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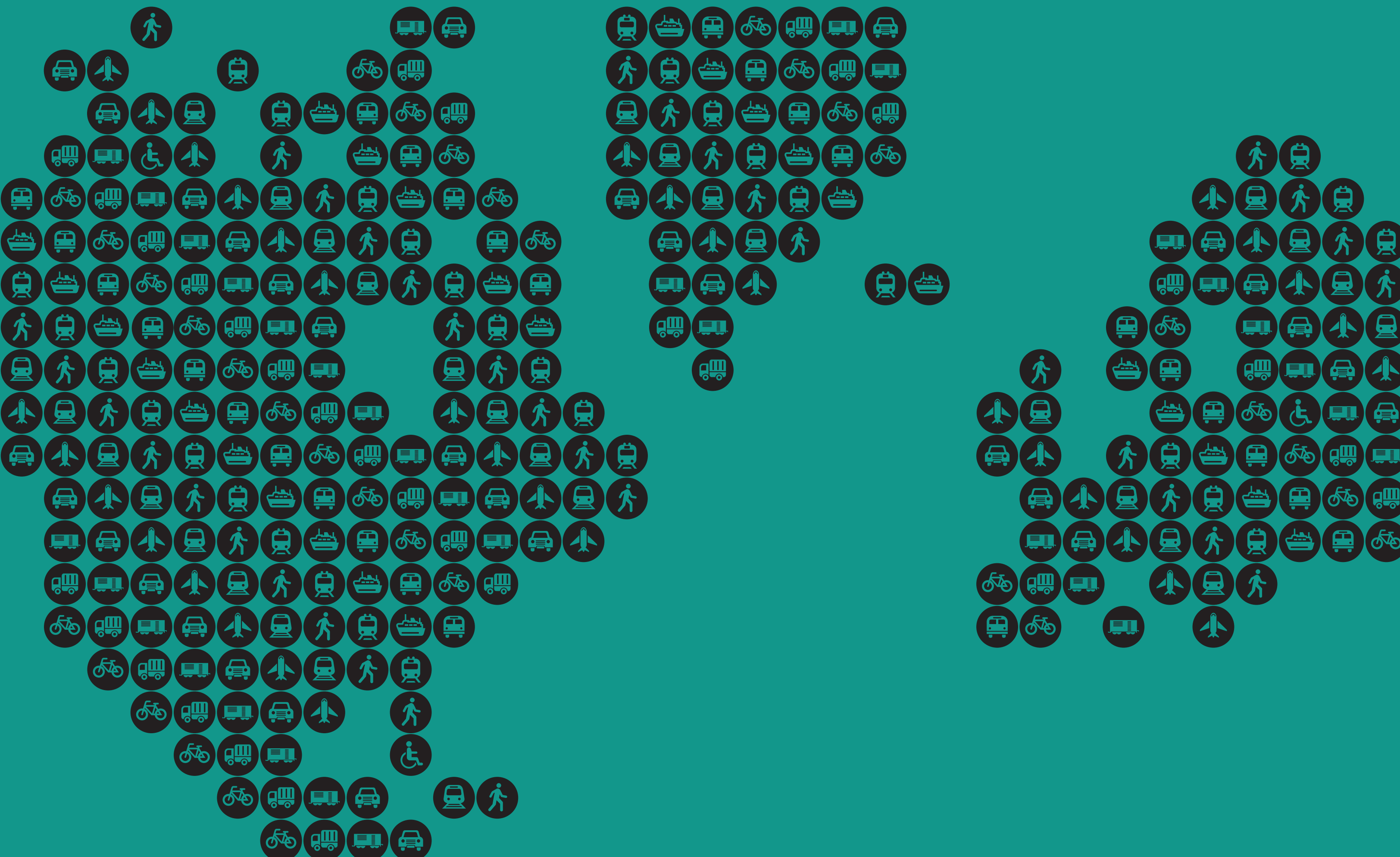

DECARBONIZING TRANSPORT FOR A SUSTAINABLE FUTURE

Mitigating Impacts of the Changing Climate

Summary of the Fifth EU-U.S. Transportation Research Symposium

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Decarbonizing Transport for a Sustainable Future

Mitigating Impacts of the Changing Climate

Summary of the Fifth EU-U.S. Transportation Research Symposium

Katherine F. Turnbull
Rapporteur

May 17–18, 2017
National Academies of Sciences Building
Washington, D.C.

Organized by the
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Transportation Research Board

The National Academies of
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Contents

Acronyms

BCA	benefit–cost analysis
BEV	battery electric vehicle
BRT	bus rapid transit
C	Celsius
CAFE	Corporate Average Fuel Economy
CAV	connected autonomous vehicle
CCCEF	Center for Climate Change and Environmental Forecasting
CO_2	carbon dioxide
DOT	Department of Transportation
EC	European Commission
EEA	European Environment Agency
EIA	Energy Information Administration
EU	European Union
F	Fahrenheit
FAA	Federal Aviation Administration
FDT	flexible on-demand transport
FFV	flex-fuel vehicle
FHWA	Federal Highway Administration
GHG	greenhouse gas
H2FCEV	hydrogen fuel cell electric vehicle
HEV	hybrid electric vehicle
ICEV	internal combustion engine vehicle
ICT	information and communication technology
IMO	International Maritime Organization
IPCC	International Panel on Climate Change
ITF	International Transport Forum
ITS	intelligent transportation systems
LDV	light-duty vehicle
MaaS	Mobility as a Service
MOU	memorandum of understanding
MPO	metropolitan planning organization

NAS	National Academies of Sciences, Engineering, and Medicine
NO_2	nitrogen dioxide
NOx	nitrogen oxides
NRC	National Research Council
PHEV	plug-in hybrid electric vehicle
PM	particulate matter
PPP	public–private partnership
SLR	sea level rise
TEN-T	Trans-European Transport Network
TfGM	Transport for Greater Manchester
TfN	Transport for the North
TNC	transportation network company
TRB	Transportation Research Board
TTI	Texas A&M Transportation Institute
U.S. DOT	U.S. Department of Transportation
UN	United Nations
VMT	vehicle miles traveled
WTW	well-to-wheels

Preface

This document summarizes Decarbonizing Transport for a Sustainable Future: Mitigating Impacts of the Changing Climate, a symposium held May 17–18, 2017, at the National Academies of Sciences, Engineering, and Medicine Building in Washington, D.C. Hosted by the European Commission and the Transportation Research Board (TRB) of the National Academies of Sciences, Engineering, and Medicine, it was the fifth annual symposium sponsored by the European Commission and the United States. The goals of these symposia are to promote common understanding, efficiencies, and trans-Atlantic cooperation within the international transportation research community while accelerating transport-sector innovation in the European Union and the United States.

The two-day invitation-only symposium brought together high-level experts to share their views on decarbonizing transport and mitigating the impacts of the changing climate. With the goal of fostering trans-Atlantic collaboration in research and deployment, symposium participants discussed policies, programs, and innovative approaches for decarbonizing the transport sector.

A bilateral planning committee was assembled by TRB and appointed by the National Research Council (NRC) to organize and develop the symposium program. Steven Cliff of the California Air Resources Board and Simon Edwards of Ricardo served as cochairs of the planning committee. Committee members provided expertise in public road and transit systems, freight, aviation, land use and transport planning, and climate science. The planning committee was responsible for organizing the symposium, identifying speakers, commissioning a white paper, and developing four exploratory topic papers to facilitate discussion at the symposium. The white paper is provided in Appendix A and the exploratory topic papers are presented in Appendixes B through E. New readers may find it advantageous to review the white paper and exploratory topic papers first to more fully understand the discussion in the breakout groups.

The exploratory topic papers addressed creating partnerships and strategies with co-benefits, the influence of the policy environment on climate mitigation strategies, approaches in megaregions, and freight transport. The papers were developed and presented by planning committee members to help frame discussions in the breakout groups, which focused on identifying research topics appropriate for EU-U.S. collaboration.

The symposium's interactive format enabled ongoing input from the assembled experts. The symposium began with a keynote presentation by Axel Friedrich of the International Council on Clean Transportation. The white paper prepared for the symposium was also presented in the opening session by coauthors David Greene of the University of Tennessee, Knoxville, and Graham Parkhurst of the University of West England, Bristol. Seleta Reynolds of the City of Los Angeles Department of Transportation and Helle Søholt of Gehl discussed examples of projects and programs that make communities more friendly for pedestrians and bicyclists while improving safety and reducing energy use.

The breakout sessions followed a common format. First, members of the planning committee summarized the key elements of the exploratory papers. Second, participants discussed challenges and opportunities and potential research needs on the topic in breakout groups. Third, planning committee members summarized the key discussion points in the closing general session. The symposium concluded with a keynote presentation by José Viegas of the International Transport Forum and final comments from the EU and TRB representatives.

This report prepared by Katherine F. Turnbull of the Texas A&M Transportation Institute, the symposium rapporteur, is a compilation of the presentations and a factual summary of the ensuing discussions at the event. The planning committee was responsible solely for organizing the conference, identifying speakers, and developing breakout session topics. The views contained in the report are those of individual symposium participants and do not necessarily represent the views of all participants, the planning committee, TRB, the European Commission or NRC.

This volume has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise in accordance with procedures approved by the NRC Report Review Committee. The purposes of this independent review are to provide candid and critical comments that will assist the institution in making the published summary as sound as possible and to ensure that it meets institutional standards for objectivity, evidence, and responsiveness to the project charge. The review comments and draft manuscript remain confidential to protect the integrity of the process.

TRB thanks the following individuals for their review of this report: Victoria Arroyo, Georgetown University; Steven Cliff, California Air Resources Board; Gabriel Pacyniak, University of New Mexico; Karl Simon, U.S. Environmental Protection Agency; and Marie Venner, Venner Consulting.

Although the reviewers listed above provided many constructive comments and suggestions, they did not see the final draft of the symposium summary before its release. The review of this summary was overseen by Susan Hanson of Clark University (emerita). Appointed by the NRC, she was responsible for making certain that an independent examination of this summary was performed in accordance with established procedures and that all review comments were carefully considered. Responsibility for the final content of this summary rests entirely with the authors and the institution. The conference planning committee thanks Katherine F. Turnbull for her work in preparing this conference proceedings summary.

Opening Session

Neil J. Pedersen, *Transportation Research Board, Washington, D.C., USA*
Robert Missen, *Directorate-General for Mobility and Transport, European Commission, Brussels, Belgium*
Kate White, *California State Transportation Agency, Sacramento, USA*
Simon Edwards, *Ricardo, Shoreham-by-Sea, United Kingdom*
Axel Friedrich, *International Council on Clean Transportation, Washington, D.C., USA*
David L. Greene, *University of Tennessee, Knoxville, USA*
Graham Parkhurst, *University of the West of England, Bristol, United Kingdom*
Seleta Reynolds, *City of Los Angeles Department of Transportation, California, USA*
Helle Søholt, *Gehl Architects, Copenhagen, Denmark*

Welcome from the Transportation Research Board

Neil J. Pedersen

Neil Pedersen provided a welcome from the Transportation Research Board (TRB) and the National Academies of Sciences, Engineering, and Medicine. He noted that TRB was pleased to host the fifth EU-U.S. Transportation Research Symposium. He reviewed the topics addressed at the first four symposia, which included urban logistics, research implementation, automated road transport, and transportation resilience and adaptation to climate change and extreme weather events. This fifth symposium builds on the resilience topic by examining the decarbonization of transport for a sustainable future.

Pedersen noted that the topics of sustainability and resilience are important to the National Academies and TRB. He stressed the importance of the partnership between the United States and the European Union in conducting the symposia, which have enhanced trans-Atlantic cooperation, information sharing, and coordination in transportation research. The symposia have provided the opportunity for individuals from public agencies, industry, and academia to discuss key issues, challenges, potential strategies, research needs, and joint activities. Pedersen reported that the results from this symposium will be used by TRB, the European Union, and other organizations in the development and conduct of critical research projects.

Pedersen recognized and thanked the members of the symposium planning committee, including Cochairs Steven Cliff of the California Air Resources Board and Simon Edwards of Ricardo. Pedersen noted that Cliff was not able to attend the symposium and thanked Kate White of the California State Transportation Agency for filling in as cochair in Cliff's absence. Pedersen praised the hard work of the planning committee in developing the scope of the symposium, identifying the white paper authors, and preparing the exploratory topic papers for the discussion groups. Additionally, he thanked Bill Anderson and Brittney Gick of TRB and Frank Smit of the European Commission for their assistance in organizing the symposium.

Pedersen invited symposium participants to attend the 2018 TRB Annual Meeting in Washington, D.C., on January 7 to 11. He reported that the 2017 Annual Meeting attracted approximately 13,300 attendees. One-fifth of the participants were international. He noted that the EU-U.S. symposia are a key part of TRB's expanding international activities and stated that there will be a session at the 2018 Annual Meeting highlighting the topics covered at this symposium.

Pedersen reported that TRB would publish the symposium proceedings, with Katie Turnbull from the Texas A&M Transportation Institute (TTI) acting as the rapporteur. The proceedings summarize the presentations and highlight the research topics discussed in the working groups.

Welcome from the European Commission

Robert Missen

Robert Missen extended a welcome from the European Commission. He recognized the planning committee members for their hard work in organizing the symposium and thanked the authors of the white paper for helping frame the topics for discussion during the breakout groups. He also thanked the participants for taking time from their busy schedules to share their ideas, experiences, and expertise.

Missen stressed the value of the trans-Atlantic partnership and the interaction of researchers, scientists, agency personnel, and industry representatives from Europe and the United States. He discussed the symposium theme focusing on decarbonizing the transport system for a sustainable future and noted the importance of the topic in the European Union.

Missen reviewed the symposium format of keynote presentations and breakout group discussions. He noted that the symposium goal was to foster dialogue and interaction among participants. He highlighted the major objective of identifying critical research topics, including those appropriate for trans-Atlantic collaboration. Missen discussed the importance of factual information for policy development and decision making. He noted that the symposium results would be of benefit and use to the European Union and to member countries.

Opening Comments by the Symposium Cochairs

Kate White and Simon Edwards

Kate White and Simon Edwards welcomed participants on behalf of the symposium planning committee. They reviewed the purpose, scope, format, and agenda of the symposium and also discussed potential follow-up activities. White and Edwards covered the topics discussed below in their presentation.

White provided a welcome from Steven Cliff, Cochair of the planning committee, who was not able to attend the symposium. She noted the recent Paris Agreement and the importance of decarbonizing the transportation sector and reducing greenhouse gas (GHG) emissions. White suggested that numerous strategies are needed to accomplish these goals, including cleaner fuels, cleaner vehicles, and reduction of the demand for driving. White noted the challenge of reducing the use of private vehicles given the convenience, social status, and economic opportunity they provide. She suggested that a new paradigm that focuses on cleaner transportation was needed.

White reviewed the symposium agenda. The first morning included an opening keynote presentation, a summary of the white paper prepared for the symposium, and two speakers who addressed current activities in Europe and the U.S. The morning concluded with presentations on the first two exploratory topics. The afternoon was spent in breakout group discussions of the two exploratory topics. The second day included presentations on the final two exploratory topics, breakout group discussions of the topics, summary reports from the breakout groups, and a concluding keynote presentation.

Edwards recognized the hard work of the planning committee in organizing the symposium. He noted that the committee, which was formed in October 2016, used two meetings and twice-monthly conference calls to identify the white paper authors, review the white paper, and develop the four exploratory topic papers. The committee also identified the keynote speakers and developed the symposium agenda.

Edwards discussed the anticipated symposium follow-up activities. He noted that TRB would publish the symposium proceedings by the end of the year. Further, a workshop highlighting key elements from the symposium would be held at the 2018 TRB Annual Meeting in January in Washington, D.C. The research topics identified during the symposium would be used to develop projects in both the European Union and the United States, including those appropriate for twinning and other methods of trans-Atlantic cooperation.

Edwards encouraged participants to share their ideas, experiences, and issues during the breakout groups. He further encouraged participants to identify good practices and research needs, including those suited for trans-Atlantic collaboration.

Keynote Address

Transport Emissions after the 21st Conference of the Parties

Axel Friedrich

Axel Friedrich discussed changes in the global climate, more frequent extreme weather events, and sea-level rise. He described potential strategies to reduce emissions from the transport sector. Friedrich's presentation covered the topics outlined below.

Friedrich described recent changes in the global climate. He noted the increases in the global mean temperature estimates based on land and ocean data from 1880 to 2020. These estimates indicated that the global temperature has been increasing over the past 140 years, with increases accelerating over the past 20 years. He said that these increases are not due to natural causes, but are attributable to human actions.

Friedrich described different climate change models, which all show similar general trends. He said that the similar outcomes of different models provide some confidence in scientists' projections of climate change in the future. Friedrich discussed the impact of changing temperature on the Arctic, noting that the Arctic summer sea ice has decreased by 40% since 1979, accompanied by increasing discharge from the Greenland ice sheet. While natural variability may explain some of the changes, the overall trend toward warming and melting has been attributed primarily to human-induced climate change. He noted this recent activity suggests a link between Arctic sea ice melt and increased glacier runoff in Greenland. It has been projected that if these trends continue, the Arctic could be ice-free by summer 2040.

Friedrich said that the changes under way in the Arctic have wide-ranging consequences for the Arctic ecosystems and people living and working in the Arctic. He noted that the Arctic also plays an important role in global climate and weather, sea-level rise, and world commerce. As a result, the impacts in the Arctic resonate far south of the Arctic Circle. A recent economic analysis of the global costs of Arctic climate change estimated the cumulative cost at $7 to $90 trillion over the period from 2010 to 2100 (http://www.amap.no/documents/doc/Snow-Water-Ice-and-Permafrost-for-Policymakers/1532).

Friedrich reviewed elements of the United Nations World Meteorological Organization *Statement on the Status of the Global Climate in 2016* (WMO 2017). WMO reported that 2016 was the warmest year on record, at about 1.1°C above the preindustrial period. Furthermore, carbon dioxide (CO_2) in the atmosphere reached new levels, the extent of global sea ice declined, and global sea levels rose. Additionally, global ocean heat was the second highest on record and severe droughts and floods displaced hundreds of thousands of people.

Friedrich reviewed elements of the Paris Agreement, which emphasized the urgent need to address the significant gap between the aggregate effect of parties' mitigation pledges, in terms of global annual emissions of GHGs by 2020, and the aggregate emissions pathways consistent with holding the increase in the global average temperature to well below the target of 2°C above preindustrial levels and with pursuing efforts to limit the temperature increase to 1.5°C above preindustrial levels. He said that it is his personal belief that it will be necessary to stop GHG emissions by 2025 to meet the goals, which is not likely.

Friedrich noted that the increases in temperature are not evenly distributed around the globe. While a few areas are getting colder, most are getting warmer. For example, temperatures at the Arctic continue to increase. The National Snow and Ice Data Center reported that the extent of the average monthly arctic sea ice declined from 1978 to 2008. In addition, he reported, the Greenland ice mass is melting. Friedrich discussed that glaciers are receding rapidly worldwide, including in the Rockies, Andes, Alps, and Himalayas. He illustrated the changes in Rongbuk, the largest glacier on Mount Everest's northern slopes, from 1968 to 2007.

Friedrich described the increase in extreme weather events throughout the world, noting the destruction and the economic impacts of these events. He reported that for dramatic damage to be avoided, the temperature rise must be limited to the target of 2°C compared with the preindustrial level. He said that to lower the risk for exceeding the 2°C limit below 30%, CO_2 reductions of 50% to 60% as compared with 1990 levels would be necessary until 2050. For industrial countries, this would mean reductions of 90% to 95% in CO_2 emissions. For the European Union, this would mean a reduction from 7.4 tons per capita to 1.0 to 1.5 tons per capita of CO_2 emissions per year until 2050.

Friedrich discussed the difficulty of achieving these targets. He described the growing demand for oil and energy worldwide and further noted that GHG emissions from the transport sector continue to increase in most countries, with the largest increases being in China, India, the Middle East, and Africa. He said that continuing along this path would have severe consequences.

Friedrich described the increase in global marine fuel consumption, noting that GHG emissions from marine transport are not covered under the Paris Agreement. He noted similar trends in increased GHG emissions in the aviation sector.

Friedrich discussed the current situation in Europe, including baseline and future projections for CO_2 emissions. He reviewed the 2050 EU GHG emissions reduction targets for the transport sector, noting that GHG emissions in other sectors decreased by 15% between 1990 and 2007, while emissions from the transport sector increased 36% during the same period. Even with improved vehicle efficiency, this increase resulted from an increase in personal and freight transport. Friedman noted that GHG emissions from transport began decreasing in 2009. Despite this trend, transport emissions in 2012 were still 20.5% above 1990 levels and would need to decline by 67% by 2050 to meet the European Union's target reduction of 60% as compared with 1990, as discussed in the European Commission's 2011 white paper, "Roadmap to a Single European Transport Area: Towards a Competitive and Resource Efficient Transport System" (EC 2011). He said that a goal of 100% reduction of GHG emissions in the transport sector was needed if the Paris Agreement target of limiting the increase in global average temperature to less than 2°C above preindustrial levels was to be achieved.

In closing, Friedrich said that on the basis of current knowledge, emissions reductions from the freight transport sector could not be achieved by a continuing reliance on trucks that use fossil fuels. He further said that the only realistic alternative is through the major modal shift of freight transport to railroads and the complete electrification of the railway system with 100% renewable electricity.

Presentation of the Symposium White Paper

Decarbonizing Transport for a Sustainable Future: Mitigating Impacts of the Changing Climate

David L. Greene and Graham Parkhurst

David Greene and Graham Parkhurst presented the white paper prepared for the symposium, "Decarbonizing Transport for a Sustainable Future: Mitigating Impacts of the Changing Climate." The complete text of the white paper is provided in Appendix A. Greene and Parkhurst's presentation covered the topics summarized below.

Greene suggested that the necessity of protecting the global climate system has created an unprecedented challenge for transportation that poses new questions for researchers. He noted that the recent Paris Agreement reaffirmed scientists' long-standing view that it is critical to keep increases in climate temperatures to less than 2°C to preserve current socioeconomic conditions. A 2014 report by the Intergovernmental Panel on Climate Change identified that the current trajectory of global emissions would increase the average global temperature beyond the 2°C goal. Reductions in GHG emissions of 80% to 90% by the United States and the European Union by 2050 are necessary to constrain the increase in global average temperature to less than 2°C.

Greene described four fundamental approaches to mitigating transportation's GHG emissions: improving vehicle energy efficiency, reducing the carbon intensity of energy sources, reducing the level of motorized transport activity, and improving the efficiency of the transport system. He suggested that all of these approaches are needed to reduce GHG emissions.

Greene noted that the Intergovernmental Panel on Climate Change defines mitigation as human intervention to reduce the sources of GHGs. He suggested that mitigation is essential to prevent dangerous anthropogenic interference with the climate system.

Greene noted that transportation is a major and growing source of GHG emissions. The white paper provides a systems perspective, examining well to wheel, cradle to grave, and the logistics chain. The paper also describes current commitments, policies, and projected outcomes and highlights two technological solutions that focus on energy efficiency and lowcarbon energy. The white paper concludes by highlighting some of the challenges in reducing GHG emissions in the transportation sector, potential measures for more radical reductions, and research questions.

Greene noted that transportation's proportion of GHG emissions in the European Union and the United States is larger than its global proportion. Transportation's GHG emissions consist almost entirely of CO_2 from the combustion of petroleum fuels. Road transport is the dominant source of emissions in both the European Union and the United States. Greene reported that aviation and marine transport produce a larger proportion of GHG emissions in the European Union than in the United States.

Greene discussed that transportation's GHG emissions are linked to the entire economy. He noted that including these linkages allows for a more comprehensive comparison of alternatives. The well-to-wheels comparison examines the impact of the supply chain for various fuel sources, including biofuels. The cradle-to-grave comparison is a more comprehensive life-cycle analysis that includes the performance of vehicle components. The logistics chain comparison examines the energy and emissions used by different modes and facilities in the chain.

Greene reviewed some of the different international commitments related to reducing GHG emissions. He noted that the Under2 Memorandum of Understanding (MOU) is a voluntary commitment by subnational jurisdictions to pursue emissions reductions consistent with a goal of reducing GHG emissions by 80% to 95% below 1990 levels by 2050, with an interim goal of 40% by 2030. The MOU also states that the parties agree to take steps to reduce GHG emissions from passenger and freight vehicles, with the goal of broad adoption of zero-emissions vehicles and the development of related zero-emissions infrastructure. The MOU also includes an agreement to encourage land use planning and development that supports public transit, biking, and walking. As outlined in its 2011 white paper, the European Commission has set a goal of 60% reduction in transportation sector emissions from 1990 levels by 2050 and a pathway to zero-emissions transport beyond. During President Obama's administration, the United States had an economywide goal of a 17% reduction from 2005 levels by 2020. California has a goal of a 40% reduction from 1990 levels by 2030.

Greene noted that official projections indicate that these goals will not be met in the transportation sector under current policy frameworks, partially due to the projected continued growth of transportation activity. He further noted that *Global Energy Assessment: Toward a Sustainable Future* reported that the single most important area of action was energy efficiency improvement in all sectors (IIASA 2012), adding, however, that energy efficiency alone would not be enough. He reported that studies indicate that for freight and air passenger travel, greater energy efficiency is likely only to restrain the growth of GHG emissions.

Greene described the estimated costs and benefits of transitioning to electric drive light-duty vehicles as reported in the National Research Council's *Transitions to Alternative Vehicles and Fuels* (NRC 2013). He suggested that energy transition presents a new problem for transportation policy. Potential challenges include the long transition timeframe, the uncertainty for future technologies and market conditions, and the need for policies to directly or indirectly subsidize the transition that may need to be sustained for decades. Additionally, he noted that early costs are likely to exceed potential benefits. He suggested that co-benefits can be critical to positive social benefits.

Greene suggested that there are reasons for optimism. First, battery system costs have been dramatically reduced while energy density has increased. Further, fuel cell vehicles have moved from experimental to commercial products over the past 20 years.

Greene emphasized that the transition to low-GHG energy systems requires answers to new research questions. He suggested that a new policy paradigm for large-scale energy transition is needed to address the long transition period and the uncertainties. He described examples of transition barriers to creating strong positive feedback and tipping points. These examples included scale economies and learning by doing, majority risk aversion and lack of diversity in choice of make or model, refueling infrastructure and vehicle sales, and institutional and regulatory infrastructure to support markets. Greene further suggested that new methods of analysis for planning investments in vehicles and infrastructure were needed and should focus on possible government and private-sector roles in managing the co-evolution of fuel and vehicle markets and in improving the reliability of estimating the costs and benefits of a transition.

Parkhurst reviewed the demand forecast to 2050 in the European Union and the United States for road transport, aviation, and waterborne transport. He noted that behavior change is a key to mitigating climate change. Parkhurst discussed how the difficulty of changing behavior makes achieving GHG reductions in the transport sector so challenging. He considered how behavior change could be increased more quickly and suggested that a better understanding of the behavior change potential of different strategies would be beneficial.

Parkhurst described the CO_2 emissions at the average occupancy for various transport modes, noting that mode choice is critical to achieving targeted goals but that other strategies are also needed. He described the dependence on the automobile and commented that society and auto mobility represent a coevolution over decades. He noted that technological change must be part of the solution, as it is difficult to reverse the automobile-oriented infrastructure and the mindset of the population. Further, progress toward the more difficult behavior change targets would also be essential.

Parkhurst reviewed the portion of the white paper that examines the challenges associated with achieving GHG reductions in the transport sector. He described how the three elements of social practice theory—materials, competence, and meaning—relate to the transport sector. Parkhurst noted that access to the automobile is not equally shared. He described the use of different modes by different income levels, with higher automobile use at the higher income levels. He stressed the importance of the sociocultural links to the automobile, with the obtaining of a driver's license considered a rite of passage in many countries.

Parkhurst noted that walking is the major mode of travel for destinations within 1 to 2 kilometers. He suggested that increasing short trips that can be made by walking or bicycling is critical for increasing low-carbon mode choice. He noted that trips over this short distance are made predominantly by automobiles and suggested that with changes in the built environment occurring relatively slowly, reducing middle-distance automobile-oriented trips, which generate most of the GHG emissions, will continue to be a challenge. Parkhurst further noted that many of these middle-distance trips are made for work, school, and other regular activities. He suggested that the planning process may overfocus on journey-to-work trips, whereas as a whole range of journey types contributes to vehicle GHG emissions. Compounding the issue is that many of these trips are not well suited for public transport.

Parkhurst discussed the costs associated with owning and operating personal vehicles. He noted that the real cost of purchasing an automobile has decreased in Europe. He further noted that operating costs, which are largely dependent on fuel costs, have also been trending downward recently. The costs associated with passenger travel by rail, air, and water are all trending upward.

Parkhurst described possible rebound effects and unintended consequences from policies and programs. He cited an example from the United States, where improvements in fuel economy driven mostly by regulatory standards have reduced fuel consumption but appear to have increased vehicle miles of travel by a relatively smaller amount.

Parkhurst described current knowledge about the impacts of the three options for reducing motorized transport—reducing the need to travel, encouraging modal shifts to higher-occupancy vehicles, and encouraging modal shifts to zero- and ultralow-GHG vehicles. He noted that there has been less focus recently on strategies to reduce the need to travel. Parkhurst discussed the importance of examining experiences with different strategies in different countries. He highlighted walking and bicycling rates in the European Union and the United States, which vary considerably, and noted the higher levels of cycling in Denmark and the Netherlands compared with other European countries.

Parkhurst described Evidence, a 3-year EU-funded project examining the quality of information about the effects of the 22 measures recommended for local authorities implementing the European Union's Sustainable Urban Mobility Plan (http://evidence-project.eu/). He noted that the literature review found a good range of high-quality and high-quantity evidence for seven measures of sustainable urban transportation, high-quality evidence for one measure, and limited quantity or quality of evidence, or both, for 14 measures. He commented that many of the measures are relevant to climate change mitigation.

Parkhurst reported that the measures in the EU Sustainability Urban Plan that he thinks have good quantity and quality of evidence included cleaner vehicles, parking management, site-based travel plans, and personalized travel planning. Other measures with good quantity and quality of evidence were enhancements to public transport systems, new public transport systems, bicycling infrastructure, and environmental zones. Parkhurst noted that measures in the EU Sustainable Urban Mobility Plan that had methodologically weak or limited evidence included battery–fuel cell electric vehicles, urban freight, access restrictions, road space reallocation, and congestion charges. The evidence for measures that addressed marketing and rewarding the integration of modes, e-ticketing, traffic management, travel information, new models of car use, walking, bikesharing, and inclusive urban design was also limited or methodologically weak. Parkhurst stressed that in some cases, the evidence was limited because the measure had only recently been adopted and evaluation information had not yet emerged.

Parkhurst highlighted examples of the impacts identified with a few measures. He noted that Measure 8, which addresses the use of parking policy as a tool for managing car traffic in and around urban areas, has been widely researched, with approximately 2,000 studies reviewed. Parkhurst reported that, on balance, the findings suggested that parking management itself does not have negative economic impacts, but that efficiency is enhanced by cash-out programs, pricing, and tax policies. He noted that the UK had the best-quality studies on Measure 9, which focuses on mobility management strategies for an organization and its site or sites. This measure seeks to reduce single-occupancy automobile use to, from, and around a site and to increase use of alternative modes. Evidence from the UK studies indicates that single-occupant automobile trips may be reduced by up to 18%, with indirect economic benefits from increased active travel. Parkhurst noted that one of the best studies addressing Measure 20, which focuses on new bicycle lanes on roadways and new off-road paths, was from North Carolina, where a large, 10-year investment in a new bicycling network returned a benefit–cost ratio of 9:1.

Parkhurst described the emergence of smart mobility or transportation network companies (TNCs), such as Uber and Lyft. He suggested that more research is needed on the impacts of these services but observed that UberPool in San Francisco reported recently that 50% of trips are shared. He noted that the impact of bikesharing also needs further research; the most successful of these programs indicate an automobile substitution rate of approximately 20%.

Noting that urban areas produce only 23% of total EU transportation GHG emissions, Parkhurst suggested that research and policies may also need to consider mobility management and behavior change for long distances and international freight transport and air travel. He noted that further discussions on the impacts of these modes would be beneficial.

Parkhurst discussed the potential impacts of autonomous vehicles on GHG emissions. He noted that the 2015 EU-U.S. Symposium was on automated road transport. He described the shared vehicle delivery model, which in theory, in optimal conditions, might require only 10% to 20% of the vehicles currently in operation. Parkhurst described the results of a recent study conducted in Bristol, UK, that asked automobile users about their willingness to use autonomous vehicles in different modalities. Approximately half the respondents reported they would use an autonomous vehicle. However, 65% reported a normal automobile as their first preference, and 25% reported an exclusive use, private autonomous vehicle as their first choice. The shared options attracted few first preferences. Parkhurst suggested more research was needed on the behavioral impacts of autonomous vehicles.

Parkhurst concluded by noting that the evolving context of mobility choices creates opportunities and threats that research could illuminate. He presented the following research questions from the white paper for discussion in the breakout groups:

- How do citizens and organizations respond to changes in the mobility context? Can the connections between choices and consequences be strengthened?
- How can the new private-sector mobility solutions be integrated effectively into a public policy framework? What is the future role of traditional public transport?
- How will changing mobility options alter the metrics for monitoring and validating GHG reductions?
- What are the GHG mitigation options for managing travel behavior for extraurban and intercontinental travel?

- What are the synergies and conflicts between GHG mitigation and other policy areas, including social justice and management of noxious pollution?
- How can the transition to automated vehicles be managed to reduce rather than increase GHG emissions?

Setting the Scene: Why We Cannot Wait

The Los Angeles Experience

Seleta Reynolds

Seleta Reynolds discussed programs and activities under way at the Los Angeles Department of Transportation (DOT) to provide a safe, equitable, reliable, and affordable transportation system in the city. She noted that the research, meetings, and conferences sponsored by TRB and other organizations provide valuable resources for addressing critical transportation issues in urban areas. Reynolds' presentation covered the topics summarized below.

Reynolds reported that approximately one-third of the households in and around downtown Los Angeles do not have access to a private vehicle. She noted that the city has some of the most well-used bus routes and passenger rail lines in the country. Additionally, the number of pedestrians in Los Angeles is among the largest in U.S. cities. The city is also characterized by sprawl development and congested freeways.

Reynolds described the current policy framework, which is based on Great Streets for Los Angeles, the Los Angeles DOT Strategic Plan (http://ladot.lacity.org/sites/g/files/wph266/f/LACITYP_029076.pdf), as well as on Los Angeles' Mobility Plan 2035 (https://planning.lacity.org/documents/policy/mobilityplnmemo.pdf) and Sustainable City pLAn (http://plan.lamayor.org/). The Mobility Plan 2035 includes ambitious goals to reshape the city around walking, bicycling, and transit. The Sustainable City pLAn contains aggressive goals to address climate change, including reducing single-occupant vehicle trips from between 75% and 80% to 50%.

Reynolds reviewed the three focus areas of the Los Angeles DOT: safe great streets, which includes a goal of zero fatalities by 2025; mobility management and providing equitable, reliable, and affordable travel options for residents and visitors; and an internal focus area, ensuring a great work environment at the Los Angeles DOT and engaging employees in achieving the agency's goals.

Reynolds reviewed some of the key elements of Vision Zero Los Angeles 2015–2025. She noted that approximately 260 fatalities from traffic crashes occur annually in the city. Pedestrians and bicyclists, although involved in only 14% of these collisions, account for almost half of the fatalities. Mapping the locations of the crashes involving pedestrians and bicyclists revealed that 66% of these crashes were concentrated on 6% of the city's streets. An additional analysis found that many of these crashes occurred in neighborhoods with negative public health outcomes. Reynolds suggested that more research is needed to explore the factors influencing these trends.

Reynolds reported that traffic fatalities, including those involving pedestrians, increased in the past year and that year-to-date figures also increased. She suggested that research on the factors contributing to these increases would be beneficial.

Reynolds presented examples of approaches the Los Angeles DOT is using to reduce crashes, especially at intersections. The Hollywood and Highland intersection, shown in Figure 1, averaged crashes involving injuries or fatalities on a monthly basis. The pedestrian scramble shown in Figure 2 was installed in November 2015. All traffic stops during the pedestrian traffic signal

FIGURE 1 Hollywood and Highland intersection before pedestrian scramble installed. (Source: Los Angeles DOT.)

FIGURE 2 Hollywood and Highland intersection after pedestrian scramble installed. (Source: Los Angeles DOT.)

phase and pedestrians may cross in any direction. Reynolds reported that there have been no injury collisions or fatalities at the intersection since the pedestrian scramble was installed.

Reynolds described a second approach in which painted strips and a bollard are added to an intersection to create more visible space for pedestrians. Figures 3 and 4 show the application of this approach on Cesar Chavez Street in the Boyle Heights neighborhood. Reynolds noted that crash reductions have been realized at this intersection, but not to the same extent as achieved with the pedestrian scramble treatment. Reynolds suggested that more research is needed to compare the results of different treatments and identify keys to successful implementation.

Reynolds reviewed the results from recent focus groups and surveys examining the perceptions of transportation projects in the city, including bicycle facilities. She noted that there has been "bikelash," or backlash against bike lanes in some areas. In one survey, a total of 50% of the survey respondents strongly agreed that bike lanes were beneficial to the city, with only 9% strongly disagreeing. The responses changed, however, when respondents were asked if bike lanes were beneficial for them, with only 39% strongly agreeing and 17% strongly disagreeing. Further, while 61% of the respondents strongly agreed, and 7% strongly disagreed, that government should make biking safer for everyone, only 46% strongly agreed that bike lanes should be added to more streets, while 15% strongly disagreed.

