84	16414.01	16414.01
YEAR	1990	18913.16	18900.86	18878.65	18814.28	18817.52
	2000	23945.53	23622.86	23116.50	19952.16	20207.71

TOTAL ANNUAL KWH AT THE POWER PLANT(MILLIONS)

ELECTRICS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
	1985	4.45	4.45	7.07	14.48	14.48
YEAR	1990	15.61	15.60	33.74	89.74	79.04
	2000	247.38	250.83	757.37	2448.30	1534.08

HYBRIDS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
	1985	0.00	2.07	0.00	0.00	0.00
YEAR	1990	0.00	8.99	0.00	0.00	8.59
	2000	0.00	190.42	0.00	0.00	676.89

TOTAL ANNUAL GALLONS(MILLIONS)

HYBRIDS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
	1985	0.00	0.04	0.00	0.00	0.00
YEAR	1990	0.00	0.18	0.00	0.00	0.23
	2000	0.00	3.95	0.00	0.00	17.02

CONVENTIONALS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
	1985	928.51	928.38	928.24	927.52	927.52
YEAR	1990	928.77	928.14	926.82	923.10	923.27
	2000	1114.29	1098.43	1072.66	920.31	932.94

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[a] CVs include only those vehicles for which EHVs could substitute.

Table A.29. Total Vehicles, VMT, and Direct Energy for Waterloo, Iowa[a]

TOTAL VEHICLES(THOUSANDS)

ELECTRICS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
	1985	0.06	0.06	0.10	0.19	0.19
YEAR	1990	0.23	0.23	0.46	1.07	0.94
	2000	3.35	3.35	8.96	27.07	17.91

HYBRIDS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
	1985	0.00	0.02	0.00	0.00	0.00
YEAR	1990	0.00	0.11	0.00	0.00	0.13
	2000	0.00	2.23	0.00	0.00	9.09

CONVENTIONALS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
	1985	170.19	170.17	170.16	170.07	170.07
YEAR	1990	181.39	181.28	181.16	180.56	180.56
	2000	201.01	198.78	195.65	174.81	174.81

TOTAL ANNUAL VMT(MILLIONS)

ELECTRICS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
	1985	0.50	0.50	0.80	1.56	1.56
YEAR	1990	1.99	1.99	3.94	10.05	8.73
	2000	33.07	34.23	103.89	341.32	214.17

HYBRIDS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
	1985	0.00	0.25	0.00	0.00	0.00
YEAR	1990	0.00	1.28	0.00	0.00	1.51
	2000	0.00	30.04	0.00	0.00	122.68

CONVENTIONALS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
	1985	1774.69	1774.44	1774.30	1773.26	1773.26
YEAR	1990	2042.45	2041.19	2039.54	2034.70	2034.69
	2000	2600.37	2567.39	2532.60	2259.85	2256.96

TOTAL ANNUAL KWH AT THE POWER PLANT(MILLIONS)

ELECTRICS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
	1985	0.36	0.36	0.57	1.17	1.17
YEAR	1990	1.29	1.29	2.77	7.22	6.35
	2000	19.84	20.16	60.85	198.44	124.36

HYBRIDS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
	1985	0.00	0.21	0.00	0.00	0.00
YEAR	1990	0.00	0.89	0.00	0.00	0.86
	2000	0.00	18.94	0.00	0.00	67.33

TOTAL ANNUAL GALLONS(MILLIONS)

HYBRIDS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
	1985	0.00	0.00	0.00	0.00	0.00
YEAR	1990	0.00	0.02	0.00	0.00	0.02
	2000	0.00	0.40	0.00	0.00	1.75

CONVENTIONALS			SCENARIO			
		LOW I	LOW II	MEDIUM	HIGH I	HIGH II
	1985	99.91	99.89	99.89	99.83	99.83
YEAR	1990	99.80	99.73	99.64	99.36	99.36
	2000	120.48	118.87	117.13	104.04	103.91

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[a] CVs include only those vehicles for which EHVs could substitute.

APPENDIX A REFERENCES

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A.3 Knorr, R., and M. Millar, *Projections of Automobile, Light Truck, and Bus Stocks and Sales, to the Year 2000*, Argonne National Laboratory Report ANL/CNSV-TM-22 (Nov. 1979).

A.4 Bernard, M.J., unpublished information (1980).

A.5 *1974 National Transportation Report: Urban Data Supplement*, U.S. Dept. of Transportation (May 1976).

A.6 U.S. Geological Survey, 1:250,000 maps.

A.7 Projection C Computer Printout, U.S. DOE Energy Information Administration (Nov. 1978).

A.8 *Statistical Abstract of the United States, 1977* Tables 353 (p. 210) and 354 (p. 211), based on the 30-yr period, 1941-1970, 98th Annual Edition, U.S. Dept. of Commerce, Bureau of the Census (1977).

A.9 *Regional Transportation Energy Conservation Data Book*, Oak Ridge National Laboratory Report ORNL-5435 (Sept. 1978).

APPENDIX B

VEHICLE CHARACTERISTICS AND VEHICLE MANUFACTURE AND FUELS PRODUCTION PROCESSES

This appendix presents the characteristics of electric, hybrid, and conventional vehicles, and the processes associated with vehicle production (including battery manufacture) and fuels production (including the transport necessary for vehicle operation).

B.1 FUTURE BATTERY CHARACTERISTICS

Greater penetration of EVs, and to a slightly lesser degree HVs, depends on the development of suitable vehicle batteries. Many electrochemical systems are potential candidates; however, only a few are expected to be successfully applied to transportation energy storage systems before 2000. Selection of the battery systems to be included in this assessment is based on three factors: (1) the scope of the study precludes the assessment of more than three or four systems, (2) systems with near-term application and with advanced characteristics are needed to give breadth to the five scenarios, and (3) the systems have to have high potential for vehicular application. This application potential is evaluated using several criteria: electrochemical performance, remaining technical barriers to commercialization, significant environmental barriers, and expected user cost. Based on a multiyear study of storage systems,[B.1] which included structured interviews with many battery manufacturers and experts in the field, Pb/acid, Ni/Fe, Ni/Zn, and Li/S systems were selected. The discussion that follows summarizes the rationale for choosing these systems and rejecting others, and presents the basic future characteristics of each system. Reference B.2 provides an excellent summary of this subject.

The most important parameters of a battery system are: (1) its specific energy storage capacity in watt-hours/kilogram (Wh/kg) measured at a three-hour discharge rate, which is a rough measure of the vehicle driving range before recharging; (2) peak specific power in watts/kilogram (W/kg) for 30 s at 80% battery discharge, which approximates maximum acceleration; and (3) cycle life, or the number of deep discharges per battery lifetime. In transportation applications, batteries are often discharged less than 50%. Such shallow cycles have less of a negative impact on battery lifetime compared to deep cycles. In other words, shallow cycles extend the practical life of the battery.

B.1.1 Pb/Acid Batteries

The Pb/acid system is the near-term battery in all five scenarios. In LOW I and II, it is the only battery of any significance until late in the century. Research and development on this battery is occurring on two fronts: (1) development of improved, state-of-the-art (ISOA) batteries and (2) development of advanced Pb/acid systems capable of about 50% higher performance.

Within the next year, these batteries should be capable of 40-45 Wh/kg and lifetimes of 500-800 deep discharge cycles. However, this performance level is still quite inadequate for most transportation applications. The low specific energy storage capacity results in excessive battery weight, unless range and EV performance are severely compromised. Vehicle range and performance can be enhanced through the use of clever designs that allow more batteries to be placed in the vehicle. However, additional battery packs tend to become excessively expensive, and energy conservation suffers as more and more energy is required to propel the battery itself. The peak power of ISOA batteries is quite marginal, especially late in the discharge and at low temperatures. This limits acceleration and other performance characteristics, particularly in the case of intermediate and compact automobiles.

On the positive side, ISOA batteries can be produced using existing production facilities and are the only EV batteries available at less than $100/kWh. Eventual costs of about $60/kWh are projected, assuming a lead cost, which is unstable, of $0.60/lb.

Whereas the ISOA batteries are a natural extension of existing technology, the advanced Pb/acid battery requires one or more major breakthroughs. Achieving the present technical goals of 60 Wh/kg and 1000 deep discharge cycles will be very difficult. Although this technology is exploratory, the successful development of the battery would have a major impact on the emerging EV market. Unfortunately, the probability that this will occur by 1990 appears to be less than one in ten.

B.1.2 Ni/Zn Batteries

Prospects for commercialization of Ni/Zn batteries have brightened since 1978, and the battery has emerged as the leading candidate for near-term transportation applications. General Motors has announced that it will begin producing EVs with this battery, which reinforces this sense of optimism.[B.3] However, a major improvement in cycle life is necessary before significant penetration of a major market will be possible. This appears to be the only remaining barrier to successful development. Prospects for improved lifetime in Ni/Zn batteries seem good, and the present cycle life of about 200 deep discharge cycles may be extended to 300-400 deep cycles by 1982. The specific energy storage capacity attainable with today's technology is about 65 Wh/kg, with an additional 25% improvement expected by 2000. Peak and sustained power characteristics are excellent throughout the discharge. The Ni/Zn battery seems well suited for transportation applications.

Assuming a nickel price of $3/lb, the initial cost of Ni/Zn batteries will be greater than $120/kWh until mass-production costs of $70/kWh are reached. U.S. nickel resources are currently subeconomic. Although introduction of recycling could recover about 95% of the nickel from batteries, both resources and prices could constrain the higher scenarios.

B.1.3 Ni/Fe Batteries

Ni/Fe is the only battery system among the major contenders with demonstrated ruggedness and long life. This battery is in a relatively mature state of development, with specific energies of 50-55 Wh/kg presently attainable. There appears to be no major technical barrier to increasing the specific energy to about 60 Wh/kg.

The major problem associated with Ni/Fe batteries is the high initial cost. However, life cycle costs may be competitive because of excellent cycle life. Another inherent problem is the evolution of large quantities of hydrogen during charging, which results in reduced energy efficiency, the need for frequent watering of the battery, and hydrogen safety problems. Because of its lower cell voltage, the battery will ultimately require about 20-40% more nickel per kilowatt-hour of capacity than the Ni/Zn battery. As a result, Ni/Fe batteries are particularly sensitive to the cost of nickel, causing the nickel availability problem to be somewhat more serious than in the case of Ni/Zn batteries.

In spite of these problems, the Ni/Fe battery is a leading contender for the near-term electric bus and truck markets. The use of Ni/Fe batteries in personal automobiles is less attractive because of the bulkiness of the battery and the high initial cost. This battery is not considered to play a significant role in the market scenarios, since it is intermediate between Pb/acid and Ni/Zn systems on most parameters.

B.1.4 Li/S Batteries

Li/S battery technology has made impressive progress during the past year, but difficult technical barriers remain. The battery is very well suited for use in EVs, more so than the others considered in this assessment. It will probably be the most compact battery by 1990. The specific energy is expected to be about 20-40% higher than that of Ni/Zn systems, and the peak power should be satisfactory. This favorable assessment holds true even when the ancillary equipment to keep the cells at 842°F and in a good vacuum are considered. Early tests show the associated safety problems with such a high temperature may not be large.

The first road test of a full-scale Li/S battery is slated for late 1980; this test should be very revealing with respect to the status of this battery technology. It is presently very difficult to assess its potential applicability for vehicles because of the absence of meaningful multicell battery tests. Also difficult to assess is future cost. Mass-production costs of $50-60/kWh may be possible, provided the price of lithium does not escalate. In summary, the cost and cycle life barriers are significant, and successful development of this battery system is far from certain.

B.1.5 Other Batteries

Other battery candidates have been judged less likely to be successfully commercialized by 2000 and, for purposes of this study, are assumed to have negligible use in the U.S. transportation fleet. The criteria listed earlier support this decision. However, a major breakthrough that overcomes technical or environmental barriers could radically improve the prospects of these other batteries. The most promising of these batteries include sodium-sulfide (Na/S), zinc-bromine (Zn/Br), Fe/air, Al/air, Zn/Cl, and various special-purpose batteries for HVs. Zn/Cl batteries have drawn special attention lately, because the remaining technological barriers seem small compared to some of the other systems. However, much work remains to determine if it is a safe battery.

B.2 FUTURE VEHICLE CHARACTERISTICS

This section presents the weight, range, performance, energy intensity, emissions, and materials characteristics for all of the EVs, HVs, and CVs used in this assessment.

B.2.1 Performance

Each characterized EV meets the acceleration (0-45 mph in 28 s) of the Society of Automotive Engineers (SAE) J227A Schedule D driving cycle.[B.4] That is, the peak specific power of each EV at 80% depth of discharge is sufficient to achieve that acceleration. This means that each EV is similar in performance to the CVs that will predominate in 2000, which will be more like the current smaller domestic and foreign cars in performance.

B.2.1.1 EV Weight and Range

EV characteristics are based, for the most part, on recent vehicle modeling experience and the most recent forecasts of battery developments (see Sec. B.1). The J227A Schedule D driving cycle has been modeled, and several hundred runs were made simulating EVs with various battery characteristics.[B.1] The results show that in 1985 approximately 0.1 Wh energy extracted from the battery is required to move 1 lb of vehicle weight 1 mi over the Schedule D cycle. The energy required to propel a vehicle over a given range is:

$$E = a \cdot GVW \cdot R \tag{B.1}$$

where:

E = energy (Wh),
GVW = gross vehicle weight (lb),
R = range (mi), and
a = proportionality constant.

This relationship holds only if the battery being examined is not power limited, i.e., is able to meet the acceleration requirements of the driving cycle. It was used as a basis for approximating GVWs of EVs powered by batteries with different assumed characteristics at specified ranges of 50, 100, and 150 mi in 1985. The proportionality constant, a, is empirically derived and accounts for various frictions and inefficiencies. In 1985 it is estimated at 0.10 Wh/lb-mi. It is changed to 0.080 Wh/lb-mi for 1990 and 0.066 Wh/lb-mi for 2000 to reflect expected improvements.

Table B.1 One Coordinate and the Slope of the Battery Peak-Power/Specific-Energy Function

Battery Type	BPP(BSE)[a] 1985	BPP(BSE) 1990	BPP(BSE) 2000	k[b] 1985-2000
Pb/Acid	66(40)	95(44)	98(47)	-2.2
Ni/Fe	102(55)	112(60)	130(65)	-3.0
Ni/Zn	125(75)	135(81)	140(85)	-4.5
Li/S	NA[c]	115(110)	130(120)	-2.1

[a] BPP in W/kg (30 s); BSE in Wh/kg (3-hr rate).

[b] Estimates; no current basis to change value with time.

[c] Not available.

It has recently become apparent that a linear relationship between battery specific energy storage capacity and peak specific power approximates the permissible energy/power tradeoff in the theoretical optimization of battery characteristics to meet specified vehicle range and power criteria. This relationship is used here to insure, at least theoretically, that the various specific energy values used in the calculations of GVW do not result in power limitations below what is required to drive the cycle. Table B.1 presents the battery peak power and related specific energies used in our EV characterization of passenger vehicles and the slope of the tradeoff function for each of the battery systems examined.

An initial assumption concerning the weight of the EV is necessary and is later corrected. The assumption is that the weight difference between an EV and CV of the same size is assumed to be the weight of the battery plus the weight of the structural material required to support the battery, which is assumed to be 0.33 times the battery weight. That is, the weight of the electric motor and its ancillaries is assumed equivalent to the engine and its ancillaries. Then, in theory, the battery and battery supporting weight required to propel the initial GVW (vehicle weight less the battery) over the specified range can be calculated for the assumed battery-specific energy. This weight is then added to the initial GVW. The resulting vehicle weight now exceeds the weight the battery is designed to propel over the specified range. Hence, a second iteration with a slightly larger battery is undertaken. The results of further iterations converge, since the difference between successive GVWs decreases with each iteration. This algorithm can be expressed as a geometric progression. For the jth iteration:

$$\mathrm{GVW}_j = \mathrm{GVW}_o + 1.33\left(\frac{a \cdot R \cdot \mathrm{GVW}_{j-1}}{\mathrm{BSE}}\right) \qquad (B.2)$$

where:

GVW_o = initial GVW, i.e., the weight of a CV plus payload or the weight of an EV where the battery weight is not included but the weight of the motor, which is assumed equivalent to the engine of the CV, is included, plus payload, when j=0 (lb),

GVWj = GVW of EV at j,

R = range at 80% discharge (mi),

BSE = battery specific energy selected for the particular vehicle application (Wh/kg),

a = proportionality constant, and

1.33 = weight propagation factor representing the additional structural frame weight required to support the battery plus additional weight for larger motors, etc.

The quantity in parentheses in Eq. B.2 represents the weight of the battery; the numerator is the energy required to propel the vehicle over a given range (see Eq. B.1), and the denominator is the energy required per unit weight of battery.

It can be shown that the progression converges to:

$$GVW_n = \frac{GVW_o}{1 - x}\ ,\ j = n \tag{B.3}$$

where:

$$x = 1.33\left(\frac{a \cdot R}{BSE}\right),\ x^2 < 1.$$

This simple relationship allows EVs to be designed for different battery systems and ranges. Figure B.1 shows a 1985 example of the family of curves that can be generated for a 6000-lb truck from this characterization equation. It shows range versus several weight variables. BW_o is the weight of the battery and its auxiliary systems (heating or cooling coils, pumps, insulation, etc.). BW_n is the total additional weight in the vehicle (i.e., above GVW_o) due to BW_o plus the additional structure and motor size necessitated by BW_o. Obviously, $GVW_n = GVW_o + BW_n$. Also shown is the battery fraction defined as BW_o/GVW_n.

The Fig. B.1 curves do not drop below a range of 50 mi; a vehicle of lesser range would not have sufficient battery power to meet the required acceleration. This is also the lower limit on weight. The upper limit is a battery fraction of about 0.25 and is at the point where excessive energy must be spent to transport the battery.

Figure B.1 indicates that a 50-mile-range vehicle is possible in 1985 for each of the four battery types. This is close to the maximum range of a Pb/acid vehicle, while a Ni/Fe truck can be designed to approach a range of 70 mi without excessive battery weight. For Ni/Zn vehicles, ranges of 50-100 mi are reasonable; for Li/S vehicles, 50-150 miles are possible. The performance characteristics of all the vehicles used in the assessment are presented in

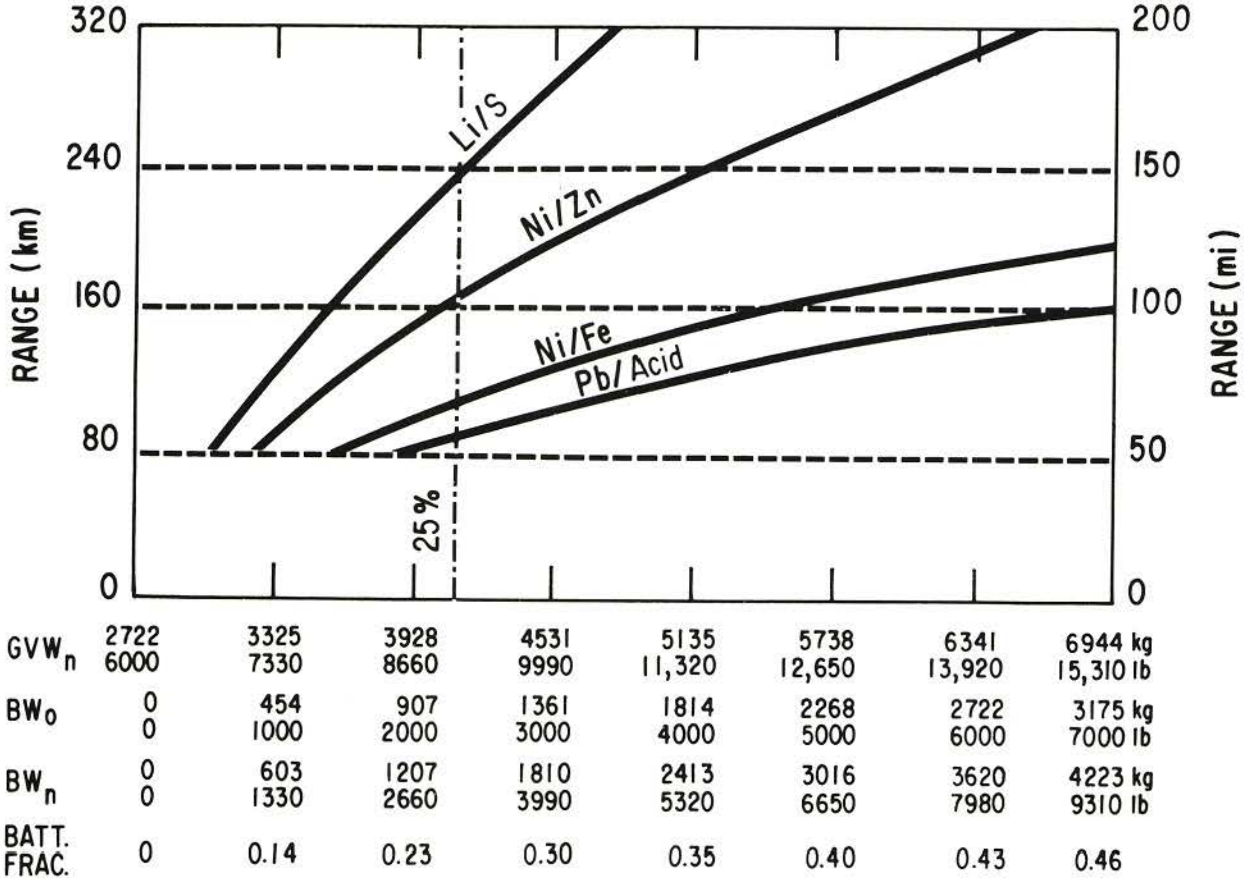

Fig. B.1. 1985 Weight/Range Relationships for a 6000-lb EV Truck

Tables B.2–B.8. The tables were generated by using Eq. B.3 for 1985 and obtaining GVW$_n$. The equation is then solved for R, and R is calculated for 1990 and 2000 by varying a only. In most cases the vehicles would be driven with less than full loads; therefore, R could be exceeded before 80% depth of discharge.

B.2.1.2 HV and CV Weight and Range

The seven HVs characterized are based on data provided by the Jet Propulsion Laboratory.[B.5] Since their model uses slightly different assumptions about future battery performance, miles per gallon, and downsizing than were used for the EVs and equivalent CVs in this assessment, small adjustments are made to make the HV characterizations compatible with those of the EVs and CVs.

Hybrid batteries are sized to allow a 47-mi range to 80% depth of discharge in 1985 (54 mi in 1990; 69 mi in 2000) with engine load leveling. The Otto engines are sized to extend the range of the vehicle through load leveling by the battery at the point the battery reaches 80% depth of discharge. The engine then maintains the battery at 80% depth of discharge.

Table B.2. Electric and Conventional 4000-lb Truck Weight/Range Characteristics[a]

	Vehicle Type						
	EV						CV
Characteristic	LT1	LT2	LT3	LT4	LT5	LT6	LT7
EV range (mi)[b]							
1985	50	50	50	100	100	150[c]	-
1990	58	58	58	116	116	174	-
2000	73	73	73	147	147	220	-
Battery type	Pb/acid	Ni/Fe	Ni/Zn	Ni/Zn	Li/S	Li/S	None
BSE (Wh/kg)[d]	45	60	85	95	128	128	-
GVW_n (lb)[e]	5927	5290	4832	5780	5185	6087	4000
Battery fraction[f]	0.244	0.183	0.129	0.232	0.172	0.258	-
Otto fraction[g]	-	-	-	-	-	-	0.091

[a] GVW_o = 4000 lb (weight of CV including 1860-lb load; hp/lb = 0.03).

[b] To 80% discharge.

[c] Not available in any scenario.

[d] Three-hour rate.

[e] Weight of vehicle plus load.

[f] Weight of battery and its auxiliary systems divided by GVW_n.

[g] Weight of engine divided by GVW_n; valid only for 1985 because of further downsizing in later years.

HV and CV powertrain downsizing assumptions are as follows: (1) for Otto engine vehicles, the 1985 powertrain will weigh 81.5% of the 1978 powertrain and, by 2000, the percentage will be 73.8%, and (2) for diesel buses, the 1985 powertrain will weigh 92.6% of the 1978 weight and, by 2000, the percentage will be 89.5%. The performance parameters of the characterized HVs and CVs are given in Tables B.2-B.8.

B.2.1.3 EHV Accessories

The range of EVs is affected by the operation of high-power accessories like air conditioners and heaters. Full-time operation of an air conditioner off a propulsion battery is estimated to reduce the range of a car by 15%.[B.6] Part-time operation would have less impact on range. Possible gasoline-powered air conditioners or other technologies, such as intermittent absorption systems,[B.7] would have little or no effect on EV range. Air conditioning is not included in this characterization of future EVs. However, EV penetration is reduced in the scenarios in regions of high ambient temperature, where air conditioning would be most required (see Sec. A.5.1).

Table B.3. Electric, Hybrid, and Conventional Medium-Light Truck Weight/Range Characteristics

	Vehicle Type								
	EV						HV		CV
Characteristic	MT1	MT2	MT3	MT4	MT5	MT6	MT7	MT8	MT9
EV range (mi)[a]									
1985	50	50	50	100	100	150[b]	47	47	-
1990	58	58	58	116	116	174	54	54	-
2000	73	73	73	147	147	220	69	69	-
Battery type	Pb/acid	Ni/Fe	Ni/Zn	Ni/Zn	Li/S	Li/S	Pb/acid	Ni/Zn	None
BSE (Wh/kg)[c]	49	66	93	93	128	128	49	93	-
GVWn (lb)[d]	8554	7709	7120	8754	7778	9131	8920	8113	6000
GVWo (lb)[e]	6000	6000	6000	6000	6000	6000	5383	5383	6000
Hp/lb	0.020	0.020	0.020	0.020	0.020	0.020	0.025	0.025	0.020
Battery fraction[f]	0.225	0.167	0.118	0.237	0.172	0.258	0.197	0.111	-
Otto fraction[g]	-	-	-	-	-	-	0.048	0.050	0.060

[a] To 80% discharge; for HVs, heat engine adds for peak power requirements only.

[b] Not available in any scenario.

[c] Three-hour rate.

[d] Weight of vehicle plus load.

[e] Weight of CV including 2450-lb load.

[f] Weight of battery and its auxiliary systems divided by GVW_n.

[g] Weight of engine divided by GVW_n; valid only for 1985 because of further downsizing in later years.

Table B.4. Electric and Conventional 8500-lb Truck Weight/Range Characteristics[a]

	Vehicle Type						
	EV						CV
Characteristic	HT1	HT2	HT3	HT4	HT5	HT6	HT7
EV range (mi)[b]							
1985	50	50	50	100	100	150[c]	-
1990	58	58	58	116	116	174	-
2000	73	73	73	147	147	220	-
Battery type	Pb/acid	Ni/Fe	Ni/Zn	Ni/Zn	Li/S	Li/S	None
BSE (Wh/kg)[d]	49	66	93	93	128	128	-
GVW_n (lb)[e]	12,118	10,920	10,087	12,402	11,019	12,935	8,500
Battery fraction[f]	0.224	0.167	0.118	0.237	0.172	0.258	-
Otto fraction[g]	-	-	-	-	-	-	0.047

[a] GVW_o = 8,500 lb (weight of CV including 3800-lb load; hp/lb = 0.020).

[b] To 80% discharge.

[c] Not available in any scenario.

[d] Three-hour rate.

[e] Weight of vehicle plus load.

[f] Weight of battery and its auxiliary systems divided by GVW_n.

[g] Weight of engine divided by GVW_n; valid only for 1985 because of further downsizing in later years.

Whether auxiliary heat is required depends on climate. Waste heat from the motor and controller would suffice in ambient temperatures of 40-50°F.[B.6] Waste heat from batteries also is a potential source of heat for passenger comfort. The heat source in future EVs is not specified in this analysis, because heaters are not required in all areas of the country. If a heater is run by the propulsion batteries, the range would be decreased. Alternatively, an auxiliary liquid fuel heater (gasoline, propane, alcohol, or methane) could be used and would not impact range. In this analysis, EV penetration is reduced in the scenarios in regions with very cold climates, where heaters would be used most often.

The air-conditioning and heating requirements of HVs also are not specified in this analysis. These requirements may be fulfilled by the sources or technologies noted above for EVs. An accessory battery to provide energy for accessories like power steering and brakes, lights, and windshield wipers is assumed for all future EHVs.

Table B.5. Electric and Conventional Small Bus Weight/ Range Characteristics[a]

	Vehicle Type						
	EV						CV
Characteristic	SB1	SB2	SB3	SB4	SB5	SB6	SB7
EV range (mi)[b]							
1985	50	50	50	100	100	150[c]	-
1990	58	58	58	116	116	174	-
2000	73	73	73	147	147	220	-
Battery type	Pb/acid	Ni/Fe	Ni/Zn	Ni/Zn	Li/S	Li/S	None
BSE (Wh/kg)[d]	49	66	93	93	128	128	-
GVW_n (lb)[e]	14,257	12,848	11,867	14,590	12,963	15,218	10,000
Battery fraction[f]	0.225	0.167	0.118	0.237	0.172	0.258	-
Otto fraction[g]	-	-	-	-	-	-	0.042

[a] GVW_o = 10,000 lb (weight of CV including 3400-lb load); hp/lb = 0.015).

[b] To 80% discharge.

[c] Not available in any scenario.

[d] Three-hour rate.

[e] Weight of vehicle plus load.

[f] Weight of battery and its auxiliary systems divided by GVW_n.

[g] Weight of engine divided by GVW_n; valid only for 1985 because of further downsizing in later years.

B.2.2 Energy Intensities

Energy intensities (the amount of energy used in operating the vehicle a given unit of distance) were derived for each of the 61 vehicles characterized and are given in Table B.9. For EVs, B is the energy extracted from the battery to move one ton of vehicle one mile (0.190, 0.165, and 0.150 kWh/ton-mi in 1985, 1990, and 2000, respectively). The efficiency of the charger, e_c, is 0.90, 0.935, and 0.95 for these three years. The charging efficiency of the battery, e_b, is 0.88, except for Ni/Fe EVs, which is 0.78 for all years. The transmission efficiency between the power plant and the user's charging facility, e_t, is 0.90. These values are based on computer simulations[B.1] and discussions with industry engineers. If the weight of the EV is W, and if $W < GVWn$ (since it is normally not fully loaded), then the electrical energy, E, produced at the power plant to travel one mile is:

$$E = \frac{B \cdot W}{e_c \cdot e_b \cdot e_t} \quad (B.4)$$

Table B.6. Electric and Conventional Large Bus Weight/ Range Characteristics[a]

	Vehicle Type						
	EV						CV
Characteristic	LB1	LB2	LB3	LB4	LB5	LB6	LB7
EV range (mi)[b]							
1985	50	50	50	100	100	150[c]	-
1990	58	58	58	116	116	174	-
2000	73	73	73	147	147	220	-
Battery type	Pb/acid	Ni/Fe	Ni/Zn	Ni/Zn	Li/S	Li/S	None
BSE (Wh/kg)[d]	53	72	100	100	128	135	-
GVW_n (lb)[e]	35,913	32,630	30,455	36,754	33,705	38,525	26,000
Battery fraction[f]	0.208	0.153	0.110	0.220	0.172	0.244	-
Otto fraction[g]	-	-	-	-	-	-	0.067

[a] GVW_o = 26,000 lb (weight of CV including 8000-lb load; hp/lb = 0.008).

[b] To 80% discharge.

[c] Not available in any scenario.

[d] Three-hour rate.

[e] Weight of vehicle plus load.

[f] Weight of battery and its auxiliary systems divided by GVW_n.

[g] Weight of engine divided by GVW_n; valid only for 1985 because of further downsizing in later years.

The CV energy efficiencies are taken directly from the references shown on the tables and projected as necessary. Little improvement after 1985 is expected. Energy efficiencies are measured on-the-road rather than by laboratory dynometers. The Jet Propulsion Laboratory provides sufficient detail with their hybrid characterizations to allow calculation of both gallons and kilowatt hours per vehicle mile. The same efficiency improvements with time are applied to hybrid electrical and heat engine components.

B.2.3 Battery Material Requirements

Projected major materials percentages for Pb/acid, Ni/Fe, Ni/Zn, and Li/S batteries are given in Table B.10. For each battery type, there is a high- and low-performance characterization. The high-performance battery is designed for use in autos and light-light trucks, and the low-performance battery is designed for use in medium- and heavy-light trucks and buses.

Table B.7. Electric, Hybrid, and Conventional Two- to Four-Passenger Automobile Weight/Range Characteristics

Characteristic	Vehicle Type											
	EV									HV		CV
	4P1	4P2	4P3	4P4	4P5	4P6	4P7	4P8	4P9	4P10	4P11	4P12
EV range (mi)[a]												
1985	50	50[b]	50	50[b]	90[c]	100[b]	100	100[b]	140[b,d]	47	47	-
1990	58	58[b]	58	58[b]	104	116[b]	116	116[b]	162[b]	54	54	-
2000	73	73	73	73	132	147	147	147	205	69	69	-
Battery type	Pb/acid	Pb/acid	Ni/Fe	Ni/Fe	Ni/Zn	Ni/Zn	Li/S	Li/S	Li/S	Pb/acid	Ni/Zn	None
BSE (Wh/kg)[e]	44	47	60	65	81	85	110	120	120	44	81	-
GVW_o (lb)[f]	2130	2130	2130	2130	2225	2250	2250	2250	2530	2881	2881	2250
GVW_n (lb)[g]	3191	3093	2817	2749	3297	3431	3065	2976	3841	4181	3332	2250
Hp/lb	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.027	0.028	0.030
Battery fraction[h]	0.250	0.234	0.183	0.169	0.244	0.259	0.200	0.183	0.257	0.216	0.122	-
Otto fraction[i]	-	-	-	-	-	-	-	-	-	0.071	0.084	0.092

[a] To 80% discharge; for HVs, heat engine adds for peak power requirements only.

[b] Not available in any scenario.

[c] A 100-mi vehicle yields an unacceptable battery fraction.

[d] A 150-mi vehicle yields an unacceptable battery fraction.

[e] Three-hour rate.

[f] Varies depending on accessories and range (weight of CV including 450-lb load).

[g] Weight of vehicle plus load.

[h] Weight of battery plus its auxiliary systems divided by GVW_n.

[i] Weight of engine divided by GVW_n; valid only for 1985 because of further downsizing in later years.

Table B.8. Electric, Hybrid, and Conventional Five- to Six-Passenger Automobile Weight/Range Characteristics

Characteristic	Vehicle Type											
	EV									HV		CV
	5P1	5P2	5P3	5P4	5P5	5P6	5P7	5P8	5P9	5P10	5P11	5P12
EV range (mi)[a]												
1985	50	50[b]	50	50[b]	90[c]	100[b]	100	100[b]	140[b,d]	47	47	-
1990	58	58[b]	58	58[b]	104	116[b]	116	116[b]	162[b]	54	54	-
2000	73	73	73	73	132	147	147	147	205	69	69	-
Battery type	Pb/acid	Pb/acid	Ni/Fe	Ni/Fe	Ni/Zn	Ni/Zn	Li/S	Li/S	Li/S	Pb/acid	Ni/Zn	None
BSE (Wh/kg)[e]	44	47	60	65	81	85	110	120	120	44	81	-
GVW_o (lb)[f]	2630	2630	2630	2630	2725	2750	2750	2750	3030	3450	3450	2750
GVW_n (lb)[g]	3940	3819	3478	3394	4038	4194	3747	3637	4600	4867	3906	2750
Hp/lb	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.028	0.028
Battery fraction[h]	0.250	0.234	0.183	0.169	0.244	0.259	0.200	0.183	0.257	0.206	0.118	-
Otto fraction[i]	-	-	-	-	-	-	-	-	-	0.072	0.075	0.083

[a] To 80% discharge; for HVs, heat engine adds for peak power requirements only.

[b] Not available in any scenario.

[c] A 100-mi vehicle yields an unacceptable battery fraction.

[d] A 150-mi vehicle yields an unacceptable battery fraction.

[e] Three-hour rate.

[f] Varies depending on accessories and range (weight of CV including 600-lb load).

[g] Weight of vehicle plus load.

[h] Weight of battery plus its auxiliary systems divided by GVW_n.

[i] Weight of engine divided by GVW_n; valid only for 1985 because of further downsizing in later years.

Table B.9. Vehicle Energy Intensities by Year, All Scenarios

Electric Vehicles (kWh/mi)[a]							
Vehicle Type	1985	1990	2000	Vehicle Type	1985	1990	2000
LT1	0.7347	0.6140	0.5494	LB1	4.4517	3.7212	3.3287
LT2	0.7398	0.6185	0.5533	LB2	4.5631	3.8142	3.4124
LT3	0.5989	0.5006	0.4479	LB3	3.7745	3.1548	2.8231
LT4	0.7164	0.5988	0.5358	LB4	4.5561	3.8078	3.4078
LT5	0.6427	0.5374	0.4807	LB5	4.1777	3.4926	3.1247
LT6	0.7545	0.6307	0.5643	LB6	4.7753	3.9912	3.5709
MT1	1.0602	0.8863	0.7930	4P1	0.3955	0.3307	0.2958
MT2	1.0779	0.9010	0.8063	4P2	0.3833	0.3204	0.2868
MT3	0.8825	0.7377	0.6600	4P3	0.3491	0.2919	0.2612
MT4	1.0850	0.9070	0.8115	4P4	0.3845	0.3213	0.2875
MT5	0.9641	0.8058	0.7211	4P5	0.4610	0.3854	0.3449
MT6	1.1317	0.9460	0.8464	4P6	0.4252	0.3554	0.3180
HT1	1.5017	1.2550	1.1234	4P7	0.3799	0.3176	0.2842
HT2	1.5264	1.2765	1.1421	4P8	0.3688	0.3083	0.2759
HT3	1.2503	1.0451	0.9351	4P9	0.4761	0.3980	0.3561
HT4	1.5370	1.2596	1.1498	5P1	0.4884	0.4083	0.3653
HT5	1.3660	1.1417	1.0215	5P2	0.4734	0.3957	0.3540
HT6	1.6035	1.3400	1.1991	5P3	0.4311	0.3603	0.3225
SB1	1.7666	1.4191	1.3213	5P4	0.4746	0.3967	0.3550
SB2	1.7973	1.5019	1.3437	5P5	0.5647	0.4721	0.4224
SB3	1.4704	1.2292	1.1001	5P6	0.5198	0.4345	0.3889
SB4	1.8083	1.5108	1.3522	5P7	0.4645	0.3882	0.3473
SB5	1.6061	1.3425	1.2017	5P8	0.4508	0.3769	0.3372
SB6	1.8866	1.5774	1.4103	5P9	0.5702	0.4766	0.4264

Hybrid Vehicles						
Vehicle Type	(kWh/mi)[a,b]			(gal/mi)[c]		
	1985	1990	2000	1985	1990	2000
MT7	0.9951	0.8318	0.7442	0.0155	0.0137	0.0129
MT8	0.9051	0.7565	0.6769	0.0146	0.0129	0.0122
4P10	0.4664	0.3898	0.3488	0.0149	0.0132	0.0128
4P11	0.3717	0.3107	0.2780	0.0179	0.0159	0.0154
5P10	0.5429	0.4539	0.4060	0.0202	0.0170	0.0160
5P11	0.4358	0.3642	0.3259	0.0268	0.0226	0.0213

Conventional Vehicles (gal/mi)[c]			
Vehicle Type	1985	1990	2000
LT7	0.0507	0.0480	0.0467
MT9	0.0613	0.0542	0.0512
HT7	0.0695	0.0628	0.0597
SB7	0.1111	0.1000	0.1000
LB7	0.1667	0.1667	0.1667
4P12	0.0469	0.0416	0.0404
5P12	0.0600	0.0506	0.0476

[a] Electricity as generated at the power plant.

[b] Based on an average mile, some of which is driven on electricity and some on gasoline.

[c] Automobile and light truck numbers based on Ref. B.8. Bus figures based on Ref. B.9.

Table B.10. Major EHV Battery Materials[a]

Pb/Acid		
Material	High Performance (%)	Low Performance (%)
Lead	60.5	65.0
Polypropylene	5.4	4.8
Glass	0.21	0.19
Rubber	1.44	1.28
H_2SO_4	29.63	26.2
Total	97.2	97.5

Ni/Fe		
Material	High Performance (%)	Low Performance (%)
Nickel	15.5	17.0
Cobalt	0.72	0.79
Steel	24.9	24.5
Fe_2O_3	17.2	16.9
Copper	3.9	3.8
KOH Soln.	26.6	26.1
(Potassium)	(6.5)	(6.4)
LiOH	1.44	1.41
Rubber	0.055	0.055
Plastic	8.3	8.1
Total	98.6	98.7

Ni/Zn		
Material	High Performance (%)	Low Performance (%)
Nickel	29.7	31.5
ZnO	22.4	24.0
Cobalt	1.6	1.7
KOH Soln.	33.7	31.1
(Potassium)	(8.2)	(7.6)
Copper	0.72	0.67
Plastic	7.2	6.7
Total	95.3	95.7

Li/S		
Material	High Performance (%)	Low Performance (%)
Li_2S	11.5	12.0
LiCl	19.5	18.9
(Lithium)	(6.7)	(7.0)
Aluminum	12.8	13.4
Iron	14.2	14.8
KCl	23.8	23.1
Cu_2S	4.3	4.49
Boron nitrides	0.81	0.79
Steel	12.4	12.0
Total	99.3	99.5

[a] Information compiled from U.S. battery developers, January, 1979.

The weights of the individual EHV batteries and of major battery materials (calculated by applying the Table B.10 percentages to the weights of the batteries) are provided in Tables B.11-B.14.

Possible additives and other minor materials requirements for these four battery types are presented in Table B.15. The probability of using any of these added materials by one or more major battery manufacturers is estimated. Additionally, the processing requirements for the Ni/Zn battery are included in Table B.16.

Table B.11 EV Battery Weight

Vehicle Type	Weight (lb)	Vehicle Type	Weight (lb)
LT1	1443.87	LB1	7453.38
LT2	969.92	LB2	4984.96
LT3	624.81	LB3	3349.62
LT4	1338.35	LB4	8085.71
LT5	890.98	LB5	5793.23
LT6	1569.55	LB6	9417.29
MT1	1920.30	4P1	797.74
MT2	1284.96	4P2	724.06
MT3	842.11	4P3	516.54
MT4	2070.68	4P4	465.41
MT5	1336.84	4P5	806.01
MT6	2354.14	4P6	887.97
HT1	2720.30	4P7	612.78
HT2	1819.55	4P8	545.86
HT3	1193.23	4P9	985.71
HT4	2933.83	5P1	984.96
HT5	1893.98	5P2	893.98
HT6	3334.59	5P3	637.59
SB1	3200.75	5P4	574.44
SB2	2141.35	5P5	987.22
SB3	1403.76	5P6	1085.71
SB4	3451.13	5P7	749.62
SB5	2227.82	5P8	667.67
SB6	3923.31	5P9	1180.45

B.2.4 Motor/Controller/Charger Major Materials

The projected materials composition of EHV motors, controllers, and chargers combined is presented in Tables B.17 and B.18. Table B.17 gives material composition and downsizing from 1978 to 1990, and is based on the following assumptions related to motors and controllers: (1) DC separately excited motors will predominate until about 1990 and (2) silicon-controlled rectifiers (SCR) will be used until about 1990. Table B.18 shows materials composition and downsizing from 1990 to 2000 and is based on the following

Table B.12. EV Battery Materials per Vehicle Type (lb)

Iron		Cu_2S		Lithium		Rubber		Boron	
LT5	126.25	LT5	38.31	LT5	59.70	LT2	0.56	LT5	7.22
LT6	222.88	LT6	67.49	LT6	105.16	MT2	0.71	LT6	12.71
MT5	197.85	MT5	60.02	MT5	93.58	HT2	1.00	MT5	18.56
MT6	348.41	MT6	105.70	MT6	164.79	SB2	1.18	MT6	18.60
HT5	280.31	HT5	85.04	HT5	132.58	LB2	2.74	HT5	14.96
HT6	493.52	HT6	149.72	HT6	233.42	4P3	0.30	HT6	26.34
SB5	329.72	SB5	100.03	SB5	155.95	4P4	0.27	SB5	17.60
SB6	580.65	SB6	176.16	SB6	274.63	5P3	0.37	SB6	30.99
LB5	857.40	LB5	260.12	LB5	405.53	5P4	0.33		
LB6	1393.76	LB6	422.84	LB6	659.21	LT1	20.86	LB5	45.77
4P7	87.02	4P7	26.35	4P7	41.06	MT1	24.58	LB6	74.40
4P8	77.51	4P8	23.47	4P8	36.57	HT1	34.82	4P7	4.96
4P9	139.97	4P9	42.39	4P9	66.04	SB1	40.97	4P8	4.42
5P7	106.45	5P7	32.23	5P7	50.22	LB1	95.40	4P9	7.98
5P8	94.81	5P8	28.71	5P8	44.73	4P1	11.49	5P7	6.07
5P9	167.62	5P9	50.76	5P9	79.09	4P2	10.43	5P8	5.41
						5P1	14.18	5P9	9.56
						5P2	12.87		

ZnO		Aluminum		Lead		LiOH		Fe_2O_3	
LT3	139.96	LT5	114.03	LT1	876.57	LT2	13.97	LT2	166.83
LT4	299.79	LT6	200.90	MT1	1248.20	MT2	18.12	MT2	217.16
MT3	202.11	MT5	179.14	HT1	1768.20	HT2	25.66	HT2	307.50
MT4	496.96	MT6	315.45	SB1	2080.49	SB2	30.19	SB2	361.89
HT3	286.38	HT5	253.79	LB1	4844.70	LB2	70.29	LB2	842.46
HT4	704.12	HT6	446.83	4P1	482.64	4P3	7.44	4P3	88.85
SB3	336.90	SB5	298.53	4P2	438.06	4P4	6.70	4P4	80.05
SB4	828.27	SB6	525.72	5P1	595.90	5P3	9.18	5P3	109.67
LB3	803.91	LB5	776.29	5P2	540.86	5P4	8.27	5P4	98.80
LB4	1940.57	LB6	1261.92						
4P5	180.55	4P7	78.44						
4P6	198.91	4P8	69.87						
5P5	221.14	4P9	126.17						
5P6	243.20	5P7	95.95						
		5P8	85.46						
		5P9	151.10						

Nickel		Cobalt		Copper		Steel		Plastic	
LT2	150.34	LT2	6.98	LT2	37.83	LT2	241.51	LT2	80.50
LT3	185.57	LT3	10.00	LT3	4.50	LT5	110.48	LT3	44.99
LT4	397.49	LT4	21.41	LT4	9.64	LT6	194.62	LT4	96.36
MT2	218.44	MT2	10.15	MT2	48.83	MT2	314.82	MT2	104.08
MT3	265.26	MT3	14.32	MT3	5.64	MT5	160.42	MT3	56.42
MT4	652.26	MT4	35.20	MT4	13.87	MT6	282.50	MT4	138.74
HT2	309.32	HT2	14.37	HT2	69.14	HT2	445.79	HT2	147.38
HT3	375.87	HT3	20.25	HT3	7.99	HT5	227.28	HT3	79.95
HT4	924.16	HT4	49.88	HT4	19.66	HT6	400.15	HT4	196.57
SB2	364.03	SB2	16.92	SB2	81.37	SB2	524.63	SB2	173.45
SB3	442.18	SB3	23.86	SB3	9.41	SB5	267.34	SB3	94.05
SB4	1087.11	SB4	58.67	SB4	23.12	SB6	470.80	SB4	231.23
LB2	847.44	LB2	39.38	LB2	189.43	LB2	1221.32	LB2	403.78
LB3	1055.13	LB3	56.94	LB3	22.44	LB5	695.19	LB3	224.42
LB4	2547.00	LB4	137.46	LB4	54.17	LB6	1130.08	LB4	541.74
4P3	80.06	4P3	3.72	4P3	20.15	4P3	128.62	4P3	42.87
4P4	72.14	4P4	3.35	4P4	18.15	4P4	115.89	4P4	38.63
4P5	239.39	4P5	12.90	4P5	5.80	4P7	75.98	4P5	53.03
4P6	263.73	4P6	14.21	4P6	6.39	4P8	67.69	4P6	63.93
5P3	98.83	5P3	4.59	5P3	24.87	4P9	122.23	5P3	52.92
5P4	89.04	5P4	4.14	5P4	22.40	5P3	158.76	5P4	47.68
5P5	293.20	5P5	15.80	5P5	7.11	5P4	143.03	5P5	71.03
5P6	322.46	5P6	17.37	5P6	7.82	5P7	92.95	5P6	78.17
						5P8	82.79		
						5P9	146.33		

Table B.13. HV Battery Weight

Vehicle Type	Weight (lb)
MT7	1755
4P10	902
5P10	1002
MT8	901
4P11	408
5P11	462

Table B.14. HV Battery Materials per Vehicle Type (lb)

Lead		ZnO	
MT7	1140.75	MT8	216.24
4P10	545.71	4P11	91.39
5P10	606.21	5P11	103.49
Polypropylene		Cobalt	
MT7	84.24	MT8	15.32
4P10	48.71	4P11	6.53
5P10	54.11	5P11	7.39
Glass		KOH	
MT7	3.33	MT8	280.21
4P10	1.89	4P11	137.50
5P10	2.10	5P11	155.69
Rubber		Copper	
MT7	22.46	MT8	6.04
4P10	12.99	4P11	2.94
5P10	14.43	5P11	3.33
H_2SO_4		Plastic	
MT7	459.81	MT8	60.37
4P10	267.26	4P11	29.38
5P10	296.89	5P11	33.26
Nickel			
MT8	283.81		
4P11	121.18		
5P11	137.21		

Table B.15. Possible Additional Ingredients in EHV Batteries

Battery Type	High Probability[a]	Medium Probability[a]	Low Probability[a]
Pb/Acid	Antimony[b] Calcium Lithium Rubber Lignins $BaSO_4$ Tin	Phosphoric acid Thallium Strontium Cerium Lanthanum	Various organic and inorganic acids
Ni/Fe	Paper pulp K_2S $FeSO_4$ Various tartarates	CdO Ammonium salts Sulfites Thiosulfites	Sodium peroxide $N_2H_4 \cdot H_2O$
Ni/Zn	Graphite Teflon Silver CdO Potassium titanate Nylon LiOH Fluorocarbons ZrO_2 Crosslinked PVA Asbestos	Bi_2O_3 $SbCl_5$ CrO_2Cl_2 CaO Cellulose Various phosphates $Ba(OH)_2$ Cadmium Neoprene Brass	$In(OH)_3$ Mercury Tin Polyvinylbutyral Thallium oxides
Li/S	Molybdenum Cobalt Sulfide Graphite NaCl	Ni_3S_2 $BaCl_2$ $SrCl_2$ MgO AlN Silicon Indium	Zinc sulfide Manganese sulfide

[a] Probability refers to the estimated likelihood of use by one or more major manufacturers: high (0.7-1.0), medium (0.3-0.7), and low (0-0.3).

[b] Grid and active material.

Source: Information compiled from U.S. battery developers, January, 1979.

assumptions related to motors and controllers: (1) AC induction motors will begin to penetrate about 1987 and will dominate the EHV market about 1990, and (2) power transistors could replace SCRs in EVs about 1990 and will dominate in 2000. One caveat is that brushless DC motors excited by a permanent magnet could compete for a market share after 1990.

Tables B.17-B.21 also include the following assumptions related to chargers: (1) all vehicles will have on-board chargers, and (2) isolation transformers will not be required.

Table B.16. Ni/Zn Battery Processing Requirements[a]

Material	Quantity Consumed (kg/kWh)
H_2SO_4 (solid)	2.8
KOH (45% solution)[b]	6.4

[a] Information compiled from U.S. battery developers, January, 1979.

[b] KOH could be replaced in future years by NaOH.

The weight of the motor/controller/charger in each vehicle type is derived by multiplying the horsepower of the vehicle (derived from Tables B.2-B.8) by the per-horsepower weight of these components (Tables B.17 and B.18) for the year in question. The amount of each material is then derived by applying the materials composition for a given year to the weight of the motor/controller/charger in that year. Table B.19 gives the motor/controller/charger weight of each vehicle in 2000. Table B.20 gives the major materials in each motor/controller/charger in 2000. For 1990, when vehicles could include either DC-motors/SCR-controllers/chargers or AC-motors/power-transistors/chargers, a fifty-fifty split is assumed.

Table B.17. DC Motor (separately excited), SCR Controller, and Charger Materials Composition, Composite Package (% of total weight)[a]

Material	1978	1985	1990
Iron	53	49	47
Silicon	2	1.7	1.5
Copper	32	33	34
Aluminum	6	8	9
Steel	1	1	1
Total[b]	94	92.7	92.5

[a] Motor/controller/charger weight per horsepower (all vehicles): 1978, 8.5 lb/hp; 1985, 7.0 lb/hp; and 1990, 6.0 lb/hp.[B.10]

[b] The following materials may occur in quantities of <1% each: silicon, carbon, organic insulation, rubber, nickel foil, brass, trace gold, trace silver, lubricant, and ceramics.

Source: Information provided confidentially by developers, January, 1979.

Table B.18. AC Induction Motor, Power Transistor, and Charger Weight Materials Composition, Composite Package (% of total weight)[a]

Material	1990	2000
Iron	48	46
Silicon	1.6	1.5
Copper	36	37
Aluminum	8	9
Steel	1	1
Total	94.6	94.5

[a] Motor/controller/charger weight per horsepower (all vehicles): 1990, 3.5 lb/hp and 2000, 3.1 lb/hp.[B.9]

[b] The following materials may occur in quantities of <1% each: silicon, carbon, organic insulation, rubber, nickel foil, brass, lubricant, ceramics, trace sulfur, and trace gold.

Source: Information provided confidentially by developers, January, 1979.

The HV motor/controller/charger weights are adjusted from the Jet Propulsion Laboratory characterizations to make them consistent with the assumptions of the EA.[B.5] They can not be derived in the same manner as for the EVs. The actual weights for the HV motor/controller/charger are given in Table B.21. The material compositions in Tables B.17 and B.18 also apply to HVs.

B.2.5 Powertrain Materials

Projected materials compositions of HV and CV powertrains are presented in Table B.22. Powertrain weight refers to that part of a CV's or HV's powertrain that would not be part of an EV and includes the internal combustion engine, fuel distribution system, emission control system, exhaust system, and the difference between the transmission and drive system of the CV or HV and the EV.

Table B.23 presents the downsizing expected to occur in the powertrain from 1978 to 2000. The major effort in downsizing the powertrain is expected to be complete by 1985 in order to meet federally mandated miles-per-gallon standards.

Table B.24 presents the projected weights of the powertrains of various CVs (except large buses). These weights are calculated in order to

Table B.19. Weight of Motor/Controller/Charger Materials in EHVs, 2000 (lb)

Vehicle Type	Weight	Vehicle Type	Weight
LT1	551.80	LB4	911.40
LT2	492.90	LB5	837.00
LT3	449.50	LB6	954.80
LT4	536.30	4P1	254.20
LT5	483.60	4P2	244.90
LT6	567.30	4P3	220.10
MT1	530.10	4P4	213.90
MT2	477.40	4P5	263.50
MT3	440.20	4P6	275.90
MT4	542.50	4P7	241.80
MT5	483.60	4P8	235.60
MT6	567.30	4P9	316.20
HT1	564.20	5P1	310.00
HT2	508.40	5P2	300.70
HT3	468.10	5P3	266.60
HT4	576.60	5P4	260.40
HT5	511.50	5P5	319.30
HT6	601.40	5P6	334.80
SB1	663.40	5P7	291.40
SB2	598.30	5P8	282.10
SB3	551.80	5P9	372.00
SB4	678.90	MT7	484
SB5	601.40	4P10	288
SB6	706.80	5P10	316
LB1	889.70	MT3	471
LB2	809.10	4P11	133
LB3	756.40	5P11	149

determine CV body weights and material composition (see Sec. B.2.6). Engine weight is calculated from the horsepower via the method presented in Ref. B.12. A powertrain-to-engine-weight ratio is then applied (1.32 for autos[B.13] and 1.5 for trucks and small buses). The 1.5 figure for trucks and small buses was projected after consultation with informed sources at the U.S. Dept. of Transportation, Jet Propulsion Laboratory, and Minibus Co., Dallas, Texas.

Table B.25 presents the projected weights of the powertrain for HVs. These are derived from the Jet Propulsion Laboratory HV characterization with an adjustment made for greater engine downsizing by 1985.[B.5]

The materials composition and downsizing projections described thus far apply to vehicles with Otto cycle engines. For the large buses with diesel engines, Tables B.26 and B.27 provide materials composition and downsizing to the year 2000. Table B.28 provides projected actual powertrain weights.[B.14] A powertrain-to-engine weight ratio of 2.0 is assumed.

Table B.20. Major Materials in Motor/Controller/Chargers in EHVs, by Vehicle Type, 2000 (lb)

Vehicle Type	Iron	Silicon	Copper	Aluminum	Steel
LT1	253.83	8.28	204.17	49.66	5.52
LT2	226.73	7.39	182.37	44.36	4.93
LT3	206.77	6.74	166.31	40.45	4.49
LT4	246.70	8.04	198.43	48.27	5.36
LT5	222.46	7.25	178.93	43.52	4.84
LT6	260.96	8.51	209.90	51.06	5.67
MT1	243.85	7.95	196.14	47.71	5.30
MT2	219.60	7.16	176.64	42.97	4.77
MT3	202.49	6.60	162.87	39.62	4.40
MT4	249.55	8.14	200.72	48.82	5.42
MT5	222.46	7.25	178.93	43.52	4.84
MT6	260.96	8.51	209.90	51.06	5.67
MT7	222.64	7.26	179.08	43.56	4.84
MT8	216.66	7.06	174.27	42.39	4.71
HT1	259.53	8.46	208.75	50.78	5.64
HT2	233.86	7.63	188.11	45.76	5.08
HT3	215.33	7.02	173.20	42.13	4.68
HT4	265.24	8.65	213.34	51.89	5.77
HT5	235.29	7.67	189.25	46.03	5.11
HT6	276.64	9.02	222.52	54.13	6.01
SB1	305.16	9.95	245.46	59.71	6.63
SB2	275.22	8.97	221.37	53.85	5.98
SB3	253.83	8.28	204.17	49.66	5.52
SB4	312.29	10.18	251.19	61.10	6.79
SB5	276.64	9.02	222.52	54.13	6.01
SB6	325.13	10.60	261.52	63.61	7.07
LB1	409.26	13.35	329.19	80.07	8.90
LB2	372.19	12.14	299.37	72.82	8.09
LB3	347.94	11.35	279.87	68.08	7.56
LB4	419.24	13.67	337.22	82.03	9.11
LB5	385.02	12.55	309.69	75.33	8.37
LB6	439.21	14.32	353.28	85.93	9.55
4P1	116.93	3.81	94.05	22.88	2.54
4P2	112.65	3.67	90.61	22.04	2.45
4P3	101.25	3.30	81.44	19.81	2.20
4P4	98.39	3.21	79.14	19.25	2.14
4P5	121.21	3.95	97.49	23.71	2.63
4P6	126.91	4.14	102.08	24.83	2.76
4P7	111.23	3.63	89.47	21.76	2.42
4P8	108.38	3.53	87.17	21.20	2.36
4P9	145.45	4.74	116.99	28.46	3.16
4P10	132.48	4.32	106.56	25.92	2.88
4P11	61.18	1.99	49.21	11.97	1.33
5P1	142.60	4.65	114.70	27.90	3.10
5P2	138.32	4.51	111.26	27.06	3.01
5P3	122.64	4.00	98.64	23.99	2.67
5P4	119.78	3.91	96.35	23.44	2.60
5P5	146.88	4.79	118.14	28.74	3.19
5P6	154.01	5.02	123.88	30.13	3.35
5P7	134.04	4.37	107.82	26.23	2.91
5P8	129.77	4.23	104.38	25.39	2.82
5P9	171.12	5.58	137.64	33.48	3.72
5P10	145.36	4.74	116.92	28.44	3.16
5P11	68.54	2.23	55.13	13.41	1.49

Table B.21. HV Motor/Controller/Charger Weights (lb)

Vehicle Type	1985	1990[a]	2000
MT7	1092	742	484
4P10	651	440	288
5P10	714	483	316
MT8	1064	722	471
4P11	301	204	133
5P11	336	229	149

[a] Weights for 1990 are for average HVs and assume a fifty-fifty split between the DC motor/controller/charger and the AC motor/power-transistor/charger.

Table B.22. Powertrain Major Materials, CVs and HVs (% of total weight)

Material	1978	1985	1990	2000
Iron	68	52	47	42
Steel	23	26	27	28
Aluminum	5	17	21	24
Other[a]	4	5	5	6
Total	100	100	100	100

[a] Other powertrain materials:
Rubber (belting and hose),
Zinc (diecastings),
Ceramics (on sparkplugs and elsewhere),
INVAR (in bimetallic strips),
Magnesium (competitor with aluminum for replacing cast iron components),
Chromium (high chromium steel in exhaust valves, catalytic converter, etc.),
ZrO_2 (in sensors),
Silicon (in electronic systems),
Inconel, and
Platinum, palladium, and rhodium (catalytic converters).

Sources: Information compiled from industry sources, January, 1979, and Ref. B.11.

Table B.23 Powertrain Downsizing for CVs

Year	Weight[a]	
1978	100 units	
1985	81.5	0.948
1990	77.3	0.955
2000	73.8	

[a] Total weight of powertrain, including engine, transmission, etc.

Source: Information obtained from industry sources, January, 1979.

Table B.24. Engine and Powertrain Weights of CVs

Vehicle Type	Horse-power	Engine Weight (lb)	Powertrain Weight (lb)[a]			
			1978	1985	1990	2000
CV4P1-4[b]	50	236	309	252	239	228
CV4P5-8	55	254	333	271	257	246
CV4P9	60	263	345	281	267	255
CV5P1-4	60	263	345	281	267	255
CV5P5-8	65	281	368	300	284	272
5P9	75	318	417	340	322	308
LT7	120	445	668	544	516	493
MT9	120	445	668	544	516	493
HT7	130	490	735	599	568	542
SB7	150	518	777	633	601	573

[a] Powertrain weight refers to that part of the CV power train that would not be part of an EV.

[b] Only one four-passenger (4P) and one five-passenger (5P) conventional auto are characterized completely in Tables B.7 and B.8. For the materials analysis, a range of conventional auto sizes within the 4P and 5P categories is used. These sizes correspond with the $\mathrm{GVW_o}$ of the 4P and 5P EVs shown in Tables B.7 and B.8. Thus, the notation for 4P and 5P conventional autos (i.e., CV4P1-4, CV5P5, etc.) in Table B.24 and elsewhere in the EA (but only where this range in 4P and 5P CV sizes is used) is slightly different from the notation for CV autos presented in Tables B.7 and B.8.

Table B.25. Engine and Powertrain Weights of HVs (lb)

Vehicle Type	1985 Engine Weight	Powertrain Weight		
		1985[a]	1990	2000
4P10	296	388	368	351
4P11	281	368	349	333
5P10	348	456	432	413
5P11	294	385	365	349
MT7	430	645	611	584
MT8	405	608	576	550

[a] 1985 weights from Ref. B.5.

Table B.26. Total Materials in Diesel Powertrain, 1978, 1985, 1990, 2000

Material	Total Weight (%)
Iron	73.4
Steel	19.6
Aluminum	2.5
Other	4.5
Total	100.0

Table B. 27. Diesel Powertrain Downsizing

Year	Total Weight
1978	100 units
1985	92.60
1990	90.92
2000	89.52

Table B.28. Engine and Powertrain Weights of Diesel Bus[a]

Vehicle Type	Diesel Hp	Engine Weight (lb)	Powertrain Weight (lb)			
			1978	1985	1990	2000
LB7	210	1893	3786	3506	3442	3389

[a] Engine weight estimate obtained from Minibus Co., Dallas, Texas.[B.14] A powertrain-to-engine-weight factor of 2.0 is used.

B.2.6 Body Materials

EV and HV body weights will be greater than those for equivalent CVs. In order to determine the materials composition of the EV and HV bodies, the following process is followed:

1. The total materials of the equivalent CV are estimated.
2. The materials in the internal combustion engine powertrain are determined (i.e., the components that would not be part of an EV).
3. The materials in the equivalent CV body are determined by subtracting (2) from (1).
4. The percentage distribution of body materials determined in (3) is assumed to be the same for EVs and HVs.

These steps are described in greater detail below.

Step 1

The materials composition of a typical automobile is shown in Table B.29. Obviously, there are some differences among the sources for this table but, within a few percentage points, all of them project substantial decreases in steel and iron and increases in aluminum and plastics. Some indicate the potential for use of advanced composite materials (graphite/glass hybrids) by 2000.[B.15]

Less information is available for light trucks and buses, since there are many more options to choose from than for automobiles. However, it can be assumed that light trucks and buses will be required by 1985 to meet environmental and safety regulations similar to those for automobiles and that they will benefit from automobile materials development. Therefore, light trucks and small buses are expected to use the same materials in roughly the same proportions. For that reason, the materials composition of conventional autos, light trucks, and small buses are assumed to be the same for this assessment.

Table B.30 percentages are assumed to apply to all CVs except the diesel large bus. Figures for the large bus are presented in Table B.31; as

Table B.29. Material Composition of a Typical Automobile (% of total weight)

Material	1975	1980	1985	1990	2000
Steel	61.2	57.1	56.0	54.2	54.2
Iron (cast and other)	16.2	14.8	11.1	7.9	7.9
Aluminum	2.9	3.6	8.2	11.9	11.9
Plastics	3.5	5.9	7.4	9.2	9.2
Advanced composite materials	-	-	-	-	1.0
Other	16.2	18.6	17.3	16.8	15.8
Total	100.0	100.0	100.0	100.0	100.0

Sources: Refs. B.6, B.16, B.17, and B.18.

can be seen, no change is projected through 2000. In fact, an increase in the use of plastics, aluminum, and fiberglass could well occur, but specific information that would allow such projections is not available.

Step 2

Powertrain materials in CVs are discussed in Sec. B.2.5. The material compositions are applied to the CV powertrain weights (also discussed in Sec. B.2.5) to determine actual material requirements per CV.

Steps 3 and 4

The materials in the CV bodies are determined by subtracting the powertrain materials determined in Step 2 from the total vehicle materials

Table B.30. Material Composition of a Typical Automobile, Light Truck, and Small Bus (% of total weight)

Material	1985	1990	2000
Steel	56.0	54.2	54.2
Iron (cast and other)	11.1	7.9	7.9
Aluminum	8.2	11.9	11.9
Plastics	7.4	9.2	9.2
Advanced composite materials	-	-	1.0
Other	17.3	16.8	15.8
Total	100.0	100.0	100.0

Table B.31. Material Composition of a Typical Large Diesel Bus, 1978, 1985, 1990, 2000

Material	Total Weight (%)
Steel	58.9
Iron	15.6
Aluminum	5.9
Plastics	3.4
Other	16.2
Total	100.0

determined in Step 1. The percentage distribution of these body materials is then calculated for each vehicle type. Tables B.32-B.35 present these material compositions. These percentage distributions, which vary by year, apply to CV bodies and are assumed to apply to EHV bodies.

Because total GVW and curb weight* remain the same for each of the scenario years and because the powertrain of the HV and CV and the motor/controller/charger of the EHV are downsized to allow detailed material impact assessment, calculated total body materials increase from 1985 to 2000. Therefore, the percentages of the various materials in the body are in error. However, because the error is not significant for this assessment and because the materials in the body are less sensitive, no adjustments for the CV are made. For the EHVs, one adjustment is made: one body weight (that calculated for 1990) is used for all scenario years. That body weight is the GVW (GVW_n from Tables B.2-B.8) minus the battery weight minus the 1990 motor/controller/charger weight minus the 1990 powertrain weight for HVs. The different body materials compositions for 1985, 1990, and 2000 are then applied to this one weight.

The percentage distribution of materials in CVs is provided in Tables B.30 and B.31. The total amounts per vehicle are given in Tables B.36-B.39.

B.3 CHARACTERISTICS OF VEHICLE PRODUCTION PROCESSES

This section characterizes the vehicle and vehicle component production process. It details the major material requirements, energy consumption, and emissions generated from domestic manufacture of EHVs by scenario. The analysis is confined to the production process, i.e., from mining the major materials through assembly of the finished vehicle. The parameters are based on the production of 100,000 vehicles in each of the assessment years. For each scenario and year, the 100,000 vehicle unit reflects the particular mix of total battery and vehicle types produced in that scenario and year. Similar tabulations are presented for CVs.

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*Weight of vehicle with no payload.

Table B.32. Materials in CV and EHV Four-Passenger (4P) Auto Bodies (% of total weight)[a]

	4P1-4[b]			4P5[b]			4P6-8[b]			4P9-11[b]		
Material	1985	1990	2000	1985	1990	2000	1985	1990	2000	1985	1990	2000
Steel	61.3	58.7	58.3	61.4	58.8	58.4	61.3	58.7	58.3	60.7	58.2	57.9
Iron	3.9	1.4	2.5	3.7	1.3	2.4	3.9	1.4	2.5	4.7	2.1	3.1
Aluminum	6.6	10.4	10.0	6.6	10.4	9.9	6.6	10.4	10.0	6.8	10.6	10.2
Plastics	8.7	10.7	10.6	8.8	10.7	10.7	8.7	10.7	10.7	8.6	10.6	10.5
Advanced composite materials	-	-	1.2	-	-	1.2	-	-	1.2	-	-	1.1
Other	19.5	18.8	17.4	19.5	18.8	17.4	19.5	18.8	17.3	19.2	18.5	17.2
Total	100	100	100	100	100	100	100	100	100	100	100	100

[a] See footnote b on Table B.24.

[b] CVs and EHVs.

Table B.33. Materials in CV and EHV Five-Passenger (5P) Auto Bodies (% of total weight)[a]

	5P1-4[b]			5P5[b]			5P6-8[b]			5P9-11[b]		
Material	1985	1990	2000	1985	1990	2000	1985	1990	2000	1985	1990	2000
Steel	60.8	58.3	58.0	61.0	58.4	58.1	60.8	58.3	58.0	60.9	58.4	58.0
Iron	4.5	2.0	3.0	4.4	1.9	2.9	4.5	2.0	3.0	4.5	1.9	3.0
Aluminum	6.8	10.5	10.2	6.7	10.5	10.1	6.8	10.5	10.2	6.8	10.5	10.1
Plastics	8.6	10.6	10.5	8.6	10.6	10.6	8.6	10.6	10.5	8.6	10.5	10.5
Advanced composite materials	-	-	1.1	-	-	1.1	-	-	1.1	-	-	1.2
Other	19.3	18.6	17.2	19.3	18.6	17.2	19.3	18.6	17.2	19.3	18.6	17.2
Total	100	100	100	100	100	100	100	100	100	100	100	100

[a] See footnote b on Table B.24.

[b] CVs and EHVs.

Table B.34. Materials in CV and EHV Truck Bodies (% of total weight)

	Light Truck 1-7			Medium Truck 1-9			Heavy Truck 1-7		
Material	1985	1990	2000	1985	1990	2000	1985	1990	2000
Steel	59.7	57.0	57.3	61.4	58.8	58.5	60.4	58.0	57.6
Iron	3.7	1.3	2.4	3.7	1.3	2.4	5.1	2.5	3.5
Aluminum	5.2	9.0	8.3	6.6	10.4	10.0	6.9	10.7	10.3
Plastics	9.9	12.1	12.0	8.7	10.8	10.7	8.5	10.5	10.4
Advanced composite materials	-	-	1.3	-	-	1.1	-	-	1.1
Other	21.5	20.6	18.7	19.6	18.7	17.3	19.1	18.3	17.1
Total	100	100	100	100	100	100	100	100	100

B.3.1 Methodological Overview

Total materials requirements for batteries, battery replacements, motors, controllers, chargers, bodies, and powertrains are calculated for each assessment year and scenario on a 100,000 vehicle unit basis. Total energy requirements are derived from the material requirements. The proportions of native or imported ore, domestic or imported concentrate, imported refined material, and scrap or salvaged materials used in the various production processes are determined.

Table B.35. Materials in Otto, Diesel, and Electric Bus Vehicle Bodies (% of total weight)

	Small Bus 1-7			Large Bus 1-7		
Material	1985	1990	2000	1985	1990	2000
Steel	59.2	56.9	56.7	68.4	68.4	68.4
Iron	6.7	4.0	4.6	1.6	1.6	1.6
Aluminum	7.3	11.0	10.8	6.7	6.7	6.7
Plastics	8.2	10.1	10.1	4.2	4.2	4.2
Advanced composite materials	-	-	1.1	-	-	-
Other	18.6	18.0	16.7	19.1	19.1	19.1
Total	100	100	100	100	100	100

Table B.36. Total Vehicle Materials of Four-Passenger (4P) CV Autos (lb)

Material	CV4P1-4			CV4P5			CV4P6-8			CV4P9		
	1985	1990	2000	1985	1990	2000	1985	1990	2000	1985	1990	2000
Steel	940.8	910.56	910.56	994	962.05	962.05	1008	975.6	975.6	1164.8	1127.36	1127.36
Iron	186.48	132.72	132.76	197.025	140.225	140.225	199.8	142.2	142.2	230.88	1674.32	164.32
Aluminum	137.76	199.92	199.92	145.55	211.225	211.225	147.6	214.2	214.2	170.56	247.52	247.52
Plastics	124.32	154.56	154.56	131.35	163.3	163.3	133.2	165.6	165.6	153.92	191.36	191.36
Advanced composite materials	-	-	16.8	-	-	17.75	-	-	18.0	-	-	20.8
Other	290.64	282.24	265.44	307.075	298.2	280.45	311.4	302.4	284.4	359.84	349.44	328.64
Total curb weight	1680	1680	1680	1775	1775	1775	1800	1800	1800	2080	2080	2080

Table B.37. Total Vehicle Materials of Five-Passenger (5P) CV Autos (lb)

Material	CV5P1-4			CV5P5			CV5P6-8			CV5P9		
	1985	1990	2000	1985	1990	2000	1985	1990	2000	1985	1990	2000
Steel	1136.8	1100.26	1100.26	1190	1151.75	1151.75	1204	1165.3	1165.3	1360.8	1317.06	1317.06
Iron	225.33	160.37	160.37	235.875	167.875	167.875	238.65	169.85	169.85	269.73	191.97	191.97
Aluminum	166.46	241.57	241.57	174.25	252.875	252.875	176.3	255.85	255.85	199.26	289.17	289.17
Plastics	150.22	186.76	186.76	157.25	195.5	195.5	159.1	197.8	197.8	179.82	223.56	223.56
Advanced composite materials	-	-	20.3	-	-	21.25	-	-	21.5	-	-	24.3
Other	351.19	341.04	320.74	367.625	357	335.75	371.95	361.2	339.7	420.39	408.24	383.94
Total curb weight	2030	2030	2030	2125	2125	2125	2150	2150	2150	2430	2430	2430

Table B.38. Total Vehicle Materials of CV Light Trucks (LT), Medium Trucks (MT), and Heavy Trucks (HT) (lb)

Material	LT7			MT9			HT7		
	1985	1990	2000	1985	1990	2000	1985	1990	2000
Steel	1198.4	1159.88	1159.88	1988	1924.1	1924.1	2632	2547.4	2547.4
Iron	237.54	169.06	169.06	394.05	280.45	280.45	521.7	371.3	371.3
Aluminum	175.48	254.66	254.66	291.1	422.45	422.45	385.4	559.3	559.3
Plastics	158.36	196.88	196.88	262.7	326.6	326.6	347.8	432.4	432.4
Advanced composite materials	-	-	21.40	-	-	35.5	-	-	47
Other	370.22	359.52	338.12	614.15	596.4	560.9	813.1	789.6	742.6
Total curb weight	2140	2140	2140	3550	3550	3550	4700	4700	4700

Table B.39. Total Vehicle Materials of Otto Small Bus (SB) and Diesel Large Bus (LB) (lb)

Material	SB7			LB7		
	1985	1990	2000	1985	1990	2000
Steel	3,696	3,577.2	3,577.2	10,602	10,602	10,602
Iron	732.6	521.4	521.4	2,808	2,808	2,808
Aluminum	541.2	785.4	785.4	1,062	1,062	1,062
Plastics	488.4	607.2	607.2	612	612	612
Advanced composite materials	-	-	66.0	-	-	-
Other	1,141.8	1,108.8	1,042.8	2,916	2,916	2,916
Total curb weight	6,600	6,600	6,600	18,000	18,000	18,000

Energy consumption for each appropriate processing step (mining, milling, smelting, refining, processing, machining, fabrication, and assembly) is used where available and applied against the proportion of material undergoing that particular step in the overall process. When specific data are not available, analogous processes or similar materials are used as an approximation of energy requirements. Vehicle machining, fabrication, and assembly energies are derived from an analysis of CV requirements.

Estimated emissions created in the production process are at best an approximation. Empirical data concerning battery production are lacking, with the exception of one report on Pb/acid batteries.[B.19] Numerous assumptions are required regarding the metal content of the ores and concentrates, the operating characteristics of the refining processes, and the emission standards in effect on the date of processing. However, emissions (air, water, and solid waste) are characterized for each appropriate processing step in the production of EHVs and CVs.

B.3.2 Materials Requirements

Total materials requirements for each scenario and assessment year on a 100,000 vehicle unit basis are the product of the materials characterizations presented in Secs. B.2.3-B.2.6 for the batteries, motors/controllers/chargers, HV powertrains, and bodies and the EHV domestic sales mix on a 100,000 unit basis. In other words, the total amount of each battery material in new vehicle batteries in a specific scenario and year is derived by taking the battery materials characterization for each vehicle type as given in Sec. B.2.3 and multiplying these materials for an individual vehicle by the total number of vehicles of that type domestically produced in that scenario and year. The total amount of each motor/controller/charger, body, and powertrain material in a scenario is similarly derived. The EHV domestic sales mix on a 100,000 vehicle unit basis is summarized in Table B.40.

The total material requirements for each scenario and assessment year also include replacement battery materials, since batteries are replaced before the vehicle itself is replaced. The equation used to calculate the number of batteries of a specific vehicle type requiring replacement is:

$$R_{jn} = \sum_{t=n-20}^{n} SR_t \cdot X_{jt} \qquad \text{(B.5)}$$

where:

j = vehicle type,

n = assessment year (1985, 1990, or 2000),

t = a previous year,

R_{jn} = total replacement batteries for the vehicle type and year,

SR_t = survival rate for vehicles sold in t (see Table B.42), and

Table B.40. EHV Domestic Sales and Manufacture by Scenario Adjusted to a 100,000 Vehicle Unit Basis (10^3 vehicles)

Vehicle Type	LOW I			MEDIUM			HIGH I		
	1985	1990	2000	1985	1990	2000	1985	1990	2000
Small bus	-	5.5	0.8	-	8.7	0.2	1.7	4.8	0.1
Large bus	-	-	1.8	-	3.2	1.9	-	5.1	0.7
Medium truck	34.8	39.7	48.4	37.3	48.5	45.6	48.3	44.3	39.2
Heavy truck	-	2.4	1.9	-	6.9	3.8	3.9	7.4	4.4
Light truck	27.8	18.0	19.5	28.2	5.1	11.1	9.1	6.4	11.5
4-passenger	18.0	13.6	7.7	16.5	9.2	13.3	7.7	6.6	18.2
5-passenger	19.4	20.8	19.9	18.0	18.4	24.1	29.3	25.4	25.9
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Vehicle Type		LOW II			HIGH II		
		1985	1990	2000	1985	1990	2000
Small bus		-	3.5	0.4	1.7	4.1	0.1
Large bus		-	-	1.0	-	4.5	0.5
Medium truck	EV	24.8	25.7	26.3	48.3	36.9	26.7
	HV	20.8	25.1	31.2	-	8.7	24.1
Heavy truck		-	1.6	1.0	3.9	6.0	2.7
Light truck		19.8	11.6	10.6	9.1	5.0	7.4
4-passenger	EV	12.9	8.8	4.2	7.7	5.9	10.8
	HV	1.9	2.1	6.0	-	1.2	5.1
5-passenger	EV	13.8	13.5	10.8	29.3	23.0	15.4
	HV	6.0	8.1	8.5	-	4.7	7.2
Total		100.0	100.0	100.0	100.0	100.0	100.0

X_{jt} = 1 if battery needs replacement and 0 if not (see Table B.41).

These batteries also include replacement batteries for vehicles originally imported. Tables B.43 and B.44 show replacement battery totals for the EHV scenarios and the conversion to the 100,000 vehicle unit basis. The total materials requirements for replacement batteries in a specific scenario are the product of the totals in Tables B.43 and B.44 and the materials composition of individual batteries as described in Sec. B.2.3.

Table B.41. Years between Replacement for Various Battery Types

	Year Battery Sold		
Battery	1980–1982	1985–1990	1990–2000
Pb/Acid	3	4	5
Ni/Fe	10	10	10
Ni/Zn	2	4	5
Li/S	–	4	5

Table B.42. Vehicle Survival Rates[a]

Vehicle Age	Survival Rate
0	1.00
1	0.99
2	0.98
3	0.96
4	0.94
5	0.90
6	0.85
7	0.77
8	0.69
9	0.60
10	0.50
11	0.40
12	0.31
13	0.23
14	0.15
15	0.10
16	0.06
17	0.04
18	0.02
19	0.01
20	0

[a] Assumes 10-yr average life and a cumulative normal distribution with a standard deviation of 4.0. Since no real experience exists for EHVs, this simulates the current automobile survival rate pattern.

