Energy Primer:

Selected Transportation Topics

TECHNOLOGY SHARING

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Introduction

"Energy", or more dramatically "the Energy Crisis," has recently become a subject of concern and analysis for individuals at state, local and federal levels. As the consumer of one-fourth of all the energy used in the United States, transportation has attracted its share of analysis. An immense amount of information has been generated in the last several years regarding the current and forecast transportation energy situation in the United States. Some of this information is quite technical and is intended for the specialist.

It is vital therefore, that this information be made available in a form comprehensible to state and local decision-makers who may not, by the nature of their responsibilities, have specialized technical backgrounds. It is equally important to provide the specialists, the planners, and the transportation engineers, with up-to-date topical information. These people must be provided with information that will enable them to consider the full range of alternatives and options made possible by the research generated and financed at the federal level.

As part of its ongoing commitment to the process of Technology Sharing, the U.S. Department of Transportation has initiated a series of publications on transportation topics, referred to as Transportation Primers, which will focus on a variety of subject areas. A Transportation Primer is a general-interest publication of an introductory nature, designed to aid the user in gaining basic familiarity with and understanding of the subject area. These publications will be updated periodically as new information becomes available.

This Energy Primer has been designed to provide broad overviews of the current and projected transportation energy situation in this country; energy statistics, supply and utilization forecasts and evaluations of conservation alternatives are the topics emphasized. A survey was made of works in the field--articles, government reports, Congressional testimony, and conference papers--and ten were chosen for inclusion. The abstracts contained in this publication have been prepared from carefully selected recent literature. The concern has been to include as much of the authors' data as possible, in order to save time by allowing the reader to consult the Primer rather than scattered original reports. Authors' tables were found to be both highly informative and neatly concise and therefore appear often.

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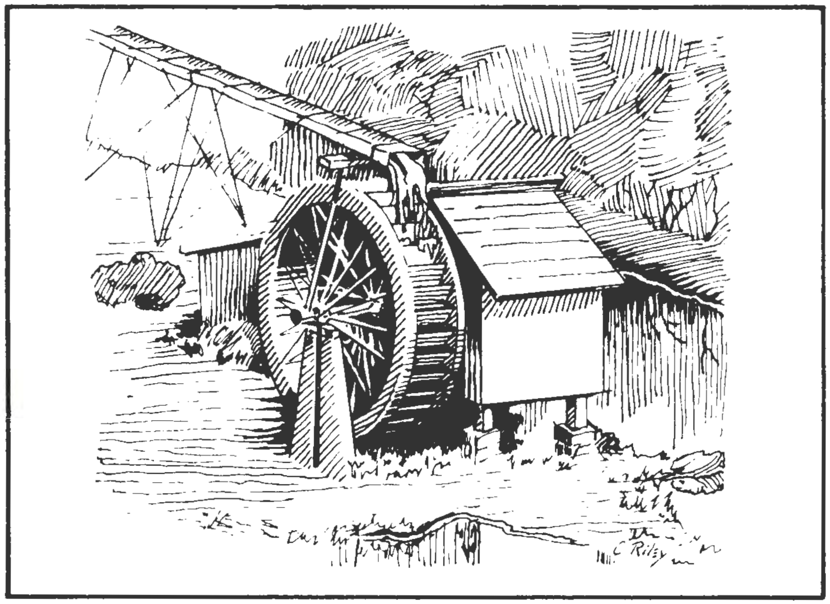
Energy Primer



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ENERGY AND ENVIRONMENTAL ASPECTS OF U.S. TRANSPORTATION

W.E. Fraize, P. Dyson, and S.W. Gouse, Jr. (MITRE Corp.)

February 1974
MTP-391

Until recently, Americans have freely used and abused our seemingly abundant energy supplies; they have been economically exploited rather than economically conserved. Our machines--most notably our automobiles--are profligate consumers of energy, sacrificing fuel economy to speed and performance. But decreasing supplies and increasing costs are finally causing a reassessment of the nature of our transportation system, especially its energy and environmental aspects. The need for conservation is now recognized. This paper advances and evaluates conservation strategies.

I. BACKGROUND

The effects of transportation on American economic and social conditions can be seen in the following statistics: transportation devours 25% of U.S. energy, consuming 53% of petroleum resources (of which a significant portion is imported); accounts for 13% of total personal expenditures; and produces 27½% (by estimated relative toxicity) of all U.S. air pollutants. Thus factors affecting transportation's future fall into two major categories: the near-term energy and environmental crisis and the long-term problems of ending the low-cost fossil fuel era and dealing with the resulting changes in the American lifestyle.

Near-term problems--those whose impact will be felt within five years--require a prompt response, and their solution should therefore not be left to slow-moving free market mechanisms or technological breakthroughs. Some governmental regulations will probably become necessary, and in any event the price and availability of petroleum are rapidly taking a dominant role in the situation. The fuel shortage has in fact already made its impact felt. Its causes are many and complex: a) consumption of petroleum has risen dramatically--annual per capita consumption increased 25% from 1960 to 1970; b) domestic petroleum production has decreased since 1970, due to the higher costs of exploiting remaining reserves and environmental constraints on new exploration; c) refinery capacity has increased very little during the past several years (oil companies blame this on environmental protection regulations and the oscillations in government import policies), with the result that U.S. refineries are operating at 100% capacity; and d) the government has delayed in relaxing its oil imports quotas. New refineries and increments in imports will not be sufficient for a few years. Regardless of these other factors, prices of fuel will doubtless continue to rise, until they are high enough to reward the oil companies for the development of domestic petroleum sources.

Federal regulations, especially recent emission and safety standards, have already begun to influence transportation. Both have had double-edged effects; though auto emission controls should almost completely eliminate atmospheric pollution caused by transportation, they have to date increased fuel consumption by 7%; and though autos can now survive low-speed collisions with little damage, the increased weight of safety structures has reduced fuel economy. Other regulations, however, have had beneficial effects on energy consumption: the Environmental Protection Agency's urban transportation regulations, initially aimed at improving ambient air quality, also cut fuel use by encouraging the use of mass transit and carpools.

The long-term prospects for transportation involve both societal and technological evolution. Changes in the American lifestyle must follow the almost certain changes in automobile ownership and use trends. One trend has already begun to be apparent: many Americans are now buying vehicles designed for specific uses (i.e., camping, commuting), rather than buying purely prestige vehicles. Unfortunately, "comfort" in the form of fuel inefficient air conditioning, automatic transmissions, power accessories, etc., is still a very important factor. And at the same time, environmentalists and conservationists are making themselves heard.

Another long-term factor which will influence the transportation energy outlook is the depletion of fossil fuels. Demands on the decreasing supplies of these fuels can be slowed by several methods: electric vehicles could be used for all but intercity trips; vehicles for intercity travel could be fueled by hydrogen or fuel cell electric engines; and synthetic petroleum could be derived from coal liquefication or oil shale.

The depletion of American petroleum reserves has already resulted in a growing dependence on foreign imports. Certainly the oil import quota system has prevented our total reliance on Middle Eastern sources of supply--imports from that area in 1972 constituted less than 5% of U.S. petroleum consumption. But Middle Eastern sources have come to play a major role in the oil companies' supply strategies. This is due to lower exploration and acquisition costs and the belief that though Western governments might impose export controls for resource management reasons, the Middle Eastern governments would not. This belief has been shown to be mistaken. The petroleum situation has shifted from a buyer's to a seller's market, with a resultant rise in price [compounded by the embargo since this report was written]. These prices could fatally disrupt the U.S. balance of payments. The problem is worsened by simultaneous shortages of other energy sources, such as natural gas and low-sulfur coal. The proposed national energy policy would take the following steps: a) change government regulations to allow the petroleum industry higher profits, thereby encouraging investment in domestic exploration and refineries and reducing dependence on imports; b) push back deadlines for meeting environmental standards, so that our abundant coal reserves can continue to be used; c) encourage conservation.

II. TRANSPORTATION STATISTICAL PROFILE

A. Market Characteristics

Over 40% of total transportation expenditures is for personal transportation. Money spent on automobiles accounts for almost all of that figure. Though statistics suggest that expenditures on cars have almost reached a saturation point, Americans will not voluntarily revolt and end the long reign of the automobile; we have become spoiled by the advantages of complete mobility. Thus even though higher prices for crude oil bring about higher gasoline prices, these increases may not be enough to persuade the public to reduce its gasoline consumption, and a rise in taxation may be deemed necessary. The examples of Europe and Japan, where taxes comprise by far the largest portion of the total price of gasoline, show that taxation is an effective conservation method.

B. Energy Characteristics

In order to evaluate the energy consumption of the various modes of transportation using a common base for comparison, the concept of "energy intensiveness" is formulated: it refers to the energy consumed (measured in Btu's) per unit of transport work (measured in passenger-miles or ton-miles).

See Table 1 for comparison of the energy intensiveness and consumption of the modes and types of travel.

Within one mode, the automobile, energy intensiveness varies considerably according to trip purpose, with load factor the most influential variable. Automobiles are least efficient when used for commuting, where the average load factor is 1.4 occupants/car, and most economical when used for intercity vacation trips, with an average load factor of 3.3 occupants/car. The energy intensiveness of the automobile has also varied with time: in the decade 1962-1972, fuel economy decreased by 7%, due mostly to increased weight. The energy intensiveness of the other modes has also varied--that of the railroads has decreased due to use of diesel power, while that of the air mode has increased (though the Federal Aviation Administration projects that fuel economy will improve through 1980).

C. Emissions

Almost all transportation-produced atmospheric pollution is caused by highway vehicles (60-75% by automobiles alone). When the Clean Air Act and amendments are complied with, almost all emissions will be controlled. Thus the authors feel that the energy aspect of transportation is the more vital problem to be dealt with, and they devote the bulk of the report to that subject.

III. OPPORTUNITIES FOR TRANSPORTATION ENERGY CONSERVATION

Five general families of conservation options for the transportation modes are presented:

1) shift to more energy-efficient modes
2) improve energy efficiencies
3) improve usage patterns
4) reduce travel demand
5) increase load factors

TABLE 1
U.S. TRANSPORTATION ENERGY – 1970

MODE	TRANSPORT WORK (pass. mi. or ton mi.)	LOAD FACTOR	ENERGY INTENSIVENESS (Btu/pass. mi. or Btu/ton mi.) (at current load factor)		ENERGY CONSUMPTION (10^{15} Btu) Subtotals	Additive Totals
PASSENGER SERVICE						
Auto: Urban	.69 x 10^{12}	1.4 pass/veh.	7550	(12.1 mpg)	5.2	
Intercity	1.04	2.5	3250	(16.0 mpg)	3.4	
(Small cars — ALTERNATE BREAKDOWN)	(.27)	1.9	3220	(21.2 mpg)	(.87)	
(Stnd. & compact cars — ALTERNATE BREAKDOWN)	(1.46)	1.9	5300	(12.9 mpg)	(7.73)	
AUTO MODE	1.73	1.9	4980	(13.6 mpg)	8.6	8.6
Light Truck	.08	1.4	9000	(10.1 mpg)		.72
Air: Short haul (<500 mi.)	.018		12200		.22	
Long haul (>500 mi.)	.101		8720		.88	
AIR MODE	.119	49%	9300		1.10	1.10
Bus: Urban	.017	10 pass/veh.	2940	(4.4 mpg)	.05	
Intercity	.028	22	1070	(5.5 mpg)	.03	
School	.052	25	770	(6.75 mpg)	.04	
BUS MODE	.097	19.2	1240	(5.5 mpg)	.12	.12
Rail: Urban	.007	25%	4300		.03	
Intercity	.011	37%	2730		.03	
RAIL MODE	.018		3300		.06	.06
ALL PASSENGER SERVICE	2.044 x 10^{12} pass. mi.		5250 Btu/pass. mi.			10.6
FREIGHT SERVICE						
Truck: Single Units	.15	1.09 ton mi./veh. mi	10650 Btu/ton mi.		1.6	
Combinations	.35	9.21	3440		1.2	
(Motor Carrier — ALTERNATE BREAKDOWN)	(.39)					
(Private Truck — ALTERNATE BREAKDOWN)	(.11)					
TRUCK MODE	.50	2.63	5600		2.8	2.8
Rail	.77		675			.52
Air	.004		37500			.15
Pipeline	.43		420			.18
Waterway	.60		750			.45
ALL FREIGHT SERVICE	2.304 x 10^{12} ton mi.		1780 Btu/ton mi.			4.1
OTHER						
General Aviation						.10
Recreational Vehicles						.20
Military						1.5
TOTAL TRANSPORTATION						16.5

*For Data Sources, see original report.

These options are discussed in detail below. Note the above table describing the energy characteristics of the transportation modes.

A. Modal Shifts

Alternatives to the heavily-used, energy-inefficient modes (such as the automobile, intercity trucking, and short-haul air transport) must be found. As an example of the complex of factors which must be considered when investigating alternative modes of travel, the authors examine the auto commuter trip. Many alternatives to commuting by auto have been advanced; they include use of express commuter buses, urban mass transit, carpooling, and bicycling or walking. Express commuter buses (whose use is limited, since they are feasible only between clearly delineated origin-destination points) are five times as energy efficient as the average auto commute and almost twice as energy efficient as a 4-member carpool travelling in a standard (6-passenger) car. The carpool, however, costs 20-40% less per passenger. And now a dimension other than cost must be examined: feasibility of implementation, in this case the capability of the bus manufacturing industry to produce thousands of buses more per year than it has constructed recently. To increase production this much is difficult not only physically but financially as well. So much capital is sunk into equipment already that it restricts new investment.

The same problems, of time and money for new equipment, appear when the alternative of shifting automobile traffic to urban mass transit is studied. (See Table 2). Though, as Table 1 shows, considerable amounts of energy could be saved, implementation would be difficult and very slow, for the reasons described above. The authors do not consider that walking can be expected to replace many automobile vehicle miles, but they do see some potential in bicycles.

Shifts among intercity travel modes offer as many potentials and pitfalls as urban shifts. Intercity bus and rail (especially the first) are significantly more efficient than intercity automobile. But so many vehicle miles are travelled by intercity automobiles that even doubling intercity bus and rail travel (with all the attendant implementation problems) would reduce intercity automobile travel by only 4%, or 0.4% of the 1970 transportation energy budget. Similarly, because short-haul air traffic accounts for so few passenger miles, shifting even 50% of that traffic to bus and rail would save only 0.6% of the 1970 transportation energy expenditures. Shifting 50% of all air traffic (both long- and short-haul) from conventional to wide-body jets would produce slightly higher savings of 0.9% of the 1970 budget. Shifting 10% of the intercity trucking to rail would effect an energy saving of 0.6% of the 1970 base.

TABLE 2
TRANSIT EQUIPMENT REQUIRED FOR A SHIFT FROM AUTOMOTIVE COMMUTING TO MASS TRANSIT (BUS)

Automotive Vehicle Miles = 890.8×10^9 in 1970

Commuting Vehicle Miles = 34% of all automotive vehicle miles

Urban Commuting to City Center Vehicle Miles = 20% of all Commuting Vehicle Miles

Passenger Loading for Commuting = 1.4 passenger/vehicle

Urban-to-City Center Commuting Passenger Miles

$=(.34)\ (.20)\ (891)\ (1.4)\ 10^9$

$= 85 \times 10^9$ in 1970.

At 36 passenger/bus, 25 miles/trip (considerably longer than the U.S. average of 9.4 miles/commuting trip), a 5% shift of urban automotive city-center commuting to bus would require

9,200 additional buses

and yield an energy savings of: $.05(.085 \times 10^{12})\ (7680\text{-}1440)$

$= .027 \times 10^{15}$ Btu

= .16% of the 1970 U.S. Transportation energy budget

Bus purchases by transit industry have averaged <2500/year for the period 1960 - 1971.

Transit industry now operates 49,000 buses.

*For Data Sources, see original report.

Before considering other strategies for energy conservation, it must be emphasized that shifting traffic among the modes requires many readjustments and much time, due to the weight of sunk capital in existing equipment.

B. Increase in Load Factor

The energy efficiency of a mode may be improved if the load factor (proportion of potential full load) per trip is increased, thereby decreasing the number of individual trips and cutting down on vehicle miles travelled. Load factor in private automobiles may be increased by sharing their use, by carpooling or hitch-hiking for example. Though computer matching systems are now more and more frequently employed, encouraging the sharing of private cars raises complex questions, so that even this seemingly simple expedient presents implementation problems.

Increasing load factors of common carriers would be easier to do. Machinery for their governmental regulation already exists, and to enforce a policy of fuel conservation would not create new bureaucratic red tape. Unscheduled services (charter buses and planes, oil tankers, etc.) already have high load factors due to their flexibility. Several methods could be used to increase the load factors of scheduled services: off-peak service could be reduced, secondary loads could be given lower time priority so that they could be used to fill later loads, and price incentives could be used to attract travellers to off-peak trips.

C. Reduction in Demands

Reducing personal travel can save a great deal of transportation energy, but this strategy has far-reaching social effects--the dependence of Americans on the automobile has already been discussed. In spite of the wrench they would cause, steps to reduce travel demand are highly desirable. Three types of strategy could be used with particular efficacy:

1) The government can use taxation as a disincentive by raising gasoline taxes and/or taxing on a mileage basis.

2) Communication systems can be developed as a substitute for travel.

3) Land use can be planned so that origins and destinations (i.e., homes and places of work) are in closer proximity, pedestrian malls can be built, etc.

D. Improved Energy Conversion Efficiency

The authors concentrate here on bettering automobile fuel economy, which is currently so low that it offers the greatest opportunities for improvement. One means of improving energy conversion efficiency is reducing power demand, which can be done in the following ways:

1) Encourage smaller, lighter vehicles: vehicle weight and fuel economy have a direct relationship. If 50% of standard and intermediate size cars were replaced with small cars, the savings could equal 9.3% of the 1970 transportation energy expenditure.

2) Reduce tire and aerodynamic drags. The authors postulate that reduction of drag could save 15% of automobile fuel consumption, equaling 7.8% of the 1970 transportation energy budget.

3) Reduce demands on power from accessories, the most draining of which is the air conditioner. It is broadly estimated that air conditioning reductions could save 2-4% of automotive fuel consumed, thus saving 1-2% of the 1970 transportation energy expenditure.

4) Reduce performance requirements, i.e., reduce the power-to-weight ratio. Decreasing the ratio by 20% results in a decrease of fuel consumption of 15%, thereby saving 7.8% of the 1970 transportation energy budget.

The other major means of improving energy conversion efficiency is to increase the efficiency of the propulsion system itself. Available options for doing this include:

1) Development and use of more efficient engine and transmission systems. Engines currently under scrutiny and holding some promise of energy efficiency are the diesel, Stirling, stratified charge, Rankine cycle, and Brayton cycle.

2) Enforcement of more stringent vehicle maintenance requirements. Judging that badly out-of-tune vehicles can lose 25% fuel economy, and assuming that 1 of every 10 cars is out of tune, a program enforcing careful maintenance could save 1.3% of the 1970 transportation energy budget.

3) Use of drive trains possessing energy-storage capacity.

The authors point out that direct regulation would not be necessary to implement the options discussed above:

TABLE 3
SUMMARY ASSESSMENT OF TRANSPORTATION ENERGY CONSERVING OPTIONS

APPROACH	TIME FRAME(1)	BENEFIT(2)	MEANS(3)				LIKELIHOOD OF IMPLEMENTATION(4)
			R	A	E	T	
Shifts Among Modes							
Auto commuters to express buses	M	L		X	X		M
Auto commuters to mass transit	M	L	X	X	X		M
Intercity auto to bus and rail	M	L	X	X	X		L
Short-haul air to bus and rail	M	L	X	X	X		L
Short-haul air to TLV systems	L	L	X	X		X	M
Conventional jet to wide-body jet	M	L	X	X	X		M
Short-trip auto to human-powered systems	M	L		X	X		M
Intercity trucking to rail	M	L	X			X	M
Increased Load Factor							
Carpooling	S	H	X	X	X		M
Air	M	M	X		X		M
Truck	M	M	X		X		L
Rail	M	L	X		X		L
Tankers	M	L			X	X	L
Urban Mass Transit	M	L	X	X	X		L
Reduced Demand							
Telecommunications	L	L			X		H
Improved land use and urban planning	L	H	X		X		H
Fuel tax or surcharge	M	H	X		X		H
More efficient trip planning	S	M		X			M
Increased Energy Conversion Efficiency							
Smaller autos	L	H	X	X	X		H
Reduced drag	L	H			X	X	L
More efficient engines	L	M			X	X	H
Better maintenance	M	M	X	X	X	X	H
Hybrid auto systems	L	H			X	X	L
Reduced accessory load	S	M	X	X	X		L
Reduced performance demand	S	M	X	X	X		M
Improved Usage Patterns							
Traffic management	M	M	X	X			H
Better driving techniques	M	M		X	X		H
Improved aircraft operations	S	L	X	X		X	M

(1)TIME FRAME: Time required to implement program so that at least 50% of maximum practical benefit in energy reduction for the particular approach could be achieved. S<1 year; M = 1-5 years; L>5 years.

(2)BENEFIT: % reduction in total transportation energy consumption, accounting for resulting energy changes in all sectors: L<1% of transportation energy; M = 1-5% of transportation energy; H>5% of transportation energy.

(3)MEANS: R = Regulation; A = Attitude (voluntary actions from influencing public opinion)
T = Technology; E = Economic (includes taxes and fees imposed by regulatory bodies).

(4)LIKELIHOOD OF IMPLEMENTATION: The probability that a particular approach will be implemented within the next 10 years: L = <10% probability; M = 10-50% probability; H = >50% probability.

economic incentives would probably suffice. It would be several years, however, before implementation of the options would be noticeably effective, due to the slow change of the fleet mix.

E. Improved Usage Patterns

Changes in the manner of operation of highway and air vehicles can have considerable fuel economy effects. For automobiles, cruising at lower speeds, accelerating more slowly, and using brakes less lead to lower gasoline consumption. Improved traffic management by coordinating signal systems, metering access to freeways, etc., also saves fuel.

IV. CONCLUSIONS

Table 3 which precedes makes evident several conclusions:

1) Encouraging more efficient use of existing modes and transportation systems is the only conservation strategy which can be employed for results in the near future.