Suggesting that transportation professionals needed a new language to communicate with the public, Reynolds described some of the negative words people associate with responses to climate change and possible mitigation measures. She noted that using terms related to organized, comfortable, and safe streets seems to resonate better with the public. She also stressed the need to listen to people, to understand their concerns, and to learn what improvements and changes they would like. Reynolds described the Los Angeles DOT People Street program, which can transform underutilized streets into parks and other activities on the basis of community input. Figures 5 and 6 illustrate one example of this approach in Leimert Park in South Los Angeles. She also described the Play Streets Program, which temporarily closes streets to traffic and sets up play equipment. She reported that the response to both programs has been very positive.

Reynolds described job accessibility by transit and by automobile in the city. Currently, 12 times as many jobs can be reached by automobile in an hour as by transit. She stressed that transportation has to provide people with connections to opportunities. She compared the reach of the Metrorail system with the service areas of Uber and other transportation network companies (TNCs). Much of the TNC service area also has frequent bus and rail service. She noted that research is needed to examine the impact of TNCs on transit use, bicycling, and walking. Although there is a lot of anecdotal evidence, accurate information on the possible impacts of TNCs on these modes and on traffic congestion is lacking.

Reynolds also discussed the possible impacts of automated vehicles on the city. A transportation technology strategy for Los Angeles has been developed. This strategy, presented in the report *Urban Mobility in a Digital Age: A Transportation Technology Strategy for Los Angeles*, presents a framework or platform for innovation (Hand 2016). The platform focuses on setting public policy and structuring investments to prepare for the arrival of con-

FIGURE 3 Cesar Chavez Street before installation of treatment. (SOURCE: **Los Angeles DOT.**)

FIGURE 4 Cesar Chavez Street after installation of treatment. (SOURCE: **Los Angeles DOT.**)

FIGURE 5 Leimert Park before plaza treatment. (SOURCE: Los Angeles DOT.)

FIGURE 6 Leimert Park after plaza treatment. (SOURCE: Los Angeles DOT.)

nected, automated, shared, and electric vehicles. The five elements include building a solid data foundation, leveraging technology and designing for a better transportation experience, creating partnerships for more shared services, supporting continuous improvement through feedback, and preparing for an automated future. The platform also includes data as a service, infrastructure as a service, and mobility as a service.

Reynolds described possible elements of data as a service, which focuses on the rapid exchange of real-time data on transportation conditions. Information may be exchanged between customers, service providers, government agencies, and the infrastructure to optimize safety, efficiency, and the transportation experience. Data-sharing agreements with Waze and other similar companies are one example of this approach.

Infrastructure as a service focuses on a dynamic pay-as-you-go approach to more closely align the costs of providing infrastructure with how it is used. Providing improved information on on-street parking schedules and costs, along with more convenient payment methods, is an example of the approach cited by Reynolds. Reynolds suggested that temporary infrastructure, such as creating temporary pop-up bike lanes, may play a more important role in the future.

Reynolds described the mobility-as-a-service approach, which includes access to a suite of transportation mode options through a single platform and payment to simplify access to mobility choices. The LA Promise Zone will provide one example of this approach. Using funding from several sources, the LA Promise Zone will include car-sharing services in a low-income community and building mobility hubs that bring together carsharing, bikesharing, taxis, and transit. It will also include community enhancements and treating residents with respect. Reynolds noted that all of these approaches will help mitigate climate change and improve safety, equity, mobility, and quality of life in the region. She also noted the importance of ensuring that current residents can continue to afford to live in neighborhoods that experience these improvements.

The Importance of the Social Infrastructure in Cities

Helle Søholt

Helle Søholt discussed the influence of the built environment and the social infrastructure on behavior change and mobility in cities. She provided examples of projects in Copenhagen and New York City to enhance streets and public spaces. Søholt's presentation covered the topics summarized below.

Søholt noted that Gehl approaches projects both as social scientists and as designers. She described the importance of using surveys, focus groups, and other methods to gain better insights into people's travel behavior, especially walking and bicycling trips.

With cities accounting for approximately 97% of new trips globally, Søholt stressed the challenge of building cities for all segments of society. She described the fabric of cities, including public spaces. Streets, sidewalks, and parks are all part of the public space.

Søholt highlighted some of the keys to success in the mobility approaches used in Copenhagen, including incremental change, focusing on hardware and software, single-agency oversight, and the use of metrics that reflect local values. She suggested that elements of public life in the city include equity and health. Public space elements focus on streets, parks, playgrounds, and the harbor. Walking, bicycling, transit, and passenger rail are key elements of an integrated transport system that provides mobility to all groups.

Søholt noted that vehicle emissions have been reduced by 50% in Copenhagen. She described the incremental changes and continual improvements in bicycle and pedestrian facilities in the city. The steady increase in the bicycle lane network since the 1930s is one example of this incremental approach. The network is consistent with the bike lanes and bike track always located on the right-hand side of the roadway.

Søholt described the culture of cycling in Copenhagen. She summarized information from a document called *Copenhagen City of Cyclists: Bicycle Account 2010*, including the results from surveys of bicyclists in the city. One of the questions asked respondents why they cycled. The most frequently cited reason, reported by 63% of the respondents, was that cycling was easy, fast, and convenient. Other responses were exercise (17%), financial reasons (15%), and the environment (5%). In addition, 70% of the respondents reported that they continue to bike in the winter.

Søholt discussed the importance of developing a shared understanding of roadway use among motorists and bicyclists. She noted that approximately 66% of all motorists in Copenhagen are also cyclists and that 33% of cyclists are also motorists. Søholt reported that although there was a 50% increase in automobile ownership over the past 10 to 15 years, there also was an increase in cycling. Additionally, she reported that approximately 25% of families with two or more children own a cargo bicycle. Søholt described the integration of the bicycle network with other modes, including allowing bicycles on local trains.

Søholt outlined the benefits of having a single agency responsible for the bicycle network. The City of Copenhagen has control over the design, development, and operation of the roadway system, including the bicycle network. She compared this approach with areas in Miami, where agencies at the city, county, and state levels have responsibility for different aspects of the roadway and bicycle systems.

Søholt described some of the policies, plans, and metrics used in Copenhagen that reflect community values. Goals focus on increasing walkability, increasing the amount of time people spend using public spaces, and increasing satisfaction with urban life.

Søholt provided examples of transferring the Copenhagen model to New York and other cities. She described projects in New York City to transform streets from focusing solely on automobiles to focusing also on pedestrians and bicyclists. She highlighted the change in Times Square from 89% road space and 11% people space to 100% people space. She noted that design can change behavior and urban culture. She described some of the benefits from the Times Square project, which include a 17% improvement in travel time, an 11% increase in pedestrian numbers, a 63% decrease in pedestrian injuries, and 80% fewer pedestrians walking in the street. Additionally, 74% of individuals who completed a survey reported that Times Square had improved dramatically.

Søholt discussed the link between mobility and affordability. She noted that approximately 75% of the 100 largest cities in the U.S. do not meet the 15% open space guideline. Further, many low-income and minority neighborhoods lack open space.

Søholt described the New York City Plaza Program, which provides funding through a competitive application process to transform underutilized streets into plazas and public spaces. The program partners with community groups that commit to operate, maintain, and manage the public space. She noted that over the past 10 years, the program has created more than 60 plazas in the city. She reported that surveys conducted by the Gehl Institute indicate that lower-income individuals are more likely to make new connections with other people through the plazas.

In closing, Søholt presented four challenges for the future and possible solutions:

- The infrastructure built in the 1960s, which creates barriers rather than connections in communities and which is in need of repair. A possible solution is to remove and renovate this infrastructure to enable social and physical connectivity and to enhance mobility.
- The lack of low-carbon infrastructure (i.e., infrastructure that, for example, reduces carbon emissions and decreases urban congestion). The absence of low-carbon infrastructure contributes to urban health concerns. A possible solution to this challenge would be connecting public health policies to the creation of low-carbon infrastructure.
- Action driven by top-down decision making. Søholt suggested addressing this challenge by reversing the trend so as to establish action driven by bottom-up input.
- The fracturing of communities by regulatory boundaries. A possible solution would be for federal agencies to act as facilitators to promote coordination between cities and counties. Søholt commented that a better method for enabling input from citizens, community groups, advocacy organizations, and local agencies was needed for developing future urban transport systems.

Søholt suggested that addressing these four challenges would make cities livable, equitable, and connected places for people.

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Abbreviations

EC	European Commission
IIASA	International Institute for Applied Systems Analysis
NRC	National Research Council
WMO	World Meteorological Organization

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Presentation of Exploratory Topics and Suggested Research Needs

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This section summarizes the presentation of the exploratory topic papers by the symposium planning committee members. The summaries of suggested research topics discussed in the breakout groups, as presented by the planning committee members, are also highlighted. The presentations and breakout groups followed a common format. The exploratory topic papers were presented in general sessions. Symposium participants discussed challenges and opportunities and potential research needs in breakout groups, which were facilitated by the planning committee members. There was no intent to rank or rate the research ideas discussed, nor was there any attempt to prioritize the potential research topics. The planning committee members presented summaries of the breakout group discussions in the general session prior to the closing speaker.

Exploratory Topic 1

Breaking Silos and Human Cocreation on Multiple Levels: The Key to Transforming the Current Sociotechnical Transport System Regime?

Daniel Kreeger and Malin Andersson

Daniel Kreeger and Malin Andersson discussed the first exploratory topic area, which focused on breaking down silos and on human cocreation on multiple levels as a key to transforming the current sociotechnical transport system regime. The paper on this exploratory topic is provided as Appendix B. Kreeger and Andersson's presentation covered the points summarized below.

Andersson discussed that the transportation system is essential for people's daily lives. Automobiles, buses, trams, passenger rail, walking, bicycling, ferries, and other modes provide people with mobility throughout the world. She noted that although it is known that vehicles burning fossil fuels contribute to global warming and have other negative impacts, people continue to use them. Additionally, she questioned why new solutions are not penetrating the transport system and why change is so difficult.

Andersson described the sociotechnical system of transportation, which includes transport regulations and policies, the maintenance and distribution system, the production and industry structure, markets and user practices, the fuel infrastructure, the road infrastructure, and cultural and symbolic meanings. She noted that thinking outside the box challenges current perspectives and challenged symposium participants to think outside the box during the breakout group discussions.

Andersson discussed the importance of supporting elements for successful policies and changes in behavior. She noted the challenge of overcoming the status quo and the difficulty of identifying the main obstacles for change in the transport system. She compared the potential obstacles to Russian nested dolls, noting that for each obstacle you overcome, there is another obstacle—or doll—at another level.

Andersson reviewed the four areas identified in the exploratory topic paper that may present obstacles and opportunities for change: leadership and human capital, the effects of bold political action, the valley of death for new business opportunities, and the power of convenience paired with a fear of the unknown.

Andersson discussed needed leadership and human capital for innovation in the transport sector. Kreeger asked participants to consider the following situation: in 30 years, gravity is either 30% stronger or 30% weaker. He noted that either change would have significant impacts on the world as known today. Kreeger suggested that the transport system has been built on the basis of the notion that everything about the world is predictable, stable, and consistent. Any variance is assumed to be within an acceptable range. He further suggested that these assumptions are no longer valid. Kreeger identified the changes in leadership and human capital that will be needed to adjust to this new situation as one topic for discussion in the breakout groups.

Andersson described a second area for discussion in the breakout groups that focused on the need for bold political action, citing the example of removing parking spaces in city centers. She noted the difficulty of introducing new and innovative strategies and programs in the transport sector. Kreeger suggested that all political actions require public understanding. He further suggested that policies addressing greenhouse gas (GHG) emission reductions are unsustainable without a public understanding of climate change. He identified a question for discussion in the breakout groups that related to methods for developing public understanding of climate change and support for changes in behavior.

Andersson discussed approaches for new business opportunities to bridge the valley of death in introducing innovative transport products and services. She cited Uber as one example, noting that some customers have expressed satisfaction that, in some markets, local regulations have excluded Uber from operating. She suggested that the solution does not "fit in the Russian doll." Kreeger noted the importance of addressing the potential for unintended consequences when new programs are implemented, for example, the consequences of transportation network companies' use of high-emissions vehicles.

Andersson discussed the final area for discussion in the breakout groups: identifying ways to overcome the potential inconvenience and unknowns of new services and program. She used the introduction of electric buses in the city of Gothenburg and the unknowns associated with the charging requirements of electric buses as one example of addressing new technologies.

In closing, Andersson and Kreeger stressed the need to address innovation in the transport sector as a complex problem that requires a diversity of solutions. They also highlighted the importance of the participation of public- and private-sector groups in the development and implementation of new policies and programs.

Suggested Future Research

The participants in the breakout groups identified ideas for future research related to Exploratory Topic 1, breaking down silos and transforming the current sociotechnical transport system. These ideas are listed below. The research ideas were detailed in the closing session by the planning committee members responsible for the exploratory topic. In addition, the rapporteur reviewed notes from the breakout groups in developing the following list.

- Explore the travel behavior of the millennial and the digitalized generations. Identify changes from the travel behavior of older generations and assess the potential impacts on mode use, vehicle miles traveled, and GHG emissions. Examine decarbonizing policies and programs that may appeal to these younger generations.
- Examine the co-benefits from transport decarbonization policies and programs and how they relate to factors that people value, such as quality of life and livable communities. Explore messages that focus on the co-benefits rather than the mitigation programs themselves.
- Examine whether areas that are prone to flooding or other impacts of extreme weather events are more proactive in developing and implementing mitigation policies and programs. The research could include assessing the perceptions of residents and policy makers, the actual mitigation policies and programs implemented, and lessons that could be shared with other areas.
- Examine current public knowledge of climate change, GHG emissions, and policies and strategies for decarbonizing transport. Identify the most effective communication messages and techniques for addressing the need for mitigation strategies and the potential benefits. Identify best practice examples and develop approaches for use in different situations and with different groups.
- Examine policies and programs supporting bicycle use and identify the most effective approaches for different areas and situations. The analysis could include policies and programs, such as bikesharing, and infrastructure, including bike lanes, bike paths, bike stations, and other facilities.
- Assess the potential impacts on current jobs and possible training and retraining needs associated with different elements of decarbonizing the transport sector. Examine changing workforce skills associated with electric vehicles, other alternative fuels, mitigation strategies, and assessment techniques.

• Examine stakeholder involvement techniques used with transport mitigation strategies. Identify methods to actively engage all groups in the discussion of reducing GHG emissions and the development of mitigation policies and programs. Explore ways to break down silos and work across agencies, organizations, and the private sector. Share best practice examples.

• Conduct pilots and demonstrations of different mitigation strategies. Document the results and share best practices and lessons learned with others.

• Explore the role of different leadership styles, including inclusive leadership, in developing and implementing mitigation programs.

• Collect and share best practice examples of mitigation programs between the European Union and the United States. Use information and databases developed for recent projects, such as the Evidence Project, and collect recent experiences.

• Examine the steps and actions needed to transition to a mostly electric or renewable fuels transport system. Consider the roles of the public and private sectors, public–private partnerships and other financial models, and implementation methods. Analyze potential transition paths, scalability, and uncertainty. Explore the infrastructure, policy changes, funding, and other resources needed in the transition.

• Assess current forecasting methods for transport GHG emissions and mitigation strategies. Explore the use of backcasting methods for application in transport planning. Examine the use of economic analyses with mitigation strategies.

• Examine the impact on funding from changes to electric vehicles and renewable fuels. Explore how these changes will influence the reliance on fuel taxes and identify other potential funding sources.

• Assess how changes to electric vehicles and renewable fuels will influence different industries and the possible social impacts and consequences for consumers. Explore potential unintended consequences.

Exploratory Topic 2

The Influence of Policy Environment Factors on Climate Change Mitigation Strategies in the Transport Sector

Timothy Sexton and Oliver Lah

Timothy Sexton and Oliver Lah discussed the second exploratory topic, which addressed the influence of policy factors on climate change mitigation strategies in the transport sector. They discussed building coalitions and developing policies with co-benefits to help promote actions to reduce GHG emissions and offered questions to help frame the breakout group discussions on this topic. The paper on this exploratory topic is provided as Appendix C. Sexton and Lah's presentation covered the points summarized below.

Lah described the different policy environments in the United States and the European Union. He noted a previous comparison of the United States and the European Union that drew on the fable of the tortoise and the hare. The United States was the hare—fast and agile, moving quickly in one direction and then quickly moving in a different direction, with periodic naps. The European Union was the tortoise—steady, slow, and headed in one direction. He commented that sharing policy approaches and results was still beneficial, even with these different environments.

Lah described concerted policy integration and consensus-driven governance. He outlined a conceptual approach based on concerted or fragmented policy integration and minimal majority or multiactor coalition governance:

• Concerted policy integration with a minimal majority results in limited mitigation actions through a comprehensive and ambitious policy agenda and minimal majority coalitions for specific actions that are based on political support from progressive parties.

• Concerted policy integration with multiactor coalitions provides integrated polices, including local- and national-level measures, implemented by multilevel, multiactor coalitions based on broad consensus.

• Fragmented policy integration with a minimal majority would result in some efficiency gains, but very little mitigation. There would be little action beyond incremental technology improvements, with no majorities for climate change mitigation actions.

• Fragmented policy integration with multiactor coalitions would result in limited mitigation actions through singular measures at the local or national levels or both, with implementation depending on the authority of the actors and minimal majorities, as well as coalitions between some political actors.

Lah discussed coalitions for implementing long-term climate change and mobility strategies. He noted that consensus is required on the need for policy measures and on specific strategies. Additionally, he noted the benefits of a strategic, coherent, and stable operating environment.

Lah cited the importance of a strong political commitment to a policy agenda, even when investments are only cost-effective over the mid- to long-term. He noted that linking and packaging policies can generate synergies and co-benefits between measures, including linking GHG reductions with other sustainable development goals. He further suggested that an integrated policy approach with coalitions of diverse stakeholders can help overcome implementation barriers, minimize rebound effects, and motivate people, businesses, and communities.

Lah noted that low-carbon fuels play a key role in the decarbonization of the transport system but that other strategies reflect a broader sustainable transport perspective. He described the GHG mitigation potential and some of the possible co-benefits with different strategies. For example, compact cities and mixed-use developments may reduce trip distance and travel times, provide more equitable access to all groups, and improve air quality, public health, and safety.

Lah described some of the governance factors for the success of sustainable development and climate change policies. One factor was political continuity and societal consensus to enable policy considerations and ensure stability. A second factor was an integrated policy approach combining various measures to provide a basis for political coalitions. He also noted that political continuity and policy integration efforts are affected by the institutional context and the policy–operating environment.

Lah outlined possible elements of a multimodal, multilevel sustainable transport package. Examples of measures at the national level included fuel taxes, vehicle fuel efficiency regulation, and vehicle taxes based on fuel efficiency or carbon dioxide emissions. Complementary measures included vehicle standards to ensure a supply of efficient vehicles, taxation to help steer consumer behavior, and fuel taxes to encourage efficient use of vehicles. Examples of local and state measures included compact city design and integrated planning, public transport, walk and bike infrastructure, and parking pricing. Possible complementary benefits included shorter trips, affordable access, and increased revenues.

Lah discussed policy continuity and consensus. He noted that interactions between different levels of government on climate change policy may vary between key political and societal actors. He suggested that shared methods and values can help mitigate political volatility and that knowledge communities can play important roles in generating consensus on major policy issues.

Lah discussed policy integration and coalition building. He suggested that combining policy measures can create a basis for coalitions and long-term climate action strategies. He also noted that synergies between socioeconomic and political objectives can help overcome opposition. Lah described the benefits of involving all groups, including those who may not favor an approach, and incorporating their policy objectives into the process.

Sexton provided an example from the United States. He noted that the Minnesota Department of Transportation (DOT) recently adopted a statewide goal to reduce GHG emissions from the transportation sector by 30%. He noted that one of the challenges in meeting this goal is that the Minnesota DOT does not have authority over county and local roads. The Minnesota DOT also does not have control over all federal and state transportation funding. To achieve the 30% reduction in GHG emissions, Sexton reported, the Minnesota DOT realized the need to form coalitions horizontally with other state agencies and vertically with local and federal agencies. He suggested that while forming and maintaining these coalitions takes time and resources, it is critical for achieving the desired goal.

Lah suggested that characteristics of both the tortoise and the hare are needed in policy making. He noted that steadiness is beneficial in policy approaches but that quickness and agility are also needed to respond to rapidly changing conditions and to take advantage of opportunities as they arise.

Sexton reviewed the following questions for discussion in the breakout groups on this topic:

- What factors influence the policy environment in which transport policies for mitigating climate change can be successful over the long term?
- What policies have been effective at decarbonizing transportation in the European Union and the United States?
- What types of policies—taxes, incentives, and other approaches—are most effective at the different levels of government?
- What specific policy and governance challenges exist for decarbonizing transportation?
- Are there examples of jurisdictions overcoming these obstacles and can their experiences be transferred to other jurisdictions?
- How can policies be designed to create a basis for broad political and societal coalitions?
- How can policy and institutional frameworks be improved to be more resilient?
- Where is research needed to support governance efforts or models to decarbonize transportation?

Suggested Future Research

The participants in the breakout groups identified ideas for future research related to Exploratory Topic 2, the influence of policy environment factors on climate change mitigation strategies in the transport sector. These ideas are listed below. The research ideas were detailed in the closing session by the planning committee members responsible for the exploratory topic. In addition, the rapporteur reviewed notes from the breakout groups in developing the following list.

- Examine the effectiveness of different mitigation policies in different policy environments. Identify the policies that are likely (*a*) to be adopted and (*b*) to be successful in various policy settings.

- Examine the influence of different organizational structures on mitigation planning policies. A traditional organizational structure focuses on separate agencies at the national, state, and local levels. Regional organizations represent a newer approach. Assess the benefits and limitations of different organizational structures and of approaches that fit best with different structures.
- Assess the potential equity impacts of low-carbon transport systems. Explore questions associated with access, cost, and other impacts on low-income groups, disabled individuals, minority populations, and other disadvantaged groups.
- Identify and analyze any unintended consequences from climate mitigation measures and programs. Develop responses to resolve these unintended consequences.
- Assess the time lag and the cost of various mitigation actions.
- Develop policies and programs to accelerate technology transfer and the adoption of low-carbon transport technologies. Conduct pilots and tests of different technologies and strategies. Monitor and assess the results of different approaches.
- Develop improved communication methods, strategies, and messages to describe the benefits of sustainable transportation to policy makers, the public, and industry. Assess the policies needed for an integrated approach to mitigation, including technology and incentives and disincentives to promote behavior change.

Exploratory Topic 3

Megaregions: Policy, Research, and Practice

Ray Toll and Delia Dimitriu

Delia Dimitriu and Captain Ray Toll presented the third exploratory topic, which addressed megaregions. They described the need for common solutions to address decarbonization in megaregions. Examples from Europe focused on metropolitan areas, while those from the United States addressed both mitigation and adaptation strategies simultaneously in megaregions. The paper on this exploratory topic is provided as Appendix D. Dimitriu and Toll's presentation covered the points summarized below.

Dimitriu noted that the International Transport Forum (ITF) *ITF Transport Outlook 2017* states that the transportation sector will not achieve the international community's climate ambitions of zero emissions by the year 2050 (*1*). She suggested that megaregions provide the geographical scale for addressing a mix of policies and strategies to reduce transport emissions.

Dimitriu defined megaregions as large networks of metropolitan areas that share transport infrastructure, settlement, land use, and economic patterns. She noted that megaregions can provide the focus for integrated, inclusive, seamless, and low-carbon transportation systems. She suggested that rapid urbanization requires equally rapid measures. Further, incorporating land use development concepts into regional transportation planning in the early stages would be beneficial.

Dimitriu noted that it may be easier to identify megaregions in the United States than in Europe because of development patterns and geographic scales. She discussed some of the possible low-carbon transport solutions appropriate at the urban and regional levels, including transit, ride sharing, and electric vehicles. She noted that solutions need to be integrated, address all transport modes, and embrace a new mobility culture. Additionally, these solutions will require a substantial paradigm shift and a comprehensive strategy that focuses on more than just vehicles. She suggested that behavioral change will be needed to address the decarbonization of transport in megaregions.

Dimitriu reviewed the EU approach to megaregions, noting that by 2020, cities are expected to host 80% of the EU's population, which will put pressure on urban transportation systems. She commented that metropolitan areas in Europe are linked together for passenger and freight movements, with the aim of economic growth. This system is recognized by the European Union as the Trans-European Transport Network, or TEN-T, which includes roads, railways, railway terminals, inland waterways, inland and maritime ports, airports, and associated infrastructure. The 2016 European strategy for low-emissions mobility focuses on the right policy mix for addressing the network. She noted decarbonization and air quality are two challenges with similar solutions.

Dimitriu discussed the paradigm shift toward cleaner urban mobility focusing on a multimodal transport systems approach, which prioritizes captive fleets and shifting fleets from diesel-based engines to fuel cell or electricity. She noted the need for safe and secure European standards and tools to accurately measure vehicle pollution emissions. She highlighted the development of sustainable urban mobility plans along with the combination of active mobility and healthy lifestyle.

Dimitriu discussed two European case studies focusing on decarbonization through integrated regional mobility. The first case study was the Blue Banana: The European Megalopolis or Manchester (United Kingdom)–Milan (Italy) Axis, with a focus on the Transport for the North and the Manchester region as the selected case study. The second case study was the Golden Banana: The Sun Belt of Valencia, Spain, in the west and Genoa, Italy, in the east. This case study includes the Barcelona Metropolitan Region. Both of the case studies were presented at a March 2017 workshop in Manchester that included representatives from several European cities.

The north of England is part of the Blue Banana case study. The north of England is home to 16 million people and contributes approximately £290 billion toward the UK economy. It is home to multiple world-class universities and is a key contributor to the freight and logistics industry. The Manchester region has approximately 2.7 million residents. Transport for Greater Manchester is leading an innovative multiagency approach that includes smart mobility solutions such as flexible on-demand transport, which connects users to shared mobility services for door-to-door, door-to-employer, and door-to-public-transit services. Linking rural and urban areas is also covered in this type of flexible transportation-on-demand service, which builds on existing services such as Ring and Ride and LocalLINK. The Greater Manchester Transport Strategy 2040 provides a sustainable urban mobility plan for the region (2). Dimitriu described elements of the plan presented at the Reimagining Public Transport Workshop in March 2017. Elements included technology, place, data analytics, and behavior.

In describing the Golden Banana case study, Dimitriu focused on the Barcelona Metropolitan Region, which includes 164 municipalities and 5.2 million residents. The intergovernmental consortium is focusing on promoting a modal shift to more efficient modes, promoting efficient and less-polluting mobility, and fostering electric mobility. Nine master mobility plan proposals address passengers and freight in the region and include 75 measures. A focus of the mobility plan is on avoiding, shifting, and improving trips and services. Both of the case studies presented impressive goals for carbon reductions.

Toll described a case study focusing on the Hampton Roads region of the U.S. state of Virginia. The Hampton Roads Sea Level Rise Preparedness and Resilience Intergovernmental Pilot Project was facilitated by Old Dominion University. The Hampton Roads region includes the largest naval base in the world, the third-largest commercial harbor on the eastern seacoast, commercial fisheries, manufacturing facilities, tourism, and residential and commercial developments.

Toll noted that the development of the intergovernmental blueprint for community resiliency was one of three White House National Security Council climate change pilots and one of three Department of Defense pilots responding to the 2013 Presidential Executive Order on Preparing the United States for the Impacts of Climate Change. The pilot included the cities of Norfolk and Virginia Beach, Virginia, four Virginia cabinet departments, 11 federal agencies, the Virginia Port Authority, three nonprofit organizations, and several businesses. Old Dominion University facilitated the pilot project.

Toll reviewed the mission of the pilot project, which was to establish a regional whole-of-government and whole-of-community organizational framework and procedures in the Hampton Roads area that could also be used as a template for other regions. A 15-member steering committee and a federal liaison provided overall coordination. The main focus areas were legal issues, infrastructure, land use planning, citizen engagement, and public health. Committees on economic impacts, private infrastructure, and municipal planning supported the pilot project, and senior advisors and science teams also assisted in the process.

Toll noted the unique role of Old Dominion University as a trusted partner and its ability to provide a test bed for ideas and strategies. Toll highlighted examples of the recommendations from the pilot, including linking infrastructure interdependencies by sharing maps, plans, and other resources among jurisdictions and municipalities. Examples of follow-up activities Toll cited were a joint land use study, institutionalizing the whole-of-government and whole-of-community relationships, and synchronizing and integrating federal and nonfederal resilience planning and implementation.

Toll described the importance and interrelationship of adaptation and mitigation measures. He noted that the transportation network was a key infrastructure backbone for the Hampton Roads case study. He commented that an integrated network for monitoring climate change for any region or megaregion was a requirement for both mitigation and adaptation. Further, he suggested that both mitigation and adaptation measures must be considered in any megaregion plan.

Toll concluded the presentation by outlining the following questions for consideration in the discussion groups:

- What will it take to create an integrated megaregion climate framework for the transport sector that considers mitigation and adaptation measures at the same time?
- What steps are needed to promote regions working together toward an integrated low-carbon system?
- What policy scenarios can be used to address a projected doubling of passenger traffic by 2030 and 2050?
- What topics should be considered for a joint EU-U.S research program on transport and climate change?

Suggested Future Research

The participants in the breakout groups identified ideas for future research related to Exploratory Topic 3, megaregion policy, research, and practice. These ideas are listed below. The research ideas were detailed in the closing session by the planning committee members responsible for the exploratory topic. In addition, the rapporteur reviewed notes from the breakout groups in developing the following list.

- Develop and test a framework for assessing adaptation and mitigation strategies in megaregions, identifying barriers to implementation, and presenting best practice examples. Table 1, which presents a starting point for developing a framework was discussed in one of the breakout groups.
- Develop and assess spatial planning scenarios focusing on different measures to reduce the transportation carbon footprint in megaregions. The scenarios could be used to provide information to policy makers and the public on the impacts of different measures on land use and carbon reduction.
- Assess the impacts on the transportation network and GHG emissions from new services, such as Amazon and IKEA deliveries in short time frames. Examine approaches to better monitor the impacts and to identify possible policies to reduce unintended consequences and possible negative impacts.
- Explore the concept of developing a policy umbrella for megaregions with a mix of policies for consideration and adoption in individual regions. The research could define the concept and develop multiple scenarios with different policies, projects, technologies, and land uses. The scenarios could focus on how to address increasing passenger traffic in megaregions in the future, targeting 2030 and 2050. The scenarios could be tested and refined in different megaregions in the United States and Europe.
- Assess the barriers and the opportunities for transferring existing policies and practices on decarbonizing the transportation sector from one megaregion to other megaregions or between areas within a megaregion.
- Examine the impact of three-dimensional printing and other technologies on changes in industry and freight transport within megaregions and possible changes in GHG emissions.
- Assess the potential to reuse or repurpose aging transport infrastructure in megaregions to support decarbonized travel modes.
- Examine methods to promote, encourage, and incentivize the use of low-carbon transport modes within megaregions.
- Examine the impact of energy production in megaregions on possible approaches to decarbonizing the transportation system.
- Explore ways to develop political support for low-carbon transportation options across the multiple jurisdictions and governmental units in megaregions.
- Share best practice examples of decarbonizing strategies among megaregions in Europe and the United States.

Exploratory Topic 4

Decarbonizing the Logistics and Long-Distance Transportation of Freight

Kate White and Simon Edwards

Kate White and Simon Edwards presented the fourth exploratory topic, which addressed decarbonizing the logistics and long-distance transportation of freight. They described the complexity of long-distance freight transportation and logistics, highlighted some of the challenges associated with reducing GHG emissions from freight transport, and summarized two case studies for discussion in the breakout groups. The paper on this exploratory topic is provided as Appendix E. White and Edwards' presentation covered the points summarized below.

Edwards noted that long-distance freight transportation has been identified as one of the most difficult socioeconomic activities to decarbonize. In addition, its share of total transportation GHG emissions is predicted to rise from 42% in 2010 to 60% in 2050. The carbon intensity of freight movement in Europe would have to drop to about one-fifth of its 1990 level to meet the European Commission's 2011 target of a 60% reduction in carbon dioxide emissions from passenger and freight transport between 1990 and 2050.

Edwards discussed the logistical elements of long-distance freight transportation, which includes the activi-

TABLE 1 Starting Point for Developing a Framework for Assessing Adaptation and Mitigation Strategies

Topic Area	Information and Research Need
Land use planning	Assess the impact of carbon footprint reduction, infrastructure, legal barriers, and regulations and policies on different urban development patterns.
Stakeholder consultation based on whole-of-government and whole-of-community concept	Develop awareness and communicate needs and benefits. Investigate the adaptability of this concept in different megaregion settings in the United States and Europe.
Assessment and management	Consider all elements: planning, infrastructure, operations, market-based measures, technology, and communication.
Best practice examples	Assess barriers and opportunities for implementation in other megaregions.

ties of all the vehicles—trucks, locomotives, aircraft, and harbor craft—and all types of equipment used to move freight at seaports, airports, rail yards, warehouses, and distribution centers. He noted that long-distance freight transportation also includes the use of oceangoing freight and intercontinental airfreight as well as the first- and last-mile components of freight. Long-distance freight transportation involves the use of the road networks, land ports of entry, railways, airports with their airways, inland waterways, freight hubs, and other infrastructure.

Edwards noted that population growth, increasing demand for goods, sudden changes in commodity demand and movement patterns, the need to remain competitive in an increasingly complex global marketplace, and the aging transportation infrastructure are straining freight transportation systems around the world. He commented that the level of investment in freight-specific transportation has not kept pace with growing economies in some areas, which has added to this strain. Given the inherent importance of global and regional freight logistics, Edwards suggested that it was important to establish substantial, continuing, multimodal, reliable, and dedicated funding in order to decarbonize the freight system. Additionally, he suggested that freight funding should not be limited to vehicles and equipment alone. It should also include transportation and energy infrastructure as well as workforce development to help workers transition to a decarbonized transportation system. He suggested that freight funding should recognize future needs and constraints to support projected population and economic growth.

Edwards discussed the complexity of long-distance freight transportation and the need to include numerous stakeholders in the development and deployment of strategies to reduce GHG emissions. He noted that some groups argue that future advances will reduce the intensity of freight transportation in the global economy. Some of these advances include the reshoring of manufacturing activity, the relocalization of food supplies, miniaturization, digitization, and localized additive manufacturing. He suggested that as the global population continues to increase, more freight movement can be expected.

Edwards briefly described five parameters that help determine the carbon intensity of logistics and freight transportation:

- Structure of the logistics chain,
- Freight modes,
- Utilization of facilities and vehicles,
- Energy efficiency of facilities and vehicles, and
- Carbon basis of the energy consumed.

The structure of the logistics chain, said Edwards, determines the amount of freight movement per unit of delivery. Vertical integration of production—the combination in one company of two or more stages of production normally operated by separate companies—has reduced the number of links in the logistics chain in some sectors. Edwards noted that this has not happened in the manufacturing sector, where supply lines have usually lengthened. Further, larger single-market regions have tended to centralize distribution, increasing transport-related emissions while reducing inventories in a just-in-time world. He suggested that, if climate change mitigation targets are to be approached, there is a need to reexamine the balance of carbon intensity across the logistics supply chain versus the cost..

Edwards discussed the modalities of freight transportation, noting that the average carbon intensity of freight transport modes varies enormously. Globally, there are opposing trends in changes between modalities for a wide variety of reasons. For example, the European Commission has set ambitious targets to change from road to rail or water modes. Edwards noted that the carbon cost of the investment and maintenance needed to achieve these modal shifts and the net societal economic costs are not always well understood. It is also important to note that rail is efficient in terms of GHGs per unit of freight moved but tends to emit more particulate matter and nitrogen oxides that affect air quality and undermine other sustainability goals.

Edwards described the utilization of facilities and vehicles, noting that improving utilization in all aspects normally results in a reduction in carbon intensity with relatively few downsides. He suggested that it was important to consider infrastructure and facilities first. While these factors are complex and involve public and private players, there are often good practice guidelines to increase utilization. Edwards also noted that business practices may play a positive role in improving utilization. Because business is driven by commercial considerations, there is often a positive correlation between economic and carbon costs. This correlation results in practices such as just-in-time delivery or facility collaboration, which have a net benefit on carbon intensity. Edwards further noted that there are typically opportunities to improve vehicle utilization, which naturally reduces carbon intensity. He suggested that quantifying underutilized capacity can be difficult, however.

In addressing the energy efficiency of facilities and vehicles, Edwards reported that while improvements in vehicle technology have significantly improved energy efficiency over the past decades, compromises with other emissions-related aspects have not necessarily been made. He suggested that significant improvements in vehicle efficiency are still possible, even at the ultralow emissions levels now being achieved. Edwards noted that this is true particularly for on-road transportation. He commented that the challenge is to encourage the commercial application of these fuel-saving technologies. He also noted the improvements in the energy efficiency of logistic hubs being made in many areas.

Edwards discussed the carbon basis of energy consumed, noting that it had not been a major focus of this symposium. Freight transportation is a fossil fuel–intensive operation, and the repowering of logistics operations with low-carbon energy is at a very early stage. The possibility to electrify freight, for example, is mode dependent, with the mass and volume energy density requirements at the vehicle level being the determinant, and the benefit therefrom constrained by the local electrical energy supply mix. In the short term, Edwards suggested, the decarbonization of liquid fuels for long-distance transport is the main option for aircraft, ships, freight trains, and heavy-duty commercial road vehicles. The electrification of the highway road network, together with increasing levels of electric hybrid vehicles, is one possible medium-term option.

White described the two scenarios included in the paper, which address online shopping for shoes and manufacturing Tesla electric vehicles. The scenarios were developed to help focus decisions during the breakout sessions.

Figure 7 illustrates the online shopping scenario, in which a consumer orders five pairs of shoes online with a request for delivery within a 2-hour window. The consumer keeps one pair of shoes and returns the other four pairs. Major steps in the supply chain include producing the shoes in China, loading the shoes into a container and transporting the container by truck to a seaport, and shipping the container by an ocean vessel to a California port, where the container is unloaded and placed on semi-trailer truck. The semi-trailer truck travels to a distribution center where the container is unpacked. These steps occur before the consumer orders the shoes. Once the online order is made, the shoes are transferred to a smaller truck and delivered to the consumer. In the scenario, the consumer keeps one pair and travels to a local package delivery store to return four pairs, which are transported back to the distribution center by a medium-sized truck.