Table B.43. EV Replacement Batteries (10^3)

	Vehicles with Batteries Replaced in 1990 (vehicle purchased new in 1986)			Adjusted to Pattern for 100,000 Vehicles		
Scenario and Battery	Total Low Performance	Total High Performance	All Batteries	Low Performance	High Performance	All Batteries
LOW I						
Pb/Acid	7.76	11.76	19.52	14.10	21.37	35.47
Ni/Zn	0.14	0.23	0.37	0.25	0.42	0.67
Total	7.90	11.99	19.89	14.35	21.79	36.14
MEDIUM						
Pb/Acid	5.07	3.99	9.06	4.01	3.16	7.17
Ni/Zn	7.52	26.33	33.85	5.95	20.83	26.78
Total	12.59	30.32	42.91	9.96	23.99	33.95
HIGH I						
Pb/Acid	21.67	9.87	31.54	6.93	3.16	10.09
Ni/Zn	9.49	39.48	48.97	3.04	12.63	15.67
Li/S	0.52	16.26	16.78	0.17	5.20	5.37
Total	31.68	65.61	97.29	10.14	20.99	31.13

	Vehicles with Batteries Replaced in 2000 (vehicle purchased new in 1988, 1990, 1995)			Adjusted to Pattern for 100,000 Vehicles		
LOW I						
Pb/Acid	110.51	179.02	289.53	14.70	23.82	38.52
Ni/Fe	0.21	0.30	0.51	0.03	0.04	0.07
Ni/Zn	21.32	28.49	49.81	2.84	3.79	6.63
Li/S	-	-	-	-	-	-
Total	132.04	207.81	339.85	17.57	27.65	45.22
MEDIUM						
Pb/Acid	75.30	70.09	145.39	3.20	2.97	6.17
Ni/Fe	0.27	0.31	0.58	0.01	0.01	0.02
Ni/Zn	366.98	245.68	612.66	15.59	10.43	26.02
Li/S	1.02	79.14	80.16	0.04	3.36	3.40
Total	443.57	395.22	838.79	18.84	16.77	35.61
HIGH I						
Pb/Acid	146.13	166.12	312.25	2.01	2.29	4.30
Ni/Fe	-	-	-	-	-	-
Ni/Zn	531.67	849.28	1380.95	7.32	11.69	19.01
Li/S	338.29	405.03	743.32	4.66	5.57	10.23
Total	1016.09	1420.43	2436.52	13.99	19.55	33.54

All materials from all vehicle components are summed to derive the total materials requirements for the five scenarios on the 100,000 vehicle unit basis. Tables B.45-B.50 give the materials requirements totals for the scenarios. Table B.51 shows the total CV materials requirements for the same domestic sales mix as the 100,000 EHVs.

Production process materials beyond those used in the vehicle itself are generally not characterized here. For example, shop scrap and material losses during mining raw ore and during solution preparation and battery filling are not accounted for. However, it is generally expected that such material losses will not be significant. While this assumption may not be entirely valid, it is certainly likely that any additional material requirements resulting from material losses are within the uncertainty of the base data.

Table B.44. EHV Replacement Batteries (10^3)

Scenario and Battery	Vehicles with Batteries Replaced in 1990 (vehicle purchased new in 1986)			Adjusted to Pattern for 100,000 EHVs		
	Total Low Performance	Total High Performance	All Batteries	Low Performance	High Performance	All Batteries
LOW II						
EV Pb/Acid	7.76	11.76	19.52	9.12	13.83	22.95
EV Ni/Zn	0.14	0.23	0.37	0.17	0.27	0.44
HV Pb/Acid	9.4	2.44	11.84	11.05	2.87	13.92
Total	17.3	14.43	31.73	20.34	16.97	37.31
HIGH II						
EV Pb/Acid	21.67	9.87	31.54	7.14	3.26	10.40
EV Ni/Zn	9.49	39.48	48.97	3.13	13.01	16.14
HV Ni/Zn	-	-	-	-	-	-
Total	31.16	49.35	80.51	10.27	16.27	26.54

	Vehicles with Batteries Replaced in 2000 (vehicle purchased new in 1988, 1990, 1995)			Adjusted to Pattern for 100,000 Vehicles		
LOW II						
EV Pb/Acid	110.51	179.02	289.53	7.98	12.94	20.92
EV Ni/Fe	0.21	0.30	0.51	0.02	0.022	0.04
EV Ni/Zn	21.32	28.49	49.81	1.54	2.06	3.60
HV Pb/Acid	131.25	53.85	185.1	9.48	3.89	13.37
Total	263.29	261.66	524.95	19.02	18.91	37.93
HIGH II						
EV Pb/Acid	146.13	166.12	312.25	1.95	2.21	4.16
EV Ni/Fe	-	-	-	-	-	-
EV Ni/Zn	531.67	849.28	1380.95	7.09	11.33	18.42
HV Ni/Zn	448.0	117.7	565.7	5.97	1.57	7.54
Total	1125.8	1133.1	2258.9	15.01	15.11	30.12

B.3.3 Energy Consumption

The energy required to mine, purify, and convert materials and to fabricate and assemble the vehicles under each scenario are quantified below on the 100,000 vehicle unit basis. The direct energy consumed by equipment and materials handling, the energy required to produce the energy used in the production process (i.e., energy to extract oil), and some indirect energy also are included.

B.3.3.1 Battery Manufacturing

The energy requirements of Pb/acid battery materials and manufacturing processes are presented as energy per megawatt hour of battery output over its designed life cycle in Ref. B.19. These figures are then converted to energy input for each major component of the battery, including lead, sulfuric acid, plastic battery cases, and battery assembly. Among these constituents, sulfuric acid manufacture is exothermic, yielding useful heat energy which then can be used in other areas of the acid plant, and is considered as an energy credit. Similarly, intermediate plastics processing yields sizable process streams that can be used as fuel in other segments of the processing

Table B.45. EV Battery Material Requirements per 100,000 Vehicles by Scenario (10^6 lb/100,000 EVs)[a]

Scenario	Year Required	Battery Category (performance)	Lead	H_2SO_4[b]	Glass	Rubber	Plastic[c]	Nickel	Cobalt	LiOH	KOH	Copper	Steel
LOW I	1985	Low	41.97	16.91	0.12	0.83	3.19	0.30	0.01	0.01	0.34	0.02	0.12
		High	43.06	21.09	0.15	1.02	3.97	0.43	0.02	0.02	0.54	0.03	0.15
		Total	85.03	38.00	0.27	1.85	7.16	0.73	0.03	0.02	0.88	0.05	0.27
	1990	Low	56.83	22.91	0.17	1.12	4.96	3.34	0.18	0.01	3.39	0.11	0.24
		High	30.07	14.73	0.10	0.72	3.19	2.03	0.11	0.01	2.36	0.07	0.13
		Total	86.90	37.64	0.27	1.84	8.15	5.37	0.29	0.02	5.75	0.18	0.37
	2000	Low	58.86	23.73	0.17	1.16	5.91	7.17	0.39	0.01	7.14	0.18	0.18
		High	26.45	12.95	0.09	0.63	3.04	2.69	0.14	0.01	3.08	0.08	0.11
		Total	85.31	36.68	0.26	1.79	8.95	9.86	0.53	0.02	10.22	0.26	0.29
MEDIUM	1985	Low	17.27	6.96	0.05	0.34	2.63	6.20	0.34	0.01	6.18	0.16	0.16
		High	10.50	5.14	0.04	0.25	3.47	10.25	0.55	0.02	11.72	0.28	0.27
		Total	27.77	12.10	0.09	0.59	6.10	16.45	0.89	0.03	17.90	0.44	0.43
	1990	Low	27.40	11.04	0.08	0.54	6.94	23.03	1.25	0.01	22.80	0.51	0.96
		High	1.46	0.71	0.01	0.03	1.98	7.62	0.41	–	8.67	0.19	0.27
		Total	28.86	11.75	0.09	0.57	8.92	30.65	1.66	0.01	31.47	0.70	1.23
	2000	Low	11.89	4.79	0.03	0.23	5.51	21.62	1.17	0.01	21.42	0.49	1.12
		High	4.14	2.03	0.01	0.10	2.83	10.09	0.54	0.00	11.46	0.25	0.89
		Total	16.03	6.82	0.04	0.33	8.34	31.71	1.71	0.01	32.88	0.74	2.01
HIGH I	1985	Low	48.33	19.48	0.14	0.95	4.58	4.76	0.26		4.70	0.10	
		High	16.20	7.93	0.06	0.39	2.64	4.89	0.26		5.55	0.12	
		Total	64.53	27.41	0.20	1.34	7.22	9.65	0.52		10.25	0.22	
	1990	Low	21.16	8.53	0.06	0.42	7.52	28.02	1.51		27.67	0.60	2.96
		High	1.39	0.68	0.00	0.03	2.32	9.09	0.49		10.32	0.22	0.56
		Total	22.55	9.21	0.06	0.45	9.84	37.11	2.00		37.99	0.82	3.52
	2000	Low	6.63	2.67	0.02	0.13	4.43	18.54	1.00		18.31	0.39	3.73
		High	4.02	1.97	0.01	0.10	2.53	8.95	0.48		10.16	0.22	2.57
		Total	10.65	4.64	0.03	0.23	6.96	27.49	1.48		28.47	0.61	6.30

Table B.45 (Cont'd)

Scenario	Year Required	Battery Category (performance)	Fe_2O_3	ZnO	Li_2S	LiCl	Aluminum	Iron	KCl	CuS	BN	Other	Total
LOW I	1985	Low	0.08	0.16								1.69	65.75
		High	0.11	0.25								2.08	72.91
		Total	0.19	0.41								3.77	138.66
	1990	Low	0.16	2.42								2.65	98.49
		High	0.09	1.47								1.73	56.81
		Total	0.25	3.89								4.38	155.30
	2000	Low	0.13	5.36								3.26	113.65
		High	0.08	1.98								1.65	52.98
		Total	0.21	7.34								4.91	166.63
MEDIUM	1985	Low	0.11	4.64								1.52	46.57
		High	0.19	7.60								2.11	52.39
		Total	0.30	12.24								3.63	98.96
	1990	Low	0.11	17.46	0.80	1.36	0.89	0.98	1.54	0.30	0.05	4.12	122.17
		High	0.03	5.73	0.22	0.37	0.24	0.27	0.45	0.08	0.02	1.26	30.02
		Total	0.14	23.19	1.02	1.73	1.13	1.25	1.99	0.38	0.07	5.38	152.19
	2000	Low	0.12	16.38	0.95	1.62	1.06	1.17	1.83	0.36	0.06	3.37	95.20
		High	0.04	7.58	0.77	1.31	0.88	0.96	1.60	0.29	0.05	1.83	47.65
		Total	0.16	23.96	1.72	2.93	1.94	2.13	3.43	0.65	0.11	5.20	142.85
HIGH I	1985	Low		3.63								2.55	89.48
		High		3.69								1.50	43.23
		Total		7.32								4.05	132.71
	1990	Low		21.35	2.96	5.03	3.30	3.65	5.70	1.11	0.19	4.44	146.18
		High		6.86	0.52	0.88	0.58	0.64	1.07	0.19	0.04	1.55	37.43
		Total		28.21	3.48	5.91	3.88	4.29	6.77	1.30	0.23	5.99	183.61
	2000	Low		14.13	3.73	6.34	4.17	4.60	7.18	1.40	0.25	2.48	100.13
		High		6.75	2.39	4.05	2.66	2.95	4.94	0.89	0.17	1.70	57.51
		Total		20.88	6.12	10.39	6.83	7.55	12.12	2.29	0.42	4.18	157.64

[a] Battery mix depends on scenario.

[b] Specific gravity = 1.30.

[c] Polypropylene.

Table B.46. EV Replacement Battery Material Requirements per 100,000 Vehicles by Scenario (10^6 lb/100,000 EVs)[a]

Year and Scenario	Battery Type	Lead	H_2SO_4	Glass	Rubber	Plastic	Nickel	Cobalt	LiOH	KOH	Copper	Steel
1990												
LOW I	Pb/Acid	33.09	14.65	0.11	0.71	2.68						
	Ni/Zn					0.04	0.16	0.01		0.17		
	Total					2.72						
MEDIUM	Pb/Acid	7.40	3.15	0.02	0.15	0.58						
	Ni/Zn					1.56	6.64	0.36		7.31	0.16	
	Total					2.14						
HIGH I	Pb/Acid	11.98	5.01	0.04	0.24	0.92						
	Ni/Zn					0.97	4.12	0.22		4.54	0.10	
	Li/S											0.86
	Total					1.89						
2000												
LOW I	Pb/Acid	35.74	15.69	0.11	0.76	2.87						
	Ni/Fe					0.01	0.01			0.02		0.02
	Ni/Zn					0.65	2.88	0.16		3.02	0.06	
	Total					3.53	2.89			3.04		
MEDIUM	Pb/Acid	7.11	3.02	0.02	0.15	0.55						
	Ni/Fe									0.01		0.01
	Ni/Zn					2.60	11.83	0.64		12.12	0.26	
	Li/S											0.56
	Total					3.15				12.13		0.57
HIGH I	Pb/Acid	4.36	1.88	0.01	0.09	0.34						
	Ni/Zn					2.06	9.17	0.49		9.59	0.21	
	Li/S											2.06
	Total					2.40						

Table B.46 (Cont'd)

Year and Scenario	Battery Type	Fe_2O_3	ZnO	Li_2S	LiCl	Aluminum	Iron	KCl	CuS	BN	Other	Total
1990												
LOW I	Pb/Acid										1.40	52.64
	Ni/Zn		0.12								0.02	0.52
	Total										1.42	53.16
MEDIUM	Pb/Acid										0.30	11.60
	Ni/Zn		5.02								1.02	22.07
	Total										1.32	33.67
HIGH I	Pb/Acid										0.48	18.67
	Ni/Zn		3.12								0.63	13.70
	Li/S			0.52	0.59	0.58	0.65	1.08	0.20	0.04	0.02	4.54
	Total										1.13	36.91
2000												
LOW I	Pb/Acid										1.50	56.67
	Ni/Fe	0.01									–	0.07
	Ni/Zn		2.19								0.42	9.38
	Total										1.92	66.12
MEDIUM	Pb/Acid										0.29	11.14
	Ni/Fe	0.01									–	0.03
	Ni/Zn		8.99								1.69	38.13
	Li/S			0.53	0.91	0.60	0.66	1.07	0.20	0.04	–	4.57
	Total										1.98	53.87
HIGH I	Pb/Acid										0.18	6.86
	Ni/Zn		6.96								1.33	29.81
	Li/S			2.01	3.41	2.24	2.247	3.96	0.75	0.14	0.07	16.97
	Total										1.44	53.64

[a] Battery mix depends on the scenario.

Table B.47. EV Motor/Controller/Charger and Body Materials Requirements by Scenario (10^6 lb/100,000 EVs)

		LOW I			MEDIUM			HIGH I		
		1985	1990	2000	1985	1990	2000	1985	1990	2000
Motors/Controllers/ Chargers	Iron	48.8	31.0	21.9	45.2	33.5	20.1	47.5	34.9	20.4
	Steel	1.0	0.7	0.5	0.9	0.7	0.4	1.0	0.7	0.4
	Aluminum	8.0	5.6	4.3	7.4	6.0	3.9	7.8	6.3	4.0
	Copper	32.9	22.8	17.6	30.4	24.7	16.2	32.0	25.7	16.4
	Silicon	1.7	1.0	0.7	1.6	1.1	0.7	1.7	1.1	0.7
Total		92.4	61.1	45.0	85.5	66.0	41.3	90.0	68.7	41.9
Bodies	Iron	8.9	5.0	7.3	8.8	7.0	7.3	11.1	6.7	7.1
	Steel	140.6	159.3	176.1	139.8	218.7	174.6	166.2	232.8	160.1
	Aluminum	14.6	28.9	28.0	14.5	37.7	28.0	18.0	38.1	26.6
	Plastic	20.6	29.6	29.8	20.5	35.1	29.2	23.7	34.7	28.4
Total		184.7	222.8	241.2	183.6	298.5	239.1	219.0	312.3	222.2
Other materials										
Motors/Controllers/ Chargers		7.3	4.2	2.6	6.7	4.6	2.4	7.1	4.7	2.4
Bodies		46.0	50.9	55.3	45.7	66.6	54.5	53.3	70.2	50.6
Total		53.3	55.1	57.9	52.4	71.2	56.9	60.4	74.9	53.0
Total materials	Iron	57.7	36.0	29.2	54.0	40.5	27.4	58.6	41.6	27.5
	Steel	141.6	160.0	176.6	140.7	219.4	175.0	167.2	233.5	160.5
	Aluminum	22.6	34.5	32.3	21.9	43.7	31.9	25.8	44.4	30.6
	Copper	32.9	22.8	17.6	30.4	24.7	16.2	32.0	25.7	16.4
	Silicon	1.7	1.0	0.7	1.6	1.1	0.7	1.7	1.1	0.7
	Plastic	20.6	29.6	29.8	20.5	35.1	29.2	23.7	34.7	28.4
	Other	53.3	55.1	57.9	52.4	71.2	56.9	60.4	74.9	53.0
Total		330.4	339.0	344.1	321.5	435.7	337.3	369.4	455.9	317.1

Table B.48. Summary of EV Major Materials Requirements by Scenario (10^6 lb/100,000 EVs)[a]

Material	LOW I			MEDIUM			HIGH I		
	1985	1990	2000	1985	1990	2000	1985	1990	2000
Lead	85.03	119.99	121.05	27.77	36.26	23.14	64.53	34.53	15.01
Nickel	0.73	5.53	12.75	16.45	37.29	43.54	9.65	41.23	36.66
Copper	32.93	23.02	17.93	30.85	25.53	17.19	32.22	26.64	17.23
Copper sulfide	-	-	-	-	0.38	0.85	-	1.50	3.04
Iron	57.74	35.96	29.18	53.92	41.77	30.23	58.64	46.58	37.51
Iron oxide	0.19	0.25	0.22	0.30	0.14	0.17	-	-	-
Steel	141.89	160.36	176.92	141.10	220.61	177.65	167.14	237.63	168.87
Aluminum	22.60	34.40	32.39	21.87	44.78	34.49	25.73	48.77	39.70
Cobalt	0.03	0.30	0.69	0.89	2.02	2.35	0.52	2.22	1.97
Lithium hydroxide	0.02	0.02	0.02	0.03	0.01	0.01	-	-	-
Lithium sulfide	-	-	-	-	1.02	2.25	-	4.00	8.13
Lithium chloride	-	-	-	-	1.73	3.84	-	6.80	13.80
Potassium hydroxide	0.88	5.92	13.26	17.90	38.78	45.01	10.25	42.53	38.06
Potassium chloride	-	-	-	-	1.99	4.50	-	7.85	16.08
Zinc oxide	0.41	4.01	9.53	12.24	28.21	32.95	7.32	31.33	27.84
Silicon	1.69	1.01	0.71	1.57	1.09	0.66	1.65	1.14	0.67
Boron nitride	-	-	-	-	0.07	0.15	-	0.27	0.56
Sulfuric acid	38.00	52.29	52.37	12.10	14.90	9.84	27.41	14.22	6.52
Glass	0.27	0.38	0.37	0.09	0.11	0.06	0.20	0.10	0.04
Rubber	1.85	2.55	2.55	0.59	0.72	0.48	1.34	0.69	0.32
Plastic	27.77	40.43	42.23	26.57	46.13	40.70	30.93	46.40	37.71
Other[b]	57.11	60.91	64.73	56.08	77.89	64.11	64.41	82.07	58.63
Total	469.14	547.33	576.90	420.32	621.43	534.17	501.94	676.50	528.35

[a] Vehicle mix depends on the scenario.

[b] Includes materials in some vehicle items not expected to vary between EHVs and CVs. In particular, it includes glass in windows, rubber in tires, and materials in Pb/acid accessory battery.

Table B.49. LOW II Major Material Requirements (10^6 lb/100,000 EHVs)

Year	Used for	Lead	H_2SO_4	Glass	Rubber	Plastic	Nickel	Cobalt	LiOH	KOH	Copper	Steel
1985	EV Battery	60.58	27.08	0.19	1.32	5.10	0.52	0.02	0.01	0.63	0.04	0.19
	HV Battery	28.46	11.88	0.08	0.58	2.17						
	EV M/C/C[a]										23.43	0.71
	HV M/C/C										9.33	0.26
	EV Body					14.68						100.19
	HV Body					7.64						53.94
	HV Pt[b]											4.40
	Total	89.04	38.96	0.27	1.90	29.59	0.52	0.02	0.01	0.63	32.80	159.69
1990	EV Battery	56.24	24.36	0.17	1.19	5.27	3.48	0.19	0.01	3.72	0.12	0.24
	HV Battery	34.71	14.51	0.10	0.72	2.66						
	EV M/C/C										14.78	0.42
	HV M/C/C										8.22	0.24
	EV Body					19.13						103.13
	HV Body					11.56						63.21
	HV Pt											5.29
	Subtotal	90.95	38.87	0.27	1.91	38.62	3.48	0.19	0.01	3.72	23.12	172.29
	EV R Battery[c]	21.42	9.48	0.07	0.46	1.76	0.10	0.01		0.11		
	HV R Battery	14.26	5.89	0.04	0.29	1.08						
	Subtotal	35.68	15.37	0.11	0.75	2.34	0.10	0.01		0.11		
	Total	126.63	54.24	0.35	2.66	41.46	3.58	0.20	0.01	3.93	23.12	172.29
2000	EV Battery	46.32	19.92	0.14	0.97	4.86	5.35	0.29	0.01	5.55	0.14	0.16
	HV Battery	44.03	18.48	0.13	0.70	3.38						
	EV M/C/C										9.56	0.26
	HV M/C/C										7.22	0.21
	EV Body					16.15						75.63
	HV Body					14.61						79.99
	HV Pt											6.70
	Subtotal	90.35	38.40	0.27	1.87	39.00	5.35	0.29	0.01	5.55	16.92	182.95
	EV R Battery	19.41	8.52	0.06	0.41	1.92	1.57	0.09		1.65	0.03	0.4
	HV R Battery	13.00	5.46	0.03	0.27	1.00						
	Subtotal	32.47	13.98	0.09	0.68	2.72	1.57	0.09		1.65	0.03	0.01
	Total	122.82	52.38	0.36	2.55	41.92	6.92	0.38	0.01	7.20	16.95	182.96

Table B.49. (Cont'd)

Year	Used for	Fe_2O_3	ZnO	Li_2S	LiCl	Aluminum	Iron	KCl	CuS	BN	Silicon	Other	Total
1985	EV Battery	0.14	0.29									2.69	98.80
	HV Battery											1.14	44.31
	EV M/C/C[a]					5.68	34.78				1.20	5.22	71.02
	HV M/C/C					2.25	13.91				0.49	2.07	28.31
	EV Body					10.42	6.36					32.78	164.43
	HV Body					5.85	3.42					17.18	88.03
	HV PT[b]					2.89	8.78					0.84	16.91
	Total	0.14	0.29			27.09	67.25				1.69	61.92	511.81
1990	EV Battery	0.16	2.51									2.83	100.49
	HV Battery											1.39	54.09
	EV M/C/C					3.59	20.06				0.65	2.73	42.23
	HV M/C/C					1.99	11.13				0.36	1.52	23.46
	EV Body					18.67	3.21					32.94	177.08
	HV Body					11.23	1.56					20.12	107.68
	HV PT					4.11	9.21					0.99	19.60
	Subtotal	0.16	2.51			39.59	45.17				1.01	62.52	524.63
	EV R Battery[c]		0.08									0.92	34.41
	HV R Battery											0.57	22.13
	Subtotal		0.08									1.49	56.54
	Total	0.16	2.59			39.59	45.17				1.01	64.01	581.17
2000	EV Battery	0.11	3.99									2.67	90.48
	HV Battery											1.76	68.68
	EV M/C/C					2.32	11.39				0.39	1.42	25.84
	HV M/C/C					1.77	8.99				0.28	1.06	19.53
	EV Body					15.21	3.95					30.01	160.95
	HV Body					13.73	3.51					25.18	137.02
	HV PT					5.71	10.00					1.43	23.84
	Subtotal	0.11	3.99			38.74	38.34				0.67	68.53	526.34
	EV R Battery	0.01	1.19									1.04	25.91
	HV R Battery											0.57	20.39
	Subtotal	0.01	1.19									1.61	56.20
	Total	0.12	5.18			38.74	38.74				0.67	65.14	582.60

[a] M/C/C = motor/controller/charger.

[b] Pt = powertrain.

[c] R Battery = replacement battery.

Table B.50. HIGH II Major Materials Requirements (10^6 lb/100,000 EHVs)

Year	Used for	Lead	H_2SO_4	Glass	Rubber	Plastic	Nickel	Cobalt	LiOH	KOH	Copper	Steel	Fe_2O_3
1985	EV Battery	64.53	27.41	0.20	1.34	7.22	9.65	0.52		10.25	0.22		
	EV M/C/C[a]										32.00	0.97	
	EV Body					23.71						166.17	
	Total	64.53	27.41	0.20	1.34	30.93	9.65	0.52		10.25	32.22	167.14	
1990	EV Battery	23.23	9.49	0.06	0.46	10.14	38.23	2.06		39.13	0.84		
	HV Battery					0.71	3.26	0.17		3.34	0.07		
	EV M/C/C										21.92	0.63	
	HV M/C/C										2.66	0.07	
	EV Body					29.59						198.73	
	HV Body					4.63						25.29	
	HV Pt[b]											1.94	
	Subtotal	23.23	9.49	0.06	0.46	45.07	41.49	2.23		42.47	25.49	226.66	
	EV R Battery[c]	10.23	4.28	0.03	0.20	1.61	3.52	0.19		3.88	0.09		
	HV R Battery												
	Subtotal	10.23	4.28	0.03	0.20	1.61	3.52	0.19		3.88	0.09		
	Total	33.46	13.77	0.09	0.66	46.68	45.01	2.42		46.35	25.58	226.66	
2000	EV Battery	10.32	4.50	0.03	0.22	6.74	26.63	1.43		27.58	0.59		
	HV Battery					1.83	8.44	0.45		8.56	0.18		
	EV M/C/C										10.54	0.28	
	HV M/C/C										4.84	0.13	
	EV Body					18.05						101.83	
	HV Body					11.64						63.87	
	HV Pt											4.39	
	Subtotal	10.32	4.50	0.03	0.22	38.26	35.07	1.88		36.14	16.15	171.00	
	EV R Battery	2.77	1.20	0.01	0.06	1.53	5.83	0.31		6.10	0.13		
	HV R Battery					0.41	1.90	0.10		1.90	0.04		
	Subtotal	2.77	1.20	0.01	0.06	1.94	7.73	0.41		8.00	0.17		
	Total	13.09	5.70	0.04	0.28	40.20	42.80	2.29		44.14	16.32	171.00	

Table B.50. (Cont'd)

Year	Used for	ZnO	Li_2S	LiCl	Aluminum	Iron	KCl	CuS	BN	Silicon	Other	Total
1985	EV Battery	7.32									4.05	132.71
	EV M/C/C[a]				7.76	47.52				1.65	7.08	96.98
	EV Body				17.97	11.12					53.28	272.25
	Total	7.32			25.73	58.64				1.65	64.41	501.94
1990	EV Battery	29.06									6.40	159.10
	HV Battery	2.48									0.48	10.51
	EV M/C/C				5.32	29.74				0.97	4.04	62.62
	HV M/C/C				0.64	3.62				0.12	0.50	7.61
	EV Body				32.49	5.74					59.93	326.48
	HV Body				4.50	0.64					8.05	43.11
	HV Pt[b]				1.51	3.37					0.35	7.17
	Subtotal	31.54			44.46	43.11				1.09	79.75	616.60
	EV R Battery[c]	2.66									0.95	27.64
	HV R Battery											
	Subtotal	2.66									0.95	27.64
	Total	34.20			44.46	43.11				1.09	80.70	644.24
2000	EV Battery	20.23									4.22	102.49
	HV Battery	6.41									1.23	27.10
	EV M/C/C				2.56	13.11				0.43	1.57	28.49
	HV M/C/C				1.17	6.03				0.19	0.73	13.09
	EV Body				16.95	4.51					32.17	173.51
	HV Body				10.97	2.79					20.13	109.40
	HV Pt				4.19	7.33					1.04	17.45
	Subtotal	26.64			35.84	33.77				0.62	61.09	471.53
	EV R Battery	4.43									0.96	23.33
	HV R Battery	1.44									0.27	6.06
	Subtotal	5.87									1.23	29.39
	Total	32.51			35.84	33.77				0.62	62.32	500.92

[a] M/C/C = motor/controller/charger.

[b] Pt = powertrain.

[c] R Battery = replacement battery.

Table B.51. CV Major Materials Requirements by Scenario (10^6 lb/100,000 vehicles)

	LOW I			LOW II			MEDIUM			HIGH I			HIGH II		
Material	1985	1990	2000	1985	1990	2000	1985	1990	2000	1985	1990	2000	1985	1990	2000
Iron	28.0	23.1	27.3	30.2	23.9	26.2	28.8	34.9	27.4	32.7	38.2	23.7	32.7	36.3	24.0
Steel	141.5	158.6	171.6	152.6	164.0	171.2	145.1	211.8	171.9	164.7	218.4	156.9	164.7	209.6	162.2
Aluminum	20.7	34.8	35.4	22.3	36.0	36.3	21.2	42.4	35.3	24.1	41.5	33.6	24.1	40.4	34.8
Plastic	18.7	26.9	27.0	20.2	27.8	27.8	19.2	32.2	26.9	21.8	31.0	25.8	21.8	30.3	26.8
Other	43.8	49.2	52.5	47.2	50.9	52.7	44.9	64.5	52.6	50.9	65.8	48.4	50.9	63.2	49.7
Total	252.7	292.6	313.8	272.5	302.6	314.3	259.2	385.8	314.1	294.2	394.9	288.4	294.2	379.8	297.5

facility and is considered a net credit to the intermediate manufacturing step. These energy credits are accounted for in this analysis and are legitimate in that they reduce the demands for external energy supplies.

Manufacturing and assembly operations of the Ni/Fe battery are listed in Ref. B.20. No specific data have been found to determine the energy requirements of Ni/Zn battery manufacture and assembly operations. However, two major references intimated that battery assembly would be essentially the same as for the Ni/Fe battery.[B.21,B.22] Certain differences in the fabrication and assembly operations because of the use of metals and pastes led to estimating an increase in anticipated power requirements over the Ni/Fe battery by 25%. In any case, energy requirements for assembly are comparatively insignificant in total battery manufacture.

Few data are available for the manufacturing and assembly operations for the Li/S battery. Mixing, drying, and forming operations are assumed to be similar to the Ni/Fe battery, and an allowance for energy consumption in the steel-case forming operation is included.[B.23]

B.3.3.2 Vehicle Fabrication and Assembly

Energy used in the fabrication of parts and assembly of the vehicles is derived from Tables 9.7 and 9.8 of Ref. B.6. Energy requirements for materials manufacture (metallic and other), when converted to energy units per pound, are subtracted from the total energy requirements to yield the energy required for fabrication and assembly, i.e., 13.085×10^9 Btu/10^6 lb.

B.3.3.3 Materials Mining, Milling, and Refining

The mining, milling, and refining of materials contained in the finished vehicles require substantial amounts of energy. For each million pounds of pure aluminum from bauxite, 122×10^9 Btu are required.[B.24] However, only 4.25% of the aluminum produced is derived from domestic bauxite. Another 26.96% is from imported bauxite and 11.09% from imported alumina, which is a concentrated form. Recycled aluminum scrap amounts to 57.7% of the total feed. After weighting energy requirements for each processing phase by the share processed, composite energy requirements for aluminum amount to 58.57×10^9 Btu for each million pounds of pure aluminum.

Similarly, electrolytic nickel consists of various proportions of domestic ore (5%), recycled metal (25%), imported ore (30%), nickel concentrate imports (35%), and imported nickel sulfide ores (5%). Introducing these feeds at the proper processing stage and computing energy consumption results in energy use of 45.4×10^9 Btu per million pounds of nickel.[B.24]

The copper produced in this country is from domestic ore (66%), imported ore (9.3%), refined metal imports (14.1%), and refined scrap (10.6%). The calculated weighted composite energy requirement is 43.9×10^9 Btu per million pounds of refined copper.[B.25]

Iron and steel energy requirements are 10.86×10^9 Btu for each million pounds of iron and 12.53×10^9 Btu for each million pounds of steel, based on a composite feed of natural ores (18%), pelletized taconite (54%), and recycled scrap (28%). Two reports are used to structure a composite energy requirment schedule that recognizes existing technology and sources of raw material supply.[B.24,B.26]

Lithium requires 197.8 x 10^9 Btu for each million pounds.[B.27] However, each pound of Li_2S contains 30.2% lithium and 69.8% sulfur, the latter material requiring 4.68 x 10^9 Btu per million pounds. On a weighted average basis, Li_2S requires 63 x 10^9 Btu for each million pounds contained in the batteries. Calculating in a similar manner and based on lithium comprising 16.04% of the lithium salt, LiCl requires 36.40 x 10^9 Btu for each million pounds in the batteries. It is assumed that all lithium to be used in the 100,000 vehicle unit will be mined from domestic ores.

Energy data for the production of zinc by the electrothermic process are adjusted to derive the energy required before the electrothermic reduction process that converts the zinc oxide to zinc metal.[B.27] Then, the 42% of final zinc oxide derived from domestic ores, the 13% imported ore (that does not require domestic energy for mining, crushing, and beneficiation), the 6% of secondary scrap that enters at the roasting stage, and the 39% that is imported in final form are combined to yield an energy requirement of 5.98 x 10^9 Btu for each million pounds of zinc oxide. For comparison, one million pounds of domestically produced zinc oxide (from ore to finished product) requires 11.9 x 10^9 Btu.

Potassium hydroxide can be manufactured as a by-product in the production of chlorine gas from a naturally occurring brine. The process requires 4.68 x 10^9 Btu per million pounds of potassium hydroxide.[B.25] Silicon requires 60 x 10^9 Btu per million pounds.[B.24]

The above composite feed material percentages are based on present data and may be different in 2000. For example, there may be more recycling of some of the above materials. Two examples of the implication of recycling on energy consumption in the production of EHVs are discussed later in Sec. B.3.5.

The following assumptions are made in calculating the energy requirements of the other materials.

1. Copper sulfide and cobalt require the same energy as copper, i.e., 43.97 x 10^9 Btu per million pounds of metal.
2. Potassium chloride requires the same energy as potassium hydroxide, i.e., 4.68 x 10^9 Btu per million pounds.
3. Plastic requires the same energy as that required for the plastic battery cases in Ref. B.19, i.e., 4.80 x 10^9 Btu per million pounds.
4. Iron oxide requires the same energy as iron, i.e., 10.86 x 10^9 Btu per million pounds.
5. Lithium hydroxide requires approximately the same energy as lithium, i.e., 197.8 x 10^9 Btu per million pounds.

B.3.3.4 Specific Energy Consumption by Scenario

Based on the foregoing information and assumptions, energy requirements are derived for each scenario. Tables B.52-B.55 present the energy requirements for producing the four battery types. Tables B.56 and B.57 indicate the energy requirements for production of the motors/controllers/chargers and bodies of the EHVs. Replacement battery energy requirements are derived in the same way as new battery requirements and are given in Tables B.58 and B.59. Table B.60 provides the energy requirements for the HV powertrain.

CV energy requirements are based on the same materials and assembly processes as are used in the EHV motor/controller/charger and body tables. Table B.61 presents a summary of the energy requirements for EHVs and CVs.

Energy requirements for certain materials are not included in the calculations. Glass, rubber, and boron nitride are included in certain EHV batteries but in such small amounts that the energy requirements are not calculated. More importantly, the undefined "other" materials in EHVs and CVs make up roughly 12% and 17%, respectively, of the EHV or CV weight and that the energy requirements for these "other" materials are not calculated here. However, a reasonable estimate of these energy requirements can be made by extrapolating from the energy requirements of the defined materials.

In the early years of all the scenarios, less than 100,000 vehicles/yr are produced. Therefore, the energy consumption from production could actually be higher in these years than the estimates because of the inefficiency of low-volume production.

B.3.4 Emissions Generation

The source for Pb/acid battery production emissions is Ref. B.19. Reports on Ni/Fe and Ni/Zn batteries do not yield definitive data concerning emissions.[B.20,B.21] The Li/S battery is notable for a complete lack of information regarding emissions. In general, emissions from the fabrication of all four batteries have been assumed by others to be negligible, because the operations will be carried on in a closed cycle in order to meet new environmental quality regulations.[B.19,B.20,B.21]

Tables B.62-B.74 summarize the basic data used to derive the pollutants by scenario. Air emissions have been estimated from Ref. B.28. Because emission standards will be more severe for operations in 1985 and beyond, air emissions reported here are those that might escape a good state-of-the-art control technology. State-of-the-art equipment includes electrostatic precipitators, venturi scrubbers, and baghouses.[B.28]

Water emissions that might be expected are patterned after those defined in Ref. B.19, which assumes the level of emissions that would result from application of best available technology. Solid wastes arise principally in mining and milling where overburden, waste rock, and tailings predominate. Solid wastes generated in refining or processing will probably be recycled, and ultimate waste disposal may consist primarily of water treatment sludges and nonmetallic components of the concentrated ores. Amounts shown in Tables

Table B.52. Pb/Acid Battery Production Energy Requirements by Scenario, New Batteries (10^9 Btu/100,000 EHVs)[a]

	LOW I			LOW II			MEDIUM			HIGH I			HIGH II		
	1985	1990	2000	1985	1990	2000	1985	1990	2000	1985	1990	2000	1985	1990	2000
Material															
Lead: mine, refine, recover, manufacture, transport[b]	497.4	509.8	499.0	516.6	533.0	528.5	162.5	168.7	93.7	377.5	136.5	77.7	–	135.9	60.4
Sulfuric acid: mine, manufacture, preparation, transport	0.1	0.2	0.2	0.1	0.2	0.2	0.1	-	-	0.1	0.1	–	–	–	–
Plastic: manufacture	33.1	20.1	18.3	33.9	32.1	26.8	10.6	7.5	3.3	23.9	3.6	2.4	–	8.3	3.7
Assembly	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1	0.2	0.3	0.2		0.2	0.2
Total	530.8	530.3	517.7	550.8	565.5	555.7	173.4	176.4	97.1	401.7	140.5	80.3		144.4	64.3

[a] Requirements based on Ref. B.19.

[b] 49% mined, 51% recovered (scrap, recycle, etc.).

Table B.53. Ni/Fe Battery Production Energy Requirements by Scenario, New Batteries (10^9 Btu/100,000 EHVs)

	LOW I			LOW II			MEDIUM			HIGH I and HIGH II		
	1985	1990	2000	1985	1990	2000	1985	1990	2000	1985	1990	2000
Material												
Nickel: mine, refine, transport	8.2	11.1	8.8	5.9	7.1	4.8	12.8	6.1	7.0			
Cobalt: mine, refine, transport	0.4	0.5	0.4	0.3	0.3	0.2	0.6	0.3	0.3			
Copper: mine, refine, transport	1.9	2.5	2.0	1.4	1.6	1.1	3.0	1.4	1.6			
Steel: mine, refine, transport, convert	3.5	4.6	3.6	2.5	2.9	2.0	5.5	2.5	2.9			
Ferric oxide: mine, refine, transport	2.1	2.8	2.2	1.5	1.8	1.2	3.3	1.5	1.7			
Lithium hydroxide: mine, process, transport	3.2	4.2	3.3	2.3	2.7	1.8	5.0	2.3	2.6		No Ni/Fe Batteries	
Potassium hydroxide: mine, process, transport	1.4	1.8	1.5	1.0	1.1	0.8	2.2	1.0	1.1			
Plastic cases (4.763 x 10^9 Btu/10^6 lb)	5.3	7.1	5.6	3.8	4.5	3.0	8.4	3.9	4.4			
Manufacture and assembly[a,b]												
Electricity (11.55 x 10^6 Btu/10^6 lb)	-	-	-	-	-	-	-	-	-			
Fuel oil (5.58 x 10^6 Btu/10^6 lb)	-	-	-	-	-	-	-	-	-			
Total	26.0	34.6	27.4	18.7	22.0	14.9	40.8	19.0	21.6			

[a] Requirements from Ref. B.20.

[b] Requirements are <0.05 x 10^9 Btu for each scenario.

Table B.54. Ni/Zn Battery Production Energy Requirements by Scenario, New Batteries (10^9 Btu/100,000 EHVs)

	LOW I			LOW II			MEDIUM			HIGH I			HIGH II		
	1985	1990	2000	1985	1990	2000	1985	1990	2000	1985	1990	2000	1985	1990	2000
Material															
Nickel: mine, refine, transport	24.8	233.2	438.6	17.9	149.8	238.2	734.1	1385.0	1432.5	438.2	1685.0	1247.7	438.2	1883.7	1588.8
Zinc oxide: mine, refine, transport	2.5	23.3	43.9	1.8	15.0	23.8	73.2	138.6	143.3	43.7	168.7	124.8	43.7	188.6	158.9
Cobalt and copper: mine, refine, transport	1.9	17.2	32.3	1.4	11.1	17.5	54.8	101.9	105.7	32.5	123.9	92.1	32.5	138.5	117.3
Potassium hydroxide: mine, refine, transport	2.8	25.1	46.4	2.0	16.1	25.2	81.7	146.2	152.7	48.0	177.8	133.2	48.0	198.8	169.6
Plastic cases	0.6	5.5	10.2	0.4	3.5	5.5	17.8	32.0	33.4	10.5	38.9	29.1	10.5	43.5	37.1
Processing and assembly[a]															
Electricity (125% x 11.55 x 10^6 Btu/10^6 lb [0.0144])	0.1	0.2	0.4	0.1	0.1	0.2	0.8	1.4	1.5	0.5	1.7	1.3	0.5	1.9	1.7
Fuel oil (110% x 5.58 x 10^6 Btu/10^6 lb [0.00614])	-	0.1	0.2	-	0.1	0.1	0.3	0.6	0.6	0.2	0.7	0.5	0.2	0.8	0.6
Total	32.7	304.6	572.0	23.6	195.7	310.5	962.7	1805.7	1869.7	573.6	2196.7	1628.7	573.6	2455.8	2074.0

[a] Ref. B.20 data for Ni/Fe battery with 125% electricity for electrolytic process.

Table B.55. Li/S Battery Production Energy Requirements by Scenario, New Batteries (10^9 Btu/100,000 EHVs)

	LOW I, LOW II, and HIGH II			MEDIUM			HIGH I		
	1985	1990	2000	1985	1990	2000	1985	1990	2000
Material[a]									
Lithium sulfide				-	63.9	110.8	-	219.0	385.4
Lithium chloride				-	62.7	106.7	-	215.1	378.1
Aluminum				-	66.3	112.7	-	227.3	399.6
Iron		No Li/S Batteries		-	13.6	23.1	-	46.6	82.0
Potassium chloride				-	9.3	16.1	-	31.7	56.7
Steel (case and cover)				-	12.9	22.4	-	44.1	79.0
Copper sulfide				-	16.7	28.5	-	57.1	100.5
Total materials				-	245.4	420.3	-	840.9	1481.3
Manufacture and assembly									
Mixing, drying, forming[b]									
Electricity (12×10^6 Btu/10^6 lb)				-	0.1	0.2	-	0.4	0.6
Natural gas (8.5×10^6 Btu/10^6 lb)				-	0.1	0.1	-	0.3	0.4
Fuel oil (4.5×10^6 Btu/10^6 lb)				-	0.1	0.1	-	0.1	0.2
Case forming									
Electricity (6×10^6 Btu/10^6 lb)				-	0.1	0.1	-	0.2	0.3
Total				-	245.9	420.8	-	841.9	1482.8

[a] Energy required to mine, refine, process, recover and transport materials is included.

[b] These numbers assume that the requirements and proportions are the same as for Ni/Fe batteries.

Table B.56. Motor/Controller/Charger and Body Production Energy Requirements in LOW I, MEDIUM, and HIGH I (10^9 Btu/100,000 EVs)

	LOW I			MEDIUM			HIGH I		
	1985	1990	2000	1985	1990	2000	1985	1990	2000
Material									
Iron	626.6	391.0	317.1	586.4	439.8	297.6	636.4	451.8	298.7
Steel	1,774.2	2,004.8	2,212.8	1,763.0	2,749.1	2,192.8	2,095.0	2,925.8	2,011.1
Aluminum	1,323.7	2,020.7	1,891.8	1,282.7	2,559.5	1,869.4	1,511.1	2,600.5	1,792.2
Copper	1,446.6	1,002.5	773.9	1,336.7	1,086.1	712.3	1,407.0	1,130.0	721.1
Silicon	102.0	60.0	42.0	96.0	66.0	42.0	102.0	66.0	42.0
Plastic	98.9	142.1	143.0	98.4	168.5	140.2	113.8	166.6	136.3
Total	5,372.0	5,621.1	5,380.6	5,163.2	7,069.0	5,254.3	5,865.3	7,340.7	5,001.4
Fabrication and assembly (13.085×10^9 Btu/10^6 lb)	4,323.3	4,435.8	4,502.5	4,206.8	5,701.1	4,413.6	4,833.6	5,965.5	4,149.3
Total	9,695.3	10,056.9	9,883.1	9,370.0	12,770.1	9,667.9	10,698.9	13,306.2	9,150.7

Table B.57. Motor/Controller/Charger and Body Production Energy Requirements in LOW II and HIGH II (10^9 Btu/100,000 EHVs)

	LOW II			HIGH II		
	1985	1990	2000	1985	1990	2000
EVs						
Materials	3,827.3	3,637.9	2,921.1	5,865.3	6,264.0	3,186.3
Fabrication and assembly	3,080.2	2,870.8	2,444.4	4,833.6	5,090.5	2,643.4
Total	6,907.5	6,508.7	5,365.5	10,698.9	11,354.5	5,829.7
HVs						
Materials[a]	1,891.1	2,144.8	2,448.2	0	816.5	1,932.1
Fabrication and assembly	1,521.9	1.716.7	2,048.8	0	663.5	1,602.9
Total	3,413.0	3,892.0	4,497.0	0	1,480.0	3,535.0
Total	10,320.5	10,400.7	9,862.5	10,698.9	12,834.5	9,364.7

[a] HV materials proportions (iron, steel, plastic, aluminum, etc.) are identical to EV scenarios.

Table B.58. Replacement Battery Production Energy Requirements in LOW I, MEDIUM, and HIGH I (10^9 Btu/100,000 EVs)

	LOW I		MEDIUM		HIGH I	
Battery	1990	2000	1990	2000	1990	2000
Pb/Acid						
Lead	192.17	209.06	43.30	41.57	70.10	25.50
Sulfuric acid	0.07	0.08	0.02	0.01	0.02	0.01
Plastic	12.66	13.65	2.75	2.63	4.37	1.64
Assembly	0.02	0.02	0.01	0.01	0.01	0.01
Total	204.92	222.81	46.08	44.22	74.50	27.16
Ni/Fe						
Nickel		0.48		0.22		
Lithium hydroxide		0.18		0.08		
Potassium hydroxide		0.08		0.04		
Copper and cobalt		0.13		0.06		
Steel		0.20		0.09		
Ferric oxide		0.12		0.06		
Manufacture		-		-		
Total		1.19		0.55		
Ni/Zn						
Nickel	7.38	130.92	301.67	536.93	187.18	416.32
Zinc	0.74	13.09	30.04	53.75	18.64	41.59
Copper and cobalt	0.55	9.69	23.00	39.50	14.05	30.78
Potassium hydroxide	0.82	14.13	34.20	56.70	21.27	44.87
Plastic	0.18	3.08	7.44	12.40	4.63	9.80
Total	9.67	170.91	396.35	699.28	245.77	543.36
Li/S						
Lithium sulfide				33.17	32.95	126.36
Lithium chloride				33.14	32.28	124.00
Aluminum				34.90	34.10	131.03
Iron				7.16	7.01	26.88
Potassium chloride				5.00	5.03	18.54
Steel				6.97	7.02	25.81
Copper sulfide				8.80	8.80	32.90
Total				109.74	127.19	485.52
Total	214.59	394.91	442.43	873.79	447.46	1056.04

Table B.59. Replacement Battery Production Energy Requirements in LOW II and HIGH II (10^9 Btu/100,00 EHVs)

Battery	LOW II 1990	LOW II 2000	HIGH II 1990	HIGH II 2000
Pb/Acid				
Lead	216.06	197.39	59.85	16.20
Sulfuric acid	0.07	0.06	0.02	0
Plastic	13.33	12.16	3.62	1.00
Assembly	0.02	0.02	0.01	0.01
Total	229.48	209.63	63.50	17.21
Ni/Fe				
Total	0.65			
Ni/Zn				
Nickel			159.81	350.94
Zinc			15.91	35.10
Copper and cobalt			12.29	25.46
Potassium hydroxide			18.16	37.44
Plastic			4.05	8.23
Total	6.26	92.80	210.22	457.17
Total	235.74	303.08	273.72	474.38

Table B.60. HV Powertrain Weights, Composition, and Production Energy Requirements

	LOW II 1985	LOW II 1990	LOW II 2000	HIGH II 1985	HIGH II 1990	HIGH II 2000
Powertrain weight (10^6 lb)	16.91	19.60	23.84		7.17	17.45
Composition (weight %)						
Steel	26.0	27.0	28.1		27	28
Aluminum	17.1	21.0	24.0		21	24
Iron	51.9	47.0	41.9		47	42
Other	5.0	5.0	6.0		5	6
Total	100.0	100.0	100.0		100	100
Production energy (10^9 Btu)	319.8	407.4	527.5		149.0	386.1

Table B.61. Summary of EHV and CV Energy Requirements by Scenario (10^9 Btu/100,000 vehicles)

	Scenario														
	LOW I			LOW II			MEDIUM			HIGH I			HIGH II		
	1985	1990	2000	1985	1990	2000	1985	1990	2000	1985	1990	2000	1985	1990	2000
EVs or EHVs															
New vehicle batteries	589	869	1,117	592	783	881	1,177	2,247	2,409	976	3,179	3,192	976	2,600	2,138
Motors/controllers/chargers and bodies	5,372	5,621	5,381	5,719	5,783	5,370	5,163	7,069	5,254	5,865	7,341	5,001	5,865	7,081	5,118
Powertrains	-	-	-	320	407	528	-	-	-	-	-	-	-	149	386
Replacement batteries	-	215	395	-	236	303	-	442	874	-	447	1,056	-	274	474
Machining, fabrication, and assembly[b]	4,323	4,436	4,502	4,602	4,588	4,493	4,207	5,701	4,414	4,834	5,965	4,149	4,834	5,754	4,246
Total	10,284	11,141	11,395	11,233	11,797	11,575	10,547	15,459	12,951	11,675	16,932	13,398	11,675	15,858	12,362
CVs															
Materials	3,380	4,405	4,650	3,646	4,555	4,691	3,465	5,671	4,648	3,935	5,731	4,315	3,935	5,532	4,460
Machining, fabrication, and assembly[b]	3,307	3,829	4,106	3,567	3,959	4,112	3,392	5,049	4,110	3,850	5,167	3,775	3,850	4,970	3,893
Total	6,687	8,234	8,756	7,213	8,514	8,803	6,857	10,720	8,758	7,785	10,898	8,090	7,785	10,502	8,353

[a] Energy for undefined "other materials" and materials present in small amounts are not included in this table.

[b] Energy requirements for the vehicle only. Battery assembly included elsewhere.

B.62-B.74 are from reported data and, in most cases, would be reduced in the future through tighter operating controls.

The Pb/acid battery emission factors for lead, plastic, sulfuric acid, and assembly are derived from Ref. B.19 (see Tables VI-2, VI-3, VI-4, and VI-7). These figures are adjusted from pounds per megawatt hour to pounds per million pounds of specific material contained in the final battery.

Estimated emissions from assembly of Ni/Fe batteries include emissions from the processing of nickel, iron and steel, copper, potassium hydroxide,

Table B.62. Lead Trajectory Emissions ($lb/10^6$ lb Pb)[a]

Residual	Mine	Mill	Primary Refining	Scrap	Secondary Refining
Air pollutant					
SO_x			4,376		419
Particulates	- - - 1,479 - - -		2,974		507
Heavy metals	- - - 49 - - -		1,225	350[b]	179
Water pollutant[c]					
TDS	NA[d]		412	1,607	
TSS	56		4	4	
BOD_5	NA				
Oil and grease	31				
Pb	0.8		0.1	0.1	
Zn	0.5		0.8		
Solid waste					
Waste rock	1.50×10^6				
Tailing		8.0×10^6			
Slag and sludge			174,440	85,680	82,110

[a] These emissions take into account the correct proportions of lead that will be processed at each stage, i.e., lead is 49% primary lead and 51% secondary recycle.

[b] 350 $lb/10^6$ lb Pb in PbO manufacture.

[c] Assumes a level of emissions that would result from use of 1983 best available technology (BAT) controls.

[d] Not available.

Source: Ref. B.19, Table VI-2, p. V-5.

Table B.63. Plastics Trajectory Emissions ($lb/10^6$ lb plastic)

Residual	Domestic Oil/Gas Onshore	Domestic Oil/Gas Offshore	Crude Refining	Natural Gas Process Plants	Intermediate Manufacture	Final Product Manufacture
Air pollutant						
SO_x		0.6	425	0.4	3,150	
NO_x		8.5	352	85	10.5	
HC		0.7	421	28	756	34,000
CO		1.8	3	0.3	10.5	
Particulates		0.6	48.5	13.0	10.5	1,000
Water pollutant[a]						
TDS			352			220
TSS			1.3			20
BOD_5			1.3			30
Oil and grease			0.3			
Heavy metals			0.2			
Solid waste	20,204	2,608	1,015			6,620

[a] Assumes a level of emissions that would result from use of 1983 best available technology (BAT) controls.

Source: Ref. B.19, Table VI-4, p. VI-11.

plastic, and battery assembly. Of particular interest are the copious quantities of sulfur dioxide generated in nickel refining. However, emissions are captured and used as feed to a sulfuric acid plant. In iron processing as in steelmaking, large quantities of carbon monoxide are created but are used within the plant as process fuel and little, if any, escapes the facility. Steelmaking may create hazardous emissions, such as hydrogen fluoride gas and calcium fluoride in slag or water treatment sludges. Copper sulfides and lead sulfides escape as particulates, but it is anticipated that more than 90% of the quantities anticipated would be captured and recycled through use of electrostatic precipitators. Potassium hydroxide, a coproduct with chlorine in the chloralkali process, represents captured air emissions that have migrated through the water flow to wind up in the solid waste segment in the brine purification mud.

In the Ni/Fe battery assembly, an indication of things to come is the absolute limits set on total suspended solids by Connecticut.[B.22] No more than 3.75 lb of Ni and 0.6 lb of Cd may be released by a battery processing plant in any day. This may become a national standard.

In the Ni/Zn oxide battery summary, the only new item is the zinc oxide constituent. Air pollutants from the primary refining process are considerable.[B.22] Sulfur trioxide (SO_3) emissions are equivalent to 110% (by weight) of the zinc formed, but these emissions would be captured and used as feed to a sulfuric acid plant. Particulates are approximately 66% in the form of zinc sulfide, with the balance containing lead sulfide. Electrostatic precipitators would result in almost total recovery of these pollutants.

Table B.64. Sulfur Trajectory Emissions (lb/10^6 lb H_2SO_4)[a]

Residual	Mine	Recover	H_2SO_4 Manufacture
Air pollutant			
SO_x	0.6	653	2000
NO_x	168		
HC	2.8		
CO	16		
Particulates	7		188
Water pollutant[b]			
TDS	30		
TSS	7.5		
Sulfides	2.5		

[a] These emissions take into account the correct proportions of sulfur that will be processed at each stage, i.e., sulfur is 33% sulfur ore, 33% sulfur recovered from other sources, and 33% SO_2 captured from other processes.

[b] Assumes a level of emissions that would result from use of 1983 best available technology (BAT) controls.

Source: Ref. B.19, Table VI-3, p. VI-8.

Reference B.28 indicates that 350 parts per million (ppm) fugitive dust will be emitted from the mining and concentration of spodumene ore to yield lithium for lithium sulfide batteries.[B.28] In primary refining, the calcination step generates carbon dioxide that is vented. Water emissions for lithium treating are taken from the new source performance standards for mining.[B.28] These standards mention that the tailings from ore concentrations can contain hazardous materials like heavy metals, sulfides, and sulfur. These are usually disposed of in tailings ponds where the solids settle. The supernatant water is then treated and released. Water treatment sludge is returned to the settling pond.

Producing aluminum for the lithium battery (and for the structural components of the vehicles) creates substantial particulates.[B.28] In bauxite grinding, 75 ppm of total particulates enter the electrostatic precipitator and about 18.7 ppm are emitted. Calcination of aluminum hydroxide creates 1180 ppm of particulates that are reduced to 624 ppm in an electrostatic precipitator. The 57.7% of the aluminum that is recycled releases some 1952 ppm of particulates after baghouse treatment of the emissions. In the anode baking furnace, a self-induced spray treatment captures most of the particulates, but 30 ppm total particulates are still released along with some 18.6 ppm of gaseous fluorides. Treatment of the air pollutants from the prebaked

Table B.65. Nickel Trajectory Emissions (lb/10^6 lb Ni)[a]

Residual	Mine	Mill	Primary Refining	Scrap	Recycle Material
Air pollutant					
SO_x			b,c	c	
Particulates	--- 145 ---		4500	--- 250 ---	
Heavy metals	--- 5 ---		1870	--- 87.5 --	
Water pollutant[d]					
TDS	NA[e]	NA			
TSS	1	5.6			
BOD_5	NA	196			
Oil and grease	0.2	2.1			
Solid waste					
Waste rock	1.6×10^4				
Tailings		2975[f]			
Smelting slag			3150[g]		

[a] These emissions take into account the correct proportions of nickel that will be processed at each stage, i.e., nickel is 5% domestic ore, 5% nickel sulfide, 30% imported ore, 35% imported concentrate, and 25% recycle/secondary.

[b] Typical Ni smelt yields 221 tons/day (TPD) SO_2 captured and fed to a sulfuric acid plant.

[c] Refining and recycle may produce nickel carbonyl.

[d] Assumes a level of emissions that would result from use of 1983 best available technology (BAT) controls.

[e] Not available.

[f] Tailings are returned to mine (Ref. B.22, Table 3-13, pp. 3-58).

[g] Slag is disposed of.

Source: Ref. B.22.

reduction cell yields 1010 ppm of total particulates, which contain 253 ppm of particulate fluorides and 123 ppm of gaseous fluorides. Iron oxide, silica, and other impurities are found in waste waters and are captured in water treatment sludges.

The emissions shown in Tables B.62-B.74 reflect, for each material, the proportion of the 10^6 lb of that material that enters each individual processing step in the United States. That is, mining emissions are applied to the proportionate share contributed by domestic ore, and milling or concentrating

Table B.66. Iron Trajectory Emissions ($lb/10^6$ lb Fe)[a]

Residual	Mine	Mill	Primary Refining	Scrap
Air pollutant				
CO			b	
Particulates	- - - 2088 - - -		1305[c]	
Heavy metals	- - - 72 - - -			
Water pollutant[d]				
TDS	NA[e]	NA		896
TSS	14.5	11.5		2.2
BOD_5	NA	403		
Oil and grease	2.2	4.3		
Pb	0.1	0.2		
Zn	0.1	0.15		
Heavy metals	1.2	0.2		0.03
Solid waste				
Waste rock	3.6×10^4			
Tailings		5.472×10^4[f]		
Smelting slag			1.8×10^3[g]	

[a] These emissions take into account the correct proportions of iron that will be processed at each stage, i.e., iron is 72% primary ore (18% natural and 54% pellets) and 28% recycle.

[b] Carbon monoxide is created but is not included here, because it is captured and used as a process fuel.

[c] Ref. B.28, Table 7-51.

[d] Assumes a level of emissions that would result from use of 1983 best available technology (BAT) controls.

[e] Not available.

[f] Ratio of tailings to waste rock (Ref. B.22, pp. 3-53).

[g] 500 lb slag/ton Fe (Ref. B.29, p. 266).

Sources: Refs. B.22, B.28, and B.29.

Table B.67. Steel Trajectory Emissions (lb/10^6 lb steel)[a]

Residual	Mine	Mill	Primary Pig Iron	Scrap	Steel Production
Air pollutant					
CO			b		b
Particulates	- - - 2088 - - -		1305[c]		197[c] (includes 17 CaF_2)
Heavy metals	- - - 72 - - -				
Gaseous fluoride					14.3
Water pollutant[d]					
TDS	NA[e]	NA		896	135
TSS	14.5	11.5		2.2	2.5
BOD_5	NA	403			
Oil and grease	2.2	4.3			
Pb	0.1	0.2			
Zn	0.1	0.15			
Heavy metals	1.2	0.2		0.03	0.03
Fluorides					NA
Solid waste					
Waste rock	3.6×10^4				
Tailings		5.472×10^4[f]			
Smelting slag			1.8×10^3[g]		2072[h]

[a] These emissions take into account the correct proportions of iron that will be processed at each stage, i.e., iron is 72% primary ore (18% natural, 54% pellets) and 28% recycle. Steel production is 26.4% open hearth, 55.2% basic oxygen, and 18.4% electric arc furnaces; includes iron, scrap, and recycle metals (Ref. B.22, Table 3.8).

[b] Carbon monoxide is created but is not included here, because it is captured and used as a process fuel.

[c] Ref. B.28, Table 7-5.1.

[d] Assumes a level of emissions that would result from use of 1983 best available technology (BAT) controls.

[e] Not available.

[f] Ratio of tailings to waste rock (Ref. B.22, pp. 3-53).

[g] 500 lb slag/ton Fe (Ref. B.29, p. 266).

[h] Steel slag may contain fluorides.

Sources: Refs. B.22, B.24, B.28, and B.29.

Table B.68. Copper Trajectory Emissions (lb/10^6 lb Cu)[a]

Residual	Mine	Mill	Primary Refine	Scrap
Air pollutant				
Particulates	--- 1,914 ---			
Heavy metals	--- 66 ---			
Other			CuS 12,050[b] PbS 4,970	
Water pollutant[c]				
TDS				339
TSS	13.2	12.0	520	0.8
BOD_5		422		
Oil and grease	2.0	4.5		
Heavy metals	1.1	0.2	360[d]	0.05
Solid waste				
Waste rock	1.32×10^4			
Tailings		1.13×10^3		
Smelting slag			2.7×10^5	

[a] These emisions take into account the correct proportions of copper that will be processed at each stage, i.e., copper is 66% domestic ore, 9.3% imported ore, 10.6% scrap, and 14.1% imported product. The emissions are modeled on those of electrolytic zinc.

[b] Assumes 90% capture of CuS; electrostatic precipitator could recapture 99.7%.

[c] Assumes a level of emissions that would result from use of 1983 best available technology (BAT) controls.

[d] With 95% copper recycle (Ref. B.22, pp. 3-39).

Source: Ref. B.22.

emissions are applied to the total share of ore processed (including domestic and foreign ore). Refining emissions are applied to that portion of the total element that is refined, i.e., imported refined metal is excluded. To preserve the purity of the metal or compound, recycled materials would probably undergo essentially the same processes as for the ore but would be entered at the appropriate step in the manufacturing process. Recycled materials would bypass the preliminary metal-forming steps necessary for ore but would undergo substantial cleaning and separation.

Table B.69. Potassium Hydroxide Trajectory Emissions ($lb/10^6$ lb KOH)

Residual	Mine	Manufacture
Air pollutant		
Particulates	2,900	
Chlorine (product)		446,000
Hydrogen (product)		12,730
Water pollutant[a]		
TSS		500
NaCl		38,800
$HgCl_4$		Some
Solid waste		
Brine purification[b]		7,599
Waste treatment solids[c]		27,400
Drummed waste[d]		50

[a] Assumes a level of emissions that would result from use of 1983 best available technology (BAT) controls.

[b] Brine purification: muds containing $CaCO_3$, $Mg(OH)_2$, $BaSO_4$, NaCl, and $HgCl_4$.

[c] Waste treatment solids containing graphite, filter-aid, and Hg_2S.

[d] Chlorinated hydrocarbons.

Source: Ref. B.22.

These weighted emissions are then multiplied by the quantity of material required for that element or compound in each appropriate scenario and category to yield total anticipated emissions on a 100,000 vehicle unit basis. Emissions for boron nitride, glass, rubber, silicon, cobalt, and "other materials" are not included. Also, no difference is anticipated between EHVs and CVs in emissions from vehicle fabrication and assembly; therefore, they have also been excluded.

B.3.5 Energy and Emissions Impact of Changing Metals Recycle Ratio

In the above discussion, present recycling, import, etc. rates are assumed. However, recycling metals is becoming much more significant and gathering and processing should be even more highly developed by the year 2000. The soaring demand between now and 2000 for certain metals under the

Table B.70. Potassium Chloride Trajectory Emissions (lb/10^6 lb KCl)[a]

Residual	Mining and Processing
Air pollutant	Negligible
Water pollutant[b]	No discharge
Solid waste	3.22×10^6[c]

[a] These emissions take into account 14% solution mining and processing and 86% sylvite ore mining and processing.

[b] Assumes a level of emissions that would result from use of 1983 best available technology (BAT) controls.

[c] Solid waste includes NaCl, KCl, K_2SO_4, $MgSO_4$, alumina, and clays.

Sources: Refs. B.22 and B.30.

five scenarios means that significantly greater quantities of used metal for recycling will be needed just to maintain the same proportion of recycled material as exists now in the final metal product (averaging all products using a specific metal). If battery materials are recycled, the proportion of recycled materials in the final metal product (again averaging all products using a specific metal) could substantially increase for some of the materials under some of the scenarios.

To provide some perspective on the potential impact on energy requirements and emissions of recycled materials, increased and decreased recycling of nickel and zinc were examined. The proportion of recycled materials in 2000 of the MEDIUM scenario is halved and then doubled for each of the two metals to observe changes in energy requirements and in emissions. All other contributions to the final metal product are assumed to keep their same relative proportions.

Energy requirements are given in Table B.75. Compared to the energy projections used in this assessment, halving the recycle rate for nickel and zinc oxide increases total vehicle energy requirements by 0.06%. If the recycle rate is doubled, energy requirements decrease by 0.11%. If these changes are examined in terms of battery manufacture only, as opposed to total vehicle energy requirements, the rates of change shown above must be quadrupled, because the battery represents just 25.4% of the total vehicle energy requirements (in MEDIUM 2000).

Changes in emissions given in Table B.76 are based on emissions per 100,000 new vehicles. Differences among the different degrees of recycling are noticeable. Increased recycling rates result in an overall decline in the total pollutant burden of the materials trajectory.

Table B.71. Zinc Trajectory Emissions (lb/10^6 lb Zn)[a]

Residual	Mine	Mill	Primary Refining	Scrap
Air pollutant				
SO_x			60.56×10^3[b]	
Particulates[c]	1,218		235.8 Zn + 132.7 Other	
Heavy metals	42			
Water pollutant[d]				
TDS				192
TSS	8.4	6.7	380	0.5
BOD_5		23.5		
Oil and grease	1.3	2.5		
Heavy metals	0.7	0.14	264	0.01
Solid waste				
Waste rock	8,400			
Tailings		630		
Smelting slag			198,000	

[a] These emissions take into account the correct proportions of zinc that will be processed at each stage, i.e., zinc is 42% domestic ore, 13% imported ore, 39% imported metal, and 6% scrap.

[b] SO_3 emissions are 110% of zinc and are captured and sent to the sulfuric acid plant. SO_x is reduced 90% by capture and fed to the sulfuric acid plant and used for lime slurry treatment.

[c] Particulates include ZnS and PbS. They can be reduced by 99.7% by electrostatic precipitators.

[d] Assumes a level of emissions that would result from use of 1983 best available technology (BAT) controls.

Source: Ref. B.22.

B.4 FUELS PRODUCTION AND TRANSPORT RESIDUALS

This section characterizes the residuals associated with fuels production and transport for EHV and CV operation. The fuels evaluated (uranium, coal, oil, and natural gas) are those discussed in App. F as producing the electricity for EHV operation. Other energy sources have no significant role in electricity generation for EHV operation. Residuals from the production and transport of gasoline and diesel fuel for HV and CV operation also are characterized. The energy required for fuels production and transport for EHV and CV operation is characterized in Sec. C.2.

Table B.72. Lithium Trajectory Emissions (lb/10^6 lb Li)[a]

Residual	Mine	Mill	Primary Refining	Li_2S Mfr.	LiCl Mfr.
Air pollutant					
CO			Trace		1
Particulates	- - Fugitive dust 350[b] - -				
Heavy metals	- - - - -Grindings - - - -				
CO_2 from calcine			Vented		Vented
Water pollutant[c]					
TDS	NA[d]		NA	NA	
TSS	20[e]		20[f]		
BOD_5	NA		NA	NA	
Oil and grease	3[e]		3[f]		
Lead	0.1[e]		0.1[f]	0.1	
Zinc	0.1[e]		0.1[f]	0.1	
Heavy metals	1.6[e]				
Sulfides			Trace	10[g]	
Chlorides					Diluted HCl
Solid waste					
Waste rock	167.5 x 10^6[h]				
Slag			6.65 x 10^6[i]		
By-product spodumene		10 x 10^6[j]			
By-product mica, feldspar, and quartz		50 x 10^6			

[a] Combined Li_2S and LiCl.

[b] Per 8.20.2 Emissions Rock Quarry, EPA Compilation.[B.28]

[c] Assumes a level of emissions that would result from use of 1983 best available technology (BAT) controls.

[d] Not available.

[e] May contain traces of a ferrosilicon gravity separating medium (Ref. B.22, pp. 3-27).

[f] Same standards as mining assumed because of indefinite data.

[g] Estimated metal sulfide from reaction in water.

[h] Rock gravel overburden. Sold as a by-product or used as landfill back in mine.

[i] Insoluble filter cake from leaching and includes discarded $AlSi_2$ residue and spodumene ($LiAlSi_2O_6$) (Ref. B.22, pp. 3-44).

[j] Underflow spodumene (6% Li_2C) is often sold for ceramic applications.

Sources: Refs. B.22 and B.28.

Table B.73. Aluminum Trajectory Emissions (lb/10^6 lb Al)[a]

Residual	Mine	Mill	Primary Refining[b]
Air pollutant			
Particulates	- - - 110 - - -		3,250[c]
Gaseous fluorides			142
Water pollutant[d]			
TDS	NA	NA	NA
TSS	20	145	200[e]
BOD_5	NA	NA	NA
Oil and grease	3	3	3
Heavy metals	1.7	13.3	100
Chlorinated fluorocarbons			Slight
Solid wastes			
Waste rock	85,000[f]		
Slag			1.18×10^6[g]

[a] These emissions take into account the correct proportions of aluminum that will be processed at each stage, i.e., aluminum is 4.25% domestic bauxite ore, 26.96% imported bauxite ore, 11.09% imported alumina, and 57.7% recycled aluminum.

[b] Recycled aluminum included in primary refining.

[c] Includes CaF_2.

[d] Assumes a level of emissions that would result from use of 1983 best available technology (BAT) controls.

[e] Includes FeO, SiO_2, and other impurities, which are treated to form sludge.

[f] Estimate two cubic yards of rock and gravel per cubic yard of bauxite mined.

[g] Bauxite at 26.4% Al, 31.2% bauxite treatment.

Source: Ref. B.28.

Table B.77 lists the steps from fuel extraction to refined fuel delivery for each of the fuels considered. In deriving the residuals associated with these steps, two sources are used. The first document, Ref. B.31, contains thorough discussions of the production processes for each of the nuclear and fossil fuels, from extraction through consumption for thermal energy.[B.31] For each step, total residuals are estimated. (This input expressed as material tonnage is highly variable for uranium fuel.) These residual estimates, however, draw heavily on sources that precede issuance both of EPA's 1975 new source performance standards (NSPS) and of the 1978 revision to include mobile source emission factors.[B.32,B.33] Because total

Table B.74. Battery Assembly and Manufacture Emissions (lb/10^6 lb battery)

Residual	Battery Type			
	Pb/Acid	Ni/Fe	Ni/Zn	Li/S
Air pollutant				a
SO_x	0.13			
NO_x	39.00			
HC	0.67			
CO	3.79			
Particulates	2.23	0.79	0.97	
Lead	422.5			
Water pollutant[b]				a
TDS	0	0	0	
TSS	0	0	0	
BOD_5	0	0	0	
Oil and grease	0	0	0	
Lead	0	0	0	
Zinc	0	0	0	
Heavy metals	0	0	0	
Sulfides	0	0	0	
Other	0	c	c	
Solid waste	0	3.97	4.56	a

[a] No data available. Manufacturing process has not been clearly defined.

[b] Assumes a level of emissions that would result from use of 1983 best available technology (BAT) controls.

[c] State of Connecticut standard: $\leq$ 3.7 lb/day Ni and 0.65 lb/day Cd.

Sources: Ref. B.19 and B.28.

emissions from the transport of all fuels have been computed in Ref. 31, the total residuals burden arising from product transportation (but not the relative burden distributed among transport modes) may be overstated.

The second document consulted, Ref. 34, is more recent than Ref. 31. However, estimates of residuals from the production, transportation, and storage of crude oil (except for refinery emissions) and natural gas are not included. Ref. 34 draws many of its assumptions and numbers from Ref. 31, but a significant amount of material has been updated. Particularly significant

Table B.75. Impact on Energy Requirements of Recycle Rate Change for Nickel and Zinc Oxide (10^9 Btu/100,000 vehicles)

Component	Half the Recycle Rate	Base Case[a]	Double the Recycle Rate
New batteries			
Pb/Acid (NC)[a]	141.3	141.3	141.3
Ni/Fe			
Nickel contribution	7.03	7.0	6.95
Other (NC)	14.6	14.6	14.6
Total	21.63	21.6	21.55
Ni/Zn			
Nickel contribution	1,437.87	1,432.5	1,422.71
Zinc contribution	143.78	143.3	142.58
Other (NC)	293.9	293.9	293.9
Total	1,875.55	1,869.7	1,859.19
Li/S (NC)	392.3	392.3	392.3
Total - new batteries	2,430.78	2,424.9	2,414.34
Motor controllers and bodies (NC)	9,667.9	9,667.9	9,667.9
Replacement batteries			
Pb/Acid (NC)	44.2	44.22	44.22
Ni/Fe			
Nickel contribution	0.22	0.22	0.22
Other (NC)	0.33	0.33	0.33
Total	0.55	0.55	0.55
Ni/Zn			
Nickel contribution	538.94	536.93	533.26
Zinc contribution	53.93	53.75	53.48
Other (NC)	108.6	108.6	108.6
Total	701.47	699.28	695.34
Li/S (NC)	120.94	120.94	120.94
Total - replacement batteries	867.18	864.99	861.05
Total energy requirements (10^9 Btu/100,000 new vehicles)	12,965.86	12,957.7 9	12,943.29
Variation - % of base	+0.062	-	-0.112

[a] No change.

Table B.76. Impact on Emissions from Varying Recycle Rates, Ni and Zn, MEDIUM Scenario, 2000 (lb/100,000 vehicles)

Recycle Rate	Nickel Trajectory				Zinc Oxide Trajectory				
	Mine	Mill	Primary Refining	Recycle	Mine	Mill	Primary Refining	Scrap	Recycle
Half recycle rate									
Air pollutant									
SO_x							2.06×10^6		
Particulates	- - - 7,372 - - -		228,729	5,446	41,420		12,528		
Heavy metals	- - - 253 - - -		95,326	1,906	1,417				
Water pollutant									
TDS								3.63	
TSS	50.6	285			286.7	227.4	12,916	8.24	
BOD_5		9,976				800.7			
Oil and grease	10.04	107			44.2	85.7			
Lead	5.22	5.22			1.65	4.94			
Zinc	5.22	5.22			1.65	3.95			
Heavy metals	5.22				23.72	4.61	8,963	0.16	
Solid waste									
Waste rock	814,709				285,623				
Tailings		151,222				21,418			
Smelting slag			160,110				6.732×10^6		
Original recycle rate									
Air pollutant									
SO_x							1.995×10^6		
Particulates	- - - 6,313 - - -		195,930	10,885	40,133		12,142		
Heavy metals	218		81,638	3,810	1,384				
Water pollutant									
TDS									6,326
TSS	43.5	243.8			276.8	220.8	12,521		16.48
BOD_5		8,534				774			
Oil and grease	8.71	91.4			42.8	82.4			
Lead	4.35	4.35			1.65	4.94			
Zinc	4.35	4.35			23.07	4.61	8,699		0.33
Heavy metals	4.35								

Table B.76. (Cont'd)

	Nickel Trajectory				Zinc Oxide Trajectory				
	Mine	Mill	Primary Refining	Recycle	Mine	Mill	Primary Refining	Scrap	Recycle
Original recycle rate (Cont'd)									
Solid waste									
Waste rock	696,640				276,780				
Tailings		129,532				20,759			
Smelting slag			137,151				6.524×10^6		
Double recycle rate									
Air pollutant									
SO_x							1.87×10^6		
Particulates	- - - 4,235 - - - -		130,701	21,784	37,565		11,365		
Heavy metals	- - - 143.7 - - -		54,459	7,624	1,285				
Water pollutant									
TDS								12,653	
TSS	30.5	161.2			260.3	207.6	11,730	32.95	
BOD_5		5,682				758			
Oil and grease	5.67	61.02			39.5	75.8			
Lead	3.05	3.05			1.65	4.61			
Zinc	3.05				1.65	3.95			
Heavy metals	3.05				21.75	4.61	8,139	0.66	
Solid wste									
Waste rock	479,240				259,229				
Tailings		86,394				19,441			
Smelting slag			91,491				6.107×10^6		

Table B.77. Steps in the Production of Electricity, Gasoline, and Diesel Fuels

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Uranium

1. Mining (open pit or underground).
2. Milling (conversion to U_3O_8).
3. Conversion from U_3O_8 to UF_6.
4. Enrichment (increase of U_{235} content by gaseous diffusion or ultracentrifuge).
5. Fuel fabrication.
6. Transport (mine-mill-conversion-enrichment-fabrication-reactor-disposal).
7. Reprocessing.
8. Vitrification (conversion of high-level liquid waste to glassy solid).
9. Waste disposal.

Coal

1. Mining (strip or underground).
2. Washing (beneficiation).
3. Transport to utility.

Oil products

1. Extraction (domestic only).
2. Transport to refinery.
3. Refinery processing.
4. Transport to utility or transport to bulk terminal and retail petroleum outlet.

Natural gas

1. Extraction (domestic).
2. Processing, including removal of vapor and impurities and "sweetening" (removal of H_2S fraction).
3. Pipeline transport.

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is the distinction drawn among the water pollutant totals that can be expected under each of four possible effluent enforcement conditions: base year (1974 standards); best practical control technology currently available (BPCTCA), effective 1977; best available technology economically achievable (BATEA), effective 1983; and best available demonstrated technology (BADT), applicable to all new sources. This analysis assumes BATEA.

Table B.78 lists the air and water pollutants and solid residuals that are generated during the production and transport of nuclear and fossil fuels.[B.31,B.34] A brief description of the significance or deleterious impact of each pollutant also is included.

Various assumptions are necessary in order to characterize residuals. In general, estimates of environmental residuals are based on the experience of existing technologies for the extraction and processing of nuclear and fossil fuels, except where there is substantial concurrence that a promising new technology will be in place on at least a limited scale by 1990. An example of the former is that this analysis assumes that crude petroleum will arise chiefly from traditional sources rather than shales or tar sands. An example of the latter is uranium hexafluoride (UF_6) enrichment by ultracentrifuge.

Additional and more specific assumptions are as follows:

1. No reactors other than light water fission reactors are considered.
2. By 1990, 20% of uranium fuel enrichment will be accomplished by the ultracentrifuge method, which leaves 80% to be enriched by gaseous diffusion. By 2000, this percentage will grow to 30%. This assumption is based on the fact that demand for enriched fuel is expected to exceed the currently available (gaseous diffusion) capacity early in the 1980s and that private nuclear energy production consortia favor the ultracentrifuge technique for new facilities. The ultracentrifuge enrichment procedure is significantly "cleaner." However, even if it is not in place to the extent assumed above, it is likely that stricter emission controls on gaseous diffusion enrichment operations will greatly reduce process pollutants (particularly SO_2) by 1990, resulting in at least a "surrogate" 20% substitution by ultracentrifuge with respect to residuals production.
3. Utilities will use western and eastern bituminous coals for utility boiler steam production.
4. The percentage of domestic coal strip-mined will be 56% in 1990 and rise to 57% in 2000. In 1990, western coal will account for 43% of total domestic production and rise to 50% by 2000. These projections are derived from forecasts by the National Coal Association and the Electric Power Research Institute.[B.35]

Table B.78. Pollutant Residuals from the Production and Transport of Nuclear and Fossil Fuels

Air	
TSP SO_2 NO_x HC CO	These are the five principal pollutants for which national ambient air quality standards have been promulgated. Total suspended particulates and SO_2 are termed "Set I" pollutants, because they arise chiefly from stationary sources. Nitrogen oxides, HC, and CO are "Set II" pollutants that are attributed primarily to mobile sources. Hydrocarbons are significant precursors to ozone (O_3) and usually are not harmful in their own right, except in massive concentrations.
Aldehydes	Although not currently regulated, aldehyde emissions are known to cause pathological inhibition of normal organic function in mammals, and some have been identified as mutagenic agents.
Water	
TDS	Excessive dissolved solids are undesirable and can be physiologically harmful in public drinking supplies.
TSS	Excessive suspended solids can inhibit the transmission of oxygen and sunlight to the lower depths of bodies of water, thus imperiling deep-water life forms.
BOD_5 (biochemical oxygen demand as identified by the five-day test, which distinguishes between organically and inorganically oxidizable materials)	Excessive biological oxygen demand robs fresh and marine water of dissolved oxygen required to sustain plant and animal life; this condition often results from excessive levels of dissolved nitrogen.
COD (chemical oxygen demand index, which does not distinguish between organically and inorganically oxidizable materials)	Excessive chemical oxygen demand also reduces oxygen levels as above but with inorganic reductants.
Sulfate/sulfite/sulfide	These anions form compounds that degrade drinking water quality by increasing its laxative properties and may contribute to eutrophication; in the case of hydrogen sulfide, toxicity to many species of fish has been established.
Nitrate	Nitrate reduces to nitrite in solution; nitrate compounds are toxic in young children, leading to the development of methemoglobinemia.

Table B.78 (Cont'd.)

Metal cations	
Aluminum	Toxic to fish in moderate concentrations.
Iron	Toxic to aquatic life in high concentrations; disagreeable in drinking water.
Zinc	Lethally toxic in many species of fresh water fish in hard water.
Nickel	Same as above, but also toxic to plants at moderate concentrations.
Manganese	Disagreeable in drinking water; toxic to certain cash crops.
Chromium	Extremely toxic to animal life in hexavalent form; toxic to cash crops in trivalent form.
Other Anions	
Chlorides	Toxic to aquatic life in high concentrations.
Fluorides	Excessive concentrations may lead to dental and epidermal fluorosis in mammals.
Ammonia	A primary source of dissolved nitrogen (contributes to high BOD) and resistant to standard chlorination treatment for water purification.
Solid Waste	
Displaced overburden	The quantity of soil and other surface material that must be removed from the surface or from underground workings to expose a coal seam or uranium ore. This report assumes a linear relationship between tons of ore produced and tons of overburden displaced.
Mine tailings	Residues produced in the separation at the mine site of uranium ore and coal from other constituent materials.
Beneficiation process residues	For uranium: waste materials arising from uranium hexafluoride conversion, fuel fabrication, reprocessing, vitrification, and packaging of transuranic waste. For coal: waste materials arising from the beneficiation (washing/desulfurization) of coal at the mine site or utility to reduce ash and/or sulfur content. For oil: residual waste (usually oily sludges) from refinery processing.

5. Because of problems associated with runoff control, the majority of underground coal mines in operation during the forecast years will not be in compliance with federal new mine performance regulations. (It is believed that such a conservative estimate is advisable here because of the great variability in mine conditions.)