2) In a moderate time frame, mode shifts could be effected. But they would not allow significant energy savings, since without enormous capital expenditures for system expansion they could not bear substantial traffic shifted from automobiles.

3) Several strategies could be used to achieve energy savings by the end of 25 years: more efficient propulsion systems and alternative fuels could be developed, congestion could be reduced through traffic engineering, and land use could be planned with reducing the need for travel in mind.

4) Economic processes, without governmental regulation except in the form of fees or taxes, are effective for the implementation of most of the conservation options.

5) Automobiles offer the greatest opportunities for energy conservation. This can be done through technological improvements and attitudinal changes.

ENERGY REQUIREMENTS FOR PASSENGER GROUND TRANSPORTATION SYSTEMS

W.P. Goss and J.G. McGowan (University of Massachusetts, Amherst)
Paper presented at the Intersociety Conference on Transportation, Denver, Colorado, September 23-27, 1973
ASME Paper 73-ICT-24

This paper differs from other investigations of the energy efficiencies of the transportation modes in that it calculates the energy consumed by one traveller using a variety of modes, for a variety of trip types, rather than emphasizing overall modal energy use. Three types of trips are analyzed: the intraurban commute, the suburban-to-urban commute, and the intercity trip.

The first section of the paper discusses current trends in the energy consumption of transportation, especially its heavy dependence on petroleum fuels: in 1970, 95.5% of transportation energy was provided by petroleum (using 55% of U.S. petroleum production) and it is predicted that in the year 2000, transportation will consume 70% of petroleum output. Thus improvements in the energy efficiency of transportation could save significant fuel.

The second section calculates the energy efficiencies of the most important current and potential ground transportation modes: automobiles (including diesel, gas turbine, and electric propulsion systems, as well as the conventional internal combustion engine); buses (diesel, gasoline, gas turbine, Rankine, and Stirling); rail transit (subway and elevated, trolley coach, electric, diesel, and gas turbine); motorcycles; and personal rapid transit. The authors measure energy efficiency as passenger miles/gallon of fuel (N.B.: this is inversely proportional to Hirst's concept of "energy intensiveness."). Only direct energy costs are calculated, because analyses of indirect costs (i.e., the energy used for manufacturing and transporting automobiles, refining gasoline, etc.) for all the modes have not been undertaken and because the transportation user, at whom this paper is aimed, has little control over these costs. The authors point out that the energy efficiency of a system can vary greatly, as it is influenced by the data source and by operating conditions.

The following tables provide data on block speed, fuel consumption in miles per gallon, seating capacities and load factors, and passenger miles per gallon of various modes in intraurban, suburban-to-urban, and intercity travel. Predictions are included for potential future systems (gas turbine buses, VTOL and STOL aircraft, TACV's, etc.) as well.

TABLE 1
TRANSPORTATION/ENERGY DATA FOR INTRAURBAN SYSTEMS

MODE	BLOCK SPEED (mph)	AVERAGE FUEL CONSUMPTION (mpg)	PASSENGER LOADING		$\eta_{T/E}$ (PASSENGER-MILES / GALLON)	
			LOAD RANGE (pass/veh)	LOAD FACTOR (%)	Range	Average
A. Automobiles						
1. Luxury	5-20	12.5	1-6	28.3	13-75	21
2. Full Size	5-20	13.2	1-6	28.3	13-80	22
3. Intermediate	5-20	14.1	1-6	28.3	14-85	24
4. Compact	5-20	17.3	1-4	42.5	17-70	30
5. Subcompact	5-20	26.5	1-4	42.5	27-105	45
6. Diesel	5-20	24.0	1-5	34	24-120	40
B. Motorcycles	10-25	30-80	1	110	35-90	60
C. Bus Transit						
1. Full Size Diesel	5-15	4.1	41-53	45	75-100	90
2. Medium Size Diesel	5-15	5.5	25-33	45	60-80	70
3. Medium Size Gasoline	5-15	4.5	25-33	45	50-70	60
4. Full Size Rankine	5-15	0.6-1.1	41-53	45	10-25	18
5. Minibus Gasoline	5-15	7.2	15-25	45	50-80	65
6. Van Gasoline	5-15	9.0	6-10	45	25-40	32
D. Rail Transit						
1. Subway and Elevated	15-30	2.5	50-80	35	45-70	60
2. Surface Rail	15-25	3.0	50-70	35	50-75	65
3. Trolley Coach	10-25	3.2	40-60	35	45-70	55
E. Potential Future Systems						
1. Electric Auto	5-20	20-25	1-4	42.5	20-100	40
2. Stirling Bus	5-15	5-7	31	45	70-100	85
3. Rankine Bus	5-15	2.3-3.3	41-53	45	40-80	60
4. Personal Rapid Transit (PRT)	10-30	25-30	4-6	26-32	35-50	40

TABLE 2
TRANSPORTATION/ENERGY DATA FOR SUBURBAN/URBAN SYSTEMS

MODE	BLOCK SPEED (mph)	AVERAGE FUEL CONSUMPTION (mpg)	PASSENGER LOADING		$\eta_{T/E}$ (PASSENGER-MILES / GALLON)	
			LOAD RANGE (pass/veh)	LOAD FACTOR (%)	Range	Average
A. Automobiles						
1. Luxury	15-35	12.5	1-6	23	13-75	18
2. Full Size	15-35	13.2	1-6	23	13-79	19
3. Intermediate	15-35	14.1	1-6	23	14-85	20
4. Compact	15-35	17.3	1-4	35	17-69	24
5. Subcompact	15-35	26.5	1-4	35	27-106	37
6. Diesel	15-35	24	1-5	28	24-120	35
B. Motorcycles	15-40	30-80	1	130	40-105	70
C. Bus						
1. Full Size Diesel	10-35	6.5	41-53	45	120-155	140
2. Medium Size Diesel	10-35	8.0	25-33	45	90-120	105
3. Medium Size Gasoline	10-35	5.5	25-33	45	70-80	75
4. Full Size Rankine	10-35	2.0	41-53	45	40-50	45
D. Commuter Rail						
1. Electric	25-45	1.9	70-125	35	50-85	65
2. Diesel	25-45	1.6	50-90	35	30-50	40
3. Gas Turbine	25-45	1.0	60-80	35	20-30	25
E. Potential Future Systems						
1. Hybrid Electric Auto	10-30	15-24	1-4	35	15-100	30
2. Gas Turbine Auto	15-35	12-14	1-5	30	18-21	20
3. Stirling Bus	10-35	5-7	41-53	45	90-170	130
4. Rankine Bus	10-35	2.3-3.3	41-53	45	40-80	60
5. TACV	40-60	.3-.4	60-120	62.5	10-30	25
6. TVS						
a. Pneumatic	40-60	1.7-2.5	60-120	50	50-150	100
b. Non-Pneumatic	40-60	1.3-1.7	60-120	50	40-100	60

TABLE 3
TRANSPORTATION/ENERGY DATA FOR INTERCITY SYSTEMS

MODE	BLOCK SPEED (mph)	AVERAGE FUEL CON-SUMP-TION (mpg)	PASSENGER LOADING		$\eta_{T/E}$ $\left(\frac{\text{PASSENGER-MILES}}{\text{GALLON}}\right)$	
			LOAD RANGE (pass/veh)	LOAD FACTOR (%)	Range	Average
A. Automobile						
1. Luxury	40-60	12.5	1-6	35	13-75	26
2. Full Size	40-60	13.2	1-6	35	13-79	28
3. Intermediate	40-60	14.1	1-6	35	14-85	30
4. Compact	40-60	17.3	1-4	53	17-69	36
5. Subcompact	40-60	26.5	1-4	53	27-106	56
6. Diesel	40-60	24.0	1-5	42	24-120	50
B. Buses						
1. Highway Coach Diesel	40-60	7.0	41-53	46	130-170	150
2. Highway Coach Gas Turbine	40-60	2.5	41-53	46	50-60	55
C. Rail						
1. Electric	50-70	2.5	70-125	37	65-115	90
2. Diesel	50-70	2.1	50-90	37	39-70	55
3. Gas Turbine	50-70	.5-.7	140-240	37	28-61	50
D. Air						
1. Short Range	200-300	.2-.4	75-150	50	10-30	15
2. Long Range	400-500	.2-.4	150-350	50	10-40	20
E. Potential Future Systems						
1. Gas Turbine Bus	50-70	4-5	41-53	50	80-130	105
2. Stirling Bus	50-70	5-7	41-53	50	100-190	140
3. TACV	100-250	.4-.5	60-120	63	15-40	30
4. TVS						
a. Pneumatic	100-300	1.1-1.9	60-120	55	35-125	80
b. Non-Pneumatic	100-300	.8-1.1	60-120	55	25-75	50
5. VTOL	125-200	.24-.37	50-100	55	7-20	15
6. STOL	125-200	.33	100	55	10-20	18

Detailed information on the energy efficiency of human beings walking, running, or bicycling is also calculated and shown below in Table 4; it is pointed out that a person consumes as much petroleum (used in the production and distribution of his food) walking fairly quickly as the bus he rides uses at full capacity covering an equal distance.

TABLE 4
DATA BASED ON 154 LB (70 Kgm) MAN TRANSPORTATION/ENERGY EFFICIENCY FOR HUMAN ACTIVITY

ACTIVITY	AVERAGE SPEED (mph)	METABOLIC RATE (Kcal/hr.Kgm)	RELATIVE METABOLIC RATE	TRANSPORTATION/ENERGY EFFICIENCY	
			SPEED (Kcal/Kgm Km)	FOOD BASIS	PETROLEUM BASIS
Sitting	0	1.43		0	0
Walking Slowly	2.6	2.86	0.342	889	178
Walking Moderately Fast	3.75	4.28	0.472	644	129
Walking Fast	5.3	9.28	0.921	330	66.1
Running	5.3	8.14	0.787	367	73.5
Bicycling Slow	10	4.28	0.177	1720	344
Bicycling Fast	20	9.28	0.244	1055	250

The next section of the paper treats the energy consumed by an individual using a variety of modes. Please see the following tables for data, including: trip distances, total time, block velocity, individual energy consumed (daily and yearly figures), and out-of-pocket costs (daily and yearly) on these trips. The authors feel that if this data, especially that on cost, is presented to the public, it could be effective in persuading travellers to switch to cheaper and more energy efficient modes.

TABLE 5
INTRAURBAN TRIP ENERGY CONSUMPTION – NEW YORK CITY
(UPPER EAST SIDE TO MIDTOWN MANHATTAN COMMUTE)

MODE(S)	TRIP DISTANCE (miles)	TOTAL TIME (minutes)	BLOCK VELOCITY (miles/hour)	INDIVIDUAL ENERGY CONSUMED (gallons)	YEARLY INDIVIDUAL ENERGY CONSUMED (gallons)	OUT-OF-POCKET COSTS (dollars)	YEARLY OUT-OF-POCKET COSTS (dollars)
Walk/Subway	2.47	30	4.9	0.011	5.3	$0.35	$ 168
Bus/Bus	2.44	32	4.6	0.012	5.8	0.35	168
Bus/Subway	2.53	45	3.4	0.015	7.2	0.70	336
Taxi	2.48	15	9.9	0.310	149	2.15	1032
Private Auto	2.44	22	6.7	0.375	180	9.97	1856
Walk	2.40	38	3.8	–	–	0.00	0

Costs Based On:
- Private Auto – 15 ¢/mile
- Parking – $60/month at Apartment Building, $6.50/day or $80/month midtown Manhattan
- Fares – Subway (35¢), Bus (35¢), Taxi ($2.15)
- 240 working days/year times 2 trips/day = 480 total trips/year

TABLE 6
SUBURBAN/URBAN COMMUTE ENERGY CONSUMPTION – HUNTINGTON, LONG ISLAND TO MANHATTAN (7TH AVE. AND 53RD ST.)

MODE(S)	TRIP DISTANCE (miles)	TOTAL TIME (hrs:mins)	BLOCK VELOCITY (miles/hour)	INDIVIDUAL ENERGY CONSUMED		OUT-OF-POCKET COSTS	
				Gallons/Trip	Gallons/Year	Dollars/Trip	Dollars/Year
Auto/Train/Subway	40.3	1.33	26	0.24	113	$2.72	$ 864
Auto/Subway	35.0	1.32	23	1.48	710	3.85	1848
Private Auto	35.2	1.36	22	2.57	1233	8.53	3480
Bicycle	35.2	3.30	10	–	–	0.31	150

Trip Descriptions

Private Auto – use Long Island Expressway – Queens Midtown Tunnel – Crosstown drive in city
Auto/Subway – drive to Shea Stadium parking lot – Subway to Manhattan
Auto/Train/Subway – drive to Huntington – Long Island Railroad to Penn Station – Uptown Subway
Bicycle – follow same route as private automobile/not recommended for safety reasons

Costs Based On:

Parking in Manhattan – $6.50/day or $80/month
Private Auto – 15¢/mile
Parking at Shea Stadium - $1.00/day
Subway Fare – 35¢
Train Fare – $12.37/trip or $58/month
Bicycle – $150/year
480 trips/year

TABLE 7
INTERCITY TRIP ENERGY CONSUMPTION – NEW YORK CITY
(ROCKEFELLER PLAZA TO WASHINGTON, D.C., U.S. CAPITOL BUILDING)

MODE(S)	TRIP DISTANCE* (miles)	TOTAL TIME (hrs:mins)	BLOCK VELOCITY (miles/hr)	INDIVIDUAL ENERGY CONSUMED		OUT-OF-POCKET COSTS	
				Gallons/Trip	Gallons/Year	Dollars/ Trip	Dollars/Year
Private Auto	220	4:40	47	16.1	773	$42.20	$2026
Rented Auto	220	4:45	46	16.1	773	37.20	1786
Taxi/Airplane/Taxi	220	2:25	91	8.57	411	35.00	1680
Subway/Bus/ Airplane/Taxi	220	3:40	91	7.82	375	29.10	1397
Taxi/Train/Taxi	220	3:40	60	1.84	88	14.15	679
Subway/Train/Taxi	220	3:40	60	1.60	77	13.10	629
Taxi/Bus/Taxi	220	4:35	48	1.54	74	14.50	604
Taxi/Bus/Bus	220	4:45	46	1.34	64	13.50	580

Trip Descriptions (*All trip lengths assumed to be 220 miles, actually there are small differences)

Private and Rented Auto: Crosstown to Lincoln Tunnel – New Jersey Turnpike – J.F.K. Memorial Highway – Balto/Wash Parkway – Ana Costia Freeway – Pennsylvania Avenue – to Capitol

Local/Bus/Local: Taxi or Subway to 8th Avenue Bus Terminal – Intercity Bus to D.C. – Local Bus or Taxi to Capitol

Local/Train/Taxi: Local Taxi or Subway to Penn Station – Metroliner to D.C. – Taxi to Capitol

Local/Airplane/Taxi: Local Taxi or Subway/Bus to Laguardia Airport – fly to Wash. National Airport – Taxi to Capitol

Costs Based On:
- Private Automobile - 15¢/mile
- Parking in Washington, D.C. - $3.50/day
- Highway Tolls (N.Y.C. to D.C.) - $4.70
- Rented Automobile - $11.00/day and 11¢/mile plus $2.00 Insurance Waiver
- Metroliner Fare - $11.25 one way
- Bus Fare - $11.80 one way - $22.45 round trip
- Plus Local Subway (35¢), Bus (50¢), and Taxi ($1.20 to $6.50)
- 48 one way trips per year (one round trip every two working weeks)

The following are specific recommendations for improving transportation energy efficiency:

A. Technological

1. Research, develop, then introduce to the fleet more efficient engines.

2. Develop traffic control systems which allow vehicles to move more smoothly and quickly, evaluate and implement promising systems.

3. Develop and introduce innovative, efficient mass transit systems (i.e., dual-mode, personal rapid transit, etc.) to woo travellers away from the automobile.

4. Develop alternative fuels and bring them to market.

5. Develop a research program to analyze passenger attitudes toward transportation modes in order to make mass transportation more attractive; take steps to introduce the more appealing features of the automobile (privacy, door-to-door service, etc.) to mass transit.

B. Institutional

1. Encourage the already noticeable trend toward smaller and lighter automobiles. This could be effected by taxing vehicles on a size and/or horsepower basis; taxing petroleum fuels more heavily; rationing gasoline; and restricting urban parking for large cars. In 5 to 10 years, severe constraints on the size and use of automobiles in urban areas could be imposed.

2. Alert the public to the energy efficiencies of the various modes.

3. Subsidize and make capital grants to the modes which are the most energy efficient.

4. Investigate and experiment with total restrictions on automobile use in the central cores of selected cities.

5. Examine trip distribution; determine if some trips could be made on more efficient modes or if these trips could be replaced by telecommunications.

6. Promote increased load factors: encourage automobile carpooling and subsidize bus and subway fare reductions.

THE AUTOMOBILE: ENERGY AND ENVIRONMENT. A TECHNOLOGY ASSESSMENT OF ADVANCED AUTOMOTIVE PROPULSION SYSTEMS.

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I. INTRODUCTION

The impact of the automobile on life in America needs little discussion. The magnitude of a few figures suffices as demonstration: in 1970, 108 million drivers drove 87 million passenger cars over 3.7 million miles of roads. Most analyses of this phenomenon, however, are general, in that they treat the automobile as a unity, rather than as an aggregate of many separate components, each of which has its own impacts. The most important of these components is the engine, which in today's car is almost invariably spark-ignition internal combustion. Today's internal combustion engine, after years of production and refinement, remains far from the ideal propulsion system; its most notable defects are its low efficiency in converting fuel to power and its polluting emissions. These drawbacks are now being recognized, and improvements and alternative engines are being sought. Thus this technology assessment was commissioned "to examine systematically the consequences of the numerous proposed alternatives to the internal-combustion engine (the Otto cycle), then the nearly universal power plant for automobiles. It was anticipated that, in order to meet the mandated clean air requirements, some major changes, if not entirely new systems, would be required for mass manufacture." This report undertakes to: define the environmental, economic, social, political, and technological roles of the current automobile and ICE (internal combustion engine); identify alternatives to the ICE propulsion system; evaluate policy options which could effect the replacement of the ICE with more advanced, less polluting systems; and evaluate the impacts of such transitions, considering especially unintended, indirect, and delayed consequences.

II. METHODOLOGY OF ASSESSMENT

A nine-step procedure was followed to assess the impacts of a transition from today's ICE powered car to one or more advanced systems. This procedure is discussed in detail below.

A. Establishment of Impact Areas

Though it was recognized that many levels of impact result from a new technology introduction, it was impossible to consider all of them in the scope of this project. Four major impact areas were selected. The following table summarizes their characteristics.

TABLE 1
IMPACT AREAS OF NEW PROPULSION TECHNOLOGIES

Primary Level Characteristic	Component Level Characteristic
Materials Demand	(a) Raw materials requirements for engine and directly related components (b) Materials required to fabricate and process (a) (c) Petroleum and other materials required for operation and maintenance of ICE (d) Scrap and waste generated for reprocessing and reuse at all stages (e) Scrap and waste generated for disposal at all stages
Energy Demand (electrical power requirements associated with (a)–(f))	(a) Obtaining raw materials (b) Processing raw materials (c) Fabricating materials and components (d) Reprocessing and recycling (e) Maintenance (f) Disposal
Environmental Impact (air, water and/or land pollution effects associated with (a)–(d))	(a) Processing or fabricating of raw materials and recovered materials to end use products (b) Operation of ICE (c) Maintenance of ICE (d) Disposal of ICE and related components and materials
Socioeconomic Impact	(a) Employment of ICE and associated industries by number and skill category (b) Industrial revenues associated with ICE activity (c) Capital expenditures associated with ICE, by component (d) Sociological and life style patterns which are unique to the ICE (e) Other human ecology factors tied to ICE use patterns

The facts and projections used in the assessment of the social impacts deserve more detailed explanation, since little work has been done to date on this subject. The authors start by drawing an important conclusion from automobile drivers' behavior during the gasoline shortages of 1973-1974: "The car owner values his personal mobility above all else. He may be willing to drive more slowly, accelerate more slowly, sacrifice vehicle size, sacrifice automatic transmissions and air conditioning, and pay higher operating costs as long as he is able to own and drive his car." Several projections are then made in order to assess the demand for new vehicles:

1) Americans will continue to use the automobile to preserve their mobility and independence. A great majority (over 80%) of Americans will continue to own at least one car.
2) The trend toward multi-car ownership will continue.
3) The population of the suburbs will continue to expand, with attendant increased automobile ownership and usage.
4) Americans will still need cars, and as the population becomes more dispersed so that public transportation becomes less practicable, an even greater percentage may need them.
5) Automobile usage patterns will remain basically as they are today, though some attempts may be made at decongestion.
6) Though concern over the adverse effects of the automobile is growing, government intervention will probably be needed to translate this concern into action.
7) As leisure time increases, so will the recreational use of the automobile.

B. Establishment of the Characteristics and Impacts of the Baseline Automobile (ICE)

A 4000-lb, 350-cubic inch engine, six-passenger 1971 automobile was chosen as the baseline for comparison with the alternative systems examined. Materials consumed in its production and use (including aftermarket--i.e., after initial sale--requirements) are determined; its energy consumption, both direct and indirect (energy used in mining and processing the metals used, transporting, producing, maintaining, and repairing the automobile), is computed; its environmental effects (including pollutants emitted during operation and wastes created during the manufacture, maintenance, and retirement of the vehicle) are quantified; and its socio-economic impacts are estimated, using an input/output matrix for calculating the labor and capital requirements of 44 industries with direct economic ties to the automobile industry. The expectations of the consumer regarding his automobile are perceived as follows. The automobile shall provide:

1) Personal transportation.
2) Reliable starting and performance, especially powerful acceleration.
3) Easy and economical operation.
4) Long cruisng range.
5) Many conveniences in accessories and appointments.