The second scenario, which addresses the manufacture of Tesla electric vehicles, is illustrated in Figure 8. The supply chains for vehicle parts include shipping aluminum sheets from Japan, battery materials from Asia, and other components from throughout the United States to the Tesla manufacturing factory in Fremont, California. The assembled vehicles are loaded onto trucks for delivery to consumers throughout the country.

White offered the following framing questions for discussion in the breakout groups:

- How do other trends interact with the decarbonization of freight transportation?
- What additional policy options for decarbonizing freight transportation are there?
- What other ideas for the decarbonization of freight transportation should be considered?
- What are the correct measures for evaluating the decarbonization of freight?
- How may infrastructure solutions be developed in time?
- What other social or political difficulties associated with the decarbonization of freight can be foreseen?

Suggested Future Research

The participants in the breakout groups identified ideas for future research related to Exploratory Topic 4, decarbonizing the logistics and the long-distance transportation of freight. These ideas are listed below. The research ideas were detailed in the closing session by the planning committee members responsible for the exploratory topic. In addition, the rapporteur reviewed notes from the breakout groups in developing the following list.

- Examine technologies to decarbonize long-distance freight transportation modes. Connected, automated, and autonomous vehicle technology should be included in the assessment. Rail electrification, fuel cells on ships, and other technologies should also be examined.
- Develop, conduct, and analyze pilots and demonstrations of different technology applications to decarbonize long-distance freight transport. Monitor and evaluate the pilots and share the results.
- Analyze the use of big data in long-distance freight transport and logistics. Examine the use of big data analytics to obtain greater efficiency in supply chains and to reduce the carbon footprint of freight transport.
- Assess the viability of disruptive technologies, such as the Hyperloop and intermodal hubs in the air, and analyze their potential impact on decarbonizing long-distance freight transportation.
- Examine the forecast changes in the future economy and the impact of these changes on freight transportation and supply chains. Assess the nature of the changes, the likelihood of the changes actually occurring, and the impact of the changes on meeting targets to decarbonize long-distance freight transportation.
- Assess the advantages and the limitations of different fiscal instruments and policies, such as a carbon added tax and incentives for reducing GHG emissions, to promote or require decarbonization in long-distance freight transportation.
- Analyze the effectiveness of different mixes of policies to reduce GHG emissions in long-distance freight transport. Model the short- and long-term impacts of different combinations of policies and identify supporting infrastructure elements needed to ensure the success of these policies.

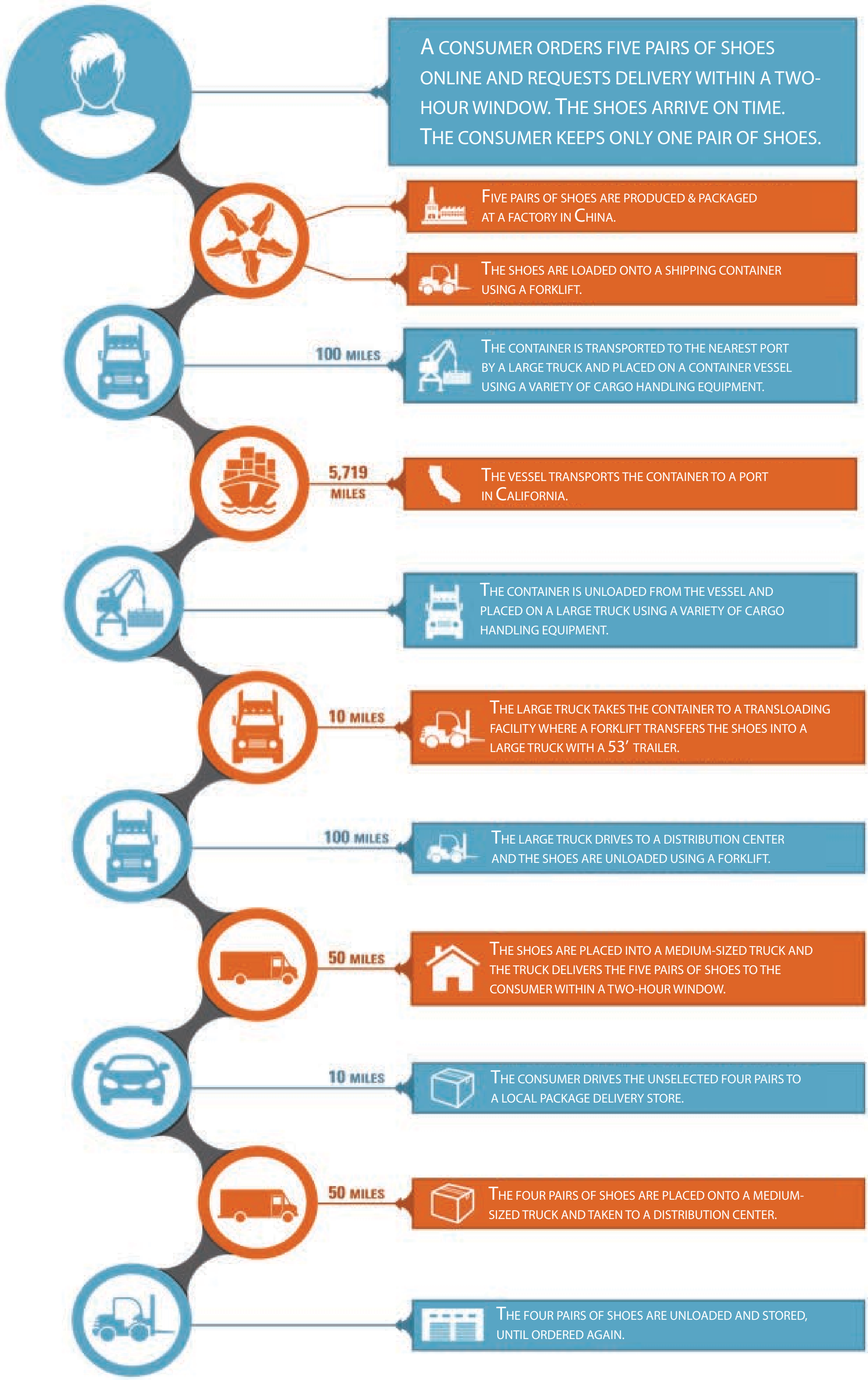

FIGURE 7 Online shopping scenario.

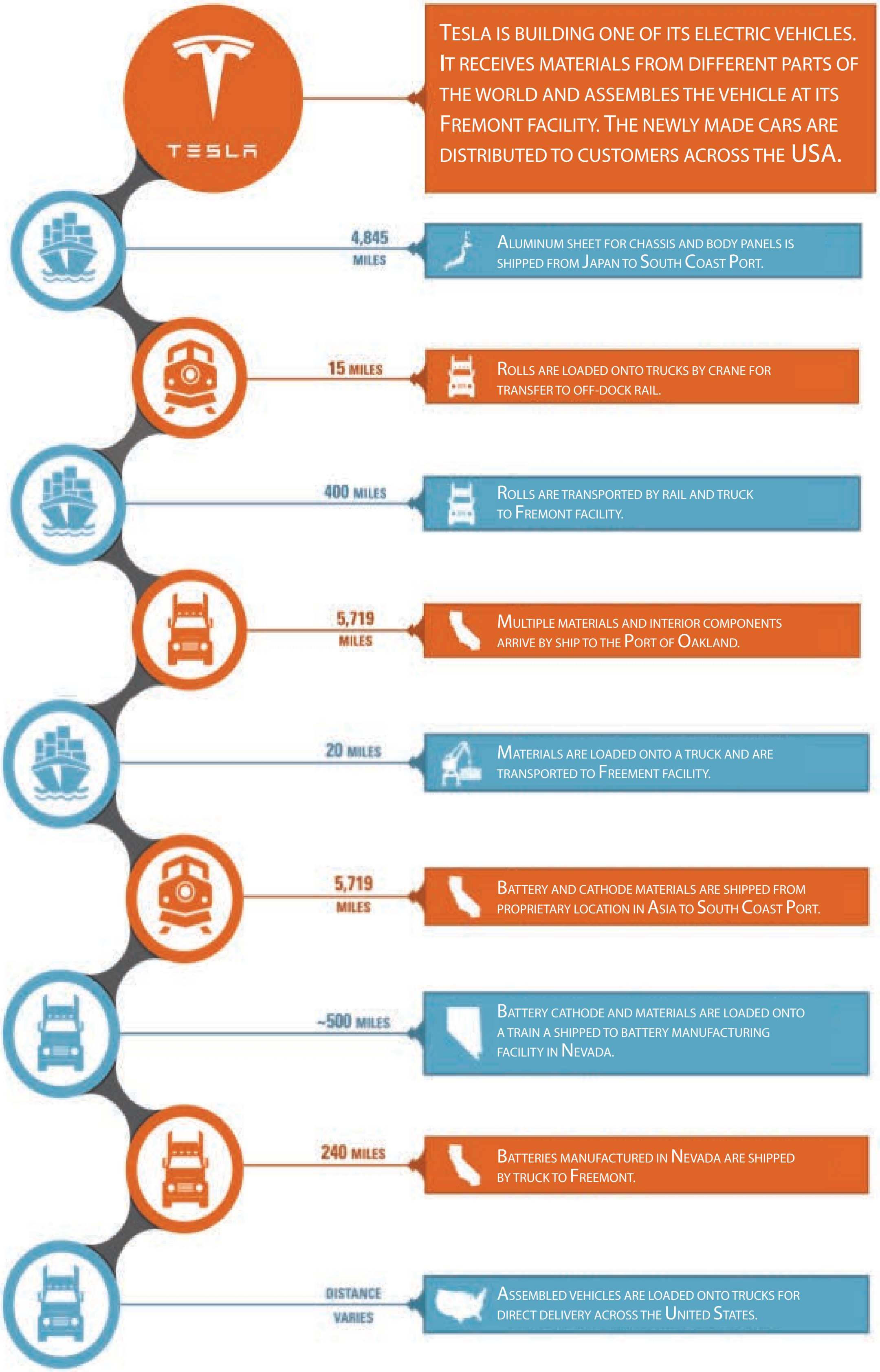

FIGURE 8 Manufacturing of Tesla electric vehicles.

- Examine the impacts of decarbonizing long-distance freight transportation on different market segments, ownership groups, and industries. For example, one beneficial research project could assess the impacts of different decarbonization strategies, including the impact of electric vehicles on truck owner–operators, large trucking firms, and business-owned trucking fleets. Other research projects could examine potential impacts by market segments and industry types.
- Examine new approaches for measuring the energy impacts of freight transport and defining convenience. For example, product kilometers traveled may be one possible measure.
- Explore the viability of different fuel sources, including electric, for long-distance freight transportation. Elements to examine in the research include assessing the availability, feasibility, economic viability, and transition time of different low-carbon fuels.
- Assess the impact of truck platooning on reducing GHG emissions through actual pilots and demonstrations. Conduct research on the impacts of combining other strategies and approaches with truck platooning and additional automated and connected vehicle technologies.
- Examine the potential need for, and benefits from, the international standardization of freight transport systems and the development of standard measures of carbon reduction.

References

Abbreviation

ITF International Transport Forum

1. *ITF Transport Outlook 2017*. International Transport Forum, Organization for Economic Co-operation and Development, Paris, 2017. http://www.oecd.org/regional/itf-transport-outlook-2017-9789282108000-en.htm.
2. Greater Manchester Transport Strategy 2040. http://www.tfgm.com/2040/Pages/default.aspx.

Closing Session

José Viegas, *International Transport Forum, Organisation of Economic Co-operation and Development, Paris*
Neil J. Pedersen, *Transportation Research Board, Washington, D.C., USA*
Robert Missen, *Directorate-General for Mobility and Transport, European Commission, Brussels, Belgium*

Concluding Keynote Presentation

Decarbonizing Transport: To Life in a Sustainable World—What Did We Learn, What Can We Do?

José Viegas

José Viegas provided the closing keynote presentation. He described recent studies by the International Transport Forum (ITF) and highlighted strategies to reduce greenhouse gas (GHG) emissions in the transport sector. Viegas covered the following topics in his presentation:

Viegas reviewed information from *ITF Transport Outlook 2017* (http://www.oecd.org/about/publishing/itf-transport-outlook-2017-9789282108000-en.htm). He noted that global transport volumes are projected to continue to increase. Passenger transport is forecast to more than double by 2050. Global vehicle stock is projected to increase from 1 billion in 2015 to 2.4 billion in 2050. Freight transport is projected to triple by 2050. The report suggested that if unchecked, transport carbon dioxide (CO_2) emissions could increase by 60% by 2050.

The report notes that new technologies will not be enough to reduce freight CO_2 emissions. While higher fuel efficiency and alternative fuels can reduce freight CO_2 emissions by 40%, new technologies alone cannot curb the trend of growing freight emissions. Strategies such as truck sharing, route optimization, relaxing delivery windows, and more operational efficiency generally can hold 2050 emissions at 2015 levels.

Viegas suggested that a new approach to urban mobility that focuses on more than technology was needed. He outlined two guidelines for this new approach. The first guideline was to focus on access to jobs, public facilities, and social interaction as the key objective. He noted that mobility was a way to gain access, not the objective. The second guideline Viegas suggested was to leverage the upcoming radical changes affecting transport supply to radically reorganize the mobility system. Examples he cited of these radical changes included digital connectivity, electrification, and automated vehicles.

Viegas described more of the anticipated technology changes. He noted that due to advances in computation, information technology, and material science, digital connectivity will be available everywhere and at any time. Other changes he cited included the electrification of vehicle power trains and automated driving. He further suggested that these technologies will force radical change in the fiscal regime of automobiles and will be accompanied by an evolution of consumers' preferences, with car sharing becoming prevalent and vehicle ownership no longer necessary.

Viegas discussed some of the first-order impacts of these changes. He noted that electric vehicles would provide cleaner air and lower GHG emissions and that they would also likely lower operating cost per kilometer. He reported that automated vehicles should enhance safety, but that by allowing better use of an individual's in-vehicle time, they may also induce longer trips. Further, he noted that automated vehicles may lower the cost of professional services such as taxis and buses. Viegas suggested that the acceptance of car sharing reduces the pressure to own an automobile, which releases highly underutilized capital for other uses. He cautioned that the simple combination of these impacts might lead to even higher levels of congestion and asymmetry of accessibility. As a result, he commented that other strategies are needed.

Viegas discussed ways to make changes acceptable and appealing to the public. He noted that the urban landscape and lifestyles have been aligned with the private vehicle paradigm for the past 70 years and thus represented an entrenched sociotechnical system. He suggested that changes beyond technology must be made in directions that still provide a good match with those settings. For car owners, this approach might mean providing the essential features of the private automobile, including availability, comfort, and speed. New public transport that provides direct rides to avoid transfers will also be needed. He noted that costs will need to be reduced in both cases.

Viegas described an example of a radical organizational change focusing on shared mobility solutions. He summarized the approaches, which included shared taxis and taxi buses (a simpler name for demand-responsive microbuses). He noted that this approach provides a high quality of service at a much lower cost than the types of services in operation today. Further, he noted, the public policy impacts of better and more equitable accessibility, a reduction of traffic volumes and emissions, and the release of large quantities of parking spaces for use by pedestrians and cyclists would be realized.

Viegas discussed an analysis focusing on this approach that was conducted for Lisbon, Portugal, by the ITF in 2016. The analysis was based on providing shared mobility with a fleet of six-seat shared taxis that provided on-demand, door-to-door service in conjunction with a fleet of eight- and 16-person minibuses. The existing rail and subway network continued in operation. For a 24-hour period, the simulation results showed that the same number of trips could be provided with only 3% of the current vehicles. Further, there was a 34% reduction in CO_2 emissions and a 95% reduction in the number of parking spaces needed. He also noted that the use of small, demand-responsive buses provided improved and more equal access for residents.

Viegas highlighted a more recent analysis conducted in 2017 for the Lisbon metropolitan area in which an attraction decay curve calibrated for the region was used to estimate accessibility impacts. He reported that taxi buses alone or in combination with suburban rail improved access to jobs over the current public transport system. He noted that ITF was currently studying similar schemes for Helsinki, Finland; Dublin, Ireland; and Auckland, New Zealand.

Viegas described a potential smarter fiscal regime for road transport. He noted that currently in the European Union, fuel duties represent on average about 8% of the total fiscal revenue of the member states. He noted that the fuel duties were created as an instrument to fund road construction, but have evolved to also fund maintenance, upgrades, and off-transport uses in Europe. He suggested that replacing the fuel duties with a smart distance-based charge was logical. Digital connectivity would make it possible to assign higher tariffs in central areas with priority use by active modes for vehicles providing exclusive rides, and for vehicles with higher emissions.

Viegas discussed spatial and urban planning, noting that it should ensure a more equitable distribution of opportunities without the need for motorized transport. He suggested that density and functional diversity were important elements of urban areas, along with the quality design of public areas. He commented that good design for use of active modes (walking and cycling) encourages their safe use. He noted that bicycles were increasingly replacing automobile trips in some areas and suggested that parking spaces released by the wide adoption of shared mobility could be allocated for active modes and public amenities.

Viegas provided suggestions for managing change. He noted that people prefer stability, but with a bit of change. He commented that a ratio of 80% stable and 20% new fit this approach. He commented that the upcoming technological revolution provides a natural turbulence that facilitates introducing other changes, including shared mobility solutions and new fiscal treatment of road transport. He suggested that a critical mass of measures was needed to obtain visible results, to generate positive feedback, and to gain public support.

Viegas suggested that a new style of regulation may be needed, as digitally connected systems will generate large amounts of data, and part of that data must be supplied unfiltered to authorities for performance assessment and planning purposes. He further suggested that regulations should evolve in consonance with key objectives and constraints, so as to define acceptable ranges for parameters while allowing innovation and data-led approaches.

Viegas discussed that major changes will occur in the transport sector over the next 15 years. These changes will occur across all modes, especially in urban areas. Technological evolution will make transport cleaner and safer, but it will not necessarily provide a better quality of life. He suggested that other instruments will be necessary to address congestion, promote better and more equitable accessibility, and accelerate the reduction of GHG emissions. He noted that the number of options available provides opportunities but that the multiplicity of objectives and of decision makers adds complexity. He suggested that inclusive political leadership was essential to lead, explain, include, and share data.

Viegas provided several concluding thoughts. He suggested that faster progress was likely to be made in urban areas through the adoption of electric vehicles for passengers and freight. He noted that the focus would be on providing access rather than on mobility, with land use policies used in tandem with transport strategies. He commented that shared mobility options may have the best potential to relatively quickly reduce congestion and emissions, as well as to release public space from parking to active modes and amenities and to provide improved and more equitable accessibility.

Viegas further suggested that smarter fiscal regimes for road transport can stimulate behavioral alignments. He noted that decarbonizing transportation in rural areas and in long-distance travel was a bigger challenge. He suggested that ridesharing in rural areas was possible, but that a different paradigm was needed. He said that clean fuels are needed in aviation and shipping, and that long-distance transport also requires new managerial practices related to logistics, road sharing, and rail service quality. He stressed that a combination of measures is needed to decarbonize transport. According to Viegas, providing coherence across actions, players, and time will continue to be a challenge.

Viegas concluded by outlining the following potential directions for research:

- Research on propulsion and information technologies.
- Exploration of key aspects of the sociotechnical system blocking change and their low-carbon surrogates.
- Identification of key scarce resources for deploying those surrogates. Viegas cited legislation, capital, space, and skills as examples of such resources.
- Development of viable business models that would be able to support the value propositions based on those features.
- Identification of public governance schemes that would be less likely to create blockages to the evolution of the business models. Viegas commented that since there will be a 15- to 20-year period of radical changes, these research topics should be revisited every 5 years.

Closing Comments from the Transportation Research Board

Neil J. Pedersen

Neil Pedersen provided closing comments from the Transportation Research Board (TRB) and the National Academies. Noting the high energy level and excellent discussions, he thanked the planning committee, speakers, and participants for their active involvement throughout the symposium.

Pedersen reported that the information presented at the symposium and breakout group discussions provided numerous research ideas and issues that TRB can pursue. He noted that suggestions on research topics, information sharing, and collaboration opportunities will be shared with TRB committees, the TRB Executive Committee, and the cooperative research programs. He discussed opportunities to twin on research projects between the European Union and United States.

Pedersen stressed the importance of ongoing trans-Atlantic cooperation and collaboration. Noting that there is much to be learned from the different approaches and experiences in Europe and the United States, he encouraged participants to continue the dialog initiated at the symposium. To support this ongoing discussion, Pedersen reported that there would be a session at the 2018 TRB Annual Meeting highlighting the key topics from this symposium. He extended an invitation to all symposium participants to attend the 2018 Annual Meeting.

Pedersen thanked the white paper authors and the keynote speakers for their insightful presentations. He expressed his gratitude to the planning committee members for their hard work in planning the symposium, developing and presenting the exploratory topic papers, and facilitating the breakout discussion groups. He recognized Bill Anderson and Brittney Gick of TRB and Frank Smit of the European Commission, for their assistance in making the symposium a success.

Closing Comments from the European Commission

Robert Missen

Robert Missen provided closing comments on behalf of the European Commission. He thanked TRB for hosting the symposium. He noted the productive discussions in the breakout groups and thanked the participants for sharing their ideas, experiences, insights, and issues.

Missen stressed the value to the European Union of the information presented at the symposium and the identified research topics. He noted that the research topics will be considered in the Horizon 2020 program, including projects that may be appropriate for twinning with U.S. projects. Missen noted the importance of objective facts and knowledge for developing policies and the benefits of ongoing collaboration and cooperation between the European Union and the United States. He invited participants to attend the next Transport Research Arena (TRA) in Vienna, Austria, on April 16–18, 2018.

Potential Portfolio for EU-U.S. Research on Decarbonizing Transport for a Sustainable Future

Katherine F. Turnbull, *Texas A&M Transportation Institute, College Station, Texas, USA, Rapporteur*

Katherine Turnbull served as the rapporteur for the symposium. She summarized the keynote speakers, exploratory topic presentations, and breakout group reports. She also attended the breakout groups to gain a better understanding of the challenges and research topics discussed by participants. Several common cross-cutting challenges and research topics emerged from the symposium.

The rapporteur developed a potential portfolio for EU-U.S. research on the symposium theme: decarbonizing transport for a sustainable future—mitigating impacts of the changing climate. The potential research topics are grouped below by the following subject areas: transport policies, planning, and projects; technology and innovation; communication strategies and methods for stakeholders involvement; and logistics and long-distance freight transportation.

These research topics may be considered by the European Commission, the cooperative research programs managed by the Transportation Research Board (TRB), and other groups. The potential research projects are also appropriate for twinning. The opportunity also exists to build on the research ideas identified in the 2015 and 2016 EU-U.S. symposia addressing road transport automation and transportation resilience. In addition, opportunities for ongoing trans-Atlantic information sharing and coordination activities are highlighted.

Transport Policies, Planning, and Projects

The following possible research topics related to transport policies, planning, and projects were discussed during the symposium. Research on these topics can consider different geographical levels, including international, national, megaregions, states, and local communities.

- Collect and share best practice examples of mitigation programs between the European Union and the United States. Use information and databases developed for recent projects, such as the Evidence Project, and collect recent experiences.
- Examine the co-benefits from transport decarbonization policies and programs and how they relate to factors that people value, such as quality of life and livable communities. Explore policies and messages that focus on the co-benefits rather than the mitigation programs themselves.
- Assess current forecasting methods for transport greenhouse gas (GHG) emissions and mitigation strategies. Explore the use of backcasting methods and economic analyses with planning and mitigation strategies.
- Examine the impact on funding from changes to electric vehicles and renewable fuels and how these changes will influence the reliance on fuel taxes. Identify other potential funding sources.
- Assess how changes to electric vehicles and renewable fuels will influence different industries.
- Examine the effectiveness of different mitigation policies in different policy environments. Identify the policies that are likely to be adopted and be successful in various policy settings.
- Examine the influence of different organizational structures on mitigation planning policies, including traditional organizational structures and new approaches. Assess the benefits and limitations of different organiza-

tional structures, and approaches that fit best with different structures.

- Assess the potential equity impacts of low-carbon transport systems. Explore questions associated with access, cost, and other impacts on low-income groups, disabled individuals, minority populations, and other disadvantaged groups. Identify and analyze any unintended consequences from climate mitigation measures and programs. Develop responses to resolve these unintended consequences.
- Develop and test a framework for assessing adaptation and mitigation strategies in all areas, identifying barriers to implementation, and presenting best practice examples. Develop and assess spatial planning scenarios that focus on different measures to reduce the carbon footprint of transportation in all areas. The scenarios could be used to provide information to policy makers and the public on the impacts of different measures on land use and carbon reduction.
- Assess the barriers and the opportunities for transferring existing policies and practices on decarbonizing the transportation sector from one area to other areas.
- Examine policies and programs supporting bicycle use and identify the most effective approaches for different areas and situations. The analysis could include policies and programs, such as bikesharing, and infrastructure, including bike lanes, bike paths, bike stations, and other facilities.
- Examine the use of big data to assist in all aspects of planning for mitigation strategies to reduce GHG emissions at all geographic levels and transport modes.

Technology and Innovation

The following possible research topics were considered by some participants to be related to new technologies and innovative approaches for monitoring and responding to extreme weather events as well as evolving transport technologies:

- Explore the travel behavior of the millennial and the digitalized generations. Identify changes from the travel behavior of older generations and assess the potential impacts on mode use, VMT, and GHG emissions. Examine decarbonizing policies and programs using new technologies and innovative approaches that may appeal to these younger generations.
- Develop policies and programs to accelerate technology transfer and the adoption of low-carbon transport technologies. Conduct pilots and tests of different technologies and strategies. Monitor and assess the results of different approaches.
- Assess the impacts of new services on the transportation network and GHG emissions. Examine approaches to better monitor the impacts and to identify possible policies to reduce unintended consequences and possible negative impacts.
- Examine the impact of three-dimensional printing and other technologies on changes in industry and freight transport within all areas and possible changes in GHG emissions.

Communication Strategies and Methods for Stakeholder Involvement

Several participants believed that the following research topics could enhance communication and stakeholder involvement, including breaking down silos within and between agencies, organizations, and the private sector to develop and implement mitigation strategies and programs:

- Examine current public knowledge of climate change, GHG emissions, and policies and strategies to decarbonize transport. Identify the most effective communication messages and techniques for addressing the need for mitigation strategies and their potential benefits. Identify best practice examples and develop approaches for use in different situations and with different groups.
- Examine stakeholder involvement techniques used with transport mitigation strategies. Identify methods to actively engage all groups in the discussion of reducing GHG emissions and the development of mitigation policies and programs. Explore ways to break down silos and work across agencies, organizations, and the private sector. Share best practice examples.
- Explore the role of different leadership styles, including inclusive leadership, in developing and implementing mitigation programs.
- Develop improved communication methods, strategies, and messages to describe the benefits of sustainable transportation to policy makers, the public, and industry. Assess the policies needed for an integrated approach to mitigation, including technology and incentives and disincentives to promote behavior change.
- Develop case studies of public–private partnerships and multiagency coordination in planning, implementing, and assessing different mitigation strategies.
- Develop support tools to facilitate multiagency and multilevel coordination and cooperation.

Logistics and Long-Distance Freight Transport

One of the exploratory topics focused on logistics and decarbonizing long-distance freight transport. Several research ideas were discussed in the breakout groups and additional suggestions were provided in the open session. Opportunities may exist to coordinate with twinning projects and research activities identified during the Third EU-U.S. Transportation Research Symposium, Towards Road Transport Automation (*1*). The following research topics related to logistics and decarbonizing long-distance freight transport discussed during the symposium may be appropriate for twinning:

- Explore the viability of different fuel sources, including electric vehicles for long-distance freight transportation. Elements to examine in the research include assessing the availability, feasibility, economic viability, and transition time of different low-carbon fuels.
- Examine technologies to decarbonize long-distance freight transportation modes. Include connected, automated, and autonomous vehicle technology in the assessment, along with rail electrification, fuel cells on ships, and other technologies. Consider the role of the public and private sectors in implementing these technologies.
- Develop, conduct, and analyze pilots and demonstrations of different technology applications to decarbonize long-distance freight transport. Monitor and evaluate the pilots and share the results.
- Assess the impact of truck platooning on reducing GHG emissions through actual pilots and demonstrations. Conduct research on the impacts of combining other strategies and approaches with truck platooning and additional technologies for automated and connected vehicles. Coordinate with existing research projects in the European Union and the United States.
- Examine the impacts of decarbonizing long-distance freight transportation on different market segments, ownership groups, and industries.
- Examine the possible changes in the future economy and the impact of these changes on freight transportation and supply chains. Assess the nature of the changes, the likelihood of the changes actually occurring, and the impact of the changes on meeting targets to decarbonize long-distance freight transportation.
- Assess the advantages and the limitations of different fiscal instruments and policies, such as carbon added taxes and incentives for reducing GHG emissions, to promote or require decarbonization in long-distance freight transportation.
- Analyze the effectiveness of different mixes of policies to reduce GHG emissions in long-distance freight transport. Model the short- and long-term impacts of different combinations of policies and identify supporting infrastructure elements needed to ensure the success of these policies.
- Analyze the use of big data in long-distance freight transport and logistics, including using big data analytics to obtain greater efficiency in supply chains and to reduce the carbon footprint of freight transport.

Information Sharing and Ongoing Coordination

Several opportunities for ongoing trans-Atlantic information sharing, coordination, and collaboration were suggested by individual participants during the symposium:

- Distribute the symposium proceedings to diverse stakeholders at the global, national, state, regional, and local levels.
- Provide presentations on the symposium by participants and agency staff at conferences and other appropriate venues, including those sponsored by the European Union and by TRB. A PowerPoint presentation highlighting the symposium is available for use by all interested parties.
- Publish an article on the symposium in *TR News* as well as follow-up articles on related research and activities as appropriate.
- Convene symposium participants at the 2018 TRB Annual Meeting for an information-sharing meeting.
- Develop a general session or workshop on the key topics addressed at the symposium for the 2018 TRB Annual Meeting and promote sessions at future annual meetings and specialty conferences and workshops.
- Pursue possible conferences, workshops, and meetings sponsored or cosponsored by the symposium hosts and other organizations and groups.
- Continue the involvement of the TRB Executive Committee task force, groups, sections, and committees in developing statements of research needs, coordinating research and outreach activities, and organizing Annual Meeting sessions, conferences, and workshops.
- Pursue twinning research projects and facilitate transatlantic research and sharing of results. Encourage ongoing EU–US dialogue and information sharing through a variety of mechanisms.
- Develop best practice case studies of mitigation efforts from throughout the world and share at conferences and meetings.

Reference

1. *Conference Proceedings 52: Towards Road Transport Automation: Opportunities in Public–Private Collaboration*. Summary of the Third EU-U.S. Transportation Research Symposium. Transportation Research Board, Washington, D.C., 2015. http://dx.doi.org/10.17226/22087.

APPENDIX A: WHITE PAPER

Decarbonizing Transport for a Sustainable Future

Mitigating Impacts of the Changing Climate

David L. Green, *University of Tennessee, Knoxville, USA*
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1 Introduction

Mitigating greenhouse gas (GHG) emissions is essential to preventing dangerous anthropogenic interference with the climate system. The recent Paris Agreement reaffirmed the long-standing view of scientists that it is critical to keep the increase below 2°C to preserve the socioeconomic conditions of current civilization. The current trajectory of global emissions will increase the average global temperature beyond the 2°C goal (IPCC 2014a, p. 113). Reductions in GHG of 80% to 90% by the United States and the European Union by 2050 are necessary to constrain the increase in global average temperature to less than 2°C. Therefore, additional mitigation actions, defined as "human intervention to reduce the sources or enhance the sinks of greenhouse gases" (IPCC 2014a, p. 142), will be necessary.[1]

Within this cross-sectoral objective, this paper clarifies the importance of mitigating transportation's large and growing share of anthropogenic GHG emissions as a critical contribution to moderating the dangerous impacts of climate change. There are four fundamental ways to reduce transport's direct GHG emissions across the range of fossil fuel–dependent passenger and freight transport modes:

1. Improve vehicle energy efficiency,
2. Reduce the carbon intensity of energy sources,
3. Reduce the level of motorized transport activity, and
4. Improve the efficiency of the transport system.

In addition, this paper discusses indirect means of reducing emissions, such as through changes to spatial form and land use. However, none of these measures alone is sufficient. A comprehensive mitigation strategy for transport is required to achieve GHG reductions of 80% to 90% by 2050.

The purpose of this paper is to provide context for the deliberations of the Fifth EU-U.S. Transportation Research Symposium, the topic of which is mitigating the impacts of the changing climate. The paper is arranged as follows:

- Section 2 summarizes the problem of climate change and describes transportation's role.
- Section 3 presents projections of future emissions under current policies.
- Section 4 considers the barriers to more radical change.
- Section 5 explores the kinds of policy strategies and behavioral changes that might achieve 80% to 90% reductions in transport emissions by 2050.
- Section 6 suggests key research questions for consideration by symposium participants.

2 The Global Climate Change Problem and the Role of Transport

This section considers how both global temperature and carbon emissions have shown marked increases over the past three to four decades and the main mechanisms for increased carbon emissions, notably fossil fuel–based industrialization. It then considers some of the impacts and consequences and the importance of limiting the

[1] "Mitigation" is distinguished from "adaptation," which is "[t]he process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities" (IPCC 2014b, p.117). Adaptation was the theme of the Fourth EU-U.S. Transport Research Symposium (TRB 2016).

average increase in global temperature to 2°C before discussing the contribution of the transportation sector from three perspectives: tail pipe, well to wheels, and cradle to grave.

Summary of Key Global Climate Change Evidence and Mechanisms

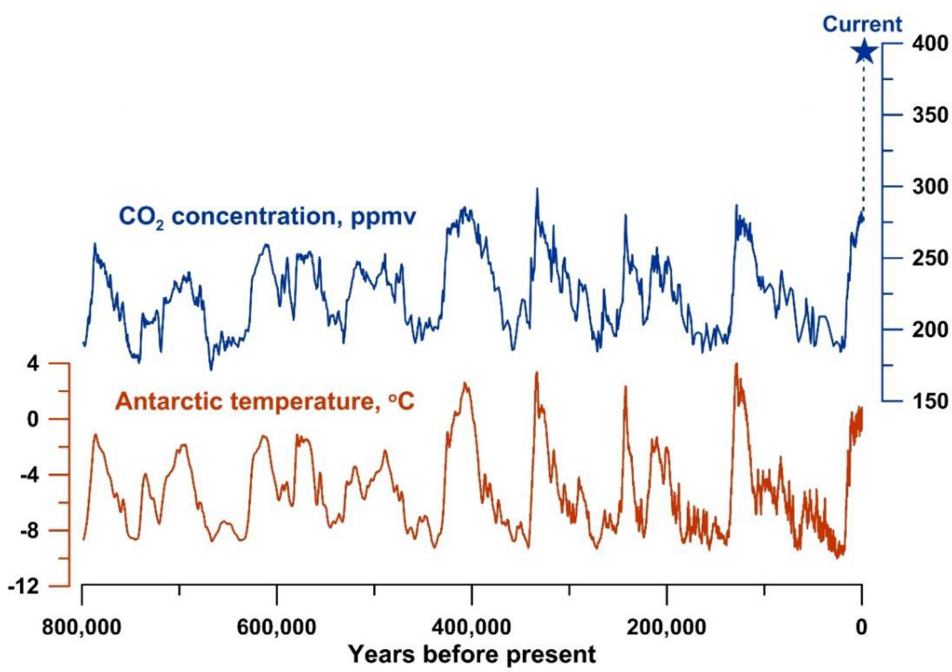
The Earth's lower atmosphere and surface are warming at an increasing rate (Figure 1). While there have always been periods of cyclical fluctuations in temperature and atmospheric carbon dioxide (CO_2) concentrations, the extent of the increase in concentrations in the past 40 years is greater than any changes recorded in the past 800,000 years. Concentrations are now 25% higher than previous peaks, which is approximately double the historical average (Schwartz and Tavasszy 2016, p. 3). Indeed, the data since 1980 show a particularly clear increase in trend, with no annual observations below the 1901 to 2000 average and new records set in the past 3 years (Figure 2). Looking to the future, the projections for potential increases would take average global temperatures higher than humans have ever experienced.

Following are the principal mechanisms for anthropogenic GHG emissions:

- Extraction of hydrocarbon minerals, such as coal and oil, from subsurface deposits for energy and to produce consumer goods;
- Deforestation for timber and fuel and to clear land for cultivation or development;
- Land cultivation—turning over the soil encourages decomposition of organic material and produces CO_2 and methane (CH_4); and
- Intensive animal husbandry, which increases CH_4 emission from animal digestive tracts.

The absolute contribution of industrialization to current CO_2 concentrations since 1751 has been estimated at 400 billion metric tons of carbon from the consumption of fossil fuels and cement production. The period since 1850 is of main relevance, with half of that contribution having arisen in just the past 30 years (Boden et al. 2015) (Figure 3).

The origins of industrialization, first in Western Europe then North America, mean the greatest benefits and socioeconomic changes have occurred on those continents. In this context, the European Union



The 800,000-year record of admospheric CO_2 from the EPICA Dome C and Vostok ice cores, and a reconstruction of local Antarctic temperature based on deuterium/hydrogen ratios in the ice. The current CO_2 concentration of 392 ppmv is shown by the blue star. (Data from Lüthi et al., 2008, *Nature*, 453, 379–382, and Jouzei et al., 2007, *Science*, 317, 793–797.)

FIGURE 1 Correlation between temperature and CO_2 (ppmv = parts per million volume) (Shakun et al. 2012).