6. Based on trends reported by the National Coal Association.[B.36] the following distribution among coal transport modes to utilities is assumed for the forecast years:

Mode	Ton-Miles (%)
Unit train	63
Conventional train	27
Waterway	7
Truck	3

7. Oil-fired utility boilers will consume No. 6 residual oil only.

8. 1983 BATEA is assumed for refinery water pollutants.

9. No liquefied natural gas will be used for electricity generation.

10. Residuals associated with hydropower production (e.g., volatilization or discharge of lubricants at the generating station) are not considered.

Composites for each of the residuals for each of the fuels considered are presented in Table B.79. Residuals from the production of gasoline, diesel fuel, and No. 6 fuel oil reflect their respective allowable proportions of the total residuals of a refinery producing 10^{12} Btu over an average spectrum of fuels, factored by the number of refinery "runs" necessary to produce 10^{12} Btu of each of the three fuels. Moreover, the values for petroleum-based fuels in the table presume that tanker trucks will move a greater proportion of refined gasoline and diesel fuel than of No. 6 oil to intermediate and final destinations, the latter fuel relying more heavily on rail and barge transport.

Table B.79. Residuals Burden of Processing and Transport of Fuel Input to Power Plant or Motor Vehicle (short tons/10^{12} Btu)

	Fuel													
	Uranium			Coal			No. 6 Oil		Natural Gas		Diesel Fuel		Gasoline	
Medium	Residual	Year	Burden	Residual	Year	Burden	Residual	Burden	Residual	Burden	Residual	Burden	Residual	Burden
Air	TSP	1990	47.42	TSP	1990	22.80	TSP	2.002	TSP	0.327	TSP	2.102	TSP	2.202
		2000	41.42		2000	22.95	SO_2	12.43	SO_2	0.01	SO_2	13.53	SO_2	14.03
	SO_2	1990	185.818	SO_2	1990	3.585	NO_x	18.604	NO_x	4.81	NO_x	23.100	NO_x	28.200
		2000	163.318		2000	3.585	HC	5.4	HC	0.724	HC	5.7	HC	6.4
	NO_x	1990	50.153	NO_x	1990	5.59	CO	9.39	CO	0.007	CO	11.91	CO	14.65
		2000	44.353		2000	5.54	Aldehydes	0.8	Aldehydes	0.177	Aldehydes	0.85	Aldehydes	0.96
	HC	1990	0.679	HC	1990	2.720								
		2000	0.579		2000	2.715								
	CO	1990	1.489	CO	1990	4.55								
		2000	1.389		2000	4.50								
				Aldehydes	1990	0.56								
					2000	0.55								
Water	Sulfate/ sulfide	1990	0.5	TDS	1990	241	TDS	578.5			TDS	603.2	TDS	670.2
		2000	0.4		2000	241.5	TSS	0.19			TSS	0.20	TSS	0.22
	Nitrate		1.35	TSS	1990	10.3	BOD_5	0.21			BOD_5	0.22	BOD_5	0.24
	Iron	1990	0.018		2000	10.0	COD	1.3			COD	1.4	COD	1.5
		2000	0.016	Sulfate/ sulfite	1990	125.0	Sulfide	0.0007			Sulfide	0.0007	Sulfide	0.0008
	Chloride	1990	0.34		2000	125.0	Chromium	0.002			Chromium	0.002	Chromium	0.002
		2000	0.30	Aluminum	1990	1.741	Ammonia	0.05			Ammonia	0.05	Ammonia	0.06
	Fluoride		1.623		2000	1.644	Organics	2.16			Organics	2.26	Organics	2.48
	Ammonia		0.6	Iron	1990	13.071								
					2000	12.771								
				Zinc	1990	0.065								
					2000	0.061								
				Mangenese	1990	0.364								
					2000	0.332								
				Chloride	1990	3.78								
					2000	3.70								
				Fluoride	1990	0.05								
					2000	0.05								
				Ammonia	1990	0.559								
					2000	0.549								
Solid waste	Overburden removed 1.5 x 10^5 Mine and mill tailings 19,115 Ash and other process residues 6.5			Mine tailings 540 Beneficiation residues 35,400			Dry residue 9.7				Dry residue 10.1		Dry residue 11.2	

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APPENDIX C

MATERIALS AND ENERGY ANALYSES

This appendix details the analysis of the major materials requirements of EHVs and the energy consumption comparison between EHVs and CVs.

C.1 MAJOR MATERIALS REQUIREMENTS

The nine metals listed in Table C.1, which gives U.S. reserves, resources, and production figures, are the major materials that would be impacted by the introduction of the EHVs characterized in App. B. In this discussion, the methods used to calculate the amounts required for each scenario are presented, along with the totals. Both direct materials (those in the vehicle) and indirect materials (those used in manufacturing and processing) are considered.

C.1.1 Methodology for Direct Materials Requirements

The methodology used to determine the materials requirements for each scenario and year on a 100,000 vehicle unit basis (see Secs. B.3.1 and B.3.2) also is used to determine total materials requirements for projected domestic manufacture of vehicles and replacement batteries by scenario and assessment year. Since recycling of batteries and motors/controllers/chargers may well occur, total materials requirements projected in this appendix also assume recycling. An extension of the method discussed in Sec. B.3.2 is made to include recycling.

Table C.1. U.S. Bureau of Mines Domestic Reserves, Resources, and Production (10^3 short tons)

Material	Reserves	Resources	1976 Mine Production	1976 Secondary Recovery
Lead	28,400	79,000	610.0	580.0
Cobalt	0	800	0	0.2
Nickel	200	15,100	13.7	50.0
Zinc	24,000	49,000	458.0	85.0
Copper	93,000	413,000	1,610.0	390.0
Boron	20,000	NA[a]	1,246.0	0
Lithium	400[b]	3,200[b]	3.9	0
Aluminum	0	400	2.2	449.0
Iron	4,480,000	121,000,000	89,600	97,000.0

[a] Not available.

[b] Estimates vary widely.

Sources: Refs. C.1–C.8.

No recycling of battery materials is assumed for 1985, and 95% is assumed for 1990 and 2000. At 95%, the total weight of new battery material required in a year with recycling is the weight in the new vehicle batteries plus 5% of the weight in replacement batteries (since 95% of the old battery is assumed to be recycled as battery material) less 95% of the weight in the batteries recycled from vehicles taken out of service due to age or accidents.

For recycling of motors/controllers/chargers, copper is the only major material of concern. No recycling is assumed in 1985, and 90% recycling of copper as motor/controller/charger material is assumed in 1990 and 2000. No replacement is assumed, because components are expected to last the average 10-yr life of the vehicle.

C.1.2 Direct Materials Requirements

Tables C.2-C.10 list the amounts of major materials needed for EHVs by scenario and assessment year. The tables include BOM estimates of total U.S. demand for each metal, the direct EHV demand both with and without recycling, and the percentage that each of the demand figures is of projected U.S. demand. The results without recycling are included because many technological barriers remain before 95% recycling is possible. The barriers vary considerably from metal to metal.

C.1.3 Indirect Materials Requirements

The method for calculating indirect materials impacts (additional materials required in the manufacture and distribution of EHVs) is quite different from the direct impact method. An input/output model described in Sec. G.2.1 is used to calculate the expected change in dollar output resulting from the EHV market scenarios. Lead, zinc, and copper smelting are the industries expected to exhibit maximum change. Table C.11 shows the output changes for 1990 and 2000 in the HIGH scenarios. Since a different baseline and method were applied, these results can not be compared to the direct materials figures of Tables C.2-C.10. However, the changes in Table C.11 are considered to be within the growth capacity of the industries. Therefore, the indirect effects do not change the results of the direct effects analysis.

C.2 ENERGY USE COMPARISON

This analysis compares the energy embodied in the production and operation of EHVs with that of equivalent numbers of CVs by scenario in the assessment years 1990 and 2000. Where the energy necessary for some aspect of the operation and production of EHVs and CVs was determined to be the same or virtually the same, it was not included.

C.2.1 Total Resource Requirements for Vehicle Operation

Figure C.1 illustrates the energy supply pathways of the fuel resources required to operate EHVs and CVs. For each fuel resource used to generate electricity for EHVs, the fuel must be extracted, processed, transported to

Table C.2. EHV Lead Demand with and without Recycling: Comparison with U.S. Bureau of Mines Projections by Scenario (10^3 short tons)

Scenario	Year	A U.S. Bureau of Mines Estimate of Probable U.S. Demand	B EHV Requirement	C Recycle	D EHV Demand after Recycle	$\frac{B}{A}$ x 100 (%)	$\frac{D}{A}$ x 100 (%)
LOW I	1985	1780	6.8	0	6.8	0	0
	1990	1960[a]	33.2	9.4	23.8	2	1
	2000	2330	461.6	169.6	292.1	20	13
LOW II	1985	1780	10.0	-	10.0	0	0
	1990	1960[a]	54.0	15.6	38.5	3	2
	2000	2330	856.6	288.1	568.5	37	24
MEDIUM	1985	1780	4.4	0	4.4	0	0
	1990	1960[a]	16.6	4.5	12.2	1	1
	2000	2300	272.3	99.3	173.0	12	7
HIGH I	1985	1780	18.8	0	18.8	1	1
	1990	1960[a]	54.0	9.1	34.9	3	2
	2000	2330	544.9	199.4	345.5	23	15
HIGH II	1985	1780	18.8	-	18.8	1	1
	1990	1960[a]	54.0	19.1	34.9	3	2
	2000	2330	544.9	199.4	345.5	23	15

[a] Linear interpolation of U.S. Bureau of Mines projections.

Table C.3. EHV Nickel Demand with and without Recycling: Comparison with U.S. Bureau of Mines Projections by Scenario (short tons)

Scenario	Year	A U.S. Bureau of Mines Estimate of Probable U.S. Demand	B EHV Requirement	C Recycle	D EHV Demand after Recycle	$\frac{B}{A}$ x 100 (%)	$\frac{D}{A}$ x 100 (%)
LOW I	1985	330,000	58	-	58	0	0
	1990	407,000[a]	1,530	-	1,530	0	0
	2000	560,000	48,100	17,900	30,100	9	5
LOW II	1985	330,000	58	-	58	0	0
	1990	407,000[a]	1,530	-	1,530	0	0
	2000	560,000	48,100	17,900	30,100	9	5
MEDIUM	1985	330,000	2,616	-	2,616	1	1
	1990	407,000[a]	23,545	4,529	19,016	6	5
	2000	560,000	508,856	174,752	334,104	91	60
HIGH I	1985	330,000	2,809	-	2,809	1	1
	1990	407,000[a]	64,471	6,981	57,490	16	14
	2000	560,000	1,330,000	413,159	917,914	237	164
HIGH II	1985	330,000	2,810	-	2,810	1	1
	1990	407,000[a]	69,400	7,320	62,100	17	15
	2000	560,000	1,720,000	45,000	1,170,000	306	210

[a] Linear interpolation of U.S. Bureau of Mines projections.

Table C.4. EHV Cobalt Demand with and without Recycling: Comparison with U.S. Bureau of Mines Demand Estimates by Scenario (short tons)

		A	B	C	D	$\frac{B}{A}$ x 100	$\frac{D}{A}$ x 100
Scenario	Year	U.S. Bureau of Mines Estimate of Probable U.S. Demand	EHV Requirement	Recycle	EHV Demand after Recycle	(%)	(%)
LOW I	1985	13,100	3	-	3	0	0
	1990	15,500[a]	82	-	82	1	1
	2000	20,200	2,590	75	1,840	13	9
LOW II	1985	13,100	3	-	3	0	0
	1990	15,500[a]	82	-	82	1	1
	2000	20,200	2,590	750	1,840	13	9
MEDIUM	1985	13,100	141	-	141	1	1
	1990	15,500[a]	1,296	244	1,052	8	7
	2000	20,200	27,434	9,423	18,011	136	89
HIGH I	1985	13,100	151	-	151	1	1
	1990	15,500[a]	3,478	376	3,102	22	20
	2000	20,200	71,792	22,275	49,516	355	245
HIGH II	1985	13,100	151	-	151	1	1
	1990	15,500[a]	3,700	394	3,350	24	22
	2000	20,200	92,700	29,374	63,300	459	314

[a] Linear interpolation of U.S. Bureau of Mines projections.

Table C.5. EHV Copper Demand with and without Recycling: Comparison with U.S. Bureau of Mines Projections by Scenario (short tons)

Scenario	Year	A U.S. Bureau of Mines Estimate of Probable U.S. Demand	B EHV Requirement	C Recycle	D EHV Demand after Recycle	$\frac{B}{A}$ x 100 (%)	$\frac{D}{A}$ x 100 (%)
LOW I	1985	3,000,000	2,647	-	2,647	0	0
	1990	3,700,000[a]	6,858	433	6,425	0	0
	2000	5,100,000	67,576	18,723	48,853	1	1
LOW II	1985	3,000,000	3,700	-	3,700	0	0
	1990	3,700,000[a]	12,000	713	11,295	0	0
	2000	5,100,000	124,000	32,700	101,000	3	2
MEDIUM	1985	3,000,000	4,904	-	4,904	0	0
	1990	3,700,000[a]	15,549	1,064	14,485	0	0
	2000	5,100,000	211,908	59,491	152,417	4	3
HIGH I	1985	3,000,000	9,337	-	9,337	0	0
	1990	3,700,000[a]	43,222	2,534	40,688	1	1
	2000	5,100,000	736,078	193,870	542,208	14	11
HIGH II	1985	3,000,000	11,000	-	11,000	0	0
	1990	3,700,000[a]	56,400	2,140	54,300	2	1
	2000	5,100,000	896,000	174,000	723,000	18	14

[a] Linear interpolation of U.S. Bureau of Mines projections.

Table C.6. EHV Lithium Demand without Recycling: Comparison with U.S. Bureau of Mines Projections by Scenario (short tons)[a]

Scenario	Year	A U.S. Bureau of Mines Estimate of Probable U.S. Demand	B EHV Requirement
LOW I	1985	NA[b]	1
	1990	NA	6
	2000	NA	77
LOW II	1985	NA	1
	1990	NA	6
	2000	NA	77
MEDIUM	1985	NA	4
	1990	NA	380
	2000	NA	15,805
HIGH I	1985	NA	0
	1990	NA	3,368
	2000	NA	172,847
HIGH II	1985	NA	0
	1990	NA	0
	2000	NA	0

[a] Lithium demand with recycle is not estimated, because it is unclear whether EHV materials requirements would be significant enough to necessitate initiation of lithium recycling.

[b] Not available.

Table C.7. EHV Boron Demand without Recycling: Comparison with U.S. Bureau of Mines Projections by Scenario (short tons)[a]

Scenario	Year	A U.S. Bureau of Mines Estimate of Probable U.S. Demand	B EHV Requirement	$\frac{B}{A} \times 100$ (%)
LOW I	1985	152,000	0	0
	1990	186,000[b]	0	0
	2000	278,000	0	0
LOW II	1985	152,000	0	0
	1990	186,000[b]	0	0
	2000	278,000	0	0
MEDIUM	1985	152,000	0	0
	1990	186,000[b]	43	0
	2000	278,000	1,824	1
HIGH I	1985	152,000	0	0
	1990	186,000[b]	387	0
	2000	278,000	19,940	7
HIGH II	1985	152,000	0	0
	1990	186,000[b]	0	0
	2000	278,000	0	0

[a] Boron demand with recycle is not estimated, because EHV materials requirements would not necessitate initiation of boron recycling.

[b] Linear interpolation of U.S. bureau of Mines projections.

Table C.8. EHV Zinc Demand with and without Recycling: Comparison with U.S. Bureau of Mines Projections by Scenario (short tons)

Scenario	Year	A U.S. Bureau of Mines Estimate of Probable U.S. Demand	B EHV Requirement	C Recycle	D EHV Demand after Recycle	$\frac{B}{A}$ x 100 (%)	$\frac{D}{A}$ x 100 (%)
LOW I	1985	1,630,000	33	-	33	0	0
	1990	1,820,000[a]	1,110	-	1,110	0	0
	2000	2,200,000	35,800	10,600	25,300	2	1
LOW II	1985	1,630,000	33	-	33	0	0
	1990	1,820,000[a]	1,110	-	1,110	0	0
	2000	2,200,000	35,800	10,600	25,300	2	1
MEDIUM	1985	1,630,000	1,947	-	1,947	0	0
	1990	1,820,000[a]	17,812	3,423	14,389	1	1
	2000	2,200,000	385,123	132,554	252,569	18	11
HIGH I	1985	1,630,000	2,129	-	2,129	1	1
	1990	1,820,000[a]	48,972	5,275	43,697	27	24
	2000	2,200,000	1,010,000	329,842	680,786	50	31
HIGH II	1985	1,630,000	2,130	-	2,130	0	0
	1990	1,820,000[a]	52,700	5,530	47,200	3	3
	2000	2,200,000	1,310,000	409,000	897,000	59	41

[a] Linear interpolation of U.S. Bureau of Mines projections.

Table C.9. EHV Aluminum Demand without Recycling: Comparison with U.S. Bureau of Mines Projections by Scenario (short tons)[a]

Scenario	Year	A U.S. Bureau of Mines Estimate of Probable U.S. Demand	B EHV Requirement	$\frac{B}{A}$ x 100 (%)
LOW I	1985	NA[b]	1,817	-
	1990	NA	9,486	-
	2000	20,000,000	121,538	1
LOW II	1985	NA	3,055	-
	1990	NA	16,852	-
	2000	20,000,000	272,200	1
MEDIUM	1985	NA	3,480	-
	1990	NA	26,403	-
	2000	20,000,000	375,949	2
HIGH I	1985	NA	7,488	-
	1990	NA	66,568	-
	2000	20,000,000	1,112,744	6
HIGH II	1985	NA	7,488	-
	1990	NA	76,647	-
	2000	20,000,000	1,689,200	8

[a] Aluminum demand with recycle is not estimated, because there are no significant EHV materials problems for aluminum.

[b] Not available.

Table C.10. EHV Iron and Steel Demand without Recycling: Comparison with U.S. Bureau of Mines Projections by Scenario (short tons)[a]

Scenario	Year	A U.S. Bureau of Mines Estimate of Probable U.S. Demand	B EHV Requirement	$\frac{B}{A}$ x 100 (%)
LOW I	1985	103,000,000	16,043	0
	1990	NA[b]	55,131	-
	2000	129,000,000	776,852	1
LOW II	1985	103,000,000	24,085	0
	1990	NA	93,663	-
	2000	129,000,000	1,533,381	1
MEDIUM	1985	103,000,000	31,056	0
	1990	NA	164,719	-
	2000	129,000,000	2,449,141	2
HIGH I	1985	103,000,000	65,422	0
	1990	NA	442,825	-
	2000	129,000,000	7,505,095	6
HIGH II	1985	103,000,000	65,422	0
	1990	NA	495,803	-
	2000	129,000,000	10,692,994	8

[a] Iron and steel demand with recycle is not estimated, because there are no significant EHV materials problems for iron and steel.

[b] Not available.

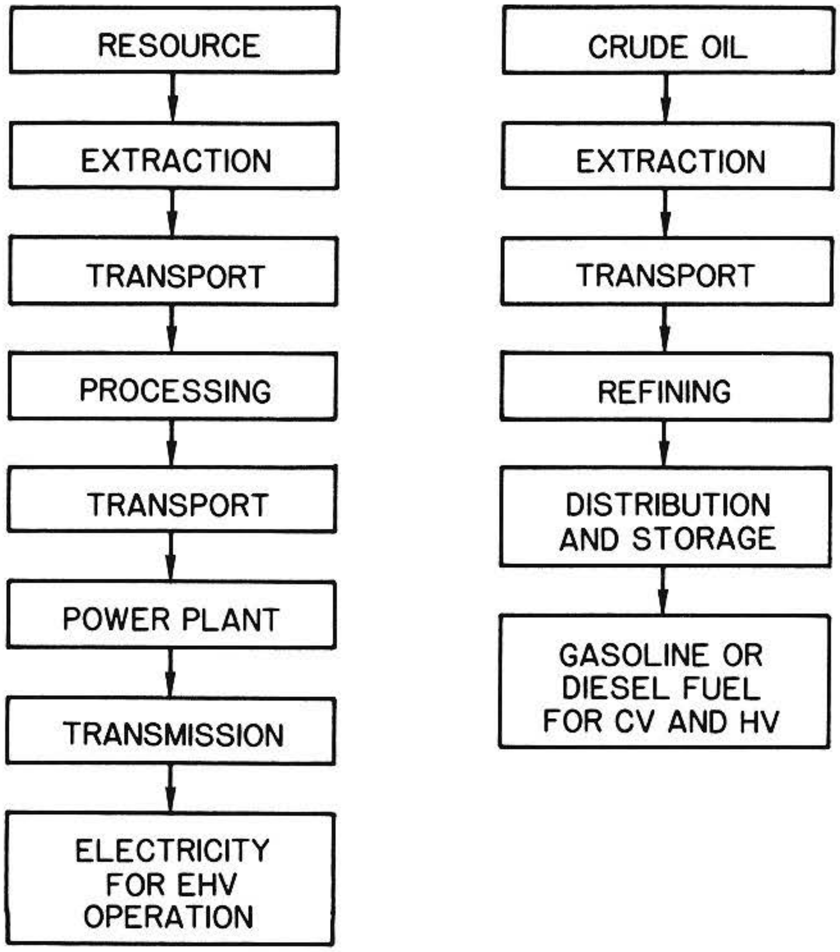

Fig. C.1. Vehicle Operation Energy Flow

the power plant, and transmitted to the battery charger. Energy is used at each step. Crude oil for gasoline or diesel fuel production for CVs and HVs must be extracted, transported to the refinery, refined, stored, and distributed. Again, energy is consumed at each step. Energy is also required to construct and maintain the facilities that process the fuel resources. This latter energy and the portion of it that can be attributed to the total energy consumed by EHV and CV operation is described and included in this analysis.

Energy also is required for other activities related to vehicle operation, such as highway construction and maintenance, vehicle servicing, insurance and regulation, and enforcement. Analysis of these types of energy requirements is not included here, because the energy needed for these activities usually is virtually the same between EHVs and CVs or has only marginal, if any, impact on the overall results of the analysis. For example, because of the good performance capabilities of EHVs, no changes are expected in highway construction requirements. As a result, the focus of the following vehicle operation analysis is on the total energy requirements associated with generating electricity for EHVs and providing gasoline and diesel fuel for CVs and HVs.

Table C.11. Input and Output Model Results for Lead, Zinc, and Copper Smelting

Material	Scenario	Output (10^9 1979$) 1990	Output (10^9 1979$) 2000	Percentage Increase in Output over BASE (all CVs) 1990	Percentage Increase in Output over BASE (all CVs) 2000
Lead	BASE	2.13	2.67	-	-
	LOW I	2.13	3.38	0	27
	LOW II	2.13	3.91	0	46
	MEDIUM	2.13	3.38	0	27
	HIGH I	2.13	4.98	0	87
	HIGH II	2.13	4.09	0	53
Zinc	BASE	2.13	2.49	-	-
	LOW I	2.13	2.49	0	0
	LOW II	2.13	2.49	0	0
	MEDIUM	2.13	2.85	0	14
	HIGH I	2.13	2.49	0	0
	HIGH II	2.13	3.91	0	57
Copper	BASE	5.33	5.69	-	-
	LOW I	5.33	5.69	0	0
	LOW II	5.33	5.87	0	3
	MEDIUM	5.33	5.69	0	0
	HIGH I	5.33	5.87	0	3
	HIGH II	5.33	5.87	0	3

C.2.1.1 Methodology

Energy Resource Requirements at the Power Plant and Service Station Pump

Energy intensities (kilowatt hours per mile for EVs and HVs and gallons per mile for HVs and CVs) for each type of vehicle by scenario and assessment year are given in Sec. B.2.2. The electricity used is calculated at the power plant busbar and takes into account transmission losses between the power plant and user and the efficiencies of the charger and the battery. The total annual kilowatt hours of electricity required to operate EHVs by scenario and assessment year are presented in Table C.12.

Also included in Table C.12 is the composition of fuels used to generate this electricity (see App. F). Appendix F provides the conversion efficiencies for oil, coal, natural gas, and nuclear fuel, and the total resource requirements at the power plant for each fuel type by scenario and assessment year. Table C.13 presents these total resource requirements, including resource requirements for hydro and pumped storage. These latter requirements are derived by assuming a conversion efficiency of 10,600 Btu/kWh for these facilities, which approximates the average resource input required if the electricity were generated by another type of power plant.

Table C.12. Electricity Generation Necessary for EHV Operation by Fuel Type

	Scenario									
	LOW I		LOW II		MEDIUM		HIGH I		HIGH II	
Fuel	%	10^6 kWh	%	10^6 kWh	%	10^6 kWh	%	10^6 kWh	%	10^6 kWh
1990										
Nuclear	27.7	320.6	27.8	546.8	27.9	703.0	27.4	1,806.0	27.4	1,804.2
Coal	51.3	593.4	51.3	1,008.6	51.5	1,294.8	51.0	3,356.5	51.0	3,353.0
Oil (base and peak)	16.6	191.7	16.5	325.1	16.6	417.3	17.4	1,147.2	17.4	1,146.0
Natural gas (base and peak)	3.5	40.9	3.5	68.1	3.4	86.9	3.4	226.9	3.4	226.7
Other[a]	0.9	11.1	0.9	17.4	0.6	14.2	0.8	49.7	0.8	49.1
Total	100.0	1,157.7	100.0	1,966.0	100.0	2,516.2	100.0	6,586.4	100.0	6,579.0
2000										
Nuclear	39.6	7,078.3	38.7	13,659.0	38.4	21,066.3	36.3	64,496.4	36.3	62,582.0
Coal	44.5	7,967.3	44.2	15,598.0	44.1	24,187.3	44.7	79,257.7	44.7	76,830.1
Oil (base and peak)	12.5	2,242.0	13.6	4,779.5	13.9	7,635.6	15.2	26,982.2	15.2	26,129.6
Natural gas (base and peak)	2.8	499.0	2.7	955.8	2.7	1,470.0	2.4	4,273.1	2.4	4,149.6
Other[a]	0.6	103.6	0.8	278.8	0.9	475.7	1.4	2,455.6	1.4	2,368.1
Total	100.0	17,890.2	100.0	35,271.1	100.0	54,834.9	100.0	177,465.0	100.0	172,059.4

[a] Hydro and pumped storage.

Source: App. F.

Table C.13. Resource Requirements at Power Plant for EHV Operation (10^{12} Btu)

Fuel	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
1990					
Nuclear	3.42	5.83	7.50	19.27	19.24
Coal	6.04	10.26	13.18	34.16	34.12
Oil (base and peak)	2.08	3.53	4.53	12.45	12.43
Natural gas (base and peak)	0.44	0.73	0.94	2.45	2.44
Other[a]	0.12	0.18	0.15	0.53	0.52
Total	12.10	20.53	26.30	68.86	68.75
2000					
Nuclear	75.51	145.70	224.71	687.99	667.56
Coal	81.07	158.73	246.13	806.52	781.82
Oil (base and peak)	24.90	53.30	85.27	311.89	301.90
Natural gas (base and peak)	5.40	10.34	15.89	46.23	44.89
Other	1.10	2.96	5.04	26.03	25.10
Total	187.98	371.03	577.04	1878.66	1821.27

[a] Hydro and pumped storage.

Source: App. F.

Gallons of gasoline and diesel fuel are measured at the service station (or other vehicle-fueling facility) pump. All CVs and HVs use gasoline except the conventional large buses, which use diesel fuel. The total annual gallons of gasoline and diesel fuel and equivalent Btu necessary for CV and HV operation in the various scenarios are shown in Tables C.14 and C.15. CV fuel consumption is for VMT equivalent to the VMT projected for EHVs. The conversion factor for gasoline is 5.248 x 10^6 Btu/bbl of oil (1 bbl = 42 gal) and for diesel fuel is 5.825 x 10^6 Btu/bbl.

Energy Supply Pathways

The resources shown in Table C.13 are those required at the power plant. They do not include the energy losses that occur before the fuels are delivered to the power plant. Similarly, the petroleum requirements in Table C.15 for CV and HV heat engine operation do not include losses associated with petroleum extraction and refining. An accurate accounting of the total energy requirements of different types of vehicles must include such losses.

Table C.14. Total Gasoline and Diesel Fuel Requirements for HV Heat Engine Operation and for CV Operation (10^6 gal)[a]

Vehicle	Scenario LOW I	LOW II	MEDIUM	HIGH I	HIGH II
Hybrid					
1990		16.15			20.96
2000		359.15			1,557.46
Conventional					
1990 - Gasoline	91.556	150.941	184.639	448.175	458.124
- Diesel			11.804	52.530	46.966
2000 - Gasoline	1,402.336	2,769.564	4,372.099	14,319.428	14,405.799
- Diesel	51.941	51.941	225.399	344.821	139.889

[a] Gallons of gasoline and diesel fuel used by CVs are for CVs traveling equivalent VMT as EHVs in the several scenarios and measured at the service station pump.

Table C.15. Total Fuel Required for HV Heat Engine Operation and for CV Operation (10^{12} Btu)[a]

Vehicle	Scenario LOW I	LOW II	MEDIUM	HIGH I	HIGH II
Hybrid					
1990		2.01			2.62
2000		44.89			194.68
Conventional					
1990	11.44	18.87	24.72	63.31	63.78
2000	182.49	353.40	577.77	1837.76	1820.12

[a] Btu used by CVs are for CVs traveling equivalent VMT as EHVs in the several scenarios and measured at the service station pump.

The methodology for this analysis is adapted from Refs. C.9, C.10, and C.11. Using a combination of process analysis and input-output analysis, these studies delineate for each fuel the energy losses and subsidies in fuel extraction, production, and transport associated with the delivery of a specified amount of energy to a distribution point (i.e., power plant or pipeline). The losses and subsidies include physical losses of fuel, internal consumption of fuel, and external energy. External energy includes the fuels, electricity, materials, and equipment required to operate and construct the fuel processing system. Petroleum production, natural gas production, coal strip mining, underground coal mining, nuclear electricity, and other energy supply pathways are examined in this way.

Table C.16 is based on the energy supply pathways developed in Ref. C.9 and presents the factors used to determine the total energy resource requirements associated with EHV and CV operation. The first column gives the in situ resource required to support the delivery of 1 Btu of energy to a power plant or service station pump; the second gives the recovered (mined or produced) resource required; and the third gives the external subsidies required, which are measured from the mine or wellhead. The first and third columns deserve special comment.

In situ resource is defined as the recovered or above-ground resource plus the unrecovered resource. Unrecovered resources are those left in the ground, damaged, lost, or otherwise degraded and which are generally unavailable to today's society given current extractive technology and economics. For example, the pillars of coal that support the mine roof and that are left in the mine are an unrecovered resource.

Table C.16. Energy Resource Requirements Associated with Energy Supply Pathways (Btu)

Resource	In Situ Resource	Recovered Resource	External Subsidy[a]	To Deliver
Petroleum	3.24	1.09	0.083	1 Btu to power plant
Natural gas	1.70	1.19	0.023	1 Btu to power plant
Coal				
Surface	1.15	1.15	0.038	1 Btu to power plant
Underground	2.01	1.15	0.043	1 Btu to power plant
Nuclear	1.30	1.24	0.055	1 Btu to power plant
Petroleum	3.26	1.09	0.107	1 Btu at service station pump

[a] External subsidies for power plant fuels include operating subsidies for the power plant and the transmission system.

Source: Ref. C.9.

The purpose of including unrecovered resource requirements in energy analysis is to recognize that only a portion of the total in situ resource is currently available. This method is an attempt to address the issue of the finiteness of fossil fuel resources and their rates of depletion. While future generations may recover some of the presently unrecovered resources, they will probably do so at high capital and energy costs and with presently uneconomic or undeveloped technologies. For today's society, however, fuel resources are depleted by more than the recovered resource. Other fuel resources are made unavailable.

For some of the fuel pathways, the amount of unrecovered resource left behind by current extractive technologies is substantially greater than what can be recovered economically. The petroleum pathway is the most inefficient with respect to resource recovery among those energy pathways considered here. The petroleum recovery rate is presently estimated at 33%. Even if tertiary recovery were to become economical, estimates suggest that the petroleum recovery rate would only increase to approximately 50%. Such inefficiencies dramatically affect the energy analysis of this EA. For this reason, the results of the energy comparison of EHVs with CVs are presented in two ways: one compares the in situ resource requirements and the other compares recovered resource requirements only.

Several comments should be made with regard to the external subsidies.

1. Some of the subsidies developed in Ref. C.9 have been modified for this analysis. For example, because EHV commercialization is estimated to have little or no impact on utility capacity requirements (see App. F), the energy required to construct power plants, transmission systems, and capital equipment is excluded from the external subsidies used in this analysis. However, the operating energy associated with the power plants and transmission systems is included.
2. The pathways developed in Ref. C.9 do not include subsidies for the electricity distribution system. While additional distribution lines and line transformers and upgraded substations in some localities may be required with EHV commercialization, no attempt is made here to include the energy subsidies associated with this activity or the operating subsidies associated with distribution. These expenditures should be quite small.
3. No modification is made to account for gasoline requiring a greater external subsidy than diesel fuel at the refinery. The external subsidy factor used here represents all petroleum products.

Table C.16 does not include supply pathways for hydroelectric or pumped storage facilities because none of the reports examined included them. As stated previously, an average value of 10,600 Btu/kWh is used to determine energy resources that would be required if power plants other than hydroelectric or pumped storage generated the electricity. In fact, hydroelectric facilities are among the most efficient energy-producing systems, having actual efficiencies of 75-80%.[C.12] Pumped storage facilities, while less efficient than hydro units, also are significantly more efficient than other power plant types. In some evaluations, hydroelectricity is not converted to a fossil fuel equivalent value. Because of the above factors and because hydro and pumped storage units together account for no more than 1.5% of total electricity generation in any of the EHV scenarios, the only energy requirements assumed for these power plant types in this analysis are those shown in Table C.13.

Finally, Ref. C.9 disaggregates the external energy subsidies into both operating and capital components and further disaggregates those components into their fuel sources (coal, oil, etc.). This level of detail is unnecessary for this analysis, because external energy subsidies in the fuel pathways are small relative to resource fuel requirements. For all fuels except petroleum, they are less than 5% of the recovered resource fuel requirements. For petroleum, they are 8-10%.

C.2.1.2 Vehicle Operation Energy Resource Requirements by Scenario

Total resource requirements associated with electricity generation in each EHV scenario are derived by applying the resource factors presented in Table C.16 to the resource requirements at the power plant shown in Table C.13. As stated previously, the values given in Table C.13 for "other" are assumed to be the total resource requirements for hydro and pumped storage energy. The results for each fuel type are presented in Tables C.17-C.21 and are combined in Tables C.22 and C.23. It should be noted that EIA projects that 56% of the coal supply will be from surface mines in 1990 and 57% in 1995.[C.13] This analysis assumes 56% in 1990 and 57% in 2000.

Total resource requirements associated with gasoline and diesel production for HVs and CVs also are derived by applying the resource factors presented in Table C.16 to the Btu requirements at the service station pump presented in Table C.15. The results for HVs are given in Table C.24 and for CVs in Table C.25.

Tables C.26 and C.27 compare the energy resource requirements of EHVs and CVs. Table C.26 shows that the total in situ resources required (including external subsidies) to operate EHVs are less in all scenarios and both assessment years than those required for CVs traveling the same VMT. In 1990, the in situ requirements for the EV-only scenarios are 57-59% of the requirements for CVs. In 2000, the range drops to 52-54% as a result of the decreased use of oil for electricity generation. For the scenarios with HVs, the in situ resource requirements as a percentage of CV resource requirements are somewhat higher than those for the EV-only scenarios because of the resource requirements for gasoline for the HVs. Even so, EHV in situ resource requirements are 63-69% of the CV requirements in 1990 and 64-67% in 2000.

Table C.27 compares the recovered resource energy requirements (including external subsidies) for EHV and CV operation. In all scenarios and both assessment years, EHVs require more energy for operation. The scenarios with HVs show the greatest increase, i.e., from 12% to 20% in 2000. The EV-only scenarios require no more than a 5% increase over what would be required by CVs in 2000.

Table C.17. Energy Resource Commitment for EHV Operation on Batteries, Petroleum (10^{12} Btu)

Year	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
1990					
Resource required at power plant	2.08	3.53	4.53	12.45	12.43
Initial resource required	6.74	11.44	14.68	40.35	40.29
Recovered resource required	2.27	3.84	4.93	13.56	13.54
External subsidy	0.17	0.29	0.38	1.03	1.03
2000					
Resource required at power plant	24.90	53.30	85.27	311.89	301.90
Initial resource required	80.70	172.75	276.36	1010.84	978.46
Recovered resource required	27.12	58.04	92.86	339.65	328.77
External subsidy	2.06	4.42	7.07	25.85	25.02

Several comments are appropriate here. The results given in Table C.26 do not include tertiary recovery of petroleum. If 50% recovery of petroleum is assumed, the CV in situ resource requirements decrease substantially and improve relative to the EHV requirements, but the EHV in situ requirements remain lower. The results shown in Table C.27 also would change with 50% recovery. Using Ref. C.9 factors for tertiary recovery in three scenarios in 2000, EHV recovered resource requirements are actually lower than those for CVs, though the difference is very small. At worst, EHV total recovered resource requirements in LOW II are 3% higher than those for CVs. Tertiary recovery technologies require greater external subsidies, thereby impacting the CV total requirements more than the EHV total requirements.

Further, it has been suggested that EHVs will replace vehicles with better fuel economy than has been assumed in this assessment. This is particularly true for the four- and five- passenger autos, since it is assumed that CAFE standards are constant after 1985. Any improvement in CV fuel economy over that used would obviously improve the CV totals relative to the EHV totals. However, it would take a dramatic increase in fuel economy to bring CV in situ resource requirements in line with those for EHVs. For example, in the MEDIUM scenario in 2000, a doubling of the fuel economy of all CVs used for comparison would be required to lower the CV requirements to the point

Table C.18. Energy Resource Commitment for EHV Operation on Batteries, Coal from Surface Mines (10^{12} Btu)[a]

Year	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
1990					
Resource required at power plant	3.38	5.75	7.38	19.13	19.11
Initial resource required	3.88	6.61	8.48	21.98	21.96
Recovered resource required	3.88	6.60	8.47	21.96	21.94
External subsidy	0.13	0.22	0.28	0.72	0.72
2000					
Resource required at power plant	46.21	90.48	140.27	459.72	445.64
Initial resource required	53.10	103.96	161.19	528.22	512.04
Recovered resource required	53.05	103.87	161.05	527.76	511.59
External subsidy	1.74	3.41	5.29	17.32	16.79

[a]Assumes 56% from surface mines in 1990 and 57% in 2000.

where they were equal to the EHV in situ requirements. However. such a doubling of fuel economy would improve the CV recovered resource requirements to such an extent that EHVs would require twice the total recovered resource energy of CVs. Such a drastic weight reduction and downsizing for CVs, however, should also allow for smaller and more efficient EHVs.

Finally, the EHV scenarios do, obviously, save on petroleum consumption in vehicle operation. Table C.28 provides the direct petroleum savings in Btu from EHV operation in each scenario in 1990 and 2000. In this instance, direct petroleum means fuel oil consumed at the power plant to generate electricity for EHV operation and gasoline and diesel fuel at the pump. Fuel oil consumed in generating electricity for EHVs and gasoline for HVs has been subtracted from the petroleum that would have been consumed by CVs. The EHV scenarios use 13-28% of the petroleum required by the BASE scenario. If the petroleum savings are converted into barrels of crude oil, 2-9 million barrels would be saved in 1990 and 27-263 million barrels in 2000, depending on the scenario. If petroleum losses in extraction, refining, and transport were considered, the petroleum savings of the EHV scenarios would be 10% higher.

Table C.19. Energy Resource Commitment for EHV Operation on Batteries, Coal from Underground Mines (10^{12} Btu)[a]

Year	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
1990					
Resource required at power plant	2.66	4.51	5.80	15.03	15.01
Initial resource required	5.36	9.08	11.68	30.27	30.23
Recovered resource required	3.05	5.18	6.66	17.25	17.23
External subsidy	0.12	0.20	0.25	0.65	0.65
2000					
Resource required at power plant	34.86	68.25	105.84	346.80	336.18
Initial resource required	70.21	137.46	213.16	698.46	677.07
Recovered resource required	40.02	78.35	121.50	398.13	385.93
External subsidy	1.52	2.97	4.60	15.08	14.61

[a]Assumes 44% from underground mines in 1990 and 43% in 2000.

C.2.2 Total Resource Requirements for Vehicle Production

To determine the energy consumed in the production of vehicles, the quantities of major materials required to produce the vehicles, the energy resources needed to produce these materials, and the energy resources necessary to assemble the vehicles are required. Section B.3.3 provides the energy consumed in the production of EHVs and CVs on a 100,000 vehicle unit basis for the assessment years of each scenario. The energy required for each appropriate processing step (mining, milling, smelting, refining, processing, machining, fabrication, and assembly) is included. Eighteen major materials are examined. Only domestically produced vehicles are characterized.

Section B.3.3 does not include the energy needed to produce the unspecified and relatively minor materials found in all parts of the vehicle. These materials account for 11-13% of EHV total materials and 17% of CV total materials. In order to account for the energy embodied in these materials, an average of the energy requirements for the 18 major materials in CVs is utilized in this analysis, i.e., 17.8×10^9 Btu/10^6 lb.

Using this average, Table C.29 gives the total energy consumed in the production of all domestically produced EHVs in each scenario in 1990 and

Table C.20. Energy Resource Commitment for EHV Operation on Batteries, Natural Gas (10^{12} Btu)

Year	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
1990					
Resource required at power plant	0.44	0.73	0.94	2.45	2.44
Initial resource required	0.75	1.24	1.60	4.16	4.14
Recovered resource required	0.52	0.87	1.12	2.91	2.90
External subsidy	0.01	0.02	0.02	0.06	0.06
2000					
Resource required at power plant	5.40	10.34	15.89	46.23	44.89
Initial resource required	9.16	17.55	26.97	78.45	76.18
Recovered resource required	6.42	12.28	18.88	54.92	53.33
External subsidy	0.13	0.24	0.37	1.07	1.04

2000 and the energy requirements for domestic production of comparable CVs. As the table shows, EHV production requires substantially more energy: 35-53% more in 1990 and 30-62% more in 2000. This difference can be attributed generally to the greater weight of the EHVs.

Table C.29 includes the energy required to produce the energy used in the production process (e.g., the energy to extract oil though not the energy to transport it), the direct energy consumed by equipment and materials handling, and some indirect energy.

In order to estimate in situ energy requirements for vehicle production and oil consumption in EHV production, national industrial energy consumption fuel shares of the Btu requirements shown in Table C.29 were estimated (see Table C.30). These estimates are based on EIA Series C (mid-supply, mid-demand) projections.[C.14] Since year 2000 fuel shares are not projected, it is assumed here that the shares for 2000 would be similar to those of 1995. Reference C.14 provides industrial consumption projections; in this analysis, electricity is converted to its primary form, again using EIA projections.

Table C.31 presents the results of applying the Table C.30 fuel shares to the total Btu requirements for vehicle production shown in Table C.29. Obviously, EHV production requires greater amounts of all fuel types. Since all of the figures include external subsidies, no conversion of the

Table C.21. Energy Resource Commitment for EHV Operation on Batteries, Nuclear (10^{12} Btu)

Year	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
1990					
Resource required at power plant	3.42	5.83	7.50	19.47	19.24
Initial resource required	4.45	7.58	9.76	25.07	25.03
Recovered resource required	4.23	7.21	9.27	23.82	23.78
External subsidy	0.19	0.32	0.42	1.07	1.07
2000					
Resource required at power plant	75.51	145.70	224.71	687.99	667.56
Initial resource required	98.24	189.56	292.35	895.07	868.50
Recovered resource required	93.33	180.09	277.74	850.36	825.10
External subsidy	4.19	8.08	12.46	38.16	37.03

increase in petroleum consumption to equivalent barrels of oil is attempted here.

In order to derive the in situ resource requirements associated with EHV production, the relationships presented in Table C.16 between recovered resource requirements and in situ resource requirements for each fuel type are applied to Table C.31. The results are shown in Table C.32. Again, EHV production has higher in situ resource requirements.

A number of factors should be considered in evaluating the results of the analysis of the energy expended in vehicle production. First, the greater energy consumed per vehicle in low-volume production has not been accounted for in this analysis. Mass production lines, which are more energy efficient, would not be implemented until market demand is at least 100,000 units per year. In the LOW scenarios in 1990, less than 100,000 EHVs are produced. In the same year in the other scenarios, many of the EHVs are serially produced. By 2000, mass production should be in effect, but some small domestic manufacturers may still be serially producing some EHVs. In effect, the energy totals shown in Table C.29 for producing EHVs should be somewhat higher. The CV production energy totals are probably correct, since the CVs that EHVs would replace would probably be mass produced.

Table C.22. Total Resource Commitment from All Fuels for EHV Operation on Batteries, In Situ Resource Requirements (10^{12} Btu)

Year	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
1990					
Petroleum	6.74	11.44	14.68	40.35	40.29
Total coal	9.24	15.69	20.16	52.25	52.19
Natural gas	0.75	1.24	1.60	4.16	4.14
Nuclear	4.45	7.58	9.76	25.07	25.03
External subsidy	0.62	1.05	1.35	3.53	3.53
Other[a]	0.12	0.18	0.15	0.53	0.52
Total	21.92	37.18	47.70	125.89	125.70
2000					
Petroleum	80.70	172.75	276.36	1010.84	978.46
Total coal	123.31	241.42	374.35	1226.68	1189.11
Natural gas	9.16	17.55	26.97	78.45	76.18
Nuclear	98.24	189.56	292.35	895.07	868.50
External subsidy	9.64	19.12	29.79	97.48	94.49
Other[a]	1.10	2.96	5.04	26.03	25.10
Total	322.15	643.36	1004.86	3334.55	3231.84

[a] Hydro and pumped storage.

Second, while energy subsidies for fabricating and assembling the vehicles are included in the total production energies, energy spent in converting CV production facilities to EHV production facilities is not included. In addition, the energy spent in constructing new production lines for EHVs over that which might have been required for new production lines for the BASE scenario is not included. Both of these would increase the EHV totals.

C.2.3 Total Resource Requirements for Vehicle Operation and Production per Year

The combined results of the operation and production analyses are presented in Sec. 3.3. In reviewing the results, it should be recognized that the two approaches of the analyses are not entirely consistent. For example, external subsidies appear to be more fully represented in the vehicle operation analysis. However, in deriving the combined in situ resource table, the in situ resources of the external subsidies are included in the vehicle

Table C.23. Total Resource Commitment from All Fuels for EHV Operation on Batteries, Recovered Resource Requirements (10^{12} Btu)

	Scenario				
Year	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
1990					
Petroleum	2.27	3.84	4.93	13.56	13.54
Total coal	6.93	11.78	15.13	39.21	39.17
Natural gas	0.52	0.87	1.12	2.91	2.90
Nuclear	4.23	7.21	9.27	23.82	23.78
External subsidy	0.62	1.05	1.35	3.53	3.53
Other[a]	0.12	0.18	0.15	0.53	0.52
Total	14.69	24.93	31.95	83.56	83.44
2000					
Petroleum	27.12	58.04	92.86	339.65	328.77
Total coal	93.07	182.22	282.55	925.89	897.52
Natural gas	6.42	12.28	18.88	54.92	53.33
Nuclear	93.33	180.09	277.74	850.36	825.10
External subsidy	9.64	19.12	29.79	97.48	94.49
Other[a]	1.10	2.96	5.04	26.03	25.10
Total	230.68	454.71	706.86	2294.33	2224.31

[a] Hydro and pumped storage.

production numbers but are not included in the vehicle operation numbers. Further, in the vehicle production analysis, only energy consumed domestically to produce domestic vehicles is included. In the vehicle operation analysis, while some energy consumption in the extraction of petroleum in foreign countries might have been excluded, it is not. In effect, domestic energy sources for all operational fuel requirements of the BASE and EHV scenarios are assumed. However, for purposes of providing perspective on the total energy requirements associated with EHV introduction, it is still worthwhile to combine the analysis results.

C.2.4 Per Mile Analysis

The method used to compare EHVs and CVs on an energy-consumed-per-mile basis (including operating and production energies) is as follows:

1. For a specific scenario and year, the production energy determined in Sec. B.3.3 for both 100,000 EHVs and CVs,

Table C.24. Energy Resource Commitment for HV Heat Engine Operation, Gasoline (10^{12} Btu)

	Scenario			
	LOW II		HIGH II	
	1990	2000	1990	2000
Resource required at pump	2.01	44.89	2.62	194.68
Initial resource required	6.55	146.21	8.53	634.07
Recovered resource required	2.20	49.11	2.87	212.98
External subsidy	0.21	4.79	0.28	20.78

Table C.25. Energy Resource Commitment for CV Operation: Gasoline and Diesel Fuel (10^{12} Btu)[a]

	Scenario				
Year	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
1990					
Resource required at pump	11.44	18.87	24.72	63.31	63.78
Initial resource required	37.26	61.46	80.51	206.20	207.73
Recovered resource required	12.52	20.64	27.04	69.26	69.78
External subsidy	1.22	2.01	2.64	6.76	6.81
2000					
Resource required at pump	182.49	353.40	577.77	1837.76	1820.12
Initial resource required	594.37	1151.00	1881.80	5985.58	5928.13
Recovered resource required	199.64	386.62	632.08	2010.51	1991.21
External subsidy	19.48	37.72	61.67	196.16	194.28

[a] CV VMT equal to EHV VMT in each scenario.

Table C.26. Comparison of Total Resource Commitment for EHV and CV Operation, In Situ Resource Requirements (10^{12} Btu)[a]

Year	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
1990					
Electricity generation	21.92	37.18	47.70	125.89	125.70
Gasoline for HVs		6.76			8.81
Total CV	38.48	63.47	83.15	212.96	214.54
Total EHV	21.92	43.94	47.70	125.89	134.51
CVs minus EHVs	16.56	19.53	35.45	87.07	80.03
$\frac{EHV}{CV}$ x 100 (%)	57.0	69.2	57.4	59.1	62.7
2000					
Electricity generation	322.15	643.36	1004.86	3334.55	3231.84
Gasoline for HVs		151.0			654.85
Total CV	613.85	1188.72	1943.47	6181.74	6122.41
Total EHV	322.15	794.36	1004.86	3334.55	3886.69
CVs minus EHVs	291.70	394.36	938.61	2847.19	2235.72
$\frac{EHV}{CV}$ x 100 (%)	52.5	66.8	51.7	53.9	63.5

[a] Same VMT for EHVs and CVs in each year of each scenario. Data include external subsidies.

but increased by the energy required for unspecified "other" materials as described in Sec. C.2.2, is assumed to apply to 100,000 vehicles produced five years earlier. In addition, a similar distribution of vehicles produced is assumed. The production energy per year for the life of these vehicles is determined by dividing the total production energy by 10 yr.

2. The above process provides production energy on a recovered resource basis for 100,000 vehicles in each scenario. To determine in situ resource requirements for producing these 100,000 vehicles, the energy determined in step 1 is factored up by the same factors that were used to determine for all vehicles in each scenario the total in situ energies required for production shown in Table C.32.

Table C.27. Comparison of Total Resource Commitment for EHV and CV Operation, Recovered Resource Requirements (10^{12} Btu)[a]

Year	Scenario LOW I	LOW II	MEDIUM	HIGH I	HIGH II
1990					
Electricity generation	14.69	24.93	31.95	83.56	83.44
Gasoline for HVs		2.41			3.15
Total EHV	14.69	27.34	31.95	83.56	86.59
Total CV	13.74	22.65	29.68	76.02	76.59
CVs minus EHVs	0.95	4.69	2.27	7.54	10.00
$\frac{EHV}{CV}$ x 100 (%)	107	121	108	110	113
2000					
Electricity generation	230.68	454.71	706.86	2294.33	2224.31
Gasoline for HVs		53.9			233.76
Total EHV	230.68	508.61	706.86	2294.33	2458.07
Total CV	219.12	424.34	693.75	2206.67	2185.49
CVs minus EHVs	11.56	84.27	13.11	87.66	272.58
$\frac{EHV}{CV}$ x 100 (%)	105	120	102	104	112

[a] Same VMT for EHVs and CVs in each year of each scenario. Data include external subsidies.

3. For the same 100,000 vehicles (both EHVs and CVs), total VMT and energy consumption (in kilowatt hours and gallons) can be determined by applying the annual VMT per vehicle type and energy per mile per vehicle type to the total number of vehicles of each specific vehicle type in the distribution of vehicles. VMT and energy intensity for the specific vehicle types produced in a given year are assumed to be the same as fleet averages for these specific vehicle types five years from the time of vehicle production.

4. The total kilowatt hours used by EHVs and gallons by HVs and CVs for these 100,000 vehicles are then converted to Btu and taken as a proportion of the total Btu consumed in the scenarios (for equivalent VMT) at the power plant or at the pump (shown in Tables C.13-C15), and that proportion is applied to the total in situ resource

Table C.28. Direct Petroleum Savings from Introduction of EHVs, Vehicle Operation Only (10^{12} Btu)[a]

Year	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
1990					
Fuel oil for electricity generation	2.08	3.53	4.53	12.45	12.43
Gasoline for HVs		2.01			2.62
EHV petroleum total	2.08	5.54	4.53	12.45	15.05
CV petroleum total	11.44	18.87	24.72	63.31	63.78
Savings	9.36	13.33	20.19	50.86	48.73
Savings (10^6 bbl)[b]	1.61	2.30	3.48	8.77	8.40
2000					
Fuel oil for electricity generation	24.90	52.30	85.27	311.89	301.90
Gasoline for HVs		44.89			194.68
EHV petroleum total	24.90	98.19	85.27	311.89	496.58
CV petroleum total	182.49	353.40	577.77	1837.76	1820.12
Savings	157.79	255.21	492.50	1525.87	1323.54
Savings (10^6 bbl)[b]	27.17	44.00	84.91	263.07	228.19

[a] Gasoline and diesel fuel for CVs and HVs at pump; fuel oil for EVs and HVs at power plant. Same VMT for EHVs and CVs in each year of each scenario.

[b] Crude oil equivalent of 138,000 Btu/gal applied.

commitments generated in Table C.26 for all vehicles in a scenario to determine the total in situ resource commitments for operation of these 100,000 vehicles. Similarly, that same proportion is applied to the total recovered resource commitments generated in Table C.27 for all vehicles in a scenario to determine the total recovered resource commitments for operation of the 100,000 vehicles.

5. Steps 1-4 provide production energy for the same number of EHVs and CVs and operation energy for equivalent VMT by EHVs and CVs for a year. In order to account for the fact that CVs actually would travel more miles annually and thus in their lifetime, a ratio of total EHV VMT to total CV VMT is applied to the production energy of the CVs to determine a revised lower production energy requirement for CVs. In other words, fewer CVs than EHVs would be required to operate equivalent total annual VMT.

Table C.29. Energy Requirements for Production of Vehicles[a]

Year	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
1990					
Number of vehicles produced[b]	55,000	85,000	126,400	312,500	303,400
EHV energy requirements (10^{12} Btu)	6.76	11.05	21.31	57.54	52.51
CV energy requirements (10^{12} Btu)	5.01	8.01	15.00	37.72	35.28
$\frac{\text{EHV energy}}{\text{CV energy}} \times 100$ (%)	135	138	142	153	149
2000					
Number of vehicles produced[b]	751,500	1,384,000	2,353,900	7,265,000	7,498,300
EHV energy requirements (10^{12} Btu)	94.68	176.96	331.99	1,050.40	1,010.62
CV energy requirements (10^{12} Btu)	72.83	134.82	229.19	650.38	692.74
$\frac{\text{EHV energy}}{\text{CV energy}} \times 100$ (%)	130	131	145	162	146

[a] Includes energy required to produce the energy used in the production process, the direct energy consumed by equipment and material handling, and some indirect energy.

[b] Number applies to both EHVs and CVs.

6. The production and operating energies for 100,000 vehicles determined in steps 1, 2, 4, and 5 on an annual basis are then divided by the VMT determined in step 3 to get a total Btu/mile comparison between EHVs and CVs. That comparison is made on both an in situ and recovered resource basis.

The results of this analysis (see Sec. 3.3) are representative of a typical vehicle (truck, bus, and auto combined) produced in 1985 and operating in 1990 and produced in 1995 and operating in 2000. The variation shown, especially within the EHV requirements, is caused by different vehicle compositions in the scenarios with different battery types that require different production and operating energies. Although it is not apparent in the tables, the energy required for operation is far more significant for both EHVs and CVs than the energy required for production.

Table C.30. Industrial Energy Consumption Fuel Shares, 1990 and 2000[a]

Fuel	Primary Energy (%)	
	1990	2000
Oil	26.8	24.7
Natural gas	24.2	18.7
Coal	36.4	42.7
Nuclear	9.2	9.5
Other	3.4	4.4
Total	100.0	100.0

[a] Adaptations made to the source tables include assuming that 1995 fuel shares apply to 2000 and converting end-use to primary consumption.

Source: Ref. C.14.

Table C.31. Energy Requirements for Production of Vehicles by Fuel Type, Recovered Resource Requirements (10^{12} Btu)[a]

	Scenario									
	LOW I		LOW II		MEDIUM		HIGH I		HIGH II	
	EHV	CV	EHV	CV	EHV	CV	EHV	CV	EHV	CV
1990										
Oil	1.81	1.35	2.96	2.15	5.71	4.02	15.42	10.11	14.07	9.46
Natural gas	1.64	1.21	2.67	1.94	5.15	3.63	13.91	9.12	12.70	8.53
Coal	2.46	1.82	4.02	2.91	7.75	5.46	20.93	13.72	19.10	12.83
Nuclear	0.62	0.46	1.02	0.74	1.97	1.38	5.31	3.48	4.84	3.25
Other	0.23	0.17	0.38	0.27	0.73	0.51	1.97	1.29	1.80	1.21
Total	6.76	5.01	11.05	8.01	21.31	15.00	57.54	37.72	52.51	35.28
2000										
Oil	23.39	17.99	43.71	33.30	82.00	56.36	259.45	160.64	249.62	171.11
Natural gas	17.74	13.65	33.16	25.26	62.22	42.76	196.84	121.88	189.39	129.82
Coal	40.38	31.06	75.47	57.50	141.59	97.32	448.00	277.39	431.03	295.45
Nuclear	8.99	6.92	16.81	12.81	31.54	21.68	99.79	61.79	96.01	65.81
Other	4.18	3.21	7.81	5.95	14.64	10.07	46.32	28.68	44.57	30.55
Total	94.68	72.83	176.96	134.82	331.99	228.19	1050.40	650.62	1010.62	692.74

[a] Includes external subsidies. Same number of CVs produced as EHVs.

Table C.32. Energy Requirements for Production of Vehicles, Total In Situ Resource Requirements (10^{12} Btu)[a]

Year	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
1990					
EHV	12.04	19.69	37.97	102.51	93.55
CV	8.93	14.27	26.72	67.20	62.85
2000					
EHV	164.63	307.70	577.26	1826.44	1757.27
CV	126.64	234.43	396.78	1130.88	1204.54

[a] Includes external subsidies. Same number of CVs produced as EHVs.

APPENDIX C REFERENCES

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APPENDIX D

ECOSYSTEM AND PHYSICAL ENVIRONMENT ANALYSES

D.1 ECOSYSTEM ANALYSIS

D.1.1 Ecological Effects of Waterborne Pollutants

This section deals primarily with the ecosystem effects of waterborne pollutants generated during the mining and manufacturing phases of vehicle production, the mining and refining phases of fuels production, and the electricity generation phase of vehicle operation.

Direct discharges of metals occur during milling and smelting operations. Equally important, however, is the transport of metals from the land surface to water as a result of the leaching of overburden, lean (noncommercial) ore strippings, and waste rock (tailings).

Mining and milling frequently involve three other types of potential pollution: (1) erosion and sedimentation, (2) nitrate residues from blasting agents, and (3) chemical additives (usually organic) in the milling system that are used for various functions, such as flotation, precipitation, emulsification, and flocculation. Chemical additives are not discussed, because they vary enormously, depending on function, composition, and reclaim processes. Also discussed are the potential for damage to ecosystems from thermal pollution and power plant cooling water discharges.

D.1.1.1 Vehicle Production Impacts

Metals

All of the EHV scenarios require greater quantities of metals for vehicle production than would be required in the BASE scenario. Therefore, mining and manufacturing result in the discharge of greater quantities of metals than would occur without EHV production. Metals from mining and manufacturing generally enter the environment through mining, milling, and smelting. It is difficult to define specifically the ecological impacts of these processes, since impact assessment must consider a complex interaction of local conditions. Furthermore, metals used for the manufacture of vehicles could come from any number of sources, each with its own unique ore body mineralogy, milling circuit, and environmental and climatological conditions. In other words, local factors tend to dictate the magnitude of water quality impacts and, therefore, the specific aquatic ecosystem impacts.

Mobilization. The mining processes are associated with three major types of metallic ore bodies: sulfides, oxides, and native metals. Metals frequently associated with sulfides include: iron, molybdenum, lead, arsenic, antimony, mercury, copper, zinc, and nickel. Metals associated with oxides include: iron, manganese, chromium, tungsten, copper, and titanium. Deposits of gold, silver, and copper can be found as native metals. Aluminum silicates are a special group. These metals and metal cations enter the ecosystems and have a strong bearing on potential water pollution and treatment.

Mining and milling of metallic ore bodies results in the following types of materials: (1) waste rock and/or other overburden, (2) lean ore, (3) commercial ore, and (4) tailings (waste rock from which most of the metals have been removed). Lean ore may be a more important source of pollution than tailings, because tailings no longer contain appreciable quantities of metals.

Since all products, by-products, and waste products of mining and milling are stockpiled, rainfall percolates through the piles and leaches available metals. For example, in northern Minnesota, water percolating through a lean ore dump containing 0.2% copper and 0.05% nickel contained levels of copper and nickel that were more than a thousand times higher than background levels.[D.1] A recent study of copper-nickel mining impacts in northern Minnesota indicates that best available technology is necessary in order to comply with established standards.[D.2] The runoff from such strippings must be treated until it no longer contributes elevated levels of pollutants to aquatic ecosystems.

Metals also are mobilized from the walls and floor of open pit mines that are no longer active. This mobilization commonly occurs during the gradual filling and overflow of the mine pit in areas of the country where precipitation exceeds evaporation. Such interaction of pit lakes and their associated metals with other watershed ecosystems is an unsolved problem both in terms of technical feasibility and economics.

The chemical interaction of the metals and the pit water is not well understood. Does the pit-lake water stratify, thereby depleting the oxygen supply and slowing down the solution of the metals; or does it mix and provide a constant supply of oxygen? What role do organics play in the solution equilibria? Will grouting of the pit surface retard the rate of metal solution? There does not seem to be any proven technology at present that guarantees permanent compliance with water quality standards.

<u>Transport</u>. Once metals are in the environment, there are at least two modes of transport. One is through increased solubility of metals with decreasing pH (increased acidity), and the other is through attachment to solid particles in the water. This second mode is related to the fact that many metals are hydrophobic. In other words, they fix themselves to solid particles in the water rather than remain in the dissolved ionic state. Since metals are more mobile when they are fixed to solid particles, an increase in the amount of suspended or dissolved solids (see "Erosion and Sedimentation") causes a corresponding increase in the concentration of metals. Although removal of these solids through filtration, finite storage, or other methods also removes some of the metals, many solids are too small (less than 0.45μ in diameter) to be filtered. They and the metals affixed to them remain suspended indefinitely.

Both of these metal transport modes often occur simultaneously and produce significant metals concentrations and important ecosystem changes. For example, in northern Minnesota, dissolved organics that can pass a

0.45μ filter can absorb ionic metals, such as nickel, from the water.D.3 This allows additional nickel sulfides from the host rock to ionize. The combined nickel concentrations (ionic and absorbed) increase beyond those predicted by a pH/solubility curve. This results in nickel concentrations a thousand times greater than the background level produced at neutral or basic pHs.

To illustrate further why site-specific ecological analysis is necessary, it has been suggested that the process described in the above paragraph could be used to filter nickel out of the environment. For example, passing nickel-laden waters through a peat bog would absorb most of the nickel into the peat, which has a high nickel-holding capacity. Concentrations by weight of 1-2% nickel in peat have been observed. These concentrations would classify the peat bog itself as a high-grade ore body. The full impact of the process has not yet been evaluated, but the process does illustrate that natural assimilation of metals does occur and depends on localized soil characteristics. Therefore, the magnitude of the impacts may vary.

Fate. Metals in aquatic ecosystems undergo differential uptake by biota. Bioaccumulation (the ability of an organism to concentrate an element above abiotic levels), bioconcentration within an organism, and biomagnification (the tendency of metals to be concentrated with trophic level transfer) are three major concerns.

Bioaccumulation and biomagnification of metals depend on a number of factors. To date, no single encompassing theory adequately describes the observed cycling of metals through biota. This is probably due to the different behavior of metals in different aquatic systems. Uptake and transfer through trophic interactions are modified by the physiochemical form (ionic or particulate) of the trace element and by the nature of organisms, including their habitat, substrate-sediment associations, and food habitats. As stated previously, all of these considerations are site specific.

Erosion and Sedimentation

Erosion and sedimentation are this nation's most serious water quality problem. The impacts are varied and affect aqueous ecosystems, water treatment systems, human use, flood control costs, and property damage. Because more materials are used in EHVs, more mining is expected, and erosion and sedimentation will increase over the BASE scenario. The magnitude and significance of the increases, however, can be determined only on a site-specific basis.

All streams transport suspended solids derived from natural erosional processes. Indeed, natural waters may be heavily laden with silts and clays because of land use practices or because the watershed contains highly erodible soils. Each stream system maintains a balance between the amount of suspended material and many hydraulic and erosional characteristics unique to each system. Pollution occurs when additional amounts of sediment are introduced, which disturbs the previous balance. When this occurs, the stream adjusts to a new balance that changes the previous ecosystem and hydraulics. Such adjustments and changes likely will occur to a greater degree with market penetration of EHVs.

Increased sediments due to the incremental mining and manufacturing activity associated with the production of EHVs can cause the following effects:

1. Increased water treatment costs.
2. Degraded water intended for consumptive use.
3. Damaged water distribution systems.
4. Decreased water storage capability in reservoirs.
5. Filling of lakes and ponds, which reduces their depth and makes them susceptible to winterkill and excessive vegetation.
6. Flooding and channel changes downstream.
7. Increased levels of plant nutrients, insecticides, herbicides, heavy metals, and bacteria and viruses because of the sediments' capability to act as a medium for transport.
8. Raised water temperatures accompanied by reduced amounts of oxygen available to fish.
9. Smothered bottom-dwelling organisms, which are the foundation of the food chain. This can reduce or change fish populations.
10. Irritated fish gills causing fish disease.
11. Reduced sunlight penetration.
12. Disturbed nutrient cycles.
13. Shifts in aquatic vegetation from bottom-anchored plants to algae.

The duration of the sediment discharge is equally important. During peak natural flows (i.e., short-term, periodic, storm runoff), large amounts of suspended solids occur but are readily accommodated by the existing ecosystem. Thus, a short-term (several-days) increase in sediment discharge may not cause significant damages. However, a long-term increase in sediment load can not be accommodated without ecosystem adjustments.

There are several possible sources of sediment in a mining area:

1. Uncontrolled runoff.
2. Poorly designed or maintained roads.
3. Pit dewatering.
4. Dredging.
5. Fugitive dust from crushers and haul roads.

Technologies have been developed to reduce and control these sources, thereby reducing the ecological impact of suspended solids. Nevertheless, market penetration of EHVs can be expected to have some impact, although its magnitude and significance can be predicted only on a site-specific basis.

Uncontrolled runoff is by far the greatest potential contributor of sediments. Prior to starting production in open pit mines, overburden material must be removed and stockpiled. This material (usually topsoil, glacial till, or weathered rock) is easily eroded. In addition, the newly created steep, uncompacted, unvegetated slopes of the pit wall and the stripping stockpiles are not in equilibrium with the environment and disrupt the the watershed.

Figure D.1 shows existing technology for control of this type of erosion. In general, it is more desirable to prevent erosion from occurring, rather than catch the soil after it has been displaced. Therefore, one should employ the techniques in Fig. D.1 in the order listed, until the runoff water meets applicable water quality standards.

Roads within the mine area are another main source of erosion. Most of these roads exist for the duration of the mining and have low permeability. Therefore, most direct precipitation does not infiltrate and runs along the surface, eroding vulnerable soils. Roads with long and steep grades, unstable cut-and-fill areas, and portions adjacent to streams and stream crossings are major problems. Proper siting, slope stabilization, well-designed foundations, proper drainage, armoring, and maintenance should assure a stable, nonpolluting road.

Pit dewatering is another possible source of sediment pollution. If a metal deposit extends well below the water table, the water table must be lowered in order to gain access to the deposit. Pollution can be avoided by: (1) surrounding the pit area with wells that pump clean (filtered) groundwater or (2) pumping out water from a sump (low point) in the pit, where water from the remainder of the working pit gathers. If sufficient settling time is provided, discharge water can easily meet standards.

Dredging is another possible source of sediment. Digging up the bottom of a stream, river, or lake clearly has the potential for disrupting delicate ecosystems. The amount of fine sediments that might become suspended in a stream or river from a dredging operation is highly dependent on the amount of fines in the deposit, the body of water, and hydraulic characteristics, such as stream gradient and discharge velocity.

The other source of stream sediment is fugitive dust from crushers and haul roads. Such dust may be deposited by wind into nearby streams or pushed into drainageways and carried to nearby waters. Dust control is the most viable solution.

Nitrate Residues

Nitrate, a residue from ammonium nitrate and fuel oil explosives, is another type of pollutant. Nitrate levels in mine waters have been observed as high as 23.0 mg/L (nitrate as nitrogen) compared to a background level of 0.03 mg/L. Increases in mining activity anticipated with the manufacture of EHVs will mean increased nitrate levels.

Nitrogen cycles in aquatic systems are complex (see Fig. D.2). Increases in nitrate concentrations would cause a "bulge" in the cycle, thus disrupting the equilibrium maintained in the ecosystem. Such an impact would

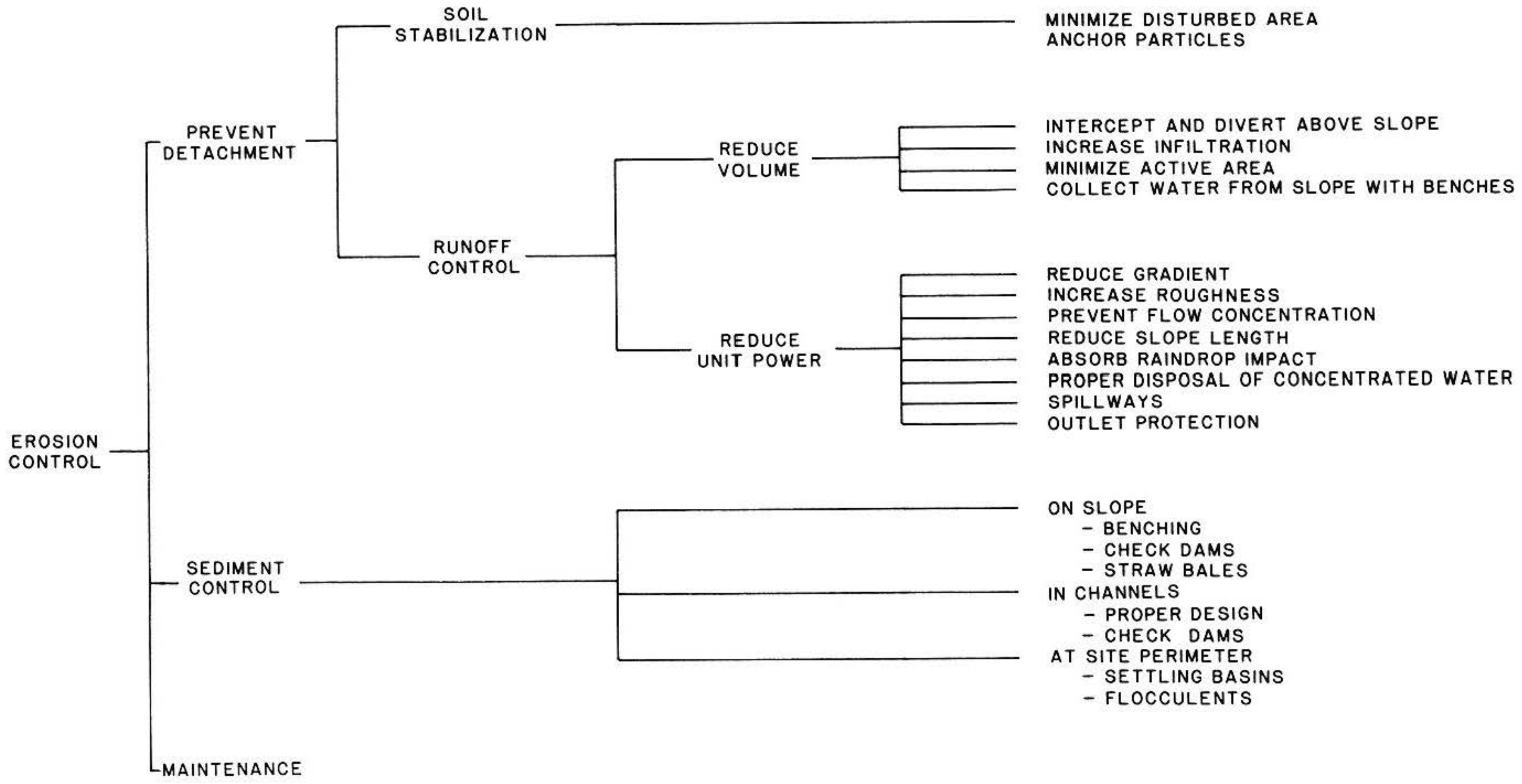

Fig. D.1. Existing Technology for Erosion Control (Source: Ref. D.4)

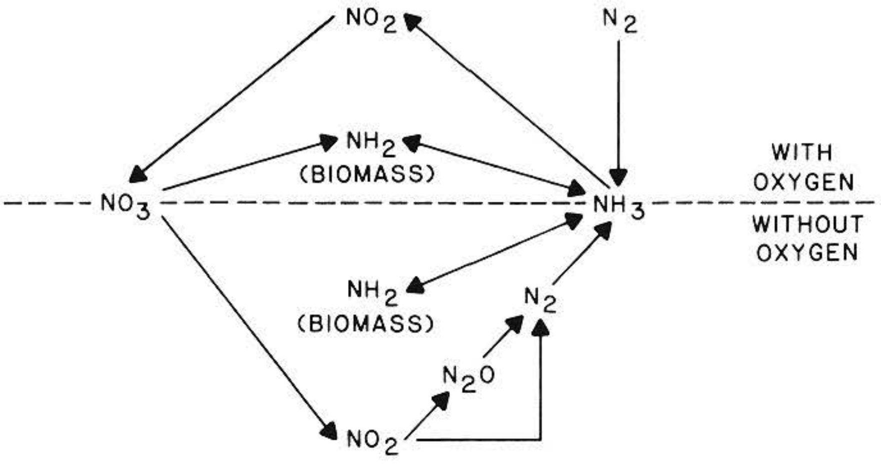

Fig. D.2. Nitrogen Cycle

be greatest in the oxygen-free hypolimnion of lakes, where nitrate is reduced to ammonia. Increased concentrations of nitrate also have secondary impacts on the concentrations of cations (including metals) in the water and lake bed sediments.

As with the other impacts discussed in Sec. D.1, site-specific evaluation is necessary. The sensitivity of an aquatic ecosystem to increased nitrates depends on seasonal variations in the climate, the concentrations of other nutrients, the degree of stratification, the status of eutrophication, sediment composition, watershed land use, and many other factors. Therefore, the impacts in specific local areas as a result of EHV market penetration can not be identified.

D.1.1.2 Fuels Production Impacts

The preceding discussion of ecosystem impacts from mining and refining of materials for vehicle production also applies to the mining and refining of fuels for EHV electricity generation and CV operation. The ecosystem impacts of fuels production for EHVs vary in type from those for CVs, since EHVs and CVs generate dissimilar quantities of certain pollutants. For example, in the fuels production and transport phase, EHV scenarios generate more sulfates, while CVs generate more BOD and COD. The specific locations of the ecosystem impacts also vary, depending on whether the fuels are for EHVs or CVs.

Of special ecosystem concern with respect to EHV fuels extraction is the impact on water quality and drainage in mining areas with semiarid climates, where limited availability of water has already posed problems. In particular, the extensive present and projected coal stripping operations in Montana and Wyoming and the open pit uranium mining in the Southwest will generate considerable waste rock. Although high mine performance standards should characterize these operations, it is possible that mining will contribute to erosion, stream aggradation, and mineral contamination of fresh water resources, particularly under conditions of high demand for fuels. Negative impacts on water pathways will likely result from vastly expanded western strip-mine operations, irrespective of EHV penetration. However, incremental impacts will occur as a result of EHV commercialization. Again, site-specific studies will be required to resolve these issues.

D.1.1.3 Potential Regional Impacts of Vehicle and Fuels Production

As with all ecosystem impacts, specific impacts in a region resulting from the commercialization of EHVs can be determined only on a site-specific basis. However, based on existing metal sources, regional topography, and average annual runoff rates, a qualitative discussion of water impacts on a metal-by-metal basis is possible. The following discussion is not comprehensive but does highlight potential impacts.

Metals

Lead. Although 15 states produce small amounts of lead, the principal domestic source of lead is Iron County, Missouri, which has 5-10 in. of runoff per year. Iron County is located on a watershed divide in the Ozarks. Three problems may be exacerbated by EHV manufacture:

1. Water supply.
2. Accelerating erosion from rapid runoff.
3. Acid mine drainage from underground workings.

Lead also is found in the Coeur d'Alene district in Idaho, in the San Juan Mountains and central region of Colorado, and near Salt Lake City, Utah. Each of these areas is mountainous with little upstream watershed. Runoff is fast, allowing little reaction time. However, self-contained mill water circuits have eliminated direct discharge into receiving streams.

Nickel. Located in the Klamath Mountains of the southwestern part of the state, Reddle, Oregon, is the only present domestic miner of nickel. The ecological impact from mining derives from the area's extreme climate and topography. Since the runoff rate is high, rock weathering is rapid. Specifically, exposure of lean ores at the surface greatly accelerates metal loadings in receiving streams.

The Duluth gabbro formation in northern Minnesota contains large amounts of nickel. In 1979 the results of a regional environmental study costing $5 million were released.[D.2] In considering development alternatives, the study concludes that the formation's proximity to the Boundary Waters Canoe Area, a federal wilderness area, would require the use of best available technology for water treatment. In general, the study raises more questions than it answers about the interaction of sulfides with the environment. For example, the problem of post-mining water quality maintenance is not solved, nor are the metal pathways clearly understood. The role of organics in metal transport was first discovered during this project.

Cobalt. Cobalt also is found in the Duluth gabbro in northern Minnesota. Other cobalt resources are in Idaho, Missouri, Maine, Alaska, and Pennsylvania. No cobalt is currently produced in the United States, and any new development will be subject to new source standards and will presumably meet environmental standards.

Ocean mining of cobalt has not been studied thoroughly. The impacts and pollution paths are probably mostly related to disturbing the bed. Such disruption could resuspend materials already settled out by delicate chemical processes.

Lithium. Lithium is mined in the Blue Ridge Mountains of North Carolina. High rainfall and steep topography make erosion very hard to control. Settling ponds generally are required to trap dislodged sediment. Leaching is rapid in this climate. The role of lithium in aqueous environments has not been studied to date.

Copper. Most domestic copper is mined in the arid, mountainous regions of the Southwest. Water supply is likely to be the limiting factor in the mining of copper. For example, lack of precipitation presents major problems for reclamation in this area. Vegetation may not reestablish itself to control erosion. Despite its infrequency, rainfall is the major eroding force in this area. Because evaporation exceeds precipitation, discharge of milling water is unnecessary, and seepage is minimized to retain precious water.

Copper resources in Minnesota, Wisconsin, and Michigan are subject to a different climate. Rainfall is more than adequate, and seepage and/or discharge are necessary. These areas have extensive peat bogs, which are a source of organic materials for metal transport or filtration. Here again, specific incremental effects from EHV production would need to be addressed on a site-by-site basis.

Minnesota's regional environmental study mentioned in the section on nickel also addresses copper.[D.2] The study concludes that best available technology is necessary in order to comply with established water quality standards. Wisconsin's Department of Natural Resources has determined that the mining of a massive copper deposit located on the flood plain of the Flambeau River could be accomplished within acceptable limits of degradation.[D.5]

Boron. Boron is mined in Death Valley and in the Sierra Nevada Mountains of California. Boron has a relationship to chloride concentration and is frequently found in the beds and waters of saline lakes as well as in coastal waters. The presence of such soluble boron minerals in a solid state indicates very little contact with water. The deposits frequently occur in basins with no flowage outlet. Under normal conditions, seepage waters should not change character due to mining.

Zinc. Seventy percent of our domestic zinc supply comes from Tennessee, Missouri, New York, Colorado, and New Jersey. A major new discovery has been made in Wisconsin. Zinc has been shown to be markedly toxic to aquatic life in concentrations of 0.65 ppm.

Aluminium. Bauxite is mined in the foothills of the Ouachita Mountains in Arkansas. Aluminium concentrations in water are minimal at a pH of 7 and increase above or below this pH. There appears to be a process for precipitating aluminium in aqueous environments. The chemical impact of aluminum on biota is not well understood. Aluminium ores, such as bauxite and laterite, and the soils associated with them are earthy minerals and depend on their cohesion for erosion control. Once the ores are disturbed, they erode easily. Sediment basins are frequently necessary.

Iron. Sixty percent of domestic iron production comes from Minnesota. Other states mining iron include Michigan, Wisconsin, New York, and California. Iron plays a very important role in the aquatic systems of rivers and lakes. It serves as a vehicle for other metals and organics, and can regulate the release and fixation of phosphate and sulfur. Iron is found in relatively high concentrations in most waters.

In Minnesota, seepage from tailings basins contains high levels of dissolved iron because of the anaerobic conditions of the groundwater. When the seep emerges and the water is exposed to oxygen, iron precipitates out. This is usually a localized phenomenon, but several streams have been degraded in local reaches.

Most iron is mined by open pit mining methods, which produce large stripping piles. In the glaciated area of the Great Lakes iron district, strippings are mainly erodible soil. Therefore, rain and snowmelt can cause severe erosion in a short time. Design technology exists to control this erosion, and new reclamation regulations appear to address the problem.

Fuels for Electric Power Generation

Uranium. Most domestic uranium for light water reactors is produced in the arid Southwest. Much of the extraction takes place below local water tables, resulting in large quantities of outflow that have to be channeled to reservoirs or recycled in the mining/milling operation. For uranium extraction, availability of water is not a limiting factor. However, in the event of a large increase in fuel demand, water supply for ancillary work force populations could become a major problem if water quality were to be further diminished by sedimentation and nitrification from tailings solutions and spoils runoff.