C. Definition of Advanced Systems and Selection of Systems to be Modeled

The following propulsion systems were identified as possible replacements for the ICE:

TABLE 2
ADVANCED PROPULSION SYSTEM

	Ref. ICE (lbs)	1 Adv. ICE ('76)	2 Adv. Diesel	3 Rotary	4 Rankine	5 Gas Turbine	6 Stirling	7 Heat Engine Electric ICE/Ni-Zn	8 Heat Engine-Flywheel	9 Alkali Metal Battery	10 Fuel Cell
Cast Iron	450	348	584	6	336	341	522	276	339	–	–
Low Carbon Steel	206	236	272	264	416	269	523	319	254	156	144
Alloy and Stainless Steel	29	105	37	77	100	18	60	70	150	115	225
Superalloys	–	20	–	–	–	21	70	–	–	–	–
Iron	746	668	904	427	764	606	1067	643	716	242	300
Aluminum	49	57	54	150	100	27	120	129	107	129	128
Lead	23.5	21.5	23	21	20	20	20	3	22	–	–
Copper	20	42	19	25	20	5	10	103	37	93	112
Zage	12	0.5	2.5	2	1	–	1	180	9	9	13
Nickel	0.3	10.2	0.5	0.4	5.2	12.3	34	171	0.6	12	502
Chromium	1.2	5.1	1.2	0.5	12.4	3.5	25.6	0.3	0.8	20	38
Molybdenum	0.2	2.1	0.2	0.2	0.2	0.6	6.3	0.2	0.4	T	120
Manganese	5	5	6	2	3	4	6.5	4	5	0.7	0.6
Silicon	11	9	14	13	7	8	11	10	7.2	S	S
Tin	1.8	1.8	1.8	1.5	<1	<1	<1	1	1	T	S
Syn. Rubber	15	18	17	18	13	13	13	7	18	–	–
Plastics	3	3	3	3	1	1	1	63	3	12	203
Ethylene Glycol	19	16	16	16	–	–	64	16	16	–	–
Electrolyte	11(1)	11(1)	11(1)	11(1)	11(1)	11(1)	11(1)	43(3)	11(1)	144(2)	500
Petrol. Lubricants	14	15	15	15	13	3	15	12	22	4	4
Magnesium	–	–	–	–	40	–	40	–	–	–	–
Sulfur	T	T	T	T	T	–	T	T	T	541	–
Non-Metallurgical Carbon	T	T	T	T	T	T	T	T	T	72	149
Ceramic	<<1	T	T	T	–	40	–	–	T	–	–
Synthetic Lubricant	–	–	–	–	–	4	–	–	–	–	–
Alumina	–	–	–	–	–	–	20	–	–	–	–
Lithium	–	–	–	–	–	–	–	–	–	109	–
Platinum	–	0.15 oz	–	–	–	–	–	–	–	–	1.1
Other Emissions Catalyst	–	–	NA	NA						–	–
Semiconductors	S	S	S	S	S	S	S	S	0.5	1	2
Asbestos	2	4	4	1	–	10	–	–	1	–	–
Tungsten	–	–	–	–	–	0.4	0.4	–	–	–	–
Cobalt	–	3	–	–	–	2.0	1.1	–	–	–	–
Approximate Total Unfueled Weight(5)	965	930	1125	730	1145	783	1560(6)	1480	1010	1410	2110

T – trace
S – small amount as alloy
(1) – Sulphuric acid
(2) – LiCl-NCl
(3) – KOH
(5) – Total includes metallurgical carbon not listed
(6) – Includes 52 pounds of water

NOTE: All data are for system including transmission but not drive shaft and differential axle assembly.

Hittman Associates, Inc.

TABLE 3
CHARACTERISTICS OF ALTERNATE PROPULSION SYSTEMS

System	Power	Weight (lb)	Economy (mpg)	Unit Cost ($)
Baseline - Current Standard ICE	165 hp	965	13.4	910
Advanced Spark Ignition ICE	150 hp	930	12.8	1,277
Advanced Diesel System	150 hp	1125	16.7	1,845
Rotary Combustion (Wankel) System	150 hp	730	13.8	1,231
Rankine Cycle System	150 hp	1145	11.0	1,320
Brayton Cycle (Gas Turbine) System	150 hp	785	11.0	2,220
Stirling Cycle System	150 hp	1560	19.5	3,780
Hybrid: Heat Engine/Electric (Ni-Zn)	Engine 100 hp Storage 11.3 Kw-hr	1480	12.5	2,380
Hybrid: Heat Engine/Flywheel	Engine 100 hp Storage .37 Kw-hr	1010	12.5	1,451
Electric: Alkali Metal Battery (Li-S)	150 hp	1410	1.6 Kw-hr/mi	10,673
Electric: Fuel Cell	150 hp	2110	14.0	10,000

Note: Values are for engines only, as synthesized in 1971

TABLE 4
MEASURE OF IMPACT OF THE ALTERNATIVE PROPULSION SYSTEMS WITH 100 PERCENT TRANSITION

	Advanced ICE	Advanced Diesel	Rotary Engine	Rankine	Gas Turbine	Stirling	Heat Engine/ Electric	Heat Engine/ Flywheel	Battery	Fuel Cell
Change in Jobs (relative to present ICE, in thousands)	−10	+40	−85	+50	−70	+170	+150	+10	+130	+270
% change in cost of engine	+40	+105	+35	+45	+145	+535	+160	+60	+1000	+1000
% change in ownership costs	+5	+5	0	0 (w) +5 (o)	+10	+30	+10	+5	?	?

(w) = water working fluid
(o) = organic working fluid

To reduce this analysis to manageable size, several of these systems were eliminated by applying the following criteria:

1) The system's projected energy and economic impact must be reasonable.

2) Where several systems have very similar impacts, only one shall be analyzed in depth.

3) At least one new and unique system should be chosen for analysis.

4) The systems chosen should all be capable of production by 1985; at least one should be capable of introduction by 1976.

Thus the fuel cell system, the lithium battery, and Stirling-cycle, stratified charge, and diesel engines were not studied in depth.

Following are the characteristics of those systems which were analyzed in the technology assessment, presented according to the size vehicle which it is envisioned they would power.

1) Size 1: full-size, 4000-lb, six-passenger sedan with driving range of 200 miles. The propulsion system studies for this class include:

a) the baseline ICE.

b) an advanced Otto-cycle engine with catalytic emission controls. Today's spark-ignited ICE is an Otto-cycle engine. An advanced Otto cycle is simply this basic engine modified to produce fewer emissions. Several means of controlling these emissions are available: a leaner (higher in oxygen) air/fuel ratio in the carburetor--this both decreases emissions and increases fuel economy; a stratified charge engine, which offsets the driveability defects of a lean air/fuel mixture by injecting more fuel near the spark plug so that the rich volume of air ignites easily and sets off the leaner main air/fuel mixture; a combination of a thermal reactor and catalytic converters; and an exhaust gas recirculation system. This last method was chosen because it is the only one which Detroit is capable of introducing by 1976.

c) a Rankine-cycle engine using "fluorocarbon 85" as the working fluid. A Rankine cycle is comprised of the following processes: the heating of a working fluid (often water, hence the popular name "steam engine") in a burner external to the cycle, transforming the liquid to pressurized vapor; the expanding of the vapor through a machine (i.e., turbine or piston) which converts the heat energy to mechanical energy; and the condensing of the vapor for its return to the boiler. This type of engine has two important advantages. It produces few emissions, and it can burn a great variety of fuels ranging from coal to kerosene to gaseous fuels. But it is much heavier than a conventional ICE, and its best potential fuel economy is only 11 mpg. If a mixture of water and organic "fluorocarbon 85" is used, the engine can operate at lower temperatures and pressures but its thermal efficiency suffers.

d) a gas-turbine, or Brayton-cycle, system. This system operates on the same principle as the jet engine: a rotary compressor compresses incoming air, thus increasing the pressure, which is further raised by combusting fuel; the pressurized air then expands through a turbine, thereby propelling the drive train. This system is considerably (180 lb) lighter than an ICE, and moreover is very compact and smooth running. It can burn low grades of fuel and emits low levels of pollutants. But it is expensive to build such an engine, with its continuous high speed and pressure operation.

2) Size 2: subcompact, 2500-lb, four-passenger sedan with a driving range of 200 miles. The propulsion systems studied for this class of vehicles include:

a) a small advanced Otto-cycle engine with catalytic emission controls.

b) a rotary-engine Otto cycle with catalytic emission controls. The rotary, or Wankel, engine is of the internal combustion type, but its "piston" is a flat, slightly rounded triangle which rotates off-center within the "cylinder," which is shaped like an oval slightly pinched in the middle. This engine is very light, smooth running, and has few moving parts. There are a few technical problems yet to be remedied, and this engine gets slightly lower fuel economy than a conventional Otto-cycle engine. Because it is an ICE, it requires emission controls.

c) a flywheel hybrid system. A hybrid system is one in which a small (less than 100 hp) ICE supplies energy to an energy storage system, in this case a flywheel, which then provides propulsion energy as needed. This type of system does not have a high initial cost and has good fuel economy.

3) Size 3: small, 1600-lb, two-passenger electric urban vehicle. Systems studied for this class include:

a) lead-acid battery with a range of 50 miles.

b) sodium-sulfur battery with a range of 150 miles.

Table 5 below is a summary of the characteristics of advanced propulsion systems as defined in the Hittman document.

TABLE 5
SUMMARY OF CHARACTERISTICS OF SELECTED ADVANCED SYSTEMS

Propulsion System	Abbreviation	Vehicle (Weight) (lb)	Payload (Passengers)	Range (Miles)	Approximate Cost ($)	Fuel Economy (mpg)	Base Emissions(1) (HC, CO, NO_x)
Internal Combustion Engine	ICE	4075	6	200	3670	13.4	(2) (2) (2)
Advanced Otto Cycle	AOC	4005	6	200	3990	11.0	.41 3.4 0.8
Small Advanced Otto Cycle	SOC	2500	4	200	2600	16.0	.41 3.4 0.4
Rotary Otto Cycle (Wankel)	ROT	2345	4	200	2500	16.0	.41 3.4 0.4
Rankine (Organic)	RAN	4200	6	200	4120	10.3	.13 0.2 0.26
Gas Turbine	GT	3867	6	200	4815	11.0	.12 0.7 0.4
Flywheel/ Hybrid	FLH	2500	4	200	3500	17.0	.2 1.7 0.4
Lead Acid Battery	BAT	1600	2	30	2560	$.58 \frac{\text{Kw-hr}}{\text{mi}}$	(3) (3) (3)
Sodium Sulfur Battery	SSB	874	2	150	2810	$.5 \frac{\text{Kw-hr}}{\text{mi}}$	(3) (3) (3)

(1) Emissions are for Federal Driving Cycle.

(2) Emissions for ICE vary according to model year.

(3) Battery emissions are accounted for through central power stations and decrease through the year 2000.

D. Develop a Computer Model to Analyze the Impacts of Transition

The details of the model need not be described here; but its input and output data should be provided, to allow evaluation of the utility and reliability of the program.

The following input data was used:

a) original equipment and aftermarket materials requirements.

b) energy consumed in production, maintenance, and scrapping of each vehicle.

c) energy consumed for operation of each vehicle.

d) calculation of scrap and waste produced during the lifetime of the vehicle, from its manufacture to its disposal.

e)evaluation of the amount of this scrap which could be feasibly recycled.

f) computation of the emissions produced by each vehicle.

g) modification of an input/output model for analyzing the economic impact of the ICE and advanced systems.

h) estimation of vehicle fleet between now and the year 2000.

i) determination of the mean life, by model year, of existing and advanced vehicles.

The model manipulates this information and produces the following output for each propulsion system studied:

a) the yearly consumption of thirty different materials.

b) total yearly energy consumption.

c) national and some regional figures for carbon monoxide, hydrocarbons, nitrogen oxides, sulfur oxides, and particulate emissions.

d) capital and labor requirements per year.

E. Evaluate Government Policy Options

Almost 100 policy options were evaluated in considering which of the advanced systems might come into use. These options can be grouped into three main categories: government subsidies, taxation, and regulation. Table 6 presents the interrelationship of these policies, the advanced systems analyzed, and the scenarios (hypothesized futures) projected by the model. It should be pointed out that any policy directing replacement of the advanced Otto-cycle engine must include a method of forcing the transition, since both manufacturers and consumers favor use of that engine as a minimally disturbing course of action.

TABLE 6
INTERRELATIONSHIP OF POLICIES, SYSTEMS, AND SCENARIOS

	System							Scenario						
	RAN	CT	AOC	SOC	ROT	BAT	FLM	I	II	III	IV	V	VI	VII
A. Government Subsidies														
1. Industry Focus														
a. Massive R&D new prop. ses.	+	+				+	+	+					+	
b. Govt. assumes mfg. tooling costs	+	+		+	+	+	+	+	+				+	
c. Subsidize worker relocation	+	+				+	+	+					+	
d. Govt. support field trials	+	+				+	+	+					+	
e. Govt. support non-polluting fuels	+	+			+	+		+					+	
f. Relief for industries hurt by requirement								+					+	+
2. Consumer Focus														
a. Subsidize non-polluting models														
(1) Lump sum for Δcost	+	+						+					+	
(2) Tax ded. for Δcost	+	+						+					+	
(3) Financial arrangements	+	+						+					+	
(4) Free parking	+	+						+					+	
(5) Free fuel	+	+						+					+	
3. Local Government Focus														
a. Subsidize mass transit											+			
b. Grants to reduce trip generating bldg. & activities											+			
c. Govt. relief to compensate from loss of gas sales											+			
4. Subsidize Scrap Reuse						+								+
B. Tax Policies														
1. Federal and State														
a. Taxes impacting on individuals														
(1) Road taxes											+			
(2) Fuel taxes				+	+	+	+	+	+	+		+	+	
b. Taxes impacting mfgs. and/or individuals														
(1) Emission taxes	+	+		+	+	+	+	+	+		+	+	+	
(2) Size and weight taxes				+	+	+	+		+		+		+	
(3) Horsepower taxes				+	+	+	+		+		+		+	
2. Local														
a. Taxes to control peak hr. traffic														
(1) Parking charges								+			+		+	
(2) Commuter charges											+			
(3) Road or bridge charge											+			
b. Charges not related to peak														
(1) Snow removal—police, etc. charges											+			
3. Reduce Taxes on Scrap Reuse														+

TABLE 6
INTERRELATIONSHIP OF POLICIES, SYSTEMS, AND SCENARIOS—CONTINUED

	System							Scenario							
	RAN	CT	AOC	SOC	ROT	BAT	FLM	I	II	III	IV	V	VI	VII
C. Regulation														
1. Federal-State Emission Requirements														
a. Mfg. regulation + inspection														
(1) Retain maintenance to mfg.	+	+				+	+	+					+	
(2) Mfg. warrantee of performance	+	+				+	+	+					+	
b. User regulation and inspection														
(1) Periodic inspection	+	+				+	+	+					+	
(2) Frequent inspection—older models	+	+				+	+	+					+	
(3) Spot inspection—heavy fines for removal of emission controls	+	+				+	+	+					+	
c. Modify 1976 standards														
(1) Raise 1970 NO_x from 0.4 to 2.0 gm/mi			+						+	+		+		
(2) Impose more stringent standards after 1976 for HC, CO, NO_x	+	+					+	+			+		+	
(3) Introduce SO_x and part standards								+			+			
(4) Vary standards by region	+	+				+	+	+					+	
2. Production Ceilings														
a. Auto manufacturer										+	+			
b. Fuel production				+	+	+	+	+	+	+	+		+	
3. Comprehensive Land Use and Transportation Planning														
a. Mass transit and alt. modes														
(1) Personal mass transit (BAT)						+	+				+		+	
(2) Elect. highways						+	+				+		+	
(3) Elect. utility autos in cities						+	+						+	
(4) Rent vs. own cars													+	
(5) Increased use of taxis													+	
(6) Bicycles											+			
b. Closer living-working arrangements														
(1) Encourage bus move to suburbs											+			
(2) Govt. planning of resid. land use											+			
4. Restrict Fossil Fuel from Certain Areas														
a. Ban FF autos downtown						+	+	+			+		+	
b. Zone areas for intensive land use (autos not necessary)											+			
c. Ban free parking by employers						+	+				+		+	
d. Develop two-vehicle policy				+	+		+		+			+	+	
c. What number and location gas stations					+									
5. Moratorium on Road Building											+			
6. Ration Gas, Oil, Tires				+	+	+	+	+	+	+	+	+	+	
7. Modify Land, Rates, Prop. to											+			
8. Retard Scrap Fraction for Related Materials														+

F. Develop Logical Scenarios of Transition

1. Scenario I - Introduction of very clean vehicles.

Legislation is passed aimed at protecting the environment from automobile pollution. The 1976 and 1977 emissions standards are maintained. Development of the Rankine and gas-turbine systems is subsidized so that they can be introduced in 1977.

A Rankine-cycle engine is very attractive from an emissions standpoint. Its major materials impact is in its heavy consumption of aluminum, but this is not a limiting factor. It has a slightly adverse economic impact since capital and labor requirements would be increased by about 10%, but its projected sales price of $100 more per vehicle than an advanced Otto-cycle vehicle is not prohibitive. Its major drawback--and it is a serious one--is its poor fuel economy (36% higher energy consumption than the baseline ICE by the year 2000).

The gas-turbine engine is also attractive from an emissions standpoint, and does not have a limiting materials impact. But otherwise it is probably unacceptable: it has poor fuel economy and an extremely adverse economic impact (it would cost $800 more than a comparable advanced Otto-cycle engine and has doubtful market acceptability).

2. Scenario II - Introduction of small cars.

In this scenario, both environmental impact and fuel economy are the main concerns of the policy-makers. Full-size advanced Otto-cycle engines do not prove able to meet the fuel economy standards legislated and two new, small vehicles are developed, one rotary and one ICE, both achieving 16 mpg and meeting emissions standards.

This is the recommended strategy for choosing future vehicles. It consumes a minimum amount of energy, produces acceptably low amounts of emissions, and has minimum materials and economic impact. Moreover, production of small cars could be rapidly implemented by the manufacturers. Recommended policies for promoting this scenario include vehicle weight taxes; a graduated excise tax on vehicles achieving less than 18 mpg; higher gasoline taxes; and parking taxes on large cars in urban areas. It is further recommended that the government provide heavy funding for development of the stratified charge engine, in order to avoid the necessity of using expensive, fuel-wasteful catalytic emission controls.

3. Scenario III - No drastic changes.

Transition is made to the advanced Otto-cycle engine, and emission standards are nominally maintained except that a nitrogen oxides level of 0.8 gm/mi, rather than 0.4 gm/mi, is the best effort made by Detroit.

This scenario has a severe energy impact--by the year 2000, the advanced Otto-cycle engine vehicles would consume 20 billion gallons more gasoline than would the baseline ICE. Materials impact, especially that on platinum (which we import, making us uncomfortably dependent on our suppliers) is also unfavorable. The economic impact is significant but not catastrophic, and the emissions are the same as those produced by small Otto-cycle cars. This scenario is therefore judged to be undesirable.

4. Scenario IV - Increase in mass transit.

The government funds heavily urban and intercity mass transit systems. In 1970, mass transit carried 1% of the passenger miles travelled; the authors assume that this percentage could be increased to 14% and that passenger miles will increase to 3000 billion by the year 2000. A 21-fold increase in the capacity of the mass transit systems, requiring a truly massive implementation program, would be necessary to carry this much traffic. A concomitant decrease in automobile ownership is projected, but the decrease would only be from 150 million to 129 million private passenger vehicles. The goal of reducing vehicle demand could be more easily achieved through promotion of heavier load factors--i.e., more passengers/vehicle. This scenario assumes that such a reduction is possible.

Advanced Otto-cycle engine materials and energy requirements are reduced in direct proportion to vehicle demand reduction. Significant decreases in gasoline use and emissions occur.

But despite the gasoline savings, full-scale promotion of mass transit could have negative energy effects, due to the massive effort required to build and expand transit systems. Moreover, this energy would be required in the decades 1975-1994, when fossil fuel supplies will be lowest. Ironically, fossil fuel savings could begin to accrue around the year 2000, but by then other sources of energy (nuclear, solar, geothermal) should be available.

In summary, this scenario is not considered promising--there are few indications that automobile demand could be reduced, and even if it could be, the energy and other savings may not be worth the effort expended.

5. Scenario V - Relaxation of the nitrogen oxides standard.

After study of its environmental effects, the nitrogen oxides standard is increased from 0.4 gm/mi to 2.0 gm/mi. This allows continued production of the advanced Otto-cycle engine without catalytic converters. It would cause an energy consumption increase 50% less than that of the advanced Otto-cycle engine with emission controls, even though the predominant vehicle would probably continue to be a 4000-lb, six-passenger automobile rather than a smaller vehicle. Relaxation of the nitrogen oxides standard would also make use of diesel engines more feasible. It is therefore recommended that nitrogen oxides effects be reevaluated with an eye to relaxing the standard, and if this is done, lightweight diesel engines should be developed.

6. Scenario VI - Two-vehicle strategy.

Socio-political pressures lead to a two-car strategy: non-polluting (in this case, battery-powered) vehicles are introduced into urban areas, where concentrations of pollutants are highest, and heat engine (here, Rankine cycle) vehicles are used outside the cities. Two types of batteries, lead-acid and sodium-sulfur, are considered. Materials impacts of the advanced Otto cycle-battery-Rankine scenario are serious, especially for lead. Its energy impact is also unfavorable--50% higher energy consumption than the ICE by the year 2000. Its environmental impacts, however, are the lowest of any scenario studied.

It is recommended that development of a lightweight battery using abundantly available materials, such as a sodium-sulfur battery, be encouraged. In addition, a more detailed analysis of this strategy should be carried out.

7. Scenario VII - Increased materials recycling.

The transition from the advanced Otto-cycle vehicle to the Rankine vehicle is examined with particular attention paid to aluminum, lead, chromium, nickel, and iron waste. It is concluded that increased recycling of scrap material should be carried out.

ENERGY CONSUMPTION FOR TRANSPORTATION IN THE UNITED STATES

Eric Hirst (Oak Ridge National Laboratory)
Report prepared for the ORNL-NSF Environmental Program
March 1972
ORNL-NSF-EP-15

This report provides a broad view of past, present, and projected future patterns of transportation energy consumption in the United States. In 1970, transportation used 24% of the total U.S. energy budget, an increase of 52% since 1960. A projection of future consumption (referred to as Future I) is made based on this current trend of growth; another projection (Future II) is computed on an assumption of a moderate but steady shift toward more energy-efficient modes. Possible changes in technology which could affect energy use are not taken into account in the second projection. Both models are calculated with the same passenger-miles and freight ton-miles.