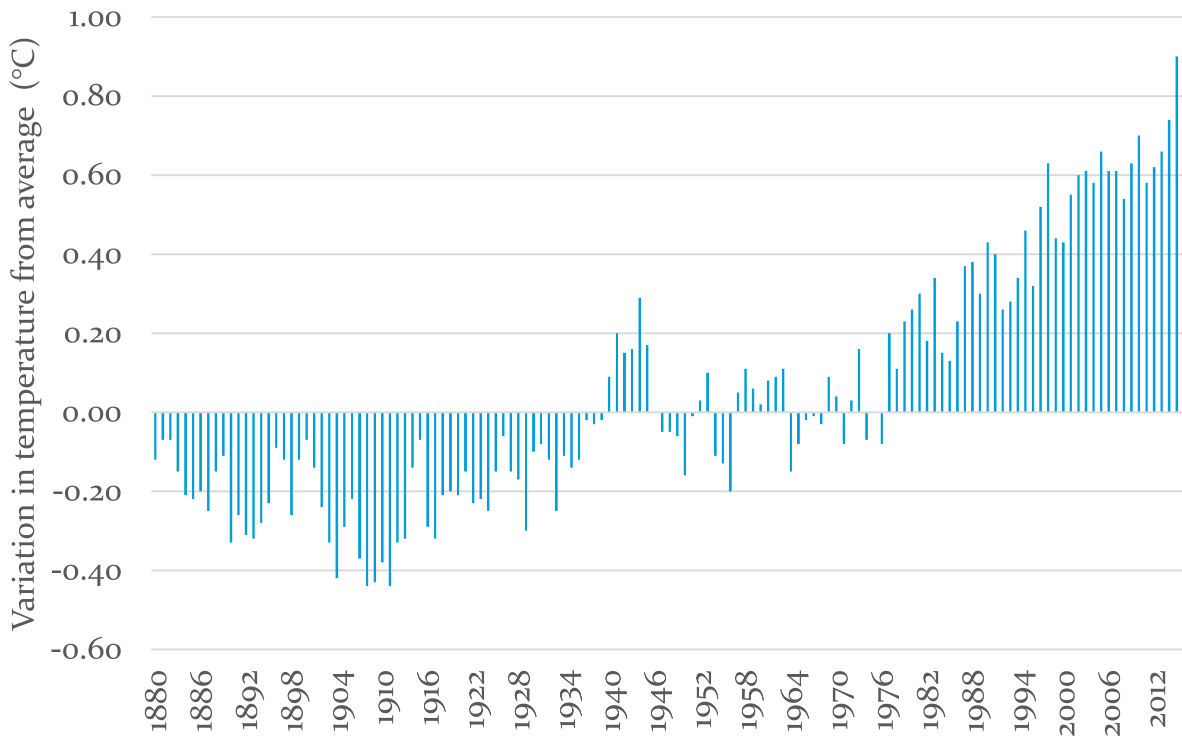


FIGURE 2 Annual global (land and ocean) temperature variations since 1880 against average for 1901 to 2000. (Data source: NOAA 2017.)

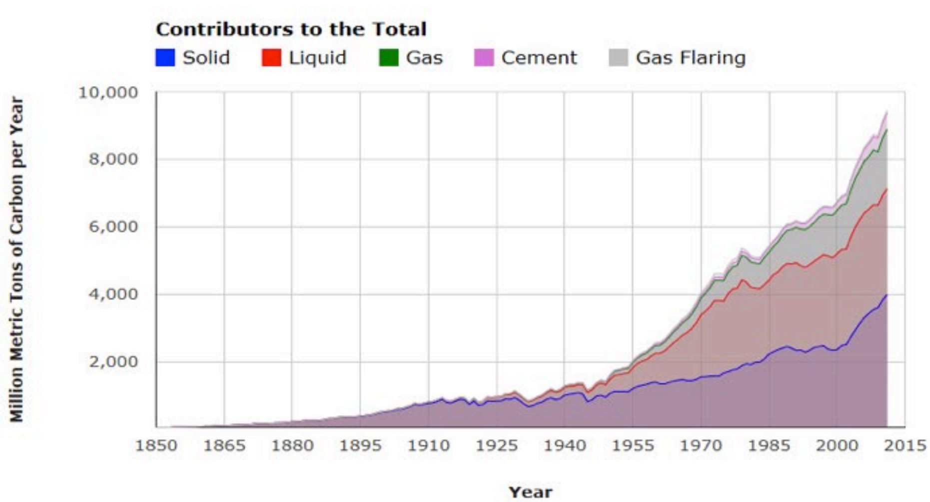


FIGURE 3 Cumulative carbon emissions from fossil fuel consumption and cement production since 1850 (Boden et al. 2015).

and the United States have particular responsibilities to lead global action to counter climate change. Given that much of the future potential growth in GHG emissions will come from the industrializing nations, they also have vested interests in developing and sharing effective mitigation strategies around the globe.

Impacts and Consequences of Climate Change

As identified by Schwartz and Tavasszy (2016, p. 4), four principal climate impacts are expected:

1. Sea level rise of at least 0.5 to 1.0 meters by 2100, as a result of ice sheet melt, notably that of Greenland. The increases will not have a uniform effect around the world because of localized land subsidence and rebound and varying atmospheric pressure. However, the U.S. Gulf Coast is one area expected to be particularly affected by subsidence.
2. Higher temperatures and longer heat waves, with average surface temperature increasing by 2.6°C to 4.8°C by 2100. Only part of this increase is still avoidable, as summarized in Figure 4 below.
3. Changes in precipitation patterns. These changes are projected to result in greater drought in some locations and higher rain and snowfall in others, as warmer air can carry more moisture. These effects are hard to quantify, but an increase in frequency of up to five times in severe drought or extreme precipitation is expected.
4. Increased wind intensity of storms and hurricanes. There is some uncertainty about the effect of climate change on hurricane frequency but more certainty about the intensity of storms and hurricanes increasing, with implications in terms of both wind damage and storm surges.

The secondary consequences of these changes will be an increase in coastal flooding, wildfire, and landslides—events that will damage natural and built environments (infrastructure and property) and contribute to higher rates of injury and human loss of life. More than 1.5 billion people, from 2005 through 2015, were affected by disasters that caused more than 700,000 deaths and more than 1.4 million injuries and destroyed 23 million homes (Galperin and Wilkinson 2015).

Transportation infrastructure, along with energy and telecommunications networks, is spatially extensive and often has coastal locations or follows coastal routes to take advantage of flat land or provide access to the sea. Such infrastructure is on the front line of exposure to climate change. Reliance of modern transportation systems on energy and communications networks makes them both directly and indirectly vulnerable. Similarly, coastal communities can be regarded as high-risk areas because of their exposure to extreme weather events in the short run and sea-level rise in the future.

The longer-term secondary consequences of climate change will be ecological, as the environmental range of animal and plant species and diseases changes global distribution as the zones of climatic tolerance for each shift toward the poles and to increased altitude. Human agriculture will also be affected, so that adaptation in farming practices or diet or both will be required. The worst scenarios envisage increased instances and extent of famine as the net availability and productivity of agricultural land falls and also changing patterns of human infectious diseases, as many of these are dependent on vector species (e.g., malaria is dependent on the mosquito). As resources become scarcer and parts of the planet, such as parts of the Middle East, become physiologically intolerable for humans,[2] mass migration and conflict can be expected to increase.

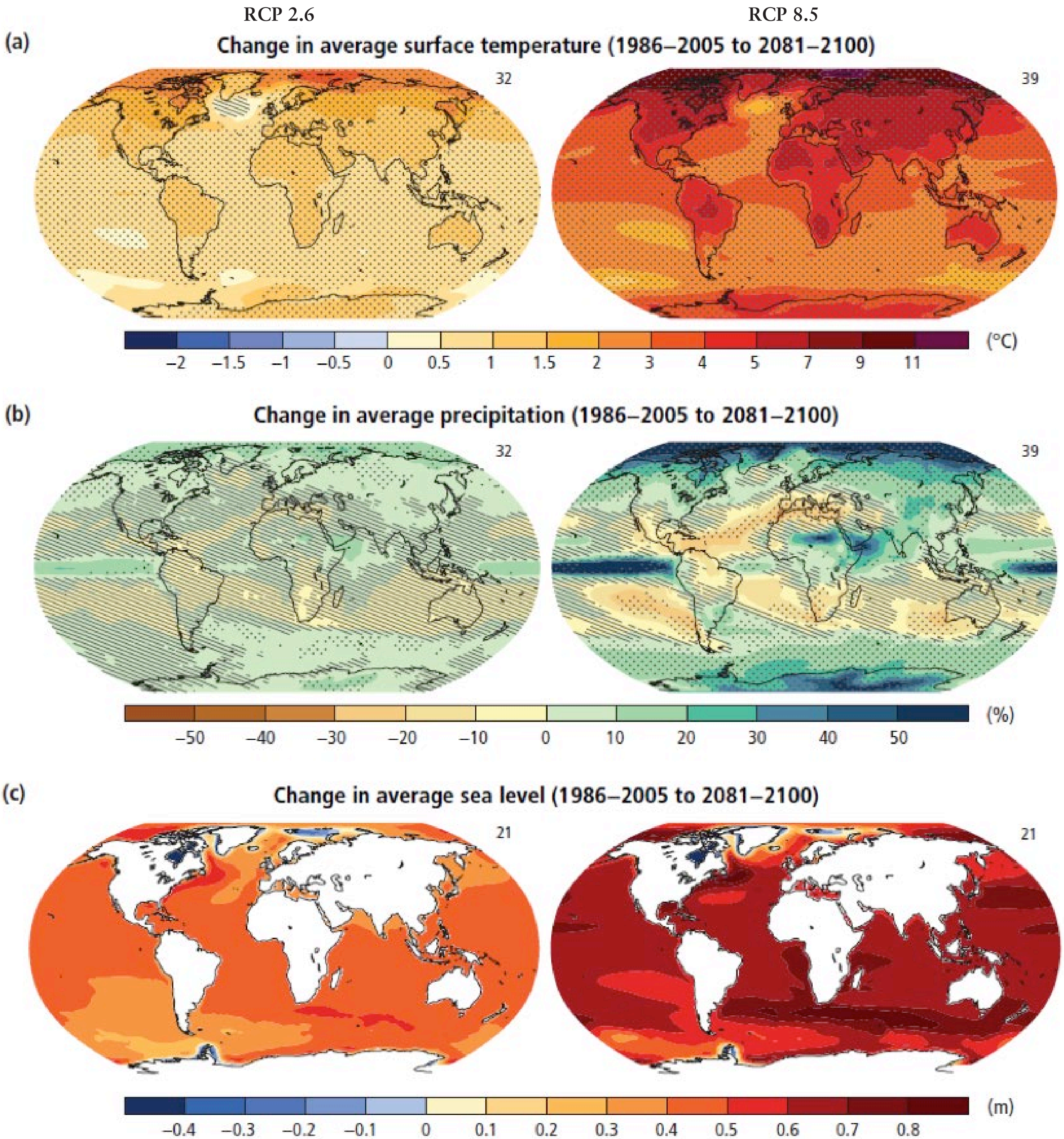
On balance, transportation networks will be negatively affected by climate change. Road network managers in some regions may experience a reduction in winter treatment costs if the incidence of snow and ice falls, but this will be countered by an increase in damage from severe flooding events. While the Northwest Passage is now approaching commercial viability for nonspecialized shipping (Hennig 2016), there are threats to pipelines and railways built across permafrost (Guo and Sun 2015). Commercial aviation economics will be negatively affected by higher temperatures reducing surface air pressures and reducing takeoff payloads, while changing jet stream patterns will increase fuel burn and reduce schedule reliability (Williams and Joshi 2013). The potential for growing disruption linked to geopolitics remains unclear, but potentially may close infrastructure such as the Suez Canal or sections of airspace.

The consequences of climate change will not be equally distributed. Many of the states expected to suffer the greatest consequences currently lack the financial, technical, or political capital to adapt. However, there will be considerable variation in the effects of climate change even within the European Union and the United States. Figure 5 shows the broad range of effects—some already observed, others expected—associated with the different geoclimatic regions in Europe.

Importance of the 2°C Limit

On November 4, 2016, the first legally binding global agreement to limit climate change was ratified (the Paris Agreement of 197 parties). The principles of that agree-

[2] Wet bulb temperature (WBT) is a combined measure of temperature and humidity. Above a WBT of 35°C, for example, 46°C air temperature and 50% humidity, survival is limited to a few hours. However, for less than fully fit people, the fatal WBT is lower. WBTs of 35°C are already close to being reached in the Middle East (Pal and Eltahir 2016).



Coupled Model Intercomparison Project Phase 5 (CMIP5) multimodal mean projections (i.e., the average of the model projections available) for the 2081–2100 period under the RCP 2.6 (left) and RCP 8.5 (right) scenarios for (***a***) change in annual mean surface temperature and (***b***) change in annual mean precipitation, in percentages, and (***c***) change in average sea level. Changes are shown relative to the 1986–2005 period. The number of CMIP5 models used to calculate the multimodal mean is indicated in the upper right corner of each panel. Stippling (dots) on (*a*) and (*b*) indicates regions where the projected change is large compared to natural internal variability (i.e., greater than two standard deviations of internal variability in 20-year means) and where 90% of the models agree on the sign of change. Hatching (diagonal lines) on (*a*) and (*b*) shows regions where the projected change is less than one standard deviation of natural internal variability in 20-year means. *(WGI Figure SPM.8, Figure 13.20, Box 12.1)*

FIGURE 4 Projections for 2100 global temperature, precipitation, and sea level changes over 1986 to 2005 average under Representative Concentration Pathway (RCP) 2.6 (1°C average increase) and RCP 8.5 (3.7°C increase) (IPCC 2014c).

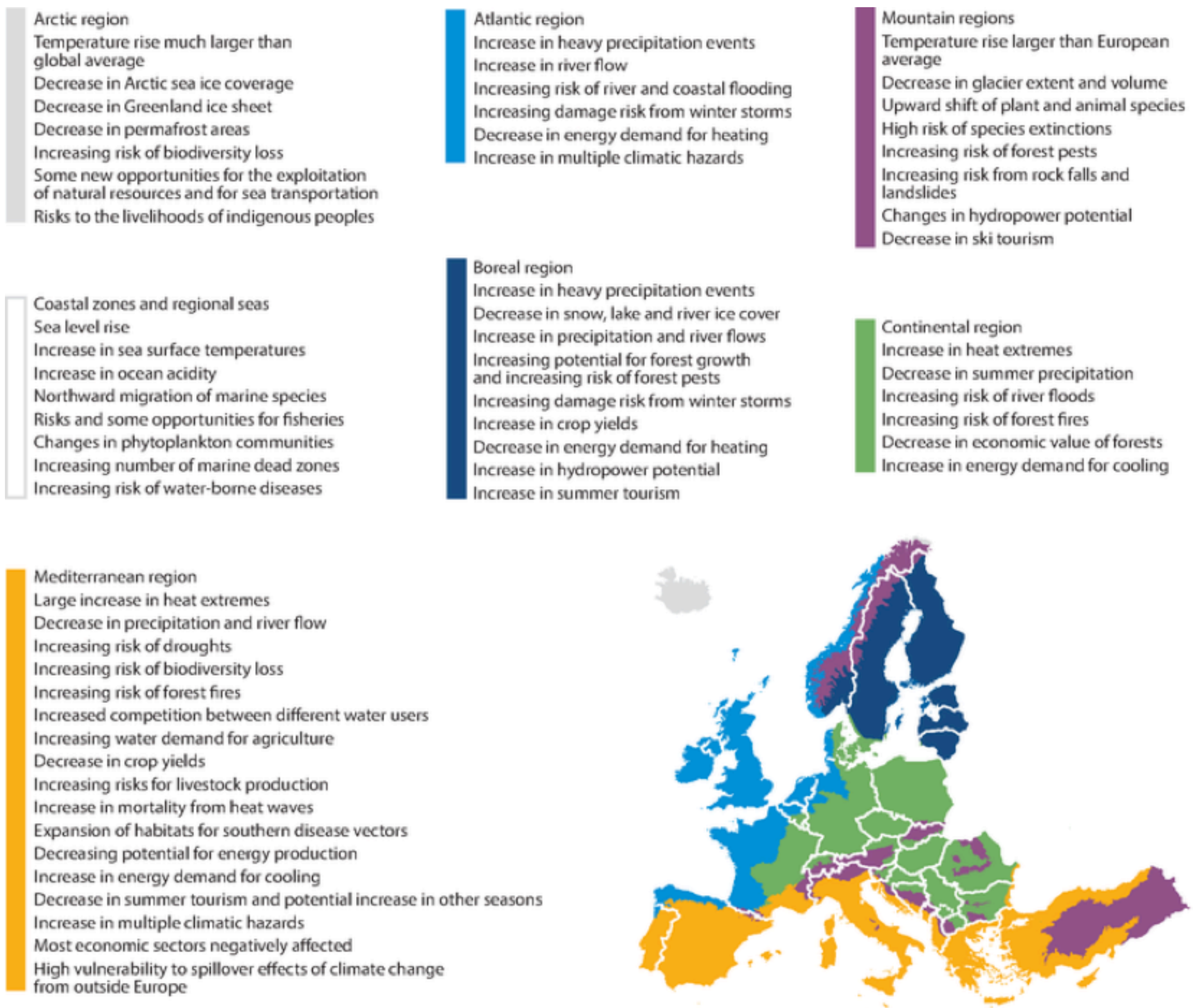


FIGURE 5 Observed and projected climate change impacts for the main biogeographical regions in Europe.

ment emphasize mitigation, with the goal of avoiding a large part of the potential global temperature increase. The agreement reaffirmed the importance of keeping the increase below 2°C from preindustrial levels and further agreed to the desirability of limiting increases to 1.5°C. The importance of early peaking and rapid reduction in global emissions was also reemphasized. A decade earlier, Stern (2006) considered the feasibility of GHG trajectories from an economic perspective. Figure 6 exemplifies how the later and higher the peak, the more dramatic the necessary decline to achieve the 2°C goal. The economic costs of missing the target were estimated at 1% of annual global GDP by 2050 (ranging from a 1% gain to a 3.5% reduction), although the extensive application of carbon capture and storage was envisaged.

Indeed, in both the power generation sector and the transportation sector, the key political challenge is how much to seek early reduction from behavior and consumer change and best available technologies and how much to rely on future technological change. Future technological change can be a politically attractive option, as it offers effective and affordable measures able to achieve greater total reductions and at a higher rate of reduction than the late peaks imply. The clear risk of such a strategy is that technologies that are as effective and affordable as hoped do not emerge, meaning that targets can only be met with more difficult behavioral change that may possibly require coercive measures such as rationing. Political consensus may break down under such conditions.

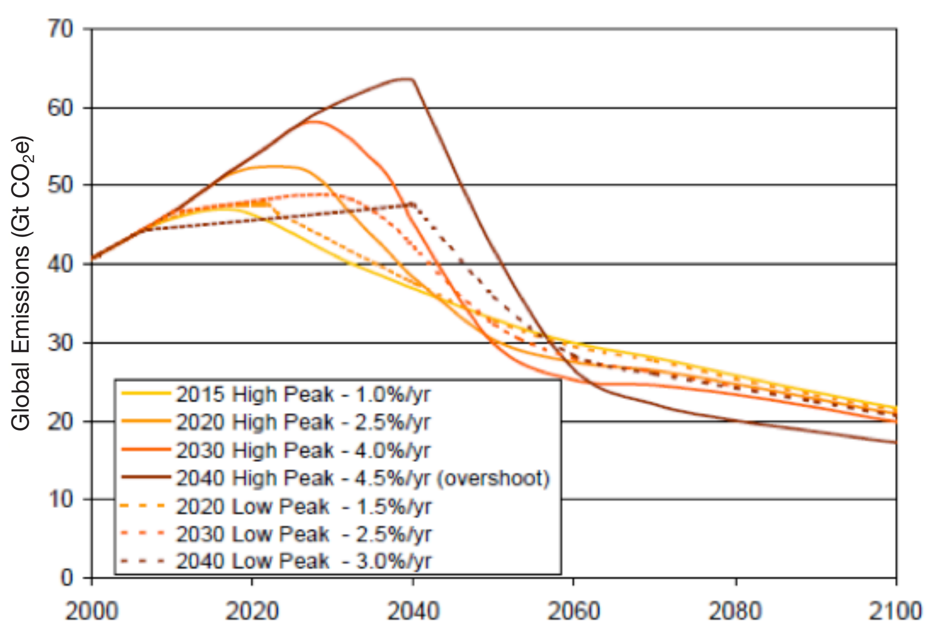


FIGURE 6 Illustrative emissions paths to stabilize at 550 ppm CO_2e (Stern 2006, Figure 3).

Importance of Transportation to Global GHG Emissions

Transportation is a large and growing source of global greenhouse gas emissions. Globally, transportation produces about one-seventh of anthropogenic GHG emissions (Figure 7). This total includes developing and developed economies and emissions from agriculture, forestry and land use changes, and energy use. Transportation's share is larger than the global average of 14% in the European Union (Figure 8*a*: 25%) and the United States (Figure 8*b*: 27%) because of higher levels of transportation activity and motorization (EEA 2016b; EPA 2017a). When international bunker fuels are included, transportation's share increases to 30% or more (Table 1).

While total EU GHG emissions [4,282 metric tons carbon dioxide equivalent (CO_2e) in 2014] have been declining and were 24% below 1990 levels in 2014, transportation was the only major sector whose GHG emissions in 2014 were higher than in 1990 (EEA 2016a).

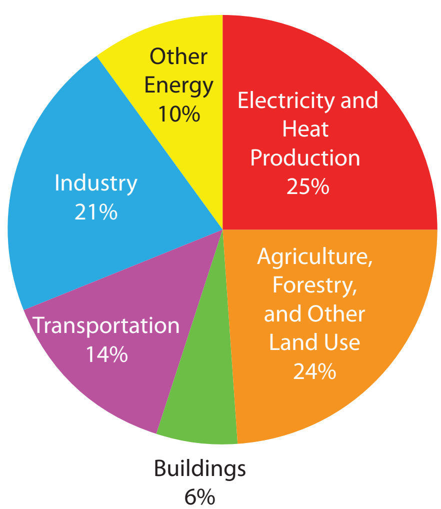


FIGURE 7 Global greenhouse gas emissions by economic sector (EPA 2017b, 2017c, using data from IPCC 2014a).

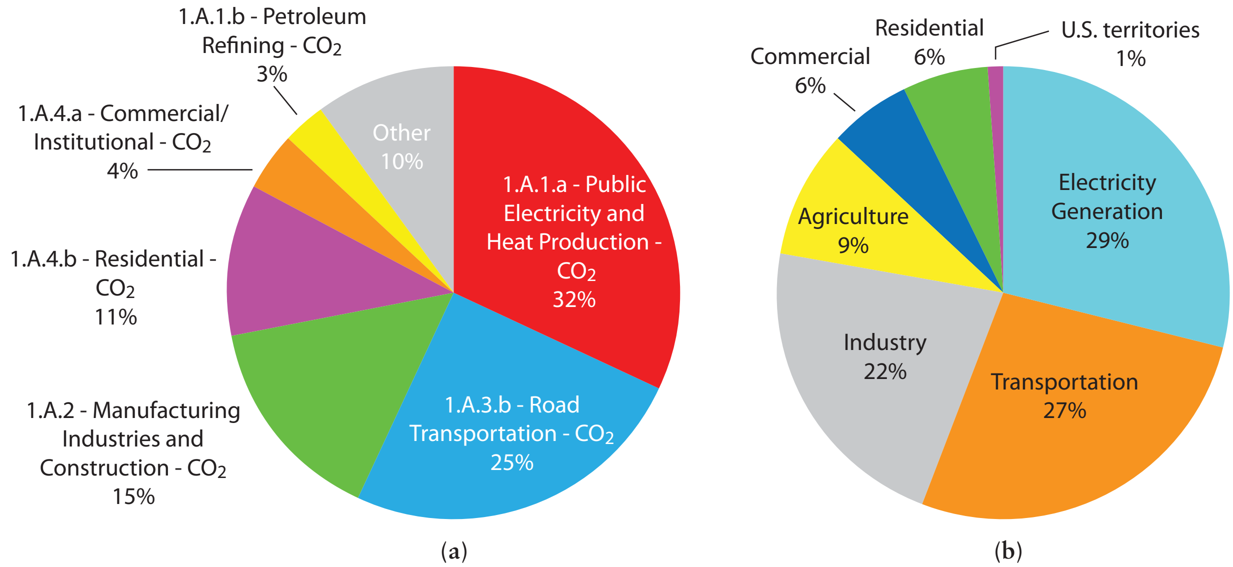


FIGURE 8 Greenhouse gas emissions by economic sector: (*a*) European Union 2014 (EEA 2016b, Figure 3.2) and (*b*) United States, 2015 (6,586 million metric tons CO_2e) (EPA 2017a, Table ES-6).

Total U.S. GHG emissions from transportation were 3% higher in 2015 than in 1990, but 9% lower than the peak level in 2005 (EPA 2017a). In the United States, transportation's GHG emissions surpassed those of the electric power sector for the first time in 2016, making transport the largest source of CO_2 emissions in the U.S. economy (EIA 2017a).

Unlike other sectors of the economy, transportation's GHG emissions consist almost entirely of CO_2 from fossil fuel use in internal combustion engines (Figure 9). CO_2 comprises 96% of transport's GHG emissions in the United States and the European Union (EIA 2017a). The next largest component (<3%) consists of fluorinated gases used in automotive air conditioners and mobile refrigeration. For the past half century, whether globally, in the European Union, or in the United States, approximately 95% of transport's energy has come from petroleum (EIA 2017a). The lack of diversity in both energy use and GHG gases makes transportation unique among economic sectors.

On-road vehicles create the majority of transportation's GHG emissions, producing 73% of transport GHG emissions in the European Union, followed by aviation and navigation at 13% each (EC 2017). Rail travel accounts for less than 1% (Figure 10). Because most modes rely predominantly on petroleum fuels for energy, emissions are strongly correlated with energy use, with the most notable exception of rail, whose share of GHG emissions is less than half its share of energy use owing to substantial electrification.

In the United States, more than 85% of transportation's CO_2 emissions comes from on-road vehicles, and three-quarters of that is from passenger cars and light trucks (Figure 11). Air travel is the next largest source, producing 9% of U.S. transportation's CO_2 emissions. Emissions by both freight and passenger rail constitute only 3% of the total, while domestic waterborne vessels are responsible for less than 2%. Neither the air nor the water mode numbers include international operations.

TABLE 1 Greenhouse Gas Emissions by Energy Subsector, 2013

	Greenhouse Gas Emissions (millions of tons CO_2e) by Energy Subsector							
Location	Electricity and Heat	Manufacture and Construction	Transport	Transport (%)[a]	Other	Fugitive	Bunker Fuels	Total
EU-28	1,414	418	861	30	713	69	269	3,743
United States	2,380	441	1,688	32	649	338	117	5,612
World	15,301	6,110	7,383	23	4,141	2,585	1,105	36,626

[a]Transport percent includes bunker fuels.
SOURCE: EEA 2016.

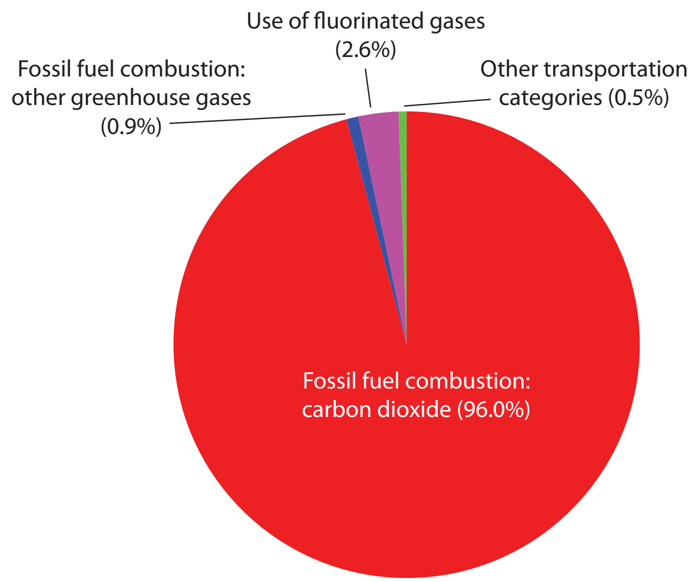


FIGURE 9 U.S. greenhouse gas emissions from the transportation sector, 2014 (emissions in million metric tons CO_2e) (EPA 2017b, 2017c).

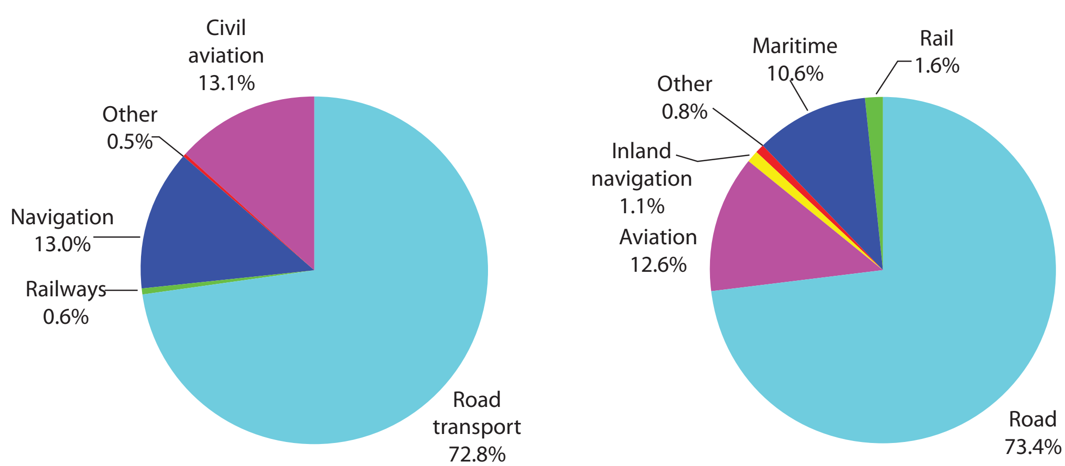


FIGURE 10 EU transport GHG emissions and shares by mode, 2014 (EEA 2016b).

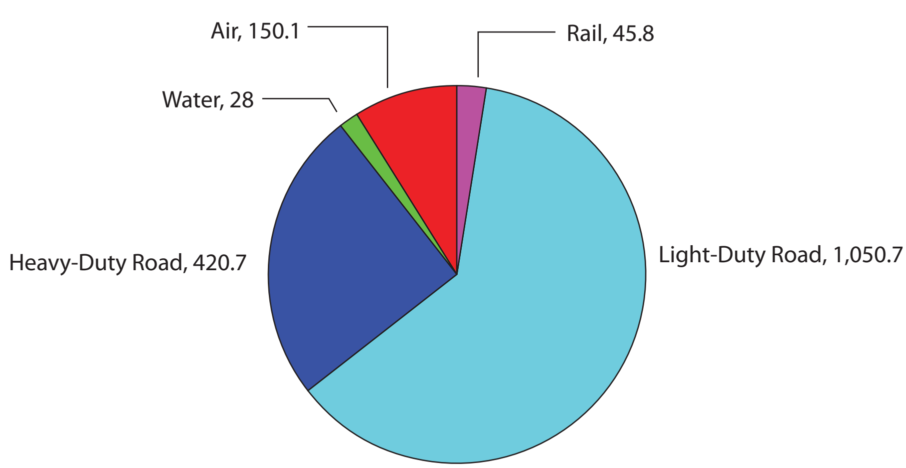


FIGURE 11 U.S. transport GHG emissions (metric tons CO_2e) by mode, 2014 (Davis et al. 2016, Table 11.8).

Well-to-Wheels Emissions

Direct emissions from motor vehicles can understate the impact of transportation on the global environment. GHGs are produced at all phases of the exploration, extraction, transport, conversion, and delivery of the fuel for propelling motor vehicles. Well-to-wheels (WTW) analysis attempts to measure these upstream emissions in order to enable a more comprehensive comparison of fuel and vehicle systems. WTW analysis, like life-cycle analysis in general, has limitations:

- A boundary that limits what impacts are assessed must be drawn around the system. For example, WTW analysis excludes GHGs from the production and disposal of the vehicles themselves.
- When advanced technologies in a future economy are compared, assumptions must be made about the GHG intensity of linked economic sectors. For example, the WTW emissions of grid-connected electric vehicles depend strongly on the carbon intensity of the electricity grid.
- WTW analysis is geographically and temporally specific. For example, upstream emissions depend on the carbon intensity of electricity generation, the distances energy resources and fuels must be transported, and the modal structure of freight transport.

Despite such limitations, WTW analysis provides a more complete basis for comparing fuels and vehicle technologies and understanding their potential to mitigate transportation's GHG emissions than tailpipe emissions alone.

WTW GHG emissions for gasoline and diesel passenger cars for model years 2010 to 2020 are shown in Figure 12. A typical 2010 gasoline vehicle in the European Union is estimated to emit about 185 grams CO_2e/kilometer on a WTW basis (about 295 grams CO_2e/mile)—substantially less than a similar vehicle in the United States, which is estimated at 409 grams CO_2e/mile or 254 grams CO_2e/kilometer (Davis et al. 2016, Figure 11.4). In the European Union, diesel vehicles with 2010 technology emit about 145 grams CO_2e/kilometer (about 235 grams CO_2e/mile).

By 2020, improvements in fuel economy are expected to enable hybrid gasoline vehicles in the European Union to emit less than 85 grams CO_2e/kilometer and diesel hybrids less than 80 grams CO_2e/kilometer. By 2020, all-electric vehicles in the European Union are expected to emit about 60 grams CO_2/kilometer with electricity from the average EU generation mix, but essentially zero if electricity is generated entirely by wind or nuclear power.

Cradle-to-grave analysis extends WTW analysis by including GHG emissions associated with the vehicle's life cycle:

1. Raw material recovery and extraction,
2. Material processing and manufacturing,
3. Vehicle and component production and assembly, and
4. Vehicle disposal and recycling.

For the United States, including the full vehicle life cycle adds about 10% to the WTW emissions for a conventional light-duty gasoline-powered vehicle, which increases estimated life-cycle emissions from 435 to 479

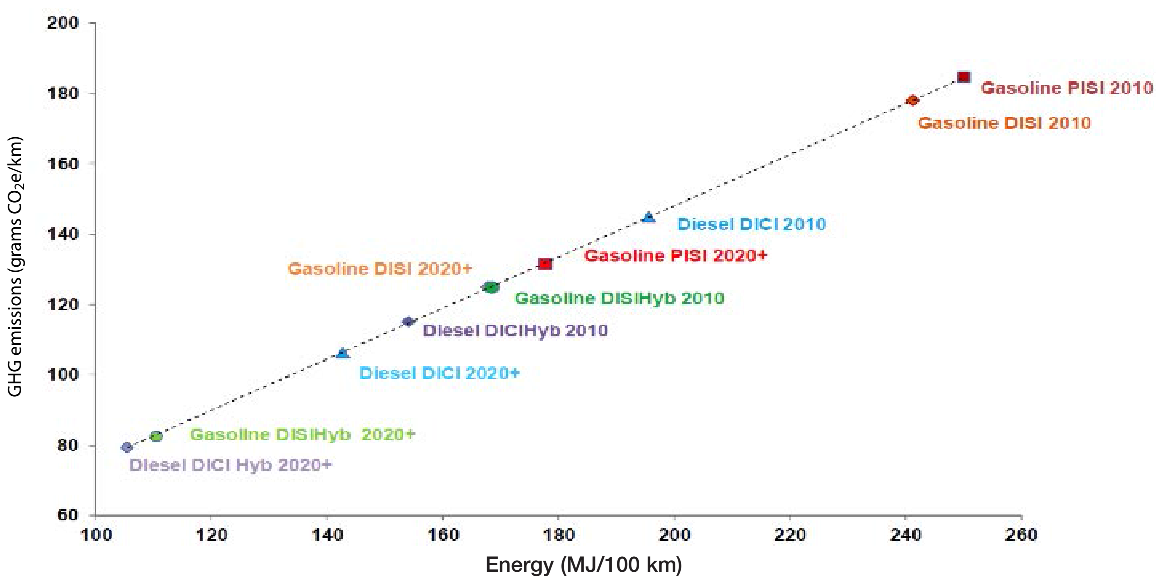


FIGURE 12 WTW energy expended versus GHG emissions for conventional internal combustion engine and hybrid vehicles in the European context [DI = direct injection, PI = port injection, CI = compression ignition (i.e., diesel), SI = spark ignition (i.e., gasoline), Hyb = hybrid] (EC 2014, Figure 3.2.2-1).

grams/mile (270 to 298 grams/kilometer) (Elgowainy et al. 2016). The potential for future 2025 to 2030 light-duty vehicles and fuels to reduce cradle-to-grave GHG emissions is illustrated in Figure 13 for gasoline and diesel internal combustion engine vehicles (ICEVs), hybrid electric vehicles (HEVs), flex-fuel vehicles (FFVs) that run on gasoline–ethanol blends of up to 85% ethanol (E85) , plug-in hybrid electric vehicles with a 35-mile electric range (PHEV35), hydrogen fuel cell electric vehicles (H2FCEVs), and battery electric vehicles with 90- and 210-mile ranges (BEV90 and BEV210, respectively). Efficiency improvements alone were estimated to reduce GHG emissions from about 450 grams CO_2e/mile to 300 to 350 grams CO_2e/mile for gasoline-powered vehicles. Substitution of biofuels, especially those produced thermochemically, appears to have the potential to reduce cradle-to-grave emissions to 75 to 150 grams CO_2e/mile. H2FCEVs and BEVs powered by solar- or wind-generated electricity are estimated to reduce GHG emissions to about 50 grams CO_2e/mile, which is very close to the GHG emissions from vehicle manufacture and disposal alone.