Coal. Northern Appalachia continues to dominate the domestic production of coal. However, the sulfur content of Appalachian coal has become a central issue as buyers search for steam coal capable of meeting environmental standards. It is anticipated that production and transport of low-sulfur western coal to eastern markets will be on the increase through most of the remainder of the century. Western coal production may overtake that of Appalachia, although production of eastern coal is likely to double. This will mean that the problem of total dissolved solids generation could become a significant localized ecosystem problem in mining regions by the year 2000. Coal washing (beneficiation) at the minehead, with its attendant large-scale displacement of waste solids and mine seepage, characteristically produces large quantities of waterborne iron, alumina, and sulfates in the East and suspended and dissolved solids in the West. The problem of waterborne iron, alumina, and sulfates is likely to diminish with enforcement of promulgated mine performance standards. However, these standard do not directly attack the problem of suspended and dissolved solids generation.

Oil. Total dissolved solids also loom as a problem in oil refining operations. However, they are likely to continue to be sufficiently dispersed and controlled to preclude major localized problems in an ecosystem's water pathways.

D.1.1.4 Thermal Pollution and Cooling Water Discharges

Water also provides a primary medium for thermal pollution and power plant cooling water discharges, both of which may cause damage to ecosystems.

The basic operation of a steam electric power plant is quite simple. Water enters a boiler where heat from fossil or nuclear fuel converts it to steam at high temperature and pressure. The steam operates a turbine connected to an electric generator. After passing through the turbine, the steam enters a condenser, where it is cooled by water flowing around the condenser tubes, converted back to water, and returned to the boiler. The warmed cooling water flows out of the condenser and is usually returned to its source, i.e., an artificial reservoir or a natural body of water. In some cases, it is pumped into a cooling tower, where waste heat is dissipated to the atmosphere via evaporation, before being returned to its source.

The amount of water required for once-through cooling depends primarily on the rate of waste heat discharge and the temperature rise permitted in the cooling water as it passes through the condenser. For example, a 200 megawatts electric (MWe) fossil fuel unit having a fuel-to-electricity conversion efficiency of 42% and a cooling water temperature rise of 18°F would require a daily flow of 15.0×10^7 gal for full-power operation. A nuclear unit of equivalent generating capacity, but having a conversion efficiency of only 33%, would discharge 47% more waste heat than the fossil fuel unit and require 47% more cooling water per day. Operating at full capacity and equipped with cooling towers, heat dissipation for the fossil fuel plant would require evaporation of 2.71×10^6 gal of water per day. Comparable water consumption for the nuclear plant would be 3.98×10^6 gal per day.

Thus, the amount and rate of waste heat discharge are proportional to the amount, rate, and efficiency of electricity generation. For the coal-fired unit described above, the waste heat discharge would amount to 4712 Btu/kWh compared to 6928 Btu/kWh for the nuclear unit. For power plants using once-through cooling, water discharged from the condenser may be as much as 27°F higher than that of the water entering the condenser. Thus, the temperature of heated cooling water discharge to an artificial or natural body of water may exceed the maximum temperature tolerance of benthic algae, benthic invertebrates, and organisms in the water column.

Many important impacts on the aquatic environment are related to the circulation of power plant cooling water; most of these impacts are more pronounced for plants using once-through cooling than for plants equipped with closed-cycle cooling systems. All cooling water intake structures are equipped with fixed or moving screens designed to prevent large, solid objects from entering the pumps. Impingement is the process whereby larger fish and shellfish are killed or injured as a result of being trapped on these screens. Organisms small enough to pass through the screens are drawn into the cooling system and exposed to sudden temperature and pressure changes as well as purely mechanical damage. This process, called entrainment, is detrimental to plankton, young fish, and small, free-swimming shellfish. Death results in most instances.

In addition to heat, various toxic or potentially harmful substances may be added to cooling water discharges. Copper, for example, is normally eroded from condenser tubes, and chlorine (or other biocides) is routinely added to cooling water to reduce bacterial growth in the condenser tubes and/or to control other types of fouling organisms in other parts of the cooling system. (Biocides also are required to control fouling in the operation of cooling towers.) Ammonia from the hydrazine used to scavenge dissolved oxygen in boiler water also may be discharged in cooling water. The substances discharged with cooling water, including the so-called "blowdown" from cooling towers and boilers, enter aquatic ecosystems where, in sufficiently high concentrations, they may be harmful to sensitive organisms. In nuclear plants, large quantities of tritium and small amounts of other radionuclides are routinely released to the cooling water discharge stream.

In addition to the above, water vapor from cooling towers may cause a local increase in the frequency and/or severity of fog and winter icing conditions. Drift (water droplets from cooling towers) may contain salts or biocides that could damage the vegetation on which they are deposited.

The impacts from the EHV scenarios with respect to thermal pollution and cooling water discharges will be localized and depend on the intake and discharge characteristics of the plant, the water itself, and the associated aquatic ecosystems of the receiving water body. National or regional impacts, therefore, can not be accurately or meaningfully assessed. However, water effluent standards promulgated by the U.S. Environmental Protection Agency and regulations of state agencies responsible for issuing power plant construction and operation permits should mitigate many of the potentially negative impacts.

Even though thermal pollution from power plants should increase under the EHV scenarios, CVs also emit waste heat through the exhaust. This waste heat contributes to the formation in urban areas of heat islands that affect local weather conditions. With EHV penetration, the contribution of CV operation to such heat island formation will be decreased, though perhaps only slightly.

D.1.2 Ecological Effects of Airborne Pollutants

In Sec. D.2, regional and national analyses are provided that compare the major air pollutant emissions resulting from the production and operation of EHVs and CVs. For each pollutant, the significance for terrestrial or aquatic ecosystems varies widely and depends on both the regional load of emissions and the sensitivities of individual plant and animal ecosystem components. Impacts can be beneficial, detrimental or, in circumstances where pollutant concentrations are well below toxic thresholds, of no demonstrable effect.

Adverse effects can result when pollutants stress ecosystem elements. Such impacts can occur directly or more indirectly through alteration of the physical habitat or food chain. Acute impacts, direct or indirect, are evidenced by relatively rapid, identifiable changes in morbidity and mortality patterns. The effects of chronic injury, on the other hand, can be more subtle. For example, lessened productivity can occur, either through retardation of growth or outright inhibition of reproduction. The weakening of an organism by any stress can result in increased susceptibility to infection or predation. The following sections summarize the major known ecological effects of airborne pollutants and their respective modes of impact.

D.1.2.1 Carbon Monoxide

Carbon monoxide is a by-product of the incomplete combustion of fossil fuels and is not known to have adverse effects on vegetation, visibility, or materials. For animals, however, CO is toxic. It binds with hemoglobin, the substance in the blood that normally carries oxygen to body tissues, much more readily than oxygen, resulting in oxygen deprivation. Heart and brain tissues are the most sensitive to oxygen depletion. At high concentrations, for example, CO can be fatal by paralyzing brain activity. At lower concentrations, CO temporarily impairs time-interval discrimination and other psychomotor functions.

Carbon monoxide is a pollutant of highly localized impact. For the most part, concentrations at toxic levels are found only in the immediate vicinity of large stationary combustion sources, near heavily traveled or congested roadways, or where a combustion source is improperly vented. The potential for significant effects on regional or national ecosystems from CO as a result of EHV commercialization is virtually nil. Nevertheless, the EHV scenarios will reduce local CO emissions, particularly in congested urban areas. This should contribute to a reduction in regional and national CO loadings.

D.1.2.2 Suspended Particulates

Particulate emissions are removed from the atmosphere by one of three processes: (1) sedimentation under the influence of gravity; (2) impaction on obstacles to air flow; and (3) deposition in rain, snow, and other forms of precipitation. Sedimentation is the major mode for larger, heavier particles. Removal of very fine particles occurs primarily through impaction. The tiny hairs on the surfaces of plants are among the most effective sinks for fine particulates.

In extreme cases, sedimentation can be so great as to plug the stomata of plants, hence inhibiting or preventing photosynthesis. Deposition of trace elements may have adverse effects for aquatic and terrestrial biota. Among the elements toxic to plants are boron, cadmium, cobalt, copper, chromium, fluorine, and nickel; for animals, the toxic elements are beryllium, cadmium, fluorine, mercury, nickel, zinc, and selenium. Polycylic aromatic HC, a fraction of the fine particulates, are metabolically active, and some compounds are known to be carcinogenic.

In the atmosphere, particulates can contribute to a reduction in photosynthesis if quantities are sufficient to reduce available light. Fine particulate emissions may provide added nuclei for the formation of rain droplets, thus altering precipitation patterns.

Particulate emissions associated with EHV manufacture and fuels production for electricity generation are higher than for CV manufacture and fuels production. However, particulate emissions from EHV operation are substantially lower than those from CV operation. When particulate emissions from all phases of vehicle manufacture, fuels production, and vehicle operation are combined, EHVs generate slightly fewer particulates than CVs.

D.1.2.3 Photochemical Oxidants

Photochemical oxidants have been estimated to be "the most damaging air pollutants affecting agriculture and forestry in the USA."[D.6] Formation of these pollutants results from a complex series of photochemical reactions that depend on the amount of precursor pollutants (HC and NO_x), insolation, and time of day. Under conducive meteorological conditions, especially during the passage of large high-pressure systems, oxidant formation and transport can occur over extremely long distances. Thus, oxidant pollution is both a regional and a national problem.

The susceptibility of conifer species to chronic oxidant exposure has been well demonstrated. Mortality as high as 8% has been reported for some California forests. Oxidant injury to ponderosa pines has been shown to predispose the trees to infestation by the pine bark beetle.[D.6]

Annual damage to agricultural crops also is great. Particularly susceptible crops include soybeans and other dry beans, tobacco, grapes, and potatoes.

Elevated oxidant concentrations cause eye and lung irritation for humans. Impacts to other ecosystems are not well understood, although it has been speculated that severe injury to vegetation may alter the availability of food and ground cover for wildlife. Because of their strong oxidizing potential, it is assumed that oxidants act at the surface of soil and water bodies, thus posing no direct threat to soil or aquatic ecosystems.

Present control programs for oxidants focus on reducing the HC precursor pollutants (as opposed to NO_x). Since the EHV scenarios result in lower HC emissions, they may contribute to oxidant control.

D.1.2.4 Nitrogen Oxides

Worldwide, more than 90% of NO_x is the product of natural processes.[D.7] Nevertheless, local levels of NO_x can be high in comparison to ambient background concentrations.

Artificially high NO_x levels are required to demonstrate morbidity or mortality in animals. Although vegetation is more sensitive, concentrations of NO_x sufficiently high to affect sensitive species are confined to localized areas that use or manufacture nitric acid. Even in major cities, NO_x concentrations usually are well below threshold levels where effects on plant metabolism first occur.

Nitrogen oxides are significant, however, as precursors to the more toxic oxidant pollutants and figure importantly in the problem of acid precipitation, which is discussed in Sec. D.1.2.5. With respect to total NO_x emissions, the EHV scenarios generate significantly less of this pollutant.

D.1.2.5 Sulfur Oxides

Although sulfur is a necessary nutrient for all organisms, it is toxic in inappropriate concentrations. Although atmospheric SO_x are toxic for animals, the dosage required to produce an adverse effect is higher than is generally required for acute injury to vegetation. Thus, adverse impacts for animals are most likely to occur indirectly through alteration of the vegetative habitat.

Where soils are deficient in sulfur, sulfur oxide deposition can improve plant growth. These situations are rare. Where sulfur accumulates to excess, acceleration of nutrient leaching from the soil occurs and an accompanying loss of vegetation can result.

Oxides of sulfur also are directly injurious to plants. They act by damaging the foliage, thereby reducing photosynthesis. Injury is greatest during warm, sunny periods with high humidity, and certain species are more susceptible at certain stages of development. In extreme cases (e.g., in the vicinity of uncontrolled ore smelting), outright denudation of the landscape occurs.

This pollutant contributes substantially to annual crop losses (e.g., approximately \$6.2 million in 1971).[D.6] Conifers and a variety of fruits are highly susceptible, as are soybeans, cotton, and other crops.

Atmospheric sulfur is removed by two processes: (1) it can be deposited in a dry state on exposed surfaces or (2) it can be dissolved in precipitation. Dissolved sulfur forms strong acids, leading to the term "acid precipitation."

Of all the ecological effects of air pollutants, acid precipitation is among the most extensive geographically and is potentially the most ecologically damaging. Approximately 60% of current acid precipitation is attributed to sulfur pollutants.[D.6] Oxides of nitrogen also contribute substantially to the problem, as do hydrochloric and other dissolved organic acids.

Over 95% of SO_x emissions occurs through industrial processes, with nearly 75% from generation of electric power.[D.8] The pollutants are emitted to the atmosphere, generally from high stacks, and can be transported over long distances. Although internal combustion vehicles emit small amounts of sulfur oxides, these ground-level emissions do not contribute effectively to the acid precipitation problem.

Acid precipitation affects the terrestrial environment by leaching essential plant nutrients from the soil. Impacts on aquatic environments also are severe. Eutrophication of lakes can be accelerated by the added nutrient deposition of oxides of sulfur and nitrogen. In addition, above-normal amounts of acids in water cause extraction of toxic metals, such as cadmium and lead, from bottom sediments. These metals can be toxic to aquatic species and can be concentrated through the food chain, possibly posing a risk for humans.

Typically, water bodies affected by acid rain show a decline in species diversity, a growing preponderance of fungi in relation to bacteria in bottom sediments and, in more severe instances, either gradual or sudden loss of fish populations. Gradual declines are generally due to the intolerance of fish roe and young fry to low pH. Massive kills of both the young and adults of susceptible fish species have been reported following the spring melt of acid-bearing snows. It has been estimated that 50,000 lakes in the Adirondacks and Canada have become acidified to the point where fish populations have declined or been destroyed.

Regions especially susceptible to acidification are those underlain by granitic bedrock, which has a generally poor buffering capacity in fresh water bodies. These sensitive regions include the northeastern United States, the coastal area from New York to Texas, the Ozarks, parts of the eastern Rocky Mountains, and much of the northwestern coast.

In all the EHV scenarios and in all phases of vehicle and fuels production and vehicle operation, significantly more SO_x is generated than in the BASE scenario.

D.1.3 Ecological Effects of Solid Waste

During the production and operation of EHVs, many types of solid wastes are generated. The ecological impacts of these wastes are difficult to evaluate on a national or regional scale, because they are site specific (i.e., they depend on local conditions, such as soils, geology, climate, hydrology, and topography). Many of the ecosystem impacts associated with mining and manufacturing of EHVs and the production of fuels as discussed in Sec. D.1.1 are similar for solid wastes. Besides these impacts and the immediate impact of the land area consumed by the landfilling of solid wastes, other areas of concern are evident:

1. Formation of leachates, which may contaminate surface and subsurface water.
2. Erosion and sedimentation.
3. Production of decomposition gases.
4. Production of fuel residues.
5. Formation of sludges.

Leachates are produced by decomposition of solid wastes in the presence of water. Their composition will vary considerably but, in almost all cases, they are toxic and can contaminate groundwater supplies. Leachates can be controlled by proper design and engineering of the landfill. Installing an impervious lining before the solid waste is placed will contain the leachates. Placing an impermeable cover over the solid wastes will stop infiltration of water and prevent leachates from being produced. Also, through proper grading and drainage, surface runoff can be intercepted and diverted away from landfill areas.

Erosion and sedimentation impacts are varied, with their magnitude and significance depending on the amount of land disturbed by landfilling operations. Erosion and sedimentation can be controlled by several techniques: (1) immediately stabilizing and protecting disturbed areas, (2) maintaining low runoff velocities, (3) minimizing the extent of disturbed areas, (4) protecting disturbed areas from runoff, and (5) retaining sediment within the site area.

As the organic constituents in landfills decompose, various gases are produced. Methane, carbon dioxide, and gases with obnoxious odors present the greatest problems. Methane is the most hazardous, because it forms an explosive mixture with air. Carbon dioxide increases the hardness and acidity of water. Acidity, in turn, increases the leaching of soluble constituents in the solid wastes and surrounding earth materials. The use of impermeable covers to force gases laterally to vents provides a satisfactory solution to this problem.

Generating electricity for charging EHV batteries produces solid wastes at power plants. These wastes generally are of two types: (1) residues from fuels and (2) sludges from pollution control equipment. Fuel residues are primarily ash, which consists predominantly of silicones, with trace amounts of manganese, zinc, iron, copper, and aluminum. In the bottom ash that falls from the boilers, the trace metals are fused within a glassy substance, thereby minimizing their mobilization. In contrast, the trace metals found in powdery fly ash are more available for mobilization by water. Ash is usually disposed of in a wet or dry state at an on-site landfill.

Sludge from scrubbers is a limestone slurry containing sulfides and sulfates. The sludge is most often disposed of in a landfill at the power plant site. The ecological impacts of solid wastes generated by coal combustion are impossible to evaluate on a national or regional scale. The impacts are site specific and depend totally on site conditions and operating procedures. Nevertheless, the potential ecological impacts would be similar to those of landfills and to those discussed in Sec. D.1.1.

Regulations for the safe disposal of hazardous wastes are provided for in RCRA.[D.4] Assuming that the regulations are properly enforced and that appropriate methods for disposal of other wastes, as discussed above, are utilized, the potential adverse impacts from solid wastes resulting from EHV market penetration can be minimized.

D.2 AIR QUALITY

The air pollutants considered in the air quality analysis are SO_x, NO_x, HC, CO, particulates, and CO_2. Other air pollutants emitted, either in the production or the operation of vehicles, are discussed in Sec. E.2. The analysis is for 1990 and 2000; no 1985 analysis is presented because the number of EHVs does not result in significant air quality changes.

D.2.1 Method Overview

Three separate air quality assessments are performed. The first assessment is of vehicle production impacts. The impacts are evaluated nationally but are not distributed to regions or UAs, because the locations of materials mining and manufacturing can not be estimated. Material distributions for EHVs and CVs produced domestically by scenario and year; the emission rates for specific materials and processes; and the emission totals, by scenario and year, for the production of 100,000 EHVs and 100,000 CVs are presented in Sec. B.3. In this analysis, total emissions for all EHVs produced by scenario and year for a corresponding number of CVs are calculated and analyzed.

The second assessment is of vehicle operation impacts. Both the direct emissions from CVs and HVs operating in the heat engine mode and the indirect emissions from the power plants supplying electrical energy for battery recharging are considered. Air pollution resulting from vehicle operation in each scenario is determined, not only on a national scale but on a regional and on a UA basis. The totals for CVs are based on an equivalent number of CVs driven the same distance as the EHVs. At the local level, CO hotspots are examined.

The third analysis is related to vehicle operation. Emissions from the production of fuels required for EHV operation in the EHV scenarios and for a corresponding number of CVs driven the same distance as EHVs are calculated and analyzed on a national basis only.

D.2.2 Vehicle Production

Tables D.1-D.10 present the national air pollutants from the mining and manufacturing processes necessary to produce the EHVs in the EHV scenarios and to produce a corresponding number of CVs for 1990 and 2000. The major assumptions made in developing the emissions are:

1. Where no emissions are shown in the tables, the emissions are projected as either insignificant or eliminated by best available control technology (BACT). For example, SO_x and NO_x, which are not only air pollutants but which interact with precipitation to form acid rain, are assumed to be eliminated through use of BACT for certain material processes. This assumption is made in the emissions characterization of materials mining and manufacturing in Sec. B.3.

Table D.1. Vehicle Production Air Pollutant Emissions, LOW I EHVs and the Same Number of CVs, 1990 (10^3 lb)

Pollutant	Domestic Sales (10^3)	Lead	Nickel	Iron	Steel	Plastic	Aluminum	H_2SO_4	KOH	Copper	ZnO_x	Battery Assembly	LiS/LiCl	KCl	Total
EHV	55.04														
CO						0.3		0.5				0.4			1.2
SO_x		317				80		76			13	0.01			486.01
NO_x						10		5				4			19.0
HC						783		0.1				0.1			783.2
Particulates		328	15	67	317	24	64	6	9	24	4	0.2			858.2
HM[a]		119	6	1	6					0.8		44			176.8
CV															
CO						0.2									0.2
SO_x						53									53
NO_x						6									6
HC						521									521
Particulates				43	313	16	64								436
HM				1	6										7
EHV-others															
CaS															
PbS										63					63
CaF_2 ppt.[b]															
Gas fluorides					1		3								4
CO[c]															
Cl_2 (product)									1455						1455
H_2 (product)									42						42
CuS										153					153
CV-others															
Gas fluorides					1		3								4
CO[c]															

[a] Heavy metals.

[b] Precipitate.

[c] Captured and used as process fuel.

Table D.2. Vehicle Production Air Pollutant Emissions, LOW I EHVs and the Same Number of CVs, 2000 (10^3 lb)

Pollutant	Domestic Sales (10^3)	Lead	Nickel	Iron	Steel	Plastic	Aluminum	H_2SO_4	KOH	Copper	ZnO_x	Battery Assembly	LiS/LiCl	KCl	Total
EHV	751.47														
CO						4		6				5			15
SO_x		4,361				1134		1044			434	0.2			6,973
NO_x						145		64				56			265
HC						11,172		1				1			11,174
Particulates		4,512	469	744	4,775	340	815	77	289	258	114	4			12,397
HM[a]		1,640	188	16	95					9	3	606			2,557
CV															
CO						3									3
SO_x						726									726
NO_x						93									93
HC						7,143									7,143
Particulates				696	4,629	218	894								6,437
HM				15	93										108
EHV-others															
CaS										1,624					1624
PbS										670					670
CaF_2 ppt.[b]															
Gas fluorides					19		35								54
CO[c]															
Cl_2 (product)									44,482						44,482
H_2 (product)									1,268						1,268
CuS															
CV-others															
Gas fluorides					19		38								57
CO[c]															

[a] Heavy metals.

[b] Precipitate.

[c] Captured and used as process fuel.

Table D.3. Vehicle Production Air Pollutant Emissions, LOW II EHVs and the Same Number of CVs, 1990 (10^3 lb)

Pollutant	Domestic Sales (10^3)	Lead	Nickel	Iron	Steel	Plastic	Aluminum	H_2SO_4	KOH	Copper	ZnO_x	Battery Assembly	LiS/LiCl	KCl	Total
EHV	85.04														
CO						0.5		0.7				0.6			1.8
SO_x		516				126		122			13	0.02			777.02
NO_x						16		8				7			31.0
HC						1242		0.1				0.1			1242.2
Particulates		534	15	130	526	38	113	9	15	38	3	0.4			1421.4
HM[a]		194	6	3	11					1	0.1	71			286.1
CV															
CO						0.4									0.4
SO_x						85									85
NO_x						11									11
HC						832									832
Particulates				69	503	25	103								700
HM				1	10										11
EHV-others															
CaS															
PbS										98					98
CaF_2 ppt.[b]															
Gas fluorides					2		5								7
CO[c]															
Cl_2 (product)									2247						2247
H_2 (product)									64						64
CuS										237					237
CV-others															
Gas fluorides					2		2								4
CO[c]															

[a] Heavy metals.

[b] Precipitate.

[c] Captured and used as process fuel.

Table D.4. Vehicle Production Air Pollutant Emissions, LOW II EHVs and the Same Number of CVs, 2000 (10^3 lb)

Pollutant	Domestic Sales (10^3)	Lead	Nickel	Iron	Steel	Plastic	Aluminum	H_2SO_4	KOH	Copper	ZnO_x	Battery Assembly	LiS/LiCl	KCl	Total
EHV	1,384.03														
CO						9		12				10			31
SO_x		8,149				2,074		1,924			434	0.3			12,581.3
NO_x						265		118				104			487
HC						20,421		2				2			20,425
Particulates		8,433	468	1,800	4,612	622	1,801	141	289	448	114	6			18,734
HM[a]		3,065	189	39	183					15	3	1,126			4,620
CV															
CO						6									6
SO_x						1,381									1,381
NO_x						176									176
HC						13,595									13,595
Particulates				1,229	8,526	414	1,690								11,859
HM				26	172										198
EHV-others															
CaS															
PbS										1,165					1,165
CaF_2 ppt.[b]															
Gas fluorides					36		76								112
CO[c]															
Cl_2 (product)									44,444						44,444
H_2 (product)									1,269						1,269
CuS										2,826					2,826
CV-others															
Gas fluorides					34		40								74
CO[c]															

[a] Heavy metals.

[b] Precipitate.

[c] Captured and used as process fuel.

Table D.5. Vehicle Production Air Pollutant Emissions, MEDIUM EHVs and the Same Number of CVs, 1990 (10^3 lb)

Pollutant	Domestic Sales (10^3)	Lead	Nickel	Iron	Steel	Plastic	Aluminum	H_2SO_4	KOH	Copper	ZnO_x	Battery Assembly	LiS/LiCl	KCl	Total
EHV	126.4														
CO						0.9		0.3				0.3	0.003		1.5
SO_x		220				208		39			216	0.01			683.01
NO_x						25		3				3			31
HC						2,052		0.1				0.05			2,052.15
Particulates		227	231	179	1,001	63	190	4	142	62	57	0.3	1		2,157.3
HM[a]		83	93	4	20					2	2	30			234
CV															
CO						0.6									0.6
SO_x						146									146
NO_x						19									19
HC						1,433									1,433
Particulates				150	961	44	180								1,335
HM				3	19										22
EHV-others															
CaS															
PbS															
CaF_2 ppt.[b]															
Gas fluorides					4		8								12
CO[c]															
Cl_2 (product)									21,881					1,122	23,003
H_2 (product)									624					32	656
CuS															
CV-others															
Gas fluorides					4		8								12
CO[c]															

[a] Heavy metals.

[b] Precipitate.

[c] Captured and used as process fuel.

Table D.6. Vehicle Production Air Pollutant Emissions, MEDIUM EHVs and the Same Number of CVs, 2000 (10^3 lb)

Pollutant	Domestic Sales (10^3)	Lead	Nickel	Iron	Steel	Plastic	Aluminum	H_2SO_4	KOH	Copper	ZnO_x	Battery Assembly	LiS/LiCl	KCl	Total
EHV	2,353.88														
CO						15		4				3	0.1		22.1
SO_x		2,613				3,426		615			4,697	0.1			11,351.1
NO_x						436		38				33			507
HC						33,729		1				0.6			33,730.6
Particulates		2,700	5,016	2,415	15,018	1,027	2,726	45	3,073	774	1,231	5	50		34,080
HM[a]		979	2,062	52	306					26	32	362			3,819
CV															
CO						10									10
SO_x						2,263									2,263
NO_x						289									289
HC						22,300									22,300
Particulates				2,189	14,523	679	2,789								20,180
HM				47	292										339
EHV-others															
CaS															
PbS										2,010					2,010
CaF_2 ppt.[b]															
Gas fluorides					59		115								174
CO[c]															
Cl_2 (product)									472,518					47,252	519,770
H_2 (product)									13,488					1,349	14,837
CuS										4,875					4,875
CV-others															
Gas fluorides					59		118								177
CO[c]															

[a] Heavy metals.

[b] Precipitate.

[c] Captured and used as process fuel.

Table D.7. Vehicle Production Air Pollutant Emissions, HIGH I EHVs and the Same Number of CVs, 1990 (10^3 lb)

Pollutant	Domestic Sales (10^3)	Lead	Nickel	Iron	Steel	Plastic	Aluminum	H_2SO_4	KOH	Copper	ZnO_x	Battery Assembly	LiS/LiCl	KCl	Total
EHV	312.53														
CO						2		1				0.6	0.033		3.633
SO_x		517				519		118			593	0.02			1,747.02
NO_x						66		7				7			80
HC						5,106		0.1				0.1			5,106.2
Particulates		535	631	494	2,666	156	512	9	385	159	155	0.8	12		5,714.8
HM[a]		195	253	11	53					6	4	71			593
CV															
CO						2									2
SO_x						347									347
NO_x						44									44
HC						3,411									3,411
Particulates				405	2,450	104	436								3,395
HM				9	49										58
EHV-others															
CaS															
PbS										414					414
CaF_2 ppt.[b]															
Gas fluorides					11		22								33
CO[c]															
Cl_2 (product)									59,282					10,943	70,225
H_2 (product)									1,692					312	2,004
CuS										1,003					1,003
CV-others															
Gas fluorides					10		18								28
CO[c]															

[a] Heavy metals.

[b] Precipitate.

[c] Captured and used as process fuel.

Table D.8. Vehicle Production Air Pollutant Emissions, HIGH I EHVs and the Same Number of CVs, 2000 (10^3 lb)

Pollutant	Domestic Sales (10^3)	Lead	Nickel	Iron	Steel	Plastic	Aluminum	H_2SO_4	KOH	Copper	ZnO_x	Battery Assembly	LiS/LiCl	KCl	Total
EHV	7,265.17														
CO						43		7				7	1.6		58.6
SO_x		5,231				9,796		1,257			12,249	0.2			28,533.2
NO_x						1,251		77				67			1,395
HC						96,437		2				1			96,440
Particulates		5,405	13,041	9,249	44,049	2,938	,684	93	8,019	2,398	3,210	12	559		98,657
HM[a]		1,962	5,238	196	872					80	85	727			9,160
CV															
CO						30									30
SO_x						6,708									6,708
NO_x						856									856
HC						65,998									65,998
Particulates				5,841	40,976	2,011	8,195								57,023
HM				124	821										945
EHV-others															
CaS															
PbS										6,219					6,219
CaF_2 ppt.[b]															
Gas fluorides					174		407								581
CO[c]															
Cl_2 (product)									1,233,248					6,397	1,239,645
H_2 (product)									35,200					1,840	37,040
CuS										15,082					15,082
CV-others															
Gas fluorides					160		349								509
CO[c]															

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[a] Heavy metals.

[b] Precipitate.

[c] Captured and used as process fuel.

Table D.9. Vehicle Production Air Pollutant Emissions, HIGH II EHVs and the Same Number of CVs, 1990 (10^3 lb)

Pollutant	Domestic Sales (10^3)	Lead	Nickel	Iron	Steel	Plastic	Aluminum	H_2SO_4	KOH	Copper	ZnO_x	Battery Assembly	LiS/LiCl	KCl	Total
EHV	303.41														
CO						2		1				0.6			3.6
SO_x		487				506		111			628	0.02			1,732.02
NO_x						65		7				6			78
HC						4,986		0.1				0.1			4,986.2
Particulates		504	668	444	2,470	152	453	8	408	149	165	0.8			5,421.8
HM[a]		183	269	9	49					5	4	67			586
CV															
CO						1									1
SO_x						329									329
NO_x						42									42
HC						3,237									3,237
Particulates				374	2,283	99	412								3,168
HM				8	46										54
EHV-others															
CaS															
PbS										386					386
CaF_2 ppt.[b]															
Gas fluorides					10		19								29
CO[c]															
Cl_2 (product)									62,721						62,721
H_2 (product)									1,790						1,790
CuS										935					935
CV-others															
Gas fluorides					9		10								19
CO[c]															

[a] Heavy metals.

[b] Precipitate.

[c] Captured and used as process fuel.

Table D.10. Vehicle Production Air Pollutant Emissions, HIGH II EHVs and the Same Number of CVs, 2000 (10^3 lb)

Pollutant	Domestic Sales (10^3)	Lead	Nickel	Iron	Steel	Plastic	Aluminum	H_2SO_4	KOH	Copper	ZnO_x	Battery Assembly	LiS/LiCl	KCl	Total
EHV	7,498.83														
CO						46		7				6			59
SO_x		4,709				10,779		1,134			14,764	0.2			31,386
NO_x						1,378		70				60			1,508
HC						106,142		2				1			106,145
Particulates		4,867	15,710	8,594	46,020	3,233	9,029	83	9,599	2,339	3,869	15			103,358
HM[a]		1,762	6,239	180	922					82	103	655			9,943
CV															
CO						32									32
SO_x						7,187									7,187
NO_x						916									916
HC						70,752									70,752
Particulates				6,104	43,673	2,156	8,616								60,549
HM				127	877										1,004
EHV-others															
CaS															
PbS										6,082					6,082
CaF_2 ppt.[b]															
Gas fluorides					180		382								562
CO[c]															
Cl_2 (product)									1,476,249						1,476,249
H_2 (product)									42,136						42,136
CuS										14,750					14,750
CV-others															
Gas fluorides					174		210								384
CO[c]															

[a] Heavy metals.

[b] Precipitate.

[c] Captured and used as process fuel.

2. Present materials recycling rates are assumed. If the rates were to increase, the total air pollutant load associated with vehicle production would decrease.
3. Emissions from vehicle production are calculated only for vehicles and replacement batteries made and sold in the United States. The emissions related to the mining and manufacturing processes required to make foreign vehicles imported to the United States are not included.
4. As assumed in the scenarios, EHVs substitute for CVs on a one-for-one basis.
5. The tables represent a comprehensive though incomplete assessment of the emissions generated in the production of vehicles. Emissions from materials small in quantity and/or shared equally by CVs and EHVs are not included.

Some general conclusions can be drawn concerning the production of EHVs versus CVs:

1. The mining and manufacturing processes associated with the EHV scenarios result in more total emissions and different types of pollutants than the BASE scenario. Both EHV and CV production result in the generation of CO, SO_x, NO_x, HC, particulates, heavy metals, and gaseous fluorides. The generation of these pollutants by EHV production is always greater. EHV production also generates other pollutants, including lead, sulfides, chlorine, and hydrogen.
2. For all materials mining and manufacturing processes, the most significant air pollutants are particulates, HC, and SO_x, which are listed in decreasing order of loadings.
3. The production of plastics results in more emissions than occur during the production of any of the other materials.

The above results may represent a worst case for emissions from vehicle production. Higher materials recycling rates could reduce the total air pollutant load. In addition, stricter standards for industrial processes will be established within the next five years. Air pollutant emissions reported here are those that might escape state-of-the-art control technology.

D.2.3 Vehicle Operation

D.2.3.1 Method and Assumptions

The sources of the air pollutants from the operation of EHVs differ from those of CVs. EVs do not themselves emit any of the pollutants under consideration.* However, they are indirectly a source of pollutants because of the generation of electricity to charge the batteries. The quantities and types of power plant emissions are determined by the type of fuel used -- nuclear, coal, oil, or gas. For HVs, using the battery produces indirect air pollution similar to EVs; using the heat engine produces air pollution similar to CVs.

EHV emissions from battery charging are calculated using the fuel requirements at power plants for the EHV scenarios (see App. F) and the 1975 and 1979 new source performance standards (NSPS) for power plants.[D.10,D.11] Although the utility impact analysis is more optimistic about nuclear power than might be warranted by current debate, it allows in this air quality impact analysis a useful contrast between UAs with predominantly coal-generated electricity and UAs with predominantly nuclear-generated electricity. CV and HV heat engine emissions are calculated from VMT using published emission rates per mile.

The analysis compares the EHV and CV air pollutants and assumes that the VMT by EHVs exactly replace the VMT by CVs for each scenario. This allows direct comparisons to be made. The total emissions of the scenarios (i.e., all vehicles of all types projected to be in operation in a specific assessment year) combined with total emissions from all other sources are estimated for several UAs to show the impact of EHVs on the air quality of specific UAs.

Three of 10 federal regions are analyzed: (1) Federal Region II (New York-New Jersey), (2) Federal Region IV (South Atlantic), and (3) Federal Region VIII (North Central). Federal Region II represents the highest penetration of EHVs of the 10 regions. Federal Region IV falls in the middle of the market penetration rates, and Federal Region VIII has the lowest market penetration rate.

The particular UAs chosen for analysis facilitate comparisons among UAs of similar size having similar VMT and pre-EHV emissions and similar market penetration rates, but with different fuels for electricity generation. The different fuels result in different emission loadings.

Figure D.3 depicts the UA selection process, and Table D.11 summarizes the UA characteristics. A large UA is defined as a SMSA with a population of 1.2-1.5 million persons, and a medium-sized UA is one with 300,000-450,000 persons. The high market penetration rate for EVs is assumed to have a variation of 1.00 or greater and the low market penetration rate a variation of 0.88 or lower (see Sec. A.5 for a discussion of regional variation in EHV market penetration).** The emissions in UAs using predominantly oil, nuclear,

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*Ozone is produced from arcing during DC motor operation. However, AC motors with an inverter package and brushless DC motors produce little or no arcing and, thus, little or no ozone. Since these latter types of motors are expected to dominate the EHV market by 1990, ozone emissions from EHV operation are only a short-range concern and are not quantified in this analysis.

**Milwaukee's EV penetration rate is below 1.0. However, within the large UA category, Milwaukee has one of the highest penetration rates of UAs in which nuclear-generated electricity is predominant.

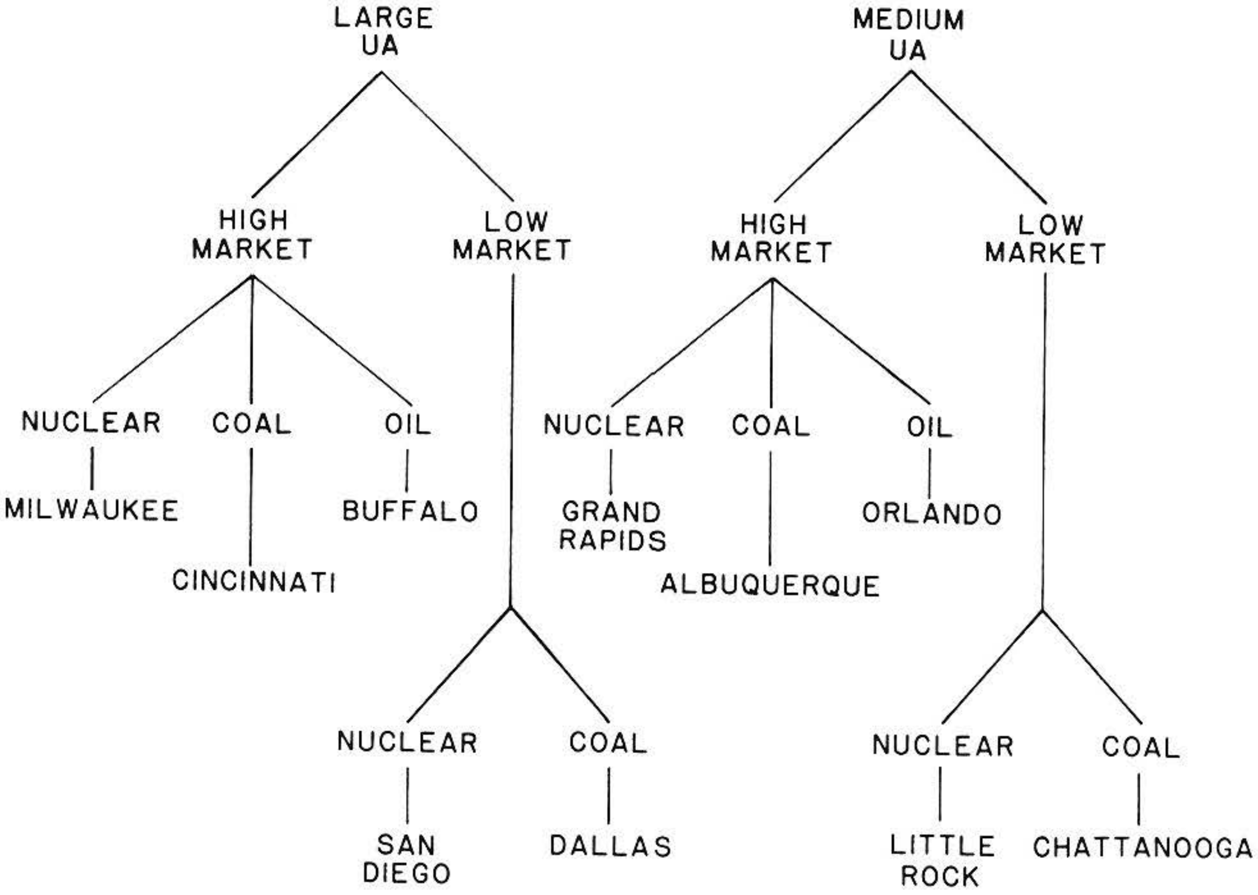

Fig. D.3. Urbanized Area Selection Process

or coal fuels are determined and compared in areas of high market penetration. The air emissions in UAs using predominantly nuclear or coal fuels are compared where EHVs have low market penetration. (It was not necessary to study oil-based emissions in all cases. Nuclear and coal emissions provided the greatest contrast.) The predominant fuel projection for each of the UAs is based on Ref. D.12. While the current questioning of the future of nuclear power may drastically change the projections for some UAs, the analysis is valid in its identification of the emission contrasts among fuel sources. One final criterion for the selection of UAs was to select, where possible, UAs in which an EV demonstration project is scheduled (i.e., Orlando, Florida, and Chattanooga, Tennessee).

Several assumptions are made in the calculation of the pollutant loadings resulting from the operation of the various types of vehicles:

1. Table D.12 reflects the power plant emissions levels used to determine air pollutants from electrically powered vehicles. It summarizes the 1975 NSPS mandated by EPA for fossil fuel power plants built after 1975. (Nuclear power plants do not generate SO_x, NO_x, HC, CO, or particulates.) Some plants built prior to 1975 may be used to generate electricity for EHVs, but it has been assumed

Table D.11. Selected UAs, EHV Markets, and Fuels for Off-Peak Electricity Generation, 1990 and 2000

UA	Market Penetration	Size Category	Major Fuels for EHV Electricity 1990	Major Fuels for EHV Electricity 2000
Albuquerque	High	Medium	Coal	Coal
Buffalo	High	Large	Oil	Oil, coal
Chattanooga	Low	Medium	Coal	Coal, nuclear
Cincinnati	High	Large	Coal	Coal
Dallas	Low	Large	Coal	Coal, nuclear
Grand Rapids	High	Medium	Coal, nuclear	Nuclear
Little Rock	Low	Medium	Nuclear, coal	Nuclear
Milwaukee	High	Large	Nuclear	Nuclear
Orlando	High	Medium	Oil	Oil, coal, nuclear
San Diego	Low	Large	Oil, nuclear	Nuclear

that plants used for off-peak charging will usually meet or surpass 1975 NSPS, if not 1979 NSPS (see Table D.13). The tables presenting EHV operation emissions for the nation, federal regions, and UAs in Sec. D.2.3 reflect the 1975 NSPS.

2. New source performance standards applicable to plants built after June, 1979, were promulgated during the course of this study (see Table D.13). These standards reduce the allowable emissions of particulates from coal-, oil-, and gas-fired power plants by 70% from the 1975 NSPS. For coal-fired power plants, the 1979 NSPS allowable NO_x emissions are reduced by nearly 30%. For

Table D.12. 1975 New Source Performance Standards for Power Plants

Fuel	Emissions ($lb/10^6$ Btu) TSP	SO_x	NO_x	HC	CO
Coal	0.1	1.2	0.7	0.011	0.038
Oil	0.1	0.8	0.3	0.007	0.033
Gas	0.1	0.0006	0.2	0.00095	0.016

Source: Ref. D.10.

Table D.13. 1979 New Source Performance Standards for Power Plants[a]

	Emissions ($lb/10^6$ Btu)		
Fuel	TSP	SO_x	NO_x
Coal	0.03	1.2[b]	0.5
Oil	0.03	c	c
Gas	0.03	c	c

[a] No new standards were promulgated for HC and CO.

[b] Emissions limited to 1.2 $lb/10^6$ Btu, and a 90% reduction in emissions is required at all times except when emissions are less than 0.6 $lb/10^6$ Btu, in which case a 70% reduction in emissions is required at all times.

[c] No new standards were promulgated; 1975 standards remain in effect.

Source: Ref. D.11.

SO_x (emitted as SO_2) from coal-fired power plants, the standards are more complicated. The SO_x emissions are limited to 1.2 $lb/10^6$ Btu like the 1975 NSPS for SO_x from coal-fired power plants, but in the 1979 NSPS, a 90% reduction in potential emissions is required at all times, except when emissions are less than 0.6 $lb/10^6$ Btu. In the latter case, a 70% reduction in potential emissions is required. Essentially, the new standards will result in SO_x emissions no greater than and more than likely less than 1.2 $lb/10^6$ Btu. The effects of the 1979 NSPS are not presented in the tables in Sec. D.2.3 but are discussed in the text.

3. In particular, it is difficult to predict with any accuracy the effect of the 1979 NSPS for SO_x on SO_x emissions resulting from the EHV scenarios because: (a) on a national basis, and to a lesser extent on a regional basis, variations in the sulfur content of coal make it hard to generalize what the actual SO_x emissions will be; (b) the sulfur content of coals used in power plants will be determined largely by the economic trade-offs between coal transportation costs and the costs and reliability of control technologies, not to mention politics; and (c) it is not known what proportion of the energy supplied by coal-fired power plants in the EHV scenarios in 1990 and 2000 will come from plants built after June, 1979.

4. However, in an effort to assess the effect of the 1979 NSPS on SO_x emissions, data reported in Ref. D.12 on "coal delivered to utilities" between 1972 and 1977 are analyzed. The data include, among other things, information on the state, utility company, power plant, coal source, type of coal, and minimum and maximum sulfur content. A random selection of states, utility companies, power plants, types of coal, and sulfur content is taken, from which it is determined that average sulfur content is 2%. Assuming that coal-fired power plants using bituminous coal emitted "1.45 S" $lb/10^6$ Btu of sulfur, where "S" represents the sulfur content based on Ref. D.10, and assuming 26.2×10^6 Btu/short ton,[D.13] the average national coal-fired power plant SO_x emission factor (without any controls) is 2.9 $lb/10^6$ Btu. Since the 1979 NSPS require a 90% reduction through use of BACT, the national SO_x emission factor is 0.3 $lb/10^6$ Btu.

   A similar process is conducted for the federal regions. The sulfur content of coal being used by power plants in the states within each of the regions is sampled and an average sulfur content determined. In Federal Region II, the average is 1.6%; in Federal Region IV, 2.1%; and in Federal Region VIII, 0.6%. The resulting emission factors are 0.23 $lb/10^6$ Btu for Federal Region II, 0.30 $lb/10^6$ Btu for Federal Region IV, and 0.13 $lb/10^6$ Btu (assuming lignite) for Federal Region VIII.

   Similarly, average sulfur content and emission factors are determined for the 10 UAs. Since no data are available for Arkansas, the sulfur contents of coals used in power plants close to the borders of Missouri and Arkansas and Tennessee and Arkansas are analyzed to determine sulfur content and are assumed to be representative of Little Rock. Also, Texas uses predominantly

UA	Average Sulfur Content (%)	Emission Factor ($lb/10^6$ Btu)
Milwaukee	2.4	0.35
Cincinnati	2.9	0.42
Buffalo	2.0	0.30
San Diego	No coal	-
Dallas	0.5	0.11[a]
Grand Rapids	2.8	0.41
Albuquerque	0.7	0.10
Orlando	2.3	0.33
Little Rock	3.5	0.51
Chattanooga	2.9	0.42

[a] Assumes lignite.

lignite coal. Therefore, an emission factor of 2.2395 lb/10^6 Btu and 13.45 x 10^6 Btu/short ton are used.[D.10,D.13]

4. Electrical energy required in the operation of EHVs takes into account the energy lost in distribution and transmission.
5. Table D.14 reflects the proportion of VMT that HVs are assumed to travel on gasoline and electricity.
6. It is assumed that there is one-for-one replacement of EHV VMT for CV VMT in each scenario. Using this assumption, two approaches to comparing EHV emissions from operation with those for CVs are used in this analysis. One approach is to compare emissions generated by EHVs in the EHV scenarios with emissions generated by CVs operating equivalent VMT (BASE scenario). The other is to analyze the impact of total EHV and CV emissions (including emissions from all CVs of all types) relative to air emissions from all sources in selected UAs.
7. Tables D.15 and D.16 give the emission factors used for 1990 and 2000 for the various types of CVs and for HVs operating in the heat-engine mode. The emission rates for all but San Diego are derived from Ref. D.14. The emission factor tables in that reference are based on Ref. D.15. For San Diego, HC, CO, and NO_x emission rates are obtained from MOBILE1 and reflect stricter California emission standards. For SO_x and particulates, for all locations including San Diego, the source document is Ref. D.10. High-altitude emission rates for Albuquerque are not available. Therefore, the emission rates shown in Tables D.15 and D.16 are assumed. It should be noted that emission rates for HC, CO, and NO_x generally are lower for CVs in the year 2000 than in 1990.

   The particulate emission rates used for CVs and for HVs operating in the heat-engine mode include particulates from tire wear. Since such particulates also are generated by EV operation and by HV operation on battery,

Table D.14. Percentage of HV VMT on Battery and Heat Engine, 1990 and 2000

Vehicle Fuel	Scenario			
	LOW II		HIGH II	
	Truck	Car	Truck	Car
Electricity	74.6	67.6	75.3	60.3
Gasoline	25.4	32.4	24.7	39.7

Table D.15. Emission Factors for CVs, Excluding High Altitude and California Locations (g/vehicle-mi)

Year and Pollutant	Light-Duty Gasoline Vehicle[a]	Light-Duty Gasoline Truck I[b]	Light-Duty Gasoline Truck II[c]	Heavy-Duty Gasoline Truck[d]	Heavy-Duty Diesel Truck and Bus
1990					
HC	1.5	2.3	3.1	5.8	2.0
CO	14.2	25.2	32.2	103.0	16.8
NO_x	1.9	2.0	2.5	8.0	7.5
SO_2[e]	0.13	0.18	0.18	0.36	2.8
Particulates[e]	0.54	0.54	0.54	1.11[g]	1.3
2000[f]					
HC	1.3	1.8	2.2	4.8	1.9
CO	12.8	19.0	22.8	90.3	16.7
NO_x	1.8	2.0	2.3	7.5	5.2
SO_2[e]	0.13	0.18	0.18	0.36	2.8
Particulates[e]	0.54	0.54	0.54	1.11[g]	1.3

[a] Automobile.

[b] <6000 lb.

[c] 6000-8500 lb.

[d] >8500 lb.

[e] Ref. D.10.

[f] Emission factors are for 1999, since year 2000 factors are not available.

[g] Assumes four tires on vehicle.

Sources: Refs. D.10, D.14, and D.15.

Table D.16. California Emission Factors for CVs (g/vehicle-mi)

Year and Pollutant	Light-Duty Gasoline Vehicle[a]	Light-Duty Gasoline Truck I[b]	Light-Duty Gasoline Truck II[c]	Heavy-Duty Gasoline Truck[d]	Heavy-Duty Diesel Truck and Bus
1990					
HC[e]	1.48	1.92	2.58	4.86	1.99
CO[e]	12.83	18.64	24.81	105.07	16.73
NO_x[e]	1.74	1.92	2.46	6.95	6.88
SO_2[f]	0.13	0.18	0.18	0.36	2.8
Particulates[f]	0.54	0.54	0.54	1.11	1.3
2000[g]					
HC[e]	1.38	1.55	1.83	4.40	1.90
CO[e]	12.10	14.87	18.43	91.2	16.71
NO_x[e]	1.74	1.90	2.34	7.16	5.06
SO_2[f]	0.13	0.18	0.18	0.36	2.8
Particulates[f]	0.54	0.54	0.54	1.11	1.3

[a] Automobile.

[b] <6000 lb.

[c] 6000-8500 lb.

[d] >8500 lb.

[e] Ref. D.15. Emission factors obtained from run of MOBILE1 program with California emission standards and the following assumptions: (1) 60°F ambient temperature, (2) 30-mph speed, (3) 100% warm start for heavy-duty gasoline and diesel trucks, (4) for light-duty vehicles, 27% catalyst-equipped hot start, 20% catalyst-equipped cold start, and 20% noncatalyst-equipped cold start, and (5) national average VMT per vehicle. These factors are estimated to be within 2% of the emission factors that could be computed using California average VMT per vehicle.

[f] SO_2 and TSP factors are the same as the national factors.

[g] Emission factors are for 1999, since year 2000 factors are not available.

Sources: Refs. D.10 and D.15.

a factor to account for this should have been applied in this assessment. It was not; therefore, it is recommended that the implications of not applying such a factor be resolved in the recommended EIS.

8. It is assumed that power plant emissions occur in the same general location as vehicular operation. This is not always true. However, for the analysis, emissions in specific UAs and regions due to vehicular operation are assumed to consist of power plant emissions plus direct vehicular emissions from CVs and heat-engine-powered HVs in each location.

The above discussion applies particularly to the analysis of SO_x, HC, NO_x, CO, and particulates. The methodology and assumptions used for the analysis of CO_2 are discussed in Sec. D.2.3.8.

D.2.3.2 General Results

From the analysis in Secs. 2.3.3-2.3.5, many trends can be identified that are similar on a national, regional, and UA basis. Variations are the result of: (1) different emission rates in different years; (2) variation in the EHV VMT across the scenarios; and (3) differences in the VMT by gasoline- versus diesel-fueled buses, by the two types of light-duty trucks, and by truck and auto HVs, which differ in their use of the battery.

The general trends are:

1. EHV scenarios result in lower emissions than the BASE scenario for all years, except for SO_x.
2. For HC, CO, and NO_x, the scenarios including HVs result in more emissions than the EV-only scenarios, because a portion of the HV VMT is gasoline-fueled.
3. In specific regions or UAs where a high percentage of electricity for the EHV scenarios will be supplied by coal-fired power plants, the EHV emissions are a smaller percentage of the corresponding CV emissions in the MEDIUM and LOW II scenarios than in the other scenarios. Where little, if any, coal is used to supply electricity, the HIGH scenarios are more competitive with the MEDIUM and LOW II scenarios for relatively low emissions.
4. The effect of the 1979 NSPS varies across the nation, regions, and UAs, as well as among the scenarios. However, there are some general trends. Assuming that all the power plants comply with the 1979 NSPS, in the three EV-only scenarios particulate emissions due to battery charging are reduced by 70% for the nation, regions, and UAs. In the two scenarios with HVs, the reduction is somewhat less and depends on the percentage of VMT by HVs on their heat engine. The effect of the 1979 NSPS on NO_x varies, depending on the amount of energy supplied by coal, oil, and gas. Where coal-fired and/or nuclear plants supply all electrical energy (i.e., Cincinnati, Federal Region VIII), NOx emissions due to EHV operation are reduced by nearly 30% for the EV-only

scenarios and somewhat less for the scenarios with HVs, depending on the proportion of gasoline-powered HV VMT. As the percentage of energy supplied by coal-fired power plants decreases, there is a reduction in the absolute effects of the 1979 NSPS.

The effect of the 1979 NSPS on SO_x emissions also varies by location, which is discussed in Secs. D.2.3.3-D.2.3.5. In general, however, SO_x emissions from the EHV scenarios still exceed those from the BASE scenario. Exceptions include Little Rock in 2000, Milwaukee in 1990 and 2000, and Grand Rapids in 2000.

5. The CV emissions being replaced in the EHV scenarios are a small portion of the total CV emissions generated when all VMT are traveled by CVs. The CV emissions associated with VMT equivalent to the VMT of EHVs generally represent less than 1% of total roadway emissions in 1990 for all pollutants and all scenarios. In 2000, the LOW I, LOW II, and MEDIUM scenario emissions represent 1-5% of total roadway emissions generally and, in the HIGH scenarios, emissions are 12-20% of total roadway emissions.

D.2.3.3 National Results

Tables D.17 and D.18 present the national results. In addition to the general conclusions discussed above, several other conclusions national in scope can be reached. If 1979 NSPS are assumed for all power plants, the SO_x due to battery charging would be reduced from the totals shown in the tables by about 60% over all scenarios in both 1990 and 2000. Sulfur oxide emissions from the EHV scenarios would still exceed those from the BASE scenario, though by a lesser amount. For NO_x, the 1979 NSPS would cause a reduction of about 20% in 1990 and 20-25% in 2000.

D.2.3.4 Regional Results

Conclusions unique to Federal Regions II, IV, and VIII can be drawn from Tables D.19-D.21 and can be summarized as follows:

1. Assuming 1975 NSPS, the SO_x and NO_x emissions for the EHV scenarios exceed those from corresponding CVs by a greater percentage in Federal Region VIII than in Federal Regions II or IV. This is not surprising, because power plant energy is supplied solely by coal (which emits more SO_x and NO_x than oil- or gas-fired plants) in Federal Region VIII and predominantly by coal and oil in Federal Regions II and IV.

2. The above trend is reversed for SO_x if 1979 NSPS are assumed for all power plants. Again this is not surprising because the sole source of energy (coal) in Federal Region VIII is affected by the new standard. In Federal

Table D.17. National Vehicle and Power Plant Emissions to the Air Due to the Operation of EHVs and the Same VMT by CVs, by Scenario, 1990 (10^6 lb)

Emissions Due to EHV Battery Charging

	Scenario				
Pollutant	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	8.9	15.1	19.3	51.0	51.0
NO_x	5.8	9.8	12.5	33.2	33.0
HC	0.09	0.07	0.15	0.5	0.5
Particulates	0.84	1.47	1.8	4.7	4.7
CO	0.29	0.21	0.62	1.63	1.63

HV Heat Engine Emissions

	Scenario				
Pollutant	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	0	0.1	0	0	0.1
NO_x	0	1.4	0	0	1.9
HC	0	1.4	0	0	1.8
Particulates	0	0.4	0	0	0.5
CO	0	14.8	0	0	18.7

Total EHV Emissions

	Scenario				
Pollutant	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	8.9	15.2	19.3	51.0	51.1
NO_x	5.8	11.2	12.5	33.2	34.9
HC	0.09	1.5	0.15	0.5	2.3
Particulates	0.84	1.8	1.8	4.7	5.2
CO	0.29	5.0	0.62	1.63	20.3

Emissions if VMT by CVs

	Scenario				
Pollutant	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	0.56	0.99	1.75	4.86	4.86
NO_x	9.13	13.46	19.97	49.10	48.13
HC	9.28	13.34	19.1	45.38	44.9
Particulates	2.18	3.30	4.55	11.51	11.40
CO	102.47	149.85	216.25	493.74	486.3

Table D.18. National Vehicle and Power Plant Emissions to the Air Due to the Operation of EHVs and the Same VMT by CVs, by Scenario, 2000 (10^6 lb)

Emissions Due to EHV Battery Charging

Pollutant	Scenario LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	117.0	232.01	363.01	1,222.03	1,178.93
NO_x	65.2	128.7	200.8	671.4	648.1
HC	1.11	2.21	3.42	11.44	11.04
Particulates	1.1	22.2	34.7	116.6	112.7
CO	3.99	3.0	12.6	42.2	40.7

HV Heat Engine Emissions

Pollutant	Scenario LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	0	2.41	0	0	10.39
NO_x	0	30.04	0	0	132.3
HC	0	25.77	0	0	59.63
Particulates	0	8.07	0	0	35.86
CO	0	64.97	0	0	1,140.45

Total EHV Emissions

Pollutant	Scenario LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	117.0	234.42	363.01	1,222.03	1,189.32
NO_x	65.2	158.74	200.8	671.4	730.4
HC	1.11	27.98	3.42	11.44	70.67
Particulates	11.1	30.27	34.7	116.6	148.56
CO	3.99	272.97	12.6	12.2	1,181.15

Emissions if VMT by CVs

Pollutant	Scenario LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	8.84	20.56	30.2	116.57	111.76
NO_x	85.11	236.76	420.98	1,342.58	1,228.93
HC	115.25	201.53	351.71	1,125.42	1,042.63
Particulates	35.62	63.09	111.9	361.15	329.14
CO	1,198.3	2,036.14	3,633.05	11,559.33	10,720.18

Table D.19. Federal Region II Vehicle and Power Plant Emissions to the Air Due to the Operation of EHVs and the Same VMT by CVs, by Scenario, 1990 and 2000 (10^6 lb)

Total EHV Emissions, 1990

	Scenario				
Pollutant	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	1.9	3.22	4.3	12.2	11.02
NO_x	1.09	2.03	2.4	6.1	6.27
HC	0.02	0.28	0.03	0.1	0.37
Particulates	0.13	0.31	0.36	1.0	1.07
CO	0.06	2.70	0.12	0.37	3.32

Emissions if VMT by CVs, 1990

	Scenario				
Pollutant	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	0.072	0.18	0.30	0.88	0.85
NO_x	1.56	2.41	3.42	3.4	3.31
HC	1.61	2.55	3.31	7.86	7.9
Particulates	0.37	0.58	0.77	1.95	1.94
CO	17.8	27.62	37.7	35.93	35.88

Total EHV Emissions, 2000

	Scenario				
Pollutant	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	27.2	51.61	83.2	271.5	257.14
NO_x	13.8	30.64	41.1	131.97	146.0
HC	0.29	5.0	0.8	2.6	21.17
Particulates	2.7	6.45	8.4	27.94	32.07
CO	0.9	48.26	2.9	9.61	201.9

Emissions if VMT by CVs, 2000

	Scenario				
Pollutant	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	2.16	3.75	7.01	20.01	18.39
NO_x	23.41	43.06	72.01	227.53	220.4
HC	20.1	37.39	60.72	192.81	190.25
Particulates	6.1	11.26	18.97	60.65	58.30
CO	209.29	338.0	628.96	1985.88	1964.1

Table D.20. Federal Region IV Vehicle and Power Plant Emissions to the Air Due to the Operation of EHVs and the Same VMT by CVs, by Scenario, 1990 and 2000 (10^6 lb)

Total EHV Emissions, 1990

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	1.4	2.41	3.20	8.3	8.22
NO_x	0.8	1.50	1.60	4.3	4.55
HC	0.01	0.24	0.03	0.07	0.32
Particulates	0.14	0.24	0.3	0.8	0.87
CO	0.05	2.24	0.11	0.3	2.83

Emissions if VMT by CVs, 1990

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	0.09	0.15	0.25	0.72	0.70
NO_x	1.31	2.03	2.85	1.97	6.92
HC	1.32	2.1	2.71	6.42	6.47
Particulates	0.31	0.49	0.66	1.64	1.64
CO	14.61	22.75	30.77	69.78	69.98

Total EHV Emissions, 2000

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	20.5	40.42	63.7	216.3	205.51
NO_x	10.83	25.24	33.9	117.8	123.35
HC	0.15	3.79	0.6	2.0	11.34
Particulates	2.02	4.89	6.06	19.9	22.17
CO	0.7	36.28	2.11	7.22	103.12

Emissions if VMT by CVs, 2000

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	1.74	3.08	5.66	16.46	15.28
NO_x	19.15	35.8	49.55	190.51	185.04
HC	16.25	30.75	49.66	159.33	157.71
Particulates	5.07	9.45	15.86	51.63	49.46
CO	168.32	318.22	512.61	1635.93	1623.19

Table D.21. Federal Region VIII Vehicle and Power Plant Emissions to the Air Due to the Operation of EHVs and the Same VMT by CVs, by Scenario, 1990 and 2000 (10^6 lb)

Total EHV Emissions, 1990

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	0.3	0.502	0.6	1.5	1.503
NO_x	0.2	0.33	0.3	0.9	0.94
HC	0	0.03	0.01	0.01	0.05
Particulates	0.02	0.047	0.05	0.1	0.11
CO	0.01	0.33	0.02	0.05	0.43

Emissions if VMT by CVs, 1990

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	0.01	0.02	0.03	0.09	0.09
NO_x	0.17	0.28	0.37	0.92	0.92
HC	0.17	0.28	0.35	0.85	0.87
Particulates	0.04	0.07	0.09	0.22	0.22
CO	1.86	3.04	3.89	1.09	0.93

Total EHV Emissions, 2000

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	4.0	8.15	12.5	40.7	39.82
NO_x	2.4	5.35	7.3	23.8	25.97
HC	0.04	0.65	0.1	0.4	2.8
Particulates	0.3	0.87	1.0	3.4	4.08
CO	0.1	6.03	0.4	1.3	25.85

Emissions if VMT by CVs, 2000

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	0.23	0.42	0.75	2.2	2.12
NO_x	2.47	5.01	8.05	25.99	25.93
HC	2.07	4.27	6.66	21.54	21.9
Particulates	0.66	1.33	2.16	7.06	6.98
CO	21.48	44.1	68.57	220.48	224.95

Regions II and IV, only a portion of the generating capacity is affected. In Federal Region II, the 1979 NSPS reduce EHV-related SO_x emissions by about 70% in 1990 and 40-60% in 2000; in Federal Region IV, 50-55% in 1990 and 55-60% in 2000; and in Federal Region VIII, nearly 90% in 1990 and 2000.

D.2.3.5 Urbanized Area Results

Milwaukee, Cincinnati, and Buffalo are compared as large UAs with high EHV market penetration but with different fuels used to generate off-peak electricity for EHV charging. The results are presented in Tables D.22-D.26, and the conclusions to be drawn are summarized below.

1. In 1990 and 2000, nuclear power plants are projected to provide 92-98% of the off-peak electricity in Milwaukee. While this projection may change, the results are interesting. The SO_x emissions for the EHV scenarios exceed those for the BASE scenario by significantly less than in UAs where power plants are fossil fueled. In fact, for scenarios LOW I, LOW II, and MEDIUM, 1990 EHV SO_x emissions are about equal to those of the BASE scenario. For the HIGH scenarios, the SO_x emissions associated with the EHV scenarios exceed those for the BASE scenario by about 50% and 25%, respectively. In 2000, except in HIGH II, the EHV SO_x emissions are lower than those from the BASE scenario. For all other pollutants for 2000, the emissions associated with the operation of EHVs are a smaller percentage of those emitted by the BASE scenario compared to other UAs where more coal is used.
2. The effect of the 1979 NSPS is much less on absolute emissions in Milwaukee because of the predominance of nuclear power plants. The SO_x emissions due to vehicle battery charging in 1990 and 2000 are reduced by approximately 35% by the standards. The absolute reduction in emissions, however, is small because of the predominance of nuclear fuel.
3. Coal-fired power plants are projected to provide 100% of the off-peak electricity in 1990 in Cincinnati and nearly 90% in 2000. As a result, SO_x emissions from EHV scenarios exceed those of the BASE scenario in both 1990 and 2000 by a larger percentage than in other UAs using a smaller percentage of coal. In fact, the sole use of coal in 1990 causes EHV SO_x emissions to be 15-30 times greater than those for the BASE scenario. With 90% coal-generated electricity in 2000, SO_x emissions are only 15-20 times larger on an equivalent VMT basis.
4. The 1979 NSPS have a greater effect in Cincinnati than in Milwaukee and, to some extent, than in Buffalo because of the predominance of coal. In both 1990 and 2000, SO_x emissions in the EV-only scenarios are

Table D.22. Milwaukee Vehicle and Power Plant Emissions to the Air Due to the Operation of EHVs and the Same VMT by CVs, by Scenario, 1990 and 2000 (10^6 lb)

Total EHV Emissions, 1990

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	0.01	0.01	0.01	1.5	0.06
NO_x	0.01	0.02	0.01	0.03	0.03
HC	0	0.01	0	0	0.02
Particulates	0	0	0	0	0
CO	0	0.15			0.17

Emissions if VMT by CVs, 1990

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	0.01	0.01	0.01	0.04	0.04
NO_x	0.07	0.12	0.16	0.41	0.42
HC	0.08	0.13	0.16	0.39	0.37
Particulates	0.02	0.03	0.04	0.10	0.10
CO	0.83	1.39	1.77	4.19	4.28

Total EHV Emissions, 2000

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	0.03	0.11	0.1	0.9	1.00
NO_x	0.02	0.35	0.08	0.5	1.78
HC	0	0.26	0	0.01	1.17
Particulates	0	0.09	0.01	0.07	0.42
CO	0	2.68	0	0.03	11.27

Emissions if VMT by CVs, 2000

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	0.11	0.20	0.35	1.00	0.96
NO_x	1.16	2.29	3.48	11.39	11.62
HC	0.98	1.97	2.96	9.57	9.97
Particulates	0.30	0.60	0.92	3.05	3.09
CO	10.25	20.50	30.70	98.38	102.73

Table D.23. Buffalo Vehicle and Power Plant Emissions to the Air Due to the Operation of EHVs and the Same VMT by CVs, by Scenario, 1990 and 2000 (10^6 lb)

Total EHV Emissions, 1990

Pollutant	Scenario LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	0.08	0.1	0.2	0.5	0.5
NO_x	0.03	0.05	0.06	0.2	0.21
HC	0	0.01	0	0	0.01
Particulates	0.01	0.01	0.02	0.06	0.06
CO	0	0.12	0.01	0.02	0.17

Emissions if VMT by CVs, 1990

Pollutant	Scenario LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	0.01	0.01	0.01	0.04	0.04
NO_x	0.07	0.11	0.16	0.39	0.39
HC	0.07	0.12	0.15	0.33	0.37
Particulates	0.02	0.03	0.04	0.09	0.09
CO	0.80	1.26	1.68	3.92	3.94

Total EHV Emissions, 2000

Pollutant	Scenario LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	1.3	2.82	4.7	14.3	13.59
NO_x	0.46	1.45	2.0	6.5	7.29
HC	0.01	0.25	0.04	0.13	1.04
Particulates	0.21	0.42	0.5	1.6	1.79
CO	0.05	2.33	0.14	0.6	10.01

Emissions if VMT by CVs, 2000

Pollutant	Scenario LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	0.10	0.17	0.32	0.94	0.87
NO_x	1.09	2.04	3.28	10.88	10.55
HC	0.92	1.75	2.83	9.08	8.97
Particulates	0.29	0.54	0.91	2.94	2.82
CO	9.58	18.06	29.17	93.12	92.29

Table D.24. Cincinnati Vehicle and Power Plant Emissions to the Air Due to the Operation of EHVs and the Same VMT by CVs, by Scenario, 1990 and 2000 (10^6 lb)

Total EHV Emissions, 1990

Pollutant	Scenario LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	0.2	0.3	0.3	0.9	0.9
NO_x	0.09	0.22	0.2	0.5	0.52
HC	0	0.02	0	0.01	0.03
Particulates	0.01	0.02	0.03	0.07	0.08
CO	0	0.18	0.01	0.03	0.24

Emissions if VMT by CVs, 1990

Pollutant	Scenario LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	0.01	0.01	0.02	0.05	0.05
NO_x	0.10	0.16	0.21	0.53	0.53
HC	0.10	0.16	0.20	0.49	0.49
Particulates	0.02	0.04	0.05	0.12	0.13
CO	1.08	1.73	2.28	5.27	5.33

Total EHV Emissions, 2000

Pollutant	Scenario LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	2.0	4.03	6.4	21.8	21.12
NO_x	1.2	2.75	3.7	12.7	13.74
HC	0.02	0.35	0.06	0.2	1.50
Particulates	0.2	0.39	0.5	1.8	2.22
CO	0.06	3.25	0.2	0.7	14.04

Emissions if VMT by CVs, 2000

Pollutant	Scenario LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	0.13	0.24	0.43	1.26	1.13
NO_x	1.46	2.80	4.54	14.53	13.77
HC	1.23	2.40	3.78	12.12	12.25
Particulates	0.38	0.74	1.21	3.92	3.85
CO	12.62	24.82	38.98	124.39	126.00

Table D.25. Comparison of Emissions Due to EHV Operation, by Scenario, Milwaukee, Cincinnati, and Buffalo, 1990

Milwaukee Emissions as a Percentage of Cincinnati Emissions

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	5	3	3	7	1
NO_x	0.8	0.7	0.2	0.2	0.2
HC	0	3	0	0	1
Particulates	0	0	0	0	0
CO	0	5	0	0	1

Milwaukee Emissions as a Percentage of Buffalo Emissions

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	13	10	5	12	2
NO_x	33	40	17	15	15
HC	0	100	0	0	200
Particulates	0	0	0	0	0
CO	0	125	0	0	100

Buffalo Emissions as a Percentage of Cincinnati Emissions

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	40	30	67	56	56
NO_x	33	23	30	40	40
HC	100	50	100	100	33
Particulates	100	50	67	86	75
CO	100	67	100	67	71

reduced by some 65%. The reduction realized is somewhat less in the scenarios with HVs because of the gasoline-powered HV VMT, which are not affected by standards for fossil fuel power plants.

5. Buffalo was selected as a case study UA because of the predominant use of oil to generate electricity. In 1990, 100% of the electricity generation for EHVs will be oil-

Table D.26. Comparison of Emissions Due to EHV Operation, by Scenario, Milwaukee, Cincinnati, and Buffalo, 2000

Milwaukee Emissions as a Percentage of Cincinnati Emissions

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	2	3	2	4	5
NO_x	2	13	2	4	13
HC	0	74	0	5	74
Particulates	0	23	2	4	19
CO	0	82	0	4	80

Milwaukee Emissions as a Percentage of Buffalo Emissions

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	2	4	2	6	7
NO_x	4	24	4	8	24
HC	0	100	0	8	107
Particulates	0	21	2	4	23
CO	0	115	0	5	113

Buffalo Emissions as a Percentage of Cincinnati Emissions

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	65	70	73	66	64
NO_x	38	53	54	51	53
HC	50	71	67	65	69
Particulates	105	108	100	89	81
CO	83	72	70	86	71

based and, in the year 2000, approximately 80% will be oil, with the remainder, coal. The air pollutant trends in Buffalo are similar to those in Cincinnati, since oil-fired power plant emissions are similar to coal-fired power plant emissions. The SO_x emissions for the EHVs exceed by 8-20 times those generated by equivalent CV VMT in 1990 and by 13-17 times in 2000.

6. The 1979 NSPS have no effect in Buffalo in 1990 because of the assumption that all electricity will be provided by oil-fired power plants, and only minimal effect in 2000. The 1979 NSPS reduce the SO_x emissions in 2000 due to EHV battery charging by about 5% in LOW I, by about 15-20% in LOW II and MEDIUM, and by about 25% in HIGH I and HIGH II. In all cases, the SO_x emissions exceed those from the corresponding CV mileage.

The most striking differences in emissions occur between Milwaukee, which is predominantly nuclear, and Cincinnati, which is predominantly coal-based (see Tables D.25 and D.26). The notable differences are in SO_x emissions and, to some extent, in NO_x and particulates. This is not surprising, since HC and CO are emitted in greater quantities from CVs. Irrespective of pollutants, in 1990 Milwaukee area power plants emit 0-7% of the power plant emissions in Cincinnati due to EHV VMT. In the year 2000, EHV-related emissions in Milwaukee may be: (1) 2-5% of the SO_x emissions in Cincinnati; (2) 2-4% of the NO_x emissions for the three EV-only scenarios and 13% for the two scenarios with HVs; (3) 0-4% of the particulate emissions for the EV-only scenarios and 19-23% for the scenarios with HVs; and (4) 0-5% of the HC and CO emissions for the EV-only scenarios and 74-82% for the scenarios with HVs. For all emissions except SO_x in 2000, the totals due to EHVs converge slightly because of increased use of coal in Milwaukee and of nuclear power in Cincinnati.

The projected difference between Milwaukee and Buffalo, the latter providing predominantly oil-fired energy, is less striking. In 1990, about 5% of Milwaukee's power comes from coal and 100% of Buffalo's power comes from oil. Therefore, it is not surprising that Milwaukee EHV-related SO_x emissions are about 2-13% of those emitted in Buffalo. For NO_x, Milwaukee EHV emissions are about 15-40% of Buffalo's in all scenarios; for particulates, Milwaukee emissions are insignificant in comparison to Buffalo's. In 2000, the trends change slightly because approximately 2.5% of Milwaukee's electricity will be from coal, while Buffalo's electricity will be about 20% coal-based. Milwaukee EHV-related SO_x emissions are less than 10% of Buffalo SO_x emissions in all scenarios. Milwaukee NO_x emissions are 4-8% of Buffalo emissions in the EV-only scenarios and about 25% in the scenarios with HVs.

The differences between Buffalo and Cincinnati are even less striking.

Dallas and San Diego are large UAs with low EHV market penetration but with different primary sources of fuel used in power plants. Tables D.27-D.29 present the comparison.

1. San Diego, which is regulated by California standards, has slightly lower CV emission rates for NO_x, CO, and HC. The California emission rates are 75-100% of the national rates, depending on the pollutant and vehicle type. The particulate and SO_x rates are the same. The slight difference in emission rates does not significantly affect emission trends.

Table D.27. San Diego Vehicle and Power Plant Emissions to the Air Due to the Operation of EHVs and the Same VMT by CVs, by Scenario, 1990 and 2000 (10^6 lb)

Total EHV Emissions, 1990

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	0.06	0.1	0.1	0.4	0.4
NO_x	0.02	0.06	0.05	0.2	0.22
HC	0	0.02	0	0	0.02
Particulates	0.01	0.02	0.02	0.05	0.06
CO	0	0.17	0.01	0.02	0.22

Emissions if VMT by CVs, 1990

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	0.01	0.01	0.02	0.06	0.06
NO_x	0.10	0.17	0.22	0.51	0.54
HC	0.09	0.16	0.19	0.43	0.47
Particulates	0.02	0.04	0.04	0.13	0.14
CO	0.97	1.61	1.71	4.73	4.85

Total EHV Emissions, 2000

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	0	0.02	0.01	0.1	0.25
NO_x	0	0.14	0	0.04	1.92
HC	0	0.25	0	0	1.49
Particulates	0	0.14	0	0.01	0.52
CO	0	7.31	0	0	14.05

Emissions if VMT by CVs, 2000

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	0.14	0.26	0.47	1.33	1.33
NO_x	1.50	3.01	4.74	14.90	15.79
HC	1.17	2.37	3.68	11.71	12.49
Particulates	0.40	0.82	1.29	4.11	4.82
CO	11.31	22.72	35.27	110.84	118.89

Table D.28. Dallas Vehicle and Power Plant Emissions to the Air Due to the Operation of EHVs and the Same VMT by CVs, by Scenario, 1990 and 2000 (10^6 lb)

Total EHV Emissions, 1990

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	0.1	0.3	0.3	0.8	0.8
NO_x	0.08	0.12	0.2	0.4	0.52
HC	0	0.02	0	0.01	0.03
Particulates	0.01	0.02	0.02	0.06	0.07
CO	0	0.19	0.01	0.02	0.23

Emissions if VMT by CVs, 1990

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	0.01	0.01	0.02	0.05	0.05
NO_x	0.08	0.14	0.18	0.44	0.45
HC	0.08	0.15	0.18	0.42	0.44
Particulates	0.02	0.03	0.04	0.11	0.11
CO	0.91	1.63	1.97	2.80	4.77

Total EHV Emissions, 2000

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	1.3	2.94	4.1	13.9	14.57
NO_x	0.8	2.14	2.4	8.1	10.56
HC	0.01	0.42	0.04	0.1	2.01
Particulates	0.11	0.31	0.3	1.2	1.76
CO	0.04	4.12	0.1	0.4	20.20

Emissions if VMT by CVs, 2000

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	0.12	0.23	0.38	1.08	1.09
NO_x	1.26	2.64	3.88	12.20	13.13
HC	1.09	2.31	3.29	10.39	11.42
Particulates	0.33	0.69	1.02	3.24	3.46
CO	11.37	24.00	34.07	107.20	118.01

Table D.29. Comparison of Emissions Due to EHV Operation, by Scenario, San Diego and Dallas, 1990 and 2000

San Diego Emissions as a Percentage of Dallas Emissions, 1990

Pollutant	Scenario LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	60	33	33	50	50
NO_x	25	50	25	50	42
HC	100	100	100	0	67
Particulates	100	100	100	83	86
CO	100	89	100	100	96

San Diego Emissions as a Percentage of Dallas Emissions, 2000

Pollutant	Scenario LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	0	0.7	0.2	0.7	2
NO_x	0	7	0	0.5	18
HC	0	60	0	0	74
Particulates	0	45	0	0.8	30
CO	0	56	0	0	70

2. In 1990, 55% of San Diego EHV electricity is supplied by oil-fired power plants, while 45% is supplied by nuclear plants. The projection shows that in 2000, only 0.2% is from oil-fired power plants, and 99.8% from nuclear plants. It is not surprising, therefore, that EHV SO_x emissions exceed those of the BASE scenario in 1990 but are less than those of the BASE scenario in 2000.

3. Since San Diego is projected to use no coal-fired power plants, 1979 NSPS have no effect on estimated SO_x and NO_x emissions. As with all other UAs, federal regions, and the nation, EHV VMT-related particulates are reduced by 70%.

4. Coal-fired power plants are projected to provide all of the electricity in Dallas in 1990 but only 65% by 2000. The remaining plants in 2000 are nuclear. In both years, EHV SO_x emissions exceed those of the BASE scenario.

5. The 1979 NSPS reduce EHV SO_x by 65% in 1990 and 90% in 2000, but emissions still exceed those generated by equivalent CV VMT. The 1979 NSPS reduce the EHV NO_x emissions by nearly 30% in the EV-only scenarios and by approximately 25% in the two scenarios with HVs in 1990; comparable percentage reductions occur in 2000.

The greatest difference between San Diego and Dallas is in 2000, when San Diego's power is predominantly nuclear. In 2000, San Diego EHV-related SO_x emissions are less than 2% of those emitted in Dallas. Table D.29 presents the results for each pollutant.

Medium-sized UAs with a high EHV market penetration but with different sources of fuel for electricity generation for EHVs are represented by Grand Rapids, Albuquerque, and Orlando. Their emissions are shown in Tables D.30-D.33.

1. In 1990, 90% of the off-peak electricity in Grand Rapids is projected to be generated by coal and the remainder to be generated by nuclear plants. In 2000, only 0.4% is generated by coal and 99.6% by nuclear. Such a change causes EHV-related SO_x emissions to vary greatly. In 1990, EHV SO_x emissions exceed by 10 to 15 times the emissions generated by equivalent CV VMT. In 2000 in all scenarios, EHV SO_x emissions are less than those of CVs.
2. The 1979 NSPS affect the SO_x emissions in 1990 and 2000. In 1990, they reduce EHV SO_x emissions by 65%; when significantly less coal is used in 2000, SO_x emissions for the EV-only scenarios are reduced by 65% and by 35-40% for the scenarios with HVs. However, the absolute reduction in emissions is significantly less in 2000, because much less coal is used to supply the necessary energy.
3. In both 1990 and 2000 in Albuquerque, 100% of the electricity to charge EHV batteries comes from coal-fired power plants. As a result, SO_x emissions associated with the EHV scenarios are substantially greater than those associated with the BASE scenario. EHV NO_x emissions are either virtually the same as or less than the NO_x emissions of the BASE scenario.
4. The 1979 NSPS have a substantial effect in Albuquerque because of the sole use of coal. In 1990 and 2000, the 1979 NSPS reduce EHV SO_x emissions by 92%. In 1990, EHV SO_x emissions are approximately the same as those of CVs. In 2000, EHV SO_x emissions are only 50-60% greater than the emissions generated by equivalent CV mileage. This represents a significant improvement. In 1990 and 2000, EHV-related NO_x emissions are reduced by 25-30%. The overall effect is that the NO_x emissions of the EHV scenarios are always less than those of the BASE scenario.