Growing consumption of energy by the transportation sector, its increasing dependence on petroleum as a source (95% of the energy used by transportation comes from petroleum), the rising volume of petroleum imports, and a probable future shortage of oil supplies, make necessary an examination of transportation energy consumption. This report constitutes such an examination and demonstrates that increases in energy efficiency are possible without retooling for new technologies and without cutting back total passenger and freight traffic. The increased efficiency could be achieved by shifting from energy intensive to energy economical modes of transport.

Intercity freight transport consumes a significant portion (12%) of the transportation energy budget. It travels by a wide variety of modes (pipelines, waterways, railroads, trucks, and airways) which vary widely both in energy efficiency and in percentage of total freight ton-miles carried. The following table provides figures for past and future traffic and energy consumption. Future I figures are calculated assuming that modal mix changes continue to exhibit the same trends that they have followed for the past twenty years, moving away from railroads towards trucking. Future II figures show the effect of a shift toward more energy-efficient modes.

TABLE 1
INTERCITY FREIGHT TRAFFIC AND ENERGY CONSUMPTION[a]

Year	Ton-Miles Freight (10^9)	Percent of Total Ton-Miles: Railroads	Trucks	Waterways	Pipelines	Airways	Total Freight Energy (10^{12} Btu)	Inverse Efficiency (Btu/ton-mile)
1950	1090	57.4	15.8	14.9	11.8	0.03	980	900
1955	1300	50.4	17.2	16.7	15.7	0.04	1180	910
1960	1330	44.7	21.5	16.6	17.2	0.06	1320	1000
1965	1650	43.7	21.8	15.9	18.6	0.12	1680	1020
1970	1930	40.1	21.4	15.9	22.4	0.18	1980	1030
Future I – Continuation of Current Trends								
1980	2400	37	21	16	25	0.4	2620	1090
1990	2900	35	21	15	28	0.7	3470	1200
2000	3400	34	21	15	29	1.0	4430	1300
Future II – Shift to Greater Energy-Efficiency								
1980	2400	41	18	16	25	0.2	2340	970
1990	2900	42	14	16	28	0.1	2500	860
2000	3400	44	11	16	29	0.1	2760	810

[a]Data from Statistical Abstract (1970) and from Transportation Facts and Trends (1971).

Intercity passenger traffic, moved primarily by automobiles but also by airplanes, buses, and railroads, consumes 33% of transportation energy. Efficiencies for these modes are quite varied: buses consume 1090 Btu's/passenger-mile; railroads, 1700; automobiles, 4250; and airplanes, 9700. From 1950 to 1970, the proportion of intercity passenger traffic carried by automobile remained fairly constant. Bus and train passenger miles fell, with a concomitant rise in airline traffic. This switch to energy-inefficient air travel is mainly responsible for the 14% decline in the energy efficiency of intercity passenger transportation. This decline and the 130% increase in the volume of traffic, together account for a 170% increase in energy consumption for intercity passenger traffic during the last two decades. The following table presents figures for those decades and the two projected futures; the modal shift envisioned in Future II would result in an energy efficiency 31% greater than the figure for the year 2000 in Future 1.

TABLE 2
INTERCITY PASSENGER TRAFFIC AND ENERGY CONSUMPTION[a]

Year	Total Passenger-miles (10^9)	Percent of Total Passenger-miles				Total Energy (10^{12} Btu)	Inverse Efficiency (Btu/passenger-mile)
		Automobile	Airplane	Bus	Railroad		
1950	510	86.8	2.0	5.2	6.4	2,040	4,030
1955	720	89.5	3.2	3.6	4.0	3,000	4,210
1960	780	90.1	4.3	2.5	2.8	3,390	4,340
1965	920	88.8	6.3	2.6	1.9	4,100	4,470
1970	1,180	87.0	9.7	2.1	0.9	5,510	4,690
Future I – Continuation of Current Trends							
1980	1,710	85	13	1.5	0.5	8,370	4,890
1990	2,240	84	15	1.0	–	11,280	5,040
2000	2,770	83	17	–	–	14,340	5,180
Future II – Shift to Greater Energy-Efficiency							
1980	1,710	86	7	4	3	7,570	4,430
1990	2,240	85	3	6	6	9,120	4,070
2000	2,770	84	2	7	7	10,970	3,960

[a]Data from Statistical Abstract (1970) and from Transportation Facts and Trends (1971).

Urban passenger traffic accounts for another large segment (29%) of transportation energy use; 95.4% of the urban passenger miles travelled are covered in automobiles, the most energy intensive (i.e., uneconomical) of all modes. Between 1950 and 1960, energy consumption by urban passenger traffic grew by 166%, due to a decline in energy efficiency of 4.3% and an increase in traffic of 154%. Table 3 shows present and projected modal mixes. In Future I, where automobiles carry 97% and buses only 3% of the traffic, energy efficiency declines 2% between 1970 and 2000. In Future II, where walking and bicycling move 3% of urban passenger traffic, energy efficiency increases 8% between 1970 and 2000.

TABLE 3
URBAN PASSENGER TRAFFIC AND ENERGY CONSUMPTION[a]

Year	Total Passenger-miles (10^9)	Percent of Total Passenger-miles			Total Energy (10^{12} Btu)	Inverse Efficiency (Btu/passenger-mile)
		Automobiles	Buses	Walking, Bicycles		
1950	388	89.6	10.4	–	1,810	4,670
1955	466	91.5	8.5	–	2,200	4,730
1960	585	92.6	7.4	–	2,790	4,770
1965	764	94.0	6.0	–	3,690	4,830
1970	987	95.4	4.6	–	4,820	4,880
		Future I – Continuation of Current Trends				
1980	1,410	97	3	–	6,970	4,950
1990	1,830	98	2	–	9,120	4,980
2000	2,250	98.5	1.5	–	11,250	5,000
		Future II – Shift to Greater Energy-Efficiency[b]				
1980	1,410	91	6	3	6,590	4,680
1990	1,830	89	8	3	8,420	4,600
2000	2,250	87	10	3	10,180	4,520

[a]Data from Statistical Abstract (1970) and Federal Highway Administration (1971).

[b]The transportation energy required for walking/bicycling is not included in this table because these energies are small relative to motor vehicle energy requirements.

For a summary of Future I and II projections of transportation energy requirements, see Table 4. It should be emphasized that the 20% reduction in energy consumption shown in Future II could be achieved simply by shifting to more energy efficient modes; reduction in total freight and passenger mileage and technological improvements in energy efficiency would presumably save even more energy.

TABLE 4
TOTAL COMPUTED TRANSPORTATION ENERGY REQUIREMENTS AND ACTUAL TOTAL[a]

Year	Intercity Freight (10^{12} Btu)	Intercity Passenger (10^{12} Btu)	Urban Passenger (10^{12} Btu)	Total Computed (10^{12} Btu)	Total Actual (10^{12} Btu)	Computed / Actual (%)
1950	980	2,040	1,810	4,830	8,724	55.4
1955	1,180	3,000	2,200	6,380	9,904	64.4
1960	1,320	3,390	2,790	7,500	10,881	68.9
1965	1,680	4,100	3,690	9,470	12,771	74.2
1970	1,980	5,510	4,820	12,310	16,495	74.6
		Future I – Continuation of Current Trends				
1980	2,620	8,370	6,970	17,960	21,557	83.3
1990	3,470	11,280	9,120	23,870	–	–
2000	4,430	14,340	11,250	30,020	42,883	70.0
		Future II Shift to Greater Energy-Efficiency				
1980	2,340	7,570	6,590	16,500		
1990	2,500	9,120	8,420	20,040		
2000	2,760	10,970	10,180	23,910		

[a]Data in 2nd through 4th columns from Tables 1, 2, and 3. Column 5 is sum of preceding three columns. Last column is the quotient of the two preceding columns.

TABLE 5
TOTAL ENERGY REQUIREMENTS FOR AUTOMOBILES IN THE U.S.[a]

	1960 (10^{15} Btu)	1968 (10^{15} Btu)	1970[b] (10^{15} Btu)
1. Gasoline Consumption	5.60	7.96	8.95
2. Petroleum Refining	1.15	1.64	1.84
3. Automobile Manufacturing	0.78	1.05	0.71
4. Automobile Retail Sales	0.77	0.99	0.82
5. Repairs, Maintenance, Insurance, Replacement Parts, Accessories, Parking, Tolls, Taxes, Etc.	3.03	3.95	4.44
TOTAL (10^{15} Btu)	11.33	15.59	16.76
Total Automobile Mileage (10^9 miles)	588	814	901
Total Energy Required (Btu/mile)	19,270	19,150	18,620
(milles/gallon)	7.06	7.10	7.31
Total U.S. Energy Consumption (10^{15} Btu)	44.96	62.45	68.81
Percent of Total Energy Consumption Devoted to Automobiles	25.2	25.0	24.4

[a]The figures presented here are approximate.

[b]The 1970 figures are low for manufacture and sale of automobiles. This is probably due to the economic condition of the country that year, and may not represent a long-term secular decline in automotive energy consumption.

All the figures presented thus far assume that modal energy efficiencies remain the same over a period of time. This is not really the case, however; for instance, during the 1950's and 1960's, the energy efficiency of the railroads increased by almost 500% due to the switch to diesel locomotives. During the same period, the energy efficiency of airplanes dropped sharply due to the higher average speeds at which they now travel. Automobiles, buses, and trucks also showed declines in energy efficiency over the last twenty years, and emission control regulations could further cut into fuel economy.

In 1950, automobiles alone consumed 8.95×10^{15} Btu's of fuel, using 55% of the transportation energy budget, or 13% of the total energy expenditure. However, when the indirect energy (used to refine petroleum, build highways, manufacture automobiles, etc.) consumed by automobiles is considered, we discover that automobiles devour a total of 24.4% of the U.S. energy budget. Table 5 shows the total energy requirements for automobiles in 1960, 1968, and 1970. (The figures for manufacture and sale of automobiles are low for 1970, a situation probably caused by the nation's economic condition that year.) The author points out that his calculations are very approximate, especially those of the energy needed to maintain, repair, insure, park, tax, etc., automobiles; conclusions drawn from them should be considered with caution.

This report demonstrates the many energy-saving benefits which could be derived from shifts to more efficient modes. There are additional incentives: a decrease in fuel consumption, for example, would reduce vehicle emissions, a large contributor to air pollution. However, these incentives have not sufficed to prevent the shift over the last two decades to more energy intensive modes. Hirst does not investigate the reasons for this, but he does examine the U.S. Department of Transportation's Statement on National Transportation Policy (1971) for possible explanations. He finds some in the varying degrees of regulation which the federal government imposes on the transportation modes. Automo-

TABLE 6
DISTRIBUTION OF ENERGY WITHIN THE TRANSPORTATION SECTOR

	% of Total Energy	
	1960	**1970**
1. Automobiles		
urban	25.2	28.9
intercity	27.6	26.4
	(52.8)	(55.3)
2. Aircraft		
freight	0.3	0.8
passenger	3.8	6.7
	(4.1)	(7.5)
3. Railroads		
freight	3.7	3.2
passenger	0.3	0.1
	(4.0)	(3.3)
4. Trucks		
intercity freight	6.1	5.8
other uses[a]	13.8	15.3
	(19.9)	(21.1)
5. Waterways, freight	1.1	1.0
6. Pipelines	0.9	1.2
7. Buses	0.2	0.2
8. Other[b]	17.0	10.4
Total	100.0%	100.0%
Total Transportation Energy Consumption (10^{15})	10.9	16.5 Btu

[a]Data from Federal Highway Administration, Highway Statistics.

[b]Includes passenger traffic by boat, general aviation, pleasure boating, and non-bus urban mass transit, as well as the effects of historical variations in modal energy-efficiencies.

biles, for example, operate free of most constraints (only recently have safety and emission controls been imposed) and the highways they travel are federally financed to a large extent. In marked contrast, railroads are minutely regulated and until the establishment of Amtrak received almost no federal funding. Mass transit, too, has been noticeably under-endowed and understudied, while 65% of the FY 1970 research and development funds were spent on air transportation modes. A change in federal regulations, and a greater unwillingness to pay for the negative by-products of huge transportation energy use (such as high fuel prices, air pollution, noise pollution, and urban congestion) may instigate a shift toward greater energy efficiency for transportation.

See Table 6 for a summary of energy use within the transportation sector. The group designated "Other" includes general aviation, non-bus urban mass transit, private pleasure boating, and passenger traffic by boat.

Appendix: Details of Automobile Energy Cost Computation

This provides specific figures and sources for Hirst's calculations of total energy consumed by automobiles. For these figures, he has relied heavily on a report by W.A. Reardon (Battelle Northwest Laboratories) entitled An Input/Output Analysis of Energy Use Changes from 1947 to 1958 and 1958 to 1963. (1971)

Hirst has written a more recent report on this topic, Energy Intensiveness of Passenger and Freight Transport Modes 1950-1970 (April 1973). It was decided to abstract the earlier report rather than the later one since Energy Consumption for Transportation in the U.S. includes scenarios showing the projected effects of two responses to the need for transportation energy conservation. Figures on modal energy consumption, however, are much more detailed in the 1973 report and have therefore been included as an appendix to this abstract.

APPENDIX

The following tables are taken from:
Eric Hirst (Oak Ridge National Laboratory)
Energy Intensiveness of Passenger and Freight Transport Modes 1950-1970.
April 1973. ORNL-NSF-EP-44

TABLE 1
AUTOMOBILE TRAFFIC AND ENERGY CONSUMPTION

	IC		Urban		Total		Average EI Btu/PM
	Traffic 10^9 PM	EI Btu/PM	Traffic 10^9 PM	EI Btu/PM	Traffic 10^9 PM	Energy 10^{12} Btu	
1950	430	3200e	260	7600e	690	3300	4800
1955	630	3300e	310	7900e	950	4600	4800
1960	730	3300e	400	8000e	1130	5600	5000
1965	800	3300e	530	7900e	1330	6800	5200
1970	970	3400e	690	8100e	1670	8900	5400

TABLE 2
TRUCK TRAFFIC AND ENERGY CONSUMPTION

	IC Freight			Other		Total	
	Traffic 10^9 TM	EI Btu/TM	Energy 10^{12} Btu	Traffic 10^9 VM	Energy 10^{12} Btu	Traffic 10^9 VM	Energy 10^{12} Btu
1950	170	2400e	410e	76	1000e	91	1400
1955	220	2400e	530e	93	1300e	110	1800
1960	290	2900e	820e	98	1300e	130	2200
1965	360	2400	870	140	1800	170	2700
1970	410	2800	1140	180	2300	220	3500

TABLE 3
DOMESTIC AIRCRAFT TRAFFIC AND ENERGY CONSUMPTION

	IC Passenger		IC Freight		Subtotal Energy[a] 10^{12} Btu	Domestic Military Energy 10^{12} Btu	General Aviation Energy 10^{12} Btu	Total Energy 10^{12} Btu
	Traffic 10^9 PM	EI Btu/PM	Traffic 10^9TM	EI Btu/TM				
1950	9.3	4500e	0.30	23000e	49e	87e	12e	150e
1955	21	4800	0.49	24000	110	360e	23	490e
1960	32	6900	0.89	35000	250	540	29	820
1965	54	8200	1.9	41000	520	640	43	1200
1970	110	8400	3.4	42000	1060	620	96e	1800e

[a]Subtotal Energy is the sum of commercial passenger and freight energy.

TABLE 4
RAILROAD TRAFFIC AND ENERGY CONSUMPTION

	IC Freight		IC Passenger		Total Energy 10^{12} Btu
	Traffic 10^9 TM	EI BTU/TM	Traffic 10^9 PM	EI Btu/PM	
1950	630	3100	33	7400	2200
1955	660	1200	29	3700	890
1960	600	790	22	2900	540
1965	720	720	18	2700	570
1970	770	670	11	2900	550

TABLE 5
BUS TRAFFIC AND ENERGY CONSUMPTION

	IC		Urban		School		Total	
	Traffic 10^9 PM	EI Btu/PM	Traffic 10^9 PM	EI Btu/PM	Traffic 10^9 PM	EI Btu/PM	Traffic 10^9 PM	Energy 10^{12} Btu
1950	26	640e	24	3100	14e	760e	64e	100
1955	26	1100e	18	3400	–	–	–	110
1960	19	1500	16	3400	25e	1200e	60e	110
1965	24	1600	15	3500	–	–	–	120
1970	25	1600	13	3700	38e	1100e	76e	130

TABLE 6
URBAN MASS TRANSIT TRAFFIC AND ENERGY CONSUMPTION

	Electric		Bus[a]		Total		Average EI Btu/PM
	Traffic 10^9 PM	EI Btu/PM	Traffic 10^9 PM	EI Btu/PM	Traffic 10^9 PM	Energy 10^{12} Btu	
1950	22	3900	24	3100	46	160	3500
1955	13	3800	18	3400	31	110	3500
1960	8.9	3900	16	3400	25	89	3600
1965	7.6	3900	15	3500	22	81	3700
1970	7.2	4100	13	3700	20	76	3800

[a]Data for urban buses also included in Table 5.

TABLE 7
DOMESTIC WATERWAY FREIGHT TRAFFIC AND ENERGY CONSUMPTION

	Traffic 10^9 TM	EI Btu/TM	Energy 10^{12} Btu
1950	420e	730	310
1955	480	690	330
1960	480	620	300
1965	490	450	220
1970	600	680e	410e

TABLE 8
HISTORICAL ENERGY CONSUMPTION PATTERNS FOR TRANSPORTATION

Year	Total Traffic	Percent of Total Traffic						Total Energy (10^{12} Btu)	Average EI
		Air	Truck	Rail	Water & Pipeline	Auto	Bus[a]		
				Intercity Freight Traffic					
1950	1350[b]	0.02	13	47	41	–	–	2700	2000[d]
1960	1600	0.05	18	38	44	–	–	1800	1100
1970	2210	0.15	19	35	46	–	–	2400	1100
				Intercity Passenger Traffic					
1950	500[c]	2	–	7	–	86	5	1700	3400[e]
1960	800	4	–	3	–	91	2	2700	3400
1970	1120	10	–	1	–	87	2	4300	3800
				Urban Passenger Traffic					
1950	310[c]	–	–	–	–	85	15	2100	7000[e]
1960	430	–	–	–	–	94	6	3300	7700
1970	710	–	–	–	–	97	3	5700	8000

[a]Intercity bus or urban mass transit

[b]Billion ton-miles.

[c]Billion passenger-miles.

[d]Btu/ton-mile.

[e]Btu/passenger-mile.

TABLE 9
DISTRIBUTION OF ENERGY WITHIN THE U.S. TRANSPORTATION SECTOR

	Percent of Total Energy		
	1950	1960	1970
1. Automobiles	(38.0)	(51.4)	(54.2)
urban	22.3	29.2	34.2
intercity	15.7	22.2	20.0
2. Trucks	(16.6)	(19.8)	(21.1)
intercity freight	4.7	7.5	6.9
other	11.9	12.3	14.2
3. Railroads	(25.2)	(4.9)	(3.3)
freight	22.4	4.3	3.1
passenger	2.8	0.6	0.2
4. Airplanes	(1.7)	(7.5)	(10.8)
passenger	0.5	2.0	5.6
freight	0.1	0.3	0.8
general aviation	0.1	0.3	0.6
military	1.0	4.9	3.8
5. Buses	(1.1)	(1.0)	(0.8)
urban	0.8	0.5	0.3
intercity	0.2	0.3	0.25
school	0.1	0.2	0.25
6. Non-bus urban mass transit	1.0	0.3	0.2
7. Waterways, freight	3.6	2.8	2.5
8. Pipelines	0.7	0.9	1.2
9. Other[a]	12.1	11.4	5.9
Total Transportation Energy Consumption[b] (10^{15} Btu)	8.7	10.9	16.5

[a] "Other" (the difference between Bureau of Mines totals and the sum of lines 1-8) includes passenger traffic by boat, pleasure boating, nonfuel uses of energy (lubricants, greases), nonaviation military fuel uses, and errors due to the use of approximations and assumptions.

[b] As reported by the Bureau of Mines.

TABLE 10
INTERCITY FREIGHT TRANSPORT DATA FOR 1970

	EI Actual (Btu/TM)	Price (¢/TM)	Haul Length (miles)	Speed (mph)
Pipeline	450	0.27	300	5
Railroad	670	1.4	500	20
Waterway	680	0.30	1,000	—
Truck	2,800	7.5	300	∿40
Airplane	42,000	21.9	1,000	400

TABLE 11
PASSENGER TRANSPORT DATA FOR 1970

	EI (Btu/PM)		Load Factor (%)	Price (¢/PM)	Fatality Rate (deaths per 10^8 PM)	Haul Length (miles)	Speed (mph)
	Actual	100% LF					
			Intercity				
Bus	1600	740	46	3.6	0.10	100	45
Railroad	2900	1100	37	4.0	0.09	80	40
Automobile	3400	1600	48	4.0	3.25	50	∿50
Airplane	8400	4100	49	6.0	0.13	700	400
			Urban				
Mass transit	3800	760	20	8.3	0.26	3	∿15
Automobile	8100	2300	28	9.6	2.11	6	∿20

TRANSPORTATION ENERGY CONSERVATION: OPPORTUNITIES AND POLICY ISSUES

Eric Hirst (Oak Ridge National Laboratory)

Testimony submitted to the U.S. House of Representatives, Committee on Government Operations, Subcommittee on Conservation and Natural Resources, pursuant to hearings on the Conservation and Efficient Use of Energy

July 1973

To meet the energy shortage, we can either increase the supply of energy by developing new technologies, use the energy we have more efficiently, or do both. The advantages of the second strategy are many: it would reduce our dependence on other nations which the large volume of our present imports creates; lower our balance of payment deficits; and provide additional time for development of more efficient energy conversion and pollution control methods.