Comprehensive analysis of freight emissions considers five main determinants (Cliff et al. 2017):

- The structure of the logistics chain determines the amount of freight movement per unit of delivery.
- Modal carbon intensities vary greatly, making modal choices a critical determinant of freight GHG emissions.
- Utilization of facilities and vehicles incorporates factors such as vehicle loading and routing and recognizes the important role of facilities in the logistics chain.
- The energy efficiencies of facilities and vehicles determine the quantity of energy required by the utilization of vehicles and facilities.
- The carbon intensity of the energy used determines the quantity of GHGs per unit of energy used.

Logistics, modal choice, and the integral role of freight facilities distinguish comprehensive analysis of freight GHG emissions from those of on-road passenger vehicles.

Summary: Importance of Decarbonization in the Transportation Sector

To conclude this first section, it is clear that mitigation rather than adaptation must be the priority in order to avoid climate change, as some of the consequences would be catastrophic for societies and economies. The requirement to mitigate within the transportation sector is also paramount, given that transportation is a major source of global GHG emissions and that, particularly in

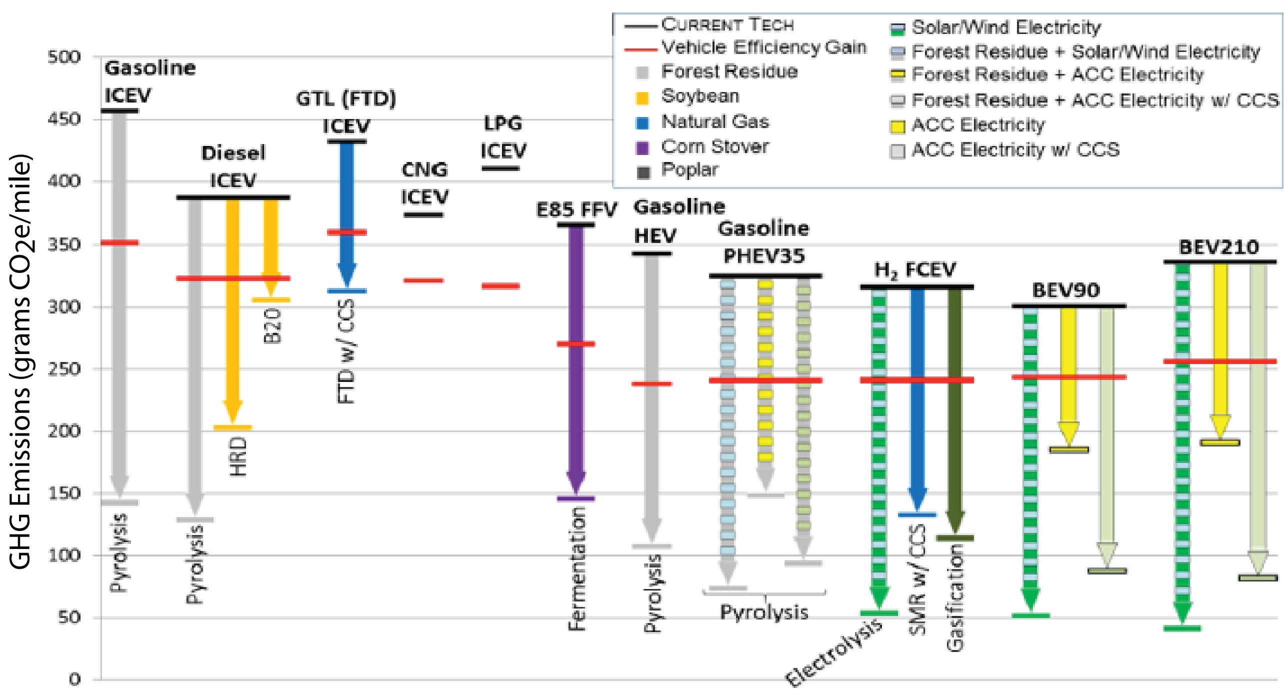


FIGURE 13 Cradle-to-grave GHG emissions of alternative fuel and vehicle technology pathways; analysis performed by using Greenhouse gas, Regulated Emissions, and Energy use in Transportation (GREET) 2014, and vehicle and fuel pathways constrained to those deemed scalable to approximately 10% of LDV fleet (HRD = hydroprocessed renewable diesel; FTD = Fischer-Tropsch diesel; ACC = advanced combined cycle; CCS = carbon capture and storage; SMR = steam methane reforming) (Elgowainy et al. 2016, Figure ES-1).

the United States and the European Union, the relative contribution of this sector is higher than the global average. Transport sector technical solutions that theoretically are able to make a major contribution to mitigation have been identified. The following sections consider the role of these solutions within the broader context of the evolving demand for mobility and transportation.

3 Progress Toward Agreed Commitments in the U.S. and EU Transport Sectors

Both the European Union and the United States have announced their intention to achieve large reductions in transportation's GHG emissions by 2050. This section begins by reviewing the goals and what official projections anticipate will be achieved by current policies. In the United States, new policy directions have been announced by the recently elected federal government that, if carried out, will diminish and delay GHG mitigation. At the time of writing, the policy changes apply predominantly to other sectors of the economy, particularly electric power generation. However, the U.S. administration has also announced its intention to reconsider the existing fuel economy and GHG standards for light-duty vehicles, a cornerstone of U.S. transport GHG mitigation policy. The assessment below is based on studies done during the previous administration, which may render the results optimistic.

The "Under 2 MOU" Commitment and the Transportation Sector

Achieving the 2°C goal will require efforts by governments at international, national, and subnational levels. The "Under 2 MOU" is a voluntary commitment by subnational jurisdictions to pursue emissions reductions consistent with a goal of reducing GHG emissions by 80% to 95% over 1990 levels by 2050, with an interim (2030) goal of 40%. The MOU observes that international efforts to date have been inadequate and that the leadership of provinces, states, and cities is needed. With respect to traffic and transportation, the Under 2 MOU commits signatories to comprehensive efforts to reduce GHG emissions:

> The Parties agree to take steps to reduce greenhouse gas emissions from passenger and freight vehicles, with the goal of broad adoption of "zero emission vehicles" and development of related zero emission infrastructure. The Parties agree to encourage land use planning and development that supports alternate modes of transit, especially public transit, biking and walking. (SGCLMU 2017)

Signatories to the MOU agree to collaborate and coordinate in a range of activities from scientific assessments to public outreach to monitoring and verifying progress. Notably, they agree to share what they learn from efforts to achieve the transition to nearly zero GHG economies.

The European Commission published a strategy for transportation that calls for at least a 60% reduction in GHG emissions from transport by 2050 in comparison with 1990 and a clear pathway to zero emissions beyond (EC 2016a, 2016b). The communication to the European Parliament identified three priority areas for action:

1. Increasing the efficiency of the transport system through digital technologies, pricing, and modal shifts;
2. Accelerating the deployment of low-emission energy such as biofuels, renewable synthetics, electricity, and hydrogen; and
3. Moving toward zero-emission vehicles.

The transportation objectives and plans are part of a broader set of measures intended to transition Europe to a low-carbon economy.

In June 2013, the United States published a climate action plan that called for achieving a previously announced goal of a 17% reduction in U.S. GHG emissions below the 2005 level by 2020 (EOP 2013). The goal was conditional on all other major economies reducing their emissions as well. Strategies for transportation focused on increasing fuel economy standards and developing and deploying advanced technologies such as biofuels, BEVs, and H2FCEVs. The plan also pledged to work to improve modal choice options at the state and local levels.

The state of California's climate change plan is more ambitious and more comprehensive than the U.S. national plan (CARB 2017). It calls for a 40% reduction in the state's GHG emissions over 1990 levels by 2030. Components of the plan include reduction of vehicle travel through land use and community designs that promote transit and nonmotorized travel, zero-emission vehicle sales mandates for manufacturers, low-carbon fuel standards, GHG emissions standards for light- and heavy-duty vehicles, a plan for sustainable freight transport, automated transportation and shared mobility, and reducing short-lived pollutants like methane and black carbon.

Estimates of Mitigation Based on Current Initiatives

The U.S. national goal of a 17% reduction in GHG emissions over 2005 by 2020 will almost certainly not be met by the transportation sector. Total transportation sector carbon emissions were 1,986 metric tons CO_2 in 2005 and are projected by the U.S. Energy Information Administration (EIA) to be 1,872 metric tons CO_2 in 2020 (EIA 2017b, Tables 7 and 19). EIA's Annual Energy Outlook Reference Projection is intended to incorporate all current policies but no new policies (Table 2). For example, current U.S. fuel economy and GHG regulations through 2025 require approximately a 45% reduction in on-road passenger car and light truck energy intensity over 2005 levels by 2050 (EPA 2017a, 2017b).[3] In the case of medium- and heavy-duty trucks, the U.S. Department of Transportation (U.S. DOT) and the Environmental Protection Agency have set fuel economy standards until 2027. The first phase of heavy-duty vehicle standards required emissions and fuel consumption reductions of 9% to 23%, depending on the type of truck, over a 2010 baseline by 2018 (EPA 2011). Phase 2 of the standards requires additional reductions of up to 25% by 2027 (EPA 2016). Together, the two phases are projected to reduce GHG emissions from medium and heavy-duty trucks by more than a billion tons of CO_2.

However, the EIA projection anticipates steady growth in transportation activity across most modes (Figure 14). Road traffic is projected to increase at just under 1% per year through 2050, with road freight traffic growing at 1.3% per year. Air travel is projected to grow at 2.2% per year until 2050. Steady improvement in the energy efficiencies of air travel and freight trucks, combined with rapid improvements in the fuel economy of light-duty vehicles that are expected to end in 2025 (Figure 15), is the main cause of declining CO_2 emissions until 2035 (Figure 16).

The European Union expects to achieve its 2020 target for reduction of GHG emissions (EEA 2016d). However, beyond 2020, the reduction scenario requires an accelerated rate of reduction, whereas the current predictions show a declining rate of reduction, even with additional measures. The transportation sector is a notable contributor to this problem, given it continues to follow a long-run trend increase (Figure 17). Current policies included in the Reference Scenario are summarized in Table 2.

The performance of the EU transportation sector against climate change objectives is an important part of the European Environment Agency's (EEA's) Transport and Environment Reporting Mechanism. The current strategy can be summarized as the transportation sector being expected to make a contribution to the overall reduction target of 60% reduction by 2050 even while transportation activity continues to grow. Indeed, growth rates comparable to those for the United States are forecast as follows: passenger transportation growth of about 40% (2010 to 2050), with aviation activity doubling, and freight transport growing by 58%. The EEA's (2016a, 2016b) assessment was that some emissions reduction would occur over the next 15 years, but the 2011 EU Transport White Paper ambition of limiting 2030 emissions to an 8% increase over 1990 will not be achieved (EC 2011b). Beyond 2030, an increase to 2050 equivalent to 15% over 1990 is currently forecast. Figure 18 presents the trends from 1990 to 2014, highlighting the effect of the global recession of the late 1990s and, for overall transport, a return to growth in recent years, also in the context of falling global oil prices.

[3] The estimate of 45% reduction was obtained by dividing the on-road fuel economy of passenger cars and light trucks of 20.2 miles per gallon in 2005 [according to U.S. DOT Federal Highway Administration Table VM-1 data (https://www.fhwa.dot.gov/policy-information/statistics/2013/vm1.cfm)] by the EIA's projected on-road 2035 light-duty vehicle fuel economy of 36.5 mpg.

TABLE 2 Summary of Policies Included in EU and U.S. Reference Scenarios

EU Policies in Reference Scenario 2016	U.S. Policies in Annual Energy Outlook 2017 Reference Case
Regulation of CO_2 from cars and vans	GHG and Corporate Average Fuel Economy (CAFE) standards for light-duty vehicles to 2025
Euro VI standards for heavy-duty vehicles	GHG emissions standards for medium- and heavy-duty vehicles through 2027
EU directive on renewable energy	Renewable Fuels Standards (projected to fall short of goals)
EU directives on vehicle charging and alternative fuels infrastructure	Tax credits and CAFE credits for plug-in, fuel cell, and alternative fuel vehicles
EU directives on freight, air, and rail operations	Requirements for fleet purchases of alternative fuel vehicles
International Maritime Organization regulations on ship efficiencies	
International Civil Aviation Organization convention on aircraft emissions	
Numerous national policies not specifically listed, promoting alternative fuel vehicles and infrastructure, road pricing, and more.	State policies: California's Zero Emission Vehicle program; CA SB-32 requiring statewide GHG reduction of 40% by 2030

Source: EC 2016b, Annex 4.1; EIA 2017b, Appendix A.

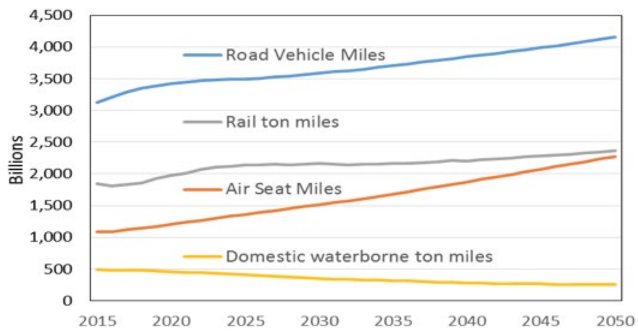


FIGURE 14 Projected U.S. transportation activity to 2050 (EIA 2017b).

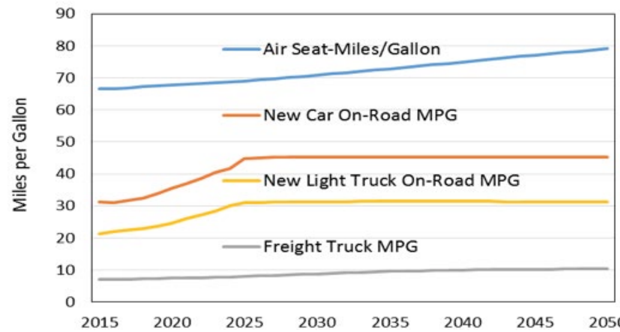


FIGURE 15 Projected U.S. modal fuel economy to 2050 (EIA 2017b).

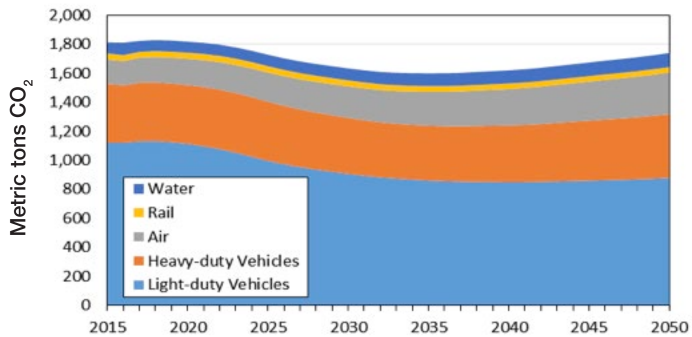


Figure 16 Projected U.S. transportation CO_2 emissions to 2050 (EIA 2017b).

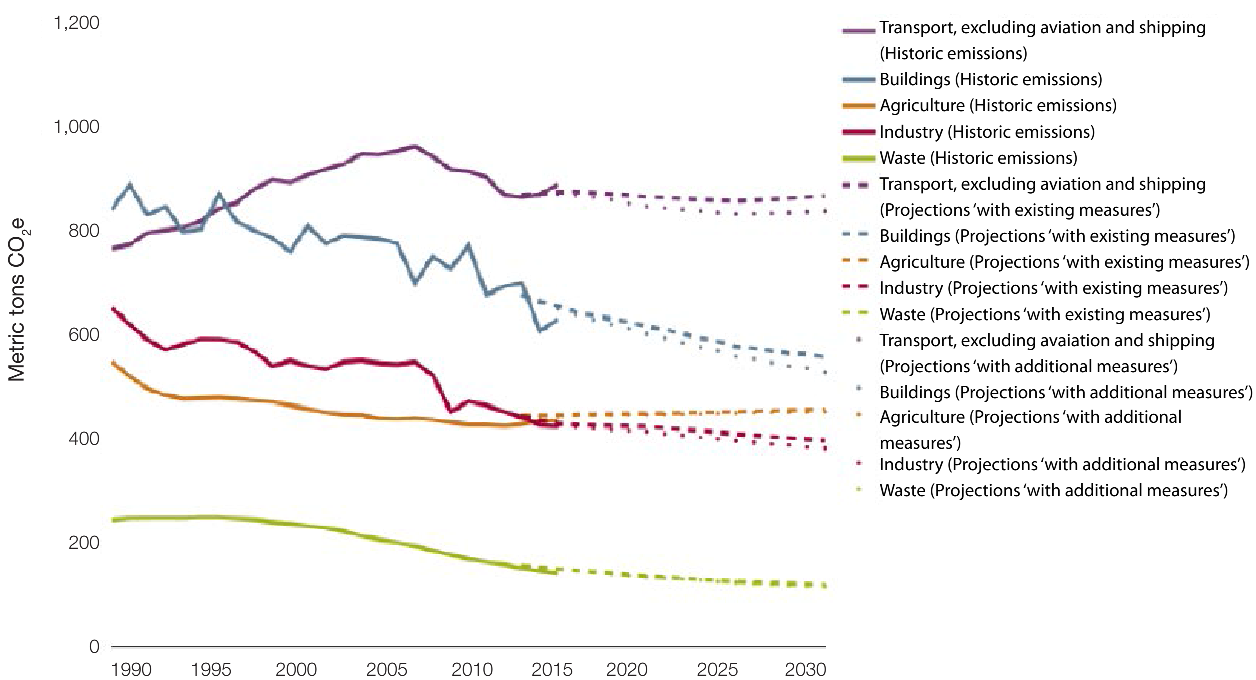


FIGURE 17 EU GHG emissions trends and projections by sector (EEA 2016d, Chart 2.4).

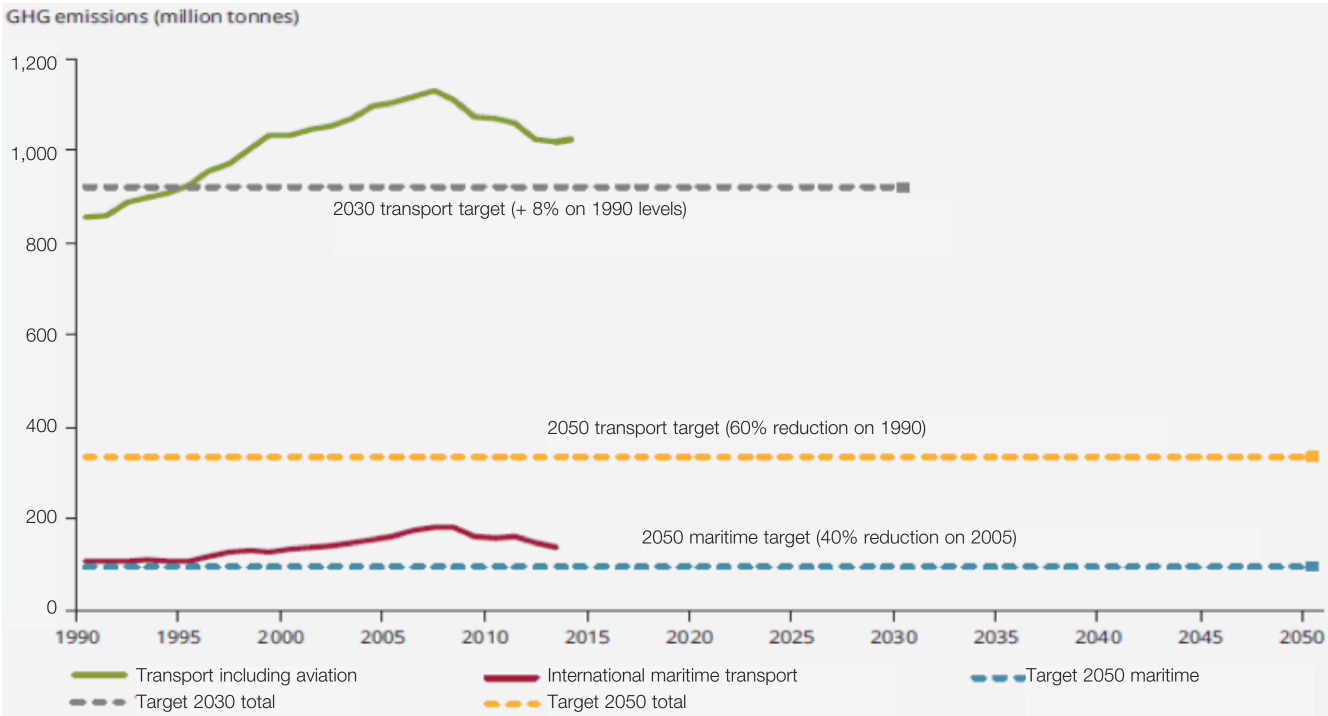


FIGURE 18 EU-28 Transport GHG emissions and targets (2014 data) (EEA 2016c, Figure 2.2).

A key aspect of the EU strategy, particularly given that passenger cars and vans account for 55% of all EU transport carbon emissions, is for the average emissions performance of new light vehicles sold to fall toward regulated targets. The sales and official emissions data showed a reduction in average emissions from new passenger cars of nearly 15% from 2010 to 2015, with the 130 grams CO_2/kilometer target for 2013 having been met 2 years early. Light-goods vehicles are a growing share of road traffic that is linked to the rise in small businesses and delivery services. The average emissions of new vans registered in the European Union already meet the 2017 target of 175 grams CO_2/kilometer by a margin of around 10% (Figure 19).

These achievements need to be set in the context of the concern that the official carbon emissions test data are very optimistic, and less accurate than those in the United States, although this is less of an issue for the monitoring

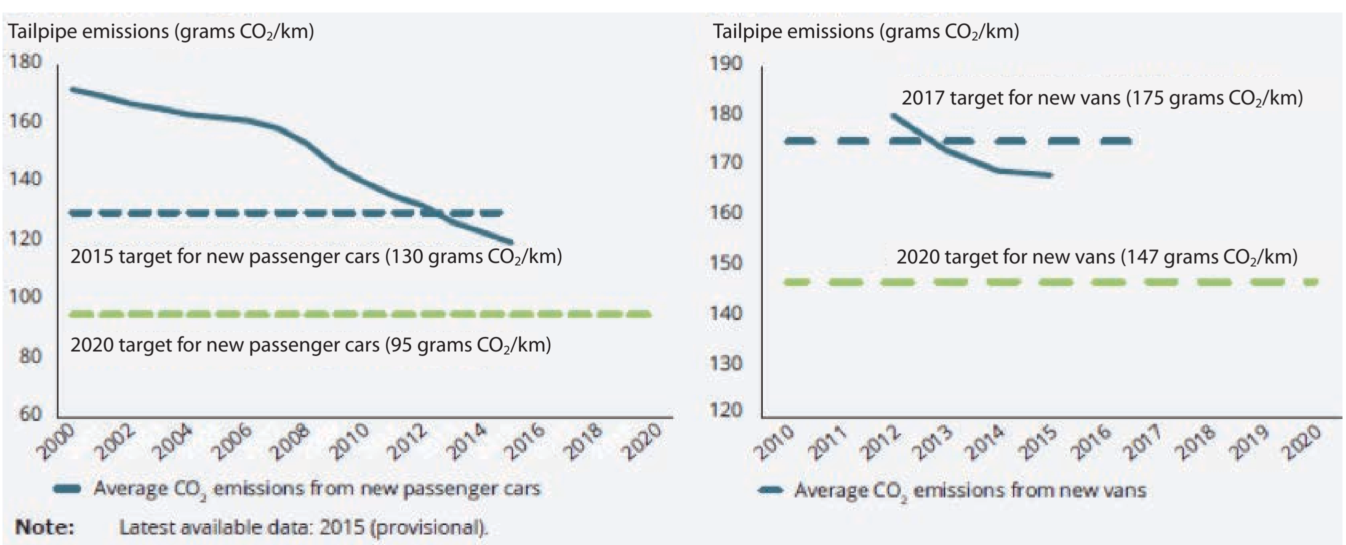


FIGURE 19 Average emissions (grams CO_2/kilometer) for new passenger cars and vans in the EU-27 (EEA 2016c, Figure 2.11).

of relative improvement over time (Mock et al. 2014). In any case, the next target, for 2021, of a 95 grams CO_2/kilometer new sales average requires a further 21% reduction, and uncertainties remain as to how this could be achieved.

Low-Carbon Fuel Standards

The state of California employs a low-carbon fuel standard that requires a 10% reduction in the carbon intensity of transportation fuels by 2020. Similarly, according to the Renewable Energies Directive 2009/28/EC, each EU member state must achieve a market share of 10% for renewable energy consumed in the transport sector by 2020. By 2015, two member states (Finland and Sweden) had achieved this requirement by more than double. The main policy measures behind this success are tax incentives for the fuels and a high market penetration of alternative (ethanol or biogas) vehicles and vehicles capable of operating on multiple fuels. Although the other member states showed much lower take-up, average market share in the European Union was 6% and growing, although with considerable variability (EEA 2016c).

Alternative Fuel Vehicles

In the United States, in contrast to the substantial increases in energy efficiency for all road vehicles required by the Corporate Average Fuel Economy and GHG Emissions Standards, the growth of alternative, low-carbon vehicles and fuels is projected to increase slowly. BEVs are projected to reach 3% of vehicles in use by 2030 and plug-in hybrids will not make up 3% of vehicles on the road until about 2040 (Table 3). H2FCEVs are projected to constitute less than 1% of light-duty vehicles even in 2050. In 2050, less than 15% of the light-duty vehicles on U.S. roads are projected to employ alternative, low-carbon technologies.

The European Union does not have a target for the adoption of alternative fuel vehicles, although policies to promote them are widespread among member states and the rate of adoption is monitored. The registrations of plug-in hybrids have shown linear but sharp growth to more than 100,000 vehicles by 2015. Electric vehicles show a less-steep but steady growth to 50,000. In contrast, from a peak of half a million vehicles in the late 2000s, liquid petroleum gas is in decline as an alternative fuel, owing to safety constraints on its use and as incentives are switched to cleaner alternatives. Natural gas remains attractive for specific applications, notably in city buses. However, both of the main gas fuels are fossil fuels with little or no carbon reduction benefit and are primarily promoted for reasons of air quality.

Summary: Current Policies Are Insufficient

Although the United States and the European Union show some differences with respect to mitigation targets and the projected impacts of current policies (listed in Table 2), both currently committed policy measures will lead to significant overshooting of the 2050 objective according to the reference scenario projections of the EC and EIA. Greater mitigation efforts will be required to achieve the 2°C goal.

4 Why is Achieving GHG Reduction in the Transport Sector So Challenging?

The transportation sector—and in particular the private car—has been fundamental to the postwar prosperity of the Western democracies. The automobile industry has been a key generator of jobs and profits, while its products have led to greater labor market flexibility and accessibility generally, as well as a key factor bringing a sense of well-being to citizens as part of the social contract of Fordist capitalism. However, automobility has resulted in societies and economies oriented around the car. This coevolution is not easily unpicked in a way comparable with retrofitting the building stock with better insulation or converting grid electricity from fossil to renewable sources. Whereas the latter changes might not be noticed or even bring comfort and cost benefits

TABLE 3 Projected U.S. Alternative Energy Vehicles in Use to 2050

Vehicle Type	2015	2020	2030	2040	2050
Battery electric vehicle (BEV)	0.29	1.19	7.91	13.62	17.23
Plug-in hybrid electric vehicle (PHEV)	0.25	1.13	5.51	8.76	10.36
Hybrid electric vehicle (HEV)	3.60	5.06	8.27	10.96	12.66
Natural gas vehicle (NGV) and liquefied petroleum gas (LPG)	0.31	0.56	0.63	0.66	0.70
Hydrogen fuel cell electric vehicle (H2FCEV)	0.00	0.08	0.88	1.44	1.70
Total alternative	4.45	8.02	23.20	35.44	42.65
Total light-duty vehicle stock	239.88	250.45	266.25	280.01	294.80

to consumers, intervention in the transportation market can imply change, and even disruption, for citizens' and businesses' established and valued practices. This section reviews some of the principal factors that pose a challenge to radical reduction of GHGs.

Insufficient Strength of the Knowledge Base, Policy Frameworks, and Infrastructure

The ability to implement public policies to mitigate transport's GHG emissions requires an understanding not only of how to formulate effective policies, but of how much can be accomplished, what the costs and benefits will be, and how policies will interact. Much is known about energy efficiency policies that have been employed for more than four decades, yet some controversy still remains.

Urgently and efficiently accomplishing large reductions in motorized vehicle use and its associated greenhouse gas emissions presents a new and complex challenge. The knowledge base for reducing motorized transportation and improving system efficiency also has a long history and has been extensively studied. On the other hand, the subject is more complex, as it depends strongly on the systemic interactions of geography, behavior, infrastructure, technology, economics, and social systems. Some changes, like parking fees or motor vehicle exclusion zones, can be implemented relatively quickly. Others, like urban densification and redesign, require decades to accomplish. Future technological changes, particularly connected and automated vehicles, are likely to have profound impacts.

Previous efforts to replace petroleum fuels have had little success, with only a few exceptions (McNutt and Rodgers 2004). The barriers to large-scale energy transitions are substantial, complex, and generally not well understood. On the other hand, much has been learned and will continue to be learned from experience promoting grid-connected electric vehicles and H2FCEVs.

Accomplishing a large-scale energy transition for transportation presents public policy with novel challenges. The time constants for large-scale, fundamental changes in vehicle and fuel technology are measured in decades rather than years (NRC 2013). Lead times for profound changes in motor vehicle manufacturing are at least 5 to 10 years. Engineering and capital constraints require that not all models can be redesigned at the same time and that a minimum of 5 years is required—and much more when there are market and technological risks. With the expected life of a new vehicle at 15 years or longer, turning over the majority of the vehicle stock takes another 15 years or so. For new fuels like hydrogen and electricity, a refueling infrastructure must be coevolved with the vehicle fleet. When this is added up, the accomplishment of an energy transition for transportation by 2050 is a daunting task on the basis of the time constants alone.

Over such a time frame, there is great uncertainty about technology and market conditions. Differences between social and market discounting of future costs and benefits can be substantial. Lack of fuel availability is a major barrier to vehicle sales during the early transition and, at the same time, the lack of fuel demand discourages investments in an alternative fuel infrastructure. Risk aversion and unfamiliarity with novel technologies are important barriers to consumer acceptance. Institutional unfamiliarity, reflected in inappropriate codes and standards, can also hinder the deployment of refueling infrastructure. Lack of diversity of choice of makes, models, and vehicle types restrains demand for alternative vehicles. On the vehicle supply side, costs for alternative vehicles and fuels can be inflated by lack of scale economies and by learning by doing. In the case of the leading zero-emission vehicle technologies, there is also a need for continued technological progress to reach a stage of development at which they could capture the majority of the motor vehicle market.

The complexity of these barriers argues for a comprehensive, multidimensional policy strategy. The barriers to energy transition diminish as markets for new vehicles and fuels develop. As a consequence, the process of energy transition contains strong positive feedback that create path dependencies and, potentially, tipping points. When uncertainty about conditions decades in the future is added, it becomes clear that public policy must learn from experience and adapt to changing conditions in order to successfully bring about the coevolution of vehicle markets and fuel infrastructures. When these factors are combined with substantial uncertainty, it becomes clear that public policies must be comprehensive, adaptable, operate at all geographical scales, and be informed by a continuously improving understanding of the barriers to the transition to low-carbon energy.[4]

Constraints: Economic and Spatial Structural Factors Limiting Change

As outlined in Section 2, both the United States and the European Union envisage significant growth in transportation demand. Carbon intensity is an indicator of the extent to which an activity, or indeed an entire economy, relies on CO_2-emitting processes or, in principle, GHGs more generally, in its accomplishment. Stern (2006, p. xi) observed that reduction of GHG emissions would need to be achieved in the context of perhaps fourfold global

[4] Further consideration is given to the issues of systemic transition toward a low-GHG transportation system in Appendix B of this volume.

economic growth. Hence, emissions per unit GDP would need to fall by 75% just to achieve stable emissions in the context of maximum likely growth. For a 60% to 70% real-terms reduction to be achieved while this level of growth is allowed for, overall carbon intensity would need to fall by more than 90% per unit GDP.

However, the economy has until now remained highly dependent on low-cost high-carbon transportation systems to reduce economic transaction costs and therefore lubricate GDP growth. Much of the emphasis on decoupling the economy from high-carbon transportation has focused on the carbon aspect of the relationship. However, the reliance on transportation itself could potentially be addressed. In this context it is important to recognize that forms of spatial development differ in their carbon intensity, principally because they are more or less attractive to different forms of mobility, which in turn differ in their efficiency. A key example in this regard is the car-oriented residential suburbs. The low density of the suburbs means average walking distances to destinations or to public transportation are high. The design of the local road network encourages relatively fast travel by car, which bus services can compete with, while the penetrability of the residential neighborhoods is often difficult for large vehicles. Minibus services, perhaps on demand, may be possible but tend to be expensive to operate. Differences in the extent of car-dependent development are one of the explanations for the rates of walking and cycling observed in Figure 20.

The critical importance of walking distance is revealed by Figure 21, which is based on data from the UK: for all trips less than 1 mile in length, more than three-quarters are already made on foot, and around a fifth are made by car. Walking rates drop to less than one-third for journeys between 1 and 2 miles, while the car dominates. Therefore, if residential developments were to offer a wider range of facilities closer to people's homes, then more of those trips would become walkable.

Second, some patterns of production and consumption are more carbon intensive than others. The globalization of world economic relationships has resulted in increases in freight demand for both raw materials and consumer goods, with production increasingly concentrated in Asia, while North America and Europe represent key consumer markets.

However, such effects can also be observed at the local and regional scale. Analysis for the United Kingdom showed the importance of medium-range commuting by car (Figure 22). Nevertheless, aside from their carbon intensity, those forms often remain problematic in terms of accessibility performance. Having been developed originally as efficient forms for societies that

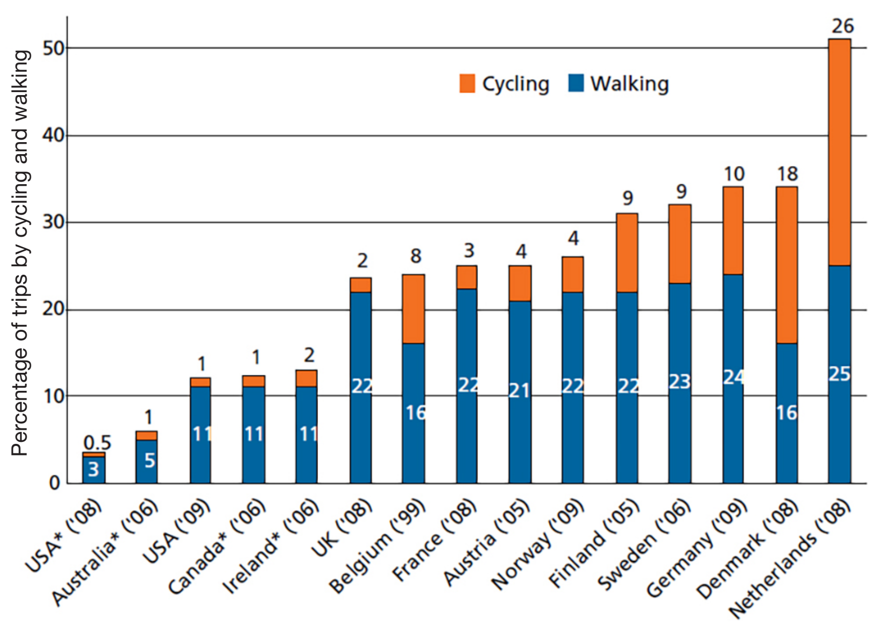


FIGURE 20 Cycling and walking share of daily trips in Europe, North America, and Australia, 1999–2009 (Buehler and Pucher 2012, Figure 1). (Note: The latest available travel surveys were used for each country; the year of the survey is noted in parentheses after each country's name. The modal shares reflect travel for all trip purposes except for those countries marked with an asterisk, which only report journeys to work derived from their censuses. Dissimilarities in data collection methods, timing, and variable definitions limit the comparability of the modal shares shown.)

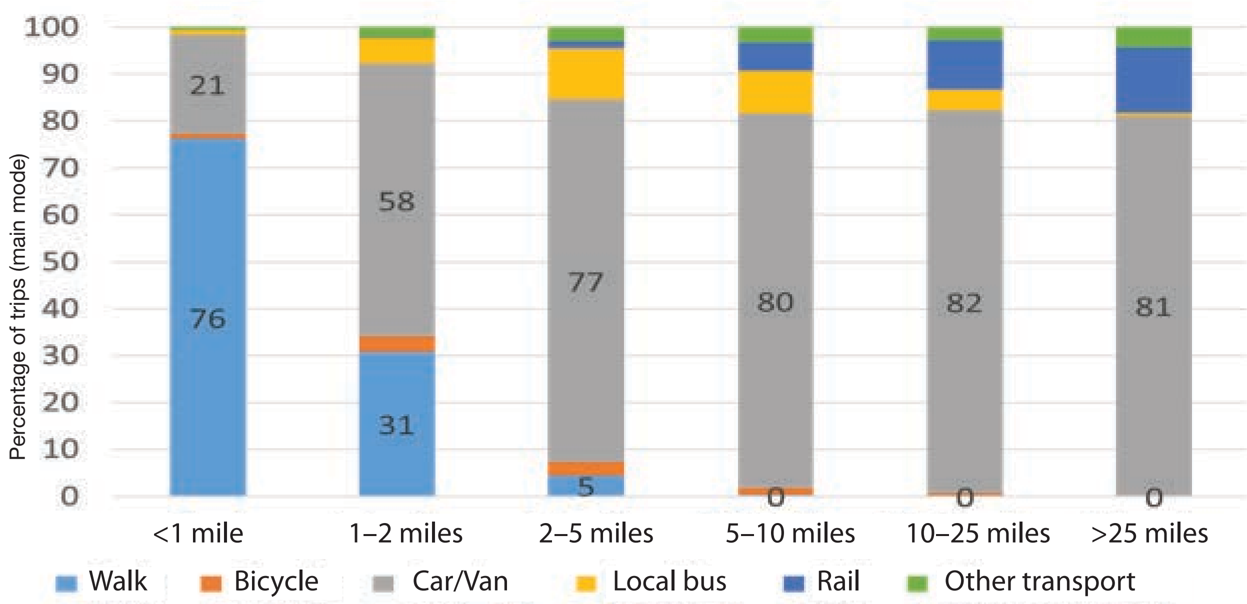


FIGURE 21 Critical importance of walking distance (DfT 2014, Table NTS0308, for England in 2014).

were intentionally becoming car dependent, they have at many times and places become overwhelmed with the traffic they have generated, which is often beyond that predicted by deterministic forecasts and which did not allow for the flexible response of human behavior.