Table D.30. Grand Rapids Vehicle and Power Plant Emissions to the Air Due to the Operation of EHVs and the Same VMT by CVs, by Scenario, 1990 and 2000 (10^6 lb)

Total EHV Emissions, 1990

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	0.05	0.08	0.1	0.3	0.3
NO_x	0.03	0.06	0.07	0.2	0.21
HC	0	0.01	0	0	0.01
Particulates	0	0.01	0.01	0.02	0.02
CO	0	0.05	0	0.01	0.08

Emissions if VMT by CVs, 1990

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	0	0	0.01	0.02	0.02
NO_x	0.04	0.06	0.09	0.21	0.21
HC	0.04	0.06	0.08	0.17	0.17
Particulates	0.01	0.01	0.02	0.05	0.05
CO	0.45	0.65	0.97	1.95	1.94

Total EHV Emissions, 2000

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	0	0.02	0.01	0.1	0.14
NO_x	0	0.11	0.01	0.07	0.57
HC	0	0.10	0	0	0.42
Particulates	0	0.03	0	0.01	0.15
CO	0	0.98	0	0	4.27

Emissions if VMT by CVs, 2000

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	0.05	0.08	0.15	0.43	0.40
NO_x	0.49	0.92	1.54	4.97	4.79
HC	0.41	0.77	1.26	4.07	3.99
Particulates	0.13	0.24	0.42	1.36	1.30
CO	4.22	7.95	12.93	41.62	40.98

Table D.31. Albuquerque Vehicle and Power Plant Emissions to the Air Due to the Operation of EHVs and the Same VMT by CVs, by Scenario, 1990 and 2000 (10^6 lb)

Total EHV Emissions, 1990

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	0.06	0.1	0.1	0.3	0.3
NO_x	0.04	0.07	0.08	0.2	0.21
HC	0	0.01	0	0	0.01
Particulates	0.01	0.01	0.01	0.03	0.03
CO	0	0.07	0.004	0.01	0.1

Emissions if VMT by CVs, 1990

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	0	0	0.01	0.02	0.02
NO_x	0.04	0.06	0.09	0.22	0.22
HC	0.04	0.06	0.08	0.20	0.20
Particulates	0.01	0.02	0.02	0.05	0.05
CO	0.43	0.68	0.88	2.10	2.13

Total EHV Emissions, 2000

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	0.9	1.81	2.9	9.6	9.05
NO_x	0.5	1.25	1.7	5.6	5.98
HC	0.01	0.14	0.03	0.09	0.64
Particulates	0.08	0.24	0.2	0.8	0.97
CO	0.03	1.34	0.09	0.3	5.95

Emissions if VMT by CVs, 2000

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	0.05	0.10	0.18	0.54	0.50
NO_x	0.61	1.17	1.96	6.48	6.22
HC	0.51	0.98	1.60	5.25	5.14
Particulates	0.17	0.32	0.54	1.79	1.71
CO	5.21	10.02	16.32	53.46	52.46

Table D.32. Orlando Vehicle and Power Plant Emissions to the Air Due to the Operation of EHVs and the Same VMT by CVs, by Scenario, 1990 and 2000 (10^6 lb)

Total EHV Emissions, 1990

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	0.06	0.09	0.1	0.3	0.3
NO_x	0.02	0.04	0.05	0.1	0.11
HC	0	0.01	0	0	0.01
Particulates	0.01	0.01	0.02	0.04	0.04
CO	0	0.08	0.01	0.01	0.11

Emissions if VMT by CVs, 1990

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	0	0.01	0.01	0.03	0.03
NO_x	0.05	0.08	0.11	0.26	0.27
HC	0.05	0.08	0.11	0.21	0.25
Particulates	0.01	0.02	0.03	0.06	0.06
CO	0.58	0.89	1.21	2.74	2.75

Total EHV Emissions, 2000

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	0.9	1.51	2.2	6.8	6.36
NO_x	0.4	0.87	1.1	3.6	4.15
HC	0.01	0.17	0.02	0.06	0.68
Particulates	0.11	0.20	0.19	0.6	0.80
CO	0.04	1.58	0.08	0.26	6.17

Emissions if VMT by CVs, 2000

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	0.07	0.12	0.22	0.65	0.60
NO_x	0.76	1.41	2.36	7.56	7.30
HC	0.64	1.21	1.96	6.31	6.21
Particulates	0.20	0.37	0.63	2.04	1.95
CO	6.66	12.48	20.26	64.77	63.89

Table D.33. Comparison of Emissions Due to EHV Operation, by Scenario, Albuquerque, Grand Rapids, and Orlando, 1990 and 2000

Grand Rapids Emissions as a Percentage of Albuquerque Emissions, 1990

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	83	80	100	100	100
NO_x	75	86	88	100	100
HC	100	100	100	100	100
Particulates	0	100	100	67	67
CO	100	71	100	100	80

Grand Rapids Emissions as a Percentage of Orlando Emissions, 1990

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	83	89	100	100	100
NO_x	150	150	140	200	191
HC	100	100	100	100	100
Particulates	0	100	50	50	50
CO	100	63	0	100	73

Orlando Emissions as a Percentage of Albuquerque Emissions, 1990

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	100	90	100	100	100
NO_x	50	57	63	50	52
HC	100	100	100	100	100
Particulates	100	100	200	133	133
CO	100	114	250	100	110

Table D.33. (Cont'd)

Grand Rapids Emissions as a Percentage of Albuquerque Emissions, 2000

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	0	1	0.3	1	2
NO_x	0	9	0.6	1	10
HC	0	71	0	0	66
Particulates	0	13	0	1	15
CO	0	73	0	0	72

Grand Rapids Emissions as a Percentage of Orlando Emissions, 2000

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	0	1	0.5	1	2
NO_x	0	13	0.9	2	14
HC	0	59	0	0	62
Particulates	0	15	0	2	19
CO	0	62	0	0	64

Orlando Emissions as a Percentage of Albuquerque Emissions, 2000

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	100	83	76	71	70
NO_x	80	70	65	64	69
HC	100	121	67	67	106
Particulates	138	83	95	75	81
CO	133	118	89	87	113

5. In 1990, Orlando EHV electricity is provided entirely by oil. However, the projections show 42% oil, 28% coal, and 30% nuclear power plants for 2000. As a result of this mix of fuels, the SO_x emissions associated with the EHV scenarios exceed the BASE scenario in both 1990 and 2000.

6. The 1979 NSPS affect only the particulate emissions in 1990 but also affect the SO_x and NO_x emissions

in 2000 because of the mix of fuels. The 2000 EHV SO_x emissions are reduced by just over 15% in LOW I, nearly 30% in LOW II, 35% in MEDIUM, and 55% in HIGH I and HIGH II. Despite these reductions, the SO_x emissions are still higher in the EHV scenarios as compared to the BASE scenario.

The trends in 1990 and 2000 are significantly different because of the fuel mix in each of the UAs (see Table D.33). In 1990, emissions in the three UAs are fairly similar. In 2000, significant differences are apparent. The greatest differences are between Albuquerque and Grand Rapids. In 2000, only 0.4% of the energy in Grand Rapids is supplied by coal and the remainder by nuclear power. In Albuquerque, 100% of the energy is supplied by coal. In the EV-only scenarios, Grand Rapids produces less than or equal to 1% of the EHV-related emissions produced in Albuquerque with respect to all of the pollutants. In the scenarios with HVs, Grand Rapids produces 1-15% of what is produced in Albuquerque for SO_x, NO_x, and particulate emissions and 65-75% of what is emitted in Albuquerque for HC and CO. The dramatic differences result from the gasoline-powered HV VMT. The differences between the emissions in Grand Rapids and Orlando are similar as shown in the tables. There are virtually no differences between Orlando and Albuquerque in 2000.

Two UAs, Little Rock and Chattanooga, are considered in the category of medium-sized UAs with low EHV market penetration. Little Rock represents a predominance of nuclear-supplied energy and Chattanooga a predominance of coal-supplied energy. Tables D.34-D.36 present this comparison.

1. Electricity generated in Little Rock is 59% nuclear and 41% coal in 1990. In 2000, nuclear power plants supply 93% of the electricity, with coal supplying the rest. Between 1990 and 2000, EHV SO_x emissions increase, but the percentage by which the SO_x emissions for EHV scenarios exceed the BASE scenario is smaller than in many other UAs because of lower EHV market penetration.
2. Because of lower market penetration, the NSPS impacts are less. However, the 1979 NSPS reduce the 1990 and 2000 EHV SO_x emissions by about 55%.
3. In Chattanooga 100% of the energy is supplied by coal in 1990, and 82% in the year 2000, with the remaining 18% derived from nuclear power. The predominant use of coal, particularly in 1990, is reflected in the EHV SO_x emissions, which exceed those generated by CVs.
4. The 1979 NSPS reduce the 1990 and 2000 EHV SO_x emissions by approximately 65%.

As anticipated, Little Rock emits fewer EHV-related pollutants than Chattanooga for all of the scenarios. The trend is more pronounced in the year 2000, when Little Rock becomes almost totally dependent on nuclear power.

Table D.34. Little Rock Vehicle and Power Plant Emissions to the Air Due to the Operation of EHVs and the Same VMT by CVs, by Scenario, 1990 and 2000 (10^6 lb)

Total EHV Emissions, 1990

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	0.01	0.03	0.03	0.08	0.08
NO_x	0.01	0.01	0.02	0.04	0.05
HC	0	0	0	0	0
Particulates	0	0	0	0	0
CO	0	0.03	0	0	0.05

Emissions if VMT by CVs, 1990

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	0.002	0.003	0.004	0.01	0.01
NO_x	0.02	0.04	0.05	0.11	0.12
HC	0.02	0.04	0.04	0.11	0.11
Particulates	0.01	0.01	0.01	0.02	0.03
CO	0.24	0.40	0.50	1.14	1.17

Total EHV Emissions, 2000

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	0.03	0.09	0.1	0.5	0.53
NO_x	0.02	0.13	0.07	0.3	0.68
HC	0	0.07	0	0	0.32
Particulates	0	0.03	0.01	0.04	0.14
CO	0	0.77	0	0.02	3.28

Emissions if VMT by CVs, 2000

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	0.02	0.05	0.09	0.27	0.27
NO_x	0.31	0.64	0.98	3.14	3.26
HC	0.27	0.55	0.82	2.62	2.78
Particulates	0.08	0.17	0.26	0.85	0.87
CO	2.77	5.70	8.42	26.92	28.60

Table D.35. Chattanooga Vehicle and Power Plant Emissions to the Air Due to the Operation of EHVs and the Same VMT by CVs, by Scenario, 1990 and 2000 (10^6 lb)

Total EHV Emissions, 1990

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	0.03	0.05	0.06	0.1	0.1
NO_x	0.01	0.03	0.03	0.08	0.08
HC	0	0	0	0	0
Particulates	0	0	0	0.01	0.01
CO	0	0.03	0	0	0.03

Emissions if VMT by CVs, 1990

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	0.001	0.002	0.03	0.01	0.01
NO_x	0.02	0.03	0.04	0.09	0.09
HC	0.02	0.03	0.04	0.08	0.09
Particulates	0	0.01	0.01	0.02	0.02
CO	0.19	0.41	0.41	0.90	0.93

Total EHV Emissions, 2000

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	0.3	0.71	1.0	3.4	3.52
NO_x	0.2	0.47	0.6	2.0	2.29
HC	0	0.07	0.01	0.03	0.28
Particulates	0.03	0.08	0.08	0.3	0.38
CO	0.01	0.62	0.03	0.1	2.63

Emissions if VMT by CVs, 2000

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	0.02	0.04	0.07	0.21	0.21
NO_x	0.25	0.50	0.76	2.44	2.54
HC	0.21	0.43	0.64	2.04	2.16
Particulates	0.06	0.13	0.25	0.66	0.68
CO	2.16	4.43	6.55	20.93	22.23

Table D.36. Comparison of Emissions Due to EHV Operation, by Scenario, Little Rock and Chattanooga, 1990 and 2000

Little Rock Emissions as a Percentage of Chattanooga Emissions, 1990

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	33	60	50	80	80
NO_x	100	33	67	50	50
HC	0	0	0	0	0
Particulates	0	0	0	0	0
CO	0	100	0	0	167

Little Rock Emissions as a Percentage of Chattanooga Emissions, 2000

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	10	13	10	15	15
NO_x	10	28	12	15	30
HC	0	100	0	0	114
Particulates	0	38	13	13	37
CO	0	124	0	20	125

D.2.3.6 EHV Impact on Total Emissions in Large UAs

Reference D.16 provides projections to the year 2000 of total emissions from all sources for the 24 AQCRs with the largest populations. These are baseline emissions that assume no EHV penetration. Five of the 10 UAs selected for analysis are included in these 24 AQCRs: Milwaukee, Cincinnati, Buffalo, San Diego, and Dallas. The impact of the emissions totals projected in this analysis on total emissions of the five AQCRs is examined below.

To determine the overall air quality impact of EHV penetration relative to the total air pollutant loading from all sources for the AQCRs cited above, EHV emissions for a given UA in a given year are added to the total emissions for the AQCR in which the UA is included and the CV emissions for equivalent VMT are subtracted. The resulting emission totals (with EHV penetration) are then divided by the baseline emission totals (assuming no EHVs) to determine the relative impact of EHV penetration on the total emissions in the AQCR. The results are shown in Tables D.37 and D.38. The ratios presented for AQCRs are assumed, for the purposes of this analysis, to apply to the UAs themselves.

Table D.37. Ratio of EHV Scenario to BASE Scenario Air Pollutant Loadings from All Sources for Selected AQCRs, 1990

Cincinnati

	Scenario				
Pollutant	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	1.000	1.001	1.000	1.001	1.002
NO_x	1.000	1.000	1.000	1.000	1.000
HC	1.000	1.000	0.999	0.999	0.999
Particulates	1.000	1.000	1.000	1.000	1.000
CO	0.998	0.998	0.997	0.992	0.992

Milwaukee

	Scenario				
Pollutant	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	1.000	1.000	1.000	1.000	1.000
NO_x	1.000	0.999	0.999	0.998	0.998
HC	1.000	1.000	1.000	1.000	1.000
Particulates	1.000	1.000	1.000	0.999	0.999
CO	0.999	0.998	0.998	0.995	0.995

San Diego

	Scenario				
Pollutant	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	1.001	1.002	1.002	1.008	1.009
NO_x	0.999	0.999	0.999	0.998	0.997
HC	1.000	0.999	0.999	0.998	0.998
Particulates	1.000	1.000	1.000	0.998	0.998
CO	0.998	0.998	0.997	0.992	0.992

Dallas

	Scenario				
Pollutant	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	1.000	1.000	1.001	1.002	1.002
NO_x	1.000	0.999	1.000	1.000	1.000
HC	1.000	1.000	1.000	0.999	0.999
Particulates	0.999	1.000	1.000	1.000	1.000
CO	0.999	0.999	0.997	0.998	0.997

Buffalo

	Scenario				
Pollutant	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	1.000	1.000	1.000	1.002	1.002
NO_x	1.000	0.999	0.999	0.999	0.999
HC	0.999	0.999	0.999	1.002	0.998
Particulates	1.000	0.999	1.000	0.999	0.999
CO	0.998	0.998	0.997	0.993	0.993

Table D.38. Ratio of EHV Scenario to BASE Scenario Air Pollutant Loadings from All Sources for Selected AQCRs, 2000

Cincinnati

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	1.005	1.010	1.015	1.052	1.050
NO_x	0.999	0.999	0.998	0.995	1.000
HC	0.999	0.998	0.996	0.986	0.988
Particulates	0.999	0.997	0.994	0.983	0.987
CO	0.979	0.965	0.936	0.797	0.816

Milwaukee

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	0.999	0.999	0.999	1.000	1.000
NO_x	0.996	0.992	0.987	0.957	0.961
HC	0.999	0.998	0.997	0.991	0.992
Particulates	0.998	0.996	0.994	0.979	0.981
CO	0.988	0.979	0.964	0.884	0.892

San Diego

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	0.995	0.992	0.984	0.957	0.962
NO_x	0.988	0.977	0.961	0.879	0.887
HC	0.995	0.991	0.984	0.951	0.954
Particulates	0.993	0.988	0.978	0.931	0.936
CO	0.980	0.972	0.937	0.801	0.811

Dallas

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	1.002	1.004	1.006	1.019	1.020
NO_x	0.999	0.999	0.997	0.992	0.995
HC	0.999	0.998	0.997	0.989	0.990
Particulates	0.999	0.999	0.999	0.998	0.998
CO	0.992	0.985	0.975	0.922	0.928

Buffalo

Pollutant	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
SO_x	1.006	1.013	1.021	1.064	1.061
NO_x	0.996	0.996	0.991	0.969	0.977
HC	0.995	0.992	0.985	0.952	0.958
Particulates	0.998	0.997	0.991	0.972	0.978
CO	0.982	0.971	0.946	0.828	0.847

From these tables and the previous analysis, the following conclusions can be made:

1. The UAs that benefit most from the introduction of EHVs are those that use nuclear power as a primary source of electrical energy. This is because fossil-fuel power plant emissions are not being substituted for emissions from the CVs that can be replaced by EHVs.
2. In 1990, the UAs with and without EHVs have essentially the same quantity of SO_x emissions. Averaged over the five UAs, SO_x emissions increase by approximately 0.1% under the EHV scenarios.
3. By 2000, SO_x emissions increase due to greater EHV penetration. In Cincinnati, overall SO_x emissions increase by as much as 5%. In Dallas, SO_x emissions increase 0.2-2.0%. In Buffalo, SO_x emissions increase 0.6-2.0% in the LOW and MEDIUM scenarios, and 6.0-6.5% in the HIGH scenarios. In Milwaukee and San Diego, where there is greater use of nuclear energy, EHV penetration decreases areawide SO_x emissions. In Milwaukee, SO_x emissions decrease by approximately 0.1%; and in San Diego by anywhere from 0.5% to 4.0%, depending on the scenario.
4. In 1990, NO_x, HC, particulate, and CO emissions decrease as a result of EHV penetration. For NO_x, emissions are reduced 0.1-0.3%; for HC and particulates, 0.1-0.2%; and for CO, 0.1-0.8%. The largest reductions are in the HIGH scenarios where the penetration rate is higher.
5. In 2000, the NO_x, HC, particulate, and CO trends are similar to those in 1990. As with other pollutants, the greatest difference between the EHV scenarios and the BASE scenario occurs when nuclear energy predominates and in the HIGH scenarios. EHV use reduces NO_x emissions in San Diego by 1.0-4.0% in the LOW and MEDIUM scenarios, and 12.0-14.0% in the HIGH scenarios. In Milwaukee, NO_x is reduced 0.4-1.3% in the LOW and MEDIUM scenarios, and 4% in the HIGH scenarios. The trends are not so pronounced in the other UAs, where coal and oil are the primary sources of energy. In Cincinnati and Dallas, NO_x emissions are reduced 0.1-0.5% over all scenarios; in Buffalo, the NO_x emissions are reduced 0.4-2.3%. In 2000, HC emissions are reduced in all UAs from 0.1-5.0% for all EHV scenarios. Likewise, particulates are reduced 0.1-7.0% for all scenarios. Carbon monoxide emissions are reduced up to 20%. The CO reduction averages 3% for the LOW and MEDIUM scenarios, and 15% for the HIGH scenarios. The overall average reduction in CO emissions over all scenarios is 8%.

While total SO_x emissions in UAs generally increase over the BASE scenario with EHV penetration, they do so in the context of what Refs. D.16 and D.17 project to be declining SO_x burdens for many AQCRs. Of the 24 AQCRs examined in Ref. D.16, 15 have lower SO_x totals in 2000 than in 1975 and none of the 24 are projected to exceed the primary SO_x standard in 2000. In 1975, four of the 24 AQCRs exceeded the SO_x standard. In Ref. D.17, a more recent analysis, 18 of the 24 AQCRs have lower SO_x totals in 2000 than in 1975, and just one of the 24 is projected to exceed the primary standard in 2000. These projections are based on stringent control of power plants, including: (1) stringent standards in state implementation plans (SIPS) affecting existing power plants, (2) retirement of many existing plants, (3) compliance with NSPS for new power plants, and (4) construction of many new power plants away from AQCRs that contain UAs. Thus, these two references conclude that, even with significant EHV penetration (such as that of the HIGH scenarios), total SO_x emissions in such AQCRs will not increase significantly. At the same time, the impact of EHVs is anticipated to be measureable and significantly more important in certain areas.

D.2.3.7 Localized Air Quality Impacts

Carbon monoxide as a pollutant is most appropriately examined at the local level. In this section, the formation of CO hotspots and their mitigation through EHV penetration are discussed. Other EHV-related air pollutant impacts at the microscale also are briefly mentioned.

A CO hotspot is a localized area of ambient concentration at levels pervasively or potentially above either the one-hour or eight-hour CO national standard. Increasingly, the potential of a location to be "hot" is getting more attention than a record of pervasive violations at a site. This is principally because examples of the latter are in short supply and, supported by knowledge of the relatively linear relationship between CO emission source intensities and ambient concentrations, it is believed that there are now many more potential hotspots, chiefly in urban areas, than have heretofore been discovered or proved. Among the primary characteristics of potential urban CO hotspot locations are weak or irregular atmospheric mixing (lack of turbulence) and regular infusion of CO from either major (e.g., steel mill) or multiple mobile but minor emission sources.

The "street canyon," a relatively narrow rectangular roadway corridor bounded on at least two sides by an unbroken line of taller buildings, is the classic example of a hotspot location. The street-level air circulation pattern identified with the canyon tends to produce a buildup of motor-vehicle-related CO on the leeward side which, combined with background CO concentrations often found in urban areas, may result in violations of standards even if roadway traffic volumes are not in excess of design capacity. Canyon-like conditions also may be created if large traffic volumes in an unenclosed road corridor move so slowly that the usual vehicle-induced, localized air turbulence fails to occur. This can result in elevated CO concentrations along both sides of and to distances well back from the roadway. High-volume intersections also are considered prime CO hotspot candidates because of lower throughput speeds, the likelihood that the intersection is bounded by development, and the high incidence of vehicle idling. In general, the failure of either natural or mechanically induced turbulence to replace air in the vicinity of moderate-to-high-volume roadways over which present-day vehicles operate leads to the creation of CO hotspots.

There is ample evidence that CO hotspots are diminishing in number and may entirely disappear within the near future. This is attributable not to dramatic changes in air circulation patterns but to the significant reduction in CO emissions per vehicle, even at low speeds. Continued turnover in the conventional passenger car and truck populations will result in an even cleaner-running vehicle stream, which is likely to be achieved more rapidly in urban areas because of the higher proportion of late-model cars in operation there (new cars being the first vehicles subject to more stringent emission controls). Trends of monitored CO concentrations support the conjecture that the urban vehicle stream is now emitting considerably less CO than at any time since passage of the 1970 Clean Air Act. For example, in Chicago, the number of monitoring stations recording violations of the eight-hour CO standard has declined from seven in 1975 to two (both located near the heart of downtown) in 1978. There have been no recorded violations of the one-hour standard in Chicago since 1973.[D.18]

In an effort to establish worst-case criteria for CO hotspots, the Division of Air Pollution Control of the Illinois Environmental Protection Agency utilized the HIWAY dispersion model to determine threshold traffic volumes by roadway type (and intersection leg) above which CO violations would occur near the roadway or intersection given maximum likely local atmospheric stability, minimum likely wind speed, and average facility delay time (increase of travel speed). Simulation traffic volumes by link for the Chicago six-county regional highway network were computer-scanned for comparison with these screening volumes, and the results are reported in Ref. D.19. Table D.39 indicates the trend toward elimination of Chicago's CO hotspots as shown in the above reference.

Continued moderate traffic growth through the 1980s is expected at most of the potential violation sites, although a leveling or even a downturn in projected volumes may occur in the 1990s in what are currently the more densely developed parts of the region. Nevertheless, the key factor is that, as the composite emissions of motor vehicles diminish, the minimum threshold

Table D.39. Possible CO Violation Sites in the Chicago Metropolitan Area at End of Years 1977, 1982, and 1987

Facility Type	1977	1982	1987 with IM[a]	1987 without IM
Arterial	4308	2234	6	164
Expressway/freeway	237	101	0	0
Intersection at grade	2480	1310	23	195
Total	7025	3645	29	59

[a] Motor vehicle mandatory emissions inspection and maintenance.

screening traffic volumes become very large -- larger than most present or predicted flows on any single roadway.

These results point to a complete disappearance of CO hotspots in metropolitan Chicago by no later than early 1989. Even without the introduction in 1983 of mandatory vehicle emissions inspection and maintenance (currently required by law under the 1977 Clean Air Act Amendments), the trend indicates such a decline prior to 1990, the first EHV scenario year for which air quality impacts are examined in detail. More recent refinements of these screening volumes have resulted in even higher minimum thresholds for all years.[D.20] Therefore, one can be reasonably confident that the CO hotspot will not remain in the Chicago metropolitan area as a problem subject to amelioration by penetration of EHVs into the vehicle stream by 1990, and in no case by the year 2000. This conclusion should also be true for other regions similar in development stage to Chicago. It is important to note that this conclusion assumes continued timely turnover of the vehicle population (i.e., at or near present rates) and eventual cessation of VMT growth in urban areas of medium to dense development.

None of the above takes into account the growth in stationary and area sources of CO emissions that would characterize a rapidly developing urban region of the kind found in the U.S. sun belt. In order to permit continued industrial, commercial, and population growth, many rapidly developing urban areas have set more stringent emission reduction goals for mobile sources than would otherwise be required merely to attain national air pollutant standards by the end of 1987. To comply fully with current legislation, all communities must demonstrate that local CO concentrations resulting from the combined effect of vehicle movement and stationary source emissions (e.g., space heating and blast furnace combustion) will meet standards by and maintain them after 1987. Therefore, the fact that zero mobile-source-related CO hotspots are expected by 1990 may not be relevant to the needs of a particular community; in fact, it may be necessary to reduce emissions from mobile sources well below local attainment thresholds for the ambient standards to permit location of planned major stationary sources at or near present hotspot sites.

The contribution that EHVs could make to such an emissions reduction is, of course, a function of the percentage of these vehicles in the urban vehicle stream. Computation of EV impact is relatively straightforward, in that each CV that is replaced by an EV corresponds to the replacement of finite and positive ground-level CO emissions by zero ground-level CO emissions for every mile traveled. In the case of HVs, about 65% of such emissions are eliminated on a per mile, per vehicle basis. Table D.40 shows the approximate percentage of the total vehicle stream (disaggregated into passenger cars, buses, and trucks) represented by EVs and HVs for each penetration scenario in 1990 and 2000. It has been assumed that these percentages are characteristic of EHV scenario year urban vehicle flows in the vicinity of roadway locations at which present conditions give rise to the formation of CO hotspots. They are derived from projections by scenario of total VMT by EVs, HVs, and CVs.

No notable impact on motor vehicle CO emission intensities is attributable to EVs or HVs in any of the scenarios for 1990. Using an average urban modal mix (cars, light trucks, medium-to-heavy gasoline trucks, heavy

Table D.40. Percentage EV and HV Participation in Urban Vehicle Streams, by Scenario, 1990 and 2000

1990

Vehicle	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
EV					
Car	0.06	0.06	1.11	0.29	0.24
Bus	1.92	-	7.69	15.38	13.85
Light truck	0.28	0.28	0.52	1.11	1.00
HV					
Car	-	0.03	-	-	0.04
Bus	-	-	-	-	-
Light truck	-	0.14	-	-	0.13
EV + HV					
Car	0.06	0.08	1.11	0.29	0.29
Bus	1.92	1.92	7.69	15.38	13.85
Light truck	0.28	0.41	0.52	1.11	1.13

2000

Vehicle	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
EV					
Car	0.69	0.69	2.85	7.97	6.29
Bus	10.34	10.34	32.76	43.10	20.86
Light truck	3.56	3.56	8.45	23.14	15.76
HV					
Car	-	0.46	-	-	1.68
Bus	-	-	-	-	-
Light truck	-	2.44	-	-	14.73
EV + HV					
Car	0.69	1.16	2.85	7.97	7.97
Bus	10.34	10.34	32.76	43.10	20.86
Light truck	3.56	6.00	8.45	23.14	30.49

diesel trucks, and buses) derived from Ref. D.21 and the emission factors for various CV types shown in Table D.15, a CO composite emission factor of under 20 g/mi in 1990 for the BASE scenario is calculated. Because this factor is relatively low and EHV penetration is low, only the HIGH I and HIGH II EHV truck penetration rates (1%+) affect the individual emission factors by more than a tiny fractional amount.

For 2000, the picture is somewhat different. Although it is hardly imaginable that CO violations will continue to occur except in very isolated, infrequent, and unpredictable circumstances and locations, the contribution of EHVs to maintaining low ambient concentrations is more than just nominal. Based on Table D.40 and present trends in the mix of vehicle types from Ref. D.21, EHVs in the vehicle stream result in from 0.8% (LOW I) to 11.3% (HIGH I) less CO being emitted by mobile sources than in the BASE scenario. For HIGH I in 2000, this implies that the CO composite emission factor for an average urban modal mix declines from about 16.7 g/mi to 14.8 g/mi, with the greatest impact experienced among light trucks. Under the same assumptions, the composite NO_x factor declines from 2.19 g/mi to 1.98 g/mi, and the composite HC factor from 1.57 g/mi to 1.38 g/mi.

The following conclusions can be drawn from the above discussion:

1. Given the expected reduction in emissions by CVs, CO hotspots should generally cease to be a problem by 1990 and 2000.
2. In some areas, however, and particularly in rapidly developing urban regions, it may be necessary to reduce emissions from mobile sources well below the local attainment threshold for the ambient standard. In such areas, EHVs could contribute to emissions reduction to an extent directly proportional to total EHV penetration into the urban vehicle stream.
3. Because EHVs also contribute to reductions of HC and NO_x emissions, they might actually come to play a significant role in the control of localized air pollution incidents if high ambient ozone levels persist as an urban problem or if NO_x hotspots come to be recognized as a phenomenon of certain types of urban development.

Finally, estimates of the impact of EHVs on air quality at the microscale as a result of vehicle accidents, especially those including fires, and the generation of other localized pollutants during normal and abnormal charging (including regenerative braking) are not made in this analysis. This area of EHV impacts should be analyzed for all battery systems assessed.

D.2.3.8 Carbon Dioxide Emissions

The focus of the discussion in Sec. D.2 has thus far been on the air pollutants for which national ambient air quality standards have been promulgated. This section discusses CO_2 generation from vehicle operation, a topic that has elicited considerable interest and concern in recent years.

Background

A steadily increasing rate of discharge of carbon into the atmosphere (chiefly in the form of CO_2) and a global increase in the atmospheric concentration of CO_2 are occurring. That is, since about 1940 the percentage composition of air has been modified by a measurable increase in CO_2 volume. Various projections indicate that the baseline atmospheric CO_2 level of the 1950s could double before the year 2025, based on its recent rate of growth and forecasts of a steep increase through the year 2000 in worldwide combustion of fossil fuels. Global climatic simulation models indicate that, owing to the "greenhouse" effect, this could result in an increase in mean global temperature of 2-4°F, which is enough to precipitate massive climatic changes worldwide and major dislocations of agriculturally viable land.[D.22] However, the explicit limitation of these simulation models is that they have not satisfactorily incorporated the role of the oceans in absorbing large quantities of CO_2 from the atmosphere. It is not yet known whether the assimilative capacities of both the surface and deep water layers of the hydrosphere will be sufficient to offset most of the expected growth in CO_2 emissions.

Current environmental policies treat CO_2 as a benign residual of energy-producing processes. Carbon dioxide is not a toxic gas, while CO, a product of incomplete and/or low-temperature combustion, most certainly is. Reducing emissions of CO (a regulated pollutant) has traditionally centered on technologies that substitute CO_2 for CO as a combustion product (e.g., raising boiler fuel combustion temperatures and installing catalytic converters on motor vehicles). Although this policy is being reconsidered, it is not expected that capture of CO_2 and recovery of its carbon, through, say, conversion to methane, will be an important aspect of fossil fuel combustion for electric power and in motor vehicles prior to 2000. Therefore, virtually all of the CO_2 generated in each of the EHV scenarios will contribute to atmospheric loading. However, even the HIGH scenario totals represent only a tiny fraction of the total CO_2 carbon loading attributable to worldwide fossil fuel combustion in 1990 and 2000.

Method and Assumptions

The algorithm from Ref. D.23 used to compute total carbon loading from CO_2 is:

$$B_a = \sum_i w_i \cdot f_i \cdot F_i \cdot r_{ia} \tag{D.1}$$

where:

B_a = total CO_2 carbon burden of scenario a,

w_i = weight (tons) or volume (ft^3) of fossil fuel i required to produce 10^{12} Btu,

f_i = carbon fraction of fossil fuel i,

F_i = proportion of carbon in i oxidized to CO_2, and

r_{ia} = energy requirement of fossil fuel i in scenario a (10^{12} Btu).

For the EV-only scenarios, i = 1, 2, and 3 (coal, residual oil, and natural gas). For the scenarios with HVs, the loading from gasoline combustion also is estimated. For CVs, only gasoline and diesel fuel combustion are considered. Fossil fuel requirements are determined from the energy and utility analyses (see Apps. C and F).

Table D.41 presents the weight or volume Btu equivalents for each of the fossil fuels in this analysis. For coal, the value is based on the average heating value of eastern and western coal weighted by the forecast proportionate split between these two sources of supply in 1990 and 2000.* For gasoline, diesel fuel, residual oil, and natural gas, the value is obtained from Tables A-3 and A-4 (p. A-4) of Ref. D.24. Table D.42 gives values of f_i an F_i for each fossil fuel.

Results

A summary by EHV scenario of the computed carbon burden of CO_2 is presented in Table D.43. The corresponding CO_2 carbon loading by CVs traveling equivalent mileage is given in Table D.44. In all 1990 scenarios, the total carbon burden of CO_2 attributable to EHV-related combustion exceeds that attributable to CVs by at least 10%. However, only in the 2000 scenarios with HVs does the CO_2 carbon burden with EHV penetration exceed that without it. The EHV CO_2 burden exceeds the CV CO_2 burden in LOW II by 7%, and in HIGH II by 3%. An explanation for the fact that the CO_2 burden is less with EVs than CVs in LOW I, MEDIUM, and HIGH I is that, between 1990 and 2000, an increase occurs in the proportion of nuclear power used for the generation of electricity for charging EHVs. Utilization of nuclear power does not contribute to the CO_2 burden from power plants. Moreover, about 3% of the energy for EVs is supplied by natural gas, which has relatively low carbon content compared to petroleum distillates. In any event, it appears that in no case is the difference between the carbon burden of each EHV scenario and that of the BASE scenario of sufficient magnitude to be considered significant (see Table D.45).

D.2.4 Fuels Production Process Emissions

Tables D.46-D.56 show the national air pollutants generated from the production and transport to utilities and/or service stations (or other vehicle servicing facility) of fuels required for EHV and CV operation. These residual totals are based on the characterization of the fuel production process described in Sec. B.4. They may represent the worst case, because stricter standards are expected for industrial processes within the next five years.

These tables show that generation of particulates and SO_2 in fuels production increases substantially with EHV introduction. Relative to other power plant fuels, production and transport of uranium contributes a greater amount of these pollutants. Additional controls on the gaseous diffusion

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*The share of western coal in total domestic supply is expected to rise from 40% in 1990 to about 50% in 2000.[D.25,D.26] Thermal content per ton of western coal is generally less than that of eastern coal.

Table D.41. Fossil Fuel Weight or Volume Btu Equivalents

Fuel	10^{12} Btu Equivalent 1990	 2000
Coal (bituminous)	47,000 tons	48,000 tons
Gasoline	25,000 tons	25,000 tons
Diesel fuel	25,600 tons	25,600 tons
Residual oil	26,300 tons	26,300 tons
Natural gas	9.5238×10^8 ft^3	9.5238×10^8 ft^3

Table D.42. Fossil Fuel Carbon Fraction and Proportion Oxidized to CO_2

Fuel	Carbon Fraction (f_i)	Proportion of Carbon Oxidized to CO_2 (F_i)	Composite Factor ($f_i \times F_i$)
Coal (bituminous)	0.7	0.99	0.693
Gasoline	0.84[a]	0.915[a]	0.796
Diesel fuel	0.84[a]	0.915[a]	0.796
Residual oil	0.84[a]	0.915[a]	0.796
Natural gas	15.29×10^{-6}[b]	0.97	14.83×10^{-6}

[a] These are average values reflecting the carbon content of crude oil.

[b] 15.29 g/ft^3.

Source: Ref. D.23.

enrichment process or a more rapid conversion to ultracentrifuge technology than is assumed here could reduce this problem.

With EHV market penetration, NO_x generation from fuels production decreases slightly, and HC and CO generation decreases substantially. These pollutants are higher for CVs because of the greater reliance on road transport for the higher-cost, lighter fuels used to operate CVs. More stringent enforcement of mobile source Set II (NO_x, HC, and CO) controls could reduce the Set II burden attributable to CV fuels transport below that for transport of fuels attributable to EHVs.

Table D.43. CO_2 Carbon Burden Generated by EHV Operation by Scenario (10^5 tons)

Fuel	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
1990					
Coal	1.939	3.295	4.230	10.964	10.953
Oil (including gasoline)	0.419	1.098	0.915	2.514	3.014
Natural gas	0.062	0.104	0.132	0.345	0.345
Total	2.420	4.497	5.277	13.82	14.31
2000					
Coal	26.532	52.062	80.731	264.540	256.438
Oil (including gasoline)	5.028	19.384	17.223	63.001	98.362
Natural gas	0.763	1.460	2.246	6.532	6.343
Total	32.38	72.91	100.2	334.1	361.1

Table D.44. CO_2 Carbon Burden of CVs Operating the Same VMT as EHVs, by Scenario (10^5 tons)

Year	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
1990	2.196	3.623	4.754	12.19	12.28
2000	35.07	67.88	111.1	353.1	349.5

Table D.45. EHV CO_2 Carbon Burden as a Fraction of CO_2 Carbon Burden of CVs Operating the Same VMT as EHVs

Year	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
1990	1.102	1.241	1.110	1.134	1.165
2000	0.923	1.074	0.902	0.946	1.033

Table D.46. Air Pollutants from Fuel Produced and Transported to Utility for EHV Operation, LOW I, 1990 (short tons)

Pollutant	Uranium[a]	Coal	Oil[b]	Natural Gas	Total
Particulates	162.1	137.7	4.2	0.1	304.1
SO_2	635.5	21.7	25.8	0.005	683.0
NO_x	171.7	33.8	38.6	2.1	246.2
HC	2.3	16.4	11.2	0.3	30.2
CO	5.1	27.5	19.5	0.003	54.4
Aldehydes	-	3.4	1.7	0.08	5.18

[a] Assumes UF_6 enrichment is 80% by gaseous diffusion method and 20% by gas centrifuge technology.

[b] Assigned as the proportion of process pollutants attributable to the production of the necessary amount of residual fuel oil.

Table D.47. Air Pollutants from Fuel Produced and Transported to Utility and Service Station for EHV Operation, LOW II, 1990 (short tons)

Pollutant	Uranium[a]	Coal	Oil[b]	Natural Gas	Gasoline	Total
Particulates	276.6	234.0	7.1	0.2	4.4	522.3
SO_2	1,083.9	36.8	43.8	0.01	28.2	1192.7
NO_x	292.5	57.4	65.6	3.5	56.7	475.7
HC	4.0	27.9	19.0	0.5	12.9	64.3
CO	8.7	46.7	33.1	0.005	29.4	117.9
Aldehydes	-	5.7	2.8	0.13	1.9	10.5

[a] Assumes UF_6 enrichment is 80% by gaseous diffusion method and 20% by gas centrifuge technology.

[b] Assigned as the proportion of process pollutants attributable to the production of the necessary amount of residual fuel oil.

Table D.48. Air Pollutants from Fuel Produced and Transported to Utility for EHV Operation, MEDIUM, 1990 (short tons)

Pollutant	Uranium[a]	Coal	Oil[b]	Natural Gas	Total
Particulates	355.8	300.4	9.1	0.3	665.4
SO_2	1393.3	47.2	56.3	0.01	1496.8
NO_x	376.0	73.7	84.2	4.5	538.4
HC	5.1	35.8	24.4	0.7	66.0
CO	11.2	60.0	42.5	0.007	113.7
Aldehydes	-	7.4	3.6	1.7	11.2

[a] Assumes UF_6 enrichment is 80% by gaseous diffusion method and 20% by gas centrifuge technology.

[b] Assigned as the proportion of process pollutants attributable to the production of the necessary amount of residual fuel oil.

Table D.49. Air Pollutants from Fuel Produced and Transported to Utility for EHV Operation, HIGH I, 1990 (short tons)

Pollutant	Uranium[a]	Coal	Oil[b]	Natural Gas	Total
Particulates	913.5	778.9	24.9	0.8	1717.1
SO_2	3579.8	122.4	154.7	0.02	3856.9
NO_x	966.2	190.9	231.6	11.8	1400.5
HC	13.1	92.9	67.2	1.8	175.0
CO	28.7	155.4	116.9	0.017	301.0
Aldehydes	-	19.1	10.0	0.43	29.5

[a] Assumes UF_6 enrichment is 80% by gaseous diffusion method and 20% by gas centrifuge technology.

[b] Assigned as the proportion of process pollutants attributable to the production of the necessary amount of residual fuel oil.

Table D.50. Air Pollutants from Fuel Produced and Transported to Utility and Service Station for EHV Operation, HIGH II, 1990 (short tons)

Pollutant	Uranium[a]	Coal	Oil[b]	Natural Gas	Gasoline	Total
Particulates	912.6	77.8	24.9	0.8	5.8	1721.0
SO_2	3576.2	122.3	154.6	0.02	36.8	3889.9
NO_x	965.2	190.7	231.3	11.7	73.9	1472.8
HC	13.1	92.8	67.1	1.8	16.8	191.6
CO	28.7	155.2	116.8	0.017	38.4	339.1
Aldehydes	-	19.1	9.9	0.43	2.5	31.9

[a] Assumes UF_6 enrichment is 80% by gaseous diffusion method and 20% by gas centrifuge technology.

[b] Assigned as the proportion of process pollutants attributable to the production of the necessary amount of residual fuel oil.

Table D.51. Air Pollutants from Fuel Produced and Transported to Utility and Service Station for EHV Operation, LOW I, 2000 (short tons)

Pollutant	Uranium[a]	Coal	Oil[b]	Natural Gas	Total
Particulates	3,127.5	1,860.6	49.8	1.8	5,039.0
SO_2	12,331.3	290.6	309.4	0.05	12,931.4
NO_x	3,348.9	449.1	463.1	26.0	4,287.1
HC	43.7	220.1	134.4	3.9	402.1
CO	104.9	364.8	233.8	0.04	703.5
Aldehydes	-	44.6	19.9	0.1	64.6

[a] Assumes UF_6 enrichment is 80% by gaseous diffusion method and 20% by gas centrifuge technology.

[b] Assigned as the proportion of process pollutants attributable to the production of the necessary amount of residual fuel oil.

Table D.52. Air Pollutants from Fuel Produced and Transported to Utility for EHV Operation, LOW II, 2000 (short tons)

Pollutant	Uranium[a]	Coal	Oil[b]	Natural Gas	Gasoline	Total
Particulates	6,034.9	3,642.7	106.7	3.4	98.8	9,886.5
SO_2	23,795.4	569.0	662.5	0.1	629.8	25,836.8
NO_x	6,462.2	879.3	991.5	49.7	1,265.9	9,648.6
HC	84.4	430.9	287.8	7.5	287.3	1,097.9
CO	202.4	714.3	500.4	0.07	657.6	2,074.8
Aldehydes	-	87.3	42.6	1.8	43.1	174.8

[a] Assumes UF_6 enrichment is 80% by gaseous diffusion method and 20% by gas centrifuge technology.

[b] Assigned as the proportion of process pollutants attributable to the production of the necessary amount of residual fuel oil.

Table D.53. Air Pollutants from Fuel Produced and Transported to Utility for EHV Operation, MEDIUM, 2000 (short tons)

Pollutant	Uranium[a]	Coal	Oil[b]	Natural Gas	Total
Particulates	9,307.7	5,648.7	170.7	5.2	15,132.3
SO_2	36,700.0	882.4	1,059.9	0.16	38,642.5
NO_x	9,966.7	1,363.6	1,586.3	76.4	12,993.0
HC	130.1	668.2	460.4	11.5	1,270.2
CO	312.1	1,107.6	800.6	0.1	2,220.4
Aldehydes	-	135.4	68.2	2.8	206.4

[a] Assumes UF_6 enrichment is 80% by gaseous diffusion method and 20% by gas centrifuge technology.

[b] Assigned as the proportion of process pollutants attributable to the production of the necessary amount of residual fuel oil.

Table D.54. Air Pollutants from Fuel Produced and Transported to Utility for EHV Operation, HIGH I, 2000 (short tons)

Pollutant	Uranium[a]	Coal	Oil[b]	Natural Gas	Total
Particulates	28,497.0	18,510.0	624.4	15.1	4.76x10^{4}
SO$_2$	112,360.0	2,891.4	3,876.7	0.5	1.191x10^{5}
NO$_x$	30,514.0	4,468.1	5,802.3	222.3	4.10x10^{4}
HC	398.3	2,189.7	1,684.2	33.5	4,305.7
CO	955.6	3,629.4	2,928.6	0.3	7,513.9
Aldehydes	-	443.6	249.5	8.2	701.3

[a] Assumes UF$_6$ enrichment is 80% by gaseous diffusion method and 20% by gas centrifuge technology.

[b] Assigned as the proportion of process pollutants attributable to the production of the necessary amount of residual fuel oil.

Table D.55. Air Pollutants from Fuel Produced and Transported to Utility and Service Station for EHV Operation, HIGH II, 2000 (short tons)

Pollutant	Uranium[a]	Coal	Oil[b]	Natural Gas	Gasoline	Total
Particulates	27,650.0	17,943.0	604.4	14.7	428.7	4.66x104
SO$_2$	109,025.0	2,802.8	3,752.6	0.4	2,731.4	1.183x105
NO$_x$	29,608.0	4,331.3	5,616.5	215.9	5,490.0	4.53x104
HC	386.5	2,122.6	1,630.2	32.5	1,246.0	5,417.8
CO	927.2	3,518.2	2,834.8	0.3	2,852.1	10,139.8
Aldehydes	-	430.0	241.5	7.9	186.9	866.3

[a] Assumes UF$_6$ enrichment is 80% by gaseous diffusion method and 20% by gas centrifuge technology.

[b] Assigned as the proportion of process pollutants attributable to the production of the necessary amount of residual fuel oil.

Table D.56. Air Pollutants from the Production and Transport to Service Station of Gasoline and Diesel Fuel Required by CVs Operating the Same VMT as EHVs, by Scenario, 1990 and 2000 (short tons)

	1990 Scenario				
Pollutant	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
Particulates	25.2	41.6	54.3	138.6	139.7
SO_2	159.9	264.7	346.0	884.4	891.3
NO_x	321.5	532.1	688.3	1,746.6	1,762.8
HC	73.0	120.8	157.0	399.9	403.3
CO	167.0	276.4	357.4	906.7	915.2
Aldehydes	10.9	18.1	23.5	59.9	60.5

	2000 Scenario				
Pollutant	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
Particulates	401.1	777.5	1,268.8	4,041.2	4,006.1
SO_2	2,556.7	4,954.7	8,088.8	25,756.2	25,527.2
NO_x	5,109.0	9,929.8	16,116.3	51,543.7	51,234.6
HC	1,162.8	2,256.8	3,673.5	11,723.1	11,636.0
CO	2,653.5	5,157.9	8,369.3	26,772.1	26,614.9
Aldehydes	174.4	338.5	550.8	1,758.2	1,745.3

D.3 WATER QUALITY

This analysis discusses projected impacts on water quality in 2000 for the five EHV scenarios. Water pollutants generated from the manufacture and operation (including fuels production for operation) of EHVs are compared with those generated by a corresponding number of CVs. The year 2000 was chosen for analysis, because it was assumed that the impacts of the earlier assessment years (1985 and 1990) would be relatively insignificant.

D.3.1 Vehicle Production

Total national discharges of significant waterborne pollutants are estimated for selected materials required in the domestic manufacture of EHVs and CVs. These totals are based on information provided in Sec. B.3. The materials evaluated are lead, nickel, iron, steel, plastic, aluminum, sulfuric acid, potassium hydroxide, potassium chloride, copper, zinc oxide, lithium sulfide, and lithium chloride. Associated pollutant loadings are estimated for TDS, TSS, BOD (five-day), oil and grease, lead, zinc, other heavy metals and, in some instances, sulfides.

Tables D.57-D.61 summarize the pollutant loadings associated with vehicle production for each of the five scenarios. The pollutant loadings for CVs are for the same number of CVs as EHVs produced in each EHV scenario. National totals are provided in the columns at the far right. The relative impacts of each of the materials are evident. As can be seen, EHV discharges exceed CV discharges in all scenarios.

Not shown in the tables, but provided in Sec. B.3, are the specific phases in product manufacture during which pollutant emissions occur (e.g., milling, mining, and primary refining). Highest discharges are usually associated with the first or second process following actual extraction of the resource. In this analysis, present materials recycling rates are assumed. If the rates were to increase, the total water pollutant load associated with vehicle production would decrease.

Table D.62 provides a comparison of the discharges between each of the EHV scenarios and the discharges for an equivalent number of CVs. Using the results of Tables D.57-D.61, the ratio of EHV to CV pollutant totals is given. Since in all cases EHV discharges exceed CV discharges, the table provides the factor of pollutant increase. Depending on the scenario and pollutant, the factor of increase ranges from 1.2 to 4.6. Comparisons are not provided for pollutants for which no appreciable CV contribution can be identified (e.g., sulfides).

D.3.2 Vehicle Operation

The energy resource allocations by scenario are used to assess the potential water quality implications of alternative scenarios. As shown in App. F, no new utility facility construction with potential water quality impacts would be required, except possibly for five utilities. Given essentially all off-peak charging for EHVs, these five utilities would probably buy from the grid rather than enter into new construction.

Table D.57. Vehicle Production Gross Water Emissions, LOW I EHVs and the Same Number of CVs, 2000

Vehicle and Pollutant	Domestic Sales (10^3)	Material (lb)										
		Lead	Nickel	Iron	Steel	Plastic	Aluminum	H_2SO_4	KOH	Copper	ZnO_2	Total
EHV	751											
TDS[a]		$1.84x10^6$	-	$1.97x10^5$	$1.38x10^6$	$1.82x10^5$	-	$1.18x10^4$	-	$4.60x10^4$	$1.38x10^4$	$3.67x10^6$
BOD_5[b]		-	$1.89x10^4$	$8.90x10^4$	$5.36x10^5$	$9.95x10^3$	-	-	-	$5.73x10^4$	$1.66x10^3$	$7.13x10^5$
Oil and grease		$2.87x10^4$	$2.26x10^2$	$1.43x10^3$	$8.67x10^3$	$7.54x10^1$	$2.26x10^3$	-	-	$9.05x10^2$	$2.26x10^3$	$4.45x10^4$
TSS[c]		$5.88x10^4$	$6.03x10^2$	$6.18x10^3$	$4.07x10^4$	$6.71x10^3$	$8.82x10^4$	$2.94x10^3$	$5.00x10^4$	$7.37x10^4$	$2.83x10^4$	$3.56x10^5$
Lead		$9.05x10^2$	-	$6.58x10^1$	$3.99x10^2$	-	-	-	-	-	-	$1.37x10^3$
Zinc		$1.21x10^3$	-	$5.48x10^1$	$3.32x10^2$	-	-	-	-	-	-	$1.60x10^3$
Heavy metals		-	-	$3.77x10^2$	$2.04x10^3$	$7.54x10^1$	$2.84x10^4$	-	-	$4.92x10^4$	$1.91x10^4$	$9.92x10^4$
Sulfides		-	-	-	-	-	-	$9.80x10^2$	-	-	-	$9.80x10^2$
CV	751											
TDS		-	-	$1.85x10^5$	$1.34x10^6$	$1.16x10^5$	-	-	-	-	-	$1.64x10^6$
BOD_5		-	-	$8.29x10^4$	$5.20x10^5$	$6.41x10^3$	-	-	-	-	-	$6.09x10^5$
Oil and grease		-	-	$1.36x10^3$	$8.44x10^3$	$7.54x10^1$	$2.49x10^3$	-	-	-	-	$1.24x10^4$
TSS		-	-	$5.35x10^3$	$4.00x10^4$	$4.37x10^3$	$9.73x10^4$	-	-	-	-	$1.47x10^5$
Lead		-	-	$6.15x10^1$	$3.87x10^2$	-	-	-	-	-	-	$4.49x10^2$
Zinc		-	-	$5.13x10^1$	$3.22x10^2$	-	-	-	-	-	-	$3.73x10^2$
Heavy metals		-	-	$3.02x10^2$	$1.96x10^3$	$7.54x10^1$	$3.13x10^4$	-	-	-	-	$3.36x10^4$
Sulfides		-	-	-	-	-	-	-	-	-	-	-

[a] Total dissolved solids.

[b] Biological oxygen demand (five-day).

[c] Total suspended solids.

Table D.58. Vehicle Production Gross Water Emissions, LOW II EHVs and the Same Number of CVs, 2000

Vehicle and Pollutant	Domestic Sales (10^3)	Material (lb)										
		Lead	Nickel	Iron	Steel	Plastic	Aluminum	H_2SO_4	KOH	Copper	ZnO_2	Total
EHV	1,384											
TDS[a]		3.43×10^{6}	-	4.76×10^{5}	2.62×10^{6}	3.32×10^{5}	-	2.17×10^{4}	-	7.89×10^{4}	1.38×10^{4}	6.97×10^{6}
BOD_5[b]		-	1.94×10^{4}	2.15×10^{5}	1.02×10^{6}	2.44×10^{4}	-	-	-	9.97×10^{4}	1.66×10^{3}	1.38×10^{6}
Oil and grease		5.26×10^{4}	1.38×10^{2}	3.32×10^{3}	1.65×10^{4}	1.38×10^{2}	4.98×10^{3}	-	-	1.52×10^{3}	2.77×10^{2}	7.94×10^{4}
TSS[c]		1.09×10^{5}	6.92×10^{2}	1.49×10^{4}	1.34×10^{5}	1.23×10^{4}	1.97×10^{5}	5.40×10^{3}	4.98×10^{4}	1.28×10^{5}	2.82×10^{4}	6.79×10^{5}
Lead		1.66×10^{3}	-	1.59×10^{2}	7.60×10^{2}	-	-	-	-	-	-	2.58×10^{3}
Zinc		2.21×10^{3}	-	1.33×10^{2}	6.33×10^{2}	-	-	-	-	-	-	2.98×10^{3}
Heavy metals		-	-	6.92×10^{2}	3.88×10^{3}	1.38×10^{2}	7.06×10^{4}	-	-	8.47×10^{4}	1.90×10^{4}	1.79×10^{5}
Sulfides		-	-	-	-	-	-	1.80×10^{3}	-	-	-	1.80×10^{3}
CV	1,384											
TDS		-	-	3.24×10^{5}	2.45×10^{6}	2.21×10^{5}	-	-	-	-	-	4.98×10^{6}
BOD_5		-	-	-	9.55×10^{5}	1.22×10^{4}	-	-	-	-	-	9.67×10^{5}
Oil and grease		-	-	2.35×10^{3}	1.55×10^{4}	1.38×10^{2}	4.57×10^{3}	-	-	-	-	2.26×10^{4}
TSS		-	-	1.02×10^{4}	7.29×10^{4}	1.33×10^{4}	1.86×10^{5}	-	-	-	-	2.82×10^{5}
Lead		-	-	1.09×10^{2}	7.11×10^{2}	-	-	-	-	-	-	8.20×10^{2}
Zinc		-	-	9.07×10^{1}	5.92×10^{2}	-	-	-	-	-	-	6.83×10^{2}
Heavy metals		-	-	5.54×10^{2}	3.60×10^{3}	1.38×10^{2}	5.70×10^{4}	-	-	-	-	6.13×10^{4}
Sulfides		-	-	-	-	-	-	-	-	-	-	-

[a] Total dissolved solids.

[b] Biological oxygen demand (five-day).

[c] Total suspended solids.

Table D.59. Vehicle Production Gross Water Emissions, MEDIUM EHVs and the Same Number of CVs, 2000

Vehicle and Pollutant	Domestic Sales (10^3)	Material (lb)											
		Lead	Nickel	Iron	Steel	Plastic	Aluminum	H_2SO_4	LiS/LiCl	KOH	Copper	ZnO_2	Total
EHV	2,353.88												
TDS[a]		$1.10\mathrm{x}10^{6}$	-	$6.38\mathrm{x}10^{5}$	$4.31\mathrm{x}10^{6}$	$5.48\mathrm{x}10^{5}$	-	$7.06\mathrm{x}10^{3}$	-	-	$1.37\mathrm{x}10^{5}$	$1.49\mathrm{x}10^{5}$	$6.89\mathrm{x}10^{6}$
BOD_5[b]		-	$2.00\mathrm{x}10^{5}$	$2.87\mathrm{x}10^{5}$	$1.69\mathrm{x}10^{6}$	$2.99\mathrm{x}10^{4}$	-	-	-	-	$1.72\mathrm{x}10^{5}$	$1.81\mathrm{x}10^{4}$	$2.40\mathrm{x}10^{6}$
Oil and grease		$1.65\mathrm{x}10^{4}$	$2.35\mathrm{x}10^{3}$	$4.71\mathrm{x}10^{3}$	$2.71\mathrm{x}10^{4}$	$2.35\mathrm{x}10^{2}$	$7.77\mathrm{x}10^{3}$	-	$8.60\mathrm{x}10^{2}$	-	$2.59\mathrm{x}10^{3}$	$2.82\mathrm{x}10^{3}$	$6.49\mathrm{x}10^{6}$
TSS[c]		$3.53\mathrm{x}10^{4}$	$6.59\mathrm{x}10^{3}$	$2.02\mathrm{x}10^{4}$	$1.27\mathrm{x}10^{5}$	$2.02\mathrm{x}10^{4}$	$2.97\mathrm{x}10^{5}$	$1.65\mathrm{x}10^{3}$	$5.73\mathrm{x}10^{3}$	$5.30\mathrm{x}10^{5}$	$2.20\mathrm{x}10^{5}$	$3.07\mathrm{x}10^{5}$	$1.56\mathrm{x}10^{6}$
Lead		$4.70\mathrm{x}10^{2}$	-	$2.13\mathrm{x}10^{2}$	$1.25\mathrm{x}10^{3}$	-	-	-	$4.30\mathrm{x}10^{1}$	-	-	-	$1.98\mathrm{x}10^{3}$
Zinc		$7.06\mathrm{x}10^{2}$	-	$1.78\mathrm{x}10^{2}$	$1.05\mathrm{x}10^{3}$	-	-	-	$4.30\mathrm{x}10^{1}$	-	-	-	$1.98\mathrm{x}10^{3}$
Heavy metals		-	-	$9.42\mathrm{x}10^{2}$	$6.36\mathrm{x}10^{3}$	$2.35\mathrm{x}10^{2}$	$9.46\mathrm{x}10^{4}$	-	$2.29\mathrm{x}10^{2}$	-	$1.46\mathrm{x}10^{5}$	$2.05\mathrm{x}10^{5}$	$4.53\mathrm{x}10^{5}$
Sulfides		-	-	-	-	-	-	$4.71\mathrm{x}10^{2}$	$1.43\mathrm{x}10^{3}$	-	-	-	$1.90\mathrm{x}10^{3}$
CV	2,353.88												
TDS		-	-	$5.79\mathrm{x}10^{5}$	$4.17\mathrm{x}10^{6}$	$3.62\mathrm{x}10^{5}$	-	-	-	-	-	-	$5.11\mathrm{x}10^{6}$
BOD_5		-	-	$2.59\mathrm{x}10^{5}$	$1.63\mathrm{x}10^{6}$	$1.98\mathrm{x}10^{4}$	-	-	-	-	-	-	$1.91\mathrm{x}10^{6}$
Oil and grease		-	-	$4.24\mathrm{x}10^{3}$	$1.46\mathrm{x}10^{4}$	$2.35\mathrm{x}10^{2}$	$7.77\mathrm{x}10^{3}$	-	-	-	-	-	$2.68\mathrm{x}10^{4}$
TSS		-	-	$1.84\mathrm{x}10^{4}$	$1.25\mathrm{x}10^{5}$	$1.34\mathrm{x}10^{4}$	$3.04\mathrm{x}10^{5}$	-	-	-	-	-	$4.61\mathrm{x}10^{5}$
Lead		-	-	$1.93\mathrm{x}10^{2}$	$1.21\mathrm{x}10^{3}$	-	-	-	-	-	-	-	$1.40\mathrm{x}10^{3}$
Zinc		-	-	$1.61\mathrm{x}10^{2}$	$1.01\mathrm{x}10^{3}$	-	-	-	-	-	-	-	$1.17\mathrm{x}10^{3}$
Heavy metals		-	-	$9.42\mathrm{x}10^{2}$	$6.12\mathrm{x}10^{3}$	$2.35\mathrm{x}10^{2}$	$9.79\mathrm{x}10^{4}$	-	-	-	-	-	$1.04\mathrm{x}10^{5}$
Sulfides		-	-	-	-	-	-	-	-	-	-	-	-

[a] Total dissolved solids.

[b] Biological oxygen demand (five-day).

[c] Total suspended solids.

Table D.60. Vehicle Production Gross Water Emissions, HIGH I EHVs and the Same Number of CVs, 2000

Vehicle and Pollutant	Domestic Sales (10^3)	Material (lb)											
		Lead	Nickel	Iron	Steel	Plastic	Aluminum	H_2SO_4	LiS/LiCl	KOH	Copper	ZnO_2	Total
EHV	7,265.17												
TDS[a]		2.20×10^{6}	-	2.44×10^{6}	1.26×10^{7}	1.57×10^{6}	-	1.45×10^{4}	-	-	4.21×10^{5}	3.88×10^{5}	1.96×10^{7}
BOD_5[b]		-	5.23×10^{5}	1.10×10^{6}	4.94×10^{6}	8.57×10^{4}	-	-	-	-	5.30×10^{5}	4.72×10^{4}	7.23×10^{6}
Oil and grease		3.63×10^{4}	6.54×10^{3}	1.74×10^{4}	7.99×10^{4}	7.27×10^{2}	2.62×10^{4}	-	9.56×10^{3}	-	7.99×10^{3}	7.99×10^{3}	1.90×10^{5}
TSS[c]		6.68×10^{4}	1.82×10^{4}	7.63×10^{4}	3.70×10^{5}	5.81×10^{4}	1.05×10^{6}	3.63×10^{3}	6.37×10^{4}	1.38×10^{6}	6.87×10^{5}	8.00×10^{5}	4.58×10^{6}
Lead		7.27×10^{2}	-	8.18×10^{2}	3.68×10^{3}	-	-	-	4.78×10^{2}	-	-	-	5.70×10^{3}
Zinc		1.45×10^{3}	-	6.81×10^{2}	3.07×10^{3}	-	-	-	4.78×10^{2}	-	-	-	5.68×10^{3}
Heavy metals		-	-	3.63×10^{3}	1.82×10^{4}	7.27×10^{2}	3.32×10^{5}	-	2.55×10^{3}	-	4.52×10^{5}	5.35×10^{5}	1.34×10^{6}
Sulfides		-	-	-	-	-	-	1.18×10^{3}	1.59×10^{4}	-	-	-	1.71×10^{4}
CV	7,265.17												
TDS		-	-	1.54×10^{6}	1.18×10^{7}	1.01×10^{6}	-	-	-	-	-	-	1.44×10^{7}
BOD_5		-	-	6.97×10^{5}	4.60×10^{6}	5.81×10^{4}	-	-	-	-	-	-	5.34×10^{6}
Oil and grease		-	-	1.09×10^{4}	7.41×10^{4}	7.27×10^{2}	2.18×10^{9}	-	-	-	-	-	1.08×10^{5}
TSS		-	-	4.43×10^{4}	3.52×10^{5}	4.00×10^{4}	8.94×10^{5}	-	-	-	-	-	1.33×10^{6}
Lead		-	-	5.17×10^{2}	3.42×10^{3}	-	-	-	-	-	-	-	3.94×10^{3}
Zinc		-	-	4.30×10^{2}	2.85×10^{3}	-	-	-	-	-	-	-	3.28×10^{3}
Heavy metals		-	-	2.18×10^{3}	1.60×10^{4}	7.27×10^{2}	2.80×10^{5}	-	-	-	-	-	2.99×10^{5}
Sulfides		-	-	-	-	-	-	-	-	-	-	-	-

[a] Total dissolved solids.

[b] Biological oxygen demand (five-day).

[c] Total suspended solids.

Table D.61. Vehicle Production Gross Water Emissions, HIGH II EHVs and the Same Number of CVs, 2000

Vehicle and Pollutant	Domestic Sales (10^{3})	Material (lb)										
		Lead	Nickel	Iron	Steel	Plastic	Aluminum	H_2SO_4	KOH	Copper	ZnO_2	Total
EHV	7,499											
TDS[a]		1.98×10^{6}	-	2.27×10^{6}	1.32×10^{7}	1.72×10^{6}	-	1.27×10^{4}	-	4.12×10^{5}	4.68×10^{5}	2.01×10^{7}
BOD_5[b]		-	6.30×10^{5}	1.02×10^{6}	5.17×10^{6}	9.45×10^{4}	-	-	-	5.17×10^{5}	5.70×10^{4}	7.49×10^{6}
Oil and grease		3.00×10^{4}	7.50×10^{3}	1.65×10^{4}	8.40×10^{4}	7.50×10^{2}	2.47×10^{4}	-	-	7.50×10^{3}	9.00×10^{3}	1.80×10^{5}
TSS[c]		6.00×10^{4}	2.10×10^{4}	7.12×10^{4}	3.98×10^{5}	6.37×10^{4}	9.75×10^{5}	3.00×10^{3}	1.65×10^{6}	6.70×10^{5}	9.64×10^{5}	4.88×10^{6}
Lead		7.50×10^{2}	-	7.60×10^{2}	3.85×10^{3}	-	-	-	-	-	-	5.36×10^{3}
Zinc		1.50×10^{3}	-	6.33×10^{2}	3.21×10^{3}	-	-	-	-	-	-	5.34×10^{3}
Heavy metals		-	-	3.75×10^{3}	1.95×10^{4}	7.50×10^{2}	3.12×10^{5}	-	-	4.57×10^{5}	6.45×10^{5}	1.44×10^{6}
Sulfides		-	-	-	-	-	-	1.07×10^{3}	-	-	-	1.07×10^{3}
CV	7,499											
TDS		-	-	1.61×10^{6}	1.25×10^{7}	1.15×10^{6}	-	-	-	-	-	1.53×10^{7}
BOD_5		-	-	-	4.90×10^{6}	6.22×10^{4}	-	-	-	-	-	4.96×10^{6}
Oil and grease		-	-	1.12×10^{4}	7.95×10^{4}	7.50×10^{2}	2.25×10^{4}	-	-	-	-	1.14×10^{5}
TSS		-	-	5.10×10^{4}	3.74×10^{5}	4.27×10^{4}	9.67×10^{5}	-	-	-	-	1.43×10^{6}
Lead		-	-	5.40×10^{2}	3.65×10^{3}	-	-	-	-	-	-	4.19×10^{3}
Zinc		-	-	4.54×10^{2}	3.04×10^{3}	-	-	-	-	-	-	3.49×10^{3}
Heavy metals		-	-	2.25×10^{3}	1.65×10^{4}	7.50×10^{2}	2.93×10^{5}	-	-	-	-	3.13×10^{5}
Sulfides		-	-	-	-	-	-	-	-	-	-	-

[a] Total dissolved solids.

[b] Biological oxygen demand (five-day).

[c] Total suspended solids.

Table D.62. Ratio of EHV Production Water Discharges to Water Discharges from Production of the Same Number of CVs, by Scenario, 2000

Residuals	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
TDS[a]	2.2	1.4	1.3	1.4	1.3
BOD_5[b]	1.2	1.4	1.3	1.4	1.5
Oil and grease	3.6	3.5	2.4	1.8	1.6
TSS[c]	2.4	2.4	3.4	3.4	3.4
Lead	3.1	3.1	1.4	1.4	1.3
Zinc	4.3	4.4	1.7	1.7	1.5
Heavy metals	3.0	2.9	4.4	4.5	4.6

[a] Total dissolved solids.

[b] Biological oxygen demand (five-day).

[c] Total suspended solids.

There are a variety of reasons why energy conversion processes as they affect water quality per se should be considered in the tradeoffs between EHVs and CVs. First, although effluent guidelines have been established to regulate the most probable waste streams, not all potential pollutants are regulated. Second, even though regulated, energy conversion facilities may provide the primary pathways for some contaminants into the environment. Ref. D.27 finds that utility boilers are the primary energy-related source of iron, mercury, selenium, zinc, chrominum, copper, and cadmium, in addition to such trace elements as arsenic, boron, and barium.

Table D.63 provides the estimated year 2000 water pollutant loadings for utilities attributable to the incremental energy requirements for charging EHV batteries. Pollutant discharge factors for nuclear power plants are taken from Ref. D.28. The nuclear power plant base unit for comparative purposes is a light water reactor. Pollutant discharge factors for coal-fired power plants are taken from the same source. A conventional boiler is assumed. Water pollutant emissions are the same for both eastern and western coal.[D.28]

Pollutant discharge factors for oil and gas are arbitrarily assumed to be the same as for the coal-fired plant, except for specific pollutants where differences could be determined from the literature. Reference D.27 notes reduced emissions from oil-fired boilers for TSS, TDS, and COD and increased emissions for phosphorous, chromium, and zinc. These differences are factored into the calculations.

Table D.64 combines the water pollutant loadings by power plant in Table D.63 into total water pollutant loadings for each scenario. Obviously,

Table D.63. Water Pollutant Loadings by Power Plant Type, by Scenario, 2000 (tons)

Residual	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
			Light Water Reactor Plant		
BOD[a]	6.79	13.17	20.20	61.89	60.20
Chlorine	79.16	153.61	235.71	721.95	702.29
Phosphates	124.40	241.39	370.40	1,134.49	1,103.60
Boron	987.66	1,916.48	2,940.73	9,007.15	8,761.88
Chromates	6.79	13.17	20.20	61.89	60.20
Acids	246.54	478.39	934.06	2,248.35	2,187.13
Organics	197.53	383.30	588.15	1,801.43	1,752.38
			Conventional Coal-Fired Plant		
BOD	114.25	224.11	347.81	1,154.35	1,114.36
COD[b]	11,115.28	21,803.39	33,838.47	112,307.21	108,416.65
TSS[c]	26.74	52.45	81.40	270.17	260.81
TDS[d]	70,779.52	138,838.86	215,475.39	715,145.91	690,371.72
Aluminum	24.40	47.68	74.00	245.61	237.10
Chromium	0.81	1.59	2.47	8.19	7.90
Nonferrous metals	9,010.22	17,608.96	27,328.79	90,702.11	87,560.00
Zinc	4.07	7.95	12.33	40.93	39.52
Sulfates	3,342.51	6,532.43	10,138.22	33,647.95	32,482.32
Nickel	294.40	575.36	892.95	2,963.64	2,860.97
Nitrates	148.02	289.27	418.94	1,490.01	1,438.39
Ammonia	4.88	9.54	14.80	49.12	47.42
Phosphorus	13.83	27.02	41.93	139.18	134.36
Surfactants	31.72	61.99	96.20	319.29	308.23
			Conventional Oil- or Gas-Fired Plant		
BOD	47.66	87.64	140.05	486.42	464.87
COD	66.07	136.12	217.53	755.50	729.34
TSS	2.11	4.35	6.95	24.15	23.31
TDS	4,758.86	9,804.49	15,667.99	54,416.36	52,532.78
Aluminum	10.18	18.65	29.80	103.49	98.91
Chromium	0.30	0.62	0.99	3.45	3.33
Nonferrous metals	3,758.76	6,886.26	11,004.55	38,219.78	36,527.09
Zinc	19.01	39.16	62.58	217.33	209.81
Sulfates	1,394.36	2,554.61	4,082.28	14,178.47	13,550.53
Nickel	122.81	225.00	359.57	1,248.81	1,193.50
Nitrates	61.75	113.12	180.78	627.86	600.05
Ammonia	2.04	3.73	5.96	20.70	19.78
Phosphorus	35.90	73.97	118.20	410.52	396.31
Surfactants	13.23	24.24	38.74	134.54	128.58

[a] Biological oxygen demand.

[b] Chemical oxygen demand.

[c] Total suspended solids.

[d] Total dissolved solids.

Table D.64. Total Water Pollutant Loadings from Power Plants, by Scenario, 2000 (tons)

Residual	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
BOD[a]	168.7	324.94	508.05	1,702.66	1,639.43
COD[b]	11,181.35	21,939.5	34,056	113,062.71	109,145.99
TSS[c]	28.85	56.8	88.35	294.32	284.12
TDS[d]	75,538.38	148,643.35	231,143.38	769,562.27	742,904.5
Aluminum	34.58	66.33	103.8	349.1	336.01
Chromium	1.11	2.21	3.46	11.64	11.23
Nonferrous metals	12,768.98	24,495.22	38,333.34	128,921.89	124,089.09
Zinc	23.08	47.11	74.91	258.26	249.33
Sulfates	4,736.87	9,087.04	14,220.6	47,826.42	46,032.85
Nickel	417.21	800.36	1,252.52	4,212.45	4,054.47
Nitrates	209.77	402.39	599.72	2,117.87	2,038.44
Ammonia	6.92	13.27	20.76	69.82	67.2
Phosphorus	49.73	100.99	160.13	549.7	530.67
Surfactants	44.95	86.23	134.94	453.83	436.81
Chlorine	79.16	153.61	235.71	721.95	702.29
Phosphates	124.40	241.39	370.40	1,134.49	1,103.60
Boron	987.66	1,916.48	2,940.73	9,007.15	8,761.88
Chromates	6.79	13.17	20.20	61.89	60.20
Acids	246.54	478.39	934.06	2,248.35	2,187.13
Organics	197.53	383.30	588.15	1,801.43	1,752.38

[a] Biological oxygen demand.

[b] Chemical oxygen demand.

[c] Total suspended solids.

[d] Total dissolved solids.

each EHV scenario results in an absolute increase in pollutant levels from vehicle operation because there is no comparable impact from CV operations.

D.3.3 Fuels Production Analysis

Based on information provided in Sec. B.4, the total national discharge of significant waterborne pollutants is estimated for the production and transport to utilities and/or service stations (or other vehicle servicing facilities) of fuels required for EHV and CV operation. Tables D.65–D.70 summarize the pollutant loadings associated with fuels production for the five scenarios in 2000. Table D.71 provides a comparison of the fuel production discharges between each of the EHV scenarios and the discharges from fuel production for CVs. Comparisons are not provided for pollutants for which no appreciable CV contribution could be identified.

The results indicate that EHV market penetration leads to a reduction of TDS, BOD_5, COD_5, chromium, and organics in the fuel production phase.

Table D.65. Water Residuals from Fuels Produced and Transported to Utility for EHV Operation, LOW I, 2000 (Short tons)

Residual	Uranium	Coal	Oil	Total
TDS[a]	-	19,579.0	14,402.0	33,981.0
TSS[b]	-	810.7	4.7	815.4
BOD$_5$[c]	-	-	5.2	5.2
COD[d]	-	-	32.4	32.4
Sulfate/sulfide	30.2	-	-	-
Sulfate/sulfite	-	10,134.0	-	10,164.22[e]
Sulfide	-	-	0.02	-
Aluminum	-	133.3	-	133.3
Iron	1.2	1,035.4	-	1,036.6
Zinc	-	4.9	-	4.9
Nickel	-	2.4	-	2.4
Magnanese	-	26.9	-	26.9
Chromium	-	-	0.05	0.05
Nitrate	101.9	-	-	101.9
Chloride	22.6	300.0	-	322.6
Fluoride	122.5	4.1	-	126.6
Ammonia	45.3	44.5	1.2	91.0
Organics	-	-	53.8	53.8

[a] Total dissolved solids.

[b] Total suspended solids.

[c] Biological oxygen demand (five-day).

[d] Chemical oxygen demand.

[e] Total of sulfate/sulfide, sulfate/sulfite, sulfide rows.

Table D.66. Water Residuals from Fuels Produced and Transported to Utility and Service Station for EHV Operation, LOW II, 2000 (short tons)

Residual	Uranium	Coal	Oil	Gasoline	Total
TDS[a]	-	38,332.0	30,381.0	30,085.0	99,248.0
TSS[b]	-	1,587.3	10.1	9.9	1,607.3
BOD$_5$[c]	-	-	11.2	10.8	22.0
COD[d]	-	-	69.3	67.3	136.6
Sulfate/sulfide	58.3	-	-	-	-
Sulfate/sulfite	-	19,841.0	-	-	1.99×10^4[e]
Sulfide	-	-	0.04	0.04	-
Aluminum	-	260.9	-	-	260.9
Iron	2.3	2,027.1	-	-	2,029.4
Zinc	-	9.7	-	-	9.7
Nickel	-	4.8	-	-	4.8
Manganese	-	52.7	-	-	52.7
Chromium	-	-	0.1	0.09	0.2
Nitrate	196.7	-	-	-	196.7
Chloride	43.7	587.3	-	-	631.0
Fluoride	236.5	7.9	-	-	244.4
Ammonia	87.4	87.1	2.7	2.7	179.9
Organics	-	-	115.1	111.3	226.4

[a] Total dissolved solids.

[b] Total suspended solids.

[c] Biological oxygen demand (five-day).

[d] Chemical oxygen demand.

[e] Total of sulfate/sulfide, sulfate/sulfite, and sulfide rows.

Table D.67. Water Residuals from Fuels Produced and Transported to Utility for EHV Operation, MEDIUM, 2000 (short tons)

Residual	Uranium	Coal	Oil	Total
TDS[a]	-	59,440.0	49,326.0	108,766.0
TSS[b]	-	2,461.3	16.2	2,477.5
BOD$_5$[c]	-	-	17.9	17.9
COD[d]	-	-	110.8	110.8
Sulfate/sulfide	89.9	-	-	-
Sulfate/sulfite	-	30,766.0	-	3.1x10^4[e]
Sulfide	-	-	0.06	-
Aluminum	-	404.6	-	404.6
Iron	3.6	3,143.3	-	3,146.9
Zinc	-	15.0	-	15.0
Nickel	-	7.4	-	7.4
Manganese	-	81.7	-	81.7
Chromium	-	-	0.2	0.2
Nitrate	303.4	-	-	303.4
Chloride	67.4	910.7	-	978.1
Fluoride	364.7	12.3	-	377.0
Ammonia	134.8	135.1	4.3	274.2
Organics	-	-	184.2	184.2

[a] Total dissolved solids.

[b] Total suspended solids.

[c] Biological oxygen demand (five-day).

[d] Chemical oxygen demand.

[e] Totals of sulfate/sulfide, sulfate/sulfite, sulfide rows.

Table D.68. Water Residuals from Fuels Produced and Transported to Utility for EHV Operation, HIGH I, 2000 (short tons)

Residual	Uranium	Coal	Oil	Total
TDS[a]	-	1.95x10^5	1.80x10^5	3.75x10^5
TSS[b]	-	8,065.2	59.3	8,124.5
BOD$_5$[c]	-	-	65.5	65.5
COD[d]	-	-	405.5	405.5
Sulfate/sulfide	275.2	-	-	-
Sulfate/sulfite	-	1.008x10^5	-	1.01x10^5[e]
Sulfide	-	-	0.2	-
Aluminum	-	1,325.9	-	1,325.9
Iron	11.0	10,300.1	-	10,311.1
Zinc	-	49.2	-	49.2
Nickel	-	24.2	-	24.2
Manganese	-	267.8	-	267.8
Chromium	-	-	0.6	0.6
Nitrate	928.8	-	-	928.8
Chloride	206.4	2,984.1	-	3,190.5
Fluoride	1,116.6	40.3	-	1,156.9
Ammonia	412.8	442.8	15.6	871.2
Organics	-	-	673.7	673.7

[a] Total dissolved solids.

[b] Total suspended solids.

[c] Biological oxygen demand (five-day).

[d] Chemical oxygen demand.

[e] Totals of sulfate/sulfide, sulfate/sulfite, sulfide rows.

Table D.69. Water Residuals from Fuels Produced and Transported to Utility and Service Station for EHV Operation, HIGH II, 2000 (short tons)

Residual	Uranium	Coal	Oil	Gasoline	Total
TDS[a]	-	1.89×10^5	1.75×10^5	1.28×10^5	4.92×10^5
TSS[b]	-	7,818.2	57.4	42.8	7,918.4
BOD_5[c]	-	-	63.4	46.7	110.1
COD[d]	-	-	392.5	292.0	684.5
Sulfate/sulfide	267.0	-	-	-	-
Sulfate/sulfite	-	9.77×10^4	-	-	9.8×10^4[e]
Sulfide	-	-	0.2	0.2	-
Aluminum	-	1,285.3	-	-	1,285.3
Iron	10.7	9,984.7	-	-	9,995.4
Zinc	-	47.7	-	-	47.7
Nickel	-	23.5	-	-	23.5
Manganese	-	259.6	-	-	259.6
Chromium	-	-	0.6	0.4	1.0
Nitrate	901.2	-	-	-	901.2
Chloride	200.3	2,892.7	-	-	3,093.0
Fluoride	1,083.5	39.1	-	-	1,122.6
Ammonia	400.5	429.2	15.1	11.7	856.5
Organics	-	-	652.1	428.8	1,134.9

[a] Total dissolved solids.

[b] Total suspended solids.

[c] Biological oxygen demand (five-day).

[d] Chemical oxygen demand.

[e] Totals of sulfate/sulfide, sulfate/sulfite, and sulfide rows.

However, very large increases in sulfate/sulfite/sulfides occur, along with increases in TSS, ammonia, nitrates, chloride, fluoride, and certain metals.

D.3.4 Total Water Pollutant Analysis

Table 3.20 sums the water pollutants from all phases of vehicle production, vehicle operation, and fuels production. Using that table as a base, Table D.72 compares the water discharges associated with the EHV scenarios with the discharges associated with an equivalent number of CVs operating equivalent VMT. For almost all water pollutants, the pollutant load of the EHV scenarios is greater than the load for an equivalent number of CVs. Comparisons are not shown for pollutants for which no appreciable CV contribution could be identified.