In 1970, transportation used 16,500 trillion Btu's of energy, or one-fourth of the total energy consumed in the United States. Intercity passenger travel accounted for 6%, urban passenger travel for 9%, intercity freight for 4%, and urban freight and other for 6% of total energy consumption. These 16,500 trillion Btu's represent almost a doubling of energy use over the past twenty years. This increase is due to the larger volume of traffic, both passenger and freight; a decline in the energy efficiency of some of the modes; and a shift of traffic towards more energy intensive (i.e., less energy efficient) modes.

Of all the modes of freight transportation, waterways and pipelines are the most efficient. Railroads are next most energy-economical (and their efficiency has increased since World War II, as a result of the change from coal-burning to steam diesel locomotives). Trucks, which have taken over a larger volume of freight traffic in the last 25 years, are only one-fourth as efficient as railroads. Over the same period, air transport became faster and less efficient--airplanes have one-sixtieth the energy efficiency of trains. Despite the energy intensiveness of trucks and airplanes and a 64% increase in freight traffic, between 1950 and 1970 energy use for inter-city freight decreased by 12%, because of the increased energy efficiency of railroads.

But in the same time span (1950-1970) energy use by intercity passenger traffic grew by 155%, due to a 14% increase in total energy intensiveness (caused by growth of the energy intensiveness of individual modes and the shift to airplanes) and a 125% increase in intercity traffic. During these two decades, energy consumption for urban passenger traffic rose 165%, due to a 132% increase in traffic and a 14% increase in energy intensiveness (caused mostly by the shift from mass transit to autos, which are less than half as efficient and which get their poorest fuel economy in cities). Thus as time passes, energy intensive modes use larger fractions of the energy supply and energy efficient modes use less.

The growth in energy consumption by transportation is explained by several factors, the most important of which (accounting for 46% of the increase) is growth in per capita passenger travel. Other factors are population growth, increase in per capita freight traffic, and the energy inefficiency of the most heavily used modes.

To slow this growth we must in effect reverse the trends which caused it, i.e.:

a) shift to energy-efficient modes

b) use existing transportation systems more heavily, (i.e., increase load factors)

c) engineer better vehicle fuel economy

d) check transportation energy demand as a whole.

The effects of shifts to more economical modes, load factor increases, and technological changes to improve fuel economy are shown in the accompanying table.

TABLE 1
TRANSPORTATION ENERGY CONSERVATION STRATEGIES

FROM 1970 Situation	TO energy-efficient alternative	ENERGY SAVINGS[a] (percent of total transportation energy)
	Passenger traffic: modal shifts	
Intercity auto	Intercity bus	0.22
Airplane	Intercity bus	0.82
Urban auto	Mass transit	0.52
Urban auto	Bicycle	0.90
	Passenger traffic: load factor increases[b]	
Urban auto (28%)	Urban auto (38%)	0.25
Mass transit (20%)	Mass transit (30%)	0.16
Intercity train (37%)[c]	Intercity train (47%)	0.07
	Passenger traffic: technological changes[d]	
Intercity auto (3400)	Intercity auto (2300)	0.13
Urban auto (8100)	Urban auto (5400)	0.33
Airplane (8400)	Airplane (5600)	0.34
Train (2900)[c]	Train (1900)	0.12
	Freight traffic: modal shifts	
Truck	Train	0.26
Airplane[e]	Train	5.01

[a]Energy savings are computed on the basis of a 20 billion passenger-mile (or ton-mile) effect, about 1% of 1970 passenger traffic (or intercity freight traffic). Total transportation energy use in 1970 was 16,500 trillion Btu.

[b]Energy savings are for a 10-percentage-point increase in load factor; numbers in parentheses are load factors.

[c]In 1970 trains carried only 11 billion passenger-miles.

[d]Energy savings are for a 33% reduction in vehicle EI; numbers in parentheses are EI values in Btu/passenger-mile.

[e]In 1970 airplanes carried only 3.4 billion ton-miles of freight.

Specific modifications which could be made to improve auto fuel economy (an efficacious strategy, since autos consume more energy than all the other modes combined) include: lightening of vehicle weight, use of more efficient engines, use of standard rather than automatic transmissions, less use of accessories such as air-conditioning, use of radial tires, better aerodynamic shaping for vehicles, and development and use of alternative power sources. Application of these steps could cut auto energy consumption by 30%. Fuel-economical modifications could be made in other modes as well: deceleration of aircraft speeds would decrease fuel consumption, and use of lightweight construction materials could save railroad energy.

The author considers at length the option of slowing down transportation energy demand, since many changes in the American lifestyle would be required. Implementation of the conservation measures suggested above will necessitate federal government involvement. Governmental regulations could be designed to "internalize external costs of transportation." Transportation services are costly to society: their price is air pollution, urban congestion, airport noise, etc. By increasing the price of transportation services, growth in energy demand could be slowed, and energy-efficient modes would become more attractive. For instance, higher gasoline taxes could make energy intensive autos less alluring.

An area over which the federal government has much more direct control is budgetary spending on transportation. In FY1973, $8 billion was spent on transportation, divided in the following way: 60% on highways, 21% on air transport, 15% on water transport, 3% on mass transit, and 2% on railroads. Thus the most energy intensive modes have been granted favored status, while energy efficient modes have been almost ignored.

Please see Table 2 for suggested policy measures to encourage energy conservation.

It must be emphasized that these alternatives should be judged in light of potential energy conservation, time frame and ease of implementation, costs to the public and individuals, predictability of impact, and interaction with other national goals such as a clean environment.

TABLE 2
SOME TRANSPORTATION POLICY MEASURES TO ENCOURAGE ENERGY EFFICIENCY

Policy	Desired impact
	Urban transportation
	a. Shift traffic from autos to mass transit, walking, and bicycles
Increase fuel taxes	b. Encourage use of cars with high fuel economy
	c. Increase average auto occupancy (e.g., carpools)
New car excise tax related to expected fuel use	(a) and (b)
Increase parking charges and bridge tolls	(a) and (c)
Increase mass transit funding and construction of bikeways	(a)
	Intercity transportation
Increase fuel taxes	a. Shift traffic from autos and airplanes to buses and trains
	b. Improve vehicle fuel economy
Increase Amtrak funding	c. Shift traffic from competing modes to rail
Reduce subsidies for short-haul air travel	d. Shift traffic from air to competing modes
Institute strict noise controls at airports	(d)

"DEMAND FOR ENERGY BY THE TRANSPORTATION SECTOR AND OPPORTUNITIES FOR ENERGY CONSERVATION"

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In: ENERGY, DEMAND, CONSERVATION AND INSTITUTIONAL PROBLEMS. Edited by Michael S. Macrakis. Cambridge: MIT Press, 1974

Civilian transportation consumes directly 25% of the U.S. energy budget (indirect consumption for production and maintenance of vehicles, facilities, fuels, etc., and consumption by military and agricultural vehicles could amount to 50% and 10-15%, respectively, of directly consumed transportation energy). Ninety-nine percent of the energy consumed is in the form of petroleum or petroleum-based fuels: transportation alone uses 50-60% of the petroleum consumed in the United States.

Automobiles and trucks account for approximately 80% of the transportation energy consumed. Thus modifications in existing automobile and truck types could save important amounts of petroleum. Following are "families" of options for petroleum conservation:

a) increase fuel economy and occupancy of vehicles. This could be done by making the vehicles themselves more efficient and by operating them more efficiently (i.e., by driving on non-stop freeways in manual transmission automobiles with no air-conditioning or emission controls).

b) shift demand from energy extravagant to energy efficient modes, and reduce overall transportation demand. This could be done by rationing fuel and travel, instituting a four-day work week, using communication links to replace some travel, designing urban areas to minimize the need for travel, encouraging more walking, etc. Most of these options, however, are controversial.

c) diversify the sources for transportation energy. This could be effected by using non-petroleum based fuels, nuclear power, or electricity. Implementation of this option depends, however, on the development of a technology drastically different from today's.

The extravagant use of energy, because it has been cheap and readily available, has become part of the American lifestyle. Moreover, transportation accounts for 20% of the GNP. Thus when considering transportation energy conservation options, several factors must be kept in mind: the conservation potential of the action contemplated; the impact on the economy, lifestyle, and transportation industry; the capital and time investments needed for implementation; the cost to the users; and the effect of the existing government policy on the proposed action.

Following are specific policies which could be pursued in order to conserve transportation energy:

1) Convert 50% of the passenger car population (which now consumes 5.6% of the transportation energy budget) to small cars with a fuel economy of 22 mpg. This would result in a 9.5% (of the 1970 total transportation energy expenditure) savings. Consumers would benefit since small cars have lower initial and maintenance costs; but the impact on the automobile manufacturers would be large and possibly negative.

2) Reduce fuel consumption by 30% in 50% of highway vehicles; this would save 12.0% in fuel consumption. The authors contend that an efficient highway vehicle providing all the comfort, safety, performance, and low emissions of today's automobiles, only at a slightly higher price, could be achieved by a combination of some of the following improvements in fuel economy:

a) 5-15% savings from modifications on the currently used engine: improvements in ignition, air induction, carburetion, and fuel injection.

b) 10-15% savings from use of a smaller engine with a power booster for acceleration.

c) 10-15% savings if a smaller engine is used with an infinitely variable transmission.

d) 15-20% savings from replacement of the present engine with a lean mixture engine.

e) 3-8% savings if the automobile accessories are driven at a constant rate.

f) 5-10% savings from the use of radial tires.

g) 3-5% savings from a non-major redesign of the automobile body to reduce aerodynamic drag.

The figure of 30% reduction in fuel consumption was arrived at by considering:

1) The preparedness of automobile manufacturers to implement changes within the next rew years.

2) The added cost of the more efficient vehicle versus the resultant savings in fuel bills. Fuel savings can also be gained by designing a light (not necessarily smaller) car.

3) Eliminate 50% of urban congestion; this would conserve 1.1% of the fuel.

4) Reduce highway speed limits to 50 mph and achieve 50% success in enforcing the limit, thus saving almost 3% in fuel.

5) Persuade 50% of urban commuters to carpool, saving 3.3% in fuel consumption (when the extra mileage added for picking up riders is taken into account).

6) Shift 50% of commuters going to and from city centers to dedicated bus service. But since this accounts for only a small percent of all highway miles travelled (6% is the figure computed), only 2.0% savings could be effected.

7) Shift 50% of the intercity automobile travel to bus and rail; this would conserve 3.2% (of the 1970 transportation energy expenditure). Such a shift would, however, require a six-fold increase in intercity bus service and a 25-fold increase in intercity train service.

8) Shift 50% of intercity trucking (defined as including only trucks travelling over 10,000 miles/year) to rail freight, thus saving 3.6% on fuel, but also forcing the trucking industry to absorb a $15 billion per year loss.

9) Shift 50% of short-haul air passengers to intercity bus, saving 0.15% of fuel consumed.

10) Persuade 50% of travellers to walk up to three miles instead of driving. This is unrealistic to expect, however.

Petroleum consumption (though not energy consumption as a whole) could also be cut by diversifying transportation energy sources. To do so, we must have the technological readiness to use non-petroleum energy and such energy must be available. "Novel fuels" (i.e., non-petroleum-based derivatives) and electrical energy are considered in depth. Nine such fuels are evaluated (see Table 1) for various properties (weight, combustion rating, tankage cost, gal/Btu, etc.) compared to gasoline.

Use of electricity as a motive power would undoubtedly save petroleum; but the automobile is the greediest of all transportation energy consumers, and the technology does not currently exist which would allow the production of an all-electric car. The impact of all-electric surface transportation on present and future national electric power generating capacity must also be considered. Based on the assumption of the use of the nuclear breeder for electricity generation, it is projected that soon after the year 2000, power generating capacity will be great enough to provide for all-electric surface transportation.

TABLE 1
RELATIVE PROPERTIES OF CERTAIN NOVEL FUELS FOR REFERENCE PURPOSES

	Relative Gallons per Btu	Relative Pounds per Btu	Weight (lb)	Bulk (cu ft)	Fire Hazard Rating	Toxicity	Combustion Rating	Distribution Logistics	Tankage Cost
Gasoline	1.0	1.0	125	3	F	1–2	G	E	E
Methane (liquid)	1.6	0.9	210	5	F	0–1	E	F	F
Propane	1.1	1.0	185	4	F	0–1	E	F	G
Methanol	1.8	2.1	250	6	G	1–3	G	F	G
Ethanol	1.4	1.6	180	3	G	1–2	G	G	E
Liquid Hydrogen	3.9	0.4	150	>13	P	0	G	P	P
Liquid Hydrogen/ Liquid Oxygen	5.7	3.6	550	>18	P	0	E	P	P
Magnesium Hydride	4.1	4.9	700	>14	P	0	E	P	P
Ammonia	2.0	2.3	300	7	G	3	P	P	F
Hydrazine	1.6	2.3	265	5	E	3	P	P	F

A PERSPECTIVE OF TRANSPORTATION FUEL ECONOMY

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MTP-396

Transportation energy consumption has recently become a subject of major concern and much discussion. The efficiencies of the modes are analyzed in terms of "energy intensiveness," or the amount of energy consumed in producing the transportation service. Energy consumption is measured in Btu's; transportation output is measured in passenger-miles or ton-miles. The preciseness of this definition belies the imprecision with which figures for modal energy consumption are calculated. Different formulas and statistics are used by each of the researchers in the field. (See Table 1 following.)

TABLE 1
REPORTED MODAL FUEL ECONOMY

INVESTIGATOR (REFERENCE)	DOT/ TSC 1	DOT/ OTEP 2	RICE 3	HIRST 4	HIRST 5	NCMP 6	DOT/ OST 7	FRAIZE 8	LIEB 9	AUSTEN 10	MOOZ 11	FLIGHT 12
UNITS	PSGR mpg	PSGR mpg	SEAT mpg	PSGR mpg	PSGR mpg	PSGR mpg	SEAT mpg	SEAT mpg	SEAT mpg	SEAT mpg	PSGR mpg	SEAT mpg
Automobile												
Subcompact							100	100	85	91		
Average	30	30	64	32	38	32				78	25	120
Intercity Bus	110	104	215	125	82	125	300	250	270		78	450
Train												
Cross Country	50	150+	144	80	46	80					50	393
Metroliner			75				210	210				
Commuter			200			100						
Suburban			400			200						
Airplane												
Wide-Bodied Jet			40			22						57-68
Average	16	14	34	14	16	21	52	52	22		18	41

REFERENCES FOR TABLE 1

1. Transportation Systems Center, "Transportation Energy Conservation Options" (DRAFT) Discussion Papers, Report No. DP-SP-11, October 1973.
2. Office of Transportation Energy Policy, U.S. DOT (informal planning papers), November 1973.
3. Rice, R.A., "System Energy as a Factor in Considering Future Transportation," ASME paper 70–WA/Ener 8, December 1970.
4. Hirst, Eric, "Energy Consumption for Transportation in the U.S.," Oak Ridge National Laboratory, ORNL-NSF-EP-15, March 1973.
5. Hirst, Eric, "Energy Intensiveness of Passenger and Freight Transportation Modes," ORNL-NSF-EP-44, April 1973.
6. National Commission on Materials Policy, Final Report, June 1973.
7. U.S. DOT, Office of the Secretary, "High-Speed Ground Transportation Alternatives Study," January 1973.
8. Fraize, W.E., P. Dyson, S.W. Gouse, Jr., "Energy and Environmental Aspects of U.S. Transportation," MITRE paper MTP-391, February 1974.
9. Lieb, J., MITRE internal memorandum D24-M2488, July 1973.
10. Austen and Hellman, "Passenger Car Fuel Economy - Trends and Influencing Factors," SAE paper 730790, September 1973.
11. Mooz, W.E., "Energy Trends and Their Future Effects Upon Transportation," RAND Corp. Paper P-5046, July 1973.
12. FLIGHT International, "Where has all the fuel gone," November 1973–NOTE: values for European vehicles.

This paper sets out to put these differing systems of measurement into perspective. As an initial attempt at clarification, the author converts the energy intensiveness term into the more familiar figure of fuel economy, quantified in passenger- or ton-miles per gallon. The terms are directly convertible in most cases, since almost all transportation is powered by petroleum and the number of Btu's per gallon is fairly constant.

The calculation of energy consumption involves many variables: sources of data (sources as diverse as the National Association of Motor Bus Owners and the Federal Highway Administration were consulted by various analysts in order to estimate intercity bus fuel consumption), reliability of records kept, measurement in passenger-miles or seat-miles, and the varying degrees of fuel economy, due to differing designs, of the vehicles within one mode.

The author chooses airline fuel consumption to review in detail, because the airlines are closely regulated and required to keep itemized records. The relative wealth of information available does not, however, simplify the calculation of the fuel economy of air transportation. Rather, it emphasizes the impossibility of arriving at a single figure for all the airlines. Flight distance, aircraft type, seating configuration, and scheduling all affect each trip's and each airline's fuel consumption. Load factor can be eliminated as a variable bv calculating seat-miles instead. When fuel economy is plotted on a graph for the three types of wide-bodied jets on the basis of gallons of fuel burned per hour, average speed, trip time, number of passengers, and number of seats, the points on the graph do not form a neat line or curve and are indeed markedly scattered. This scatter may be caused by the various seat configurations used by the airlines--some companies, for example, put more seats into the Boeing 747 than do others, thus making the basic unit of measurement, the seat-mile, a variable itself. Fuel burned for ground operations and nonrevenue trips further complicates and blurs the calculation. In spite of all the uncertainties and margins for error, an interesting similarity does come to light: DC-10's (jumbo jets) and a six-passenger automobile get roughly the same average fuel economy. "Roughly" and "average" should be emphasized; it has been shown how varied are the figures for airline fuel economy, and fuel economy varies even more widely among automobile models. Vehicle size and weight are the most influential factors, and because they are so diverse the figure for "average" fuel economy, given for a 3750-lb car, is not really representative.

Aircraft, buses, and automobiles all tend to be sized by peak load considerations; since peak conditions occur infrequently, these vehicles are run inefficiently. Railroads have an inherent advantage in their sizing flexibility. Indeed, theoretically trains have the best fuel economy potential of all the major modes: low aerodynamic drag, low rolling friction, and little necessity for fuel-wasteful stopping and starting such as ground vehicles experience in traffic. In practice, however, railroads do not achieve good fuel economy, due to their poor streamlining, low seating density, heaviness, and inefficient operating techniques. Thus, although trains have the ability to achieve the same fuel economy at 100-120 mph that buses do at 60 mph, they actually travel fewer passenger-miles per gallon than do buses.

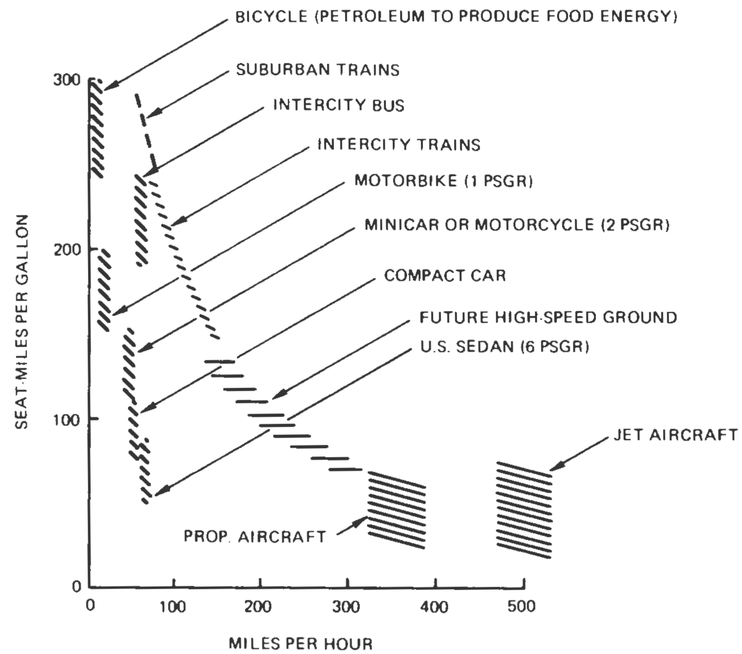

FIGURE 1. MODAL COMPARISON OF FUEL ECONOMY

As the preceding figure shows, the vehicles divide themselves into two classes of fuel economy: those achieving less than 100 seat-miles per gallon, including automobiles, aircraft, and high-speed ground transportation; and those achieving over 100 seat-miles per gallon, including bus, rail, and bicycles.

Determining modal fuel economies is not, however, an end in itself; the knowledge can be useful to planners for estimating the fuel usage of extant or planned transportation systems. But fuel economy figures, as has been emphasized, must not be blindly accepted as fact. It should be remembered that:

a) figures given are estimates, based on slanted or incomplete data.

b) figures measured in passenger-miles represent (as nearly as possible) the present fuel economy of the mode, not its potential economy; but:

c) the theoretical fuel economy potential is often unachievable in practice.

d) railroad and bus modes have the best potential fuel economy in the under 70-mph speed class.

e) automobiles, aircraft, and tracked levitated vehicles all have about the same fuel economy.

f) factors other than fuel economy, such as convenience, safety, speed, and comfort, also must be considered in evaluating a transportation system.

ENERGY EFFICIENCIES OF THE TRANSPORT SYSTEMS

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Paper presented at the SAE International Automotive Engineering Congress, Detroit, Michigan, January 8-12, 1973
SAE Paper 730066

This paper is not aimed at advocating or promoting any one transportation system for the future. Rather, having observed the heavy dependence of transportation on petroleum, the author hypothesizes [this paper was written in January 1973] a petroleum squeeze, delineates possible transportation options for dealing with it, and postulates the results of choosing one or another of these options.

It has finally been realized that the world's petroleum reserves are finite. Because the United States probably has no more than 50 billion barrels of proved reserves, and world reserves are probably little higher than 700-800 billion barrels, the author feels that presuming the availability of more than 200 billion barrels over the next 40 years would be overly optimistic. The United States will thus have to adjust to a 5 billion barrel/year petroleum budget rather than assuming a 10 billion barrel/year expenditure. How will we do this? Before suggesting some answers to this question, several assumptions are made: that only 5 billion barrels of petroleum a year are available for transportation to consume; that only 50% of this can be used for automobiles; that Americans continue to expect great personal mobility and private vehicle ownership; and that (using arbitrary figures) this means that public transport carries only 40% of urban and 30% of intercity traffic. Thus two-thirds of overland passenger travel (projected at 2500 billion passenger miles) will have to move in private door-to-door vehicles in the year 2000.