Car-dependent urban forms and societies have created winner and loser groups. Holding of a car license is in fact far from ubiquitous among the eligible population, and many citizens cannot drive a motor vehicle on grounds of age, ability, or health. Access to a car is also scarcer than patterns of license-holding suggest, as some households do not own cars and there may be competition for access to vehicles in those that do. Gender and ethnic differences are observed in the ownership and access statistics, with women and ethnic minorities underrepresented. In some cases, this underrepresentation leads to disadvantageous access to employment and social opportunities. Moreover, studies of gender and

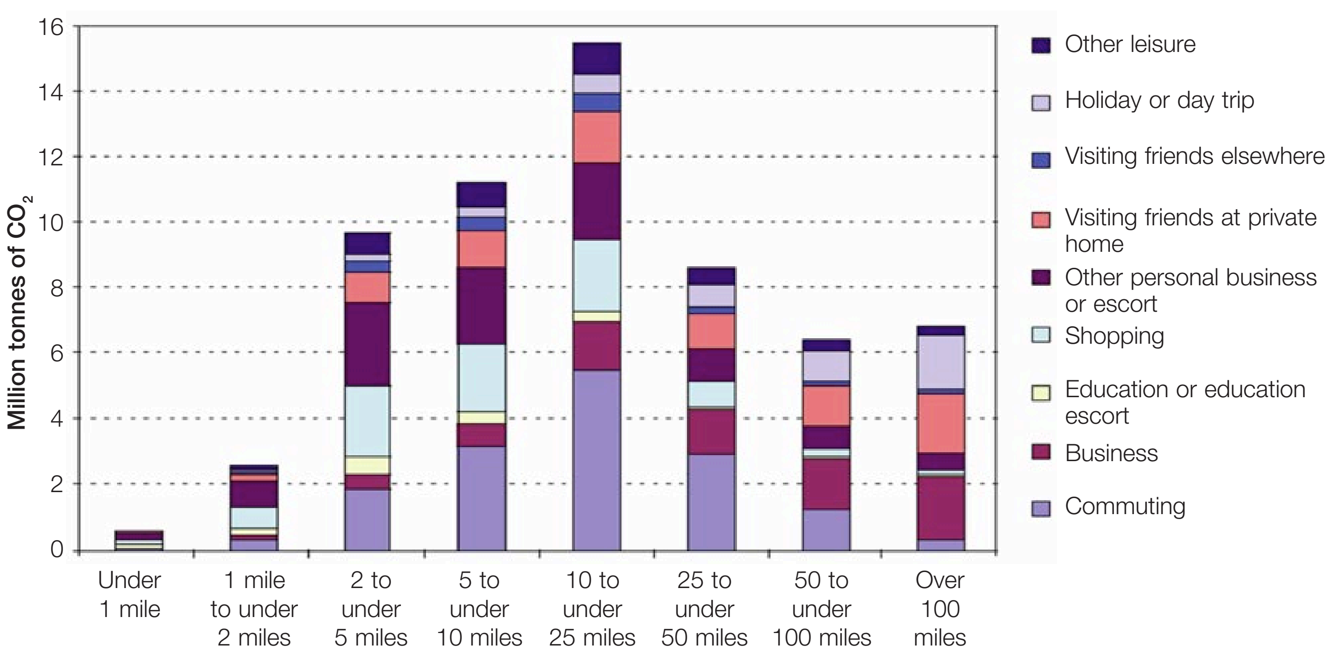


FIGURE 22 Delivering sustainable low-carbon travel (DfT 2009, Figure 2.1).

access to motor vehicles indicate that access to motor vehicles in households can be influenced more by perceived status than objective need, with women more often having complex journeys with multiple purposes linked together (Bianco and Lawson 1996).

Opportunities to address structural car dependence are considered in Section 5.

Transportation Choices Often Favor High-Carbon Options

While many transportation decisions are constrained, consumers and producers alike do often have choices. These choices can be critical for carbon dependence, as shown in Figures 23 and 24, which consider intensity in terms of emissions per unit distance traveled, as this is relevant for comparing substitute transportation modes.

When typical vehicle occupancy and energy sources are allowed for, travel in large cars and taxis emerges as particularly carbon intensive per unit distance, whereas long-haul aviation lies in the range exhibited by high-speed rail services (Figure 23). What this comparison does not consider is the typical speed of travel by the mode, which is important, as personal travel time budgets are relatively stable across cultures (Marchetti 1994). That is to say, it is not distance that is the primary influence on total desired mobility, but costs and travel time. As the United States and the European Union have increasingly invested in high-capacity, high-speed transportation systems, affordability and acceptability for long-distance travel have increased, leading to the phenomenon referred to as "hypermobility." The result is that, while emissions per kilometer from a typically full passenger car are similar to those from a typically full airplane, the distance covered means a single transatlantic return trip can in some cases contribute more to a personal carbon budget than an entire year's automobile use.

A similar account exists for the comparison of freight modal intensity. Aviation is particularly carbon intensive, and even domestic shipments tend to be relatively long haul compared with surface modes. Modern containerized sea freight is highly carbon efficient per ton-kilometer, but the quantities of tons and kilometers involved are enormous and rising in the context of economic globalization (Figure 24).

While time is more important than distance for many transportation and mobility decisions, cost is the other key logistical element in the decision. It is clear that private car travel continues to be a financially attractive solution, even for those who can make choices. The EU-28 price index shows a decade-long trend in the falling cost of investing in a private car, which is the only indexed transportation price seen to have fallen in Figure 25. Personal transportation operating costs have fluctuated, while public transportation costs show trend increases.

So rather than signaling the high external costs of car use, as recommended by many environmental and transportation economists, prices have reinforced the structural elements of decision.

Finally, it should be noted that choices reflect not only logistical factors but also social and psychological factors. For many, car travel and long-distance, high-speed travel in general are signals of personal economic progress, social esteem, and even personality. To regard these factors as the irrational side of rational decision-making factors is mistaken. While social presentation is sometimes conscious and other times unconscious, for both individuals and organizations it is a highly important matter and entirely rational and represents good value for money in that context. While low-carbon transportation choices are becoming more important for organizations concerned with the triple bottom line and with particular consumer segments that are environmentally aware, many transportation choices continue to reflect

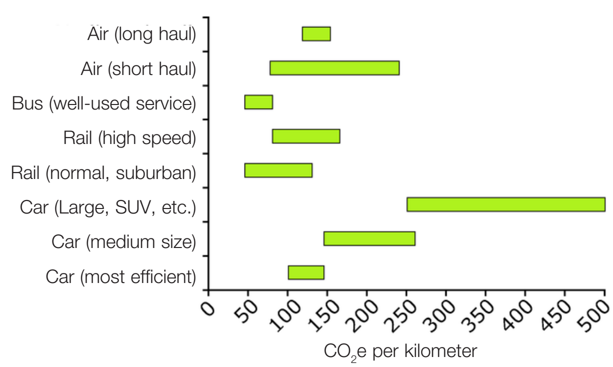
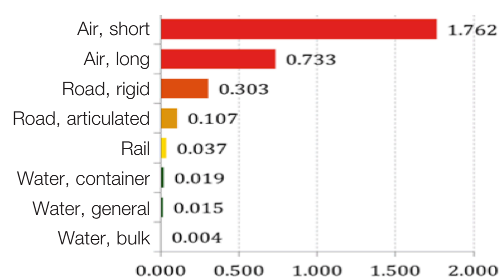


FIGURE 23 Relative GHG intensity of passenger transport modes (CO_2e/pass-kilometers) (EEA 2008, Figure 13.1).



Note: All figures are kilograms carbon dioxide equivalents per tonne kilometer (kgCO_2e/t.km). Figures based on a WTW analysis of fuel used and average loading per vehicle. For air freight, long is greater than 3,700 km while short is less than that; no radiative forcing index multiplier is used. Road vehicles are based on UK diesel truck averages. Rail is based on UK diesel and electric trains. All water vessels are ships, not ferries.

FIGURE 24 Freight transport intensity (CO_2e/tonne-kilometers). (Source: UK Department for the Environment, Food and Rural Affairs, emissions data.)

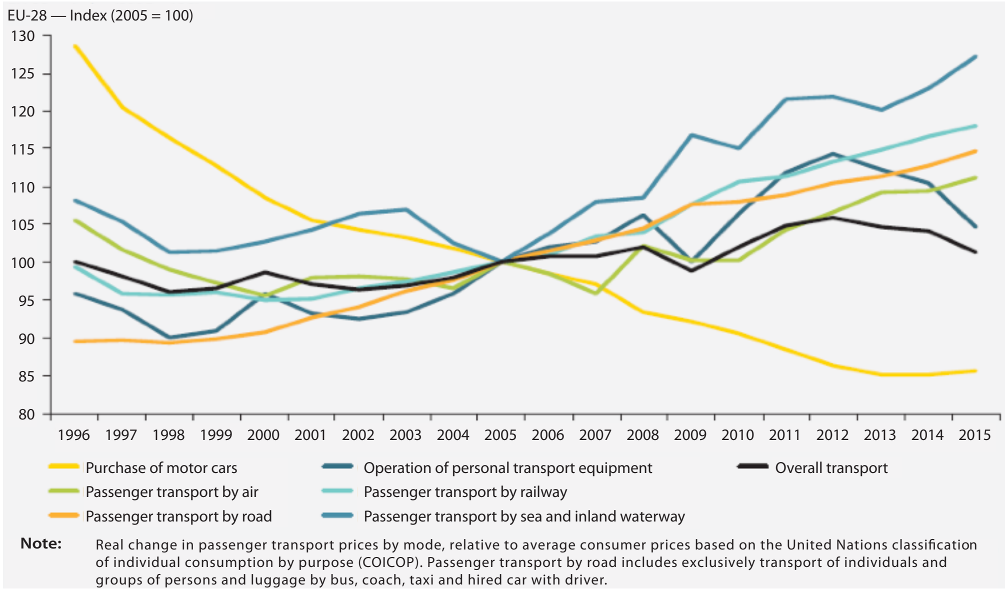


FIGURE 25 Real change in transport prices by mode in the EU-28 (EEA 2016c, Figure 2.9).

individual aspirations and the importance of projecting an image of wealth consumption in a social arena.

The Difficulty of Effecting Behavior Change and Rebound Effects

Travel behavior shows strong response to circumstances in which supply is interrupted by strikes, fuel shortages, and natural phenomena such as volcanic eruptions, earthquakes, and weather events. Individual and collective adaptation in these circumstances can be dramatic. However, those changes are typically involuntary and tend to be reversed once conditions allow. Initiatives for voluntary behavior change are complex to deliver and often intensive in their human resource demands. The outputs and outcomes are generally less tangible than those from infrastructure provision and may be hard to confirm through evaluation.

Although behavior can be hard to influence through policy, change does occur, and there is already significant variation between individuals in the same society that is not explained solely by differences in constraints or purchasing power. The resurgence in cycling in many developed countries in large part reflects the decisions of individuals who have the economic means to use private motor vehicles, and often do own cars, but choose to cycle for reasons such as health and well-being benefits.

However, past expectations about the benefits of behavior change have sometimes emerged as optimistic because of rebound effects. These typically occur when a change toward a more efficient technology is analyzed without taking sufficient account of the reductions in consumer cost that stimulate greater use of the good. For example, in the United States, fuel economy improvements driven largely by regulatory standards have reduced fuel consumption by more than a trillion gallons since 1975. However, improved fuel economy has also increased vehicle use somewhat, the rebound effect being the difference between the dark blue line (actual traffic) and the dotted line in Figure 26, which represents the estimated vehicle travel that would have evolved in the absence of the fuel economy improvement.

Summary: A Holistic Response Is Required to Maximize Change

As was demonstrated in Section 3, reducing transport GHG emissions by 80% to 90% by 2050 will require addressing the transportation system holistically, that is, considering all modes of transportation and all practical means of GHG reduction. Assessments of the potential to reduce global GHG emissions by 80% or more by 2050 conclude that "deep cuts in emissions will require a diverse portfolio of policies, institutions and technologies as well as changes in human behavior and consumption patterns" (IPCC 2014a, p. 114). The Global Energy Assessment, probably the most comprehensive analysis of alternative global energy futures, concluded

> Without question a radical transformation of the present energy system will be required over the coming decades. Common to all pathways will be very strong efforts in energy efficiency improvement for buildings, industry and transportation, offering much needed flexibility to the energy supply system. (IIASA 2012)

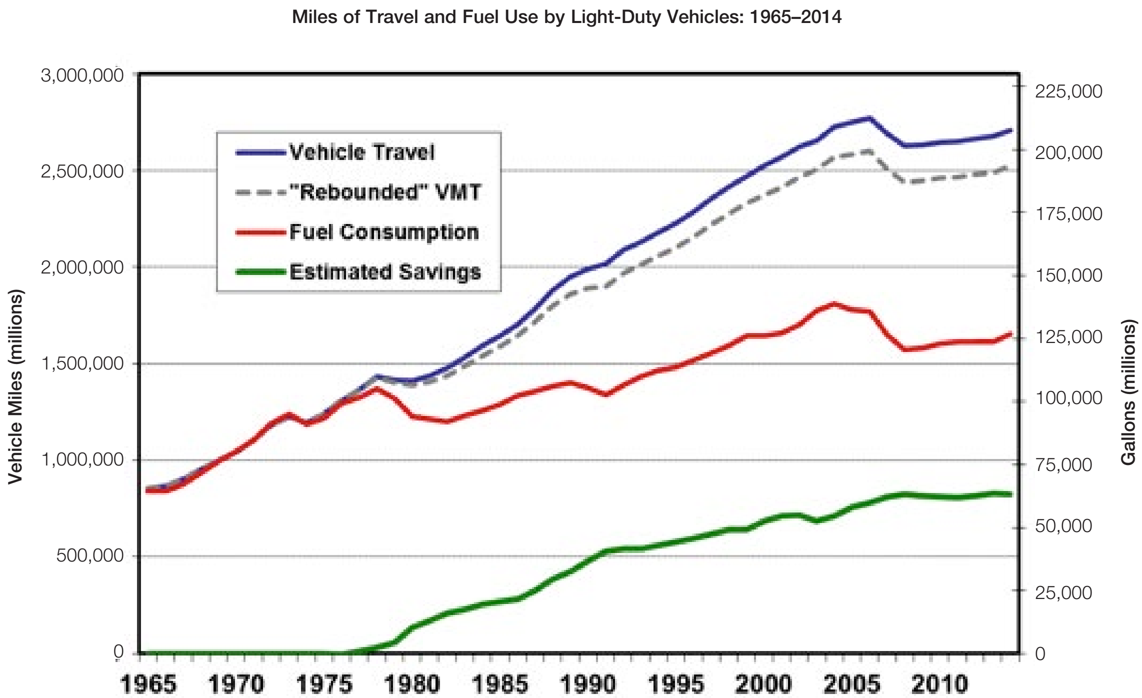


FIGURE 26 **Fuel economy improvement: disconnected U.S. vehicle travel and fuel use.**

However, energy efficiency alone is not nearly sufficient. Greatly increased use of renewable energy also appears to be an essential component of a low-GHG future. However, whereas in some economic sectors technological substitution can play a dominating effect, the goal of reducing GHG emissions by 80% to 90% requires comprehensive system change. Options to reduce emissions through behavioral change, land use and development patterns, modal structure, pricing, and system efficiency must all be taken into consideration. These various potentials are considered in the next section.

5 Mitigation Measures for Deeper, Swifter Change

The IPCC (2014a, p. 603) concluded that four fundamental dimensions must be included to have a reasonable chance of successfully reducing emissions by 80% to 90% by 2050:

- Improving vehicle energy efficiency,
- Reducing the carbon (GHG) intensity of energy sources,
- Reducing the level of motorized transport activity, and
- Improving the efficiency of the transport system.

This section is structured around these dimensions.

Improving Vehicle Energy Efficiency

The U.S. energy efficiency regulations for light-duty vehicles noted in Section 2 are a critical and important step but by themselves are not nearly enough to meet the 80% to 90% reduction goal. A recent assessment of the potential to reduce GHG emissions from U.S. passenger cars and light trucks by 80% by 2050 concluded that a tripling of efficiency for internal combustion engine vehicles over 2010 levels was feasible and would probably be cost-effective, given future advances in technology (NRC 2013), but that even this would not be nearly enough to reach an 80% reduction. Further, reductions in U.S. transportation GHG emissions of 80% to 90% cannot be accomplished without addressing the approximately 40% of emissions that come from heavy-duty vehicles and nonroad modes. However, the improvements discussed in Section 2 are already included in the Annual Energy Outlook Projections, and are expected only to restrain the growth of GHG emissions from heavy-duty vehicles.

The case of the European Union is similar: with high growth forecast to 2050, much rests on a per-vehicle improvement in energy efficiency. Indeed Figure 27 indicates transportation intensity scarcely falling for both passenger and freight transportation in the context of an increase in GDP of more than 50%, whereas energy intensity for passenger transportation actually falls and that for freight increases only by around 10%.

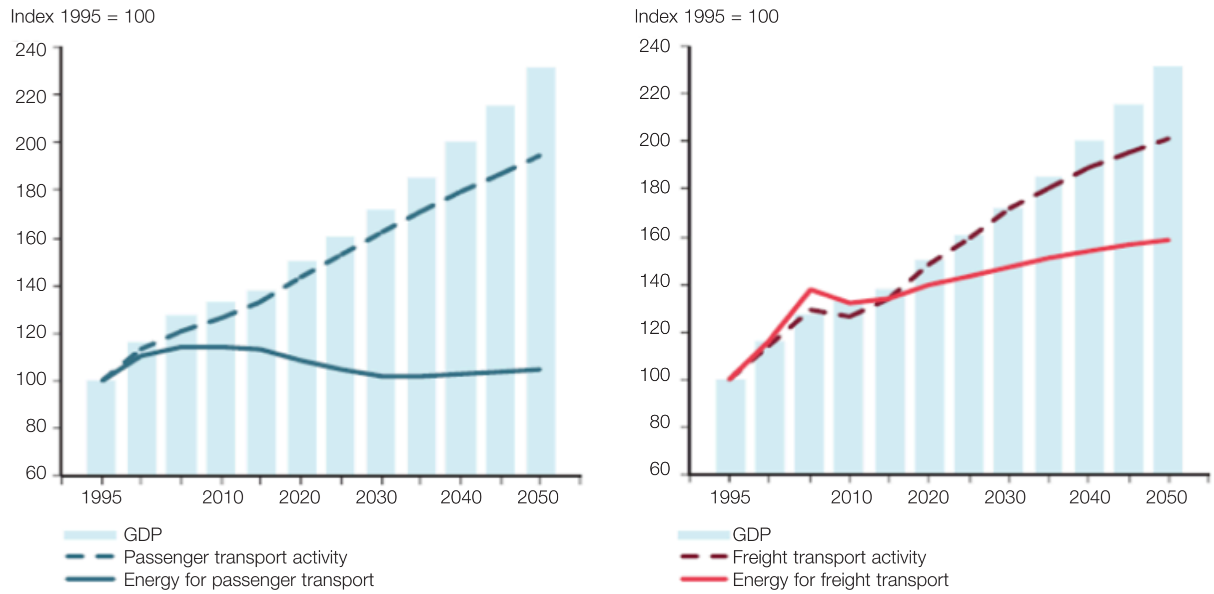


FIGURE 27 Projected EU transport energy intensity to 2050 (EEA 2016c, Figure 3.1).

Therefore, the strategies of both jurisdictions place great importance on the delivery of efficient technologies and a stabilized energy demand provided from low-carbon sources.

Reducing the GHG Intensity of Energy Sources

To date, policies to reduce the carbon intensity of fuels have had less impact than policies to increase energy efficiency, an indication of the barriers to large-scale energy transitions. However, energy efficiency improvements alone will not be able to reduce transportation's GHG emissions by 80% to 90% by 2050. Every analysis that has demonstrated the potential to meet the reduction goal has included a transition to electric drive, BEVs, H2FCEVs, and low-life-cycle GHG fuels, as well as measures to reduce demand and improve system efficiency (e.g., NRC 2013; Yang et al. 2015). Furthermore, transportation's energy transition would need to be complemented by reductions in GHG emissions from electricity generation and the production of hydrogen.

The transition to low-carbon fuels could be enhanced in the short term through the introduction and advancement of regulations such as the existent mandatory targets in California and the European Union for low-carbon fuels. Explicit targets for alternative fuel vehicles might be considered to assist in creating the market for the low-carbon fuels. In addition, governments could expand sponsorship of substantial research and development efforts to develop life-cycle (low) GHG biofuels.

Aviation is considered a particularly difficult mode to decarbonize because of the dependence of aircraft on fuels with high-energy densities. However, the U.S. Federal Aviation Administration (FAA) and the aviation industry have estimated that a 40% reduction in life-cycle aviation GHG emissions over 2005 could be accomplished by a combination of alternative fuels, airframe and engine efficiency improvements, and operational improvements (FAA 2015). A 40% reduction reflects the FAA's most aggressive GHG reduction scenario, which faces substantial technological challenges in all three areas but particularly the availability of large quantities of low-life-cycle carbon jet biofuel (Figure 28). Without demand reduction, even greater GHG reductions would require much larger quantities of low-carbon biofuels for aviation.

Noting that marine shipping is already the most energy-efficient form of cargo transportation, McCollum et al. (2009) concluded that emissions reductions of 60% from business-as-usual forecasts would be possible. The International Maritime Organization (IMO), on the other hand, projected maritime CO_2 emissions to increase by 50% to 250% by 2050 under business-as-usual and current policy scenarios, even when a 40% improvement in energy efficiency is assumed (IMO 2015). The IMO study estimated that maritime GHG emissions could be returned to the level of 2012 by 2050 with a combination of a 60% improvement in energy efficiency and substitution of liquefied natural gas for 25% of heavy fuel oil.

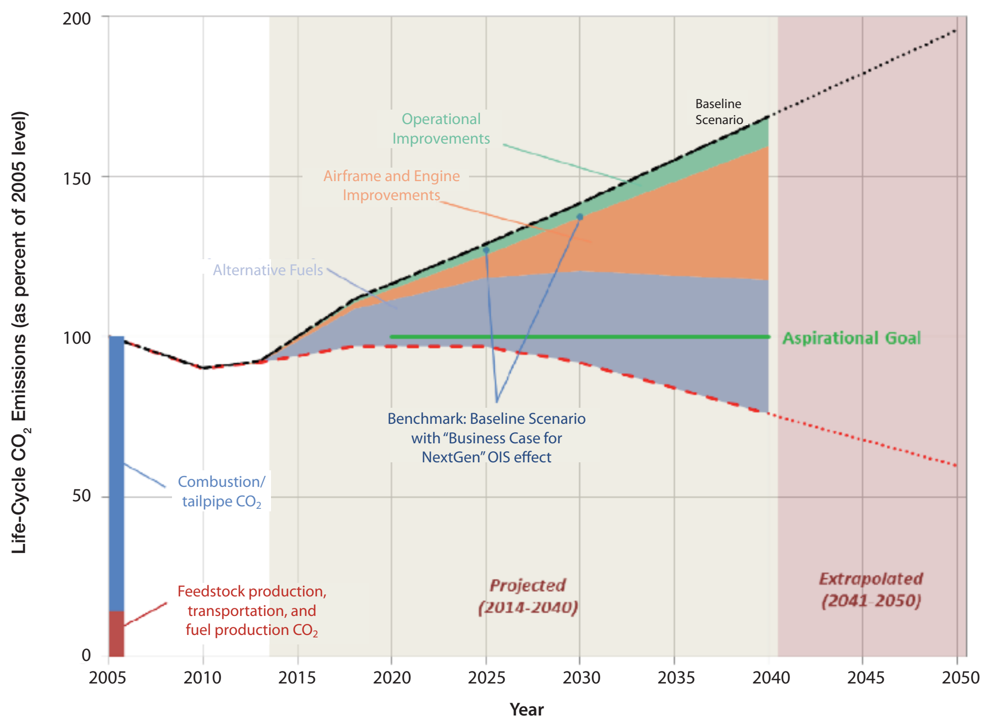


FIGURE 28 Projected impacts of life-cycle CO_2 emissions on aviation GHG emissions: aggressive system improvement scenario (OIS = ophthalmic imaging system) (FAA 2015).

Reducing the Level of Motorized Transport Activity

As introduced in Section 4, motorized vehicle travel can be reduced through pricing policies, regulations, investments in infrastructure, and changes in land use and the density of development, as well as through behavioral change. If the goal of an 80% to 90% reduction in GHG emissions by 2050 is to be achieved, restraining the growth of motorized transport will be necessary.

The U.S. DOT (2010) examined a comprehensive set of mitigation measures that included technology and policy options and covered all modes of transportation; it concluded that improvements in system efficiency could make only a modest contribution by 2030: about 3% to 6% reduction in GHG emissions. Reducing carbon-intensive travel by pricing policies, investments in infrastructure for nonmotorized transportation, land use densification, diversification, and improved neighborhood design were found to have a much greater potential impact by 2050, up to a 20% reduction. Similarly, the state of California's plan for GHG mitigation targets a 15% reduction in vehicle miles traveled in 2050 (CARB 2017, p. 105).

The European Commission–funded project EVIDENCE (2014 to 2017) reviewed the effects of 22 types of sustainable urban mobility interventions. Of these 22 interventions, four focused directly on behavior change: personalized travel planning, site-based travel planning, marketing and rewards, and travel information provision. Many of the others required behavior change toward the modes of public transportation, cycling or walking, or the sharing of assets in order to use them more efficiently (private cars, public bicycles, or urban freight consolidation). Some of the measures were associated with important changes in behavior (Black et al. 2016). For example, a review of UK implementation of organization-based travel planning that involved a range of interventions to make solo car use less attractive showed single-occupant car trips reduced by a range of 4% to 18%. Such initiatives also resulted in more efficient use of site space and roads and created indirect economic benefits in terms of health and productivity that arose from increased active travel. North American studies of introducing workplace parking and cashing out parking privileges showed reductions of single-occupant car trips of 20 to 27% (Feeney 1989; Shoup 1997). Mean vehicle kilometers driven per year by carsharing club members decreased by 27% after they joined (Martin and Shaheen 2011).

Modal Shift Away from Motorized Travel

As discussed in Section 3, the nature of the built environment represents a considerable constraint for walking. However, the range of trips realistically possible on a daily basis by bicycle is considerably greater. Cycling can also provide an access mode to public transportation nodes, thereby increasing the effective penetration of fixed-line systems. Although cycling is undergoing a renaissance in some urban areas of the United Kingdom, it continues to account for a very small share (2%) of trips. However, some other European Union member states have managed to recover and enhance their shares of cycling since the previous peak in the 1950s (Figure 29). As in the case of walking, cycling flourishes in mixed-used developments (medium or high density), road systems that accommodate different modes of travel with a fair balance of power, and cultures that have positive associations toward cycling. Flat terrain is a factor that is permissive to cycling, but modern lightweight, multigear bicycles with the option of electric assistance are reducing this factor. The relative importance of cycling in northern-European countries indicates cold weather is not a major influence on cycling rates. The recent doubling (or more) of cycling rates in cities such as Paris; London; Seville, Spain; and Bristol, England, indicates the considerable contribution that can be possible in diverse localities.

Restraining the Increase in Travel

Reducing demand for transportation not only can lower the cost of other strategies, but it can increase their potential for GHG reduction as well (Yang et al. 2015). Positive externalities may arise; as observed in Section 4, labor market flexibility is important for an efficient economy. Nonetheless, policies that make the option of living closer to work easier and more desirable could influence structural emissions without necessarily imposing economic costs. Indeed, given the personal strain of commuting experienced by many, quality of life and productivity might increase.

However, while demand restraint on motorized travel might be easier to deliver in urban areas, it needs to be emphasized that the contribution of urban transportation to GHGs is less than a quarter of the total in the European Union (Figure 30). Moreover, growth in urban road traffic is often constrained by congestion, so the substantial forecast growth will mostly occur outside urban areas, and the relative importance of extra-urban transportation to emissions will also grow.[5] This growth is predicted despite the promised technological developments in terms of telecommunication as a potential substitute for passenger travel and remote, three-dimensional printing for freight consignments.[6]

One reason for the importance of a holistic approach for GHG reduction is the long-established principle that behavior change is more likely to occur when encour-

[5] Further consideration of the future dynamics of megaregions in the United States and European Union is provided in Appendix D of this volume.

[6] Further consideration of long-distance freight logistics initiatives is provided in Appendix E of this volume.

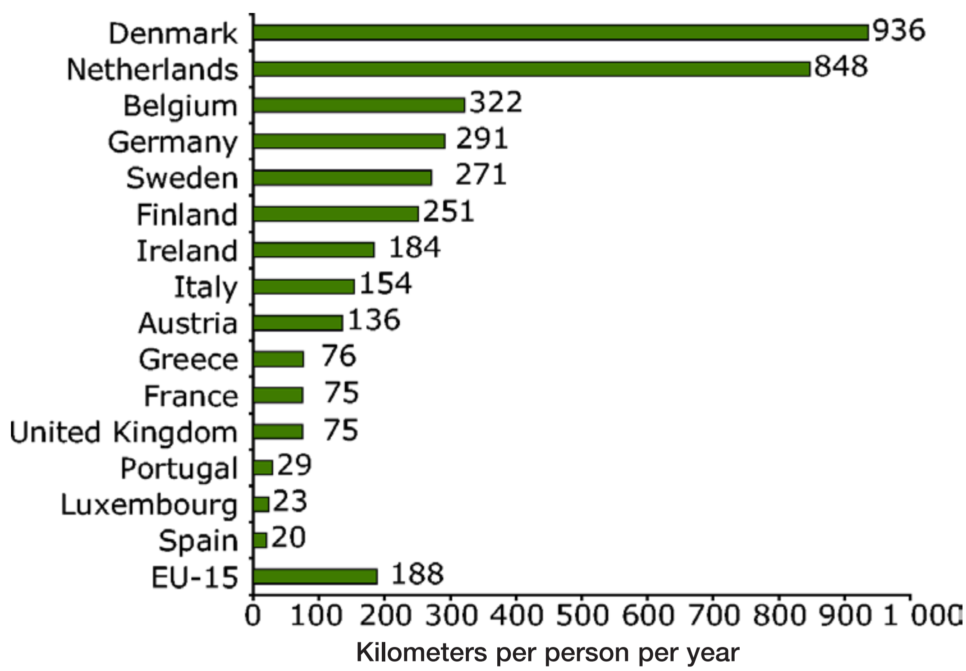


FIGURE 29 Cycling rates in 15 EU member states in 2000 (EEA 2008, Figure 11.2, based on data from Eurostat).

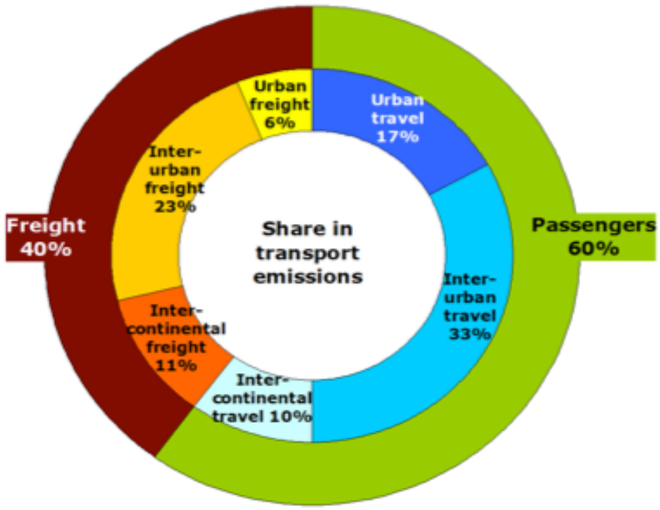


FIGURE 30 EU transport CO_2 emissions: all modes by range (EC 2011a, Figure 2).

aged through regulatory and fiscal measures. Parking management and pricing and restrictions on private vehicle access to city centers have generally been effective in influencing transportation choices and usually good for the local economy (Black et al. 2016). Moreover, a holistic approach emphasizes co-benefits, meaning that the objectives of sustainable mobility concern far more than the important matter of carbon mitigation, including congestion reduction, equity of access, the elimination of noxious pollution, and enhancing the quality of life. There are therefore important reasons to pursue behavior change initiatives in urban areas, and there can also be modest carbon mitigation benefits. However, more needs to be understood about the potential of behavior change initiatives to effect carbon mitigation, the potential of three-dimensional printing, and the relevance to interurban and intercontinental travel.

Improving System Efficiency

Policies for reducing the level of motorized transportation and improving system efficiency are more varied and implemented at a variety of scales. They include various pricing policies, from vehicle registration fees to parking fees or tolls. They also include land use planning and controls, investments in infrastructure for nonmotorized transportation, public transit and intermodal infrastructure, and restrictions on motorized vehicle use.

Price Levers

Greene and Plotkin (2011) concluded that the addition of policies such as carbon pricing, pay-at-the-pump insurance, feebates, and traffic flow improvement to technology-based energy efficiency and alternative fuels increased the potential to reduce transport GHG emissions by 6% to 21%. In contrast, IPCC (2014a, p. 604) concluded that over the period from 2030 to 2050, vehicle travel reduction measures such as urban redevelopment, transit-oriented development, and more compact urban forms that promote cycling and walking, together with supporting infrastructure investments, had the potential to reduce GHGs by 20% to 50% below a 2010 baseline by 2050.

Both the European Union and the state of California have carbon cap-and-trade systems in place that induce price increases for carbon-intensive fuels, although the EU Emissions Trading System does not yet apply to the transportation sector; the European Commission proposed its inclusion in July 2016. The approach might be introduced or further developed in both jurisdictions.

Efficiency, Vehicle Occupancy, and the Potential of Connected Autonomous Vehicle Systems

While policies to reduce trip length and increase opportunities for walking and cycling are highly desirable, the extent of past investment in car-dependent development is significant. Those localities that cannot readily be densified or made more heterogeneous in their activities also generally cannot readily be retrofitted with traditional public transportation solutions. However, new forms of collective mobility that are based on the sharing of small- to medium-sized passenger vehicles are showing considerable promise. These include informal and organized carpooling, ridesharing–liftsharing, and commercial taxi sharing. Such forms, however, should be distinguished from the high-profile smart taxi services,[7] about which there is uncertainty to date as to whether they offer carbon efficiency over the owner-driven automobile or in fact result in higher vehicle miles traveled and emissions (Rayle et al. 2016).

Indeed, much emphasis is currently placed on the potential for automation in the road transportation sector to improve environmental performance. Autonomous or driverless vehicles represent a range of technologies that are broadly divisible into levels of increasing automation on the one hand and, on the other, greater connectivity between vehicles and between vehicles and a road infrastructure system. When technical constraints alone are considered, the transition to completely driverless road vehicles is predicted to take decades (KPMG 2015). Limited-access highways are seen as the least complex environment because of the limited set of vehicle interactions and their exclusive use by powered vehicle traffic. They are followed by urban areas, where there is some segregation of flows on streets but road-user interactions, particularly in shared spaces, remain problematic. Rural roads, which have higher speeds than those in urban areas, often lack pavements and represent the toughest challenge. Indeed, such are the complexities of the latter categories that it is not certain that the entire existing public road network in all countries can be made suitable for driverless operation.

Government departments, technology developers, and industrial strategy advisors across the globe have identified numerous potential benefits from the introduction of connected autonomous vehicles (CAVs). These include Vision Zero levels of road safety by eliminating human driver error, greater social inclusion in the case that people without driving licenses or driving skills can gain access to cars, and reduced congestion and emissions if vehicle progress is smoother because the motion is being managed with respect to the road conditions and coordinated with other vehicle movements.

The business model under which such benefits would arise is not clear but tends toward one of business as usual, with most vehicles being provided on the owner–user basis. Under these circumstances, some potential for carbon savings might arise. Individual vehicle progress and overall network flow are likely to be smoother. Target speeds in free-flow conditions may fall in a regime of autonomous driving in order to give optimal fuel efficiency. The optimal amount of time may no longer be the minimum travel time but might become the time necessary to undertake a desired activity, such as sleep 7 hours, particularly in the case of a commercial driver requiring a statutory rest break, or matched to the length of a film a family wishes to watch together. The prospect of a greater variety of in-vehicle activities becoming possible may have implications for the demand for surface public transportation and even short-haul air travel. Some of these switches might have carbon benefits, while others may have carbon costs. Moreover, the prospect of connected vehicles increases the likelihood that the road network will become an increasingly managed system; traveling at different times and perhaps at different speeds might attract differential pricing to match demand efficiently to capacity to encourage optimization of carbon emissions.

However, increased demand for car travel as a consequence of CAVs is a risk for climate change mitigation. Removing the limits created by the current needs for driving skills, satisfactory health and physical ability, and being fit to be in charge of a vehicle (e.g., sufficient sleep, absence of intoxicants) would be expected to create travel demand from new travelers. Removing other deterrents such as the requirement to find a parking space or navigate and drive in unfamiliar locations would increase demand from existing users. In the highest-traffic scenarios, existing demand may be increased by travelers choosing to summon privately owned CAVs to and from the origin and destination to avoid parking charges at the location. An increase in CAVs above normal automotive use would likely be associated with a decrease in other types of travel, including walking.