To provide perspective for the evaluation, the pollutant loads shown in Table 3.20 are compared with known 1975 national waterborne pollutant levels (see Table D.73). Table D.74 shows the ratio of EHV and CV production-related water pollutants to the 1975 national background levels of

Table D.70. Water Residuals from the Production and Transport to Service Station of Gasoline and Diesel Fuel Required by CVs Operating the Same VMT as EHVs, by Scenario, 2000 (short tons)

Residual	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
TDS[a]	1.218×10^5	2.364×10^5	3.849×10^5	1.228×10^6	1.219×10^6
TSS[b]	40.0	77.6	126.4	403.2	400.1
BOD_5[c]	43.7	84.7	138.0	440.0	436.5
COD[d]	273.0	529.4	863.2	2,751.1	2,728.4
Sulfide	0.15	0.28	0.46	1.5	1.5
Chromium	0.36	0.71	1.16	3.7	3.6
Ammonia	10.9	21.1	34.3	109.7	109.0
Organics	451.0	874.9	1,425.2	4,545.5	4,509.9

[a] Total dissolved solids.

[b] Total suspended solids.

[c] Biological oxygen demand (five-day).

[d] Chemical oxygen demand.

Table D.71. Ratio of EHV Fuels Production Water Discharges to Fuels Production Discharges for CVs Operating the Same VMT as EHVs, by Scenario, 2000

Residual	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
TDS[a]	0.28	0.42	0.28	0.31	0.40
TSS[b]	20.4	20.7	19.6	20.2	19.89
BOD_5[c]	0.12	0.26	0.13	0.15	0.25
COD[d]	0.12	0.26	0.13	0.15	0.25
Sulfate/sulfite/sulfide	6.8×10^4	7.1×10^4	6.7×10^4	6.7×10^4	6.5×10^5
Chromium	0.14	0.28	0.17	0.16	0.28
Ammonia	8.3	8.5	8.0	7.9	7.9
Organics	0.12	0.26	0.13	0.15	0.25

[a] Total dissolved solids.

[b] Total suspended solids.

[c] Biological oxygen demand (five-day).

[d] Chemical oxygen demand.

Table D.72. Ratio of EHV Water Discharges to CV Discharges from Vehicle Production, Vehicle Operation, and Fuels Production and Transport, by Scenario, 2000[a]

Residual	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
TDS[b]	0.91	1.05	0.89	0.93	1.01
TSS[c]	9.0	9.2	9.4	10.0	9.5
BOD_5[d]	1.5	1.8	1.6	1.7	1.9
COD[e]	41	42	40	41	40
Sulfate/sulfite/sulfide	9.9×10^4	10.4×10^4	9.8×10^4	9.9×10^4	9.6×10^5
Lead	3.5	3.2	1.4	1.4	1.3
Zinc	144	194	152	194	176
Chromium/chromate	22	22	21	20	20
Ammonia	9.0	9.1	8.6	8.6	8.5
Oil and grease	3.6	3.5	2.4	1.8	1.6
Organics	0.56	0.70	0.54	0.54	0.64

[a] Same number of CVs produced as EHVs in each scenario and CVs operate same VMT as EHVs in each scenario.

[b] Total dissolved solids.

[c] Total suspended solids.

[d] Biological oxygen demand (five-day).

[e] Chemical oxygen demand.

Table D.73. Estimated Discharge of Selected Water Residuals, 1975 Background National Loading (lb/yr)

Residual	Discharge	Residual	Discharge
TSS[a]	1.50×10^{13}	Boron	NA[b]
TDS[c]	8.36×10^{11}	Cadmium	2.86×10^7
Ammonia	NA	Copper	1.08×10^8
Sulfate	3.74×10^{11}	Chromium	NA
Oil and grease	NA	Lead	4.4×10^8
Phosphorus	1.19×10^9	Iron	1.12×10^{10}
Chlorine	NA	Mangenese	1.43×10^8
Potassium	2.02×10^{10}	Mercury	6.38×10^5
Aluminum	NA	Nickel	NA
Arsenic	1.63×10^7	Selenium	NA
Barium	NA	Zinc	2.64×10^9

[a] Total suspended solids.

[b] Not available.

[c] Total dissolved solids.

Source: Ref. D.27.

pollutants for which information is available. Comparisons are not made for pollutants that may have been underestimated in Table 3.20. As can be seen in Table D.74, the magnitude of the emissions is very low in comparison with national totals.

D.4 SOLID WASTE

This analysis discusses the solid waste generated from the manufacture, operation (including fuels production for operation), and disposal of EHVs as it compares with the solid waste generated by a corresponding number of CVs. The year 2000 was chosen for analysis, since it was assumed that impacts of earlier assessment years would be relatively insignificant.

D.4.1 Vehicle Production Analysis

In the manufacture of EHVs and CVs, several principal metals are required, including iron, steel, aluminum, nickel, zinc, copper, lithium, and lead. The production of these primary metals involves mining, milling, smelting, and refining of ores. Although the production processes for these metals vary, there are certain common types of process solid wastes: (1) waste rock from mining operations, (2) tailings from milling and concentrating operations, and (3) slags from smelting operations. These wastes often contain hazardous materials and are usually deposited on land. Waste accumulations may result in denudation of land, alteration of surface and subsurface drainage patterns, clogging of stream channels, flooding, water pollution, erosion and sedimentation, and general disruption of local ecosystems.

The quantities of solid wastes generated during the manufacturing stage for each of the five scenarios and an analysis of their potential impact is presented in the following section. The analysis is based on emission estimates presented in Sec. B.3 for the production of 100,000 vehicles under each scenario. These estimates assume present materials recycling rates. If the rates were to increase, the total solid waste loads associated with vehicle production would likely decrease.

Table D.74. Ratio of Year 2000 Total EHV and CV Water Pollutant Discharges to 1975 National Background Discharges[a]

	Scenario									
	LOW I		LOW II		MEDIUM		HIGH I		HIGH II	
Pollutant	EHV	CV	EHV	CV	EHV	CV	EHV	CV	EHV	CV
TDS[b]	2.7×10^{-4}	2.9×10^{-4}	6.0×10^{-4}	5.6×10^{-4}	1.4×10^{-3}	9.3×10^{-4}	2.8×10^{-3}	3.0×10^{-3}	3.0×10^{-3}	2.9×10^{-3}
TSS[c]	1.4×10^{-7}	1.5×10^{-8}	2.7×10^{-7}	2.9×10^{-8}	4.5×10^{-7}	4.8×10^{-8}	1.4×10^{-6}	1.4×10^{-7}	1.4×10^{-6}	1.5×10^{-7}
Zinc	2.2×10^{-5}	1.5×10^{-7}	4.4×10^{-5}	2.3×10^{-7}	6.9×10^{-5}	4.5×10^{-7}	2.3×10^{-4}	1.2×10^{-6}	2.3×10^{-4}	1.3×10^{-6}
Phosphorus	2.9×10^{-4}	-	5.7×10^{-4}	-	8.9×10^{-4}	-	2.8×10^{-3}	-	2.7×10^{-3}	-

[a] Same number of CVs produced as EHVs in each scenario and CVs operate same VMT as EHVs in each scenario.

[b] Total dissolved solids.

[c] Total suspended solids.

D.4.1.1 Waste Rock Generated by Mining

Waste rock is produced during the exploration, development, and mining of ore deposits. It is disposed of in waste rock piles or tailings ponds, used for construction of tailings dams and mine roads, or used for mine backfill. The major problems associated with waste rock are: (1) alteration of surface drainage patterns, (2) sedimentation from storm runoff associated with surface mines, (3) destruction of vegetation, (4) effects on existing land-use patterns, and (5) local flooding or clogging of stream channels from storm runoff. The pollution impacts of waste rock are usually insignificant, because the mineral content is similar to that of the background environment.

Table D.75 projects the total quantities of waste rock generated by the mining of nickel, zinc, copper, bauxite for aluminum, iron (for iron and steel requirements), lithium, and lead for EHVs and an equal number of CVs under each of the five scenarios in 2000. Based on these data, the increase in waste rock from mining for EHVs over CVs is presented in Table D.76. Table D.77 estimates the increases in land area required for disposal of waste rock from EHV production over CV production.

All five EHV scenarios require additional land for waste rock disposal. The LOW I, LOW II, and HIGH II scenarios result in the need for an additional 37, 70, and 44 acres, respectively, in 2000. Much of this acreage is required for the disposal of waste rock from lead mining operations. Considering that most mining operations involve thousands of acres and that waste rock is often used in the mining operations for roads and dams or for reclamation purposes, these acreages do not appear significant. However, much of this waste rock may be generated in Iron County, Missouri, in which most domestic lead mining now occurs. While the total volume of waste rock in this geographical area may not be especially significant, effective disposal methods will have to be followed to avoid adverse impact.

Waste rock increases in the MEDIUM and HIGH I scenarios are more substantial. An additional 679 acres of land in the MEDIUM scenario are required for EHVs over the seven acres required for the production of the same number of CVs. In the HIGH I scenario, an additional 7335 acres are required for EHV-related waste rock disposal over the 19 acres required for the same number of CVs. While lead mining contributes somewhat to these totals, almost all of this additional acreage is due to the large amounts of waste rock generated during lithium extraction (96% in MEDIUM and 99% in HIGH I).

The addition of 12 million tons of waste rock from lithium mining in the MEDIUM scenario and 133 million tons of such waste rock in the HIGH I scenario could substantially affect surface drainage patterns, vegetation, and land-use patterns in the lithium mining areas. Much of the lithium mining is expected to occur in a few specific areas of the Carolinas, as well as Nevada, Utah, and California, under the HIGH I scenario. Further, the amounts given here are for one year only. Thus, the amount of waste rock generated by lithium extraction and the additional acreage requirements for these two scenarios, particularly for HIGH I, appear to be very significant.

One note of caution is necessary. These lithium projections assume 100% ore extraction from pegmatite and other sources of spodumene. However,

Table D.75. Total Quantities of Waste Rock Generated in EHV Production and Production of the Same Number of CVs, by Scenario, 2000 (tons)

	Scenario									
	LOW I		LOW II		MEDIUM		HIGH I		HIGH II	
Material	EHV	CV	EHV	CV	EHV	CV	EHV	CV	EHV	CV
Nickel	766.5	-	766.1	-	8,198.6	-	21,308.7	-	25,660.9	-
Zinc oxide	300.8	-	301.1	-	3,257.5	-	8,495.2	-	10,238.9	-
Copper	889.4	-	1,548.0	-	2,670.5	-	8,260.5	-	8,076.2	-
Aluminum	10,313.9	11,309.6	22,788.1	21,369.4	34,484.3	35,305.2	122,599.7	103,528.7	114,207.2	110,907
Steel	23,934.2	23,212.9	45,583.0	42,648.9	75,265.3	72,829.0	220,824.8	205,168.4	230,814.0	218,938
Iron	3,945.2	3,693.5	9,549.8	6,518.8	12,805.1	11,604.6	49,039.9	30,986.0	45,592.9	32,394
Lithium	-	-	-	-	12,005,670.7	-	133,434,836.7	-	-	-
Lead	682,240.8	-	1,274,899.2	-	408,515.9	-	817,876.5	-	736,197.6	-
Total	722,390.9	38,216.0	1,355,435.3	70,537.1	12,550,867.9	119,741.8	134,683,242.0	339.683.1	1,170,787.7	362,239

Table D.76. Comparison of Waste Rock Generated in EHV Production and Production of the Same Number of CVs, by Scenario, 2000

	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
Waste rock (tons)					
EHV	722,390.9	1,355,435.3	12,550,867.9	134,683,242.0	1,170,787.7
CV	38,216.0	70,537.1	119,741.8	339,683.1	362,230.9
EHV - CV (tons)	684,174.9	1,284,898.2	12,431,126.1	134,343,558.9	808,556.8
$\frac{\text{EHV}}{\text{CV}}$	18.9	19.2	104.8	396.5	3.2

increased demand for lithium might, to some degree, be met by extraction of lithium from brines, which would decrease the total waste rock volumes shown here.

D.4.1.2 Tailings Generated by Milling

In the milling process, the ores are crushed and processed to produce concentrates. The quantities of tailings generated vary with the percentage of metals present in the ore and whether a mine is above or below the water table. The tailings usually are disposed of in tailings ponds. For mines below the water table, acid mine water is first discharged to the tailings ponds. It is then pumped to a dispersion pond or wastewater treatment plant before being released into a river. The sludge from the treatment plant is often pumped back into the tailings pond. For relatively dry mines, the tailings pond functions as a landfill site. When a tailings pond is full, it is covered with soil and revegetated.

The environmental impact of tailings depends on the chemical composition of the tailings and the disposal methods. In general, tailings contain various heavy metals, salts, acids or bases, and synthetic organics (agents used in the concentrating process), many of which are potentially hazardous. Significant impacts can occur if these hazardous materials leach out of the tailings pond.

Table D.78 projects the total quantities of tailings from nickel, zinc oxide, copper, aluminum, steel, iron, and lead for EHVs and an equal number of CVs under each of the five scenarios. Based on these data, increases in tailings from the milling process for EHVs over CVs is presented in Table D.79.

Assuming that proper methods are used to dispose of tailings, the primary impact is one of total land area consumed. For the five scenarios, Table D.80 shows the increases in land area for the disposal of tailings for EHVs over CVs. In all five EHV scenarios, an increase in tailings and the land area required for their disposal occurs. The smallest increase is an

Table D.77. Land Area Required for Disposal of Waste Rock Generated in EHV Production and Production of the Same Number of CVs, by Scenario, 2000

	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
Waste rock generated by EHV mining					
Quantity (tons)	722,390.9	1,355,435.3	12,550,867.9	134,683,242	1,170,787.7
Land area for disposal (acres)[a]	39.44	74.01	685.28	7,353.70	63.93
Waste rock generated by CV mining					
Quantity (tons)	38,216.0	70,537.1	119,741.8	339,683.1	362,230.9
Land area for disposal (acres)[a]	2.09	3.86	6.55	18.58	19.81
EHV land area - CV land area	37.35	70.15	678.73	7,335.12	44.12
$\frac{\text{EHV land area}}{\text{CV land area}}$	18.9	19.2	104.6	395.8	3.2

[a] Average weight of waste rock assumed to be 140 lb/ft^3, and land area is taken to be fill to an average depth of 6 ft.

additional 111 acres required for tailings disposal in the MEDIUM scenario, and the greatest increase is 348 acres in LOW II. The greatest proportion of the increases is due to tailings from the milling of lead. This acreage is not necessarily significant at the national level. However, most of this country's lead mining operations occur in Iron County, Missouri, and it is reasonable to assume that the lead is milled there too. For perspective, a community of 100,000 people typically generates enough solid waste yearly to fill a land area of approximately 20 acres to a depth of six feet.[D.29]

Most of the tailings from milling lead ores are considered potentially hazardous, because they contain hazardous materials above the naturally occurring background levels. Thus, it is particularly important to use proper disposal methods for tailings from lead milling.

D.4.1.3 Slag Generated by Smelting

Slag is a by-product waste of the smelting process, which converts an ore or concentrate into the primary metal. Most of the slags generated by the metals industry are disposed of on land, and these waste piles often are extremely unsightly. More importantly, leachates from slag piles may contribute significantly to surface and groundwater pollution. Loss of vegetation and aquatic life resulting from adjacent slag piles is not uncommon.

Table D.81 projects the total quantities of slag from iron, steel, nickel, copper, zinc oxide, and lithium sulfide/lithium chloride for EHVs and an equal number of CVs under each of the five scenarios for the year 2000.

Table D.78. Total Quantities of Tailings Generated in EHV Production and Production of the Same Number of CVs, by Scenario, 2000 (tons)

	Scenario									
	LOW I		LOW II		MEDIUM		HIGH I		HIGH II	
Material	EHV	CV	EHV	CV	EHV	CV	EHV	CV	EHV	CV
Nickel	142.4	-	142.6	-	1,524.1	-	3,963.2	-	4,773.0	-
Zinc oxide	22.5	-	22.6	-	244.5	-	637.2	-	767.9	-
Copper	76.3	-	128.4	-	228.3	-	708.4	-	689.9	-
Aluminum	143,530.7	157,057.2	316,942.9	296,874.4	479,014.6	490,784.0	1,703,682.4	1,442,136.2	1,586,002.5	1,537,260.1
Steel	36,371.1	35,281.5	69,270.7	64,828.0	114,398.6	110,703.0	335,650.8	311,893.7	350,832.8	332,760.6
Iron	6,000.5	5,613.5	14,518.5	9,909.7	19,466.6	17,642.3	74,577.0	47,114.6	69,289.2	49,229.8
Lithium	-	-	-	-	-	-	-	-	-	-
Lead	3,638,617.7	-	6,799,462.6	-	2,178,751.3	-	4,362,008.1	-	3,926,387.4	-
Total	3,824,761.2	197,952.2	7,200,488.3	371,612.1	2,793,627.8	619,129.3	6,481,227.1	1,801,144.5	5,938,742.7	1,919,250.5

Table D.79. Comparison of Tailings Generated in EHV Production and Production of the Same Number of CVs, by Scenario, 2000

	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
Tailings generated (tons)					
EHV	3,824,761.2	7,200,488.3	2,793,627.8	6,481,227.1	5,938,742.7
CV	197,952.2	371,612.1	619,129.3	1,801,144.5	1,919,250.5
EHV - CV (tons)	3,626,809.0	6,828,876.2	2,174,498.5	4,680,082.6	4,019,492.2
$\frac{\text{EHV}}{\text{CV}}$	19.3	19.4	4.5	3.6	3.1

Based on these data, the increases in slag from the smelting process for EHVs over CVs is presented in Table D.82. This table shows that the increase in slag from EHVs over CVs is substantial for all scenarios. Since slag is disposed of on land, increases in the land areas necessary for disposal also occurs for each of the scenarios (see Table D.83).

The LOW I and LOW II scenarios result in the smallest increases in land for slag disposal: 1.11 and 1.71 acres, respectively. The HIGH II and MEDIUM scenarios result in increases of 18-27 acres. For both of these increases, the potential environmental impact could be severe if proper methods of slag disposal are not followed. Leachates from the slag could contribute significantly to both surface and groundwater pollution.

The HIGH I scenario results in much higher increases, with an additional 248 acres required for slag disposal. This substantial acreage is due, in large part, to the slag disposal associated with lithium refining (93% of total HIGH I slag). Again, the potential environmental impact could be severe if proper methods of slag disposal are not used.

Because of potential environmental problems and land requirements for the disposal of metal smelting slags, metal industries have been investigating ways of using slag. Slags from zinc smelters can be used as construction aggregates, as are slags from iron smelters. Some slag from nickel smelters has been used as fertilizer. It is not known whether slags from lithium refining could be similarly used. Reuse of discarded slag could minimize disposal impacts and could prove to be significant in the various scenarios.

D.4.1.4 Solid Wastes Generated during Battery Manufacture

Depending on the battery system employed, various quantities and types of solid wastes are generated during the production of batteries. Most of the solid wastes generated in the Pb/acid battery assembly trajectory are recycled and are not considered solid waste. Rejected battery grids, plates, or retrieved waste lead are all recycled, either at the battery plant or at a secondary lead plant. Solid wastes in the form of reject plastic generated during container and separator manufacturing are considered negligible.

Table D.80. Land Area Required for Disposal of Tailings Generated in EHV Production and Production of the Same Number of CVs, by Scenario, 2000

	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
Tailings generated by EHV milling					
Quantity (tons)	3,824,761.2	7,200,488.3	2,793,627.8	6,481,227.1	5,938,742.7
Land area for disposal (acres)[a]	195.06	367.22	142.48	330.54	302.88
Tailings generated by CV milling					
Quantity (tons)	197,952.2	371,612.1	619,129.3	1,801,144.5	1,919,250.5
Land area for disposal (acres)[a]	10.10	18.95	31.58	91.85	97.88
EHV land area - CV land area	184.96	348.27	110.9	238.69	205
$\frac{\text{EHV land area}}{\text{CV land area}}$	19.3	19.4	4.5	3.6	3.1

[a] Average weight of tailings assumed to be 150 lb/ft^3, and land area is taken to be fill to an average depth of 6 ft.

Table D.81. Total Quantities of Slag Generated in EHV Production and Production of the Same Number of CVs, by Scenario, 2000 (tons)

	Scenario									
	LOW I		LOW II		MEDIUM		HIGH I		HIGH II	
Material	EHV	CV	EHV	CV	EHV	CV	EHV	CV	EHV	CV
Iron	197.3	184.1	477.5	325.2	635.5	576.7	2,470.2	1,562.0	2,287.1	1,612.2
Steel	1,375.2	1,336.5	2,622.7	2,453.9	4,331.1	4,187.6	12,714.0	11,795.0	13,310.4	12,598.0
Nickel	151.0	-	150.9	-	1,614.8	-	4,195.6	-	5,054.2	-
Copper	18,189.7	-	31,673.5	-	54,625.3	-	160,991.5	-	165,199.2	-
Zinc oxide	7,089.9	-	7,097.6	-	76,784.7	-	200,239.7	-	241,311.6	-
Lithium	-	-	-	-	476,643.0	-	5,297,562.2	-	-	-
Total	27,003.1	1,520.6	42,022.2	2,779.1	614,634.4	4,764.3	5,686,173.2	13,357.0	427,162.5	14,210.2

Table D.82. Comparison of Slag Generated in EHV Production and Production of the Same Number of CVs, by Scenario, 2000

	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
Slag (tons)					
EHV	27,003.1	42,022.2	614,634.4	5,686,173.2	427,162.5
CV	1,520.6	2,779.1	4,764.3	13,357.0	14,210.2
EHV - CV (tons)	25,482.5	39,243.1	609,870.1	5,672,816.2	412,952.3
$\frac{\text{EHV}}{\text{CV}}$	17.6	15.1	129.0	425.7	30.1

Solid wastes from Ni/Zn and Ni/Fe battery assembly are primarily sludges containing nickel hydroxide and nickel nitrate salts, plastics, and scrap residues. The actual amounts of sludge and the degree of hazard will depend on the manufacturing processes (still to be developed) and the wastewater treatment method selected.

Solid wastes from Li/S battery assembly are unknown at this time, but it is anticipated that a certain amount of solid waste will be generated by the production process. There will be high risk of explosion or fire, because the wastes will contain lithium or lithium compounds, which react vigorously with water to release hydrogen gas and heat. The disposal of lithium containing solid wastes must be handled with extreme care.

The solid wastes generated by battery assembly are thought to be negligible. No quantification of total quantities or land area required for disposal is made in this analysis. At the outside, the land required for disposal would be less than 0.01 acre for the highest of the scenarios. Provided that these solid wastes can be safely disposed of, their impact should be negligible.

D.4.1.5 Solid Wastes Generated during Lead Processing

Waste rock and tailings from lead processing have already been discussed. Lead processing also produces slags and sludges. These materials contain lead hydroxide and lead sulfate, both of which can be extremely toxic. As these materials are usually deposited in a landfill, there is a high potential for lead contamination in the environment if they were to leach out of the disposal sites.

Table D.84 projects the total quantities of solid wastes generated during lead processing for the five EHV scenarios in 2000. Of the five scenarios, the LOW II scenario requires the most land for disposal, i.e., 12.72 acres. The MEDIUM scenario requires the least land, i.e., 4.08 acres.

Table D.83. Land Area Required for Disposal of Slag Generated in EHV Production and Production of the Same Number of CVs, by Scenario, 2000

	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
Slag generated by EHV smelting					
Quantity (tons)	27,003.1	42,022.2	614,634.4	5,686,173.2	427,162.5
Land area for disposal (acres)[a]	1.18	1.83	26.85	248.44	18.7
Slag generated by CV smelting					
Quantity (tons)	1,520.6	2,779.1	4,764.3	13,357.0	14,210.2
Land area for disposal (acres)[a]	0.07	0.12	0.21	0.58	0.62
EHV land area - CV land area		1.71	26.64	247.86	18.08
EHV land area / CV land area		15.3	127.9	428.3	30.2

[a] Average weight of slag assumed to be 175 lb/ft^3, and land area is taken to be fill to an average depth of 6 ft.

D.4.1.6 Solid Wastes Generated during Plastics Manufacturing

Table D.85 projects the total quantities of solid wastes generated during the manufacture of plastics for EHVs and an equivalent number of CVs by scenario in 2000. From the quantities in Table D.85, the land areas required for the disposal of solid wastes have been projected and are shown in Table D.86. In all of the scenarios, the average increase in land area required for disposal of solid wastes from EHVs as compared to CVs is 50%. Although this appears substantial, a review of the actual land area increase (0.14 acres for LOW I and 1.18 acres for HIGH II) shows that the added acreage is extremely small and insignificant.

D.4.1.7 Solid Wastes Generated from Potassium Hydroxide

Potassium hydroxide is produced as a coproduct of chlorine manufacture if potassium chloride is used as a raw material. The solid wastes generated are usually brine purification muds and sludge from wastewater treatment, both of which contain toxic materials, including asbestos, lead carbonate, and chloroform. Since land disposal of these wastes is current practice in the industry, safeguards must be provided to prevent leaching of these toxic substances.

Table D.87 projects the total quantities of KOH wastes and the corresponding land areas for disposal for the five EHV scenarios. The HIGH scenarios require the greatest acreage for disposal -- 2.5-3.0 acres each. Because of its potential toxicity, KOH-related solid wastes can be extremely hazardous and produce substantial impacts at disposal sites.

Table D.84. Total Quantities of Solid Wastes (slag and sludge) from Lead Processing in EHV Production and Land Area Required for Their Disposal, by Scenario, 2000

Scenario	EHV Solid Waste (tons)	Land Area for Disposal (acres)[a]
LOW I	155,655.7	6.81
LOW II	290,872.6	12.72
MEDIUM	93,204.2	4.08
HIGH I	186,598.6	8.16
HIGH II	167,966.3	7.34

[a] Average weight of solid waste assumed to be 175 lb/ft^3, and land area is taken to be fill to an average depth of 6 ft.

Table D.85. Comparison of Total Solid Wastes Generated from Plastics Manufacturing in EHV Production and Production of the Same Number of CVs, by Scenario, 2000

	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
Solid waste (tons)					
EHV	4,827.8	8,830.1	14,570.5	41,665.8	45,892.0
CV	3,088.5	5,878.7	9,627.4	28,515.8	30,557.7
EHV - CV (tons)	1,739.3	2,951.4	4,943.1	13,150	15,335.1
$\frac{\text{EHV}}{\text{CV}}$	1.6	1.5	1.5	1.5	1.5

D.4.1.8 Solid Wastes Generated from Potassium Chloride

Potassium chloride is produced by solution mining or dry mining of sylvite ores. Solution mining does not involve any significant discharge of solid wastes, which consist mainly of sodium chloride, silica, and alumina. Minor amounts of magnesium sulfate and potassium sulfate also are released as waste. Potassium chloride itself is released in brine solution. Major toxic impacts are not anticipated from such wastes.

Table D.88 projects the total quantities of KCl-related wastes and the corresponding land areas for disposal for the two EHV scenarios in which KCl-related wastes play a role. In the MEDIUM scenario, 10.04 acres would be required; in the HIGH I scenario, 110.71 acres.

Table D.86. Land Area Required for Disposal of Solid Wastes from Plastics Manufacturing in EHV Production and Production of the Same Number of CVs, by Scenario, 2000

	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
Solid wastes generated from plastics manufacture for EHVs					
Quantity (tons)	4,827.8	8,830.1	14,570.5	41,665.8	45,892.8
Land area for disposal (acres)[a]	0.37	0.68	1.12	3.21	3.53
Solid wastes generated from plastics manufacture for CVs					
Quantity (tons)	3,088.5	5,878.7	9,627.4	28,515.8	30,557.7
Land area for disposal (acres)[a]	0.23	0.45	0.74	2.20	2.35
EHV land area - CV land area	0.14	0.23	0.38	1.01	1.18
EHV land area / CV land area	1.6	1.5	1.5	1.5	1.5

[a] Average weight of solid waste from plastics assumed to be 100 lb/ft^3, and land area is taken to be fill to an average depth of 6 ft.

Table D.87. Total Quantities of KOH Solid Wastes in EHV Production and Land Areas Required for Their Disposal, by Scenario, 2000

	Solid Waste (tons)		
Scenario	EHV	CV	Land Area for Disposal (acres)[a]
LOW I	1,745.9	-	0.09
LOW II	1,746.4	-	0.09
MEDIUM	18,567.9	-	0.95
HIGH I	48,457.4	-	2.47
HIGH II	58,007.6	-	2.95

[a] Average weight of solid waste assumed to be 150 lb/ft^3, and land area is taken to be fill to an average depth of 6 ft.

D.4.1.9 Summary

Table D.89 summarizes the additional land areas required for disposal of solid wastes generated by the production of EHVs and the same number of CVs.

D.4.2 Vehicle Operation Analysis

During the lifetime operation of a motor vehicle, certain types of solid wastes are generated, including tires, glass, engine parts, body parts,

Table D.88. Total Quantities of KCl-Related Solid Wastes in EHV Production and Land Areas Required for Their Disposal, by Scenario, 2000

Scenario	EHV Solid Waste (tons)	Land Area for Disposal (acres)[a]
LOW I	-	-
LOW II	-	-
MEDIUM	170,539	10.04
HIGH I	1,880,865	110.71
HIGH II	-	-

[a] Average weight of solid waste assumed to be 130 lb/ft^3, and land area is taken to be fill to an average depth of 6 ft.

Table D.89. Additional Land Area Required for Disposal of Solid Wastes Generated by EHV Production over that Required by Production of the Same Number of CVs (acres)

	Scenario				
Residual	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
Waste rock	37.35	70.15	678.73	7,335.12	44.12
Tailings	184.96	348.27	110.9	238.69	205.00
Slag	1.1	1.71	26.64	247.86	18.08
Lead	6.81	12.72	4.08	8.16	7.34
Plastics	0.14	0.23	0.38	1.01	1.18
Potassium hydroxide	0.09	0.09	0.95	2.47	2.95
Potassium chloride	-	-	10.04	110.71	-
Total	230.46	433.17	831.27	7,944.02	278.67

batteries, and waste oil. When comparing solid wastes of EHVs with those of CVs during operation, many of the solid wastes generated are the same, both in type and quantity, for all vehicles. For instance, whether a vehicle is an EHV or a CV does not affect the replacement of glass, tires, and body parts. The forms and quantities of solid waste that are affected by vehicle type fall into several categories: discarded waste oils, engine parts, batteries, and power plant residues.

D.4.2.1 Waste Oil

CV operation requires oil for engine lubrication. The oil must be replaced occasionally in order to replenish that lost during use and to remove oil that is dirty or has lost its lubricating ability. As a result, large quantities of oil are used each year. In 1974 approximately 1.1 x 10^9 gal oil were used for automobiles, of which almost 50% was lost during use.[D.30] Of the 0.6 x 10^9 gal that were removed from engines, close to 56% (0.34 x 10^9 gal) were haphazardly discarded on land or in water bodies.

By 2000, the quantity of waste oil generated and discarded in the environment will decrease substantially for several reasons.[D.30] First, smaller engines and increased time between oil changes will significantly reduce oil needs. Second, it is estimated that no more than 30% will be discarded because of increased recycling.

Based on the number of CVs and HVs projected for the year 2000, the quantities of waste oil and the amount discarded in the environment for each scenario are given in Table D.90. Of the five scenarios, HIGH I and HIGH II generate the least quantity of waste oil discharged into the environment, with 51.0 x 10^6 gal and 53.8 x 10^6 gal, respectively. Although the LOW I, MEDIUM, and LOW II scenarios are slightly higher -- 58.8 x 10^6, 57.2 x 10^6, and 58.8 x 10^6 gal, respectively -- they are all relatively close, i.e., within 7 x 10^6 gal.

When each of the EHV scenarios is compared to the discarded waste oil of the BASE scenario (59.8 x 10^6 gal), the following decreases are realized: LOW I, 1.8%; LOW II, 1.8%; MEDIUM, 4.4%; HIGH I, 14.7%; and HIGH II, 10.2%. Even with these decreases, the 51.0-58.8 x 10^6 gal of discarded waste oil from the five scenarios will cause some environmental problems if discharged in high concentrations. For example, it requires 1 x 10^6 gal of oil in a water body of 1000 acres at a depth of 10 ft to create concentrations that are toxic in fresh water. This is equivalent to 1 gal of oil per 3250 gal of water.

Since the discharge of much of the waste oil is in rural areas and normally in small quantities (a gallon or less) and since a substantial decrease in waste oil is expected to occur between 1974 and 2000, pollution due to waste oil should be minimal.

D.4.2.2 Parts/Maintenance

The differences in the solid wastes generated by CV, HV, and EV parts are due to the engine and battery systems of the vehicles. One hundred percent recycling of the batteries and 95% recovery of the battery materials are

Table D.90. Discarded Waste Oil from HV and CV Operation, by Scenario, 2000[a]

	Scenario					
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II	BASE (all CVs)
Number of HVs and CVs	174,150,580	174,150,740	169,433,870	151,236,110	159,273,980	177,358,000
Oil used (gal/yr)	435,376,450	435,376,850	423,584,675	378,090,275	398,184,950	443,395,000
Waste oil (gal/yr)	217,688,225	217,688,425	211,792,337	189,045,137	199,092,475	221,697,500
Oil drained (gal/yr)	195,919,402	195,919,582	190,613,104	170,140,623	179,183,228	199,527,750
Oil discarded (gal/yr)	58,775,820	58,775,875	57,183,931	51,042,187	53,754,968	59,858,325

[a] The calculations are based on the following assumptions: (1) two oil changes per year, (2) average 5-qt capacity for all vehicles, (3) 50% of oil used lost in operation, (4) 90% of used oil drained, and (5) 30% of waste oil discarded.

anticipated. Further, the propulsion system of the EV is extremely simple and efficient, requiring almost little or no maintenance. The electric motor (which is also present in the HV) is expected to easily outlast the vehicle and can readily be reused. Parts for the EHV motor are almost nonexistent, and the parts that may be required are normally those like brushes and bearings, which are small and produce insignificant amounts of solid waste. Therefore, this section focuses on the solid waste generated from the CV and HV engine systems, which do not have such a high recycling rate. Based on 1972 data, 62% of parts sales were required for the engine and its fuel, ignition, cooling, and exhaust systems, none of which are present in the EV vehicle.[D.31]

For purposes of this analysis, the replacement rates projected for CVs are projected for HVs. The assumptions include an average 15% replacement of engine parts by weight over 10 yr; 50% recycling of replaced parts; 25% rebuilding of replaced parts, and 25% waste of replaced parts. Based on the number of CVs and HVs projected for the year 2000, the quantities of solid waste generated by engine parts for each scenario are given in Table D.91.

Land area required for the disposal of solid wastes generated by vehicle parts is given in Table D.92. The HIGH I scenario requires the least land (1.55 acres), while the BASE scenario requires the most land (1.81 acres); LOW I and LOW II require slightly less (1.78 acres). With a range of only 0.26 acres among all five scenarios and the BASE scenario, the difference is insignificant. When considered nationally, the 1.55-1.81 acres of land needed for disposal of solid waste parts are negligible.

D.4.2.3 Power Plant Solid Wastes

Solid waste is generated indirectly during operation of EHVs. Table D.93 projects solid wastes generated by coal and oil power plants for the production of electricity to recharge batteries. These quantities are then translated into land requirements for disposal: 27.7 acres for LOW I; 54.4 acres for LOW II; 110.5 acres for MEDIUM; 280.4 acres for HIGH I; and 270.7

Table D.91. Solid Waste Generated by HV and CV Engine Parts, by Scenario, 2000[a]

	Scenario					
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II	BASE (all CVs)
Number of HV and CVs	174,150,580	174,150,740	169,433,870	151,236,110	159,273,980	177,358,000
Weight replaced (tons/yr)	372,247	372,247	362,165	323,267	340,448	379,103
Parts rebuilt (tons/yr)	93,062	93,062	90,541	80,817	85,112	94,776
Parts recycled (tons/yr)	186,123	186,123	180,083	161,633	170,224	189,551
Solid waste (HV + CV) (tons/yr)	93,062	93,062	90,541	80,817	85,112	94,776
Solid waste (HV only) (tons/yr)	-	1,068	-	-	4,335	-
Solid waste from same number of CVs as EHVs in scenario (tons/yr)	1,590	2,658	4,234	12,703	12,745	-

[a] The calculations are based on the following assumptions: (1) average life span of vehicle is 10 yr, (2) average replacement of engine parts by weight over 10 yr is 15%, (3) average weight of engine is 285 lb, (4) 25% of weight replacement is rebuilt and used, (5) 50% of weight replacement is recycled, and (6) 25% of weight replacement is solid waste.

Table D.92. Land Area Required for Disposal of Solid Wastes Generated by HV and CV Engine Parts, by Scenario, 2000[a]

	Scenario					
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II	BASE (all CVs)
Solid waste (HV + CV) (tons/yr)	93,062	93,062	90,541	80,817	85,112	94,776
Land area for disposal (acres)	1.78	1.78	1.73	1.55	1.63	1.81
Solid waste (HV only) (tons/yr)	-	1,068	-	-	4,335	-
Land area for disposal (acres)	-	0.02	-	-	0.08	-
Solid waste from same number of CVs as EHVs in scenario (tons/yr)	1,590	2,658	4,234	12,703	12,745	-
Land area for disposal (acres)	0.03	0.05	0.08	0.24	0.24	-

[a] Average weight of solid waste assumed to be 400 lb/ft^3, and land area is taken to be fill to an average depth of 6 ft.

Table D.93. Power Plant Solid Wastes Generated during EHV Operation, by Scenario, 2000

	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
Solid wastes from coal (tons)[a]	1,877,473	3,682,759	7,480,341	18,969,548	18,312,310
Solid wastes from oil (tons)[b]	2,720	5,668	9,188	32,863	31,616
Total (tons)	1,880,193	3,688,427	7,489,529	19,002,411	18,343,926
Landfill (acres)c	27.7	54.4	110.5	280.4	270.7
% of total acres of landfill needed for wastes from electricity production[d]	0.24	0.47	0.95	2.43	2.35

[a] Assumes 75% eastern coal with 26,124.8 tons of solid wastes per trillion Btu and 25% western coal with 14,308.6 tons of solid wastes per trillion Btu.

[b] Assumes 110 tons of solid wastes produced per trillion Btu.

[c] Assumes average depth of landfill equals 42 ft and one ton of solid waste per cubic yard. This is different than the average 6-ft landfill because of the material, method of disposal, and space limitations at power plant sites.

[d] Total coal = 33.66 x 10^{15} Btu; total oil = 0.86 x 10^{15} Btu.

acres for HIGH II. The percentages given in the table represent that portion of the total land area required for disposal of power plant solid wastes that is required for disposal of wastes as a result of EHV market penetration.

Solid wastes produced by power plants are of two types: (1) ash from fuels and (2) sludge from pollution control devices. Ash consists primarily of silicones, with some trace metals. Sludge is a limestone slurry containing sulfides and sulfates. Both the ash and sludge are usually disposed of on site in a landfill. If proper methods are used to prevent formation of leachates and to control erosion and sedimentation, potential adverse impacts on the environment can be minimized.

Of the five EHV scenarios, the most substantial impact on land required for disposal results under the HIGH I and HIGH II scenarios, with 280.4 and 270.7 acres, respectively. However, considering total power plant solid wastes, these requirements are very small.

D.4.3 Fuels Production and Transport Analysis

Solid waste associated with fuels production and transport of fuels required for EHV and CV operation to utilities, service stations, or other vehicle servicing facilities is characterized in Sec. B.4. Based on that characterization, the solid wastes generated in fuels production for each EHV scenario and for an equivalent number of CVs operating equivalent VMT are shown in Tables D.94-D.99. Table D.100 shows the land required for solid waste disposal in each scenario. These tables show that the increase in solid waste and land required for disposal is substantial with market penetration of EHVs. Seventy-five percent of the increase in land requirements stems from uranium extraction, including associated overburden. No economies of scale or improvements in efficiency in the removal of overburden have been assumed. Land for coal beneficiation residues is the second largest component of the total acreage requirements. Disposal of these residues could be burdensome without long-term planning for alternative uses.

D.4.4 Vehicle Disposal Analysis

At the end of a vehicle's life cycle, basically four forms of solid waste are generated: (1) waste oils, (2) metallic wastes, (3) nonmetallic wastes, and (4) batteries.

D.4.4.1 Waste Oil

As stated in Sec. D.4.2.1, EVs require no lubricating oil. Therefore, in those scenarios with the highest penetration of EVs, a reduction in the potential for haphazard discharge of waste oil into the environment is realized. However, even in the BASE scenario, a significant reduction in the disposal of waste oil is expected to occur by the year 2000 because of the greater economic benefits of recycling and less oil use because of smaller engines and greater efficiency.

Table D.94. Solid Wastes from Fuels Produced and Transported to Utility for EHV Operation, LOW I, 2000 (short tons)

Uranium		Coal		Oil		Total
Overburden removed	11.3×10^6	Mine tailings	3.24×10^4	Dry residue	241.5	
Mine and mill tailings	1.4×10^6	Beneficiation residues	2.87×10^6			
Ash and other process residues	490.8					
Total	1.28×10^7		2.9×10^6		241.5	1.57×10^7

Table D.95. Solid Wastes from Fuels Produced and Transported to Utility and Service Station for EHV Operation, LOW II, 2000 (short tons)

Uranium		Coal		Oil		Gasoline		Total
Overburden removed	21.9×10^6	Mine tailings	6.35×10^4	Dry residue	517	Dry residue	503	
Mine and mill tailings	2.79×10^6	Beneficiation residues	5.62×10^6					
Ash and other process residues	947.1							
Total	2.47×10^7		5.7×10^6		517		503	3.04×10^7

Table D.96. Solid Wastes from Fuels Produced and Transported to Utility for EHV Operation, MEDIUM, 2000 (short tons)

Uranium		Coal		Oil		Total
Overburden removed	33.7×10^6	Mine tailings	9.85×10^4	Dry residue	827	
Mine and mill tailings	4.29×10^6	Beneficiation residues	8.71×10^6			
Ash and other process residues	1,460.6					
Total	3.80×10^7		8.8×10^6		827	4.68×10^7

Table D.97. Solid Wastes from Fuels Produced and Transported to Utility for EHV Operation, HIGH I, 2000 (short tons)

Uranium		Coal		Oil		Total
Overburden removed	1.032×10^8	Mine tailings	3.23×10^5	Dry residue	3025	
Mine and mill tailings	13.15×10^6	Beneficiation residues	2.85×10^7			
Ash and other process residues	4,472					
Total	1.16×10^8		2.9×10^7		3025	1.45×10^8

Table D.98. Solid Wastes from Fuels Produced and Transported to Utility and Service Station for EHV Operation, HIGH II, 2000 (short tons)

Uranium		Coal		Oil		Gasoline		Total
Overburden removed	1.001×10^8	Mine tailings	3.13×10^5	Dry residue	2,928	Dry residue	2,180	
Mine and mill tailings	12.76×10^6	Beneficiation residues	2.77×10^7					
Ash and other process residues	4,339.0							
Total	1.13×10^8		2.8×10^7		2,928		2,180	1.41×10^8

Table D.99. Solid Waste from Production and Transport to Service Station of Gasoline and Diesel Fuel Required by CVs Operating the Same VMT as EHVs, 2000 (short tons)

Scenario	Dry Residual
LOW I	2,035.9
LOW II	3,950.3
MEDIUM	6,432.9
HIGH I	20,522.3
HIGH II	20,365.3

Table D.100. Land Areas Required for Disposal of Solid Wastes from Fuels Production and Transport for EHVs and for CVs Operating the Same VMT as EHVs, by Scenario, 2000

	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
EHV					
Overburden (10^6 tons)	11.3	21.9	33.7	103.2	100.1
Land required (acres)[a]	616.98	1,195.74	1,840.02	5,634.72	5,465.46
Tailings (10^6 tons)	1.48	2.85	4.39	13.47	13.07
Land required (acres)[b]	75.6	145.53	223.81	687.12	666.72
Coal beneficiation Residues (10^6 tons)	2.87	5.62	8.71	28.5	27.7
Land required (acres)[c]	125.42	245.59	380.63	1,245.45	1,210.49
Dry process residues (tons)	732	1,967	2,288	7,497	9,447
Land required (acres)[d]	0.04	0.10	0.11	0.37	0.47
Total land required (acres)	818.04	1,586.96	2,444.57	7,567.66	7,343.14
CV					
Dry process residues (tons)	2,036	3,950	6,433	20,522	20,365
Total land required[d] (acres)	0.10	0.20	0.32	1.03	1.02

[a] Average weight of overburden is assumed to be 140 lb/ft^3, and land area is taken to be fill to an average depth of 6 ft.

[b] Average weight of tailings is assumed to be 150 lb/ft^3, and land area is taken to be fill to an average depth of 6 ft.

[c] Average weight of coal beneficiation is assumed to be 175 lb/ft^3, and land area is taken to be fill to an average depth of 6 ft.

[d] Average weight of dry process residues is assumed to be 147 lb/ft^3, and land area is taken to be fill to an average depth of 6 ft.

Another major factor affecting the impact of waste oil by the year 2000 is the recycling of vehicle hulks. Because of economic benefits, it is estimated that close to 100% of automobile hulks will be recycled by the year 2000.[D.30] Therefore, the recapture of waste oil during dismantling and size reduction will be both practical and feasible.

It is estimated that no more than 5% of the waste oil from junked vehicles will be haphazardly discharged into the environment in the year 2000 (see Table D.101).

In comparing all five EHV scenarios to the BASE scenario, the greatest difference occurs in the HIGH I scenario -- a decrease of 163 x 10^3 gal, or 14.7%. The other four scenarios result in the following decreases: LOW I, 1.8%; LOW II, 1.8%; MEDIUM, 4.5%; and HIGH II, 10.2%.

The range among all five scenarios is 143 x 10^3 gal. This quantity of oil is capable of creating toxic conditions in a 143 acre body of water with an average depth of 10 ft. Any of the five EHV scenarios, which average approximately 1,000,000 gal, is capable of causing potential environmental pollution. However, since the discharge would be dispersed nationally, the volumes would be small at any one time, and the differences between each of the five scenarios and the BASE scenario would be insignificant.

D.4.4.2 Metallic and Nonmetallic Wastes

Almost all of the solid wastes generated by EHV and CV disposal result from plastic and rubber components. Since the use of plastics is expected to increase to reduce vehicle weight, it is anticipated that landfill areas to handle the solid waste will increase but only slightly. This is because different types of plastics are going to be used that are almost impossible to reuse. Also, fire retardant additives to the plastics will limit their reuse potential as fuel.

Table D.101. Discarded Waste Oil from Junked HVs and CVs, by Scenario, 2000[a]

	Scenario					
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II	BASE (all CVs)
Number of junked HVs and CVs	17,415,058	17,415,074	16,943,387	15,123,611	15,927,398	17,735,800
Waste oil (gal/yr)	21,768,823	21,768,843	21,179,234	18,904,514	19,909,248	22,169,750
Discarded oil (gal/yr)	1,088,441	1,088,442	1,058,962	945,226	995,462	1,108,488

[a] The calculations are based on the following assumptions: (1) 10% of total vehicles will be junked during the year, (2) average oil capacity of junked vehicle equals 5 qt, and (3) 5% of waste oil is discarded.

By the year 2000, the material composition of EHVs, except for the batteries (see Sec. D.4.4.3), will differ little from the material composition of CVs. In particular, the percentage of plastic and rubber in EHVs (minus the battery) and CVs will be approximately the same. As a result, little change between the EHV scenarios and the BASE scenario is anticipated in the quantities of nonmetallic waste generated by vehicle disposal.

The metallic components of each vehicle -- steel, iron, aluminum, and copper -- will be almost entirely recycled. With improved dismantling, separation, and shredding processes, the ability to reuse the material coupled with the economic benefits will make total recycling highly feasible. For instance, in 1971, 60-80% of all autos were recycled.[D.30] Even today it has become profitable in many areas of the country to go back and recover abandoned or buried auto hulks. Therefore, it is anticipated that there will be no significant difference between the EHV scenarios and the BASE scenario in the amount of metallic wastes from vehicle disposal.

D.4.4.3 Batteries

As stated earlier, it is expected that EHV batteries will be recycled and 95% of the battery components recovered. Thus, there should be few solid wastes as a result of battery disposal. Accessory batteries in both EHVs and CVs will also be recycled.

D.4.5 Total Solid Wastes

Table D.102 gives the total solid waste generated in the EHV scenarios and for a comparable number of CVs operating equivalent VMT. Table 3.21 presents the total land required for solid waste disposal by EHV scenario and for equivalent CVs.

It is difficult to establish national waste disposal land requirements with which the EHV-related solid waste disposal acreage requirements can be compared. Rising material and energy prices make the projection of future solid waste generation extremely uncertain. Depth of disposal also can vary the acreage requirements calculated. Nonetheless, estimates for municipal solid waste acreage requirements can be made. Based on an average 3.6 lb/person/day in 2000, 35,000 acres at a depth of six feet are estimated to be required for municipal solid waste disposal in the year 2000. When the HIGH I scenario requirement for 16,000 acres (the greatest acreage among the scenarios) is compared with this estimate, HIGH I's solid waste acreage requirement appears quite substantial.

However, another way to view the scenario totals is to compare them with a rough estimate of waste disposal land requirements associated with total electricity generation in 2000. Eight thousand of the 16,000 acres required for waste disposal in the HIGH I scenario are required for fuels production (uranium, coal, oil, and gas) and utility solid wastes. The electricity requirements of the HIGH I scenario are just 3% of total U.S. demand in 2000. Thus, it can be assumed that these 8000 acres are approximately 3% of the total acreage requirements for solid waste disposal associated with all electricity demand in 2000 (fuels production for utilities

Table D.102. Total Solid Waste Attributable to Vehicle Production, Vehicle Operation, and Fuels Production and Transport for Each EHV Scenario and for Equivalent CVs, 2000[a]

Solid Waste Classification	EHVs					Equivalent CVs				
	LOW I	LOW II	MEDIUM	HIGH	HIGH II	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
Overburden moved[b]	11.30×10^6	21.9×10^6	(33.7×10^6)[c]	(1.032×10^8)	(1.001×10^8)	-	-	-	-	-
Waste rock	7.22×10^5	1.36×10^6	12.55×10^6	1.35×10^8	1.17×10^6	3.82×10^4	7.05×10^4	1.20×10^5	3.40×10^5	3.62×10^5
Total	1.20×10^7	2.33×10^7	(4.63×10^7)	(2.38×10^8)	1.01×10^8	3.82×10^4	7.05×10^4	1.20×10^5	3.40×10^5	3.62×10^5
Tailings	5.31×10^6	1.01×10^7	7.18×10^6	2.00×10^7	1.90×10^7	1.98×10^5	3.72×10^5	6.19×10^5	1.80×10^6	1.92×10^6
Smelting slag	2.7×10^4	4.2×10^4	6.15×10^5	5.69×10^6	4.27×10^5	1,521	2,779	4,764	13,357	14,210
Coal beneficiation residues	2.87×10^6	5.62×10^6	8.71×10^6	2.85×10^7	2.77×10^7	-	-	-	-	-
Total	2.90×10^6	5.66×10^6	9.33×10^6	3.42×10^7	2.81×10^7	1,521	2,779	4,764	13,357	14,210
Dry process residues of milling and manufacturing	1.63×10^5	3.03×10^5	2.99×10^5	2.16×10^6	2.81×10^5	5,124	9,829	16,060	49,038	50,923
Power plant residues	1.88×10^6	3.69×10^6	7.49×10^6	1.90×10^7	1.83×10^7	-	-	-	-	-

[a] Same number of CVs produced as EHVs in each scenario, and CVs operate same VMT as EHVs in each scenario.

[b] These wastes are disposed of primarily as landfill or construction aggregate. Overburden denotes the excess material removed in the extraction of coal and uranium. Waste rock refers to excess material created during extraction of metallic ores.

[c] Values in parentheses indicate speculative quantities that do not assume economies of scale or efficiency in the removal of overburden.

included). (The acreage totals associated with the EHV scenarios and U.S. electricity demand might well be less if greater depth of disposal were assumed.) Thus, the HIGH I scenario total of 16,000 acres appears low.

Further, much of the land required for solid waste disposal in the EHV scenarios is required for disposal of waste rock or overburden, particularly from lithium and uranium extraction. While land is required for temporary storage of this waste rock and overburden, it can be assumed that much of the waste will be returned to the mines when extraction is complete. In other words, land for permanent disposal would not be required. If the land area required for waste rock and overburden were eliminated from the totals in Table 3.21, the impact of the EHV scenarios would be significantly reduced (see Table D.103). EHV-related waste disposal would still require 27-42 times the land needed for CV-related wastes. However, on a national scale, when all the potential acreage requirements for disposal of mining, industrial, utility, municipal, and agricultural solid wastes are considered, the increase due to market penetration of EHVs is probably very small.

Table D.103. Land Required for Disposal of Solid Wastes except Waste Rock and Overburden from Vehicle Manufacture and Operation, and Fuels Production, 2000[a]

	Scenario				
	LOW I	LOW II	MEDIUM	HIGH I	HIGH II
EHV (acres)	432.27	828.18	900.65	2916.87	2483.86
CV (acres)	10.53	19.77	32.93	95.90	102.11
EHV land area - CV land area (acres)	421.74	808.41	867.72	2820.97	2381.75
$\frac{\text{EHV land area}}{\text{CV land area}}$	41.1	41.9	27.4	30.4	24.3

[a]Assumes equivalent numbers of CVs as EHVs and equivalent VMT.

APPENDIX D REFERENCES

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APPENDIX E

HEALTH AND SAFETY ANALYSES

E.1 OCCUPATIONAL HEALTH AND SAFETY

E.1.1 Methodology

Two types of occupational impacts are examined: (1) those for which quantified estimates of impact magnitude and severity could be made and (2) those that could only be qualitatively described. The quantified impact estimates are based on U.S. Dept. of Labor statistics and National Safety Council data on historical incidence rates for occupational injuries and illnesses[E.1-E.10] and on projected levels of employment for the economic sectors most impacted by market penetration of EHVs. Derivation of these employment impacts is discussed in Sec. G.2.

Two assumptions are critical in the projection of occupational impacts. Even though technological innovations, changes in federal and state regulations, and new health care techniques occurring during the assessment timeframe may result in varying incidence rates, the assumption is made that incidence rates reflecting current occupational and medical conditions remain constant. The second assumption is that these incidence rates accurately reflect the real world. Unfortunately, identification and reporting of occupational impacts is not always consistent or complete. Reporting procedures vary among recording agencies and economic sectors. Multiple sources of exposure, lag times between exposure and response, and population migration affect identification of the causes of adverse health events and, thus, the accuracy of incidence rates, especially for illnesses. However, incidence rates do provide the best basis for comparing the relative impacts of the BASE scenario and the five EHV scenarios.

The following measures of magnitude and severity are often used in projecting occupational health and safety impacts:

1. Total recordable cases (TRC) are the number of reported cases of injury resulting from an incident in the work environment plus the number of reported conditions or disorders caused by exposure to environmental factors associated with employment.

2. Person days lost (PDL) are the number of workdays (consecutive or not) an employee is away from work or is limited to restricted work activity due to occupational injury or illness.

3. Lost workday cases (LWC) are the number of TRC that involve days away from work or restricted work activity.

4. Nonfatal cases without lost workdays (NDL) are the number of TRC that do not involve days away from work or restricted work activity.

The employment data used in this analysis are not sensitive enough to allow for meaningful comparisons and impact estimates using LWC and NDL. Total recordable cases are used as an estimate of magnitude of occupational health and safety impacts, and PDL are used as an estimate of severity of impact. Figure E.1 is a flow diagram of the procedure used to quantify occupational illness and injury impacts.

Changes in employment due to each EHV scenario were screened and the 22 economic sectors most impacted by EHV development were chosen for occupational health and safety analysis. Table E.1 presents TRC and PDL projections for each of these sectors by scenario.

Some potentially significant occupational health impacts are not reflected in the TRC or PDL estimates. These impacts, identified primarily through literature review, result from the development of new technologies and/or the expansion of historically small economic sectors. They can result in workplace exposure to toxic substances and physical trauma situations that are presently unknown or minimal enough to preclude impact incidence rate information. Currently unquantifiable impacts are described qualitatively in Sec. 3.6.

E.1.2 Analysis

Projections of TRC occurring as a result of EHV development indicate that, regardless of which EHV scenario is implemented, the total number of cases will be very similar to the number occurring under the BASE scenario. The HIGH scenarios, which assume considerable federal intervention to defray private costs and to encourage development of new battery or hybrid technologies, are the only scenarios for which TRC vary by more than 10,000 from the BASE scenario for any assessment year. However, the increase in impact is only 1-2%. This variance is well within that introduced by estimating incidence rates.

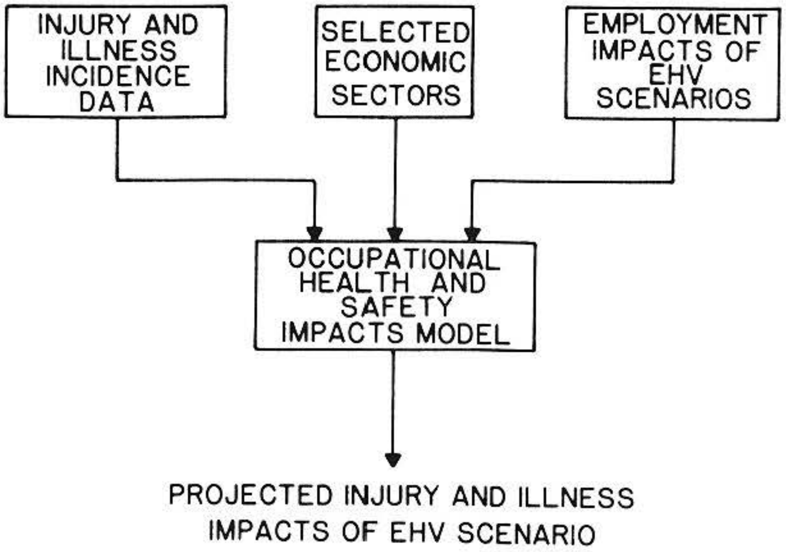

Fig. E.1. Methodology of Occupational Health and Safety Analysis

Table E.1. TRC and PDL by Scenario, Sector, and Year

BASE

SECTOR NUMBER	NAME	INCIDENCE RATE[a]	TOTAL RECORDABLE CASES 1975	1985	1990	2000
2	MINING	10	34400	36700	35100	34500
3	PETROLEUM AND GAS	9	24390	17280	12960	8910
38	PETROLEUM REFINING	8	16160	17520	16640	15840
39	TIRES AND TUBES	13	16770	21450	22880	24570
40	RUBBER PROL EX TIRES	11	22000	28600	26510	25410
41	PLASTIC PRODUCTS	11	34100	38390	41360	44770
46	IRON AND STEEL	14	124740	130200	127540	117880
47	NON-FERROUS METALS	10	32100	41200	42800	41400
50	STRUCTURAL METAL PRODUCTS	19	73910	97660	105260	105260
53	ENGINES AND TURBINES	9	10080	13590	15300	17010
55	CONST,MINE,MATRL HANDL EQ	15	42450	55050	58800	51150
56	METALWORKING MACHINERY	11	35640	46420	45650	35970
62	TRANSMORMRS,SWTHGR,EL MSR	8	17040	31840	35920	37760
63	ELECTRIC APP + MOTORS	10	23300	29800	31600	30000
65	ELEC LIGHTING + WIRING	8	15520	22640	23120	23440
69	BATTERIES,X-RAY EQ,ETC.	11	12540	14960	15840	16170
73	RAILROAD EQUIPMENT	18	16560	14580	14760	14220
76	MECH MEASURING DEVICES	8	7600	9680	9280	7760
80	RAILROADS	9	46980	38700	39240	40320
81	TRUCKING	17	227120	303960	297840	277440
82	OTHER TRANSPORT	10	62600	67100	63300	57800
87	ELECTRIC UTILITIES	8	42080	38640	41600	42640
TOTAL		247	938580	1115960	1123300	1070220

SECTOR NUMBER	NAME	INCIDENCE RATE	PERSON DAYS LOST 1975	1985	1990	2000
2	MINING	191	657040	700970	670410	658950
3	PETROLEUM AND GAS	93	252030	178560	133920	92070
38	PETROLEUM REFINING	57	115140	124830	118560	112860
39	TIRES AND TUBES	157	202530	259050	276320	296730
40	RUBBER PROL EX TIRES	87	174000	226200	209670	200970
41	PLASTIC PRODUCTS	59	182900	205910	221840	240130
46	IRON AND STEEL	97	864270	902100	883670	816740
47	NON-FERROUS METALS	111	356310	457320	475080	459540
50	STRUCTURAL METAL PRODUCTS	109	424010	560260	603860	603860
53	ENGINES AND TURBINES	48	53760	72480	81600	90720
55	CONST,MINE,MATRL HANDL EQ	81	229230	297270	317520	276210
56	METALWORKING MACHINERY	51	165240	215220	211650	166770
62	TRANSMORMRS,SWTHGR,EL MSR	40	85200	159200	179600	188800
63	ELECTRIC APP + MOTORS	58	138040	172840	183280	174000
65	ELEC LIGHTING + WIRING	42	81480	118860	121380	123060
69	BATTERIES,X-RAY EQ,ETC.	69	78660	93840	99360	101430
73	RAILROAD EQUIPMENT	144	132480	116640	118080	113760
76	MECH MEASURING DEVICES	70	66500	84700	81200	67900
80	RAILROADS	95	495900	408500	414200	425600
81	TRUCKING	158	2110880	2825040	2768160	2578560
82	OTHER TRANSPORT	128	801280	858880	810240	739840
87	ELECTRIC UTILITIES	61	320860	294630	317200	325130
TOTAL		2006	7987740	9333300	9296800	8853630

Table E.1. (Cont'd)

LOW I

SECTOR NUMBER	NAME	INCIDENCE RATE	TOTAL RECORDABLE CASES			
			1975	1985	1990	2000
2	MINING	10	34400	36600	34900	34700
3	PETROLEUM AND GAS	9	24390	17280	12960	8820
38	PETROLEUM REFINING	8	16160	17520	16560	15760
39	TIRE AND TUBES	13	16770	21450	22880	24570
40	RUBBER PROD. EX. TIRES	11	22000	28600	26510	25410
41	PLASTIC PRODUCTS	11	34100	38390	41360	44770
46	IRON AND STEEL	14	124740	129080	127400	118160
47	NON-FERROUS METALS	10	32100	41100	42700	41600
50	STRUCTURAL METAL PRODUCTS	19	73910	97660	104690	105450
53	ENGINE AND TURBINES	9	10080	13590	15120	17100
55	CONST,MINE,MATRL HANDL EQ	15	42450	55050	58650	51150
56	METALWORKING MACHINERY	11	35640	46420	45650	35970
62	TRANSFORMRS,SWTHGR,EL MSR	8	17040	31840	35440	37920
63	ELECTRIC APP.+ MOTORS	10	23300	29800	31500	30000
65	ELEC. LIGHTING + WIRING	8	15520	22640	23120	23440
69	BATTERIES,X-RAY EQ.,ETC.	11	12540	14960	16060	16500
73	RAILROAD EQUIPMENT	18	16560	14580	14760	14220
76	MECH. MEASURING DEVICES	8	7600	9680	9280	7840
80	RAILROADS	9	46980	38700	39150	40320
81	TRUCKING	17	227120	303790	297670	277440
82	OTHER TRANSPORT	10	62600	67100	63200	57700
87	ELECTRIC UTILITIES	8	42080	38640	40720	44400
TOTAL		247	938580	1114470	1120280	1073240

SECTOR NUMBER	NAME	INCIDENCE RATE	PERSON DAYS LOST			
			1975	1985	1990	2000
2	MINING	191	657040	699060	666590	662770
3	PETROLEUM AND GAS	93	252030	178560	133920	91140
38	PETROLEUM REFINING	57	115140	124830	117990	112290
39	TIRE AND TUBES	157	202530	259050	276320	296730
40	RUBBER PROD. EX. TIRES	87	174000	226200	209670	200970
41	PLASTIC PRODUCTS	59	182900	205910	221840	240130
46	IRON AND STEEL	97	864270	894340	882700	818680
47	NON-FERROUS METALS	111	356310	456210	473970	461760
50	STRUCTURAL METAL PRODUCTS	109	424010	560260	600590	604950
53	ENGINE AND TURBINES	48	53760	72480	80640	91200
55	CONST,MINE,MATRL HANDL EQ	81	229230	297270	316710	276210
56	METALWORKING MACHINERY	51	165240	215220	211650	166770
62	TRANSFORMRS,SWTHGR,EL MSR	40	85200	159200	177200	189600
63	ELECTRIC APP.+ MOTORS	58	138040	172840	182700	174000
65	ELEC. LIGHTING + WIRING	42	81480	118860	121380	123060
69	BATTERIES,X-RAY EQ.,ETC.	69	78660	93840	100740	103500
73	RAILROAD EQUIPMENT	144	132480	116640	118080	113760
76	MECH. MEASURING DEVICES	70	66500	84700	81200	68600
80	RAILROADS	95	495900	408500	413250	425600
81	TRUCKING	158	2110880	2823460	2766580	2578560
82	OTHER TRANSPORT	128	801280	858880	808960	738560
87	ELECTRIC UTILITIES	61	320860	294630	310490	338550
TOTAL		2006	7987740	9320940	9273170	8877390

Table E.1. (Cont'd)

LOW II

SECTOR NUMBER	NAME	INCIDENCE RATE	TOTAL RECORDABLE CASES 1975	1985	1990	2000
2	MINING	10	34400	36700	34900	35100
3	PETROLEUM AND GAS	9	24390	17280	12960	8730
38	PETROLEUM REFINING	8	16160	17520	16640	15760
39	TIRE AND TUBES	13	16770	21450	22880	24570
40	RUBBER PROD. EX. TIR	11	22000	28600	26510	25410
41	PLASTIC PRODUCTS	11	34100	38390	41360	44880
46	IRON AND STEEL	14	124740	130200	127260	118720
47	NON-FERROUS METALS	10	32100	41200	42700	42400
50	STRUCTURAL METAL PRO	19	73910	97660	104690	105640
53	ENGINE AND TURBINES	9	10080	13590	15120	17100
55	CONST,MINE,MATRL HAN	15	42450	55050	58650	51300
56	METALWORKING MACHINE	11	35640	46420	45650	35970
62	TRANSFORMRS,SWTHGR,E	8	17040	31840	35440	38080
63	ELECTRIC APP. + MOTO	10	23800	29800	31500	30100
65	ELEC. LIGHTING + WIR	8	15520	22640	23120	23440
69	BATTERIES,X-RAY EQ.,	11	12540	14960	15840	16610
73	RAILROAD EQUIPMENT	18	16560	14580	14760	14220
76	MECH. MEASURING DEVI	8	7600	9680	9280	7840
80	RAILROADS	9	46980	38700	39150	40410
81	TRUCKING	17	227120	303960	297500	277780
82	OTHER TRANSPORT	10	62600	67100	63200	57700
87	ELECTRIC UTILITIES	8	42080	38640	40720	44640
TOTAL		247	938580	1115960	1119830	1076400

SECTOR NUMBER	NAME	INCIDENCE RATE	PERSON DAYS LOST 1975	1985	1990	2000
2	MINING	191	657040	700970	666590	670410
3	PETROLEUM AND GAS	93	252030	178560	133920	90210
38	PETROLEUM REFINING	57	115140	124830	118560	112290
39	TIRE AND TUBES	157	202530	259050	276320	296730
40	RUBBER PROD. EX. TIR	87	174000	226200	209670	200970
41	PLASTIC PRODUCTS	59	182900	205910	221840	240720
46	IRON AND STEEL	97	864270	902100	881730	822560
47	NON-FERROUS METALS	111	356310	457320	473970	470640
50	STRUCTURAL METAL PRO	109	424010	560260	600590	606040
53	ENGINE AND TURBINES	48	53760	72480	80640	91200
55	CONST,MINE,MATRL HAN	81	229230	297270	316710	277020
56	METALWORKING MACHINE	51	165240	215220	211650	166770
62	TRANSFORMRS,SWTHGR,E	40	85200	159200	177200	190400
63	ELECTRIC APP. + MOTO	58	138040	172840	182700	174580
65	ELEC. LIGHTING + WIR	42	81480	118860	121380	123060
69	BATTERIES,X-RAY EQ.,	69	78660	93840	99360	104190
73	RAILROAD EQUIPMENT	144	132480	116640	118080	113760
76	MECH. MEASURING DEVI	70	66500	84700	81200	68600
80	RAILROADS	95	495900	408500	413250	426550
81	TRUCKING	158	2110880	2825040	2765000	2581720
82	OTHER TRANSPORT	128	801280	853830	808960	738560
87	ELECTRIC UTILITIES	61	320860	294630	310490	340380
TOTAL		2006	7987740	9333300	9269810	8907360

Table E.1. (Cont'd)

MEDIUM

SECTOR		INCIDENCE	TOTAL RECORDABLE CASES			
NUMBER	NAME	RATE	1975	1985	1990	2000
2	MINING	10	34400	36700	35000	34900
3	PETROLEUM AND GAS	9	24390	17280	12960	8640
38	PETROLEUM REFINING	8	16160	17520	16640	15680
39	TIRE AND TUBES	13	16770	21450	22880	24570
40	RUBBER PROD. EX. TIRES	11	22000	28600	26510	25520
41	PLASTIC PRODUCTS	11	34100	38390	41360	44880
46	IRON AND STEEL	14	124740	130200	127540	118020
47	NON-FERROUS METALS	10	32100	41200	42800	41700
50	STRUCTURAL METAL PRODUCTS	19	73910	97660	105070	105640
53	ENGINE AND TURBINES	9	10080	13590	15210	17100
55	CONST,MINE,MATRL HANDL EQ	15	42450	55050	58800	51150
56	METALWORKING MACHINERY	11	35640	46420	45650	35970
62	TRANSFORMRS,SWTHGR,EL MSR	8	17040	31840	35840	38000
63	ELECTRIC APP. + MOTORS	10	23800	29800	31600	30000
65	ELEC. LIGHTING + WIRING	8	15520	22640	23120	23440
69	BATTERIES,X-RAY EQ.,ETC.	11	12540	14960	15840	17380
73	RAILROAD EQUIPMENT	18	16560	14580	14760	14220
76	MECH. MEASURING DEVICES	8	7600	9680	9280	7840
80	RAILROADS	9	46980	38700	39240	40410
81	TRUCKING	17	227120	303960	297840	277610
82	OTHER TRANSPORT	10	62600	67100	63300	57600
87	ELECTRIC UTILITIES	8	42080	38640	41360	44720
TOTAL		247	938580	1115960	1122600	1074990

SECTOR		INCIDENCE	PERSON DAYS LOST			
NUMBER	NAME	RATE	1975	1985	1990	2000
2	MINING	191	657040	700970	668500	666590
3	PETROLEUM AND GAS	93	252030	178560	133920	89280
38	PETROLEUM REFINING	57	115140	124830	118560	111720
39	TIRE AND TUBES	157	202530	259050	276320	296730
40	RUBBER PROD. EX. TIRES	87	174000	226200	209670	201840
41	PLASTIC PRODUCTS	59	182900	205910	221840	240720
46	IRON AND STEEL	97	864270	902100	883670	817710
47	NON-FERROUS METALS	111	356310	457320	475080	462870
50	STRUCTURAL METAL PRODUCTS	109	424010	560260	602770	606040
53	ENGINE AND TURBINES	48	53760	72480	81120	91200
55	CONST,MINE,MATRL HANDL EQ	81	229230	297270	317520	276210
56	METALWORKING MACHINERY	51	165240	215220	211650	166770
62	TRANSFORMRS,SWTHGR,EL MSR	40	85200	159200	179200	190000
63	ELECTRIC APP. + MOTORS	58	138040	172840	183280	174000
65	ELEC. LIGHTING + WIRING	42	81480	118860	121380	123060
69	BATTERIES,X-RAY EQ.,ETC.	69	78660	93840	99360	109020
73	RAILROAD EQUIPMENT	144	132480	116640	118080	113760
76	MECH. MEASURING DEVICES	70	66500	84700	81200	68600
80	RAILROADS	95	495900	408500	414200	426550
81	TRUCKING	158	2110380	2825040	2768160	2580140
82	OTHER TRANSPORT	128	801280	858880	810240	737280
87	ELECTRIC UTILITIES	61	320860	294630	315370	340990
TOTAL		2006	7987740	9333300	9291090	8891080

Table E.1. (Cont'd)

HIGH I

SECTOR NUMBER	NAME	INCIDENCE RATE	TOTAL RECORDABLE CASES 1975	1985	1990	2000
2	MINING	10	34400	36700	35000	35700
3	PETROLEUM AND GAS	9	24390	17280	12960	7830
38	PETROLEUM REFINING	8	16160	17520	16640	15200
39	TIRE AND TUBES	13	16770	21450	22880	24570
40	RUBBER PROD. EX. TIRES	11	22000	28600	26510	25630
41	PLASTIC PRODUCTS	11	34100	38390	41360	45100
46	IRON AND STEEL	14	124740	130060	127260	118860
47	NON-FERROUS METALS	10	32100	41200	42800	42700
50	STRUCTURAL METAL PRODUCTS	19	73910	97660	105070	106590
53	ENGINE AND TURBINES	9	10080	13590	15210	17460
55	CONST,MINE,MATRL HANDL EQ	15	42450	55050	58800	51300
56	METALWORKING MACHINERY	11	35640	46420	45650	36190
62	TRANSFORMRS,SWTHGR,EL MSR	8	17040	31840	35840	33880
63	ELECTRIC APP. + MOTORS	10	23800	29800	31600	30300
65	ELEC. LIGHTING + WIRING	8	15520	22640	23120	23600
69	BATTERIES,X-RAY EQ.,ETC.	11	12540	14960	15950	20460
73	RAILROAD EQUIPMENT	18	16560	14580	14760	14400
76	MECH. MEASURING DEVICES	8	7600	9680	9280	7840
80	RAILROADS	9	46980	38700	39240	40770
81	TRUCKING	17	227120	303960	297840	278460
82	OTHER TRANSPORT	10	62600	67100	63300	57000
87	ELECTRIC UTILITIES	8	42080	38640	41440	46480
TOTAL		247	938580	1115820	1122510	1085320

SECTOR NUMBER	NAME	INCIDENCE RATE	PERSON DAYS LOST 1975	1985	1990	2000
2	MINING	191	657040	700970	668500	681870
3	PETROLEUM AND GAS	93	252030	178560	133920	80910
38	PETROLEUM REFINING	57	115140	124830	118560	108300
39	TIRE AND TUBES	157	202530	259050	276320	296730
40	RUBBER PROD. EX. TIRES	87	174000	226200	209670	202710
41	PLASTIC PRODUCTS	59	182900	205910	221840	241900
46	IRON AND STEEL	97	864270	901130	881730	823530
47	NON-FERROUS METALS	111	356310	457320	475080	473970
50	STRUCTURAL METAL PRODUCTS	109	424010	560260	602770	611490
53	ENGINE AND TURBINES	48	53760	72480	81120	93120
55	CONST,MINE,MATRL HANDL EQ	81	229230	297270	317520	277020
56	METALWORKING MACHINERY	51	165240	215220	211650	167790
62	TRANSFORMRS,SWTHGR,EL MSR	40	85200	159200	179200	194400
63	ELECTRIC APP. + MOTORS	58	138040	172840	183280	175740
65	ELEC. LIGHTING + WIRING	42	81480	118860	121380	123900
69	BATTERIES,X-RAY EQ.,ETC.	69	78660	93840	100050	128340
73	RAILROAD EQUIPMENT	144	132480	116640	118080	115200
76	MECH. MEASURING DEVICES	70	66500	84700	81200	68600
80	RAILROADS	95	495900	408500	414200	430350
81	TRUCKING	158	2110880	2825040	2768160	2588040
82	OTHER TRANSPORT	128	801280	858880	810240	729600
87	ELECTRIC UTILITIES	61	320860	294630	315980	354410
TOTAL		2006	7987740	9332330	9290450	8967920

Table E.1. (Cont'd)

HIGH II

SECTOR		INCIDENCE	TOTAL RECORDABLE CASES			
NUMBER	NAME	RATE	1975	1985	1990	2000
2	MINING	10	34400	36700	34900	35700
3	PETROLEUM AND GAS	9	24390	17280	12960	8010
38	PETROLEUM REFINING	8	16160	17520	16560	15360
39	TIRE AND TUBES	13	16770	21450	22880	24570
40	RUBBER PROD. EX. TIR	11	22000	28600	26510	25520
41	PLASTIC PRODUCTS	11	34100	38390	41360	45210
46	IRON AND STEEL	14	124740	130060	127120	119140
47	NON-FERROUS METALS	10	32100	41200	42700	43100
50	STRUCTURAL METAL PRO	19	73910	97660	104690	106210
53	ENGINE AND TURBINES	9	10080	13590	15120	17370
55	CONST,MINE,MATRL HAN	15	42450	55050	58650	51300
56	METALWORKING MACHINE	11	35640	46420	45650	36080
62	TRANSFORMRS,SWTHGR,E	8	17040	31840	35440	38640
63	ELECTRIC APP. + MOTO	10	23800	29800	31500	30200
65	ELEC. LIGHTING + WIR	8	15520	22640	23120	23520
69	BATTERIES,X-RAY EQ.,	11	12540	14960	15950	18040
73	RAILROAD EQUIPMENT	18	16560	14580	14760	14400
76	MECH. MEASURING DEVI	8	7600	9680	9280	7840
80	RAILROADS	9	46980	38700	39150	40680
81	TRUCKING	17	227120	303960	297670	278290
82	OTHER TRANSPORT	10	62600	67100	63200	57100
87	ELECTRIC UTILITIES	8	42080	38640	40800	45920
TOTAL		247	938580	1115820	1119970	1082200

SECTOR		INCIDENCE	PERSON DAYS LOST			
NUMBER	NAME	RATE	1975	1985	1990	2000
2	MINING	191	657040	700970	666590	681870
3	PETROLEUM AND GAS	93	252030	178560	133920	82770
38	PETROLEUM REFINING	57	115140	124830	117990	109440
39	TIRE AND TUBES	157	202530	259050	276320	296730
40	RUBBER PROD. EX. TIR	87	174000	226200	209670	201840
41	PLASTIC PRODUCTS	59	182900	205910	221840	242490
46	IRON AND STEEL	97	864270	901130	880760	825470
47	NON-FERROUS METALS	111	356310	457320	473970	478410
50	STRUCTURAL METAL PRO	109	424010	560260	600590	609310
53	ENGINE AND TURBINES	48	53760	72480	80640	92640
55	CONST,MINE,MATRL HAN	81	229230	297270	316710	277020
56	METALWORKING MACHINE	51	165240	215220	211650	167280
62	TRANSFORMRS,SWTHGR,E	40	85200	159200	177200	193200
63	ELECTRIC APP. + MOTO	58	138040	172840	182700	175160
65	ELEC. LIGHTING + WIR	42	81480	118860	121380	123480
69	BATTERIES,X-RAY EQ.,	69	78660	93840	100050	113160
73	RAILROAD EQUIPMENT	144	132480	116640	118080	115200
76	MECH. MEASURING DEVI	70	66500	84700	81200	68600
80	RAILROADS	95	495900	408500	413250	429400
81	TRUCKING	158	2110880	2825040	2766580	2586460
82	OTHER TRANSPORT	128	801280	858880	808960	730880
87	ELECTRIC UTILITIES	61	320860	294630	311100	350140
TOTAL		2006	7987740	9332330	9271150	8950950

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[a] RATE PER 100 FULL-TIME WORKERS PER YEAR

It is possible that the occupational injuries and illnesses occurring in EHV-related industries could be more or less severe than those occurring in the rest of the economy. However, comparing the number of PDL occurring per recordable case shows a minimal amount of variance among the BASE and all EHV scenarios for all assessment years (see Table 3.27). Thus, changes in employment in EHV-stimulated industries do not have a significant impact on severity of occupational illness and injury on a national level.

Several economic sectors experience changes in the number of TRC and PDL as a result of EHV commercialization that reflect the material, fuel, and construction requirements of EHVs. These new levels vary notably from those of the BASE scenario. As with economy-wide impacts, occupational injuries and illnesses attributable to EHVs and occurring in the individual sectors are most significant under the HIGH scenarios in 2000.

The electric utility and battery sectors experience the greatest absolute and percentage increases in the number of impacts. Mining, nonferrous metals, and structural metal products also show large absolute increases. These three sectors are integrally tied to EHV development. Petroleum and gas production is the only sector projected to experience large percentage and absolute decreases in TRC and PDL. In summary, extensive EHV development may significantly impact the number of occupational injuries and illnesses attributable to the six industries mentioned above.

E.2 PUBLIC HEALTH

In this analysis, the potential for public health impacts from exposure to air, water, and solid waste residuals resulting from the EHV scenarios is examined and compared to the risks from comparable numbers of CVs. The impact potential of vehicle-production, fuel-production, and vehicle-operation air, water, and solid waste residuals is examined on a national level. The potential for impact from air emissions resulting from EHV operation and electricity demand also is examined for 10 selected UAs. This more quantitative projection of the potential for public health effects in individual UAs from exposure to air residuals is possible because of their widespread dispersion. The site-specific nature of water and solid waste residuals and human exposure to these residuals restricts the analysis of potential impacts in these areas to a qualitative discussion.

E.2.1 Risk from Air Emissions

The potential for air quality health impacts from EHV market penetration is based on emission projections found in Sec. D.2.

E.2.1.1 Methodology and Assumptions

Ideally, projections of the number of human health effects from atmospheric emissions resulting from EHV commercialization should be made by applying dose-response relationships to population exposure estimates.

Unfortunately, neither dose-response information nor estimates of the dispersion of air emissions and resulting population exposure are available for this assessment. As a result, surrogate measures are used for comparing the health impacts of implementing the several scenarios. The measure used for comparison in national projections is "person-pounds" of pollutant; the measure used in the UA analysis is a population-normalized value referred to as "potential for impact." Both measures reflect both the quantities of air emissions and the population at risk as a result of exposure. Although these factors do not provide an estimate of the number of health effects, they do provide a relative risk estimate that is useful for assessing the potential impacts under the different scenarios and for comparisons with other emission sources.

The validity of measures like "person-pounds" and "potential for impact" involves two major assumptions: (1) that there is no threshold for response, meaning that any exposure to a pollutant results in an effect, and (2) that there is a linearity of response, meaning that any increase in exposure results in a corresponding increase in effect. Much controversy exists regarding these two assumptions. However, the controversy is of little import when the projections are measures of relative effect, as is the case in this analysis.

This study makes two further assumptions that are essential for projecting relative impact potential: (1) that there is equal dispersion of an emitted pollutant in the area of analysis (nation, county, or UA), resulting in equal exposure to the population at risk, and (2) that the population at risk is heterogeneous but similar among the areas examined.

Person-pounds, which is used in the national analysis, is simply the product of projected population (see Fig. 2.3) and emitted quantity of pollutant from Sec. D.2. For the UA analysis, the potential-for-impact values are normalized to allow comparison of UAs of different size. The UAs analyzed are broken into the "large" and "medium" categories used in Sec. D.2, which are based on population. These UAs and their 1990 and 2000 populations appear in Table E.2. The potential for impact in each UA under each scenario and for each assessment year is determined using the following equation:

$$\frac{A \cdot B}{C} \tag{E.1}$$

where:

A = pollutant emissions (10^6 lb/yr),

B = population of UA, and

C = population of all UAs in category.