The following table shows past and projected transportation energy consumption with present trends and with energy conservation measures.

TABLE 1
PROJECTED UNITED STATES TRANSPORTATION DEMAND AND ENERGY USE

Gallons and Passenger Miles (billions)	For a Typical Year 1965-1970 Period			With Present Trends 1990-2000 Period			With Energy Conservation 1990-2000 Period		
	Passenger Miles	Gal. of Fuel	PM/g, NPE	Passenger Miles	Gal. of Fuel	PM/g, NPE	Passenger Miles	Gal. of Fuel	PM/g, NPE
Short-haul air	30	2.0	15	90	6.0	15	30	1.0	30
Long-haul air	60	3.0	20	330	16.5	20	120	4.0	30
Intercity bus	25	0.3	83	50	0.5	100	250	2.0	125
Passenger trains	13	0.2	65	30	0.4	75	350	2.8	125
Intercity driving	900	26.0	35	2000	50.0	35	900	15.0	60
Passenger auto-trains	–	–	–	–	–	–	850	8.5	100
Intercity passenger	1028	31.5	32	2500	73.4	34	2500	33.3	75
Inland waterways	290	1.2	240	400	1.6	250	400	1.5	267
Oil pipelines	400	1.5	267	800	2.5	320	500	1.5	333
Regular R.R. freight	700	3.5	200	955	4.0	240	1350††	5.5	240
Intercity trucks	400	8.0	50	700	11.6	60	300	4.0	75
Rail piggyback	50	0.3	170	120	0.6	200	240	1.2	200
Air freight*	5	0.5	10	25	2.5	10	10	1.0	10
Intercity freight	1845	13.8	134	3100	22.8	136	2800	14.7	190
Utility, farming, etc.**	–	10.0	–	–	15.0	–	–	12.0	–
Transit bus and cabs	20	0.5	40	30	0.6	50	80	1.6	50
Rapid transit and RRS	12	0.2	60	18	0.3	60	70	1.0	70
Local and urban trucks	200	10.0	20	300	10.0	30	200	5.0	40
Urban gas autos	620	35.0	18	1000	50.0	20	450	16.3	27
Electric autos	–	–	–	50	2.0	40	300	6.0	50
Private aircraft	9	0.9	10	20	2.0	10	15	1.0	15
Urban and miscellaneous	861	56.6	15	1418	79.9	17	1115	42.9	26
Total United States transport†	3725	91.0	41	6998	159.1	44	6400	77.9	82

*Includes military freight.
**Repair, construction, service vehicles, farm equipment, military, etc.
†Excludes private planes, miscellaneous units, farm equipment, military, etc.
††Includes containers.

To achieve this NPE (National Propulsion Efficiency: the number of passenger- or ton-miles propelled in any system by the consumption of one gallon of transport energy in the fueled engine) of 75 passenger-miles per gallon (PM/g), using 33.3 billion gallons/year, the following performances must be achieved by each of the modes:

a) 60 PM/g in private vehicles--small automobiles carrying 2-3 passengers with a speed limit of 55 mph.

b) for intercity travel in private vehicles to yield 100 PM/g, it must be piggybacked on flatcar trains, which have a higher fuel economy.

c) air transportation could achieve 30 PM/g if air buses capable of carrying 250 passengers are used, travelling with a 60% load factor at 500 mph.

d) buses could be made roomier to increase patronage and load factor from 20-25 to 25-30 passengers, thus achieving 20 PM/g.

e) if trains carried fewer mail, express, and lounge cars, they could carry more seats and passengers. A 100-120 seat, 2400 hp, bi-level coach with a 60% occupancy rate could yield 200 PM/g at 70-90 mph.

Some alternative intercity systems which would completely replace new superhighways or conventional fast rail corridors are being considered. Seven such systems are considered: helicopter VTOL, tilt-wing VTOL, turboprop STOL, hovertrain TACV, electronic highway, and MACH 2.7 U.S. SST. The table below presents projected performance data for each system. As can be seen, only one of these, the elec-

TABLE 2
INFERRED PERFORMANCE, NEW OVERLAND PASSENGER SYSTEMS COMPUTED FROM DESIGN DATA PUBLISHED 1970-1972

	Heli-copter VTOL	Tilt-wing VTOL	Turbo-prop STOL	Hover-train TACV	Magnetic Levitation TACV	Elec-tronic Highway	MACH 2.7 United States SST
No. rev. seats	80	80	120	120(c)	120	120(c)	250
Max hp rate	12,000	15,000	12,000	10,000(e)	12,000(d)	1,000(e)	300,000
Cruise hp	10,000	8,000	9,000	8,000(c)	10,000(d)	800	240,000
Gvw, ton	40	50	70	60	70	40	375
Max speed	170	350	400	250	300	150	1,750
Cruise speed	140	300	350	225	250	125	1,650
Block speed	125	200	250	175	200	100	1,500
Fuel consumption/h, gal	650	550	600	550	650	60	20,000
Gal. fuel/mile	4.2	2.7	2.4	3.1	3.2	0.6	13.3
Average passengers	50	50	75	75	75	75	150
Cruise hp/ton (a)	250	160	130	100	130	20	700(f)
PM/g fuel (NPE)	12	19	31	24	23	125	11
Presumed TOC cost multiplier (b)	20	18	15	15+	15+	30	10.0
Cost/vehicle mile, $	8.40	4.85	3.60	4.65	4.80	1.80	13.30
Cost per passenger mile, ¢	17.0	9.7	4.8	6.2	6.5	2.4	8.8

(a) Excluding horsepower in TACV lift.
(b) To get total operating expense per mile, the "fuel cost" (at 10¢ gal.) is multiplied by this factor.
(c) Including 2000 hp for lift cushions.
(d) Including 1000 hp for magnetic leviation.
(e) Two 50-ft long, 60-seat electric buses of 500 hp each in tandem.
(f) When airborne weight is down to 340 ton.

tronic highway, can meet the desired average of 75 PM/g. The data for the electronic highway are for high-speed (120-150 mph), 20 ton, 60-seat buses, and are calculated assuming that only these common carriers use the system. However, if private automobiles are carried on the highway, the NPE decreases to the low level of a private car on a conventional highway. The author thus predicts that, due to their high costs and poor energy efficiencies, interest in VTOL, STOL, and TACV will die out, and high-speed trains (200 mph) will become the mass transportation mode of the future. The author also envisions private automobiles making intercity trips via high-speed flatcar autotrains.

Urban transportation energy reduction is also examined. The author believes that the consolidation of freight and goods deliveries and the banning of through motor freight vehicles will effectively reduce urban trucking energy consumption. Urban passenger travel is projected to reach 870 billion passenger miles by the year 2000. The author predicts that, at best, only 70 billion of these will be carried by rapid transit and suburban trains; the rest will move in buses and gasoline or electric automobiles. If half of private urban vehicles were powered by electricity, and public transportation were expanded somewhat, urban transportation energy consumption could be cut by one-third, and urban petroleum use by half.

The author thus does not see curtailment of travel or goods movement as an inevitable result of transportation energy conservation. Transportation systems are already available with much higher energy efficiencies than today's--even without electrification, the amount of petroleum consumed per unit of traffic could be cut in half. If some vehicles and modes were converted to run on electric power (provided by non-petroleum generated plants), transportation petroleum use--though not total transportation energy consumption--could be further reduced.

If petroleum consumption in the year 2000 is limited to 80 billion gallons/year, with more efficient transportation systems 6400 billion unit-miles could still be moved. This could be accomplished by shifting 30% of intercity passenger traffic to public carriers (fast buses, air-bus planes, or very high-speed trains). But 200 million private automobiles could still be owned, allowing Americans to continue their auto-dependent lifestyle with a minimum of changes. Load factors in urban gasoline-fueled automobiles would have to be increased; the present 620 billion passenger miles travelled with 1.3 occupants/auto would have to be decreased to 450 billion PM with a load factor of 1.6. But small all-electric autos could carry an additional 300 billion passenger miles.

This modal mix--which the author does not claim as the only or the best such transportation energy-conserving model--could not only allow the United States to continue to expand its transportation output and mobility in the face of the petroleum shortage, but could even double the country's transportation volume while using less petroleum and energy than at present. The use of piggybacked car carriers and small electric automobiles would even allow private automobile ownership to continue to increase.

DEFINITIONS

1. **MACH 2.7 SST**--supersonic transport aircraft moving at 2.7 times the speed of sound.
2. **STOL**, turboprop--Short Take-Off and Landing aircraft, moved by propellers driven by turbojets.
3. **TACV** (Hovertrain)--Tracked Air Cushion Vehicle, or one which moves along a track resting on a cushion of air rather than on wheels or tires. Popularly called a Hovertrain.
4. **VTOL**--Vertical Take-Off and Landing aircraft. It may be a helicopter (fixed horizontal propeller) or tilt-wing aircraft, in which the propellers (attached to the moveable wings) provide thrust when in the vertical position, and lift when in the horizontal position.

TRANSPORTATION ENERGY CONSERVATION OPTIONS (DRAFT)

David Rubin, J.K. Pollard, and Chris Hornig (U.S. Department of Transportation, Transportation Systems Center)

1973 DOT–TSC–OST–74–2

Transportation currently accounts for 25% of the direct energy consumption in the U.S., and 40% of the indirect energy consumption. Consequently, in any attempt to increase the productivity of fuel, transportation is a large factor. This report discusses conservation measures which should inhibit growth in fuel consumption without inhibiting economic growth. Only those options offering potential savings of at least one billion gallons of fuel per year and capable of implementation within 15 years are considered here. For each measure, summary sheets include the "ultimate limit," the maximum savings practicably achievable without economic disruption; a "fifteen-year limit" attainable by 1988, and a "five-year limit" attainable by 1978. It should be kept in mind that some of these measures are competitive. Savings are given in terms of refined fuel: savings in barrels of crude oil would be 1.21 times this amount. Somewhat offsetting this is the fact that any measure which saves the consumer money will lead to increased spending on other goods which are produced with energy. This will cut savings 11%.

1. High Efficiency Autos

Automobiles use over half of the transportation energy consumed. Recently, automotive fuel economy has been declining due to increases in weight and power and to stricter air pollution control requirements. Improvements in fuel economy can be accomplished by reducing auto size, weight, and power and/or by improving the efficiency of the engine and power train. The former is being informally achieved by consumer preferences for smaller cars. The latter can produce up to 50% reduction in fuel consumption through such measures as transmission improvements and shifts to stratified charge or diesel engines. Impediments to this improvement are the lack of a working production prototype, high investment requirements, and auto company preference for selling larger, more profitable, cars. Retooling of auto manufacturing plants takes at least three years, and each plant must be closed temporarily for the conversion. Operating costs of the vehicles will be lower, and air pollution will be reduced. Although small cars have been considered less safe, a well-designed and built compact is as safe as a standard size car. American cars might be able to compete with foreign cars abroad, as an additional advantage.

Summary Sheet 1

Measure: High-Efficiency Autos

Fuel Saving:
- Ultimate Limit (25-mpg fleet avg.) — 20+ %
- Practical, 15-yr. Limit (20-mpg fleet avg.) — 15.3 %
- Practical, 5-yr. Limit (14.6-mpg fleet avg.) — 4.0 %

Efficiency:
- Before Implementation (1.9 PM/VM, 13.6 mpg) — 4837 BTU/pax-mile or ton-mile
- After Implementation — 3289 BTU/pax-mile or ton-mile

Costs:
- Investment $ 10 B; 20 % Change
- User 0.5 difference in ¢/pax-mile; or ton-mile — -10 % Change

Timing: Years to Achieve Maximum Practical Benefit 20+

Travel Time: No Change % Change

Environmental:
- Air Quality: Minor Improvement (high-efficiency cars assumed to have same emission per mile as low-efficiency cars, but reduced fuel demand cuts industrial emissions)
- Non-Fuel Resources: Reduction proportional to decline in average auto weight
- Other: NA

Safety: Minor degradation

2. High Efficiency Trucks

Trucks are, in general, more efficient than cars, as most are diesel powered and have complex but highly efficient transmissions. The trend is for an even higher percentage of trucks to become diesel. Development of a light-duty diesel for single-unit trucks could improve average truck fuel economy further. Light trucks (pickups, etc.) can be categorized with cars for fuel economy purposes. Increased dieselization will require a two-billion-dollar plant conversion investment. Mechanics would also have to be retrained. The initial cost of diesel vehicles is higher, but maintenance and fuel costs are sufficiently lower to make the change economical for the consumer.

Summary Sheet 2

Measure: High-Efficiency Trucks

Fuel Savings:
- Ultimate Limit: 5.4 %
- Practical, 15 yr. Limit: 5.4 %
- Practical, 5 yr. Limit: 2.2 %

Efficiency:
- Before Implementation: 2714 BTU/ton-mile (9.38 TM/VM, 5.42 mpg combinations)
- After Implementation: 2362 BTU/ton-mile (9.38 TM/VM, 6.23 mpg combinations)

Costs:
- Investment: $ 3 B; ~20 % Change
- User: -0.3 difference in ¢/ton-mile; –(∿3) % Change (intercity freight at current fuel prices)

Timing: Years to Achieve Max. Practical Benefit: 15

Travel Time: No Change % Change

Environmental:
- Air Quality: Minor gain (as for autos)
- Non-Fuel Resources: No change
- Other: No change

Safety: No change

3. Reduced Speed Limits

Reducing the speed limit can increase fuel economy, but only if the lower limit is obeyed. The historic trend is towards increased speeds, and, after an initial period of compliance, disobedience of the lower speed has been widespread. The increased travel time has an adverse economic impact, especially on the trucking industry, as terminals are located ten hours apart at the higher speeds. On the beneficial side, lower speeds reduce the frequency and severity of accidents. Implementation of lower speed limits is relatively simple and economical, but enforcement, if necessary, might well be costly and energy consuming.

Summary Sheet 3

Measure: Vehicular Efficiency: Speed Limits

Fuel:
- Ultimate Limit (50 mph): 2.9 %
- Practical, 15 yr. Limit (50 mph): 2.9 %
- Practical, 5 yr. Limit (50 mph): 2.9 %

Efficiency:
- Before Implementation: 3470 BTU/pax-mile or ton-mile (2.4 PM/VM, 15 mpg)
- After Implementation: 3063 BTU/pax-mile or ton-mile (2.4 PM/VM, 17 mpg)

Costs:
- Investment: $ .02 B; negligible % Change
- User: -0.15 difference in ¢/pax-mile; -8 % Change (but slight savings on fuel will be wiped out by value of lost time)

Timing: Years to Achieve Maximum Practical Benefit: 3

Travel Time: Up To 40% Increase % Change

Environmental:
- Air Quality: Minor favorable effect (emissions from most engines increase as speed increases from 50 mph)
- Non-Fuel Resources: No change
- Other:

Safety: Favorable if limits obeyed, uncertain (probably unfavorable) if compliance mixed

4. Carpooling

Another measure which can be implemented in a short time is carpooling. Only 25% of commuters presently share a car, leaving a large group of potential carpoolers. Increased vehicle sharing reduces costs of the consumer, air pollution, noise, and traffic congestion, at the expense of privacy and independence. Currently, carpooling is more likely for longer distances. The physical limit for sharing averages 4.8 passenger miles per vehicle mile, but the practical limit is much lower due to geographic distribution, etc. Should carpooling become widespread, the gasoline and auto service industries are likely to suffer, as are local and state revenues from parking, tolls, and gasoline taxes. Up to 500,000 jobs might be eliminated at maximum implementation levels. It appears that a workable goal is 1.6 passenger miles per vehicle mile, resulting in a 3% savings in transportation energy.

Summary Sheet 4

Measure: Load Factor: Carpooling (work trips only)

Fuel Savings:
Ultimate Limit (3.0 PM/VM) — 10 %
Practical, 15 yr. Limit (2.0 PM/VM) — 5 %
Practical, 5 yr. Limit (1.6 PM/VM) — 3 %

Efficiency:
Before Implementation (1.34 PM/VM, 12.0 mpg) — 6510 BTU pax mile
After Implementation (2.0 PM/VM, 12.0 mpg) — 3931 BTU pax-mile

Costs:
Investment $ Negative B. — NA % Change
User -(2 to 4) ¢/pax-mile difference in — (-15 to 35) % Change

Timing: Years to Achieve Max. Practical Benefit — 2+

Travel Time +(10 to 40), highly variable % Change

Environmental:
Air Quality: Major favorable impact, proportional to VM reduction
Non-Fuel Resources: Some savings on rubber, metals, etc. for auto maintenance
Other: No change

Safety: Minor gain

5. Increased Passenger Aircraft Load Factors

To increase passenger aircraft fuel efficiency requires increasing the load factor, either by reducing the number of flights or by using smaller, less fuel-consuming planes for habitually underloaded flights. Air and noise pollution would be reduced as well, and runway congestion would decrease. Fares could be reduced or airline profits allowed to rise. A limiting factor is the potential increase in the rejection rate: that is, the number of people who must be refused service. Less aircraft travel would slow the need for airport expansion, also saving energy, but doing so at the expense of some economic growth.

Summary Sheet 5

Measure: Load Factor: Passenger Aircraft

Fuel Savings:
Ultimate Limit (83 percent load factor) — 8.0 %
Practical, 15-yr. Limit (75 percent load factor) — 6.2 %
Practical, 5-yr. Limit (70 percent load factor) — 3.5 %

Efficiency:
Before Implementation (1970 actual) — 8500 BTU/pax-mile or ton-mile
After Implementation — 5859 BTU/pax-mile or ton-mile

Costs:
Investment $ Negative B; — NA % Change
User 1 difference in ¢/pax-mile, or ton-mile — -(10 to 30) % Change

Timing: Years to Achieve Maximum Practical Benefit 5 Percent saving continues to increase because of growth in the aviation share of transportation fuel.

Travel Time: No change in flying time, but flexibility as to departure time reduced % Change

Environmental:
Air Quality: Proportional to reduction in fuel consumption
Non-Fuel Resources: Minor reduction in aircraft materials
Other: Noise reduction proportional to reduction in flight operations

Safety: Not significant

6. Increased Truck Load Factors

The load factor for trucking could also be increased to produce more ton miles per vehicle mile. The average 20-ton unit actually carries only 10.96 tons. Most trucks are owned by the manufacturer or merchant whose goods they carry, and consequently make empty backhauls. Perishable goods frequently cannot wait until a full load is ready; other goods may be so bulky that the truck is actually full with only half the allowable weight. Deregulation of common carriers by ICC would increase the efficiency of the trucking industry, but some firms would go bankrupt. Freight might also be shifted from trucking to rails which are more fuel efficient.

Summary Sheet 6

Measure: Load Factor: Trucking

Fuel Savings:
- Ultimate Limit: 4.4 %
- Practical, 15 yr. Limit: 4.4 %
- Practical, 5 yr. Limit: 3.9 %

Efficiency:
- Before Implementation: 2288 BTU[1]/ton-mile (10.96 TM/VM, 5.42 mpg combinations)
- After Implementation: 1929 BTU/ton-mile (13 TM/VM, 5.42 mpg combinations)

Costs:
- Investment $ negative B: N/A % Change
- User <1 difference in ¢/pax mile or ton-mile <10 % Change

Timing: Years to Achieve Max. Practical Benefit 10

Travel Time: Variable with situation, may increase significantly for some users. % Change

Environmental: Air Quality: Favorable, proportional to reduction in vehicle miles

Non-Fuel Resources: Minor savings on truck materials

Other: N/A

Safety: Minor gain, proportional to reduction in vehicle miles

[1] Average BTU/gallon for combination truck fuel = 136,000

7. Urban Traffic Mode Shift

Shifting auto traffic to public transit is another potential fuel economy measure. Thirty percent of passenger travel takes place in urban areas. An estimated 60% of travel to and from the central business district is potentially able to be carried by buses which are twice as fuel efficient as autos in terms of passenger miles per gallon. This diversion is limited by the number of available buses, and as most current bus production is used for replacement purposes, new plants might be necessary. Trip time will increase, so public acceptance might be a problem. Advantages are the greater safety of buses than autos, lower air and noise pollution, and less traffic congestion for those who must drive.

Summary Sheet 7

Measure: Mode Shift Auto (urban) to Transit

Fuel Savings:
- Ultimate Limit: 1.8 %
- Practical, 15-yr. Limit: 1.7 %
- Practical, 5-yr. Limit: 1.0 %

Efficiency:
- Before Implementation: 6510 BTU/pax-mile or ton-mile (1.6 PM/VM, 12.0 mpg)
- After Implementation: 2615 BTU/pax-mile or ton-mile (20.6 PM/VM, 5.4 mpg)

Costs:
- Investment $ 6.2 B: >1000 % Change (buses only)
- User depends on transit pricing policy difference in ¢/pax-mile; or ton-mile N/A % Change

Timing: Years to Achieve Maximum Practical Benefit 17

Travel Time: + (0 to 200) % Change

Environmental: Air Quality: Favorable, proportional to reduction in auto use

Non-Fuel Resources: Materials for new buses

Other:

Safety: –5 percent reduction in urban-traffic deaths

8. Intercity Traffic Mode Shift

At the intercity level, shifting 50% of auto travel to buses would save 4.1% of the transportation fuel. For passengers, trains are less efficient than buses, although still better than cars, except in high density corridors where trains have an advantage. For those who must own their own autos anyway, using buses or trains is far more costly. Rising gasoline prices may change this somewhat. Still, a 20% diversion is the maximum likely shift, resulting in a 3.2 billion gallon per year fuel saving. It will be at least 5 years before sufficient numbers of buses can be built to handle this extensive a shift.