An alternative sustainable mobility regime would envisage highly efficient shared taxis dynamically routed by using predictive algorithms to meet demand. Shared CAVs might complement a mixed-mobility lifestyle that would include public transportation, walking, and cycling. However, whether the new culture of sharing, as found in some examples of the new generation of urban mobility services, can become mainstream remains to be seen. The approach would represent a major change in mobility practices, which hitherto has been hard to achieve as an outcome of policy. More needs to be known about the following:

- Deliverability of technology,
- Travelers' willingness to share rides,
- Potential rebound effects, and
- Implications of higher car availability.

Uncertainty about the impacts of CAVs on vehicular travel is enormous. A study by the U.S. Department of Energy's National Laboratories concluded that widespread adoption of CAVs with extensive ridesharing could reduce personal vehicle travel by as much as 60% compared to a baseline forecast (Stephens et al. 2016). The study found that without any increase in ridesharing

[7] Taxis that are booked solely via a web app and use real-time spatial information to route the nearest available vehicle to the customer. Some business models vary the supply of services to real-time demand. The services also exist in a shared taxi modality, but that option is currently limited to specific locations.

ing, CAVs could increase vehicle travel by as much as 200%.

Summary: Fundamental Policy Strategies Required

Comprehensive assessments of pathways to achieving deep reductions in transportation GHG emissions invariably conclude that there are no simple solutions. A variety of strategies that address the transportation system and its social, economic, and geographical context as a whole must be used (e.g., Yang et al. 2011). Governments at all levels have a variety of policy options available to pursue these strategies, including pricing, regulation, research development and demonstration, and information dissemination. Determining which combinations of policies will be most effective for different mitigation strategies and different circumstances is an important and ongoing function for research.[8]

6 Research to Enable Reduction of GHG Emissions from Transportation by 80% to 95% by 2050

Because transportation is the source of roughly one-fourth of EU and U.S. GHG emissions, dramatic reductions in transportation's contributions are essential to meet global climate change goals. Reductions of 80% to 90% by 2050 are needed to hold the increase in global average temperatures to 2°C. This task presents unique challenges and opportunities for public policy at all levels of government. Improvement in energy efficiency is an important part of the strategy yet far from sufficient. A comprehensive strategy addressing all modes of transportation at all scales and including all of the major opportunities for emission reduction is required.

Clearly, research will play a critical role in informing and guiding strategy and decision making. Because of the scale, scope, and novelty of the GHG mitigation challenge, a great deal is missing from the knowledge base needed to support decision making. The following high-level questions illustrate the enormity of the challenge for research:

- What should transportation's GHG reduction goals be (by 2050)
  - For passenger and freight modes?
  - For public and private transport?
  - For different movement purposes?
  - At different geographical scales?
- How can progress toward the goals be reliably monitored and validated?
- How can the public and private sectors collaborate to achieve transportation's mitigation goals?
- How much can be achieved by each of the four main strategies and, therefore, how far should policy strategy rely on each of the following?
  - Improving energy efficiency,
  - Reducing the carbon intensity of energy,
  - Reducing motorized travel, and
  - Improving system efficiency.
- What policy actions and technological advances will be necessary to achieve a transition to low-carbon energy for transportation?
- How can the transition to CAVs be managed so as to reduce rather than increase GHG emissions?

The task of this symposium, identifying the critical research needs and formulating the questions that must be answered, is immensely challenging and enormously important.

[8] Further consideration of policy governance issues is provided in Appendix C of this volume.

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Abbreviations

CARB	California Air Resources Board
DfT	Department for Transport
EC	European Commission
EEA	European Environment Agency
EIA	Energy Information Administration
EOP	Executive Office of the President
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
IIASA	International Institute for Applied Systems Analysis
IMO	International Maritime Organization
IPCC	Intergovernmental Panel on Climate Change
NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council
SGCLMU	Subnational Global Climate Leadership Memorandum of Understanding
TRB	Transportation Research Board
U.S. DOT	U.S. Department of Transportation

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APPENDIX B: EXPLORATORY TOPIC 1

Breaking Silos and Human Cocreation on Multiple Levels

The Key to Transforming the Current Sociotechnical Transport System Regime?

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Daniel Kreeger, *Association of Climate Change Officers, Miami, Florida, USA*

Transportation systems are essential for creating communities of opportunity with broad-reaching impact on the structure of metropolitan and rural communities, job creation, commerce distribution, energy efficiency, housing stock, access to better schools and well-equipped doctors, economic opportunity for business, and more. These systems are used daily to transport people to work, school, and grocery stores and to transport goods and supplies to those places and more. Changes in transportation costs, accessibility, frequency, and mode options sometimes force us to alter our daily routine and sometimes force the governments and/or companies to alter their policies and practices. When an extreme event occurs, such as the eruption of the Eyjafjallajökull volcano in Iceland during April 2010 or the Snowmageddon blizzard in the United States during February 2010, transportation is diverted or shut down, which causes dramatic delays, increases costs, and increases risks for travelers, distributors, and the customers served. In those instances, mobility chaos has a cascading impact on other economic sectors and social life.

For several decades planners and policymakers have been informed and educated about a need for local, state, and national transportation networks to be planned, designed, retrofitted, and constructed so that they are economically, socially, and environmentally sustainable. Transportation needs to transition toward a low-carbon, safe, affordable, accessible, and resilient system. Since the 1970s, scientists have warned of a need for a shift toward net zero emissions to occur in a matter of just a few decades. However, despite a multitude of policy, planning, and technological solutions that would support this transition, the transportation system remains deeply unsustainable while greenhouse gas (GHG) emissions continued to increase. It is not as though mass failures in sustainability programs occurred over the past 30 years. Positive changes have been made by agencies and businesses, although a paradigm shift in communities and culture has not happened. Essentially, behavior patterns have not changed enough to support decision makers in making more-aggressive changes to address these needs.

For example, public transit agencies in the United States are planning and building bus lines that use rapid transit–like elements [e.g., bus rapid transit (BRT) lite]. BRT service increases transit efficiency, reduces travel time, and attracts choice riders away from their single-occupancy vehicles. Agencies commonly plan and build BRT lite systems to replace existing service to reduce congestion. Typically, the behavior of travelers in these communities does not alter. The BRT lite service does not attract enough choice riders to reduce congestion.

- Why are solutions not penetrating further than transportation system planning and design to influence the users of the system?
- Is it possible to redesign and implement transportation systems and services so that people would change modes or purchase more energy-efficient vehicles?
- What are the obstacles to achieving zero GHG emissions in transportation?
- How can the obstacles be overcome without adversely affecting cultures and societies?
- Once action is taken, will it be quick enough to prevent the most severe impacts of climate change?
- How can the proposed revolutionary changes take place without creating severe societal effects?

During the United Nations (UN) 21st Conference of the Parties (UN 2015b), the parties of the Kyoto Protocol made progress that led to the Paris Agreement and the 17 Global Sustainable Goals (UN 2015a) focused around the three principal concepts of transformation, integration and universality. Societal systems need to transform thoroughly. All of the goals need to be addressed simultaneously; they cannot be solved one by one by isolated actors, but need an inclusive effort involving all levels of government, the private sector, and residents.

- Who is the coordinator or what is the governance model?
- What authority is accorded to the entity or individual?
- What are the required skills, qualifications, and proficiencies of such a coordinator?
- To whom do they report?

Enabling changes in transportation requires a capacity for sustainability-driven innovation, cocreation, and change management. The objective of this paper is to provide some brief context around the key questions that will be used to develop answers (and more questions) from participants in the Fifth EU-U.S. Transportation Research Symposium, Decarbonizing Transport for a Sustainable Future: Mitigating Impacts of the Changing Climate. The symposium discussions will orbit around political dilemmas, difficulties concerning emerging business models, knowledge gaps, and the need for transition or change management.

> In the UN 2030 Agenda for Sustainable Development (UN 2015a) three key words can be identified: transformation, integration, and universality—transformation in the sense that business-as-usual is no longer an option for achieving sustainability in time because of lock-in effects and path dependencies; integration because the complexity of the issues means that work cannot be done in silos, one question at a time; and universality in that the whole world must be considered in the aim for solutions.

What Factors Prohibit Transition? Understanding Sociotechnical Systems

Societal functions such as transportation, communication, and housing are fulfilled by sociotechnical systems, which consist of a cluster of aligned elements (e.g., artifacts, knowledge, markets, regulation, cultural meaning, infrastructure, and maintenance and supply networks) (Geels 2005) (Figure 1).

A transition is a shift from one sociotechnical system to another, meaning it is a system innovation. System innovations are coevolution processes, which involve technological changes. They also demand changes in manifold social groups that reinforce and reproduce the current system. The ideal outcome is for social groups to accept the current system integration with or in place of the innovation (Figure 2).

Innovation: A Question of Leadership and Human Capital

When addressing these sorts of institutional changes and practices, one needs to consider the decision-making drivers and capacities of transportation employees and users.

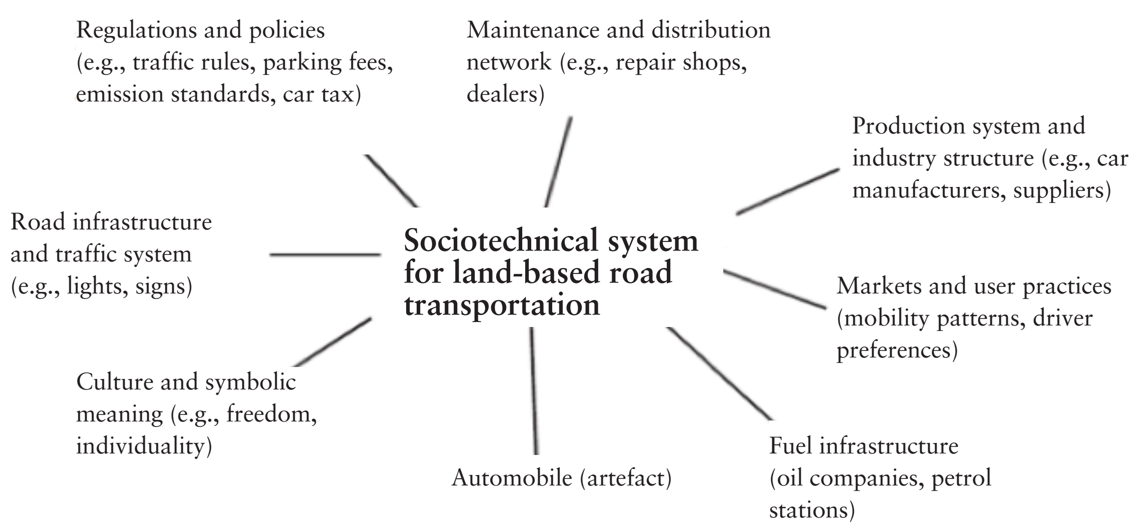

FIGURE 1 Sociotechnical system for modern car-based transportation (Geels 2005; reprinted by permission of the author).

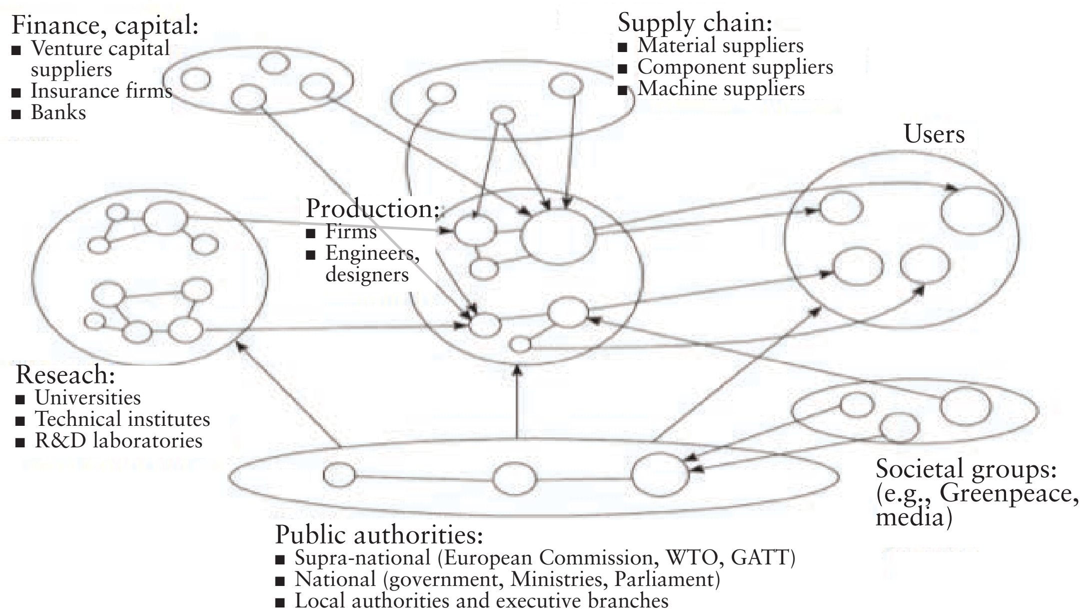

FIGURE 2 Social groups that (re)produce sociotechnical systems (Geels 2005, p. 1230; reprinted by permission of the author).

In this paper, transportation employees are those who could influence behavior change for low-carbon emissions in transportation. Employees encompass a wide spectrum of job fields such as engineering, land architecture, planning, policy making, program management, finance and pricing analysis, marketing, and more. Overcoming the mind-set that leans toward traditional practices requires a combination of organizational change, education, training, and motivation. If technical experts do not possess competencies and knowledge to perform their functions differently than before, the capacity to drive forward-thinking and innovative designs and plans will be limited. Simply put, without the right people with the right skills in the right parts of institutions, how can meaningful and sustained change take place? Key questions for catalyzing and building a sustainable transportation workforce include the following:

- What skills and knowledge do practitioners in planning, engineering, and design need in the context of driving mitigation and resilient and low-carbon transport systems? How do those skills and knowledge differ from the currently accepted competencies for those professions?
- How can policies, performance measures, professional development, and hiring practices become tools for employing these skills in the essential fields?
- What role do academic institutions and professional societies play in supporting this transition?
- What new (or revised) tools and resources are needed to support professional development or certification efforts?
- Are job descriptions written and the expectations for the position set to require these skills and proficiencies? Should they be?
- How are performance and proficiency measured for these skills?
- What is the role of research and evidence in current policy-making processes?

The challenge with respect to leadership is not wholly dissimilar. In the context of elected and appointed officials, it is highly unlikely that these individuals have enough understanding or perspective to make independent, well-informed, and proper decisions given the lack of daily exposure and education fundamental to the needed transformation. In the case of elected, appointed, and hired leaders in agencies and businesses, similar challenges exist:

- Where do decision makers get their information regarding the consideration at hand?
- How do senior management and advisors effectively engage leaders on these considerations?
- What leadership development and engagement activities will help transform decision making at this level?
- What influences and motivations are driving decision making at the highest levels of institutions (e.g., elected officials in government agencies, C-suite executives in the private sector)?
- How can the public sector attract and maintain skilled individuals?
- How can public administration become more resilient to political change?

Bold Political Action: The Dilemma of Our Time—Reelected Versus Doing the Right Thing

The ability to carry out public policies to mitigate transportation's GHG emissions requires an understanding of how to formulate effective policies as well as an understanding of how much can be accomplished, what the costs and benefits will be, and how policies will interact. An integrated policy approach that creates consensus and coalitions among diverse stakeholders and interests can help to overcome implementation barriers, minimize rebound effects, and motivate people, business, and communities to achieve a common objective. Still, public policy agenda setting and policy continuity are based on political consensus. In Europe and the United States, political consensus is usually built upon a broad and controlling public acceptance and is usually reinforced by strong incentives for the public.

Government and transportation leaders can introduce strong incentives to decrease GHG emissions. Such incentives could or already do include having transit subsidies via employee benefits, investing in safer bike lanes and bike storage, implementing parking management, increasing bus and express bus service, adding passenger commuter rail services, having congestion and road pricing, and increasing and adding new fuel taxes to fund decarbonization or GHG reduction programs. However, the solutions may increase taxes, be more time consuming, and be less convenient for people's busy and private lives; therefore, these measures are seldom popular.

How do these weakly marketed incentives implicate businesses and people?

How and when could policy makers use strong incentives or disincentives and still be appointed?

When should policy makers use transportation rightsizing initiatives to create mode shift?

> "Removing all parking spaces in the center of Ljubljana was my most difficult political decision of all time," the mayor of Ljubljana stated at the Civitas Conference 2015. It was a very unpopular decision, but he was reelected and opinion turned in his favor.

Land use structures, regardless of whether they are natural, man-made, or spatially planned, influence options for commuting and can create car dependency. Studies on congestion charges in Stockholm and Gothenburg show that even if a change in the mode of transportation would not impact the cost per trip, it could affect commuters' time budget. Then other aspects of life, such as the time available for parenting, extended family and friends, and leisure might be reduced (Berg and Karresand 2015). Growing regions may also have implications for social equality, as trip distances become longer and access to needed services changes. Studies show commuting patterns enable men's career options but can impede women's options (Gil Solá 2016). A transit system must work for all communities, including those facing long commutes, dangerous streets, and crumbling physical infrastructure.

For public administration, a complex question is, what incentives could be suggested for political decisions and in what timing? To speed up policy making answers are needed to other questions, such as

- How can transportation research be conducted to understand what public policy is and why it is accepted, and in what kind of situations?
- What actions could prepare the decision-making process prior to disruptive activities in the transport sector?
- Is it possible to create an exigency in logic in which decisions are able to be made?
- What is the effective role for public awareness and education in this political context?

New Business Opportunities: Moving Out from the Niches

Transportation research and development is flooded with good solutions, but there are difficulties penetrating the multilayered and rigid transportation system. The products of research get stuck in the "Valley of Death" (Kemp et al. 1998). The transportation system is very strong and structured on a macrosociotechnical landscape. Material and spatial arrangements of cities foster global, regional, and local movement patterns. Macrosociotechnical landscapes cannot be changed at will in the short term (Geels 2005) and are beyond the direct influence of new research products. Transportation research may develop a new brilliant solution that does not fit in the existing multimodal regime; therefore, an institutional barrier prevents implementation if the macrosociotechnical landscape is unaware of the change factors (Figure 3).

The era of digitalization paired with the newer trends of shared economies and just-in-time service certainly introduce new opportunities for business and a redefining of public transportation, such as Mobility as a Service (MaaS). These opportunities are usually driven by the private sector with support or cooperation from the government. The following quote highlights the potential of public–private partnerships:

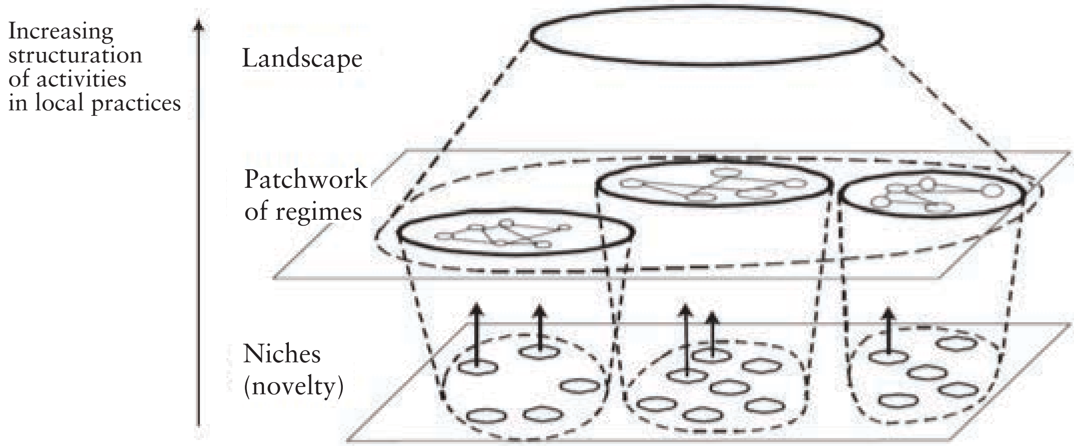

FIGURE 3 Multiple levels as a nested hierarchy (Geels 2005, p. 1231; reprinted by permission of the author).

> Public Private Partnerships (PPPs) are a promising avenue that may offer both practical and conceptual solutions to ensure productive interaction of public and private finance organizations. PPPs aim for public service delivery and, while they seek to benefit from mutually beneficial partnerships, they remain founded on public oversight. They therefore provide frameworks to ensure public leadership and accountability in tackling climate change, while enabling the ownership of certain components of climate finance to be transferred to private hands. (Gardiner et al. 2015)

Living labs on MAAS show that even with deep customer satisfaction, existing institutional frameworks prohibit or exclude new business opportunities (Karlsson et al. 2016, Strömberg 2015). For example, new rideshare businesses such as Uber are suspended from some national markets.

Innovations and opportunities are emerging, but the market is still unformed. The City of Rotterdam, Netherlands, procured a public mobility management center that operates through a business-to-business model and delivers an impact comparable to congestion charges. The City of Milan, Italy, has recently procured a full carpooling system to decrease private car ownership and increase accessibility in the city center. These are examples of how the public sector has created a market opportunity.

To speed up market opportunities, answers to the following questions are needed:

- What mechanism could better support small-scale solutions to penetrate the current sociotechnical regime?
- How can public procurement connect with research and business to create markets for new business to emerge?
- What is needed to enable PPPs to contribute to a large reduction of GHG emissions?

Ingredients of a Successful Transition Toward Sustainability

In stable sociotechnical systems, innovation occurs incrementally and leads to "technical trajectories" and path dependencies (Geels 2005). Thinking outside the box is the norm for driving change. However, the complexity of multimodal transportation requires thinking about completely different boxes, boxes that fit into another sociotechnical regime (Holmberg and Larsson 2017) (Figure 4). This is very difficult within existing transportation sociotechnical paths, which can be exemplified by the ElectriCity collaboration in Gothenburg, Sweden, and urban temporary design in New York City.

The ElectriCity collaboration in Gothenburg, in which the city is changing from a fossil fuel bus system to an electric system, provides an example of the challenges associated with making changes in the transport sector. Public uncertainties with the new buses were diverse, including the fear of the new silent buses appearing dangerously from behind. Engineers and bus operators worried about liability and circulation times. Architects worried about unattractive charging stations. Bus drivers were uncomfortable with new vehicles and the different technology. With change come uncertainties that can also be unknown possibilities. Against such clamor, it was difficult for leaders to make decisions concern-

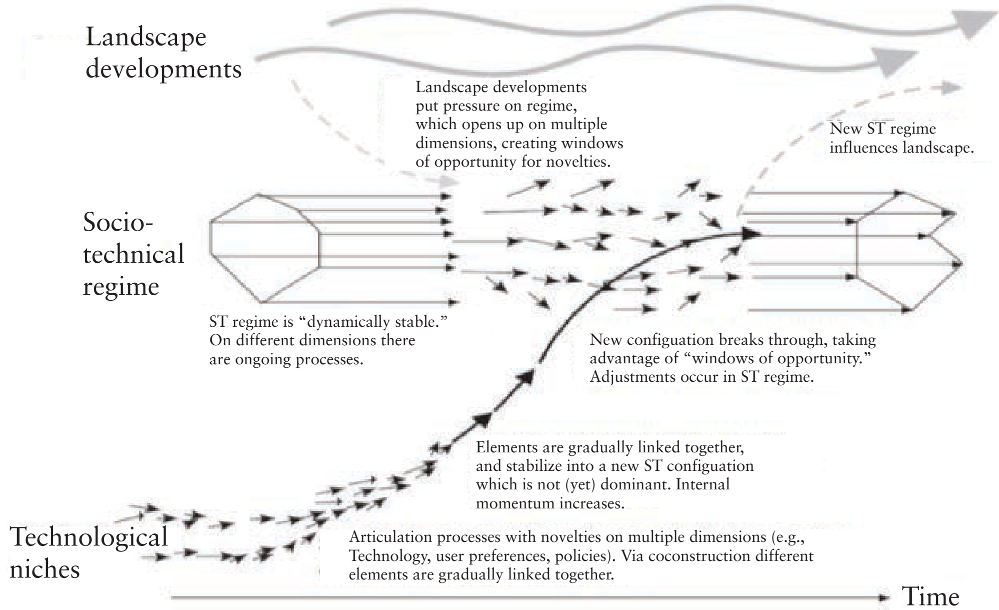

FIGURE 4 Dynamic multilevel perspective on system innovations (ST = sociotechnical) (Geels 2005, p. 1263; reprinted by permission of the author).

ing procurement or investments. For 2 years, the ElectriCity Living Lab (http://www.goteborgelectricity.se/en) has been testing a new service with real customers and stakeholder engagement on a smaller but still commercial scale. Results show greater increases in trust and willingness toward a system shift on the part of both passengers and stakeholders.

Gehl Architects became world famous for its model of turning roadways into livable urban space through simple and short-term investments. In 2008, Gehl Architects assisted New York City in bringing a people-centered approach to urban design to its streets. By New Year's Eve, Times Square and Broadway were turned into pedestrian plazas with new bike lanes. The results from these changes were mixed. Cross-town traffic became slightly more congested, but pedestrian safety improved by 39%, and the number of car collisions decreased. Overwhelmingly, New Yorkers were pleased with the changes. It appears that similar approaches may be considered in other areas of the city.

To nurture courageous change agents, mechanisms for transition management need to be better understood to enable cocreation and challenge-driven innovation.

- How can people and decision makers be prepared for change rather than frightened and threatened by change?
- How could transition arenas, living labs, and visible small-scale tests be stimulated and scaled up?
- How can communities cocreate with citizens (and vice versa) to change the social patterns that reinforce current regimes and create future innovations?
- What is the role of public leaders, chief sustainability officers, and chief resilience officers in managing the transition?

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Abbreviation

UN United Nations

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Additional Resources

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APPENDIX C: EXPLORATORY TOPIC 2

Influence of Policy Environment Factors on Climate Change Mitigation Strategies in the Transport Sector

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The transportation sector accounts for about 14% of global carbon dioxide (CO_2) emissions, as it lacks diversity and stands out by its almost complete dependence (95%) on oil. This historical dependence on a single energy source is one reason that transportation is likely the hardest sector to decarbonize (IEA 2011). However, cities, regions, and countries around the world are beginning to implement policies and projects that provide substantial reductions in greenhouse gas (GHG) emissions in addition to other benefits.

Policy and governance at all levels of government play a critical role in supporting and promoting current and future efforts at GHG reduction. For purposes of this paper, governance is defined as the rules, norms, and actions that each governing body uses to produce, sustain, and regulate decisions. The objective of this paper is to provide some brief context around the key questions that will be used to develop answers (and more questions) from the participants in the Fifth EU-U.S. Transportation Research Symposium, Decarbonizing Transport for a Sustainable Future: Mitigating Impacts of the Changing Climate.

Coalitions for the Implementation of Low-Carbon Mobility Measures

Energy and climate change policies for the transportation sector generally require consensus on the need for policy intervention and a strategic, coherent, and stable operating environment. Policy interventions, such as fuel and vehicle taxation, are highly visible and politically sensitive. They require strong political commitment to appear on the policy agenda and to remain in place as they rely on investments that are only cost-effective over the medium to long term (IEA 2010; IPCC 2014).

Developing consensus can be difficult because transportation is complex and multifaceted, and policy interventions can have unintended consequences. Linking and packaging policies is vital to generate synergies and co-benefits between measures, including linking GHG reduction goals with other sustainable development goals, such as the following:

- Reducing traffic and parking congestion,
- Mitigating climate change,
- Increasing energy security and traffic safety,
- Promoting public fitness and health,
- Reducing local air pollution,
- Improving equity and access,
- Improving affordability of transportation services, and
- Increasing economic productivity.

These co-benefits are positive impacts of transportation policy that can align different players. In both the European Union and the United States, an integrated policy approach that creates consensus and coalitions among diverse stakeholders and interests can help to overcome barriers to implementation, minimize rebound effects, and motivate people, businesses, and communities. This type of integrated policy approach is especially critical because current GHG reduction measures alone can make important contributions but cannot achieve the levels of reduction needed to shift to a 1.5°C pathway (IPCC 2014).

Vehicle efficiency and low-carbon fuels have a key role to play in decarbonizing the transportation sector and may provide the biggest potential climate change mitigation (approach = improve, Table 1). However, these strategies alone do not fully reflect a broader sustainable transportation perspective. A multimodal and integrated policy approach can minimize rebound effects, overcome split incentives, and achieve a higher level of socioeconomic co-benefits (Givoni 2014). In particular, reducing the need for travel through compact city design and a shift to low-carbon modes (approach = avoid, shift) can mitigate GHG emissions and contribute to sustainable development (Table 1).

Decision making on transportation policy and infrastructure investments is as complex as the sector itself. Rarely will a single measure achieve comprehensive impacts on climate change and also generate economic, social, and environmental benefits. Many policy and planning decisions have synergistic effects, meaning that their impacts are larger if implemented together. It is therefore generally best to implement and evaluate integrated programs rather than individual strategies. For example, by itself, a public transit improvement may cause minimal reductions in individual motorized travel and associated benefits such as congestion reductions, consumer savings, and reduced pollution emissions. However, the same measure may prove very effective and beneficial if implemented with complementary incentives, such as efficient road and parking pricing that allows travelers to have an incentive to shift away from individual car travel (Lah 2015). In fact, the most effective programs tend to include a combination of qualitative improvements such as the following:

- Alternative modes of transportation like walking, cycling, ridesharing, and public transit services;
- Incentives to discourage carbon-intensive modes through means such as efficient road, parking, and fuel pricing;
- Marketing programs for mobility management and the reduction of commuting trips;
- Reallocation of road space to favor resource-efficient modes; and
- Integrated transportation planning and land use development.

Together, these improvements could create more compact, mixed, and better-connected communities in which there is less need to travel.

A vital benefit of the combination of measures is the ability of integrated packages to deliver synergies and minimize rebound effects. For example, the introduction of fuel efficiency standards for light-duty vehicles may improve the efficiency of the overall fleet but may also induce additional travel as fuel costs decrease for the individual users. This effect refers to the tendency for the total demand for energy to decrease less than was expected after the introduction of efficiency improvements because of the resultant decrease in the cost of energy services (Sorrell 2010, Gillingham et al. 2013, Lah 2015). Ignoring or underestimating this effect while planning policies may lead to inaccurate forecasts and unrealistic expectations of the outcomes, which, in turn, leads to significant errors in the calculations of policies' payback periods (WEC 2008, IPCC 2014). The expected rebound effect is around zero to 12% for household appliances such as refrigerators, washing machines, and lighting, while it is up to 20% in industrial processes and 12% to 32% for road transportation (IEA 2013). The higher the potential rebound effect and the wider the range of possible take-back, the greater the uncertainty of a policy's cost-effectiveness and its effect upon energy efficiency (Ruzzenenti and Basosi 2008).

TABLE 1 Greenhouse Gas Mitigation Potential and Co-Benefits Potential

Approach	Area of Focus	Potential Impact	Potential Synergies
Avoid	Activity (reduction and management: short distances, compact cities, and mixed use)	Potential to reduce energy consumption by 10% to 30% (TfL 2007, Marshall 2011)	Reduced travel times; improved air quality, public health, safety, and more equitable access
Shift	Structure (shift to more energy-efficient modes)	Potential for energy efficiency gains varies greatly; 10%–30% reductions (IEA 2012, Fulton et al. 2013)	Reduced urban congestion, more equitable access, improved freight reliability, reduced maintenance costs for roads
Improve	Intensity (vehicle fuel efficiency)	Efficiency improvement of 40%–60% by 2030 feasible at low or negative costs (IEA 2012; IIASA 2012)	Improved energy security, productivity, and affordability
	Fuel (switch to electricity, hydrogen, compressed natural gas, biofuels, and other fuels)	Changing the structure of energy consumption. Mitigation and efficiency potential uncertain.	Diversification of transportation fuels contributes to climate, air quality, and energy security objectives

Source: Adapted from IPCC 2014 and Figueroa et al. 2014.

Several studies emphasize that an integrated approach is vital to cost-effective reduction of transportation GHG emissions (IPCC 2014, Figueroa et al. 2014). While emissions reductions can be achieved through several means, such as modal shift, efficiency gains, and reduced transportation activity, it is apparent that the combination of measures is a key success factor in maximizing synergies and reducing rebound effects. For example, overall travel demand reduction and modal shifts would need to be substantially stronger if not accompanied by efficiency improvements within the vehicle fleet and vice versa (Figueroa et al. 2014, Fulton et al. 2013). A vital element for this strategy is a policy package, as summarized in Table 2.

Policy and Governance Considerations

Analysis of recent research suggests that there are three vital factors for success of sustainable transportation policies:

- Political continuity and societal consensus, which enable the uptake of policies and ensure stability;
- An integrated policy approach that combines various measures to provide a basis for political coalitions; and
- Political continuity and policy integration efforts that are affected by the institutional context and the policy operating environment.

Policy Continuity and Consensus

Policy agenda setting and policy continuity are affected by political consensus, which is a result of political and institutional relationships (Fankhauser et al. 2015, Marquardt 2017). These relationships, including the interactions between different levels of government (e.g., local, state, federal, supranational) and acknowledgement of scientific consensus on climate change policy vary greatly between key political and societal actors (Never and Betz 2014). Political environments vary by country and change over time, and these characteristics affect implementation of sustainable transportation solutions and other measures for mitigating climate change. They also result in significant differences between countries' progress in reducing GHG emissions from the transportation sector. Changing political environments means that policy environments are also influenced by a level of political volatility. Hence, a shared set of methods and values is generally considered vital for setting the policy agenda, usually delivered through knowledge communities. Support from diverse political and public stakeholders is vital for the long-term success of policy and infrastructure decisions. This support can often be tied to the level of trust between stakeholders and policy makers and to the role that facts play in the decision-making process (Simmons 2016, Freitag and Ackermann 2016). Public perception and the influence of epistemic communities also play an important role in political agenda setting and consensus on major policy issues such as climate change and energy efficiency (Hagen et al. 2016, Cook and Rinfret 2015).

Policy Integration and Coalition Building

The policy environment, or context in which decisions are made, is as important as the combination of policy decisions and infrastructure investments that make up a low-carbon transportation strategy (Justen et al. 2014). This policy environment includes socioeconomic and political aspects of the institutional structures of countries. These

TABLE 2 Elements of a Multimodal, Multilevel Sustainable Transport Package

Measure	Complementarity of Measure
National Measures	
Fuel tax Vehicle fuel efficiency regulation Vehicle tax based on fuel efficiency or CO_2 emissions or both	Vehicle standards and regulations ensure supply of efficient vehicles and taxation helps steer consumer behavior. Fuel taxes encourage more efficient use of vehicles, which helps minimize rebound effects that might occur if individuals and businesses drive more or if they drive less efficiently than if they were driving a vehicle with lower fuel efficiency standards.
Local and State Measures	
Compact city design and integrated planning Provision of public transit, walking and cycling infrastructure and services Road-user charging, parking pricing, access restrictions, registration restrictions and number plate auctions, eco-driving initiatives, urban logistics	Compact and policy-centric planning enables short trips, and provision of model alternatives provides affordable access. Complementary measures at the local or state level help manage travel demand and can generate funds that can be redistributed to support low-carbon transportation modes.

structures help build coalitions but can also increase the risk that a policy package fails because one measure faces strong opposition (Sørensen et al. 2014). A core element of success is the involvement at an early stage of potential veto players and the incorporation of their policy objectives in the agenda setting (Tsebelis and Garrett 1996).

Institutional Context

The political and institutional context in which policies are pursued is a factor to be considered for the success or failure of implementation (Jänicke 1992). Institutional aspects, such as the presence or absence of an environment ministry at the national level or local level, and their respective roles in the process are likely to have an effect on the implementation of climate-related transportation measures (Fredriksson et al. 2016). The legal power, budget, and political influence of these agencies are equally important (Jänicke 2002).

Provided that technologies to reduce GHG emissions are available and policy mechanisms to support their uptake are proven to be effective, the factors that influence transportation energy-efficiency policies can be successful over the long term and are the vital factors that enable their uptake. Energy and climate change policies for the transportation sector require a stable political operating environment to enable long-term investment decisions by industry and consumers (Lakshmanan 2011, Fais et al. 2016, Spataru et al. 2015). Consensus- focused governance and institutional structures may provide such a strategic, coherent, and stable operating environment. Policies to reduce energy consumption in the transportation sector require a strong political commitment to appear on the policy agenda and to remain in place, as they rely on investments that are only cost-effective over the medium to long term (ITF 2017). Policy interventions, such as fuel and vehicle taxation, are highly visible and politically sensitive. To get a clearer picture of the feasibility of climate policy pathways, one can draw on well-established concepts from political science theory that aim to identify key institutional characteristics that influence policy processes. Considering the complexity of policy-making processes, it is challenging to draw direct conclusions from institutional settings to climate policy performance. The relationship between institutional structures and climate policy performance becomes obvious when the stability (or the lack thereof) of specific policies in different countries is being assessed.

Institutional structures, policy continuity, and implementation are vital to delivering global climate change goals in line with the Paris Agreement. The decarbonization pathways across sectors are clearly outlined (IPCC 2014) and translated into actions in the transportation sector, which highlights that targets for mitigation of global climate change will not be reached without an appropriate contribution by the transportation sector (Fulton et al. 2013, Sims et al. 2014). The potential of specific measures to mitigate climate change has been well established and shows that the technological changes necessary to reduce transportation sector GHG emissions are readily available (Figueroa et al. 2014). An integrated policy approach that aims to generate synergies rather than trade-offs between policy objectives can help maximize socioeconomic benefits and can help form coalitions that endure and are resilient to political volatility. Table 3 summarizes the main themes outlined in this paper relating to policy and governance approaches.