E.2.1.2 Emissions Risk at the National Level

The projected relative risk resulting from air pollutants from vehicle production, fuels production, and vehicle operation at the national level under each scenario for EHVs and an equivalent number of CVs traveling equivalent miles is given in Table E.3. The information in this table is based on projected emissions that are summarized in Tables 3.17 and 3.18. The relative

Table E.2. UA Populations (10^6)[a]

	Year	
	1990	2000
Large UAs		
Milwaukee	1.423	1.476
Cincinnati	1.051	1.082
Buffalo	1.329	1.359
San Diego	2.136	2.335
Dallas	1.872	1.990
Total	7.811	8.242
Medium UAs		
Grand Rapids	0.643	0.691
Albuquerque	0.552	0.614
Orlando	1.102	1.338
Little Rock	0.496	0.537
Chattanooga	0.316	0.329
Total	3.109	3.509

[a] Based on model described in Ref. E.11.

contributions of EHVs and CVs to risk from air pollutants are described briefly in Sec. 3.5.1.

The projections indicate that the relative risk of exposure to EHV-related emissions increases substantially between 1990 and 2000 for each pollutant under all scenarios. This increase occurs because greater numbers of EHVs are being produced and operated in 2000. In 2000: (1) risks from exposure to NO_x, HC, particulates, CO, heavy metals, and aldehydes from EHVs are greatest under HIGH II; (2) risks from exposure to SO_x, PbS, gas fluorides, and CuS are greatest under HIGH I; and the LOW I scenario has the lowest risk of exposure for all pollutants.

Comparing the risk of exposure associated with EHVs with that from comparable numbers of CVs indicates that the risk of exposure to SO_x, heavy metals, PbS, gas fluorides, and CuS is greater with EHVs than for an equivalent number of CVs. The increase in the risk of exposure to SO_x with EHVs is 8-10 times that for an equivalent number of CVs, depending on the scenario. The increase for heavy metals is 10-24 times that for an equivalent number of CVs. The maximum increase in risk of exposure to gas fluorides is 1.6 times that for an equivalent number of CVs. No PbS and CuS air emissions are projected to be associated with CV production. Therefore, the increase in risk of exposure to these pollutants as a result of EHVs is absolute. The risk of exposure from EHV-related emissions of NO_x, CO, HC, and aldehydes is substantially less than that from an equivalent number of CVs; for particulates, the risk is somewhat less than that from CVs.

Table E.3. Relative Risk of Exposure on the National Level to EHV and CV Vehicle Production, Vehicle Operation, and Fuels Production Emissions (person-lb x 10^{15})

	Scenario									
	LOW I		LOW II		MEDIUM		HIGH I		HIGH II	
Pollutant	1990	2000	1990	2000	1990	2000	1990	2000	1990	2000
EHV										
TSP	0.545	8.25	1.01	16.9	1.25	24.3	3.27	76.2	3.32	84.8
SO_x	2.54	36.8	4.34	73.4	5.43	111	14.3	366	14.3	358
NO_x	1.49	18.2	2.88	43.8	3.22	55.8	8.53	185	8.96	202
HC	0.221	3.21	0.678	12.4	0.552	9.75	1.41	28.6	1.81	46.1
CO	0.0945	1.33	1.24	68.1	0.201	4.19	0.528	14.1	4.96	295
Heavy metals	0.0416	0.628	0.0676	1.13	0.0553	0.938	0.140	2.25	0.138	2.44
Aldehydes	0.00473	0.0319	0.00496	0.086	0.00529	0.101	0.139	0.344	0.0151	0.425
PbS	0.0149	0.165	0.0232	0.286	0.0385	0.494	0.0978	1.53	0.0912	1.49
Fluorides	0.00095	0.013	0.00165	0.0275	0.00284	0.0427	0.00780	0.143	0.00685	0.138
CuS	0.0362	0.400	0.0560	0.694	0.0931	1.20	0.237	3.70	0.221	3.62
CV										
TSP	0.630	10.5	0.965	18.8	1.42	33.1	3.59	105	3.51	97.7
SO_x	0.220	3.61	0.379	7.82	0.612	11.9	1.65	42.9	1.65	42.7
NO_x	2.31	23.4	3.43	63.1	5.05	111	12.4	355	12.2	327
HC	2.35	30.6	3.40	53.9	4.93	93.7	11.7	298	11.6	279
CO	24.3	296	35.5	515	51.3	896	117	2865	115	2646
Heavy metals	0.00165	0.0265	0.0026	0.0486	0.0052	0.0835	0.0137	0.232	0.0128	0.247
Aldehydes	0.00515	0.085	0.00855	0.167	0.0111	0.271	0.0283	0.864	0.0286	0.857
Fluorides	0.00095	0.0140	0.00095	0.0182	0.00284	0.0435	0.00662	0.1250	0.00449	0.0943

Table E.4 illustrates projected national risk of SO_x, NO_x. HC, particulate, and CO exposure from total U.S. emissions in 1975 and from selected point sources. Comparing these values with EHV production and operation and EHV fuels production risks shown in Table E.3 provides a measure of the relative impact of EHV development, even though effluent guidelines (new source performance standards and best available control technology requirements) were not applicable in 1975 and levels of industrial activity in 1990 and 2000 are projected to be greater than 1975 levels.

In particular, the risk of exposure to SO_x from EHVs in both HIGH scenarios in 2000 represents 3% of the relative risk from total U.S. SO_x emissions in 1975. The risk from SO_x associated with EHVs in these two scenarios is slightly greater than the risk from petroleum refining but less than the risk from primary metals production and electricity generation. Sulfur oxides from an equivalent number of CVs would represent only 0.4% of the risk from total U.S. emissions. For NO_x, CO, particulates, and HC, risk of exposure associated with EHVs is less than 2% of the risk from total U.S. emissions of each of these pollutants and less than the risk associated with a corresponding number of CVs. On a national level, then, the risk of exposure to EHV-related emissions appears small. However local meteorological, geographical, and demographical conditions may result in significant human risk. Even though the potential for this impact is not assessed in this EA, it should not be overlooked.

Not all of the emissions associated with EHV production, operation, and associated fuels production are quantified in this analysis The development of new battery types (Ni/Zn, Ni/Fe, and Li/S) may result in public exposure to a variety of toxic substances not covered here. (See Table B.15 for a list of possible additional ingredients in batteries.) Both the potential for release and the magnitude of these exposures are of concern on a site-specific basis during battery raw material acquisition, manufacture, and disposal.

Table E.4. Relative Risk of Exposure to Emissions from Selected Sources and from Total U.S. Emissions, 1975 (person-lb x 10^{15})[a]

Pollutant	Total U.S. Relative Risk of Exposure	Primary Metals Production	Petroleum Refining	Municipal Incinerators	Electricity Generation
SO_x	12,171	1,195	340	4	7,943
NO_x	10,378	–	64	4	2,904
HC	12,299	85	384	4	43
Particulates	6,748	597	42	43	1,836
CO	403,590	427	555	85	128

[a] Based on emissions totals provided in Ref. E.12.

The presence of heavy metals and carbon dioxide in fossil fuel power plant emissions and in CV emissions is well documented but has not been evaluated in this analysis. In the air quality analysis (see Sec. D.2.3.8), the differences between the carbon dioxide totals in the year 2000 for the EHV scenarios and those of their counterpart CVs are shown to be of insufficient magnitude to be considered significant.

Operation of EHVs may release potentially toxic gases as a result of accidents and during battery charging, but these emissions are not quantified here. For example, current Pb/acid batteries give off gases during charging. Overcharging generates two toxic gases: stibine and arsine. The acute toxicity of both of these gases is well documented, but it is expected that proper ventilation can keep concentrations far below levels where adverse health effects might occur for anyone associated with battery charging or testing.[E.13] However, the effects of long-term, low-level exposure are not well documented. In summary, the health impact of exposure to arsine and stibine, or stibine's by-product antimony trioxide, resulting from widespread residential and commercial use of batteries is uncertain but of potential concern.

E.2.1.3 Power Plant Emissions Risk at the UA Level

Ten UAs are examined in this analysis. The process for selecting these 10 UAs for detailed examination is described in Sec. D.2, and the emissions data used in this analysis are also presented in that section. The 10 UAs vary in size, in the degree of EHV penetration, and in the fuels used for generation of EHV electricity requirements. A summary of these characteristics appears in Table D.11. The potential for health impacts from SO_x, NO_x, HC, particulates, and CO emissions due to EHV operation is projected here and compared to impacts from similar numbers of CVs operating equivalent VMT and to impacts from all other emission sources.

Risk of Exposure to Sulfur Oxides

Sulfur oxides are respiratory irritants that can cause permanent alveolar damage and exacerbate respiratory disorders when inhaled. Sulfur oxides are primary by-products of fossil fuel combustion.

Table E.5 presents the estimates of the potential for impact from exposure to SO_x under the EHV scenarios due to vehicle operation and the generation of electricity necessary for battery charging. Also included are the projections of potential for impact from exposure to SO_x from a comparable number of CVs. This table shows that the inhabitants of Dallas and Cincinnati experience greater potential for impact from EHV-related SO_x exposure than inhabitants of the other selected UAs under all scenarios, with the exception of the LOW scenarios in 2000 where they rank second and third. These two UAs are projected to use coal to supply 100% of EHV electricity demand in 1990 and 65% (Dallas) and 90% (Cincinnati) of EHV electricity demand in 2000.

Little Rock and Milwaukee experience the lowest potential for impact from EHV SO_x in both 1990 and 2000, primarily because nuclear plants (which

Table E.5. Relative Potential for Adverse Health Impact from SO_x Emissions from EHVs and CVs Operating Equivalent VMT[a]

	Scenario									
	LOW I		LOW II		MEDIUM		HIGH I		HIGH II	
UA	1990	2000	1990	2000	1990	2000	1990	2000	1990	2000
EHVs										
Milwaukee	0.00182	0.00537	0.00182	0.01970	0.00182	0.01791	0.01093	0.16117	0.00182	0.17908
Cincinnati	0.02691	0.26256	0.04037	0.52905	0.04037	0.84018	0.12110	2.86187	0.12110	2.77261
Buffalo	0.01361	0.21435	0.01701	0.46498	0.03403	0.77497	0.08507	2.35788	0.08507	2.24081
San Diego	0.01641	0	0.02735	0.00567	0.02735	0.00283	0.10938	0.02833	0.10938	0.07083
Dallas	0.02397	0.31388	0.07190	0.70985	0.07190	0.98993	0.19173	3.35610	0.19173	3.51787
Grand Rapids	0.01034	0	0.01655	0.00394	0.02068	0.00197	0.06205	0.01969	0.06205	0.02757
Albuquerque	0.01065	0.15748	0.01775	0.31671	0.01775	0.50744	0.05326	1.67979	0.05326	1.58356
Orlando	0.02127	0.34317	0.03190	0.57577	0.03545	0.83887	0.10634	2.59287	0.10634	2.42510
Little Rock	0.00160	0.00459	0.00479	0.01377	0.00479	0.01530	0.01276	0.07652	0.01276	0.08111
Chattanooga	0.00305	0.02813	0.00508	0.06657	0.00610	0.09376	0.01016	0.31878	0.01016	0.33003
CVs										
Milwaukee	0.00182	0.01970	0.00182	0.03582	0.00182	0.06268	0.00729	0.17908	0.00729	0.17192
Cincinnati	0.00135	0.01707	0.00135	0.03151	0.00269	0.05645	0.00673	0.16541	0.00673	0.14834
Buffalo	0.00170	0.01649	0.00170	0.02803	0.00170	0.05276	0.00681	0.15499	0.00681	0.14345
San Diego	0.00273	0.03966	0.00273	0.07366	0.00517	0.13315	0.01641	0.37680	0.01641	0.37680
Dallas	0.00240	0.02897	0.00240	0.05553	0.00479	0.09175	0.01198	0.26076	0.01198	0.26318
Grand Rapids	0	0.00985	0	0.01575	0.00207	0.02954	0.00414	0.08468	0.00414	0.07877
Albuquerque	0	0.00875	0	0.01750	0.00178	0.03150	0.00355	0.09449	0.00355	0.08749
Orlando	0	0.02669	0.00354	0.04576	0.00354	0.08389	0.01063	0.24785	0.01063	0.22878
Little Rock	0.00032	0.00306	0.00048	0.00765	0.00064	0.01377	0.00160	0.04132	0.00160	0.04132
Chattanooga	0.00010	0.00188	0.00020	0.00375	0.00030	0.00656	0.00102	0.01969	0.00102	0.01969

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[a] The values in this table are normalized values that allow comparison of UAs of different sizes. Two UA categories (large and medium) are represented in this table. See Sec. E.2.1.1 for methodology.

emit no SO_x) are projected to supply 90-100% of EHV electricity demand in these UAs by 2000. The substitution of nuclear electricity for oil electricity that occurs in San Diego (from 55% oil to 99% nuclear) and the shift from coal to nuclear that occurs in Grand Rapids (from 90% coal to 99% nuclear) between 1990 and 2000 account for large decreases in their potential SO_x impacts (35-100%, depending on the scenario). San Diego and Grand Rapids are the only UAs for which the potential for impact from SO_x decreases during the assessment timeframe. The potential for impacts from SO_x resulting from EHV scenarios is greatest under the HIGH scenarios in 2000 for all UAs, ranging from 10 to 35 times greater than that under the LOW I scenario, depending on the UA.

Comparison of projected potential SO_x impacts resulting from EHVs and CVs operating equivalent VMT indicates that the relative risk is a function of the type of fuel used to generate electricity for EHV battery charging. For example, in Dallas, Cincinnati, Chattanooga, Albuquerque, Orlando, and Buffalo (where fossil fuels are the primary source of EHV electricity), the relative risks of CV use is 6-10% that of EHV use under the HIGH I scenario. In San Diego, Grand Rapids, Milwaukee, and Little Rock (where nuclear plants provide EHV electricity), the relative risk of CV use is 54-1330% that of EHV use under the HIGH I scenario.

The projected potential for impact from SO_x emissions from all sources appears in Table E.6 for five AQCRs, which include five of the UAs examined in this analysis. Although no EHV penetration is assumed, the potential for impact from CV emissions is included in this BASE scenario. Comparing the figures in Table E.6 with those in Table E.5 indicates that the potential for impact from SO_x released due to EHV operation generally is small but not unimportant in some AQCRs and the UAs contained in them. (For purposes of this analysis, the percentage change in potential for impact from a pollutant in an AQCR is assumed to apply to the UA contained in the AQCR.) After reducing the baseline potential for impact by the potential for impact from the CVs being replaced by EHVs in the scenarios, the maximum increase resulting from EHV penetration in a AQCR's or UA's potential for impact is 6.5%, which occurs in Buffalo in HIGH I in 2000. A large portion of Buffalo's EHV electricity is generated by fossil fuel. Cincinnati and Dallas show increases of 5.2% and 1.9%, respectively, in HIGH I in 2000. In Milwaukee and San Diego, where nuclear fuel predominates, the potential for impact from all sources of SO_x actually decreases with EHV penetration: 0.03% and 4.4%, respectively, in HIGH I in 2000.

Risk of Exposure to Nitrogen Oxides

Nitrogen oxides are by-products of high-temperature, high-pressure combustion of the type that occurs during electricity generation and in CV internal combustion engines. They are one of the precursors necessary for the formation of photochemical oxidants in the atmosphere. Health impacts of NO_x are not well documented, but due to their highly reactive chemical nature oxidants cause potentially severe and permanent damage to respiratory mucous membranes.

A comparison of the potential for impact from exposure to NO_x from the EHV scenarios and comparable numbers of CVs appears in Table E.7. As with

Table E.6. Potential for Impact from All Sources in BASE Scenario[a]

Pollutant	Air Quality Control Region	Year	
		1990	2000
SO_x	Milwaukee	67	61
	Cincinnati	61	52
	Buffalo	35	34
	San Diego	10	8
	Dallas	115	162
NO_x	Milwaukee	43	45
	Cincinnati	49	49
	Buffalo	23	23
	San Diego	34	34
	Dallas	99	119
HC	Milwaukee	168	191
	Cincinnati	86	113
	Buffalo	32	30
	San Diego	56	67
	Dallas	189	225
TSP	Milwaukee	31	26
	Cincinnati	15	16
	Buffalo	7	8
	San Diego	14	16
	Dallas	160	220
CO	Milwaukee	160	151
	Cincinnati	87	79
	Buffalo	92	88
	San Diego	158	151
	Dallas	341	330

[a] Based on emissions totals provided in Ref. E.14.

SO_x, the greatest potential for impacts from EHV-related NO_x are projected to occur in Dallas and Cincinnati under all EHV scenarios and years. The lowest potential for impact is projected in Little Rock, San Diego, and Grand Rapids. Orlando and Buffalo experience the greatest percentage increase in projected potential for impact between 1990 and 2000, except under the HIGH II scenario, where the largest increase occurs in Milwaukee. San Diego and Grand Rapids experience the least amount of change between assessment years.

Potential for impact from NO_x is greater under the EHV scenarios that include HVs. The difference is substantial and reflects the incremental

Table E.7. Relative Potential for Adverse Health Impact from NO_x Emissions from EHVs and CVs Operating Equivalent VMT[a]

	Scenario									
	LOW I		LOW II		MEDIUM		HIGH I		HIGH II	
UA	1990	2000	1990	2000	1990	2000	1990	2000	1990	2000
EHVs										
Milwaukee	0.00182	0.00358	0.00364	0.06268	0.00182	0.01433	0.00547	0.08954	0.00547	0.31877
Cincinnati	0.01211	0.15753	0.02960	0.36102	0.02691	0.48573	0.06728	1.66724	0.06997	1.80377
Buffalo	0.00510	0.07585	0.00851	0.23909	0.01021	0.32977	0.03403	1.07177	0.03573	1.20203
San Diego	0.00547	0	0.01641	0.03966	0.01367	0	0.05469	0.01133	0.06016	0.54395
Dallas	0.01917	0.19316	0.02876	0.51669	0.04793	0.57947	0.09586	1.95571	0.12462	2.54967
Grand Rapids	0.00620	0	0.01241	0.02166	0.01448	0.00197	0.04136	0.01378	0.04343	0.11225
Albuquerque	0.00710	0.08749	0.01243	0.21872	0.01420	0.29746	0.03551	0.97988	0.03729	1.04637
Orlando	0.00709	0.15252	0.01418	0.33174	0.01772	0.41944	0.03545	1.37270	0.03899	1.58242
Little Rock	0.00160	0.00306	0.00160	0.01939	0.00319	0.01071	0.00638	0.04591	0.00798	0.10406
Chattanooga	0.00102	0.01875	0.00305	0.04407	0.00305	0.05626	0.00813	0.18752	0.00813	0.21471
CVs										
Milwaukee	0.01275	0.20774	0.02186	0.41010	0.02915	0.62321	0.07469	2.03975	0.07652	2.08094
Cincinnati	0.01346	0.19167	0.02153	0.36758	0.02826	0.59601	0.07131	1.90748	0.07131	1.80771
Buffalo	0.01191	0.17973	0.01872	0.33637	0.02722	0.54083	0.06636	1.79397	0.06636	1.73956
San Diego	0.02735	0.42496	0.04649	0.85275	0.06016	1.34286	0.13946	4.22124	0.14767	4.47338
Dallas	0.01917	0.30422	0.03355	0.63742	0.04314	0.93681	0.10545	2.94564	0.10785	3.17019
Grand Rapids	0.00827	0.09649	0.01241	0.18117	0.01861	0.30326	0.04343	0.97870	0.04343	0.94326
Albuquerque	0.00710	0.10674	0.01065	0.20472	0.01598	0.34296	0.03906	1.13386	0.03906	1.08837
Orlando	0.01772	0.28979	0.02836	0.53764	0.03899	0.89988	0.09216	2.88267	0.09570	2.78353
Little Rock	0.00319	0.04744	0.00638	0.09794	0.00798	0.14997	0.01755	0.48053	0.01914	0.49889
Chattanooga	0.00203	0.02344	0.00305	0.04688	0.00407	0.07126	0.00915	0.22877	0.00915	0.23815

[a] The values in this table are normalized values that allow comparison of UAs of different sizes. Two UA categories (large and medium) are represented in this table. See Sec. E.2.1.1 for methodology.

emissions associated with HV internal combustion engines. Potential for impacts from EHV-related NO_x is greater under the HIGH II scenario for all UAs and both assessment years.

A comparison of potential for impact from NO_x emissions from EHV use with emissions from a similar number of CVs can be drawn from Table E.7. Such a comparison indicates that for all UAs and all scenarios, CV impacts will be greater than EHV impacts. Thus, market penetration of EHVs will tend to reduce health risks from exposure to NO_x.

Table E.6 contains projections of the relative potential for impact of NO_x emissions from all sources without EHV penetration for five AQCRs. After reducing the projections shown in Table E.6 by the differences between CV and EHV potential for impact shown in Table E.7, it can be seen that the reduction in adverse health impact from NO_x associated with EHV penetration is generally low but may be significant in some AQCRs and UAs under some scenarios. For example, in the MEDIUM scenario in 2000, except for San Diego, the reduction in potential for impact is 0.2-1.4%. In San Diego, the reduction is 4%. Of all the scenarios, the greatest reduction occurs in HIGH I in 2000. The reduction in Cincinnati is 0.5%; in Dallas, 0.8%; Buffalo, 3.1%; Milwaukee, 4.3%; and in San Diego, 12.4%.

Risk of Exposure to Hydrocarbons

Hydrocarbons result from the incomplete combustion of fossil fuels and are emitted in many forms, some of which may be carcinogenic. In addition, HC are atmospheric precursors for oxidant formation.

Results of the projections of potential for impact from exposure to HC under the EHV scenarios are presented in Table E.8. Also included are projections of the potential for impact of exposure to HC resulting from operating an equivalent number of CVs. Because HC are emitted almost exclusively from CVs, the contribution of the EHV scenarios to HC exposure is minute. In fact, for the LOW I, MEDIUM, and HIGH I scenarios, there is no potential for impact in 2000. For the LOW II and HIGH II scenarios, which include significant HV usage, potential for impact is projected. However, a comparison of these values indicates that they are of minor significance compared with the potential for impact resulting from operation of a comparable number of CVs. Under the HIGH II scenario, where EHV relative impacts are greatest, EHV impacts are 5.6 (in Dallas) to 10.5 (in Little Rock) times less than impacts from comparable numbers of CVs. Therefore, market penetration of EHVs reduces health impacts from HC emissions.

Table E.6 contains projections of the relative potential for impact of HC emissions from all sources without EHV penetration for five AQCRs. After reducing the projections shown in Table E.6 by the differences between CV and EHV potential for impact shown in Table E.8, it can be seen that the reduction in adverse health impact from HC associated with EHV penetration is generally low but, in some AQCRs and UAs under some scenarios, not unimportant. For example, in the MEDIUM scenario in 2000, the reduction in potential for impact is 0.3-1.6%. Of all the scenarios, the greatest reduction occurs in the HIGH I scenario in 2000. The reduction in Milwaukee is 0.9%; in Dallas, 1.1%; in Cincinnati, 1.4%; in Buffalo, 4.9%; and in San Diego, 5.0%.

Table E.8. Relative Potential for Adverse Health Impact from HC Emissions from EHVs and CVs Operating Equivalent VMT[a]

	Scenario									
	LOW I		LOW II		MEDIUM		HIGH I		HIGH II	
UA	1990	2000	1990	2000	1990	2000	1990	2000	1990	2000
EHVs										
Milwaukee	0	0	0.00182	0.04656	0	0	0	0.00179	0.00364	0.20953
Cincinnati	0	0.00263	0.00269	0.04595	0	0.00788	0.00135	0.02626	0.00404	0.19692
Buffalo	0	0.00165	0.00170	0.04122	0	0.00660	0	0.02144	0.00170	0.17148
San Diego	0	0	0.00547	0.07083	0	0	0	0	0.00547	0.42212
Dallas	0	0.00241	0.00479	0.10141	0	0.00966	0.00240	0.02414	0.00719	0.48531
Grand Rapids	0	0	0.00207	0.01969	0	0	0	0	0.00207	0.08271
Albuquerque	0	0.00175	0.00178	0.02450	0	0.00525	0	0.01575	0.00178	0.11199
Orlando	0	0.00381	0.00354	0.06482	0	0.00763	0	0.02288	0.00354	0.25929
Little Rock	0	0	0	0.01071	0	0	0	0	0	0.04897
Chattanooga	0	0	0	0.00656	0	0.00094	0	0.00281	0	0.02625
CVs										
Milwaukee	0.01457	0.17550	0.02368	0.35279	0.02915	0.53008	0.07105	1.71382	0.06741	1.78545
Cincinnati	0.01346	0.16147	0.02153	0.31507	0.02691	0.49623	0.06593	1.59110	0.06593	1.60816
Buffalo	0.01191	0.15170	0.02042	0.28855	0.02552	0.46663	0.05615	1.49717	0.06295	1.47904
San Diego	0.02461	0.33147	0.04375	0.67143	0.05196	1.04256	0.11759	3.31750	0.12853	3.53848
Dallas	0.01917	0.26318	0.03595	0.55774	0.04314	0.79436	0.10066	2.50862	0.10545	2.75731
Grand Rapids	0.00827	0.08074	0.01241	0.15163	0.01655	0.24812	0.03516	0.80147	0.03516	0.78572
Albuquerque	0.00710	0.08924	0.01065	0.17148	0.01420	0.27997	0.03551	0.91864	0.03551	0.89939
Orlando	0.01772	0.24404	0.02836	0.46138	0.03899	0.74736	0.07444	2.40603	0.08861	2.36790
Little Rock	0.00319	0.04132	0.00638	0.08417	0.00638	0.12549	0.01755	0.40095	0.01755	0.42544
Chattanooga	0.00203	0.01969	0.00305	0.04032	0.00407	0.06001	0.00813	0.19127	0.00915	0.20252

[a] The values in this table are normalized values that allow comparison of UAs of different sizes. Two UA categories (large and medium) are represented in this table. See Sec. E.2.1.1 for methodology.

Risk of Exposure to Particulates

Particulates are a respiratory irritant that affects different sections of the respiratory tract depending on particle size. Particulates also serve as a transport medium for other health stressors (e.g., As, Cd, and Pb). A major source of particulates is combustion of fossil fuels. Some conventional engines, such as diesels, emit large amounts of particulates.

Table E.9 contains the results of projected potential for impacts from exposure to particulate emissions from EHVs and from equivalent numbers of CVs. The relative cleanliness of nuclear energy and EHVs -- at least as far as particulate emissions are concerned -- is highlighted by the results of the projections. Milwaukee, Grand Rapids, and Little Rock (three cities where nuclear energy supplies 93% or more of EHV electricity needs by 2000) are projected to experience a low level of impact from EHVs. San Diego, which switches from 45% to 99.8% nuclear by 2000, is projected to experience a decrease in impacts between 1990 and 2000 under the LOW I, MEDIUM, and HIGH I scenarios and relatively low increases under the LOW II and HIGH II scenarios. Dallas, Orlando, and Buffalo (cities that rely on fossil fuels for 65-100% of EHV electricity demand in 2000) experience the largest projected potential for impact of the EHV scenarios.

Comparison of the potential for impact from exposure to EHV-related particulates with that from the emissions of similar numbers of CVs reveals that, as with NO_x and HC, the potential for impact associated with EHVs is low compared to that of CVs. Potential for impact associated with EHVs is 1.5-8.6 times less than that associated with CVs under the HIGH II scenario, and it is under this scenario that the contribution of EHVs to particulate exposure is greatest.

Table E.6 contains projections of the relative potential for impact of particulate emissions from all sources without EHV penetration for five AQCRs. After reducing the projections shown in Table E.6 by the differences between CV and EHV potential for impact shown in Table E.9, it can be seen that the reduction in adverse health impact from particulates associated with EHV penetration is generally low but, in some AQCRs and UAs under some scenarios, not unimportant. In the MEDIUM scenario in 2000, the reduction in potential for impact is 0.08-2.3%. In the HIGH I scenario in 2000 (the scenario with the greatest reductions), the reduction in Dallas is 0.2%; in Cincinnati, 1.7%; in Milwaukee, 2.1%; in Buffalo, 2.8%; and in San Diego, 7.3%.

Risk of Exposure to Carbon Monoxide

Carbon monoxide is another product of incomplete combustion and is more prevalent in low-temperature combustion emissions than in high-temperature emissions. When inhaled and absorbed into the bloodstream, CO attaches more readily and securely to transport sites on red blood cells than does oxygen, thus limiting the oxygen-carrying capacity of the blood.

Results of projections of the potential for impact from CO under the EHV scenarios appear in Table E.10. EHV-related emissions of CO and the subsequent potential for impact are minimal. Under the LOW I scenario in 1990, there is minimal potential for impact. Although potential for impact

Table E.9. Relative Potential for Adverse Health Impact from Particulate Emissions from EHVs and CVs Operating Equivalent VMT[a]

	Scenario									
	LOW I		LOW II		MEDIUM		HIGH I		HIGH II	
UA	1990	2000	1990	2000	1990	2000	1990	2000	1990	2000
EHVs										
Milwaukee	0	0	0	0.01612	0	0.00179	0	0.01254	0	0.07521
Cincinnati	0.00135	0.02626	0.00269	0.05120	0.00404	0.06564	0.00942	0.23630	0.01076	0.29144
Buffalo	0.00170	0.03463	0.00170	0.06925	0.00340	0.08244	0.01021	0.26382	0.01021	0.29515
San Diego	0.00273	0	0.00547	0.03966	0.00547	0	0.01367	0.00283	0.01641	0.14732
Dallas	0.00240	0.02656	0.00479	0.07485	0.00479	0.07243	0.01438	0.28974	0.01678	0.42495
Grand Rapids	0	0	0.00207	0.00591	0.00207	0	0.00414	0.00197	0.00414	0.02954
Albuquerque	0.00178	0.01400	0.00178	0.04199	0.00178	0.03500	0.00533	0.13998	0.00533	0.16973
Orlando	0.00354	0.04194	0.00354	0.07626	0.00709	0.07245	0.01418	0.22878	0.01418	0.30504
Little Rock	0	0	0	0.00459	0	0.00153	0	0.00612	0	0.02142
Chattanooga	0	0.00281	0	0.00750	0	0.00750	0.00102	0.02813	0.00102	0.03563
CVs										
Milwaukee	0.00364	0.05372	0.00547	0.10745	0.00729	0.16476	0.01822	0.54620	0.01822	0.55337
Cincinnati	0.00269	0.04989	0.00538	0.09715	0.00673	0.15885	0.01615	0.51461	0.01749	0.50542
Buffalo	0.00340	0.04782	0.00510	0.08904	0.00681	0.15005	0.01531	0.48477	0.01531	0.46498
San Diego	0.00547	0.11332	0.01094	0.23231	0.01094	0.36546	0.03555	1.16438	0.03828	1.21254
Dallas	0.00479	0.07968	0.00719	0.16660	0.00959	0.24327	0.02636	0.78229	0.02636	0.83540
Grand Rapids	0.00207	0.02560	0.00207	0.04726	0.00414	0.08271	0.01034	0.26781	0.01034	0.25600
Albuquerque	0.00178	0.02975	0.00355	0.05599	0.00355	0.09449	0.00888	0.31321	0.00888	0.29921
Orlando	0.00354	0.07626	0.00709	0.14108	0.01063	0.24022	0.02127	0.77786	0.02127	0.74354
Little Rock	0.00160	0.01224	0.00160	0.02602	0.00160	0.03979	0.00319	0.13008	0.00479	0.13314
Chattanooga	0.0	0.00563	0.00102	0.01219	0.00102	0.02344	0.00203	0.06188	0.00203	0.06376

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[a] The values in this table are normalized values that allow comparison of UAs of different sizes. Two UA categories (large and medium) are represented in this table. See Sec. E.2.1.1 for methodology.

Table E.10. Relative Potential for Adverse Health Impact from CO Emissions from EHVs and CVs Operating Equivalent VMT[a]

UA	LOW I		LOW II		MEDIUM		HIGH I		HIGH II	
	1990	2000	1990	2000	1990	2000	1990	2000	1990	2000
EHVs										
Milwaukee	0	0	0.02733	0.47994	0	0	0	0.00537	0.03097	2.01826
Cincinnati	0	0.00788	0.02422	0.42666	0.00135	0.02626	0.00404	0.09190	0.03229	1.84315
Buffalo	0	0.00824	0.02042	0.38419	0.00170	0.02308	0.00340	0.09893	0.02892	1.65052
San Diego	0	0	0.04649	2.07096	0.00273	0	0.00547	0	0.06016	3.98043
Dallas	0	0.00966	0.04554	0.99476	0.00240	0.02414	0.00479	0.09658	0.05512	4.87721
Grand Rapids	0	0	0.01034	0.19298	0	0	0.00207	0	0.01655	0.84086
Albuquerque	0	0.00525	0.01243	0.23447	0.00071	0.01575	0.00178	0.05249	0.01775	1.04112
Orlando	0	0.01525	0.02836	0.60246	0.00354	0.03050	0.00354	0.09914	0.03899	2.55856
Little Rock	0	0	0.00479	0.11784	0	0	0	0.00306	0.00793	0.50195
Chattanooga	0	0.00094	0.00305	0.05813	0	0.00281	0	0.00938	0.00305	0.24659
CVs										
Milwaukee	0.15121	1.83560	0.25323	3.67120	0.32246	5.49784	0.76333	17.61815	0.77973	18.39716
Cincinnati	0.14532	1.65674	0.23278	3.25834	0.30678	5.11725	0.70910	16.32976	0.71717	16.54112
Buffalo	0.13612	1.57962	0.21438	2.97786	0.28584	4.80975	0.66697	15.35428	0.67037	15.21743
San Diego	0.26526	3.20418	0.44027	6.43668	0.46762	9.99216	1.29347	31.40150	1.32628	33.68210
Dallas	0.21809	2.74524	0.39065	5.79471	0.47213	8.22607	0.67105	25.88303	1.14319	28.49306
Grand Rapids	0.09307	0.83101	0.13443	1.56553	0.20061	2.54620	0.40330	8.19590	0.40123	8.06987
Albuquerque	0.07635	0.91164	0.12073	1.75329	0.15624	2.85565	0.37285	9.35435	0.37818	9.17937
Orlando	0.20558	2.53949	0.31546	4.75869	0.42889	7.72523	0.97121	24.69711	0.97475	24.36157
Little Rock	0.03829	0.42391	0.06381	0.87230	0.07977	1.28855	0.18187	4.11970	0.18666	4.37680
Chattanooga	0.01931	0.20252	0.04167	0.41535	0.04167	0.61412	0.09148	1.96237	0.09453	2.08426

Scenario: LOW I, LOW II, MEDIUM, HIGH I, HIGH II.

[a] The values in this table are normalized values that allow comparison of UAs of different sizes. Two UA categories (large and medium) are represented in this table. See Sec. E.2.1.1 for methodology.

increases slightly under the LOW I scenario in 2000, projected levels for this scenario and for the MEDIUM and HIGH I scenarios are small compared to projections under the LOW II and HIGH II scenarios (by a factor of 16-375, depending on scenario and year). This difference reflects the number of HVs included in the LOW II and HIGH II scenarios and their CO emissions.

Under the LOW II and HIGH II scenarios, Dallas and San Diego are projected to experience the greatest potential for impact from EHV-related CO. Chattanooga and Little Rock are projected to experience the least potential for impact. The increased penetration of HVs from 1990 to 2000 results in increased potential for impact (from 16 to 43 times that under the LOW II scenario and from 4 to 87 times that under the HIGH II scenario) depending on the UA.

Comparing the potential for impact from EHV-related CO emissions with that from emissions from a similar number of CVs indicates that the potential for impact associated with EHVs is low compared to that of CVs. The potential for impact from projected levels of CO due to EHV use under the HIGH II scenario in 2000 (the scenario for which the contribution of EHVs to CO exposure is greatest) is smaller by a factor of nine in Milwaukee, Cincinnati, and Albuquerque; by 9.7 in Orlando; by 9.5 in Grand Rapids; by 9.2 in Buffalo; by 8.7 in Little Rock, by 8.6 in Chattanooga and San Diego; and by 5.6 in Dallas than that from equivalent numbers of CVs.

Table E.6 contains projections of the relative potential for impact of CO emissions from all sources without EHV penetration for five AQCRs. After reducing the projections shown in Table E.6 by the differences between CV and EHV potential for impact shown in Table E.10, it can be seen that the reduction in adverse impact from CO associated with EHV penetration in AQCRs and UAs can be quite substantial. In the MEDIUM scenario in 2000, the reduction in potential for impact ranges from 2.5% in Dallas to 6.6% in San Diego. In the HIGH I scenario in 2000 (the scenario with the greatest reductions), the reduction in Dallas is 7.8%; in Milwaukee, 11.7%; in Buffalo, 17.3%; in Cincinnati, 20.6%; and in San Diego, 20.8%.

E.2.2 Risks from Aquatic Effluents

The assessment of potential public health effects from water pollutants generated in the EHV scenarios is based on data presented in Sec. D.3, where national loadings for major water pollutants from vehicle production, vehicle operation, and fuels production are projected. For nearly all pollutants (except TDS and organics), the EHV scenario pollutant levels are greater than those generated for a comparable number of CVs. However, when the EHV water pollutant loadings are compared with 1975 national background loadings for pollutants for which information is available, the comparisons indicate that the increases associated with the EHV scenarios will not pose a major water-related health threat.

Public health impacts may occur, however, in local areas as a result of EHV-related aquatic discharges. The physical and chemical characteristics of the receiving waters (e.g., flow, buffering capacity, and pH) and use of receiving water by human populations (as drinking water, for recreation, or for food processing) and the local ecosystems all can significantly change the potential health impacts of wastes discharged by EHV-related activities.

The most important of the assessed pollutants in terms of potential for causing human health impacts are heavy metals and dissolved solids. Other pollutants with potential direct or indirect human health consequences (e.g., TSS and BOD) can be relatively easily and inexpensively removed from effluent streams. The HIGH scenarios are projected to cause the most heavy metals and dissolved solids to be discharged from EHV-related vehicle and fuels production and vehicle operation. Site-specific characteristics regarding the discharge and transport of EHV-related aquatic pollutants will have the most impact in determining the presence and extent of human health effects.

E.2.3 Risks from Solid Wastes

The assessment of potential public health effects from solid wastes generated by mining and manufacturing of materials and fuels for, operation of, and decommissioning of EHVs is based on the solid waste residual data presented in Sec. D.4. The occurrence of public health effects from EHV-related solid wastes is a function of: (1) volume and composition of the waste, (2) disposal method, (3) mode of environmental transport, and (4) populations at risk.

Solid waste generated as a result of EHV market penetration contain toxic substances. Heavy metals and both organic and inorganic salts are found in tailings, slags, and sludges. The degree of containment of these toxic substances within the disposal site depends on the disposal methods dictated by legislation and regulation and their implementation. Inclusion of all EHV-related solid wastes under RCRA and similar local legislation is not a foregone conclusion. While highly concentrated toxic wastes, such as those generated during battery manufacture, will most likely be defined as hazardous (and thus subject to "cradle-to-grave" handling requirements), more voluminous but less harmful wastes generated during mining, milling, and electricity generation may be categorized as special or nonhazardous. These require less rigorous disposal methods, which increases the potential for environmental release.

Environmental release of toxics found in solid wastes occurs primarily as a result of transport in water. Structural failure of waste disposal sites may result in surface water contamination, but groundwater infiltration is the primary transport mode and major area of concern. Judicious site selection, impermeable disposal site liners, and chemical fixation can help reduce infiltration.

Toxics in aquatic systems may reach human populations directly via contaminated drinking water and indirectly via food chain cycling. The degree of direct exposure in terms of severity and extent depends on the proximity of populations to disposal sites, groundwater characteristics, and demography of the exposed populations. The impact of indirect cycling depends on the resistance of the toxic material to biological breakdown and the chemical and physical similarity between the toxic materials and nutrients. For example, lead is a toxic solid waste released through battery disposal that is similar to calcium and that is easily transmitted through terrestrial and aquatic food chains.

The volume of solid wastes projected under the EHV scenarios appears small relative to national solid waste volumes. Therefore, disposal of these wastes does not appear to create a national health problem. However, health impacts from solid wastes may be of concern at the site-specific level. The seriousness of the problems will be greatly affected by RCRA, siting procedures, and disposal methods.

The specific type of waste that has the most potential for adverse health impact varies with the scenarios. Lead processing wastes are greatest under LOW II, while wastes from the manufacture of plastics are greatest under HIGH II. The HIGH scenarios produce the greatest quantities of mineral tailings, and HIGH I generates the greatest amount of slag for disposal.

APPENDIX E REFERENCES

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APPENDIX F

UTILITY IMPACT ANALYSIS

F.1 METHOD

A flowchart of the overall analysis procedure is presented in Fig. F.1. First, three scenarios (LOW I, MEDIUM, and HIGH I) and two years (1990 and 2000) were selected for detailed analysis of the 158 UAs in which EHVs are projected to penetrate. Although all electricity is assumed to be off peak, a very small amount of electricity is necessary at midday for bus charging.

Second, a demand allocation analysis is performed to determine demand on a utility-service-area basis rather than on an urbanized-area basis. This step is necessary as a general practice to provide inputs for the computer analysis that is described in Sec. F.1.1. In general, there is not a one-to-one correspondence between UAs and utility service areas. For example, the New York-New Jersey UA is served by three utilities -- Consolidated Edison Co. of N.Y., Inc., Long Island Lighting Company, and Public Service Electric & Gas Company (PSE&G). Therefore, UA EHV electricity demand is prorated to each utility service area in proportion to the number of customers within the UA served by the utility. Ref. F.1 is used as the basis for proration. Conversely, one utility can service more than one UA. For example, PSE&G serves the New York-New Jersey and the Philadelphia-Trenton UAs. In this case, the fraction of the New York-New Jersey demand served by PSE&G is added to the Philadelphia-Trenton demand to obtain total PSE&G demand. The resulting demands for 164 utilities are used as input to the Recharge Capacity Projection (RECAP) model, which allocates demand by fuel type (nuclear, coal, oil base, gas base, oil peaker, gas peaker, hydro, and other).[F.2]

These data are then resubjected to the demand allocation analysis to determine utility demand by fuel type for each of the 158 UAs. The required input energy (nuclear, coal, oil, and gas) is then calculated using representative heat rates for each type of plant (see Table F.1). These data

Table F.1. Representative Heat Rates and Efficiencies

Plant Type	Heat Rate (Btu/kWh)	Efficiency (%)
Nuclear	10,666	32
Coal	10,176	34
Oil (base)	10,826	32
Oil (peak)	13,800	25
Gas (base)	10,733	32
Gas (peak)	13,800	25

Source: Ref. F.3.

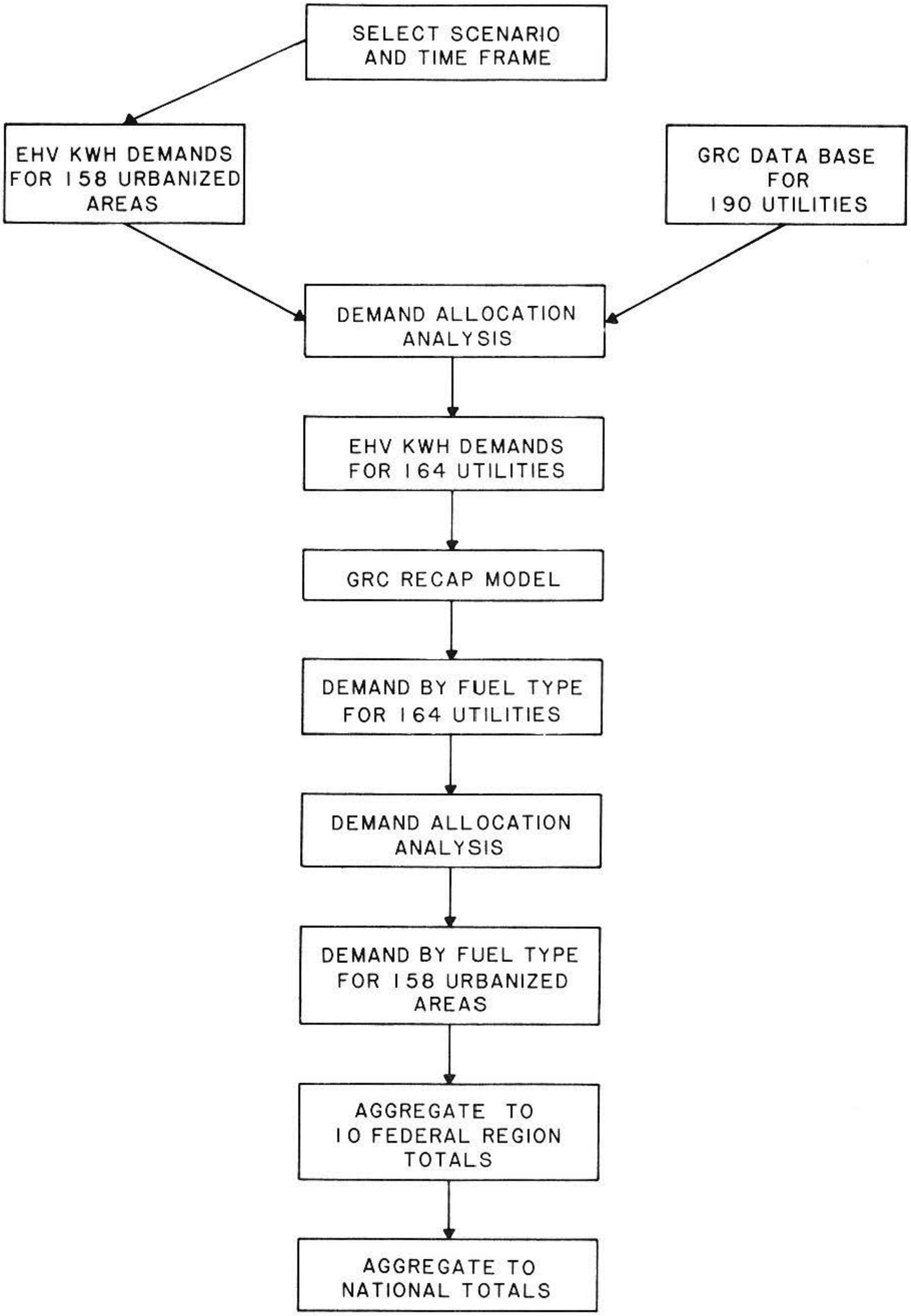

Fig. F.1. Flowchart of Analysis of EHV Electricity Demand by Fuel Type then are aggregated to provide totals for the 10 federal regions as well as national totals. (Regional and national totals for the LOW II and HIGH II scenarios are obtained by linear interpolation.)

F.1.1 Description of Model and Data Base

Figure F.2 illustrates the three RECAP modules: (1) the demand module, (2) the capacity module, and (3) the recharge capacity module.* The demand module takes individual electric utility yearly demand data, regional demand data, and regional hourly load curves for 1974 and produces estimated future hourly load curve adjustment factors for each utility. The capacity module takes current and projected individual power plant data and regional projections and produces future electric utility capacity projections by the type of fuel used in generating electricity. The third module combines the output from the first two modules and produces estimates of the capacities by fuel type available to recharge electric cars.

The model uses the March 19, 1977, Federal Power Commission (FPC) Generating Reference File to estimate future generating capacity to 1985. To estimate capacity additions after 1985, the model uses estimates reported to the FPC in April, 1976, by the nine regional electric reliability councils. Each council annually reports the anticipated load of its region and the generating capacity necessary to serve that load by year for 11-20 yr into the future. Sources of the projected capacity to be installed in this period (hydro, nuclear, fossil-fueled, peaking, unassigned, and other) are given by percentages. These capacity projections reflect current electric utility planning and take into account estimates of future regulations, fuel availability, and electricity demand. Adjustments are made for burning coal rather than oil in all new plants after 1985 and for burning oil instead of gas and coal in place of oil in plants that are designated to handle these secondary fuels on a continuous basis.

As with estimating future capacity, electricity demand is estimated on a utility-by-utility basis. Three data sources are used:

- Individual utility estimates of total megawatt-hours and peak summer and winter load through 1985.
- National Electric Reliability Council (NERC) regional estimates for total megawatt-hours and peak summer demand for 1986-1995.
- Actual 1974 hourly load data for 40 areas (power supply areas [PSAs] or groups of PSAs) in the contiguous United States.

Available recharge capacity is the difference between total net dependable capacity (adjusted to reflect maintenance requirements and equipment failures) and total demand. It must be measured on an hourly basis for each individual utility. RECAP estimates available recharge capacity for each of

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*A more detailed model and data base description can be found in Ref. F.2.

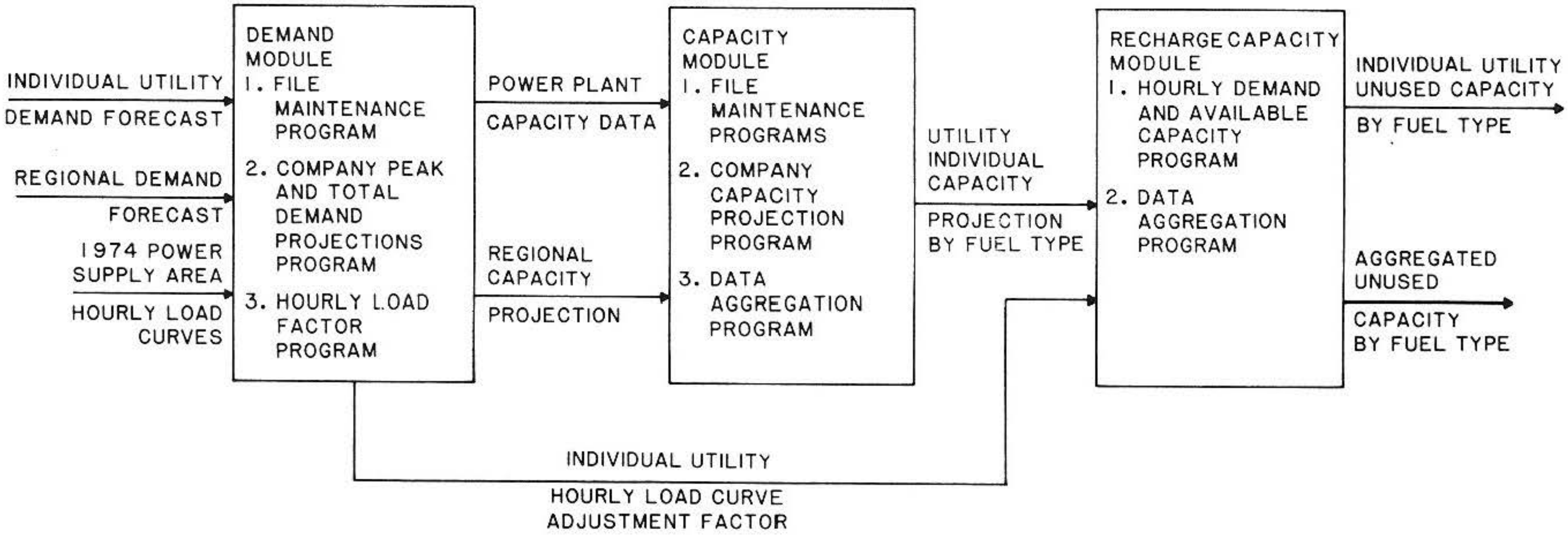

Fig. F.2. RECAP Model

190 utility systems. It also estimates the fuels that will be required to operate the generating units available to be used in the recharge process. The generating units providing the capacity are divided into 10 unit/fuel types: conventional hydroelectric, nuclear, coal, base and intermediate load oil, base and intermediate load gas, other (methanol, geothermal steam, waste heat, and refuse), pumped storage, peak load oil, peak load gas, and unknown. Generating unit scheduling for an all-thermal system is assumed to be based on operating costs. The following scheduling sequence is assumed:

- Nuclear (steam turbines).
- Coal (steam turbines).
- Oil -- base and intermediate (steam turbines, combined cycle).
- Gas -- base and intermediate (steam turbines, combined cycle).
- Other (methanol, waste heat, refuse, geothermal, steam).
- Oil -- peak load (jet engines, combustion turbines).
- Gas -- peak load (combustion turbines).

Conventional hydroelectric power plants are scheduled to be used before oil and gas units. They are also operated to use all available hydroelectric energy each day. Pumped storage is operated after base and intermediate load oil but only if there is available coal or nuclear capacity earlier in the day. The available coal and/or nuclear capacity is reduced appropriately to generate available pumped storage energy. Unknown capacity is assumed to be in proportion to the fuel mix of the utility.

F.1.2 Limitations of RECAP Model and Data Base

The version of the RECAP model and the supporting data base used for this analysis have several limitations that could affect the results presented in the next section. These limitations are largely due to the use of 1976 demand and capacity projections and to necessary simplifications made in modeling the U.S. electricity supply network.

F.1.2.1 Date Base Limitations

At the time the model was originally developed in 1977, the most current projections of electricity supply and demand were from 1976. Although this data base is being updated, the revision was not complete at the time of the analysis. Current projections differ from the 1976 projections in two ways. First, following a trend begun in 1974, current demand and supply projections are down from the 1976 projections. The current NERC projection of demand in the year 2000 is 6.2 million gigawatt hours (GWh) as against the 1976 NERC projection of 7.9 million GWh. Since EHV demand for electricity has been specified independently of the national electricity supply and demand projections, use of the 1976 NERC projections rather than current projections results in underestimating the relative overall impact of each EHV scenario by about 20%. In other words, less total capacity will be available for EHV charging than the 1976 projections would indicate.

The second disparity between 1976 and current projections concerns the role of nuclear power. Even prior to the Three Mile Island incident, a reduced role for nuclear was projected. Therefore, using the 1976 projections overestimates the quantity of nuclear energy used for charging EHVs and underestimates energy from other sources, particularly coal.

Several UAs were not part of the original Ref. F.2 data base but were approximated in that study by using data from nearby utilities: Fall River, Massachusetts; Biloxi, Mississippi; Brockton, Massachusetts; Modesto, California; and Texas City, Texas.

Several other UAs were not part of the Ref. F.2 data base and were approximated for this analysis by looking at current trends for each UA: San Juan, Puerto Rico; Ponce, Puerto Rico; Tampa, Florida; Honolulu, Hawaii; and Tucson, Arizona. This resulted in using oil for all EHV charging in Puerto Rico and Hawaii and coal in Tampa and Tucson. These five UAs represent approximately 2.4% of the total energy required for EHV charging independent of year and scenario.

F.1.2.2 Model Limitations

Modeling the U.S. electricity supply system is a very difficult task. Individual electric utilities have developed very large and expensive computer programs to assess individual system costs and performance. Therefore, some simplifications are necessary in order to model the entire U.S. supply network.

The first simplification is to ignore the role of utility interconnections and treat each utility independently. In the case of utilities that purchase a significant fraction of their electricity from neighboring utilities, the RECAP model will find very little, if any, energy available for charging of EHVs. In order to compensate for this effect, additional capacity, representative of the systems from which energy is purchased, has been assumed to be available for all unmet energy demands found by the RECAP model. This correction ranges from 2.5% of total charging energy for the 1990 LOW I scenario to 6.2% for the 2000 HIGH I scenario. However, the effect is quite large for Federal Region X, ranging from 52% for the 1990 LOW I scenario to 66% for the 2000 HIGH I scenario. Even in the cases where RECAP finds no unmet load, ignoring utility interties overestimates the consumption of oil and gas, and underestimates the consumption of coal and nuclear fuel.

The second simplification concerns scheduling units for maintenance. Individual utilities use a complicated optimization procedure to schedule units down for maintenance, which minimizes the loss of energy production from their more efficient coal and nuclear units. The RECAP model schedules maintenance uniformly throughout the year. This underestimates the contribution of coal and nuclear capacity to recharging EHVs and overestimates oil and gas consumption.

F.2 ANALYSIS

This section summarizes the electricity requirements for EHV charging and the types and amounts of fuel used to meet this demand. In Tables F.2-

F.11, the summaries are aggregated to the 10 federal regions for each of the five EHV scenarios for years 1990 and 2000.* The total row gives the U.S. summary. Types of generation other than nuclear, coal, oil, and gas have been ignored. Except for Federal Region X (Northwest), where hydro provides 9% of the charging energy in 1990 but only less than 1% in 2000, and Federal Region IX (West), where hydro and pumped storage represent 4% in 1990 and 5-10% in 2000 (depending on the scenario), all contributions from other sources are assumed negligible. The fuel resource requirements are found by multiplying the busbar energy by the heat rates in Table F.1.

Approximately 80% of all the energy used in all scenarios to charge EHVs comes from coal and nuclear capacity. The relatively high percentage of electricity generated by oil (17%) is due primarily to three of the federal regions. Federal Region IX accounts for 45% of the oil consumed in electricity generation in 1990 and 25% in 2000. This can be attributed in large part to environmental considerations, which preclude the use of coal in California. Federal Region IV (South Atlantic) accounts for 25% of the oil consumption in 1990, but this falls to 20% in 2000. This level of consumption is due entirely to Florida (67%) and Puerto Rico (33%).** In these areas, it has been more economic to burn oil than coal. Federal Region II (New York-New Jersey is the third highest oil-consuming region, accounting for 15% of the oil in 1990 and 50% in 2000. This sharp increase in oil consumption in 2000 is probably due to the heavy dependence of New York on oil and to relatively high EHV demand (see Table F.12).

Essentially all of the gas consumption comes from Federal Region VI (Southwest). This is due to the almost total dependence on natural gas in Texas. However, total gas consumption for charging EHVs declines from 40% in 1990 to 25% in 2000, as Texas switches from natural gas to coal.

Table F.12 summarizes total demand for electricity as well as the percentage of that demand required to recharge EHVs in the LOW I, MEDIUM, and HIGH I scenarios. Projected demand for the 158 UAs represents approximately 80% of total U.S. demand. The EHV demand in Federal Region II consistently represents a percentage three times higher than the national average for all scenarios. This can be attributed to the large truck and bus population in New York City. For the HIGH I scenario in 2000, EHV demand is approximately 8% of the total demand in Federal Region II. For the HIGH I scenario in 2000, EHV demand exceeds 10% of projected demand for the five utilities shown in Table F.13.

The available energy on the utility peak day generally determines the number of EHVs that can be supported without expanding generating capacity. If we assume the EHV charging demand is spread uniformly over the year, the percentage of annual utility generation that can be used to charge EHVs can

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* Section F.3 contains the results for individual UAs for HIGH I in 2000. Summaries for 10 UAs for all time periods and scenarios also are contained in Sec. F.3. See Fig. A.8 for a map of the 10 federal regions.

**For the purposes of this analysis, Puerto Rico is included in Federal Region IV.

Table F.2. Summary of Fuels Used to Charge EHVs, LOW I, 1990

Federal Region	Total Busbar (GWh)	Total Resource (10^9 Btu)	Nuclear Busbar (GWh)	Nuclear Resource (10^9 Btu)	Coal Busbar (GWh)	Coal Resource (10^9 Btu)	Oil Busbar (GWh)	Oil Resource (10^9 Btu)	Gas Busbar (GWh)	Gas Resource (10^9 Btu)
I	48	508	40.2	429	4.2	43	3.3	36	0	0
II	202	2,090	33.3	355	140.0	1,425	28.6	310	0	0
III	130	1,337	17.6	188	111.2	1,132	1.6	17	0	0
IV	164	1,711	30.2	322	85.5	870	47.9	519	0	0
V	245	2,549	103.0	1,099	139.9	1,424	1.4	16	0.8	10
VI	102	1,072	11.5	123	39.5	402	10.9	118	40.0	429
VII	52	536	13.8	147	38.1	388	0	0	0.1	1
VIII	22	222	0	0	21.8	222	0	0	0	0
IX	152	1,632	50.6	540	8.9	91	92.5	1,001	0	0
X	30	322	20.4	218	4.3	44	5.5	60	0	0
Total	1,147	11,979	321	3,421	593	6,041	192	2,077	41	440

Table F.3. Summary of Fuels Used to Charge EHVs, LOW II, 1990

Federal Region	Total Busbar (GWh)	Total Resource (10^9 Btu)	Nuclear Busbar (GWh)	Nuclear Resource (10^9 Btu)	Coal Busbar (GWh)	Coal Resource (10^9 Btu)	Oil Busbar (GWh)	Oil Resource (10^9 Btu)	Gas Busbar (GWh)	Gas Resource (10^9 Btu)
I	82	869	68.0	725	7.6	77	6.1	67	0	0
II	344	3,556	56.7	605	241.5	2,458	45.6	493	0	0
III	223	2,283	31.8	339	187.4	1,907	3.4	37	0	0
IV	278	2,909	51.7	551	145.0	1,476	81.5	882	0	0
V	416	4,328	175.0	1,867	237.8	2,420	2.5	29	0.9	12
VI	172	1,812	19.3	206	66,7	679	18.8	207	67.0	720
VII	88	907	23.4	250	64.4	655	0	0	0.2	2
VIII	36	369	0	0	36.1	367	0.2	2	0	0
IX	258	2,766	85.6	913	14.9	152	157.1	1,701	0	0
X	52	558	35.3	377	7.2	73	9.9	108	0	0
Total	1,949	20,357	547	5,833	1,009	10,264	325	3,526	68	734

Table F.4. Summary of Fuels Used to Charge EHVs, MEDIUM, 1990

Federal Region	Total Busbar (GWh)	Total Resource (10^9 Btu)	Nuclear Busbar (GWh)	Nuclear Resource (10^9 Btu)	Coal Busbar (GWh)	Coal Resource (10^9 Btu)	Oil Busbar (GWh)	Oil Resource (10^9 Btu)	Gas Busbar (GWh)	Gas Resource (10^9 Btu)
I	105	1,119	87.2	930	9.9	101	8.1	88	0	0
II	442	4,568	72.9	778	311.5	3,170	57.3	620	0	0
III	286	2,937	41.6	444	240.0	2,442	4.7	51	0	0
IV	357	3,736	66.6	710	186.0	1,893	104.7	1,133	0	0
V	534	5,555	224.6	710	186.00	1,893	3.3	38	1.0	14
VI	220	2,321	24.7	263	85.4	869	24.3	269	85.7	920
VII	113	1,166	30.1	321	82.5	840	0.3	3	0.2	2
VIII	46	467	0	0	45.9	467	0	0	0	0
IX	330	3,546	109.7	1,170	19.0	193	201.6	2,183	0	0
X	68	722	45.6	486	9.3	95	13.0	141	0	0
Total	2,502	26,137	703	7,498	1,295	13,177	417	4,526	87	936

Table F.5. Summary of Fuels Used to Charge EHVs, HIGH I, 1990

Federal Region	Total Busbar (GWh)	Total Resource (10^9 Btu)	Nuclear Busbar (GWh)	Nuclear Resource (10^9 Btu)	Coal Busbar (GWh)	Coal Resource (10^9 Btu)	Oil Busbar (GWh)	Oil Resource (10^9 Btu)	Gas Busbar (GWh)	Gas Resource (10^9 Btu)
I	274	2,909	224.9	2,399	27.2	277	21.5	233	0	0
II	1,158	12,005	189.5	2,021	776.8	7,905	191.8	2,079	0	0
III	754	7,727	99.2	1,058	638.7	6,499	15.7	170	0	0
IV	926	9,683	171.0	1,824	482.4	4,909	272.5	2,950	0	0
V	1,400	14,561	585.3	6,243	800.8	8,149	11.8	133	2.6	36
VI	575	6,076	65.8	702	220.9	2,248	65.0	722	223.8	2,404
VII	295	3,037	76.5	816	217.0	2,208	0.7	8	0.5	5
VIII	121	1,232	0.2	2	120.9	1,230	0	0	0	0
IX	863	9,266	277.7	2,955	48.6	495	537.2	5,816	0	0
X	171	1,817	116.7	1,245	23.2	236	31.0	336	0	0
Total	6,537	68,313	1,806	19,265	3,357	34,156	1,147	12,447	227	2,445

Table F.6. Summary of Fuels Used to Charge EHVs, HIGH II, 1990

Federal Region	Total Busbar (GWh)	Total Resource (10^9 Btu)	Nuclear Busbar (GWh)	Nuclear Resource (10^9 Btu)	Coal Busbar (GWh)	Coal Resource (10^9 Btu)	Oil Busbar (GWh)	Oil Resource (10^9 Btu)	Gas Busbar (GWh)	Gas Resource (10^9 Btu)
I	273	2,907	224.7	2,397	27.2	277	21.5	233	0	0
II	1,157	11,992	189.3	2,019	776.0	7,897	191.6	2,076	0	0
III	753	7,719	99.1	1,057	638.0	6,492	15.7	170	0	0
IV	925	9,673	170.8	1,822	481.9	4,904	272.2	2,947	0	0
V	1,399	14,546	584.7	6,237	799.9	8,140	11.8	133	2.6	36
VI	575	6,068	65.7	701	220.7	2,245	64.9	721	223.6	2,401
VII	294	3,034	76.4	815	216.7	2,206	0.7	8	0.5	5
VIII	121	1,231	0.2	2	120.8	1,229	0	0	0	0
IX	862	9,256	276.7	2,952	48.6	494	536.6	5,810	0	0
X	171	1,816	116.6	1,244	23.2	236	31.0	336	0	0
Total	6,530	68,240	1,804	19,244	3,353	34,120	1,146	12,434	227	2,442

Table F.7. Summary of Fuels Used to Charge EHVs, LOW I, 2000

Federal Region	Total Busbar (GWh)	Total Resource (10^9 Btu)	Nuclear Busbar (GWh)	Nuclear Resource (10^9 Btu)	Coal Busbar (GWh)	Coal Resource (10^9 Btu)	Oil Busbar (GWh)	Oil Resource (10^9 Btu)	Gas Busbar (GWh)	Gas Resource (10^9 Btu)
I	748	7,986	713.0	7,606	4.0	41	30.9	339	0	0
II	3,151	33,233	592.1	6,316	1,404.3	14,290	1,154.9	12,626	0.1	1
III	2,054	21,097	390.1	4,161	1,651.4	16,805	12.1	131	0	0
IV	2,513	26,769	664.1	7,084	1,240.9	12,627	592.1	6,886	16.0	172
V	3,813	39,980	2,363.8	25,215	1,438.2	14,635	8.9	100	2.2	30
VI	1,572	16,556	496.5	5,296	618.5	6,294	37.4	422	420.0	4,544
VII	805	8,334	290.2	3,096	514.0	5,230	0.5	5	0.3	3
VIII	331	3,366	0.5	5	330.4	3,361	0	0	0	0
IX	2,311	24,381	1,160.1	12,375	689.1	7,012	401.5	4,346	60.4	648
X	488	5,169	407.9	4,351	76.5	778	3.7	40	0	0
Total	17,786	186,871	7,078	75,505	7,967	81,073	2,242	24,895	499	5,398

Table F.8. Summary of Fuels Used to Charge EHVs, LOW II, 2000

Federal Region	Total Busbar (GWh)	Total Resource (10^9 Btu)	Nuclear Busbar (GWh)	Nuclear Resource (10^9 Btu)	Coal Busbar (GWh)	Coal Resource (10^9 Btu)	Oil Busbar (GWh)	Oil Resource (10^9 Btu)	Gas Busbar (GWh)	Gas Resource (10^9 Btu)
I	1,467	15,668	1,395.3	14,884	11.2	114	60.7	670	0	0
II	6,188	65,833	1,131.2	12,067	2,531.5	25,760	2,525.1	28,002	0.3	4
III	4,046	41,566	739.0	7,883	3,261.0	33,185	46.0	498	0	0
IV	4,954	52,636	1,290.4	13,764	2,490.6	25,345	1,140.0	13,174	32.8	353
V	7,517	78,759	4,541.4	48,444	2,948.8	30,007	23.4	258	3.7	50
VI	3,106	32,692	982.0	10,479	1,240.9	12,627	75.9	1,860	807.4	8,731
VII	1,588	16,450	589.5	6,288	997.2	10,147	0.9	9	0.6	6
VIII	656	6,671	0.8	9	654.7	6,662	0	0	0	0
IX	4,507	47,591	2,195.6	23,420	1,299.4	13,223	901.3	9,757	111.0	1,191
X	963	10,190	793.8	8,467	162.7	1,655	6.2	68	0	0
Total	34,992	368,056	13,659	145,700	15,598	158,725	4,780	53,296	956	10,335

Table F.9. Summary of Fuels Used to Charge EHVs, MEDIUM, 2000

Federal Region	Total Busbar (GWh)	Total Resource (10^9 Btu)	Nuclear Busbar (GWh)	Nuclear Resource (10^9 Btu)	Coal Busbar (GWh)	Coal Resource (10^9 Btu)	Oil Busbar (GWh)	Oil Resource (10^9 Btu)	Gas Busbar (GWh)	Gas Resource (10^9 Btu)
I	2,277	24,316	2,163.4	23,077	19.4	197	94.2	1,042	0	0
II	9,606	102,528	1,738.1	18,540	3,800.2	38,671	4,067.4	45,310	0.5	7
III	6,289	64,606	1,131.7	12,072	5,072.9	51,622	84.2	912	0	0
VI	7,701	81,753	1,995.3	21,284	3,897.4	39,660	1,756.7	20,253	51.8	556
V	11,687	122,407	6,922.6	74,590	4,649.1	47,309	39.7	435	5.3	73
VI	4,832	50,856	1,528.4	16,303	1,941.4	19,756	119.2	1,354	1,243.5	13,443
VII	2,470	25,588	926.4	9,882	1,541.1	15,682	1.3	14	0.9	10
VIII	1,021	10,389	1.2	13	1,019.7	10,376	0	0	0	0
IX	6,979	73,717	3,361.1	35,853	1,986.4	20,214	1,463.8	15,847	168.0	1,803
X	1,492	15,842	1,228.1	13,100	259.7	2,643	9.1	99	0	0
Total	54,359	572,002	21,066	224,714	24,187	246,130	7,636	85,266	1,470	15,892

Table F.10. Summary of Fuels Used to Charge EHVs, HIGH I, 2000

Federal Region	Total Busbar (GWh)	Total Resource (10^9 Btu)	Nuclear Busbar (GWh)	Nuclear Resource (10^9 Btu)	Coal Busbar (GWh)	Coal Resource (10^9 Btu)	Oil Busbar (GWh)	Oil Resource (10^9 Btu)	Gas Busbar (GWh)	Gas Resource (10^9 Btu)
I	7,345	78,427	6,932.1	73,945	148.8	1,514	264.2	2,968	0	0
II	30,889	342,444	5,816.8	62,048	11,713.3	119,195	13,333.0	160,842	26.0	359
III	20,246	207,967	3,299.6	35,197	16,453.0	167,426	493.6	5,344	0	0
IV	25,005	264,137	6,059.3	64,637	13,125.7	133,567	5,694.5	64,591	125.0	1,342
V	37,682	393,743	20,785.0	221,714	16,808.0	171,035	81.4	889	7.6	105
VI	15,731	165,288	4,969.5	53,010	6,700.3	68,182	394.1	4,479	3,667.0	39,617
VII	8,026	82,932	2,541.4	27,109	5,474.6	55,710	8.6	97	1.5	16
VIII	3,335	33,937	1.2	13	3,333.7	33,924	0	0	0	0
IX	21,911	232,620	10,310.7	109,984	4,474.1	45,528	6,680.3	72,321	446.0	4,787
X	4,840	51,128	3,780.8	40,330	1,026.2	10,443	32.5	355	0	0
Total	175,010	1,852,623	64,497	687,987	79,258	806,524	26,982	311,886	4,273	46,226

Table F.11. Summary of Fuels Used to Charge EHVs, HIGH II, 2000

Federal Region	Total Busbar (GWh)	Total Resource (10^9 Btu)	Nuclear Busbar (GWh)	Nuclear Resource (10^9 Btu)	Coal Busbar (GWh)	Coal Resource (10^9 Btu)	Oil Busbar (GWh)	Oil Resource (10^9 Btu)	Gas Busbar (GWh)	Gas Resource (10^9 Btu)
I	7,122	76,042	6,721.9	71,702	143.1	1,456	256.7	2,883	0	0
II	29,951	331,867	5,637.0	60,130	11,364.5	115,645	12,924.6	155,749	24.9	343
III	19,631	201,647	3,204.0	34,177	15,951.4	162,321	475.6	5,149	0	0
IV	24,242	256,096	5,880.2	62,724	11,718.9	129,428	5,520.9	62,637	121.8	1,307
V	36,536	381,785	20,177.0	215,228	16,272.0	165,584	79.6	869	7.5	104
VI	15,251	160,243	4,817.8	51,392	6,490.5	66,047	382.0	4,341	3,560.2	38,463
VII	7,781	80,404	2,470.2	26,350	5,301.2	53,945	8.3	93	1.5	16
VIII	3,233	32,899	1.2	13	3,231.7	32,886	0	0	0	0
IX	21,253	225,616	10,004.4	106,717	4,364.4	44,412	6,450.4	69,832	433.7	4,655
X	4,692	49,573	3,668.3	39,130	992.4	10,099	31.5	344	0	0
Total	169,692	1,796,172	62,582	667,564	76,830	781,823	26,130	301,897	4,150	44,888

Table F.12. Summary of Total Electricity Demand and EHV Percentage of that Demand by Federal Region, 1990 and 2000[a]

	1990				2000			
Federal Region	Projected Demand	LOW I	MEDIUM	HIGH I	Projected Demand	LOW I	MEDIUM	HIGH I
I	175,582	48 (0.03)	105 (0.06)	273 (0.16)	291,847	747 (0.26)	2,277 (0.78)	7,352 (2.52)
II	235,720	202 (0.09)	441 (0.19)	1,156 (0.49)	398,216	3,155 (0.79)	9,606 (2.41)	30,890 (7.76)
III	388,355	132 (0.03)	288 (0.07)	757 (0.19)	660,871	2,053 (0.31)	6,289 (0.95)	20,319 (3.07)
IV	974,051	164 (0.02)	355 (0.04)	925 (0.10)	1,736,522	2,512 (0.14)	7,698 (0.44)	25,011 (1.44)
V	778,132	245 (0.03)	534 (0.07)	1,405 (0.18)	1,335,540	3,810 (0.29)	11,684 (0.87)	37,804 (2.83)
VI	533,521	101 (0.02)	218 (0.04)	574 (0.11)	993,206	1,571 (0.16)	4,831 (0.49)	15,730 (1.58)
VII	144,204	54 (0.04)	111 (0.08)	293 (0.20)	268,515	804 (0.30)	2,469 (0.92)	8,026 (2.99)
VIII	58,654	22 (0.04)	46 (0.08)	121 (0.21)	99,057	330 (0.33)	1,020 (1.03)	3,336 (3.37)
IX	327,094	158 (0.05)	344 (0.11)	898 (0.27)	552,412	2,426 (0.44)	7,465 (1.35)	24,289 (4.40)
X	68,558	34 (0.04)	75 (0.11)	189 (0.28)	115,784	490 (0.42)	1,499 (1.29)	4,846 (4.19)
Total	3,683,871	1,158 (0.03)	2,516 (0.07)	6,586 (0.18)	6,451,970	17,890 (0.28)	54,835 (0.85)	177,465 (2.75)

[a] Projected total electricity demand includes only sales to the 158 UAs in which EHVs are projected to penetrate. These projected sales represent approximately 80% of total projected national sales. An entry in parentheses is the percentage of electricity in a region (or the nation) required to charge EHVs. Other figures are the total demand in gigawatt-hours.

Table F.13. Utilities for Which EHV Demand Exceeds Ten Percent of Projected Demand, HIGH I, 2000

Utility	Urbanized Area	Percentage Exceeds
Consolidated Edison	New York/New Jersey	20
K.C. Board of Public Utilities	Kansas City	18
Orlando Utilities	Orlando	13
Lubbock City Power and Light	Lubbock	12
Long Island Lighting Co.	New York/New Jersey	10

be expressed in terms of the utility annual and peak day load factor by the following equation:

$$PER = (1 - LFD)/LFY \tag{F.1}$$

where:

PER = percentage (EHV demand/total demand),

LFD = peak day load factor (daily energy generated/available daily energy), and

LFY = yearly load factor (annual energy generated/available annual energy).

Using Edison Electric Institute statistics for daily and yearly load factors ($0.48 \leq LFY \leq 0.78$, $0.77 \leq LFD \leq 0.92$), PER ranges from 10% to 48%. The high value corresponds to low daily and annual load factors, while the low value corresponds to high daily and annual load factors. Thus, except possibly for the five utilities mentioned above, all EHV charging can be accomplished off peak without having to expand generating capacity.

The Public Utility Regulatory Policy Act (PURPA) of 1978 (P.L. 95-617) requires utilities to develop cost-based rates. Since charging of EHVs can be accomplished during off-peak periods, EHVs should be charged off-peak rates. Using this criterion, Table F.14 summarizes Spring, 1979, fuel and operating costs for each federal region. These costs exclude state, local, or road-use taxes and any additional distribution system costs to support vehicle recharging. For comparison purposes, Table F.14 also includes estimates based on the EIA 1990 high fuel price scenario, which includes deregulation of oil and gas prices. Note that 1979 OPEC oil prices were approximately at the projected 1990 level. Except for Federal Regions VI and IX, off-peak costs are about 20-30% higher under this scenario. In Federal Region VI, costs are about 70% higher due to deregulation of natural gas and heavy dependence on natural gas. Federal Region IX costs are about 40% higher, again due to heavy dependence on oil in this region.

Table F.14. Average Power Plant Fuel and Operating Costs for Generating Electricity to Charge EHVs by Federal Region, 1990 and 2000 (¢/kWh)

Federal Region	Spring, 1979, Prices[a]				EIA 1990 High Prices[b]			
	1990		2000		1990		2000	
	LOW I	HIGH I	LOW I	HIGH I	LOW I	HIGH I	LOW I	HIGH I
I	1.2	1.2	1.1	1.1	1.4	1.4	1.2	1.3
II	1.6	1.7	2.0	2.6	2.1	2.1	2.7	3.3
III	1.4	1.5	1.4	1.5	1.8	1.8	1.8	1.7
IV	1.9	1.9	1.9	1.8	2.5	2.5	2.5	2.4
V	1.3	1.3	1.2	1.2	1.6	1.6	1.4	1.5
VI	1.8	1.8	1.5	1.5	3.2	3.2	2.5	2.4
VII	1.4	1.4	1.3	1.3	1.7	1.7	1.6	1.6
VIII	1.5	1.5	1.5	1.5	1.9	1.9	1.9	1.9
IX	2.3	2.3	1.5	1.7	3.2	3.2	2.0	2.4
X	1.4	1.4	1.1	1.1	1.8	1.8	1.2	1.3
Total	1.6	1.7	1.5	1.7	2.2	2.2	2.0	2.2

[a] Residual oil at \$16.50/bbl; distillate oil at \$20.90/bbl; coal at \$1.28/10^6 Btu; uranium at \$0.84/10^6 Btu; gas at \$1.70/10^6 Btu.

[b] Residual oil at \$24.50/bbl; distillate oil at \$25.40/bbl; coal at \$1.62/10^6 Btu; uranium at \$0.94/10^6 Btu; gas at \$4.05/10^6 Btu.

An estimate of additional distribution system costs can be obtained by calculating peak recharge demand and assigning the cost of the final line transformer to the EHV. Using a cost of \$100/kW for the line transformer, the annual cost (based on real debt and equity rates) is \$10/kW/hr.* The peak kilowatt demand and the resulting cost amortized over annual EHV consumption are given by the following relationships:

$$P = \frac{R}{E \cdot HR} \qquad (F.2)$$

$$Y = \frac{VMT}{E} \qquad (F.3)$$

$$A = 10\,\frac{P}{Y}$$

$$= 10\left(\frac{R}{VMT \cdot HR}\right) \qquad (F.4)$$

where:

P = peak charging demand (kW),

R = vehicle range (mi),

E = EHV electrical efficiency (kWh/mi),

HR = hours available for recharge,

Y = annual EHV electricity consumption (kWh/yr),

VMT = annual EHV mileage provided by battery, and

A = annual demand charge averaged over consumption (\$/kWh).

Values for E, VMT, and R are presented in App. B.

Table F.15 summarizes the results of calculations using Eqs. F.2-F.4 for various battery recharge times. Only vehicles that actually penetrate under the HIGH I scenario have been included. Costs for trucks, buses, and autos as well as costs for EVs of all types having specific ranges are shown. The range in values in Table F.15 corresponds to variations in the ratio of R and VMT. Note that distribution costs for the HVs in HIGH II are slightly lower than the ranges shown in Table F.15, since part of their daily mileage is usually on their heat engine, especially on peak usage days.

For long recharge periods (8-10 hr), costs are about equal to the fuel and operating costs in Table F.14. For rapid recharging (1 hr), costs can be as much as 10 times greater. For example, a four-passenger subcompact vehicle averaging 30 mpg and paying \$1/gal for gasoline has a fuel-related

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*There is wide variation in actual costs for line transformers depending on local utility conditions. The value used here represents a rough average of recent costs presented in marginal cost rate testimony around the country by National Economic Research Associates, Inc.

Table F.15. Average Distribution System Cost for EV Recharge (¢/kWh)[a]

Vehicle Type/ Year	Recharge Period (hr)				
	1	2	4	8	10
Truck/1985	6.2	3.1	1.6	0.8	0.6
Bus/1985	8.0	4.0	2.0	1.0	0.8
Auto/1985	5.7-9.1	2.9-4.5	1.4-2.3	0.7-1.1	0.6-0.9
1985[b]	5.7-8.0	2.9-4.0	1.4-2.0	0.7-1.0	0.6-0.8
1985[c]	9.1	4.5	2.3	1.1	0.9
Truck/2000	7.4-15.4	3.7-7.7	1.8-3.8	0.9-1.9	0.7-1.5
Bus/2000	9.1-20.0	4.5-10.0	2.3-5.0	1.1-2.5	0.9-2.0
Auto/2000	6.5-16.7	3.2-8.3	1.6-4.2	0.8-2.1	0.6-1.7
2000[b]	6.4-9.1	3.2-4.5	1.6-2.3	1.1-1.3	0.6-0.9
2000[c]	10.5-14.2	5.3-7.1	3.6-3.6	1.3-1.8	1.1-1.4
2000[d]	15.4-20.0	7.7-10.0	3.8-5.0	1.9-2.5	1.5-2.0

[a] Based on vehicles that actually penetrate under HIGH I.

[b] LT1, LT3, MT1, MT3, HT1, HT3, SB1, SB3, LB1, LB3, 4P1-2, 5P1-2. Vehicles with a 50-mi range in 1985 and a 73-mi range in 2000.

[c] LT4-5, MT4-5, HT4-5, SB4-5, LB4-5, 4P5-8, 5P5-8. Vehicles with a 90-100-mi range in 1985 and a 132-147-mi range in 2000.