Summary Sheet 8

Measure: Mode Shift: Auto (>50 miles) to Bus/Rail

Fuel Savings:
- Ultimate Limit (50 percent diversion): 2.9 %
- Practical, 15-yr. Limit (20 percent diversion): 1.3 %
- Practical, 5-yr. Limit (6 percent diversion): 0.5 %

Efficiency:
- Before Implementation (2.4 PM/VM, 15 mpg): 3470 BTU/pax-mile or ton-mile
- After Implementation (100 PM/gal): 1380 (bus) BTU/pax-mile or ton-mile

Costs:
- Investment $ 6 (bus) B; 600 (bus) % Change
- User +1.2 (bus) +2.1 (rail) difference in ¢/pax-mile; or ton-mile; +44 (bus) +78 (rail) % Change

Timing: Years to Achieve Maximum Practical Benefit 15

Travel Time: + (10 to 50) % Change

Environmental: Air Quality: Favorable, proportional to reduction in fuel saving

Non-Fuel Resources: Negligible

Other: Reduced need for highway construction

Safety: Buses 40 times safer than cars

9. Shift from Autos to Walking/Bicycling

The diversion of auto trips to walking or bicycling is potentially possible for those 15.7% of vehicle miles which are comprised of trips of less than 5.5 miles. This possible change is limited by climate, physical ability, and trip purpose (i.e., shopping for heavy or bulky items). Safety is a factor which suffers where cyclists and pedestrians do not have their own pathways. The construction of bikeways or creation of bicycle lanes out of parking lanes is cost-efficient, however, even at a fairly low rate of diversion. In addition, air and noise pollution will be reduced and health of participants improved.

Summary Sheet 9

Measure: Mode Shift: Short Auto Trips → Walking/Bicycling

Fuel Savings:
- Ultimate Limit: 1.8 %
- Practical, 15-yr. Limit: 0.9 %
- Practical, 5-yr. Limit: 0.5 %

Efficiency:
- Before Implementation (1.6 PM/VM, 12 mpg): 6510 BTU/pax-mile or ton-mile
- After Implementation (includes energy cost of cyclists food): 700 (bicycling) BTU/pax-mile or ton-mile

Costs:
- Investment $ 2+ B; N/A % Change
- User −3.5 difference in ¢/pax-mile; or ton-mile −90 % Change

Timing: Years to Achieve Maximum Practical Benefit 10

Travel Time: −50 to +50 depending on circumstances % Change

Environmental: Air Quality: Favorable, proportional to reduction in auto miles

Non-Fuel Resources: Negligible

Other: N/A

Safety: Unknown, depends on quality of facilities provided for cycling.

10. Freight Shift from Truck to Rail

As rail is inherently more energy efficient than trucking, using only one-fourth as much fuel per ton mile, switching intercity freight to rail can save fuel. Rail capacity is sufficient to handle the likely increased load, but piggyback cars and terminal facilities are limited at the present. Additionally, rail freight takes longer and is only suitable for distances of over 200 miles at the very least, and more likely 400 miles. The economic impact would be favorable on the rail industry, counteracted by unfavorable effect upon the trucking industry.

Summary Sheet 10

Measure: Mode Shift: Truck Freight to Rail

Fuel Savings:

Ultimate Limit	1.58	%
Practical, 15-yr. Limit	0.64	%
Practical, 5-yr. Limit	0.32	%

Efficiency:

Before Implementation 1778 BTU/pax-mile or ton-mile
(diesel tractor-trailer)

After Implementation 591 BTU/pax-mile or ton-mile
(trailer on flatcar, including drayage)

Costs:

Investment	$ ∿15	B;	+50	% Change
User	∿2	difference in ¢/pax-mile, or ton-mile	−30	% Change

Direct only, indirect costs of rail service make it more expensive than trucking for many users.

Timing: Years to Achieve Maximum Practical Benefit 5

Travel Time: + (25 to 100) % Change

Environmental: Air Quality: Favorable, proportional to fuel saving

Non-Fuel Resources: Negligible

Other: Negligible

Safety: Minor improvement

From consideration of these measures as summarized in Table 1, it can be seen that improvement of motor vehicle efficiency offers the greatest potential fuel savings, and has consumer support as well. Implementation time is long, however; for immediate savings, carpools are a more promising solution. In general, fuel conservation measures improve environmental quality. Investments are necessary and quite substantial for full fuel economy realization, but are justified on a cost-benefit basis.

NOTE: The above abstract is based upon a draft report only, and should be used with that caveat in mind. More recent data will be provided in **A Summary of Opportunities to Conserve Transportation Energy** by J.K. Pollard, David Rubin, and David Hiatt, of DOT/Transportation Systems Center currently in preparation.

TABLE 1
COMPARISON OF TRANSPORTATION CONSERVATION OPTIONS

	FUEL SAVING (as % of total transport fuel)			EFFICIENCY (BTU per pax mile or ton mile)		COST DIFFERENTIAL (compared with present trend)				IMPLEMENTATION TIME TO ACHIEVE MAXIMUM PRACTICAL BENEFIT (years)	TRAVEL TIME DIFFERENTIAL	ENVIRONMENTAL IMPACT		SAFETY
	Ultimate Limit	Practical 15-Year Limit	Practical 5-Year Limit	Before Implementation	After Implementation	Total Investment Billion $	Total Investment %	User Operating ¢ per PM/TM	User Operating % Change		% Change	Air Quality	Demand for Non-Fuel Resources	
1. Auto-Efficiency Improvement	20+	15.3	4.0	4837	3289	10	+20	–0.5	–10	20	no change	minor gain	reduction in use of metals	minor degradation
2. Truck-Efficiency Improvement	5.4	5.4	2.2	2714	2362	3	+20	–0.3	– 3	15	no change	minor gain	no change	no change
3. Speed Limits	2.9	2.9	2.9	3470	3063	.02	N/A	–0.15	8	3	up to +40%	minor gain	no change	favorable*
4. Carpooling (work trips)	10.0	5.0	3.0	6510	3931	N/A	N/A	–(2 to 4)	–(15 to 35)	2+	+(10 to 40)	favorable*	negligible	no change
5. Passenger Aircraft-Load Factor	8.0	6.2	3.5	8500	5859	neg.	N/A	1	–(10 to 30)	5	no change	favorable*	minor reduction in metals	negligible
6. Truck Freight Load Factor	4.4	4.4	3.9	2288	1929	neg.	N/A	– 1	–10	10	(unknown)	favorable*	minor reduction in metals	minor gain*
7. Auto (urban)→Transit Shift	1.8	1.7	1.0	6510	2615	6.2	1000	depends on fare policies	?	10	+(0 to 200)	favorable*	minor reduction in metals	minor gain*
8. Auto (intercity)→Bus/Rail Shift	2.9	1.3	0.5	3470	1380	6	600	+1.2	+44	15	+(10 to 40)	favorable*	negligible	favorable*
9. Auto (short trips)→Walking/Bicycle Shift	1.8	0.9	0.5	6510	700	2	N/A	–3.5	–90	10	–50 to +50	favorable*	negligible	unknown
10. Truck Freight→Rail Shift	1.6	0.6	0.3	1778	591	15	50	– 2	–30	15	+(25 to 100)	favorable*	negligible	minor improvement
						N/A = not applicable		+ = increase – = decrease			+ = increase – = decrease	*Proportional to degree of implementation		

GUIDELINES TO REDUCE ENERGY CONSUMPTION THROUGH TRANSPORTATION ACTIONS

Alan M. Voorhees and Associates, Inc.

Report prepared for the U.S. Urban Mass Transportation Administration
May 1974

The purpose of this report is to aid the evaluation and choice of low-cost, short-term transportation actions to reduce energy consumption while minimizing adverse effects and implementation problems. It is meant to serve as a guide to the creation of "packages" of actions which complement both one another and previously existing transportation programs.

Three factors must be considered for each action: the means by which it reduces energy consumption; its environmental and socioeconomic effects; and the practicability of implementation of the action in an urban area of a given size. There are ten "action groups" of possible measures:

1) Measures to improve the flow of high-occupancy vehicles: bus-actuated traffic signals; bus and carpool lanes and ramps; and bus priority regulations at intersections.

2) Measures to improve total vehicular flow: improved signal systems; one-way streets, reversible lanes, no on-street parking; elimination of unnecessary traffic control devices; widening of intersections; limited access highway ramp metering, freeway surveillance to detect and correct slow-downs, and displays to advise drivers of road and parking conditions; and staggered work hours to spread rush hour traffic volume over a longer time period.

3) Measures to increase car and van occupancy: carpool matching program, information campaign, and incentives (cost, convenience, and improved travel time); and neighborhood ride sharing.

4) Measures to increase transit patronage: bus, subway, and commuter rail service improvements; fare reductions and the elimination of transfer fares; traffic flow-related incentives to ridership (bus priority lanes and signals); park-ride services with express bus service; and demand-responsive systems.

5) Measures to encourage walk and bicycle modes: pedestrian malls in high-activity areas; bicycle priority regulations at intersections; pedestrian-actuated traffic signals; walkways separated from street level; bikeways; and bicycle storage facilities.

6) Improve the efficiency of taxi service and goods movement: improve taxi service by permitting higher occupancy, allowing less cruising, encouraging jitney-type services; improve urban goods movement by consolidating delivery hours, routes, and terminals, etc.

7) Measures to restrict traffic: vehicle-free or traffic-limited zones; limited hours and location of travel; and limited use of freeways.

8) Transportation pricing measures: increased bridge and highway tolls; congestion tolls; vehicle fee for entry into designated areas; increased parking charges; additional gasoline tax paid at pump on per-gallon basis; mileage tax; fees to promote energy-efficient automobiles; tune-up requirements; tax on second car ownership; and a tire tax (on replacement or retreaded tires).

9) Measures to reduce the need to travel: four-day work week; zoning of land to discourage auto-dependent development and permit diverse land uses, allowing interspersion of residential and commercial districts; home goods delivery, and communications substitutes.

10) Energy restriction measures: retail gasoline rationing with or without transferable coupons; restriction of fuel sales on a geographical basis (this is more easily administered than rationing with coupons); ban on Saturday and/or Sunday gasoline sales; and reduced speed limits.

Energy reduction impact, institutional and legal factors, and indirect socioeconomic and environmental effects of different possible actions within each group are summarized in the tables that follow.

Factors estimated in Table 1 include:

a) Regional energy consumption, given as the percent (within a range) reduction in energy use that each transportation action might effect.

b) Time to implement--all actions could be implemented within a short time (2 years or less), but a more specific estimate, given as a range of months, is provided in this column to allow for comparisons between actions.

c) Implementation cost--all actions are considered low-cost (less than $1,000,000), but ball-park estimates (L = $0 - $50,000; M = $50,000 - $250,000; and H = $250,000 to $1,000,000) are given. User and indirect effects costs are not considered.

d) Implementing agency--agency with responsibility for putting an action into effect: includes private (employers); local (county governments, traffic departments, transit authorities); and state (highway or transportation departments) agencies.

e) Organizational change required--this column indicates estimates of the amount of reorganization required to implement an action; estimates vary from none, to adapting present structures, to creating new agencies.

f) Significant legislative action--implementation of some actions may require authorization or legislation from city councils, state legislatures, or the federal government. This column indicates only whether legislation would be necessary or not.

g) Initial public reaction--may be positive (+), negative (—), or positive for some groups and negative for others (+/—). A favorable reaction by the public helps in the quick implementation of an action; but an initial negative response may become more positive as the impacts of the conservation strategy become evident.

h) Enforcement--this column indicates whether or not enforcement would be necessary to implement an action; the amount of enforcement necessary is not judged.

TABLE 1
SUMMARY TABLE: ACTIONS TO REDUCE ENERGY CONSUMPTION AND THEIR INSTITUTIONAL/LEGAL CONSIDERATIONS

Action Group	Action	Regional Energy Reduction (%)	Months to Implement	Implementation Cost	Implementing Agency	Organizational Change Required	Possibly New Legislation	Initial Public Reaction	Enforcement
1. Measures to Improve Flow of High Occupancy Vehicles	Bus-actuated signals	0 - 0.5	6 - 12	L	L,S	None	No	+/–	No
	Bus-only lanes on city streets	0 - 2.0	2 - 6	L	L,S	None	No	+/–	Maybe
	Reserved freeway bus or bus/carpool lanes and ramps	1.0 - 3.0	2 - 24	L-H	L,S	None	No	+/–	Yes
	Bus priority regulations at intersections	0 - 0.5	3 - 9	L	L,S	None	Yes	+/–	Yes
2. Measures to Improve Total Vehicular Traffic Flow	Improved signal systems	1.0 - 4.0	6 - 18	M	L,S	None	No	+	No
	One-way streets, reversible lanes, no on-street parking	1.0 - 4.0	6 - 12	M	L,S	None	No	+/–	Yes
	Eliminate unnecessary traffic control devices	0 - 2.0	3 - 6	L	L,S	None	No	+	No
	Widening intersection	0 - 1.0	6 - 12	M	L,S	None	No	+	No
	Driver advisory system	0 - 0.5	6 - 12	L-H	L,S	None-Adapt	No	+	No
	Ramp metering, freeway surveillance, driver advisory display	0 - 1.0	6 - 18	M-H	L,S	None	No	+/–	Yes
	Staggered work hours	0	4 - 12	L	P,L,S	None-New	No	+/–	No

TABLE 1
SUMMARY TABLE: ACTIONS TO REDUCE ENERGY CONSUMPTION AND THEIR INSTITUTIONAL/LEGAL CONSIDERATIONS – CONTINUED

Action Group	Action	Regional Energy Reduction (%)	Months to Implement	Implementation Cost	Implementing Agency	Organizational Change Required	Possibly New Legislation	Initial Public Reaction	Enforcement
3. Measures to Increase Car and Van Occupancy	Carpool matching programs	3.0 - 6.0	2 - 6	L	P,L,S	Adapt	No	+/–	No
	Carpool public information	2.0 - 4.0	2 - 6	L	P,L,S	Adapt	No	+	No
	Carpool incentives	4.0 - 6.0	2 - 6	L-M	P,L,S	Adapt	No	+/–	Maybe
	Neighborhood ride sharing	0 - 1.0	3 - 24	L	P,L	None-New	No	+	No
4. Measures to Increase Transit Patronage	Service improvements	1.0 - 3.0	3-18	M	P,L,S	None	No	+	No
	Fare reductions	4.0 - 6.0	2 - 12	M-H	L,S	None	Yes	+	No
	Traffic-related incentives	1.0 - 5.0	2 - 24	L-M	L,S	None	No	+/–	Maybe
	Park/ride with express bus service	0.5 - 2.5	18 - 24	M-H	L,S	Adapt	No	+	No
	Demand-responsive service	0 - 1.0	6 - 12	H	L,S	Adapt-New	Yes	+	No
5. Measures to Encourage Walk and Bicycle Modes	Pedestrian malls	0.5 - 2.5	6 - 12	M-H	L	Adapt	Yes	+	Maybe
	Second level sidewalks	0 - 0.5	6 - 12	M	L	Adapt	No	+/–	No
	Bikeway system	0.5 - 2.0	6 - 12	L-M	L,S	Adapt	Yes	+	Maybe
	Bicycle storage facilities	0 - 1.0	2 - 4	L	L,S	Adapt	No	+	No
	Pedestrian actuated signals	0 - 0.5	6 - 12	L	L,S	None	No	+/–	No
	Bicycle priority regulations at intersections	0 - 0.5	3 - 9	L	L,S	None	Yes	+/–	Yes
6. Measures to Improve the Efficiency of Taxi Service and Goods Movement	Improve efficiency of taxi service	0 - 2.0	3 - 18	M	P,L	None-Adapt	Yes	+	Yes
	Improve efficiency of urban goods movement	0 - 1.5	6 - 18	H	P,L,S	Adapt-New	Yes	+	Yes
7. Measures to Restrict Traffic	Auto-free or traffic limited zones	0.5 - 2.5	12 - 18	M-H	L	Adapt	Yes	+/–	Yes
	Limiting hours or location of travel	0 - 3.0	4 - 12	M-H	L,S	Adapt-New	Yes		Yes
	Limiting freeway usage	0 - 1.0	3 - 6	L-M	L,S	None-Adapt	Yes	–	Yes

TABLE 1
SUMMARY TABLE: ACTIONS TO REDUCE ENERGY CONSUMPTION AND THEIR INSTITUTIONAL/LEGAL CONSIDERATIONS–CONTINUED

Action Group	Action	Regional Energy Reduction (%)	Months to Implement	Implementation Cost	Implementing Agency	Organizational Change Required	Possibly New Legislation	Initial Public Reaction	Enforcement
8. Transportation Pricing Measures	Bridges and highway tolls	1.0 - 5.0	12 - 24	L-M	L,S	None-New	Yes	–	No
	Congestion tolls and road cordon tolls	1.0 - 5.0	18 - 24	M-H	L,S	Adapt-New	Yes	–	Maybe
	Increased parking costs	0.5 - 3.0	3 - 12	M	L	Adapt-New	Yes	–	Maybe
	Fuel tax	2.0 - 6.0	2 - 6	L	L,S	Adapt	Yes	–	No
	Mileage tax	2.0 - 6.0	6 - 12	M	L,S	Adapt	Yes	–	Maybe
	Vehicle-related fees	2.0 - 10.0	6 - 12	M	S	Adapt	Yes	–	No
9. Measures to Reduce the Need to Travel	Four-day work week	1.0 - 6.0	4 - 12	L	P,L,S	None-New	No	+/–	No
	Zoning	1.0 - 10.0	6 - 12	L	L,S	None-New	Yes	+/–	Maybe
	Home goods delivery	0 - 1.0	12 - 24	L	P,L	New	No	+/–	No
	Communications substitutes	0 - 1.0	18 - 24	L-H	P,L,S	None-New	No	+/–	No
10. Energy Restriction Measures	Gas rationing without transferable coupons	10.0 - 25.0	2 - 6	L-H	S,F	New	Yes	–	Yes
	Gas rationing with transferable coupons	10.0 - 25.0	2 - 6	L-H	S,F	New	Yes	–	Yes
	Restriction of quantity of sales on a geographic basis	5.0 - 20.0	0 - 6	L-M	P,L,S	New	Yes	–	Maybe
	Ban on Sunday and/or Saturday gas sales	2.0 - 10.0	1 - 6	L	P,L,S	New	Yes	–	Yes
	Reduced speed limits	0 - 2.0	1 - 6	L	L,S	Adapt	Yes	–	Yes

SYMBOLS:

Implementation Cost: L = Low, M = Medium, H = High, within the low cost constraint on type of actions considered
Implementing Agency: P = Private, L = Local, S = State
Initial Public Reaction: + = Positive, – = Negative, +/– = Positive or negative, depending on group affected

The following indirect socioeconomic effects are analyzed in Table 2 for each of the transportation actions:

a) Travel time--the action may increase, decrease, or have no effect (NE) on travel time.

b) Cost distribution--costs of the action may be paid for by the public (PU), in taxes or fares; the private sector (PR) by subsidies of carpools or shorter work hours; or the government (G), as part of general government expenditures.

c) Safety--actions which improve traffic circulation can reduce accident potential and thus improve personal safety; others have no effect (NE) on safety.

d) Lifestyle change--action's effects on mobility, driving habits, and work, shopping, and recreation times and places are considered here; they are judged to have either major, minor, or no effect (NE).

e) Economic dislocation--the effects of the actions on location and number of jobs in an area, the area's tax base, and sales in commercial districts are estimated here; impacts are rated major, minor, or as having no effect (NE).

f) Development opportunities--actions are rated according to the extent (major, minor, or NE) to which they provide opportunities to expand current programs or develop new ones.

TABLE 2
SUMMARY TABLE: ACTIONS TO REDUCE ENERGY CONSUMPTION AND THEIR INDIRECT SOCIOECONOMIC EFFECTS

Action Group	Action	Regional Energy Reduction (%)	Travel Time	Cost Distribution	Safety	SOCIO-ECONOMIC		
						Lifestyle Change	Economic Dislocation	Development Opportunities
1. Measures to Improve Flow of High Occupancy Vehicles	Bus-actuated signals	0 - 0.5	Decrease	G	Improve	NE	NE	NE
	Bus-only lanes on city streets	0 - 2.0	Decrease	G	Improve	Minor	NE-Minor	NE
	Reserved freeway bus or bus/carpool lanes and ramps	1.0 - 3.0	Decrease	G	Improve	Minor	NE	NE
	Bus priority regulations at intersections	0 - 0.5	Decrease	G	Improve	Minor	NE	NE
2. Measures to Improve Total Vehicular Traffic Flow	Improved signal systems	1.0 - 4.0	Decrease	G	Improve	NE	NE	NE
	One-way streets, reversible, no on-street parking	1.0 - 4.0	Decrease	G	Improve	NE-Minor	NE-Minor	NE
	Eliminate unnecessary traffic control devices	0 - 2.0	Decrease	G	Improve	NE	NE	NE
	Widening intersection	0 - 1.0	Decrease	G	Improve	NE	NE	NE
	Driver advisory system	0 - 0.5	Decrease	G	Improve	NE	NE	NE
	Ramp metering, freeway surveillance, driver advisory display	0 - 1.0	Decrease	G	Improve	NE	NE	NE
	Staggered work hours	0	Decrease	PR	NE	Minor/ Major	Minor	Minor/ Major

TABLE 2
SUMMARY TABLE: ACTIONS TO REDUCE ENERGY CONSUMPTION AND THEIR INDIRECT SOCIOECONOMIC EFFECTS–CONTINUED

Action Group	Action	Regional Energy Reduction (%)	Travel Time	Cost Distribution	Safety	SOCIO-ECONOMIC		
						Life-style Change	Economic Dislocation	Development Opportunities
3. Measures to Increase Car and Van Occupancy	Carpool matching programs	3.0 - 6.0	NE	PU/PR/G	NE	NE	NE	Major
	Carpool public information	2.0 - 4.0	NE	PU/PR/G	NE	NE	NE	Major
	Carpool incentives	4.0 - 6.0	NE	PU/PR/G	NE	NE	NE	Minor
	Neighborhood ride sharing	0 - 1.0	NE	G/PU/PR	NE	Minor	NE	NE
4. Measures to Increase Transit Patronage	Service improvement	1.0 - 3.0	Decrease	G	Improve	NE	NE	Major
	Fare reductions	4.0 - 6.0	NE	G	NE	NE	NE	NE
	Traffic-related incentives	1.0 - 5.0	NE	G	NE	NE	NE	NE-Minor
	Park/ride with express bus service	0.5 - 2.5	Decrease	PU/G	Improve	NE	NE	Major
	Demand-responsive service	0 - 1.0	Decrease	PU/G	Improve	NE	NE	Major
5. Measures to Encourage Walk and Bicycle Modes	Pedestrian malls	0.5 - 2.5	Decrease	PR/G	Improve	Minor	NE-Minor	Major
	Second level sidewalks	0 - 0.5	Decrease	PR/G	Improve	NE	NE	Major
	Bikeway system	0.5 - 2.0	Decrease	G	Improve	Minor	NE	Major
	Bicycle storage facilities	0 - 1.0	NE	PU/PR/G	Improve	NE	NE	Minor
	Pedestrian-actuated signals	0 - 0.5	Decrease	G	Improve	NE	NE	NE
	Bicycle priority regulations at intersections	0 - 0.5	Decrease	G	Improve	NE	NE	NE
6. Measures to Improve the Efficiency of Taxi Service and Goods Movement	Improve efficiency of taxi service	0 - 2.0	Decrease	PR	NE	NE	NE	Minor
	Improve efficiency of urban goods movement	0 - 1.5	Decrease	PR/G	NE	Minor	NE	Minor/ Major

TABLE 2
SUMMARY TABLE: ACTIONS TO REDUCE ENERGY CONSUMPTION AND THEIR INDIRECT SOCIOECONOMIC EFFECTS—CONTINUED

Action Group	Action	Regional Energy Reduction (%)	Travel Time	Cost Distribution	Safety	SOCIO-ECONOMIC		
						Life-style Change	Economic Dislocation	Development Opportunities
7. Measures to Restrict Traffic	Auto-free or traffic limited zones	0.5 - 2.5	Increase	G	Improve	Minor	NE-Minor	Major
	Limiting hours or location of travel	0 - 3.0	Increase	G	Improve	Minor/ Major	Minor/ Major	NE-Major
	Limiting freeway usage	0 - 1.0	Increase	G	Improve	Minor	NE	NE
8. Transportation Pricing Measures	Bridges and highway tolls	1.0 - 5.0	NE	PU	NE	NE-Minor	NE-Minor	NE
	Congestion tolls and road cordon tolls	1.0 - 5.0	NE	PU	NE	NE-Minor	NE-Minor	NE
	Increased parking costs	0.5 - 3.0	NE	PU/PR	NE	NE-Minor	Minor	NE
	Fuel tax	2.0 - 6.0	NE	PU	NE	NE	NE-Minor	NE
	Mileage tax	2.0 - 6.0	NE	PU	NE	NE	NE-Minor	NE
	Vehicle-related fees	2.0 - 10.0	NE	PU	NE	NE	NE-Minor	NE
9. Measures to Reduce the Need to Travel	Four-day work week	1.0 - 6.0	NE	PR	NE	Major	Minor	Major
	Zoning	1.0 - 10.0	NE	G/PR	NE	Major	Major	Major
	Home goods delivery	0 - 1.0	NE	PU/PR	NE	Minor	NE	Minor
	Communications substitutes	0 - 1.0	NE	G/PR	NE	Minor	Minor	Minor/ Major
10. Energy Restriction Measures	Gas rationing without transferable coupons	10.0 - 25.0	NE	PU/G	NE	Major	Minor/ Major	NE
	Gas rationing with transferable coupons	10.0 - 25.0	NE	PU/G	NE	Major	Minor/ Major	NE
	Restriction of quantity of sales on a geographic basis	5.0 - 20.0	NE	PU/PR/G	NE	Major	Major	NE
	Ban on Sunday and/or Saturday gas sales	2.0 - 10.0	NE	PU/PR/G	NE	Major	Minor/ Major	NE
	Reduced speed limits	0 - 2.0	Increase	G	Improve	Minor	NE	NE

SYMBOLS: Cost Distribution: G = Government
PU = Public
PR = Private
NE = No Effect

In Table 3, indirect environmental effects are analyzed; ambient air quality, noise, and congestion may be increased, decreased, or unaffected (NE) by the actions. The impacts of the conservation measures on land use may be major, minor, or cause no effect.

TABLE 3
SUMMARY TABLE: ACTIONS TO REDUCE ENERGY CONSUMPTION AND THEIR INDIRECT ENVIRONMENTAL EFFECTS

Action Group	Action	Regional Energy Reduction (%)	ENVIRONMENTAL			
			Air Pollution	Noise	Congestion	Land Use Patterns
1. Measures to Improve Flow of High Occupancy Vehicles	Bus-actuated signals	0 - 0.5	Decrease	Decrease	Decrease	NE
	Bus-only lanes on city streets	0 - 2.0	Decrease	Decrease	Decrease	NE-Minor
	Reserved freeway bus or bus/carpool lanes and ramps	1.0 - 3.0	Decrease	Decrease	Decrease	NE-Minor
	Bus priority regulations at intersections	0 - 0.5	Decrease	Decrease	Decrease	NE
2. Measures to Improve Total Vehicular Traffic Flow	Improved signal systems	1.0 - 4.0	Decrease	Decrease	Decrease	NE
	One-way streets, reversible lanes, no on-street parking	1.0 - 4.0	Decrease	Decrease	Decrease	NE-Minor
	Eliminate unnecessary traffic control devices	0 - 2.0	Decrease	Decrease	Decrease	NE
	Widening intersection	0 - 1.0	Decrease	Decrease	Decrease	NE-Minor
	Driver advisory system	0 - 0.5	Decrease	Decrease	Decrease	NE
	Ramp metering, freeway surveillance, driver advisory display	0 - 1.0	Decrease	Decrease	Decrease	NE
	Staggered work hours	0	Decrease	Decrease	Decrease	NE
3. Measures to Increase Car and Van Occupancy	Carpool matching programs	3.0 - 6.0	Decrease	Decrease	Decrease	NE
	Carpool public information	2.0 - 4.0	Decrease	Decrease	Decrease	NE
	Carpool incentives	4.0 - 6.0	Decrease	Decrease	Decrease	NE
	Neighborhood ride sharing	0 - 1.0	Decrease	Decrease	Decrease	NE

TABLE 3
SUMMARY TABLE: ACTIONS TO REDUCE ENERGY CONSUMPTION AND THEIR INDIRECT ENVIRONMENTAL EFFECTS—CONTINUED

Action Group	Action	Regional Energy Reduction (%)	ENVIRONMENTAL: Air Pollution	ENVIRONMENTAL: Noise	ENVIRONMENTAL: Congestion	ENVIRONMENTAL: Land Use Patterns
4. Measures to Increase Transit Patronage	Service improvements	1.0 - 3.0	Decrease	Decrease	Decrease	NE
	Fare reductions	4.0 - 6.0	Decrease	Decrease	NE	NE
	Traffic-related incentives	1.0 - 5.0	Decrease	Decrease	Decrease	NE
	Park/ride with express bus service	0.5 - 2.5	Decrease	Decrease	Decrease	Minor
	Demand-responsive service	0 - 1.0	Decrease	Decrease	Decrease	NE
5. Measures to Encourage Walk and Bicycle Modes	Pedestrian malls	0.5 - 2.5	Decrease	Decrease	Decrease	Minor/Major
	Second level sidewalks	0 - 0.5	Decrease	Decrease	Decrease	Minor
	Bikeway system	0.5 - 2.0	Decrease	Decrease	Decrease	Minor
	Bicycle storage facilities	0 - 1.0	Decrease	NE	NE	NE
	Pedestrian-actuated signals	0 - 0.5	NE	NE	Decrease	NE
	Bicycle priority regulations at intersections	0 - 0.5	NE	NE	Decrease	NE
6. Measures to Improve the Efficiency of Taxi Service and Goods Movement	Improve efficiency of taxi service	0 - 2.0	Decrease	Decrease	Decrease	NE
	Improve efficiency of urban goods movement	0 - 1.5	Decrease	Decrease	Decrease	Minor
7. Measures to Restrict Traffic	Auto-free or traffic limited zones	0.5 - 2.5	Decrease	Decrease	Decrease	Minor/Major
	Limiting hours or location of travel	0 - 3.0	Decrease	Decrease	Decrease	Minor/Major
	Limiting freeway usage	0 - 1.0	Decrease	Decrease	Decrease	Minor

TABLE 3
SUMMARY TABLE: ACTIONS TO REDUCE ENERGY CONSUMPTION AND THEIR INDIRECT ENVIRONMENTAL EFFECTS–CONTINUED

Action Group	Action	Regional Energy Reduction (%)	ENVIRONMENTAL			
			Air Pollution	Noise	Congestion	Land Use Patterns
8. Transportation Pricing Measures	Bridges and highway tolls	1.0 - 5.0	Decrease	Decrease	Decrease	NE
	Congestion tolls and road cordon tolls	1.0 - 5.0	Decrease	Decrease	Decrease	NE
	Increased parking costs	0.5 - 3.0	Decrease	Decrease	Decrease	NE
	Fuel tax	2.0 - 6.0	Decrease	Decrease	Decrease	NE
	Mileage tax	2.0 - 6.0	Decrease	Decrease	Decrease	NE
	Vehicle-related fees	2.0 - 10.0	Decrease	Decrease	Decrease	NE
9. Measures to Reduce the Need to Travel	Four-day work week	1.0 - 6.0	Increase/ Decrease	Increase/ Decrease	Decrease	NE-Minor
	Zoning	1.0 - 10.0	Decrease	Decrease	Decrease	Major
	Home goods delivery	0 - 1.0	Decrease	Increase/ Decrease	Decrease	NE
	Communications substitutes	0 - 1.0	Decrease	Decrease	Decrease	Major
10. Energy Restriction Measures	Gas rationing without transferable coupons	10.0 - 25.0	Decrease	Decrease	Decrease	Minor/Major
	Gas rationing with transferable coupons	10.0 - 25.0	Decrease	Decrease	Decrease	Minor/Major
	Restriction of quantity of sales on a geographic basis	5.0 - 20.0	Decrease	Decrease	Decrease	Major
	Ban on Sunday and/or Saturday gas sales	2.0 - 10.0	Decrease	Decrease	Decrease	Minor
	Reduced speed limits	0 - 2.0	Decrease	Decrease	NE	NE

SYMBOL: NE - No Effect

To formulate a transportation energy reduction package for an area, actions that are favorable according to most criteria (which vary with the area) and at the same time complement each other are grouped together. The interrelationships of the actions are very important, as some actions reinforce each other, while others have contrary effects. Actions which improve total vehicular flow are counterproductive (i.e., the objective of one action is directly opposed to the objective of the other) to actions designed to shift travel away from automobiles: light traffic and easy driving make taking the car more attractive. Carpools and transit (park-and-ride systems, for example) share a market, so that actions to increase the ridership of each (both are aided by traffic regulations favoring high-occupancy vehicles, energy restrictions, and transportation pricing actions) would probably overlap.

Energy restriction actions (i.e., gasoline rationing measures) and transportation pricing actions (calculated to make the fuel-inefficient automobile more expensive than the other modes) overlap; indeed, implementation of one type of action may preclude the effectiveness of the other, as in the case of gasoline rationing and higher fuel taxes. (Another aspect of this trade-off, as the report points out, is the tendency of pricing actions to affect the public less equitably than do restriction measures.) In contrast, actions aimed at improving taxi service and urban goods movement are generally independent of other actions.

Disincentive measures (such as traffic restriction, transportation pricing, and energy restriction actions) and incentive measures (transit improvements, walk and bike actions, and carpooling programs) are mutually enhancing; i.e., travel turned away by the disincentives can be picked up by the incentive action programs.

Sample packages of actions have been developed for areas of different-sized populations. Actions appropriate to the size of the area were chosen, keeping in mind as important criteria short lead time (0-6 months is highly favorable), minimum institutional obstacles (i.e., existence of an appropriate administrative/funding agency), favorable public reaction, and high energy reduction (more than 3%). A minimum package includes actions which are favorable according to three or four of these criteria and which do not overlap or work counter to each other. Medium package actions, based on the minimum package, include additional actions which meet two or three of the above criteria and which are not counterproductive to other actions. Maximum packages, which are based on the medium package, include any actions meeting one or two of the criteria; interrelationship constraints are dropped. Sample packages for small, medium, and large urban areas are given in Tables 4, 5, and 6 which follow.

TABLE 4
PACKAGED ACTIONS TO REDUCE ENERGY CONSUMPTION IN A SMALL URBAN AREA (50,000 – 250,000 POPULATION)

ACTION GROUP	PACKAGES		
	Minimum Package *	Medium Package *	Maximum Package *
1. Measures to Improve Flow of High Occupancy Vehicles			
2. Measures to Improve Total Vehicular Traffic Flow			Eliminate unnecessary traffic control devices, improved signal systems, widening intersections [1-4%]
3. Measures to Increase Car and Van Occupancy	Carpool Program: Public information, encourage employer programs, carpool matching guidance, possibly cost and/or convenience incentives [5-10%]	Carpool Program: Public information, encourage employer programs, carpool matching guidance, possibly cost and/or convenience incentives [5-10%]	Carpool Program: Public information, encourage employer programs, carpool matching guidance, possibly cost and/or convenience incentives [5-10%] Neighborhood ride sharing
4. Measures to Increase Transit Patronage		Fare reduction in combination with service improvements [4-7%]	Fare reduction in combination with service improvements [4-7%]
5. Measures to Encourage Use of Walk and Bike Modes		Bicycle storage facilities, bikeway systems [1-3%]	Bicycle storage facilities, bikeway system, pedestrian mall [1.4%]
6. Measures to Improve the Efficiency of Taxi Service and Goods Movement			

*The figures given in the boxes in the upper right-hand corners are expected percent regional energy reductions if only the measures in the box are implemented.

TABLE 4
PACKAGED ACTIONS TO REDUCE ENERGY CONSUMPTION IN A SMALL URBAN AREA (50,000 – 250,000 POPULATION) – CONTINUED

ACTION GROUP	PACKAGES		
	Minimum Package *	Medium Package *	Maximum Package *
7. Measures to Restrict Traffic			Auto-free zone of pedestrian mall-type [0-1%]
8. Transportation Pricing Measures		Parking-relation actions [1-2%]	Parking-related actions, possibly vehicle-related fees [1-8%]
9. Measures to Reduce the Need to Travel			Possibly four-day work week, possibly zoning-related changes [1-14%]
10. Energy Restriction Measures	Low level of restriction of quantity of sales on a geographical basis [2-6%]	Restriction of quantity of sales on a geographical basis, ban on Sunday and/or Saturday gasoline sales [5-15%]	Gas rationing with or without transferable coupons, restriction of quantity sales on a geographical basis, ban on Sunday and/or Saturday gas sales, reduced speed limits [10-25%]
CUMULATIVE PACKAGE ENERGY REDUCTION (PERCENT)	5-10%	10-16%	16-30%

*The figures given in the boxes in the upper right-hand corners are expected percent regional energy reductions if only the measures in the box are implemented.

TABLE 5
PACKAGED ACTION TO REDUCE ENERGY CONSUMPTION IN A MEDIUM-SIZED URBAN AREA (250,000 – 1,000,000 POPULATION)

ACTION GROUP	PACKAGES		
	Minimum Package *	Medium Package *	Maximum Package *
1. Measures to Improve Flow of High Occupancy Vehicles		Bus-only lanes on streets [0-2%]	Bus-only lanes on streets [0-2%]
2. Measures to Improve Total Vehicular Traffic Flow			Eliminate unnecessary traffic control devices, improved signal systems, widening intersections, staggered hours [1-5%]
3. Measures to Increase Car and Van Occupancy	Carpool Program: Public information, encourage employer programs, carpool matching guidance, areawide coordination, cost and convenience incentives [6-11%]	Carpool Program: Public information, encourage employer programs, carpool matching guidance, areawide coordination, cost and convenience incentives [6-11%]	Carpool Program: Public information, encourage employer programs, carpool matching guidance, areawide coordination, cost and convenience incentives [6-11%] Neighborhood ride sharing
4. Measures to Increase Transit Patronage		Fare reduction in combination with service improvements, traffic-related incentives [5-8%]	Fare reduction in combination with service improvements, traffic-related incentives, demand responsive service [5-10%]
5. Measures to Encourage Walk and Bicycle Modes		Bicycle storage facilities, bikeway system [1-3%]	Bicycle storage facilities, bikeway system, pedestrian mall(s) [1-5%]

*The figures given in the boxes in the upper right-hand corners are expected percent regional energy reductions if only the measures in the box are implemented.

TABLE 5
PACKAGED ACTIONS TO REDUCE ENERGY CONSUMPTION IN A MEDIUM-SIZED URBAN AREA (250,000 – 1,000,000 POPULATION) – CONTINUED

ACTION GROUP	PACKAGES		
	Minimum Package *	Medium Package *	Maximum Package *
6. Measures to Improve the Efficiency of Taxi Service and Goods Movement			
7. Measures to Restrict Traffic			Auto-free zone(s) of pedestrian mall type [0-2%]
8. Transportation Pricing Measures		Parking-related actions [1-3%]	Parking-related actions, possible bridge and/or highway tolls, possibly vehicle-related fees [1-10%]
9. Measures to Reduce the Need to Travel			Possibly four-day work week, possibly zoning-related changes [1-14%]
10. Energy Restriction Measures	Low level of restriction of quantity of sales on a geographical basis [2-6%]	Restriction of quantity of sales on a geographical basis, ban on Sunday and/or Saturday gasoline sales [5-15%]	Gas rationing with or without transferable coupons, restriction of quantity on a geographical basis, ban on Sunday and/or Saturday gas sales, reduced speed limits [10-25%]
CUMULATIVE ENERGY REDUCTION (PERCENT)	6-11%	11-18%	18-32%

*The figures given in the boxes in the upper right-hand corners are expected percent regional energy reductions if only the measures in the box are implemented.

TABLE 6
PACKAGED ACTIONS TO REDUCE ENERGY CONSUMPTION IN A LARGE URBAN AREA (1,000,000 OR MORE POPULATION)

ACTION GROUP	PACKAGES					
	Minimum Package	*	Medium Package	*	Maximum Package	*
1. Measures to Improve Flow of High Occupancy Vehicles			Bus-only lanes on streets, reserved lanes or ramps on existing freeways	1-5%	Bus-only lanes on streets, reserved lanes or ramps on existing freeways	1-5%
2. Measures to Improve Total Vehicular Traffic Flow			Staggered work hours	1-2%	Eliminate unnecessary traffic control devices, ramp metering and freeway surveillance, widening intersections, staggered work hours	2-6%
3. Measures to Increase Car and Van Occupancy	Carpool Program: Public information, encourage employer programs, carpool matching guidance, areawide coordination, cost, convenience and travel time incentives	6-12%	Carpool Program: Public information, encourage employer programs, carpool matching guidance, areawide coordination, cost, convenience and travel time incentives	6-12%	Carpool Program: Public information, encourage employer programs, carpool matching guidance, areawide coordination, cost, convenience and travel time incentives	6-12%
4. Measures to Increase Transit Patronage			Fare reduction in combination with service improvements, park/ride facilities with express bus service, traffic-related incentives	7-10%	Fare reduction in combination with service improvements, park/ride facilities with express bus service, traffic-related incentives, demand responsive service	8-12%
5. Measures to Encourage Use of Walk and Bike Modes			Bicycle storage facilities, bikeway system	1-3%	Bicycle storage facilities, bikeway system, pedestrian mall(s)	1-5%

*The figures given in the boxes in the upper right-hand corners are expected percent regional energy reductions if only the measures in the box are implemented.

TABLE 6
PACKAGED ACTIONS TO REDUCE ENERGY CONSUMPTION IN A LARGE URBAN AREA (1,000,000 OR MORE POPULATION) – CONTINUED

ACTION GROUP	PACKAGES					
	Minimum Package	*	Medium Package	*	Maximum Package	*
6. Measures to Improve the Efficiency of Taxi Service and Goods Movement	High occupancy taxi operation	1-2%	High occupancy taxi operation, restrict cruising, truck loading zones	1-3%	Combination of several truck and taxi-related actions	1-5%
7. Measures to Restrict Traffic					Auto-free zone(s) of pedestrian mall type	0-2%
8. Transportation Pricing Measures			Parking-related actions	1-3%	Parking-related actions, possibly bridge and/or highway tolls, possibly vehicle-related fees	1-10%
9. Measures to Reduce the Need to Travel					Possibly four-day work week, possibly zoning-related changes	1-14%
10. Energy Restriction Measures	Low level of restriction of quantity of sales on a geographical basis	2-6%	Restriction of quantity of sales on a geographical basis, ban on Sunday and/or Saturday gasoline sales	5-15%	Gas rationing with or without transferable coupons, restriction of quantity on a geographical basis, ban on Sunday and/or Saturday gas sales, reduced speed limits	10-25%
CUMULATIVE PACKAGE ENERGY REDUCTION (PERCENT)	7-12%		12-20%		20-35%	

*The figures given in the boxes in the upper right-hand corners are expected percent regional energy reductions if only the measures in the box are implemented.

The following conclusions became evident while developing the sample packages:

a) carpooling actions are the most generally applicable and are easy and quick to implement.

b) restrictions on gasoline sales would probably increase the effectiveness of any size package.

c) implementation of both carpooling and transit actions may not be necessary to achieve a low reduction in energy consumption; carpooling measures were selected for most packages because they may be quickly implemented.

d) incentive-type actions are preferable to disincentives for achieving high-energy reduction, as they generally meet fewer institutional obstacles and attract more favorable public reaction.

e) the action of improving total vehicular flow should be carefully considered before implementation, as it can be counterproductive to several other types of actions.

f) taxi service and goods movement improvement actions are most effective and applicable in large urban areas.

g) local factors greatly influence the effectiveness of the conservation actions. Factors which can have such an influence are institutional and policy structures, existing transportation control strategies, extent of projected application, and local attitudes toward energy conservation efforts. Thus a range of percentages of reduction of energy consumed is given.

h) due to overlapping, the total reduction of energy use effected by a package of actions will be less than the sum of the individual actions' reductions.

In conclusion, it is emphasized that the energy reduction packages developed are illustrative examples only. For existing urban areas, the conservation actions should be combined in packages tailored to fit local energy conservation goals and attitudes.

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