[d] LT6, MT6, HT6, SB6, LB6, 4P9, 5P9. Vehicles with a 205-220-mi range in 2000.

cost of $0.033/mi. A similar four-passenger EV (4P9) with a 1-hr recharge capability would pay $0.19/kWh ($0.168 for distribution and $0.022 for fuel) for electricity and consume 0.356 kWh/mile, resulting in a fuel-related cost of $0.067/mi, twice the CV cost. Admittedly, this is a worst-case example, but it does demonstrate the need for a careful tradeoff analysis between rapid recharge capability and the resulting operating cost.

In sum, the marginal cost of generating electricity off peak for EHVs in 2000 based on 1979 fuel prices ranges from approximately $0.011/kWh in Federal Regions I (New England) and X to $0.026/kWh for Federal Region II. The kW demand associated with EHV charging may require additions to the electric utility distribution system at the customer's premises. For an 8-10-hr recharge, this could add between $0.006 and $0.025/kWh to the cost of electricity, depending on the type of vehicle. A 1-hr recharge could add from $0.064 to $0.20/kWh. Thus, the total marginal cost of electricity, excluding taxes, for off-peak EHV charging ranges between $0.017 and $0.051/kWh for an 8-10-hr recharge at 1979 prices.

F.3 DATA SUMMARY

Table F.16 contains the summary for all 158 UAs for HIGH I in 2000. The key for the UAs can be found in Table A.18. Table F.17 contains a summary of all scenarios and time periods for 10 selected UAs.

Table F.16. Fuels Used for Charging EHVs by Urbanized Area, HIGH I, 2000

Urbanized Area[a]	Total Busbar (GWh)	Total Resource (10^9 Btu)	Nuclear Busbar (GWh)	Nuclear Resource (10^9 Btu)	Coal Busbar (GWh)	Coal Resource (10^9 Btu)	Oil Busbar (GWh)	Oil Resource (10^9 Btu)	Gas Busbar (GWh)	Gas Resource (10^9 Btu)
1	26,784.0	297,978	4,677.0	49,890	10,633.0	108,201	11,488.0[b]	139,528[b]	26.0[b]	359[b]
2	10,061.4	106,621	364.4	3,887	3,391.0	34,507	5,860.0	63,440	446.0	4,787
3	10,433.7	110,675	9,167.7	97,792	1,266.0	12,883	0	0	0	0
4	6,343.8	64,690	24.8	265	6,129.0	62,368	190.0	2,057	0	0
5	6,056.0	64,599	6,056.0	64,599	0	0	0	0	0	0
6	5,630.6	58,124	1,685.6	17,980	3,945.0	40,144	0	0	0	0
7	3,048.3	32,510	3,010.0	32,108	20.4	208	17.9	194	0	0
8	4,136.9	42,185	16.0	171	3,997.0	40,673	123.9	1,341	0	0
9	3,230.0	34,454	3,230.0	34,454	0	0	0	0	0	0
10	2,883.0	29,689	716.0	7,638	2,167.0	22,051	0	0	0	0
11	1,949.0	20,790	1,949.0	20,790	0	0	0	0	0	0
12	2,391.8	23,390	9.2	98	2,311.0	23,517	71.6	775	0	0
13	2,435.8	25,491	1,432.8	15,284	1,003.0	10,207	0	0	0	0
14	2,567.5	26,645	1,054.9	11,253	1,512.6	15,392	0	0	0	0
15	2,089.0	22,283	2,089.0	22,283	0	0	0	0	0	0
16	2,546.7	25,915	0	0	2,546.7	25,915	0	0	0	0
17	2,448.3	26,306	1,258.7	13,427	0	0	1,189.6	12,879	0	0
18	1,904.6	19,440	119.6	1,276	1,785.0	18,164	0	0	0	0
19	1,996.5	21,298	1,985.0	21,174	0	0	11.5	124	0	0
20	1,525.5	16,236	1,452.0	15,488	73.5	784	0	0	0	0
21	1,623.0	16,516	0	0	1,623.0	16,516	0	0	0	0
22	1,424.3	15,603	0	0	445.0	4,528	979.3[b]	11,075[b]	0	0
23	1,892.2	19,256	1.2	13	1,891.0	19,243	0	0	0	0
24	1,594.0	17,003	1,594.0	17,003	0	0	0	0	0	0
25	1,731.7	18,294	654.4	6,980	665.3	6,770	39.6[b]	547[b]	372.4	3,997
26	1,678.1	17,344	543.5	5,798	1,134.6	11,546	0	0	0	0
27	1,462.5	15,405	1,027.5	10,960	407.5	4,147	27.5	298	0	0
28	1,865.0	20,190	0	0	0	0	1,865.0	20,190	0	0
29	1,142.3	12,182	1,128.0	12,032	7.6	77	6.7	73	0	0
30	1,314.0	13,371	0	0	1,314.0	13,371	0	0	0	0
31	1,373.0	13,972	0	0	1,373.0	13,971	0	0	0	0
32	1,238.0	12,598	0	0	1,238.0	12,598	0	0	0	0

Table F.16. (Cont'd)

Urban-ized Area	Total Busbar (GWh)	Total Resource (10^9 Btu)	Nuclear Busbar (GWh)	Nuclear Resource (10^9 Btu)	Coal Busbar (GWh)	Coal Resource (10^9 Btu)	Oil Busbar (GWh)	Oil Resource (10^9 Btu)	Gas Busbar (GWh)	Gas Resource (10^9 Btu)
33	1,128.8	11,783	603.6	6,439	524.9	5,341	0.3	3	0	0
34	1,356.0	13,879	164.7	1,757	1,191.3	12,122	0	0	0	0
35	1,159.6	11,800	0	0	1,159.6	11,800	0	0	0	0
36	0	0	0	0	0	0	0	0	0	0
37	1,208.1	12,980	621.1	6,625	0	0	587.0	6,355	0	0
38	1,299.8	13,723	0	0	408.4	4,156	0	0	891.4	9,567
39	940.0	10,026	940.0	10,026	0	0	0	0	0	0
40	868.0	9,235	0	0	146.5	1,491	0	0	721.5	7,744
41	1,180.3	13,714	26	277	443.0	4,508	711.3[b]	8,929[b]	0	0
42	809.1	8,331	197.7	2,109	611.4	6,221	0	0	0	0
43	1,001.5	10,192	1.5	16	1,000.0	10,176	0	0	0	0
44	759.8	8,103	750.3	8,003	5.0	51	4.5	49	0	0
45	853.0	10,412	182.5	1,947	182.5	1,857	488.0[b]	6,608[b]	0	0
46	678.0	7,231	669.5	7,142	4.5	46	4	43	0	0
47	579.3	6,346	0	0	181.4	1,846	397.9[b]	4,500[b]	0	0
48	903.0	9,189	0	0	903.0	9,189	0	0	0	0
49	835.0	8,497	0	0	835.0	8,497	0	0	0	0
50	776.7	8,285	776.7	8,285	0	0	0	0	0	0
51	796.7	8,498	796.7	8,498	0	0	0	0	0	0
52	987.2	10,733	422.0	4,501	422.0	4,294	143.2[b]	1,938[b]	0	0
53	721.9	7,535	386.0	4,117	335.7	3,416	0.2	2	0	0
54	581.5	5,987	142.1	1,516	439.4	4,471	0	0	0	0
55	666.8	6,825	80.9	863	585.9	5,962	0	0	0	0
56	671.0	7,264	0	0	0	0	671.0	7,264	0	0
57	898.4	9,285	290.9	3,103	607.5	6,182	0	0	0	0
58	516.1	5,653	0	0	161.3	1,641	354.8[b]	4,012[b]	0	0
59	451.6	4,605	1.8	19	436.4	4,441	13.4	145	0	0
60	737.3	7,518	2.8	30	712.6	7,251	21.9	237	0	0
61	481.0	4,905	1.9	20	464.8	4,730	14.3	155	0	0
62	688.3	7,345	0	0	160.4	1,632	15.4[b]	211[b]	512.6	5,502
63	622.9	6,640	613.4	6,543	9.5	97	0	0	0	0
64	527.0	5,363	0	0	527.0	5,363	0	0	0	0

Table F.16. (Cont'd)

Urbanized Area	Total Busbar (GWh)	Total Resource (10^9 Btu)	Nuclear Busbar (GWh)	Nuclear Resource (10^9 Btu)	Coal Busbar (GWh)	Coal Resource (10^9 Btu)	Oil Busbar (GWh)	Oil Resource (10^9 Btu)	Gas Busbar (GWh)	Gas Resource (10^9 Btu)
65	866.6	9,311	445.6	4,753	0	0	421.0	4,558	0	0
66	620.0	6,609	610.5	6,512	9.5	97	0	0	0	0
67	564.3	5,890	301.7	3,218	262.4	2,670	0.2	2	0	0
68	521.0	5,558	521.0	5,558	0	0	0	0	0	0
69	425.2	4,328	0	0	424.0	4,315	0.2	2	1.0	11
70	497.7	5,065	0	0	493.3	5,020	2.7	29	1.5	16
71	785.9	7,997	0	0	785.9	7,997	0	0	0	0
72	545.0	5,803	525.4	5,604	19.6	199	0	0	0	0
73	325.3	3,563	0	0	102.2	1,040	223.1	2,523	0	0
74	483.9	5,153	466.4	4,975	17.5	178	0	0	0	0
75	431.1	4,403	0	0	405.8	4,129	25.3	274	0	0
76	424.2	4,525	424.2	4,525	0	0	0	0	0	0
77	469.8	4,995	158.4	1,690	101.4	1,032	210.0	2,273	0	0
78	419.0	4,367	209.5	2,235	209.5	2,132	0	0	0	0
79	508.5	5,175	0.8	9	507.7	5,166	0	0	0	0
80	349.0	3,722	344.6	3,676	2.3	23	2.1	23	0	0
81	317.6	3,244	0	0	299.0	3,043	18.6	201	0	0
82	406.2	4,342	0	0	30.0	305	0.4	4	375.8	4,033
83	467.2	4,984	0	0	109.0	1,109	10.4[b]	142[b]	347.8	3,733
84	469.7	4,817	76.7	818	393.0	3,999	0	0	0	0
85	372.2	3,788	0	0	372.2	3,788	0	0	0	0
86	391.3	4,117	262.8	2,803	124.7	1,269	3.8[b]	45[b]	0	0
87	410.7	4,362	371.6	3,964	39.1	398	0	0	0	0
88	312.4	3,186	1.2	13	302.0	3,073	9.2	100	0	0
89	318.8	3,263	38.7	413	280.1	2,850	0	0	0	0
90	427.4	4,383	69.7	743	357.7	3,640	0	0	0	0
91	462.9	4,710	0	0	462.9	4,710	0	0	0	0
92	262.9	2,678	0	0	262.0	2,666	0.9[b]	12[b]	0	0
93	357.4	3,637	0	0	357.4	3,637	0	0	0	0
94	457.0	4,872	451.2	4,813	5.8	59	0	0	0	0
95	350.7	3,582	0	0	330.1	3,359	20.6	223	0	0
96	360.0	3,663	0	0	360.0	3,663	0	0	0	0

Table F.16. (Cont'd)

Urbanized Area	Total Busbar (GWh)	Total Resource (10^9 Btu)	Nuclear Busbar (GWh)	Nuclear Resource (10^9 Btu)	Coal Busbar (GWh)	Coal Resource (10^9 Btu)	Oil Busbar (GWh)	Oil Resource (10^9 Btu)	Gas Busbar (GWh)	Gas Resource (10^9 Btu)
97	337.3	3,470	0	0	327.1	3,329	2.6[b]	36	7.6[b]	105[b]
98	281.4	3,000	278.0	2,965	1.8	18	1.6	17	0	0
99	263.8	2,813	260.6	2,780	1.7	17	1.5	16	0	0
100	380.8	4,062	380.8	4,062	0	0	0	0	0	0
101	334.0	3,563	0	0	77.7	791	7.4[b]	101[b]	248.9	2,671
102	411.7	4,392	411.7	4,392	0	0	0	0	0	0
103	299.8	3,051	0	0	299.8	3,051	0	0	0	0
104	212.2	2,326	0	0	66.2	674	146.0[b]	1,652[b]	0	0
105	270.9	2,763	1.1	12	261.8	2,664	8.0	87	0	0
106	198.9	2,122	198.9	2,122	0	0	0	0	0	0
107	361.6	3,680	0	0	361.6	3,680	0	0	0	0
108	263.2	2,694	31.9	340	231.3	2,354	0	0	0	0
109	240.2	2,562	240.2	2,562	0	0	0	0	0	0
110	283.9	2,931	84.9	906	199.0	2,025	0	0	0	0
111	279.3	2,978	275.9	2,943	1.8	18	1.6	17	0	0
112	232.0	2,366	0.9	10	224.2	2,281	6.9	75	0	0
113	308.0	3,163	58.6	625	249.4	2,538	0	0	0	0
114	262.3	2,798	262.3	2,798	0	0	0	0	0	0
115	209.2	2,137	0	0	197.0	2,005	12.2	132	0	0
116	213.0	2,271	210.4	2,244	1.4	14	1.2	13	0	0
117	331.4	3,464	0	0	174.0	1,771	32.4	351	125.0	1,342
118	322.5	3,282	0	0	322.5	3,282	0	0	0	0
119	289.0	2,968	55.0	587	234.0	2,381	0	0	0	0
120	211.1	2,156	0	0	198.7	2,022	12.4	134	0	0
121	285.7	3,043	275.5	2,939	10.2	104	0	0	0	0
122	209.5	2,140	0	0	197.2	2,007	12.3	133	0	0
123	266.6	2,839	257.0	2,741	9.6	98	0	0	0	0
124	247.7	2,521	0	0	247.7	2,521	0	0	0	0
125	322.5	3,301	39.1	417	283.4	2,884	0	0	0	0
126	220.0	2,239	0	0	220.0	2,239	0	0	0	0
127	300.3	3,056	0	0	300.0	3,053	0.3	3	0	0
128	271.0	2,758	0	0	271.0	2,758	0	0	0	0

Table F.16. (Cont'd)

Urbanized Area	Total Busbar (GWh)	Total Resource (10^9 Btu)	Nuclear Busbar (GWh)	Nuclear Resource (10^9 Btu)	Coal Busbar (GWh)	Coal Resource (10^9 Btu)	Oil Busbar (GWh)	Oil Resource (10^9 Btu)	Gas Busbar (GWh)	Gas Resource (10^9 Btu)
129	239.3	2,525	8	85	93.2	948	137.8	1,497	0	0
130	221.6	2,363	218.2	2,328	3.4	35	0	0	0	0
131	207.0	2,106	0	0	207.0	2,106	0	0	0	0
132	224.0	2,279	0	0	224.0	2,279	0	0	0	0
133	248.6	2,688	0	0	53.0	539	0	0	195.6[b]	2,149[b]
134	347.3	3,534	0.5	5	346.8	3,529	0	0	0	0
135	214.7	2,289	211.5	2,256	3.2	33	0	0	0	0
136	192.7	1,966	0.8	9	186.3	1,896	5.6	61	0	0
137	234.3	2,390	0.9	10	226.4	2,304	7.0	76	0	0
138	179.6	1,915	177.3	1,891	1.2	12	1.1	12	0	0
139	153.4	1,561	0	0	153.4	1,561	0	0	0	0
140	247.6	2,623	211.8	2,259	35.8	364	0	0	0	0
141	257.0	2,782	0	0	0	0	257.0	2,782	0	0
142	183.0	1,866	0.7	7	176.8	1,799	5.5	60	0	0
143	237.8	2,420	0	0	237.8	2,420	0	0	0	0
144	181.4	1,846	0	0	181.4	1,846	0	0	0	0
145	730.3	7,790	730.3	7,790	0	0	0	0	0	0
146	478.6	4,871	1.9	20	476.7	4,851	0	0	0	0
147	213.1	2,268	202.9	2,164	10.2	104	0	0	0	0
148	193.7	2,062	184.4	1,967	9.3	95	0	0	0	0
149	189.5	1,928	0	0	189.5	1,928	0	0	0	0
150	191.8	1,982	62.1	662	129.7	1,320	0	0	0	0
151	174.3	1,859	172.1	1,836	1.2	12	1.0	11	0	0
152	240.3	2,563	240.3	2,563	0	0	0	0	0	0
153	198.5	2,020	0	0	198.5	2,020	0	0	0	0
154	247.6	2,632	83.5	891	53.4	543	110.7	1,198	0	0
155	175.0	1,864	168.7	1,800	6.3	64	0	0	0	0
156	203.8	2,147	143.3	1,529	56.7	577	3.8	41	0	0
157	239.2	2,483	98.3	1,049	140.9	1,434	0	0	0	0
158	178.8	1,848	57.9	618	120.9	1,230	0	0	0	0

[a] The key for the UAs can be found in Table A.18.

[b] Represents a mix of steam and gas turbine capacity.

Table F.17. Summary of Fuels Used for Charging EHVs for Selected Urbanized Areas

Year and Scenario	Total Busbar (GWh)	Total Resource (10^9 Btu)	Nuclear Busbar (GWh)	Nuclear Resource (10^9 Btu)	Coal Busbar (GWh)	Coal Resource (10^9 Btu)	Oil Busbar (GWh)	Oil Resource (10^9 Btu)	Gas Busbar (GWh)	Gas Resource (10^9 Btu)
Cincinnati										
1985										
LOW I	3.5	35	0	0	3.5	35	0	0	0	0
LOW II	5.5	56	0	0	5.5	56	0	0	0	0
MEDIUM	5.5	56	0	0	5.5	56	0	0	0	0
HIGH I	11.3	115	0	0	11.3	115	0	0	0	0
HIGH II	11.3	115	0	0	11.3	115	0	0	0	0
1990										
LOW I	12.4	126	0	0	12.4	126	0	0	0	0
LOW II	21.0	214	0	0	21.0	214	0	0	0	0
MEDIUM	27.0	275	0	0	27.0	275	0	0	0	0
HIGH I	71.2	725	0	0	71.2	725	0	0	0	0
HIGH II	71.2	725	0	0	71.2	725	0	0	0	0
2000										
LOW I	191.2	1,959	27.5	293	163.7	1,666	0	0	0	0
LOW II	375.5	3,842	44.4	473	331.1	3,369	0	0	0	0
MEDIUM	588.0	6,015	63.8	681	524.2	5,334	0	0	0	0
HIGH I	1,904.6	19,440	119.6	1,276	1,785.0	18,164	0	0	0	0
HIGH II	1,835.3	18,733	116.7	1,245	1,718.6	17,488	0	0	0	0
San Diego										
1985										
LOW I	3.6	39	1.6	18	0	0	2.0	21	0	0
LOW II	6.1	66	2.8	30	0	0	3.3	36	0	0
MEDIUM	5.7	62	2.6	28	0	0	3.1	34	0	0
HIGH I	11.8	126	5.4	57	0	0	6.4	69	0	0
HIGH II	11.8	126	5.4	57	0	0	6.4	69	0	0
1990										
LOW I	13.1	141	6.0	64	0	0	7.1	77	0	0
LOW II	23.7	255	10.3	110	0	0	13.4	145	0	0
MEDIUM	28.8	310	12.4	132	0	0	16.4	178	0	0
HIGH I	76.0	818	29.2	311	0	0	46.8	507	0	0
HIGH II	77.3	832	29.7	316	0	0	47.6	516	0	0
2000										
LOW I	200.7	2,141	200.7	2,141	0	0	0	0	0	0
LOW II	429.3	4,579	428.7	4,572	0	0	0.6	7	0	0
MEDIUM	617.6	6,588	616.5	6,576	0	0	1.1	12	0	0
HIGH I	1,996.5	21,298	1,985.0	21,174	0	0	11.5	124	0	0
HIGH II	2,049.4	21,862	2,037.6	21,735	0	0	11.8	127	0	0

Table F.17. (Cont'd)

Year and Scenario	Total Busbar (GWh)	Total Resource (10^9 Btu)	Nuclear Busbar (GWh)	Nuclear Resource (10^9 Btu)	Coal Busbar (GWh)	Coal Resource (10^9 Btu)	Oil Busbar (GWh)	Oil Resource (10^9 Btu)	Gas Busbar (GWh)	Gas Resource (10^9 Btu)
Milwaukee										
1985										
LOW I	2.7	29	2.5	27	0.2	2	0	0	0	0
LOW II	4.5	49	4.1	44	0.4	4	0	0	0	0
MEDIUM	4.4	48	4.0	43	0.4	4	0	0	0	0
HIGH I	9.0	95	8.3	88	0.7	7	0	0	0	0
HIGH II	9.0	95	8.3	88	0.7	7	0	0	0	0
1990										
LOW I	9.7	103	8.9	95	0.8	8	0	0	0	0
LOW II	17.0	181	15.6	167	1.4	14	0	0	0	0
MEDIUM	21.3	226	19.6	209	1.7	17	0	0	0	0
HIGH I	57.8	614	53.1	566	4.7	48	0	0	0	0
HIGH II	58.0	616	53.3	568	4.7	48	0	0	0	0
2000										
LOW I	154.9	1,650	152.1	1,622	2.8	28	0	0	0	0
LOW II	312.9	3,334	306.1	3,265	6.8	69	0	0	0	0
MEDIUM	476.3	5,075	465.3	4,963	11.0	112	0	0	0	0
HIGH I	1,525.5	16,236	1,452.0	15,488	73.5	748	0	0	0	0
HIGH II	1,507.8	16,048	1,435.4	15,311	72.4	737	0	0	0	0
Buffalo										
1985										
LOW I	2.6	28	0	0	0	0	2.6	28	0	0
LOW II	3.9	43	0	0	0	0	3.9	43	0	0
MEDIUM	4.1	44	0	0	0	0	4.1	44	0	0
HIGH I	8.3	91	0	0	0	0	8.3	91	0	0
HIGH II	8.3	91	0	0	0	0	8.3	91	0	0
1990										
LOW I	9.1	99	0	0	0	0	9.1	99	0	0
LOW II	15.2	165	0	0	0	0	15.2	165	0	0
MEDIUM	19.9	215	0	0	0	0	19.9	215	0	0
HIGH I	52.7	571	0	0	0	0	52.7	571	0	0
HIGH II	52.2	566	0	0	0	0	52.2	566	0	0
2000										
LOW I	142.7	1,558	0	0	8.4	85	134.3	1,473	0	0
LOW II	272.9	2,991	0	0	25.7	261	247.2	2,730	0	0
MEDIUM	439.4	4,825	0	0	47.8	486	391.6	4,339	0	0
HIGH I	1,424.3	15,603	0	0	445.0	4,528	979.3	11,075	0	0
HIGH II	1,345.2	14,737	0	0	413.1	4,203	932.1	10,534	0	0

Table F.17. (Cont'd)

Year and Scenario	Total Busbar (GWh)	Total Resource (10^9 Btu)	Nuclear Busbar (GWh)	Nuclear Resource (10^9 Btu)	Coal Busbar (GWh)	Coal Resource (10^9 Btu)	Oil Busbar (GWh)	Oil Resource (10^9 Btu)	Gas Busbar (GWh)	Gas Resource (10^9 Btu)
Dallas										
1985										
LOW I	3.1	31	0	0	3.1	31	0	0	0	0
LOW II	5.2	53	0	0	5.2	53	0	0	0	0
MEDIUM	4.9	50	0	0	4.9	50	0	0	0	0
HIGH I	10.1	103	0	0	10.1	103	0	0	0	0
HIGH II	10.1	103	0	0	10.1	103	0	0	0	0
1990										
LOW I	10.8	110	0	0	10.8	110	0	0	0	0
LOW II	20.0	207	0	0	20.0	207	0	0	0	0
MEDIUM	23.5	244	0	0	23.5	244	0	0	0	0
HIGH I	62.6	637	0.2	2	62.4	635	0	0	0	0
HIGH II	63.9	650	0.2	2	63.7	648	0	0	0	0
2000										
LOW I	172.5	1,786	62.9	671	109.6	1,115	0	0	0	0
LOW II	369.0	3,819	131.1	1,398	237.9	2,421	0	0	0	0
MEDIUM	523.7	5,420	184.8	1,971	338.9	3,449	0	0	0	0
HIGH I	1,678.1	17,344	543.5	5,798	1,134.6	11,546	0	0	0	0
HIGH II	1,745.4	18,039	565.3	6,030	1,180.1	12,009	0	0	0	0
Orlando										
1985										
LOW I	1.8	19	0	0	0	0	1.8	19	0	0
LOW II	2.8	30	0	0	0	0	2.8	30	0	0
MEDIUM	2.9	31	0	0	0	0	2.9	31	0	0
HIGH I	5.9	63	0	0	0	0	5.9	63	0	0
HIGH II	5.9	63	0	0	0	0	5.9	63	0	0
1990										
LOW I	6.5	70	0	0	0	0	6.5	70	0	0
LOW II	10.8	117	0	0	0	0	10.8	117	0	0
MEDIUM	14.2	154	0	0	0	0	14.2	154	0	0
HIGH I	36.5	395	0	0	0	0	36.5	395	0	0
HIGH II	36.2	391	0	0	0	0	36.2	391	0	0
2000										
LOW I	98.7	1,224	16.6	177	16.7	170	65.4	877	0	0
LOW II	188.0	2,233	49.0	522	49.1	499	89.9	1,212	0	0
MEDIUM	302.9	3,533	90.6	966	90.7	923	121.5	1,644	0	0
HIGH I	987.2	10,733	422.0	4,501	422.0	4,294	143.2	1,938	0	0
HIGH II	930.4	10,137	394.5	4,208	394.5	4,015	141.4	1,914	0	0

Table F.17. (Cont'd)

Year and Scenario	Total Busbar (GWh)	Total Resource (10^9 Btu)	Nuclear Busbar (GWh)	Nuclear Resource (10^9 Btu)	Coal Busbar (GWh)	Coal Resource (10^9 Btu)	Oil Busbar (GWh)	Oil Resource (10^9 Btu)	Gas Busbar (GWh)	Gas Resource (10^9 Btu)
Grand Rapids										
1985										
LOW I	1.1	11	0.1	1	1.0	10	0	0	0	0
LOW II	1.7	18	0.2	2	1.5	16	0	0	0	0
MEDIUM	1.8	18	0.2	2	1.6	16	0	0	0	0
HIGH I	3.7	38	0.4	4	3.3	34	0	0	0	0
HIGH II	3.7	38	0.4	4	3.3	34	0	0	0	0
1990										
LOW I	4.6	47	0.5	5	4.1	42	0	0	0	0
LOW II	7.2	74	0.7	8	6.5	66	0	0	0	0
MEDIUM	10.3	106	1.0	11	9.3	95	0	0	0	0
HIGH I	24.9	255	2.3	25	22.6	230	0	0	0	0
HIGH II	24.5	251	2.3	25	22.2	226	0	0	0	0
2000										
LOW I	61.6	658	61.5	657	0.1	1	0	0	0	0
LOW II	118.2	1,261	117.7	1,256	0.5	5	0	0	0	0
MEDIUM	190.4	2,030	189.4	2,020	1.0	10	0	0	0	0
HIGH I	622.9	6,640	613.4	6,543	9.5	97	0	0	0	0
HIGH II	586.3	6,250	577.5	6,160	8.8	90	0	0	0	0
Albuquerque										
1985										
LOW I	1.5	15	0	0	1.5	15	0	0	0	0
LOW II	2.3	23	0	0	2.3	23	0	0	0	0
MEDIUM	2.3	24	0	0	2.3	24	0	0	0	0
HIGH I	4.6	47	0	0	4.6	47	0	0	0	0
HIGH II	4.6	47	0	0	4.6	47	0	0	0	0
1990										
LOW I	5.1	52	0	0	5.1	52	0	0	0	0
LOW II	8.7	89	0	0	8.7	89	0	0	0	0
MEDIUM	10.6	108	0	0	10.6	108	0	0	0	0
HIGH I	27.7	282	0	0	27.7	282	0	0	0	0
HIGH II	27.7	282	0	0	27.7	282	0	0	0	0
2000										
LOW I	75.6	769	0	0	75.6	769	0	0	0	0
LOW II	147.6	1,502	0	0	147.6	1,502	0	0	0	0
MEDIUM	236.2	2,404	0	0	236.2	2,404	0	0	0	0
HIGH I	785.9	7,997	0	0	785.9	7,997	0	0	0	0
HIGH II	739.0	7,520	0	0	739.0	7,520	0	0	0	0

Table F.17. (Cont'd)

Year and Scenario	Total Busbar (GWh)	Total Resource (10^9 Btu)	Nuclear Busbar (GWh)	Nuclear Resource (10^9 Btu)	Coal Busbar (GWh)	Coal Resource (10^9 Btu)	Oil Busbar (GWh)	Oil Resource (10^9 Btu)	Gas Busbar (GWh)	Gas Resource (10^9 Btu)
Little Rock										
1985										
LOW I	0.8	8	0.5	5	0.3	3	0	0	0	0
LOW II	1.3	13	0.8	8	0.5	5	0	0	0	0
MEDIUM	1.2	13	0.7	8	0.5	5	0	0	0	0
HIGH I	2.6	27	1.5	16	1.1	11	0	0	0	0
HIGH II	2.6	27	1.5	16	1.1	11	0	0	0	0
1990										
LOW I	2.9	30	1.7	18	1.2	12	0	0	0	0
LOW II	4.8	51	2.8	30	2.0	21	0	0	0	0
MEDIUM	5.8	61	3.4	36	2.4	25	0	0	0	0
HIGH I	15.3	160	9.0	96	6.3	64	0	0	0	0
HIGH II	15.3	162	9.1	97	6.4	65	0	0	0	0
2000										
LOW I	41.3	439	38.5	411	2.8	28	0	0	0	0
LOW II	86.2	916	79.8	851	6.4	65	0	0	0	0
MEDIUM	125.9	1,339	116.3	1,241	9.6	98	0	0	0	0
HIGH I	410.7	4,362	371.6	3,964	39.1	398	0	0	0	0
HIGH II	415.1	4,409	375.6	4,007	39.5	402	0	0	0	0
Chattanooga										
1985										
LOW I	0.6	6	0	0	0.6	6	0	0	0	0
LOW II	0.9	9	0	0	0.9	9	0	0	0	0
MEDIUM	0.9	9	0	0	0.9	9	0	0	0	0
HIGH I	1.9	19	0	0	1.9	19	0	0	0	0
HIGH II	1.9	19	0	0	1.9	19	0	0	0	0
1990										
LOW I	2.1	21	0	0	2.1	21	0	0	0	0
LOW II	3.7	38	0	0	3.7	38	0	0	0	0
MEDIUM	4.6	47	0	0	4.6	47	0	0	0	0
HIGH I	11.8	119	0.1	1	11.6	118	0	0	0	0
HIGH II	11.7	120	0.1	1	11.7	119	0	0	0	0
2000										
LOW I	32.0	328	6.5	69	25.5	259	0	0	0	0
LOW II	66.9	687	11.9	127	55.0	560	0	0	0	0
MEDIUM	98.0	1,005	16.7	178	81.3	827	0	0	0	0
HIGH I	318.8	3,263	38.7	413	280.1	2,850	0	0	0	0
HIGH II	322.2	3,297	39.1	417	283.1	2,880	0	0	0	0

APPENDIX F REFERENCES

F.1 *1977-1978 Electric World Directory of Electric Utilities*, 86th ed., McGraw-Hill, New York (1978).

F.2 Collins, M., and W. Carriere, *Projected Supply of Electricity for Electric Cars*, General Research Corporation Internal Memorandum for Energy Research and Development Adm. (July 1979).

F.3 *Monthly Energy Review*, U.S. Dept. of Energy, Energy Information Adm. (1979).

APPENDIX G

ECONOMIC ANALYSIS

G.1 COST OF TRAVEL

G.1.1 Method

Cost methodologies assuming mass production are developed for initial vehicle costs (vehicle body/chassis plus battery) and life cycle costs. An EHV of each battery type (e.g., Ni/Zn) and vehicle type (e.g., light truck) is analyzed. Thus, only 34 of the 54 EHVs characterized in App. B are analyzed. A corresponding CV is analyzed for each EHV analyzed.

G.1.1.1 Initial Vehicle Costs

Value-Added Cost Methodology for Initial Costs of EHVs

The value-added methodology is based on the concept that battery and vehicle manufacturers add a determinable value to the basic cost of resource inputs. Costs are computed for the vehicle body/chassis and the battery pack separately and then summed to get initial vehicle cost.

Equations G.1-G.5 are used to calculate vehicle body/chassis costs:

$$CM_i = \sum_{k=1}^{3} (MW_{ik})(P_k)(1.95) \qquad (G.1)$$

where:

CM_i = cost of steel, iron, and silicon in body/chassis of vehicle i,

MW_{ik} = specified material weight for material k for vehicle i,

P_k = price per unit weight of material k (see Table G.1 for price assumptions),

1.95 = value added by vehicle manufacturer for steel, iron, and silicon, and

k = steel, iron, or silicon.

$$F_i = \frac{CW_i - \sum_{k=1}^{n} MW_{ik} - APW_i}{CW_i - APW_i} \qquad (G.2)$$

Table G.1. Price Assumptions Used to Calculate Initial EHV Costs

Material	1979$/lb
Iron and steel	0.50
Copper	0.875
Silicon	0.355
Rubber	0.6825
Aluminum	0.66
Plastic	2.03
Nickel	3.40
Cobalt	25.00
Zinc	0.375
Lithium metal	16.00
Lithium hydroxide	1.40
Lead	0.58

where:

F_i = fraction of nonbattery weight that is not steel, iron, silicon, aluminum, or plastic in vehicle i,

CW_i = curb weight of vehicle i without battery, auxiliary equipment, and payload, and

APW_i = nonbattery-related weight of aluminum or plastic j for vehicle i.

$$CEAP_i = (1 + F_i)(CM_i) \qquad (G.3)$$

where:

$CEAP_i$ = cost of nonbattery materials in vehicle i, excluding aluminum and plastic costs.

$$CAP_i = (APW_{ij})(P_j)(3.4) \qquad (G.4)$$

where:

CAP_i = nonbattery-related cost of aluminum or plastic j per vehicle i, and

P_j = price per unit weight of aluminum or plastic j (see Table G.1).

The 3.4 term is a value parameter obtained from various industry sources that indicates that aluminum and plastics require more machines and tooling than other materials. Therefore, the value added is 240%.

$$TVC_i = CEAP_i + CAP_i \tag{G.5}$$

where:

TVC_i = total nonbattery-related vehicle cost per vehicle i.

Equations G.6-G.8 are used to determine battery pack costs:

$$CMBM_i = \sum_{j=1}^{n} (BW_{ij})(P_j) \tag{G.6}$$

where:

$CMBM_i$ = cost of major battery materials for battery in vehicle i,

BW_{ij} = weight of characterized major material j in battery of vehicle i,

P_j = price per unit weight of major material j in battery of vehicle i (see Table G.1), and

n = number of major materials.

$$BF_i = \frac{TBW_i - \sum_{j=1}^{n} BW_{ij}}{TBW_i} \tag{G.7}$$

where:

BF_i = fraction battery weight due to other uncharacterized materials for battery in vehicle i, and

TBW_i = total battery weight for battery in vehicle i.

$$TBC_i = (CMBB_i)(1 + BF_i)(2.34) \tag{G.8}$$

where:

TBC_i = total cost of battery in vehicle i.

The value-added factor (2.34) is derived by multiplying the battery industry value-added figure (1.95) and a 20% mark-up by the vehicle manufacturer. This is necessary if it is assumed that the vehicle manufacturer purchases a complete battery from the battery industry. Value-added mark-ups are derived from discussions with various vehicle and battery industry experts.

Other materials cost is assumed to be an average of all materials costs in the battery. However, Ni/Zn and Ni/Fe electrolyte costs would tend to be less than average material cost. Also, it may be true that the uncharacterized material costs may understate the true Li/S battery costs.

As stated earlier:

$$EHVC_i = TVC_i + TBC_i \quad (G.9)$$

where:

$EHVC_i$ = total electric vehicle cost for vehicle i.

Fixed Mark-Up Cost Methodology for Initial Costs of EHVs

The value-added methodology may overstate the Ni/Zn and Ni/Fe battery production mark-up. The higher material costs of these batteries could allow the manufacturers to lower their mark-up, since there would be a much larger materials cost base. An alternative methodology is used to capture this effect. The Pb/acid battery industry is used as a base to determine fixed mark-up. A simple fixed mark-up is determined by subtracting the materials cost per Pb/acid battery from the total value-added Pb/acid battery cost. This difference is then added to the basic materials costs of the Ni/Fe and Ni/Zn battery for each vehicle type to get the total fixed mark-up battery cost. The nonbattery vehicle cost methodology used is the same as that used in the value-added approach. Battery and nonbattery costs are summed to obtain initial EHV costs. Li/S vehicle costs are not computed using this method, because the materials costs are relatively low for these batteries. Also, the manufacturing process for Li/S batteries is not well defined at this time.

Equivalent CV Methodology for Initial Vehicle Costs

The value-added methodology is used to determine initial CV costs based on the vehicle characterizations in App. B.

G.1.1.2 Life Cycle Costs

Many different life cycle cost methodologies have been developed.[G.1-G.3] For this analysis, the Ref. G.1 methodology is used with some minor modifications for both the EVHs and CVs. All of the constants in the following equations are based on the data analysis of Ref. G.1; many are regression constants and coefficients. The value-added approach for initial costs is used for all vehicle types. This is done to provide life cycle costs for all vehicles, since Li/S fixed mark-up initial cost values could not be computed. Life cycle costs are first generated in constant 1977$, because the values of the regression parameters were derived from Ref. G.1 in 1977$. An implicit price deflator is then applied to derive 1979 life cycle costs. The formulas apply to both EHVs and CVs unless stated otherwise.

Insurance Costs

Since insurance costs vary with weight, they are computed for three vehicle classes: (1) four-passenger cars and light trucks (class 1), (2) five-passenger cars (class 2), and (3) all other trucks and buses (class 3).

$$INS_{ij} = a_j + b_j(Y_i) \tag{G.10}$$

where:

INS_{ij} = insurance costs for vehicle i in class j,
Y_i = vehicle life per vehicle i (yr),
a_j, b_j = parameters, and
j = class.

The a_j and b_j parameters have values of 223 and 138 for class 1, 258 and 143 for class 2, and 294 and 148 for class 3. They apply to both EHVs and CVs.

Garage, Parking, Tolls, Etc.

$$GPTE_i = (223)(Y_i) \tag{G.11}$$

where:

$GPTE_i$ = total cost of garaging, parking, tolls, etc., for vehicle i.

Title, Registration, License, Etc.

$$TRLE_i = (8.364 + 0.0105W_i)(Y_i) + (0.053)(RP_i) \tag{G.12}$$

where:

$TRLE_i$ = title, registration, license, etc., for vehicle i,
RP_i = retail price for vehicle i, and
W_i = weight of vehicle (kg).

Road Taxes

Road taxes are included in the retail cost of gasoline, oil, and diesel fuel. For CVs, these taxes are included in the cost of the fuel and oil. An equivalent tax, related to the vehicle weight, is assessed against EVs in the Ref. G.1 model. Road taxes for HVs are computed as though they are EVs.

$$RDTX_i = (0.00143 + 0.0000019W_i)(KM_i) \tag{G.13}$$

where:

$RDTX_i$ = road tax per EHV i, and
KM_i = total lifetime distance driven for vehicle i (km).

Tires

$$RTIR_i = (4)(26.46 + 0.0207W_i)\left(\frac{KM_i}{63{,}000} - 1\right) \qquad (G.14)$$

where:

$RTIR_i$ = cost of replacement tires for vehicle i (constant 1977$).

Repairs and Maintenance

Repairs and maintenance costs depend on distance driven and type of vehicle.

$$RP_i = (KM_i)(a_j) \qquad (G.15)$$

where:

RP_i = repairs and maintenance costs for vehicle i.

The a_j parameter value is 0.0067 for class 1 (light trucks and four-passenger EVs); 0.0074 for class 2 (five-passenger cars); and 0.0092 for class 3 (trucks and buses). Corresponding CV class parameters are 0.0175, 0.0195, and 0.0241.

Equation G.16 is used to determine repairs and maintenance costs for HVs:

$$RP_i = \left[(KM_i)(EVP_i)(a_j)\right] + \left[(KM_i)(HVP_i)(b_j)\right] \qquad (G.16)$$

where:

EVP_i = time HV_i is driven on electric power (%), and

HVP_i = time HV_i is driven on heat engine (%).

The values of a_j and b_j are 0.0067 and 0.0175 for class 1 HVs (four-passenger cars); 0.0074 and 0.0195 for class 2 HVs (five-passenger cars); and 0.0092 and 0.0241 for class 3 HVs (all trucks and buses).

CV and HV Fuel Costs

$$CF_i = (GPK_i)(KM_i)(Fuel)(1.07) \qquad (G.17)$$

where:

CF_i = lifetime fuel cost for CV_i or HV_i,

GPK_i = gallons of fuel used by vehicle i (per km), and

Fuel = fuel costs per gallon (constant 1977$) (assumed to be $1.10). These are factored by 1.07 to include costs for oil.

Electricity Costs

$$ELE_i = (KPK_i)(KM_i)(0.035) \qquad (G.18)$$

where:

ELE_i = electricity cost per vehicle lifetime, and

KPK_i = kilowatt hours per mile for vehicle i.

The total marginal cost of electricity of \$0.035/kWh is derived from the analysis presented in App. F.

Vehicle Capital Costs

Vehicle capital costs are the financing costs associated with vehicle purchase. A 10% cost of capital is assumed. The following equation from Ref. G.1 is used:

$$VCC_i = Y_i \left[\frac{(CP_i)(0.1)(1.1)^{Y_i}}{(1.1)^{Y_i} - 1.0} \right] - 1.1(CP_i) \qquad (G.19)$$

where:

VCC_i = vehicle i capital cost,

Y_i = lifetime of vehicle i (yr), and

CP_i = initial price of vehicle less battery (constant 1977\$).

Replacement Battery Costs

The costs of the replacement batteries are determined in the same manner as the costs for the initial batteries (see Sec. G.1.1.1).

Battery Capital Costs

Battery capital costs are the financing costs associated with battery purchase and replacement. A 10% cost of capital is assumed. The following equation from Ref. G.1 is used:

$$BC_i = L_j N \left[\frac{(C_i)(0.1(1.1)^{L_j}}{(1.1)^{L_i} - 1.0} \right] - S_i - C_i \qquad (G.20)$$

where:

BC_i = battery capital cost for vehicle i,

L_j = lifespan of battery type j,

C_i = cost of battery per vehicle i,

S_i = salvage value per battery per vehicle i, and

N = number of battery changes in lifetime of vehicle.

G.1.2 Other Cost-of-Travel Studies

Table G.2 summarizes the results of other studies that are used for comparative purposes in the cost-of-travel analysis.[G.4-G.9] These studies in large part confirm the result of this analysis, i.e., that the Pb/acid EHV generally has the lowest initial cost among EHVs. The results of this analysis show that Li/S EHVs rank second in relative initial costs. Of the two other studies that evaluated Li/S EHVs, one found them less expensive than all other EHVs and the second found them more expensive. All the other studies rated the nickel-based EHVs relatively high in initial cost as does this analysis.

G.2 EMPLOYMENT

G.2.1 Method

The employment results summarized in Sec. 3.10.2 are obtained using a four-step method illustrated in Fig. G.1. The method provides information on likely changes in employment and skills requirements at several levels of aggregation. It also provides information on industrial capital impacts and changes in local government expenditures.

In step 1 the direct materials requirements for EHVs without battery or motor/controller recycling are calculated. The methodology for determining battery materials is explained in Secs. B.3.2 and C.1.1. The output includes total materials requirements for each scenario and a ratio of EHV scenario requirements to BASE scenario requirements for each material. The ratios (input-output [I/O] model coefficient changes) are then used as inputs to step 2.

The second step consists of two parts: an econometrically driven 186-sector I/O model (INFORUM[G.10]) and Eq. G.21. INFORUM projects total national employment. Using the step 1 I/O technical coefficient changes for projected years and the changes in fuels requirements derived from the energy intensities of the vehicles (see Table B.10), INFORUM produces the direct and indirect employment impacts for each scenario. The direct impacts are defined as employment changes that result from actual materials requirements of EHVs. Indirect impacts are defined as additional changes required by the manufacture and distribution of EHVs. An example of indirect employment impact is the increased employment in the tool and die industry due to die requirements of EHVs.

Using Eq. G.21, Bureau of Labor Statistics (BLS) 1985 skills projection data are used to obtain skills category changes for EHVs.[G.11] Thus:

Table G.2. Ranking of Initial EHV Costs by Battery Types[a]

Rank (least cost first)	Study						
	Lawrence Livermore Laboratory[b]			Internal Memorandum to ANL from Joseph Consiglio, Consultant[c]	General Research Corporation (unpublished data)[d]	Battery Company Studies Submitted to ANL[e]	ANL Method
	1980-1982	1985-1990	1990-2000	1980-2000	1980-2000	1980-2000	1985-2000
1	Pb/acid EV	Li/S EV	Li/S EV	Pb/acid EV	Pb/acid EV	Pb/acid EV	Pb/acid EV
2	Ni/Zn EV	Pb/acid EV	Pb/acid EV	Ni/Zn HV	Pb/acid HV	Ni/Fe EV	Li/S EV
3	Ni/Fe EV	Ni/Zn EV	Ni/Zn EV	Ni/Fe EV	Ni/Zn EV	Ni/Zn EV	Ni/Fe EV[f] Ni/Zn EV[f]
4		Ni/Fe EV	Ni/Fe EV		Ni/Zn HV		Pb/acid HV[f]
5					Li/S EV		Ni/Zn HV

[a] All of the studies reported here considered only cars; ANL also included trucks and buses.

[b] Ref. G.4

[c] Ref. G.5

[d] Ref. G.6

[e] Ref. G.7-G.9

[f] This includes trucks and buses only. For passenger cars, the Ni/Zn vehicle has the highest cost.

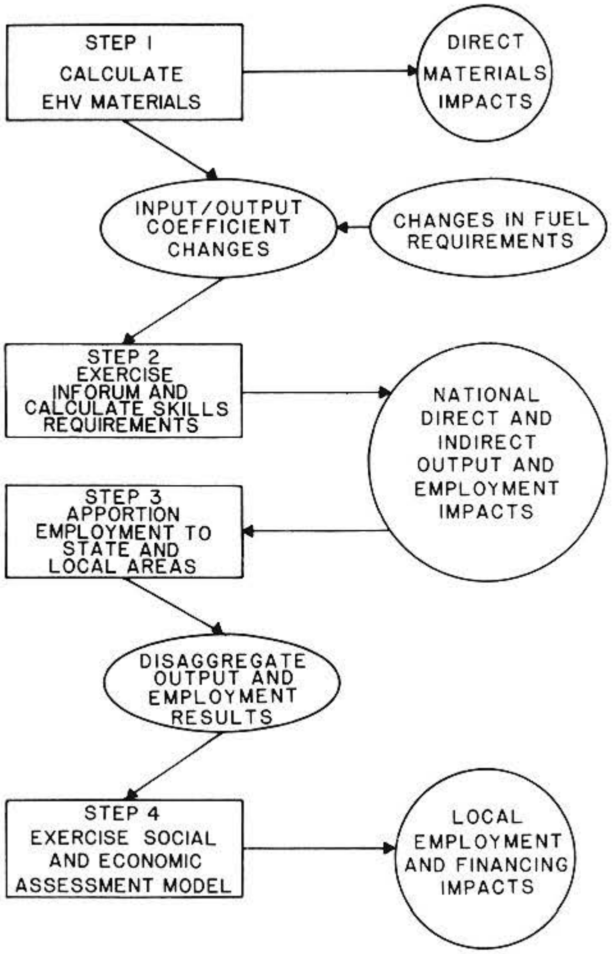

Fig. G.1. Flow Diagram of Economic Assessment Method

$$SE_{ijt} = (P_i)(E_{ijt}) \tag{G.21}$$

where:

SE_{ijt} = skills employment per industry i, for scenario j, in year t,

P_i = BLS percentage of workers in skill category in industry i for 1985, and

E_{ijt} = national employment projection in industry i, for scenario j, in year t.

Since BLS projections do not go beyond 1985, it is assumed that trends will not change from 1985 to 2000.

The national direct and indirect employment projections are apportioned in step 3 to various state and local levels by assuming that present state and local employment distributions keep their same relationships to the national totals. For this assessment, the sample case studied is the lead industry in Iron County, Missouri. Iron County was chosen because most U.S. lead mining occurs there and likely EHV impacts would be magnified. INFORUM lead processing sector output is used as a proxy for lead mining, since INFORUM has no lead mining sector. Step 3 results are then multiplied by the BLS mining sector skills projections to obtain the required skills changes for Iron County.

The basic relationship in step 3 is:

$$EIC_{jt} = \left[\frac{LO_{jo}}{LO_{jt}}\right] (BE_o) \tag{G.22}$$

where:

EIC_{jt} = Iron County direct lead sector employment for scenario j in year t,

LO_{jo} = lead sector output for scenario j in 1978,

LO_{jt} = lead sector output for scenario j in year t, and

BE_o = employment in lead mining in Iron County in 1978.

Direct Iron County employment projections are used in step 4 as the input to the social and economic assessment model (SEAM).[G.12] SEAM estimates the employment and public cost requirements for the county, including total employment, basic work force (direct labor, e.g., lead miners), available male and female community work force, population impacts of job-induced migration, and county operating expenses for services (e.g., social welfare and education).

G.2.2 Analysis

EHV commercialization should not significantly change national employment. Only five out of 90 industrial sectors examined for direct and indirect impacts have employment changes of greater than 10,000. EHV distribution and manufacturing are assumed to be absorbed by the present CV network, which explains why motor vehicle employment does not change significantly. Employment impacts of EHVs on the service station and auto repair industries are not analyzed, because EHV maintenance requirement studies are not available. It is interesting to note that EHV motor and controller requirements do not require significant employment increases in the engine electrical equipment industry. Table G.3 presents the national employment changes for selected industries by scenario.

Operatives (semiskilled) and craft categories are the skills areas most significantly impacted, since electric utilities and the mining, nonferrous producing, and battery industries rely heavily on these skills. Table G.4 shows some of the expected shifts. For example, significant increases in electric utility generation require many transmission lines to be built and reconditioned, which results in a greater need for construction craft workers. Sales, managerial, and clerical personnel are not significantly impacted.

Table G.3. National Employment for Selected Industries, 1977 to 2000 (10^3)

		Employment			
Sector	Scenario	1977	1985	1990	2000
Mining	BASE	347	367	351	345
	LOW I	347	367	350	348
	LOW II	347	367	349	351
	MEDIUM	347	367	350	349
	HIGH I	347	367	350	357
	HIGH II	347	367	349	357
Nonferrous smelting	BASE	332	412	428	414
	LOW I	332	411	427	416
	LOW II	332	412	427	424
	MEDIUM	332	412	428	417
	HIGH I	332	412	428	427
	HIGH II	332	412	427	431
Petroleum refining	BASE	206	219	208	198
	LOW I	206	219	207	197
	LOW II	206	219	208	197
	MEDIUM	206	219	208	196
	HIGH I	206	219	208	190
	HIGH II	206	219	207	192
Crude oil production	BASE	259	192	144	99
	LOW I	259	192	144	98
	LOW II	259	192	144	97
	MEDIUM	259	192	144	96
	HIGH I	259	192	144	87
	HIGH II	259	192	144	89
Electric utilities	BASE	454	483	520	553
	LOW I	454	483	509	555
	LOW II	455	483	509	558
	MEDIUM	454	483	517	559
	HIGH I	454	483	518	581
	HIGH II	455	483	510	574
Iron and steel	BASE	879	930	911	842
	LOW I	879	923	911	845
	LOW II	879	930	909	848
	MEDIUM	879	930	911	843
	HIGH I	879	929	909	849
	HIGH II	879	929	908	851

Table G.3. (Cont'd)

Sector	Scenario	Employment 1977	1985	1990	2000
Engine electrical equipment	BASE	212	298	316	300
	LOW I	212	298	315	300
	LOW II	212	298	315	301
	MEDIUM	212	298	316	300
	HIGH I	212	298	316	303
	HIGH II	212	298	315	302
Motor vehicle	BASE	876	1129	1139	1149
	LOW I	876	1129	1139	1150
	LOW II	876	1129	1139	1150
	MEDIUM	876	1129	1139	1150
	HIGH I	876	1129	1139	1150
	HIGH II	876	1129	1139	1150
Batteries	BASE	112	136	144	147
	LOW I	112	136	146	150
	LOW II	112	136	144	151
	MEDIUM	112	136	144	158
	HIGH I	112	136	145	186
	HIGH II	112	136	145	164
Plastics	BASE	511	591	612	651
	LOW I	511	591	612	651
	LOW II	511	591	612	652
	MEDIUM	511	591	612	652
	HIGH I	511	591	612	655
	HIGH II	511	591	612	656
Rubber	BASE	218	260	241	231
	LOW I	218	260	241	231
	LOW II	218	260	241	231
	MEDIUM	218	260	241	232
	HIGH I	218	260	241	233
	HIGH II	218	260	214	232

The Iron County, Missouri, case study adds an important perspective. It is clear that important county-level impacts can result from EHV commercialization. In 2000, under all scenarios, Iron County basic employment is projected to increase 97-387% and population to increase 76-400%.

G.3 MATERIALS FACTOR PRICE

Lead, zinc, nickel, copper, and cobalt are analyzed for four pricing scenarios: best case, strong/weak case, half case, and worst case. Table G.5 shows materials price projections for all four.

Table G.4. Skills Employment Changes from BASE to HIGH I and HIGH II Scenarios for the Five Most Significantly Affected Industries, 2000

Skill	Mining	Nonferrous Processing	Crude Oil Production	Electric Utilities	Batteries	Total
HIGH I						
Professional (engineers)	1,669	1,037	-2,540	3,534	378	4,078
Managerial	929	606	-1,225	1,714	9,036	11,060
Sales	28	112	-25	330	8,280	8,725
Clerical	1,170	1,491	-1,580	5,634	6,150	12,865
Crafts	2,850	2,591	-2,016	13,014	6,154	22,593
Operatives	4,771	6,124	-4,302	1,725	7,773	16,091
Services	125	255	-122	638	207	1,103
Laborers	457	784	-190	1,411	1,022	3,484
HIGH II						
Professional (engineers)	1,669	1,357	-2,117	2,650	165	3,724
Managerial	929	792	-1,021	1,285	3,939	5,924
Sales	28	146	-21	248	3,609	4,010
Clerical	1,170	1,950	-1,317	4,225	2,681	8,709
Crafts	2,850	3,388	-1,680	9,761	2,683	17,002
Operatives	4,771	8,009	-3,585	1,294	3,388	13,877
Services	125	333	-102	479	90	925
Laborers	457	1,025	-158	1,058	445	2,827

The best-case scenario assumes that no producer, country, or company is able to establish materials price control. It also assumes current prices remain constant to 2000. The worst-case scenario assumes OPEC-type materials price manipulations from 1979 to 2000 for nickel, copper, and cobalt, but no price manipulation in lead or zinc. This scenario recognizes that: (1) there are no domestic cobalt reserves, (2) 75% of U.S. cobalt supplies originate in Zaire, (3) 50% of U.S. nickel supplies are imported, and (4) a copper cartel (CIPEC) already exists. It also takes into account serious 1979 cobalt producer price manipulations and explicitly assumes that the ocean mining discussed in Sec. 3.2 does not occur before 2000. Worst-case cobalt, copper, and nickel prices are calculated by compounding the 1979 material price at 5.85% annually. This percentage is the average annual OPEC price change in constant U.S. dollars for Saudi Arabian light crude from 1974 to 1979.

Table G.5. Materials Price Projections, 1979 to 2000 (constant 1979$/lb)[a]

Materials Scenario and Year	Lead	Zinc	Nickel	Copper	Cobalt
1979 prices	0.50[b]	0.36[b]	3.80	0.96[b]	25.00
Best case					
1985	0.51	0.39	3.40	1.38	25.00
1990	0.51	0.39	3.40	1.38	25.00
2000	0.51	0.39	3.40	1.38	25.00
Strong/weak case					
1985	0.51	0.39	4.78	1.94	40.97
1990	0.51	0.39	6.35	2.58	82.50
2000	0.51	0.39	3.40	1.38	25.00
Half case					
1985	0.51	0.39	4.09	1.66	32.99
1990	0.51	0.39	4.88	1.98	53.75
2000	0.51	0.39	7.31	2.97	82.92
Worst case					
1985	0.51	0.39	4.78	1.94	40.97
1990	0.51	0.39	6.35	2.58	82.50
2000	0.51	0.39	11.22	4.55	140.83

[a] All price projections are producer prices unless otherwise noted.

[b] Spot Prices.

The half-case scenario assumes no price manipulations in zinc and lead, and that cobalt, copper, and nickel prices are midway between best- and worst-case prices. The strong/weak case accounts for ocean mining production starting in 1990. This case also assumes OPEC-type price manipulation (prices increasing at 5.85% annually to 1990) for copper, cobalt, and nickel. Then ocean mining restores competition, and best-case prices apply from 1990 to 2000. Best-case lead and zinc prices are assumed for 1979-2000.

G.4 BALANCE OF TRADE

Equation G.23 is used to determine balance of trade impacts:

$$BT_{iAzj} = (OS_{iA})(PO_{Az}) - \sum_{p-1}^{5} (MR_{iAp})(PA)(PM_{jAp}) \qquad (G.23)$$

where:

BT_{iAzj} = impact on balance of trade for EHV scenario i in assessment year A (1985, 1990, and 2000), for EIA oil scenario z, and materials scenario j (constant 1979$),

OS_{iA} = barrels of oil saved by EHVs for EHV scenario i in assessment year A (see Sec. C.2),

PO_{Az} = price of a barrel of oil in assessment year A for EIA oil scenario z (see Table 3.40),

MR_{iAp} = materials required for EHV scenario i, in assessment year A, for material p (see Tables C.2-C.10),

PA = material import percentage in assessment year A, for material p (see Table 3.1), and

PM_{jAp} = materials price for material scenario j (see Table G.5), in assessment year A, for material p.

Tables G.6-G.10 show net EHV impacts on balance of trade assuming no recycling. EHV impacts with recycling are included in Sec. 3.10.4, but no recycling of materials is assumed for 1985. For 1990 and 2000, both no recycling and recycling at 95% for major battery materials and at 90% for motor/controller/charger major materials are given. The results are mixed. Tables G.11-G.13 were generated to assist in evaluating the impacts by focusing on the nickel and cobalt import problem.

Table G.11 for the MEDIUM scenario presents several combinations of nickel, cobalt, and oil price scenario balance of trade impacts. The extremes present in the year 2000 range from a balance of trade savings of 4.6 billion constant 1979$ to a deficit of 10.6 billion constant 1979$. It is obvious that nickel and cobalt price manipulation can have a serious negative impact on balance of trade. Table G.12 presents similar results for the HIGH market scenarios. Table G.13 presents the worst-case and half-case price scenarios for cobalt and nickel balance of trade impacts using the EIA oil scenario B (see Table 3.40) and each EHV market scenario.

G.5 PRIVATE AND PUBLIC SECTOR CAPITAL COSTS

The public cost estimates for Iron County, Missouri, are derived from the public costs projection model (IPCO) component of SEAM (see Sec. G.2.1).[G.12] IPCO evaluates the impacts of new technologies in different counties and regions on a standardized basis, i.e., the dollar costs of accommodating induced growth. IPCO estimates the annual costs of constructing and operating the following public facilities and services necessary to accommodate growth: hospitals, social welfare, police, fire, sewers, water, solid waste, recreation, libraries, general government, and education. The list of evaluated services is, of course, not exhaustive of all publicly provided facilities and services. For example, county roads and local streets are not included in the list and, therefore, are not reflected in the estimates of increased public costs.

Table G.6. EHV Impacts on Balance of Trade,
LOW I (10^6 constant 1979\$)[a]

EIA Oil Scenario[b]	Materials Price Scenario			
	Best	Strong/weak	Half	Worst
1985				
A	20.21	19.65	19.93	19.65
B	25.68	25.12	25.40	25.12
C	15.16	14.60	14.88	14.60
D	11.27	10.70	10.98	10.70
E	9.77	9.21	9.49	9.21
1990				
A	85.67	69.59	77.63	69.59
B	74.23	58.14	66.18	58.14
C	57.23	41.14	49.18	41.14
D	34.04	17.96	25.99	17.96
E	21.97	5.87	13.92	5.89
2000				
A	2,460.00	2,460.00	1,944.00	1,428.00
B	2,291.00	2,291.00	1,774.00	1,259.00
C	1,429.00	1,429.00	912.80	397.00
D	760.50	760.50	244.50	-271.30
E	486.00	486.00	-30.04	-545.80

[a] Dollars of net oil saved (oil saved minus oil used in generating required electricity to fuel EHVs) minus dollars of materials imported (assuming no recycling).

[b] See Table 3.40.

The data for the public costs model were prepared exclusively for use in IPCO and contain information on both the physical quantities of public facilities and services required per capita and the costs of providing them in communities of different sizes, of different characteristics (e.g., central cities, rural areas, and dependent and independent outlying areas), and located in different regions. Within each of the nine census regions, there are five separate community types; for each community type, there are five separate classes of population size. Thus, for each of the 11 public services, there are 225 different facility requirements and cost schedules to choose from, depending on the type and size of the community and the region in which it is located.

The I/O model INFORUM was adjusted for the scenario inputs and used to produce capital spending estimates in 90 economic sectors.

Federal tax revenue losses due to EHVs are derived by multiplying the \$0.04/gal federal motor tax by gasoline and diesel fuel gallons saved by EHV commercialization. Estimated federal motor fuel tax revenues without EHV commercialization are derived for 1985, 1990, and 2000 by compounding the average annual growth rate (2.7%) in these taxes from 1975 to 1977 to the 1977 revenue figure. The tables in Sec. 3.10.5 summarize the findings of the private and public sector capital costs analysis.

Table G.7. EHV Impacts on Balance of Trade, LOW II (10^6 constant 1979$)[a]

EIA Oil Scenario[b]	Materials Price Scenario			
	Best	Strong/weak	Half	Worst
1985				
A	26.45	25.73	26.09	25.73
B	33.64	32.92	33.28	32.92
C	19.81	19.10	19.45	19.10
D	14.69	13.97	14.33	13.97
E	12.72	12.00	12.36	12.00
1990				
A	123.50	105.90	114.70	105.90
B	107.30	89.64	98.48	89.64
C	83.24	65.56	74.39	65.56
D	50.40	32.71	41.55	32.71
E	33.30	15.61	24.45	15.61
2000				
A	4,119.00	4.119.00	3,575.00	3,032.00
B	3,847.00	3,847.00	3.303.00	2,760.00
C	2,460.00	2,460.00	1,916.00	1,373.00
D	1,384.00	1,384.00	840.90	297.80
E	942.70	942.70	399.20	-143.90

[a] Dollars of net oil saved (oil saved minus oil used in generating required electricity to fuel EHVs) minus dollars of materials imported (assuming no recycling).

[b] See Table 3.40.

Table G.8. EHV Impacts on Balance of Trade, MEDIUM (10^6 constant 1979$)[a]

EIA Oil Scenario[b]	Materials Price Scenario			
	Best	Strong/weak	Half	Worst
1985				
A	17.25	8.43	12.84	8.43
B	26.07	17.24	21.66	17.24
C	9.11	0.28	4.70	0.28
D	2.83	-6.00	-1.59	-6.00
E	0.41	-8.42	-4.01	-8.42
1990				
A	77.92	-145.40	-33.87	-145.40
B	51.47	-171.90	-60.32	-171.90
C	12.20	-211.20	-99.60	-211.20
D	-41.36	-264.70	-153.20	-264.70
E	-69.25	-292.60	-181.00	-292.60
2000				
A	3,642.00	3,642.00	-1,613.00	-6,867.00
B	3,227.00	3,227.00	-2,028.00	-7,282.00
C	1,116.00	1,116.00	-4,139.00	-9,393.00
D	-521.50	-521.50	-5.777.00	-11,030.00
E	-1,194.00	-1,194.00	-6,449.00	-11,700.00

[a] Dollars of net oil saved (oil saved minus oil used in generating required electricity to fuel EHVs) minus dollars of materials imported (assuming no recycling).

[b] See Table 3.40.

Table G.9. EHV Impacts on Balance of Trade, HIGH I (10^6 constant 1979$)[a]

EIA Oil Scenario[b]	Materials Price Scenario			
	Best	Strong/weak	Half	Worst
1985				
A	50.31	40.25	45.28	40.25
B	68.35	58.29	63.32	58.29
C	33.64	23.59	28.61	23.59
D	20.78	10.72	15.75	10.72
E	15.84	5.78	10.81	5.78
1990				
A	13.32	-590.30	-288.80	-590.30
B	-36.63	-640.30	-338.80	-640.30
C	-110.80	-714.50	-413.00	-714.50
D	-212.00	-815.60	-514.10	-815.60
E	-264.70	-868.30	-566.80	-868.30
2000				
A	15,310.00	15,310.00	1,493.00	-12,320.00
B	13,880.00	13,880.00	-6,375.00	-13,750.00
C	6,608.00	6,608.00	-7,213.00	-21,030.00
D	963.70	963.70	-12,860.00	-26,670.00
E	-1,355.00	-1,355.00	-15,180.00	-28,990.00

[a] Dollars of net oil saved (oil saved minus oil used in generating required electricity to fuel EHVs) minus dollars of materials imported (assuming no recycling).

[b] See Table 3.40.

Table G.10. EHV Impacts on Balance of Trade, HIGH II (10^6 constant 1979$)[a]

EIA Oil Scenario[b]	Materials Price Scenario			
	Best	Strong/weak	Half	Worst
1985				
A	49.71	39.40	44.55	39.40
B	66.75	57.45	62.60	57.45
C	33.04	22.74	27.89	22.74
D	20.18	9.88	15.03	9.88
E	15.24	4.93	10.08	4.93
1990				
A	-30.94	-678.80	-355.20	-678.80
B	-79.76	-727.60	-404.00	-727.60
C	-152.30	-800.10	-476.50	-800.10
D	-251.10	-899.00	-575.40	-899.00
E	-302.60	-950.50	-626.90	-950.50
2000				
A	11,630.00	11,630.00	-6,203.00	-24,030.00
B	10,270.00	10,270.00	-7,565.00	-15,390.00
C	3,335.00	3,335.00	-14,500.00	-32,330.00
D	-2,044.00	-2,044.00	-19,880.00	-37,710.00
E	-4,253.00	-4,253.00	-22,090.00	-39,920.00

[a] Dollars of net oil saved (oil saved minus oil used in generating required electricity to fuel EHVs) minus dollars of materials imported (assuming no recycling).

[b] See Table 3.40.

Table G.11. Balance of Trade Impacts of MEDIUM EHV Scenario, EIA Oil Scenarios B and D, and Best-Case and Worst-Case Cobalt and Nickel Materials Price Scenarios, 1990 and 2000 (10^6 constant 1979$)

Materials Price Scenario and Year	Recycling	EIA Oil Scenario	Imported Oil Saved	Nickel Imported	Cobalt Imported	Nickel Plus Cobalt Imported	Metals Imported Minus Oil Saved	Metal Imports as a Percentage of Oil Imports Saved
1990								
Best case	No	D	118.6	80.1	64.8	144.9	26.3	122
	Yes	D	118.6	64.7	52.6	117.3	1.3	99
	No	B	211.4	80.1	64.8	144.9	66.5	69
	Yes	B	211.4	64.7	52.6	117.3	94.1	55
Worst case	No	D	118.6	149.5	213.8	363.3	-244.7	306
	Yes	D	118.6	120.8	173.6	294.4	-175.8	248
	No	B	211.4	149.5	213.8	363.3	-151.9	172
	Yes	B	211.4	120.8	173.6	294.4	-83	139
2000								
Best case	No	D	2,848.2	1,730.1	1,371.7	3,101.8	-253.6	109
	Yes	D	2,848.2	1,136.0	900.6	2,036.6	811.6	72
	No	B	6,597.1	1,730.1	1,371.7	3,101.8	3,495.3	47
	Yes	B	6,597.1	1,136.0	900.6	2,036.6	4,560.5	31
Worst case	No	D	2,848.2	5,709.4	7,727.1	13,436.5	10,588.3	472
	Yes	D	2,848.2	3,748.6	5,073.0	8,821.6	5,973.4	310
	No	B	6,597.1	5,709.4	7,727.1	13,436.5	6,839.4	204
	Yes	B	6,597.1	3,748.6	5,073.0	8,821.6	-2,224.5	134

Table G.12. Balance of Trade Impacts of HIGH EHV Scenarios, EIA Oil Scenarios, and Best-Case and Worst-Case Cobalt and Nickel Price Scenarios, 1990 and 2000 (10^6 constant 1979$)

Scenario and Year	Materials Price Scenario	EIA Oil Scenario	Recycling	Imported Oil Saved	Imported Nickel	Imported Cobalt	Nickel Plus Cobalt Imported	Metals Imported Minus Oil Saved	Metals Imports as a Percentage of Oil Imports Saved
HIGH I									
1990	Best	A	No	449.3	219.2	173.9	393.1	56.2	87
	Best	A	Yes	449.3	195.5	155.1	350.6	98.7	78
	Best	B	No	399.3	219.2	173.9	393.1	6.2	98
	Best	B	Yes	399.3	195.5	155.1	350.6	48.7	88
	Best	C	No	325.1	219.2	173.9	393.1	-68	121
	Best	C	Yes	325.1	195.5	155.1	350.6	-25.5	108
	Best	D	No	224.0	219.2	173.9	393.1	-169.1	175
	Best	D	Yes	224.0	195.5	155.1	350.6	-126.6	157
	Best	E	No	171.3	219.2	173.9	393.1	-221.8	229
	Best	E	Yes	171.3	195.5	155.1	350.6	-179.3	205
2000	Worst	B	No	22,737.7	14,922.6	20,221.0	35,143.6	-12,405.9	155
	Worst	B	Yes	22,737.7	10,298.0	13,946.7	24,245.7	-1,508	107
HIGH II									
1990	Best	D	No	218.9	236.0	185.0	421	-202.1	192
	Best	D	Yes	218.9	211.1	167.5	378.6	-159.7	173
2000	Best	D	No	9,354.8	5,848.0	3,589.6	9,437.6	-82.8	101
	Best	D	Yes	9,354.8	3,978.0	3,165.0	7,143	2,211.8	0.76

Table G.13. Balance of Trade Impacts of EIA Oil Scenario B with Half-Case and Worst-Case Nickel and Cobalt Prices, with Recycling, by EHV Scenario, 1990 and 2000 (10^6 constant 1979$)

Scenario and Year	Materials Price Scenarios	Imported Oil Saved	Imported Nickel	Imported Cobalt	Nickel Plus Cobalt Imported	Metals Imported Minus Oil Saved	Metals Imports as a Percentage of Oil Imports Saved
1990							
LOW I	Worst case	91.5	9.7	13.5	23.2	68.3	25
LOW II	Worst case	129.6	9.7	13.5	23.2	106.4	18
MEDIUM	Worst case	211.4	120.8	173.8	294.6	-83.2	139
HIGH I	Worst case	399.3	365.1	511.8	876.9	-477.6	220
HIGH II	Worst case	390.3	394.3	552.8	947.1	-556.8	243
LOW I	Half case	91.5	7.5	8.8	16.3	75.2	18
LOW II	Half case	129.6	7.5	8.8	16.3	113.3	13
MEDIUM	Half case	211.4	92.8	113.1	205.9	5.5	97
HIGH I	Half case	399.3	280.0	333.5	613.5	214.2	154
HIGH II	Half case	390.3	303.0	360.1	663.1	272.8	170
2000							
LOW I	Worst case	2,692.4	337.7	518.3	856	1,836.4	32
LOW II	Worst case	4,332.7	337.7	518.3	856	3,476.7	20
MEDIUM	Worst case	6,597.1	374.9	5,073.0	5,447.9	1,149.2	83
HIGH I	Worst case	22,737.7	10,298.0	13,946.7	24,245.7	-1,508	107
HIGH II	Worst case	21,667.9	13,127.4	17,829.1	30,956.5	-9,288.6	143
LOW I	Half case	2,692.4	220.0	305.1	525.1	2,167.3	20
LOW II	Half case	4,332.7	220.0	305.1	525.1	3,807.6	12
MEDIUM	Half case	6,597.1	244.2	2,987.0	3,231.2	3,365.9	49
HIGH I	Half case	22,737.7	6,710.0	8,211.7	14,921.7	7,816	66
HIGH II	Half case	21,667.9	8,552.7	10,497.7	19,050.4	2,617.5	88

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APPENDIX H

LIST OF ABBREVIATIONS AND ACRONYMS

Al	Aluminum
AQCR	Air quality control region
As	Arsenic
AVD	Advanced vehicle development
B	Boron
BACT	Best available control technology
BAT	Best available technology
bbl	Barrel
BLS	Bureau of Labor Statistics
BN	Boron nitride
BOD_5	Biological oxygen demand
BOM	U.S. Bureau of Mines
BPP	Battery peak power
BSE	Battery specific energy
Btu	British thermal unit
CaF_2	Calcium fluoride
CAFE	Corporate average fuel economy
CBD	Central business district
CERI	Colorado Energy Research Institute
CIPEC	Intergovernmental Council of Copper Exporting Countries
CO	Carbon monoxide
CO_2	Carbon dioxide
COD	Chemical oxygen demand
Cu	Copper
CuS	Copper sulfide
CV	Conventional vehicle
dBA	Decibel (A-weighted)
DOD	Depth of discharge
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
EA	Environmental assessment
EHV	Electric and hybrid vehicle
EIA	Energy Information Administration

EIS	Environmental impact statement
EPA	U.S. Environmental Protection Agency
EV	Electric vehicle
EVC	Electric vehicle commercialization
Fe	Iron
Fe_2O_3	Ferric oxide
FMVSS	Federal motor vehicle safety standards
FPC	Federal Power Commission
GE	General Electric Company
GM	General Motors Corporation
GNP	Gross national product
GVW	Gross vehicle weight
GWh	Gigawatt hours
H_2SO_4	Sulfuric acid
HC	Hydrocarbon(s)
HF	Hydrogen fluoride
hp	Horsepower
hr	Hour
HV	Hybrid vehicle
HVC	Hybrid vehicle commercialization
IBA	International Bauxite Association
INCO	International Nickel Company
I/O	Input-output
IPCO	Public costs projection model
ISOA	Improved state of the art
KCl	Potassium chloride
KOH	Potassium hydroxide
kWh	Kilowatt-hours
Li	Lithium
LiOH	Lithium hydroxide
Li/S	Lithium-metal sulfide
MD	Market demonstration
mi	Mile
mpg	Miles per gallon
mph	Miles per hour
Na/S	Sodium-sulfide

NAAQS	National ambient air quality standard
NERC	National Electric Reliability Council
NHTSA	National Highway Traffic Safety Administration
Ni	Nickel
Ni/Fe	Nickel-iron
Ni/Zn	Nickel-zinc
NO_x	Nitrogen oxide(s)
NSPS	New source performance standards
O_3	Ozone
OPEC	Oil Producing and Exporting Countries
OPRA	Opportunity and risk assessment
Pb	Lead
Pb/acid	Lead-acid
PbS	Lead sulfide
PDL	Person days lost
P.L.	Public law
ppm	Parts per million
PSA	Power supply area
PSE&G	Public Service Electric & Gas Company
PURPA	Public Utility Regulatory Policy Act
R&D	Research and development
RCRA	Resource Conservation and Recovery Act
RECAP	Recharge Capacity Projection
s	Second
S	Sulfur
SCR	Silicon-controlled rectifiers
SEAM	Social and economic assessment model
Short ton	2000 lb
SIP	State implementation plan
SMSA	Standard metropolitan statistical area
SO_3	Sulfur trioxide
SOA	State of the art
SO_x	Sulfur oxide(s)
TDS	Total dissolved solids
TPD	Tons per day
TRC	Total recordable cases

TSS	Total suspended solids
UA	Urbanized area
UF_6	Uranium hexafluoride
VEI	Vehicle evaluation and improvement
VMT	Vehicle miles traveled
yr	Year
Zn	Zinc
ZnO	Zinc oxide
Zn/Br	Zinc-bromine
Zn/Cl	Zinc-chlorine

APPENDIX I

ORGANIZATIONS AND INDIVIDUALS CONSULTED

This EA is the product of a multidisciplinary team comprising scientists, engineers, economists, and planners. Table I.1 lists the analysts and persons consulted.

Table I.1. Analysts and Persons Consulted

Analysts	Organization	Main Contacts	Organization
Project Manager			
Margaret K. Singh	ANL[a]	Daniel P. Maxfield (DOE sponsor)	DOE[b]
Project Supervisor			
Martin J. Bernard III	ANL		
Scenarios (Sec. 2, App. A)			
Martin J. Bernard III*[c]	ANL	Phillip W. Davis	DOE
William J. Walsh	ANL	Phillip D. Patterson	DOE
Charles L. Hudson	Interplan Corp.	Daniel P. Maxfield	DOE
Marianne Millar	ANL	Barry Scott-Walton	Stanford Research Institute
Rita E. Knorr	ANL		
Battery Characteristics (Sec. B.1)			
William J. Walsh	ANL	Over 100 contacts, including all major EV battery developers	
Vehicle Performance Characteristics (Secs. 2.3 and B.2)			
William J. Walsh*	ANL	Robert S. Kirk	DOE
Charles L. Hudson	Interplan Corp.	Kenneth Barber	DOE
Martin J. Bernard III	ANL	Frank Surber	Jet Propulsion Laboratory
Margaret K. Singh	ANL		
Robert F. Giese	ANL	Various contacts	Ford Motor Co.
		Various contacts	General Motors Corp.
		Other industrial contacts	

Table I.1. (Cont'd)

Analysts	Organization	Main Contacts	Organization
Vehicle Production Process Characterization (Sec. B.3)			
William C. Chambers*	Mittelhauser Corp.	George Kneass	Foot Mineral Co.
Margaret K. Singh	ANL	Materials industry contacts	
Christopher L. Saricks	ANL		
Fuel Production Process Characterization (Sec. B.4)			
Christopher L. Saricks	ANL		
Materials Impacts (Secs. 3.2 and C.1)			
Lawrence G. Hill	Economics consultant to ANL	William J. Walsh	ANL
		James Miller	ANL
		Ralph M. Doggett	IR&T[d]
		Staff	U.S. Bureau of Mines
Energy Use Comparison (Secs. 3.3 and C.2)			
Margaret K. Singh*	ANL	William C. Chambers	Mittelhauser Corp.
Susan S. Tobin	ANL	James Westfield	Development Sciences Inc.
		Robert F. Giese	ANL
		Linda L. Gaines	ANL
		Kenneth M. Bertram	ANL
Ecosystem Impacts (Secs. 3.4 and D.1)			
Daniel J. Lutenegger*	BAA[e]	Michael J. Costello	BAA
Lynne E. Takemoto	BAA		
Sheila K. Zelinger	BAA		
Christopher L. Saricks	ANL		

Table I.1 (Cont'd)

Analysts	Organization	Main Contacts	Organization
Physical Environment Impacts (Secs. 3.5, D.2, D.3, and D.4)			
Sheila K. Zelinger (air)*	BAA	William C. Chambers	Mittelhauser Corp.
Daniel J. Lutenegger (water)*		John R. Gasper	ANL
Lynne E. Takemoto		Robert F. Giese	ANL
Robert W. Zolomij (solid waste)*		William Hamilton	GRC[f]
Margaret K. Singh (noise, land use, aesthetic degradation)*	ANL	Michael J. Costello	BAA
		Brian C. Johnson	BAA
		Charles Mackus	PES, Inc.
Christopher L. Saricks (emissions from fuels production, CO hotspots, CO_2)*	ANL		
Occupational Health and Safety Impacts (Secs. 3.6 and E.1)			
John R. Gasper*	ANL	Sam Morris	BNL[g]
Keith C. Spivey	ANL	Lawrence G. Hill	Consultant to ANL
Public Health Impacts (Secs. 3.7.1 and E.2)			
John R. Gasper*	ANL	Sheila K. Zelinger	BAA
Margaret K. Singh	ANL	William J. Walsh	ANL
Public Safety Impacts (Secs. 3.7.2 and 3.7.3)			
Margaret K. Singh	ANL	Gerald Walker	DOE
		William J. Walsh	ANL
		Sarah J. LaBelle	ANL
Social Impacts (Sec. 3.8)			
Margaret K. Singh	ANL	William Hamilton	GRC

Table I.1. (Cont'd)

Analysts	Organization	Main Contacts	Organization
Utility Impacts (Sec. 3.9.1 and App. F)			
Robert F. Giese*	ANL	William J. Walsh	ANL
Alexander Kouvalis	ANL		
Michael Collins	GRC		
Institutional Impacts (other than utility) (Secs. 3.9.2-3.9.9)			
Margaret K. Singh*	ANL	Phillip W. Davis	DOE
Douglas Stroup	ANL	Thomas Benson	DOE
		Robert F. Giese	ANL
Cost of Travel (Secs. 3.10.1 and G.1			
Lawrence G. Hill	Economics consultant to ANL	William Hamilton	GRC
		William Curtis	GRC
		William J. Walsh	ANL
		James F. Miller	ANL
		Frank R. Wyant	ANL
		Industrial contacts	
Employment Analysis (Secs. 3.10.2 and G.2)			
Lawrence G. Hill	Economics consultant to ANL	Michael Padula	U.S. Dept. of Labor
		Eric J. Stenehjem	ANL
		Danilo J. Santini	ANL

Table I.1. (Cont'd)

Analysts	Organization	Main Contacts	Organization
Factor Prices and Balance of Trade Impacts (Secs. 3.10.3, 3.10.4, G.3, and G.4)			
Lawrence G. Hill	Economics consultant to ANL	William Hamilton Frank R. Wyant	GRC ANL
Capital Impacts (Secs. 3.10.5 and G.5)			
Lawrence G. Hill	Economics consultant to ANL	Ralph Doggett David Willis William J. Walsh	IR&T MVMA[h] ANL
Scope of Work			
Martin J. Bernard III	ANL		
Michael E. Samsa	ANL		
Final Report			
Margaret K. Singh	ANL		
Martin J. Bernard III	ANL		
Mary Tisue (editor)	ANL		
Letitia Kaatz (typist)	ANL		

Table I.1. (Cont'd)

Analysts	Organization	Main Contacts	Organization
Peer Review			
G. Scott Rutherford	G. Scott Rutherford and Associates		
Review			
Daniel P. Maxfield	DOE		

[a] Argonne National Laboratory.

[b] U.S. Department of Energy.

[c] Where more than one analyst is listed, the main analyst's name is starred.

[d] International Research and Technology Corporation.

[e] Barton-Aschman Associates.

[f] General Research Corporation.

[g] Brookhaven National Laboratory.

[h] Motor Vehicle Manufacturers Association.

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