Framing Questions

Provided that technologies to reduce GHG emissions are available (Figueroa et al. 2014; IPCC 2014) and policy mechanisms to support the uptake of these technologies are proven to be effective (Gross et al. 2009) the following questions can help frame the conversation on policy and governance during the Fifth EU-U.S. Transportation Research Symposium, Decarbonizing Transport for a Sustainable Future: Mitigating Impacts of the Changing Climate:

- What factors influence the policy environment in which transportation policies to mitigate climate change can be successful over the long term?
- What policies have been effective at decarbonizing transportation in the European Union and the United States?

TABLE 3 Pathways, Policy, and Governance Approaches for Low-Carbon Transport

Pathway	Policy Approach	Governance Approach
Toward decarbonization: 1.5°C–2°C	Integrated policies, including planning, modal shift, technology, and fuels	Multilevel governance based on broad political and societal coalitions
Limited mitigation action: 2.5°C – 3°C	Singular measures at local or national level	Minimal majority coalitions for specific actions
Some efficiency gains but very little mitigation: 3.5°C – 6°C	Little action beyond incremental technology improvements	No majorities for climate change mitigation action

- What types of policy (taxes, incentives, other) are most effective at which levels of government?
- What specific policy and governance challenges exist for decarbonizing transportation?
- Are there examples of jurisdictions overcoming these obstacles? Are their experiences transferable?
- How can policies be designed to create a basis for broad political and societal coalitions?
- How can policy and institutional frameworks be improved to be more resilient?
- Where is research needed to support governance efforts and models to decarbonize transportation?

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Abbreviations

ECMT	European Conference of Ministers of Transport
IEA	International Energy Agency
IIASA	International Institute for Applied Systems Analysis
IPCC	Intergovernmental Panel on Climate Change
ITF	International Transport Forum
OECD	Organisation for Economic Co-operation and Development
TfL	Transport for London
WEC	World Energy Council

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APPENDIX D: EXPLORATORY TOPIC 3

Megaregions

Policy, Research, Practice

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The International Transport Forum (ITF) has released its *ITF Transport Outlook 2017* report, which claims that the transportation sector "will not achieve the international community's climate ambitions" of zero emissions by the year 2050 (ITF 2017). According to ITF's General Secretary, José Viegas, "We need to both accelerate innovation and make radical policy choices to decarbonize transportation." Urban mobility in communities of high congestion is an area of great concern. Many of these cities have not taken steps to amend policies, such as integrating land use codes with transportation policies or transit-oriented development; introducing road-pricing mechanisms, such as high-occupancy toll lanes, to better manage mobility patterns; investing in accessibility and reliability; and reducing greenhouse gas (GHG) emissions. This paper explores policy framework options that would enable international communities to achieve their climate ambitions.

As stated in the white paper for this symposium, transportation is one of the highest emitters of GHGs of the economic sectors. The transportation sector, which represents 23% of all energy-related emissions, has a responsibility to reduce its emissions, as they are having a global impact on the climate. During the United Nations 21st Conference of the Parties, the parties of the Kyoto Protocol created a political pathway with 5-year reviews for national decarbonization commitments to begin in 2020. The framework establishes a common understanding of the needs for being prepared to address the challenges ahead. These needs include addressing policies, regulations, and standards. With the right policy mix, communities, even rapidly growing cities, will be in a position to develop in a sustainable way and provide today's level of mobility at the near-term goal of 2030 and the long-term goal of 2050. Community leaders should consider policy options that would accomplish the following:

- Avoid unnecessary transportation or traffic,
- Shift to a sustainable transportation system, and
- Improve efficiency (carbon fuel or switch to electricity or biofuels or both).

Additional considerations might include market-based mechanisms or incentives, such as an offsetting scheme for international aviation, which was adopted by the International Civil Aviation Organization. The Kyoto Protocol includes three such mechanisms: a clean development mechanism; joint implementation; and emissions trading. In any case, the right policy mix will be agile, so as to incorporate future innovations in transportation. Technological innovations, such as electric and autonomous vehicles, and economic innovations, such as shared mobility (i.e., cars and bicycles) and electronic payment systems, need to be analyzed to remove barriers and enable implementation. Technological progress alone will not achieve a reduction of carbon dioxide (CO_2) emission in cities.

Advancements in transportation are expected to fundamentally change passenger and freight mobility patterns, particularly in urban communities of large metropolitan areas. Regional transportation planning that focuses on modal connectivity and coordination increases mobility and accessibility options for people to live in one community while working in another. Meanwhile, travelers do not change their transportation habits as quickly without being offered some sort of incentive. For example, consumers shop without leaving home or work, saving them money on transportation costs, which also means goods movements can be better coordinated and have a lower-carbon solution. Policies and planning should account for these types of changes in transportation usage and should account for reductions to avoid building potentially unnecessary expensive infrastructure. Policies influencing behavior change, such as increased fuel taxes, low transit fares, congestion charges, or land use policies that limit urban sprawl, are needed to mitigate further GHG emissions (Polis 2016).

Lower CO_2 emissions from urban mobility are a positive side effect of policies targeting air quality and congestion. Transportation stays at the heart of the economy and connects people with places and things, so integrated regional solutions are needed for an integrated, inclusive, seamless, low-carbon transportation system. To fully realize the benefits of land use and transportation planning, should regional transportation planning incorporate land use development concepts as a central consideration from the early stages of local planning? For example, whenever new houses or retail areas are being planned, application of land use development approaches may be more capable of anticipating negative impacts from congestion caused by sustained economic growth (DfT 2011, para. 3.12).

If regional transportation planning can be used as a policy, regulatory, and standards framework to include GHG reductions, there are many questions to ask. One of the most obvious questions is, how is "regional" defined? Many sustainability and resiliency experts believe a regional construct should be viewed as a building block to a national mitigation and resilience plan. Great importance is placed on regions and on multiagency governance structure.

The Regional Plan Association (RPA), a New York–based planning organization, recommends regional planning be based on communities depending on neighboring communities for essential functions and services. Community dependencies reach farther than expected, into what RPA (2006) calls megaregions (in the United States) and metropolitan areas (in the European Union). (A megaregion is defined in several ways; here, it is a large network of metropolitan regions that share transportation infrastructure, settlement, and land use patterns.) Reaching across state and national borders, megaregions are becoming the new competitive unit in the global economy. Megaregions are defined by communities connected through environmental systems, infrastructure systems, economic linkages, land use patterns, and culture. Many of these areas of connection could address policies for the mitigation of GHG emissions that target both air quality and congestion. To work effectively in the area of decarbonization, joint efforts are needed worldwide. Policy makers and dedicated stakeholders (e.g., transportation authorities, local authorities, industry, planners) would need to implement the right policy mix to mitigate carbon emissions. In reflection, one asks how governments could adopt the right policy mix by integrating regional plans and programs for a megaregional policy framework to include mitigation of GHG emissions.

European Union Approach to Megaregions

Urban mobility is at a critical stage in Europe. By 2020, cities are expected to host around 80% of EU citizens and thus put further pressure on urban transportation systems. The European Commission's Urban Mobility Package and the EU Low-Emission Mobility Strategy (EC 2016) both provide exigency for addressing the challenges ahead. The situation in the EU is quite dramatic, as shown on PM_{10} interpolated maps (Figure 1). (The notation PM_{10} is used to describe particulate matter of 10 micrometers or less in size.) The illustration is selected to point out the EU aproach to policies that target both air quality and congestion.

Figure 1 shows substantial pollution linked to heavy traffic in two expansive regional areas:

- Northern Italy, which is walled by the Alps and hampered by other meteorological conditions, and
- Eastern Europe, which lacks general restrictions on pollution.

In Europe, metropolitan areas are bridged together by a long-distance transportation system for passenger and freight movements. This system is recognized as the Trans-European Transport Network (TEN-T network) by the European Commission and its member states. It comprises roads, railway lines, inland waterways, inland and maritime ports, airports, and railroad terminals throughout the 28 member states. This characteristic is a key factor for the network's efficient, safe, and secure operation and uses seamless transportation chains for passengers and freight. The comprehensive system includes a core network strategically selected according to vital importance for European and global transportation flows. Conceptually developed by the European Commission and subjected to broad consultation among member states and other stakeholders, TEN-T is the first method of its kind.

Considering that transportation is the backbone of national and global economies, as it connects people with places, is Europe ideally suited, with its regional and core network management of TEN-T, to integrate design

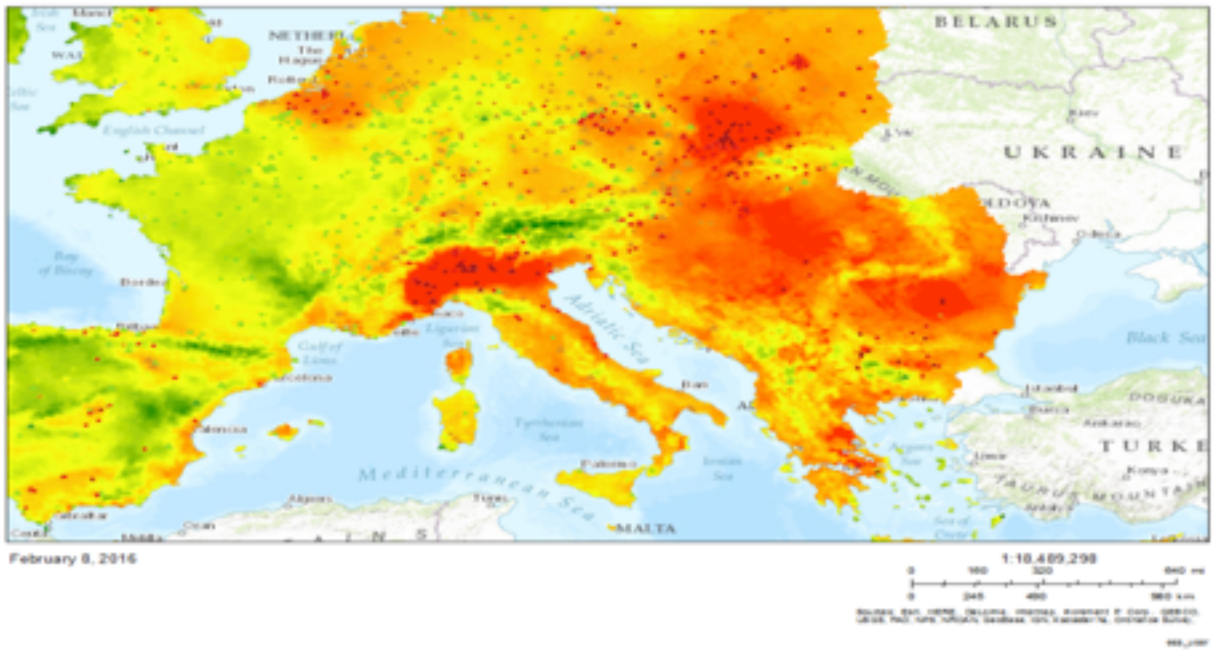


FIGURE 1 **PM_{10} interpolated maps illustrating 2016 pollution levels from traffic volumes in the European Union (EEA 2016 and Transport for Greater Manchester workshop, March 2017; reprinted by permission of Giuseppe Lupino, Istituto Sui Trasporti e la Logistica Fondazione, giuseppe.luppino@regione.emilia-romagna.it).**

and planning processes as well as implement the best air quality and CO_2 reduction solutions to mitigate the climate risks illustrated in Figure 1? The 2016 European Strategy for Low-Emission Mobility should be seen as one of the tools for modernizing the European economy and strengthening its internal market. The involvement of cities and local authorities is crucial for the delivery of this strategy, which also reiterates Europe's commitment to pursuing global efforts to control emissions from international aviation and maritime transportation.

What of the transportation systems that are outside the TEN-T? Connecting urban, suburban, and rural communities is equally considered in designing the Sustainable Urban Mobility Plan, or SUMP, for European cities and regions (Polis 2016). At the March 2017 Workshop on Decarbonizing the Transport System, held in Manchester, England, several strategic European cities and areas—including Barcelona, Spain; Budapest, Hungary; the Emilia Romagna Region of Italy; Milan Italy; and Manchester—presented their work in process as case studies (as outlined below) and described their aspirations and research needs for cities to address their challenges.

In conclusion, the right policy mix in Europe for reducing CO_2 emissions in urban transportation should consider how to include all transportation modes and create an integrated, inclusive, and seamless transportation system. This approach may be expected to be part of a new urban mobility culture and paradigm shift.

European Case Study: Decarbonization Through Integrated Regional Mobility

In this section, two of the case studies presented during the workshop in Manchester are explored. These case studies were selected for their existing agglomerations of metropolitan areas that are working toward economic growth and improved quality of life. The case studies illustrate two European regions known as "Blue Banana" and "Golden Banana."

- Blue Banana is also known as the "European Megalopolis" or the "Manchester–Milan Axis," a discontinuous corridor of urbanization in Western Europe with a population of around 111 million (Figure 2) (Hospers 2003).
- Golden Banana, or the sun belt, denotes an area of higher population density lying between Valencia, Spain, in the west and Genoa, Italy, in the east along the coast of the Mediterranean Sea. This area was defined by European Commission's 1995 Europe 2000 report as being analogous to the Blue Banana (Hospers 2003). The region is an economic center for information technology and manufacturing (Figure 3).

FIGURE 2 European Blue Banana (https://en.wikipedia.org/wiki/Blue_Banana).

FIGURE 3 European Golden Banana (https://en.wikipedia.org/wiki/Golden_Banana).

Blue Banana Case Study: Transport for the North—Integrated Seamless Transport

The North of England is part of the Manchester–Milan axis that constitutes the Blue Banana. It is home to 16 million people, 7.2 million jobs, and contributes more than £290 billion gross value added toward the UK economy. It is home to multiple world-renowned universities and centers of excellence and is a key contributor to the freight and logistics industry.

Transport for the North (TfN) aims to transform the transportation system of the North of England by connecting the region with fast, frequent, and reliable transportation links that will help drive economic growth and create a northern powerhouse. By considering roads, rail, waterways, ports, and airports jointly, TfN will ensure that people and freight can move freely and easily around the entire region. The main aim is to plan and deliver the improvements needed to truly connect the North in an integrated, seamless, low-carbon system. TfN will connect the six cities of Liverpool, Manchester, Leeds, Sheffield, Hull, and Newcastle in an ambitious economic plan (Figure 4).

An integrated approach through sustainable regional urban mobility planning could focus on a modal shift from single-occupancy vehicles to public transportation or shared mobility initiatives or both. Such an approach could obtain near-term benefits through increased efficiencies in freight mobility between rail and road networks and could improve travel times, reliability, and affordability in public transportation. Increasing the efficiency of the transportation system by making the most

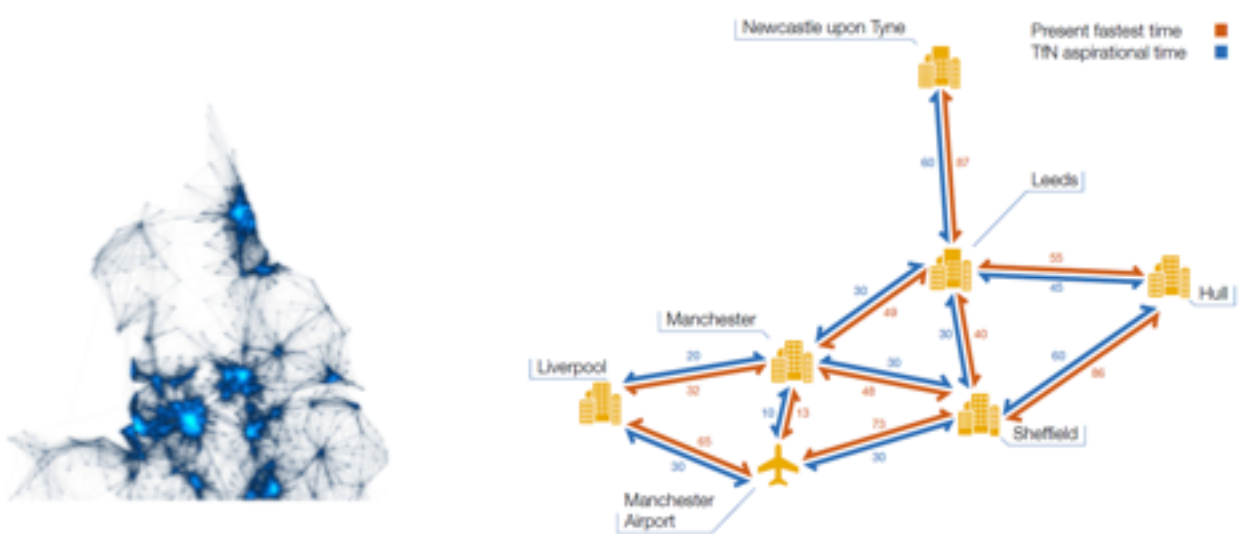


FIGURE 4 Transportation for the North, city–region network (Transport for Greater Manchester workshop, March 2017; provided by Rafael Cuesta, Transport for Greater Manchester).

of digital technologies, congestion and smart pricing, and low-carbon emission transportation modes is part of the region's 2017 and 2018 ambitions. Steps taken to integrate rail and road networks, in coordination with sustainability planning, have led to the formulation of six projects, including strategic road studies, rail franchising, and integrated and smart travel (Figure 5). The projects are all linked to achieving a low-carbon system in the TfN region.

Manchester, the capital of Greater Manchester (part of the North region), has 2.7 million residents and 7 million people within 1 hour of the city center. The region is made up of 10 local authorities that have been working together since 2011 as part of the combined authority, with Transport for Greater Manchester (TfGM) being the transportation arm for the city region. Its economic potential exceeds that of all other UK city regions outside of London. The environmental agenda is very ambitious, because transportation is responsible for a third of carbon emissions in the region. Like other city–regions, TfGM is investigating the feasibility of clean air zones. These generally impose access restrictions on vehicles (typically heavy goods vehicles and buses) below certain emission standards.

Careful evaluation is needed to ensure that benefits outweigh costs and that environmental protection would not have a negative impact on local and regional economic growth. By 2020, the city region aims to reduce CO_2 emissions by 48% by implementing smart mobility solutions to fully integrate the transport network. One solution that links urban, suburban, and rural communities is flexible on-demand transport (FDT). In testbed areas of Greater Manchester, a next-generation common operating platform of FDT connects users to shared mobility services for door-to-door, door-to-employer, and door-to-public transit services. The next generation of FDT services builds on the TfGM programs currently operating door-to-door services. Ring and Ride has been providing a mobility service for the elderly and disabled persons for several decades. This service is complemented by 25 Local Link services operated by four different companies serving about 350,000 passengers annually. Building on this experience, the next generation of FDT is expected to deliver significant reductions in CO_2 emissions by enabling more passengers to use public transit. The service will also provide more flexibility as part of integrated mobility as a service (MaaS).

Golden Banana Case Study: Metropolitan Region of Barcelona

The Metropolitan Region of Barcelona, an intergovernmental consortium created to coordinate public transportation, includes 164 municipalities and 5.2 million residents. Nearly half of the region is sloped at or above a 20% grade, which restricts the area suitable for urbanization and human inhabitants. Seventy-five percent of the surface is protected open space area. Most people live in the plains and corridors (Figure 6). The geographic challenges and congested living spaces impose several difficulties in the development of a regional master plan for transportation infrastructure.

To plan all-modes mobility of passengers and freight in the Metropolitan Region of Barcelona that utilizes GHG-reducing solutions would require the right policy mix

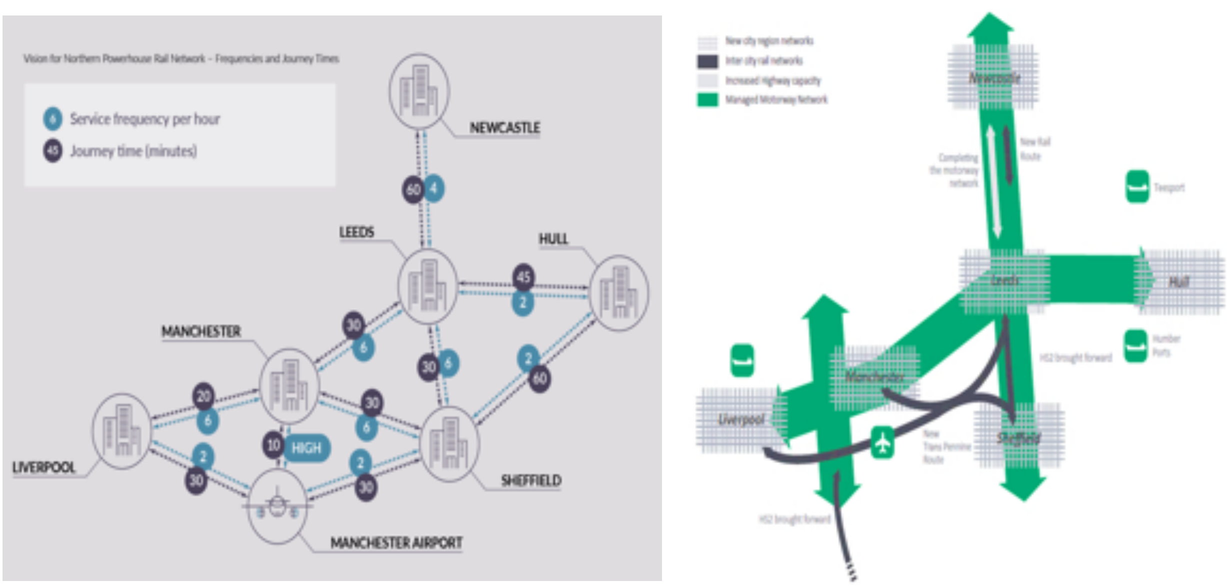


FIGURE 5 Transportation for the North, rail and road network (Transport for Greater Manchester workshop, March 2017; provided by Rafael Cuesta, Transport for Greater Manchester).

of regional planning, integrated transportation management, and pricing. These are channeled through 75 measures that are part of nine mobility area (MA) programs to be adopted in 2017 (http://81.47.175.201/project-protocol/index.php/urban-and-metropolitan-strategies):

MA1. Coordinating urban development and mobility;
MA2. Fostering a safe and well-connected network of mobility infrastructures;
MA3. Managing mobility and favoring modal transfer;
MA4. Improving the quality of railway transportation;
MA5. Achieving accessible, effective, and efficient bus service;
MA6. Modernizing logistics activity and accelerating railway infrastructure for freight mobility;
MA7. Guaranteeing sustainable access to job locations;
MA8. Promoting energy efficiency and the use of clean fuels; and
MA9. Carrying out participative management of the implementation of the Mobility Master Plan.

The environmental goals are very ambitious, indicating a 12.3% reduction of CO_2 by 2013. To achieve those goals, it is necessary to speed up the decarbonization mobility plan for the region. The programs listed above will be grouped into the following categories:

- Promoting a modal shift to more efficient modes;
- Promoting efficient and less-polluting mobility;
- Fostering electric mobility (Figure 7);

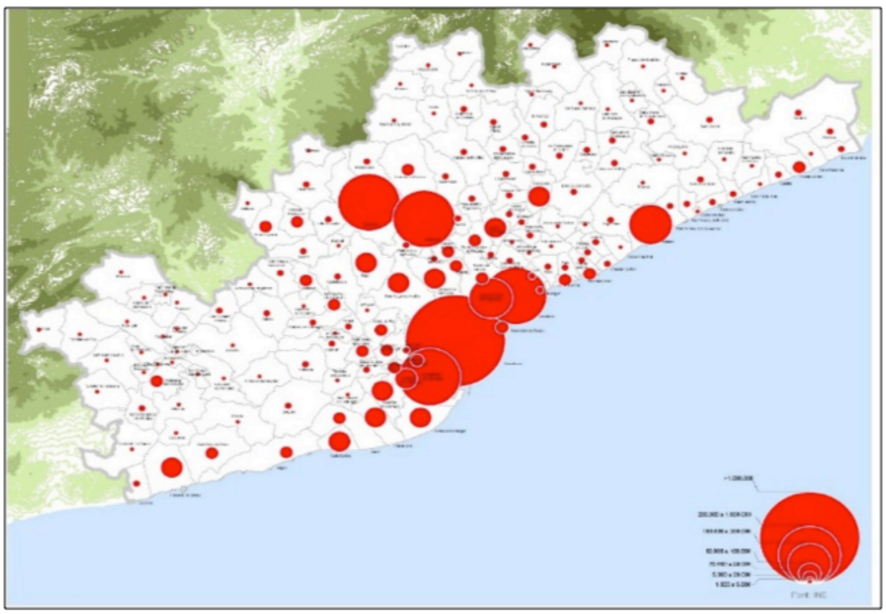
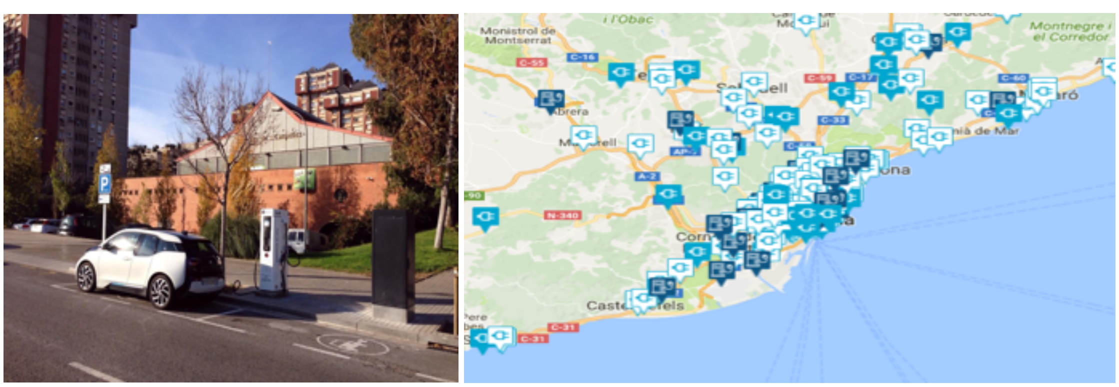


FIGURE 6 Metropolitan Region of Barcelona, 2016 (Transport for Greater Manchester workshop, April 2017; reprinted by permission of Lluís Alegre Valls, lalegre@atm.cat).



(a) (b)

FIGURE 7 Joint strategy for the gradual replacement of a fuel vehicle fleet with an electric vehicle fleet (Transport for Greater Manchester workshop, April 2017; reprinted by permission of Lluís Alegre Valls, lalegre@atm.cat).

- Placing people at the core of the decarbonization commitment as part of a participation strategy that is expected to turn some actions into powerful tools:
  - Communication and information,
  - MaaS,
  - Sharing the future,
  - Customer orientation to services, and
  - Agreement toward a decarbonized society (e.g., leaving the car, choosing clean vehicles, driving efficiently, using shared mobility services).

Despite the explicit commitment and major improvements in decarbonization that have been made by the Catalan transportation system, there is considerable room for improvement and for the implementation of new projects to reduce greenhouse emissions in the region.

U.S. Case Study: Adaptation Can Help Mitigation

The selected case study from the United States aims to bridge a research gap. This case study focuses on the interference of adaptation actions with GHG mitigation policies in the transportation sector in the Hampton Roads region of Virginia from 2014 to 2016. An intergovernmental blueprint for community resiliency, the Hampton Roads Sea Level Rise [SLR] Preparedness and Resilience Intergovernmental Pilot Project (convened by Old Dominion University and launched in June 2014) (Center for Sea Level Rise 2016), was one of three White House National Security Council pilots and one of three Department of Defense pilots in response to the 2013 Presidential Executive Order called "Preparing the United States for the Impacts of Climate Change" (EOP 2013).

Background

Boasting the largest natural coastline in the world, Southeastern Virginia has an economy and culture tied largely to the strength of its ports and waters. The Hampton Roads region's geography has attracted multiple military installations, including the largest naval base in the world, the third-largest commercial harbor on the eastern seaboard, manufacturing facilities, commercial fisheries, residential development, and tourism.

Over the past 2 years, Hampton Roads localities including Virginia Beach and Norfolk, four state-level government departments, 11 federal agencies (including the Department of Defense), the Virginia Port Authority, a variety of private businesses, and three nonprofit organizations worked together in a White House–announced intergovernmental pilot project convened by Old Dominion University to figure out how to build coastal resilience in the face of increasing sea level rise (Figure 8).

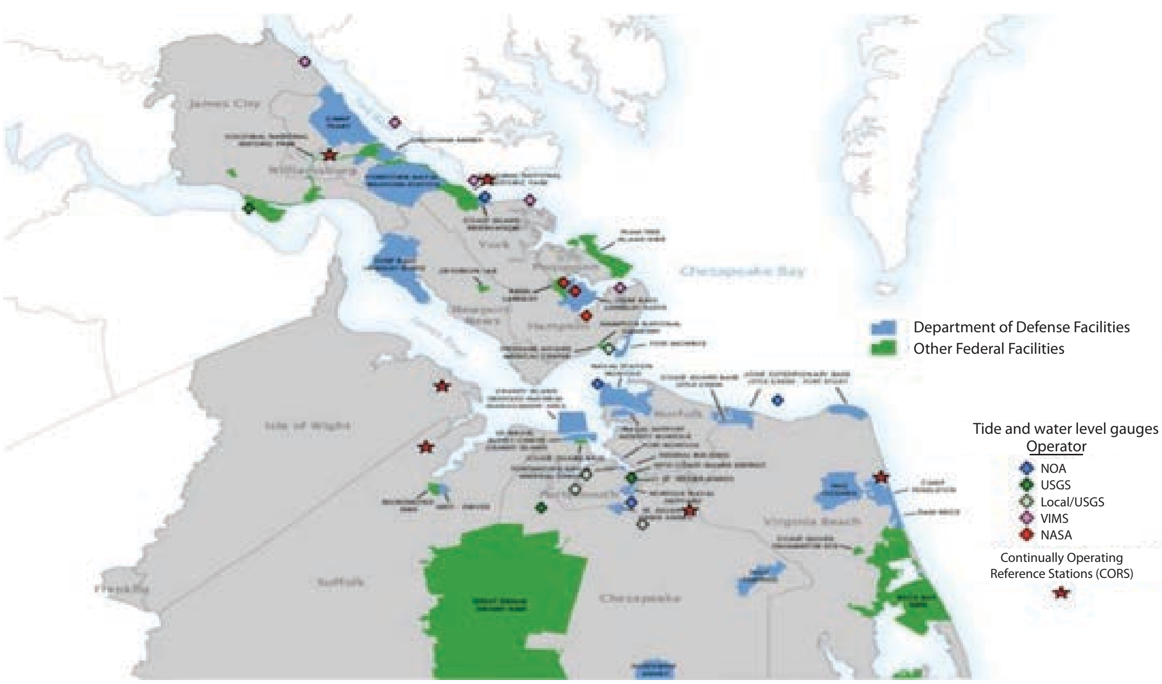


FIGURE 8 Project interaction map (ODU 2016).

Whole of Government and Community

The goal of this initiative was to establish an intergovernmental planning process to effectively coordinate SLR preparedness across multiple federal, state, and local government agencies as well as the private and nonprofit sectors while taking into account perspectives and concerns of the region's citizens (Center for Sea Level Rise 2016).

Led by a steering committee, volunteers focused on legal issues, infrastructure requirements, citizen engagement, public health, science, and economic impacts. Several aspects are worth mentioning:

- Linking infrastructure interdependencies (on and off base) by sharing maps, plans, and so forth with neighboring jurisdictions and municipalities.
- Creating and maintaining an integrated regional network to observe impacts to the economy, storm water, public health, and infrastructure. These data could be used in real time but also archived to properly monitor longer-term changes at a greater level of spatial and temporal fidelity.
- Incentivizing whole-of-government practices for each municipality through grants, requests for proposals, and other federal and nonfederal acquisition practices.
- Integrating planners' and emergency managers' plans and procedures to address real-time threats (such as Hurricanes Sandy and Matthew) and long-term trends like sea level rise.
- Improving scientific research methods through data integration and model improvement.

Success story: an integrated right policy mix approach is an absolute requirement for any (mega)region, and thus entire government–community practices are needed. The outcome of Hampton Roads can lead to greater innovation through emphasizing the integration of practices, science, and engineering solutions. It also shows the need to consider adaptation and mitigation measures at the same time when planning transportation infrastructure and systems.

Upon completion of the pilot project, Hampton Roads will have laid the groundwork for a regional whole-of-government, whole-of-community organizational framework and procedures that effectively coordinate SLR preparedness and resilience planning. (Note: EU case studies do not tackle maritime issues.) An important next step would be a U.S. Department of Transportation initiative to quantify climate change impacts. Federal transportation officials chose Hampton Roads for this work and were proactive partners throughout the 2-year pilot effort (2014 to 2016).

Lessons about decarbonizing transportation include the following:

- Effective resilience planning requires consideration of land use planning, infrastructure, private-sector organizations, science and engineering, local, state, and federal agencies, military installations for mission assurance, citizen engagement, and the municipal planning committee or local metropolitan planning organization. These and additional stakeholders are part of the current operating structure.
- A whole-of-government, whole-of-community approach can be transferred from adaptation to mitigation by showing how adaptation can help mitigation in tackling climate change in the transportation sector (Bosello et al. 2013). The Hampton Roads region has the tools and resources to move forward with a collaborative process on measures toward zero-carbon transportation.

The Research Gap: How Can Adaptation Help Mitigation?

The literature review identified gaps and barriers in adaptation and mitigation (decarbonizing) paths and suggested policy actions to better align adaptation actions with long-term mitigation goals in transportation (TRB 2016). Adaptation focuses on the identification of actions that should be implemented in the short term and tends to adopt a local, project-specific aim. Mitigation (toward zero-carbon transportation) keeps a strategic, long-term perspective, and a global focus; transportation maintenance managers, operators, or service providers will typically be involved in adaptation actions, whereas planners and decision makers will dominate mitigation policy discussions. In short, the universe of interactions between adaptation and mitigation is currently perceived as quite limited.

Research Question: How can the transportation sector be better helped to reduce impacts on climate change?

Given the regional approach presented in the Hampton Roads case study, the exploration of the need to include a path-dependency perspective to adaptation and mitigation in transportation may be useful. When policies are addressed independently, there is a significant risk of optimizing one of the two dimensions (adaptation or mitigation), while obtaining poor, if any, improvements in the other. The current institutional framework would be a significant barrier to exploring an integrated approach that could find a fair compromise between adaptation and mitigation options. Figure 9 illustrates a proposed link between adaptation and mitigation measured in transportation systems.

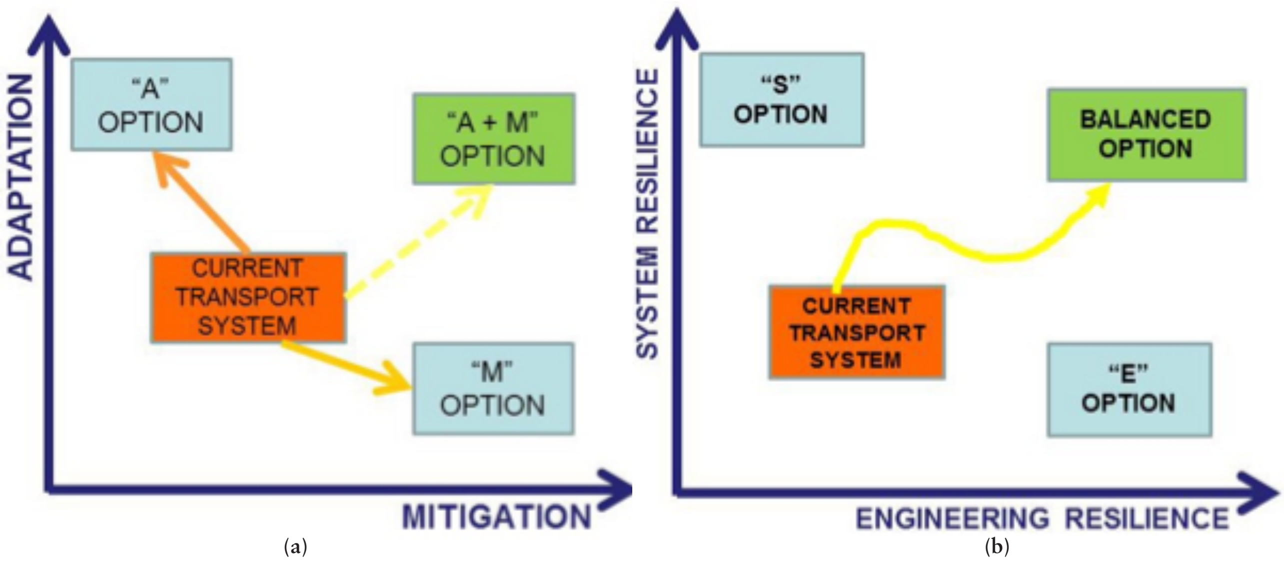


FIGURE 9 Mitigation and adaptation paths (Aparicio 2015).

Reviewing Key Approaches to Low-Carbon Transport Systems

Technological innovation, modal change, infrastructure, and services related to information and communication technology (ICT) (including traffic management and users' information) will indicate where adaptation and mitigation can work together. Technological innovations and infrastructure deployment and upgrading are expected to maintain or improve the efficiency and performance of the transportation system and thus avoid disruptions in operations. The ICT category, however, can be understood as being closer to a system resilience approach, in which ICT tools would be able to facilitate quick recovery, to gain flexibility, and to redirect users toward other routes and modes, or even to review their transportation plans in case of disruptions.

As for the modal change category, the robustness of the system as a whole and its various transportation modes is also taken for granted, although it can be argued that the concept of robustness is understood in a different way in the various transportation modes (Aparicio 2015).

What to Expect?

Certainly, the inclusion of future low-carbon traits of the transportation system in adaptation studies and actions is challenging. Mitigation strategies have not been explored in much detail with regard to how technological and nontechnological innovations would behave under a changed climate. Given that regions and megaregions face multiple impacts (e.g., weather, health, and transportation), the research community is facing the need to investigate both mitigation and adaptation pathways and the role of modal change, intelligent transportation systems, MaaS, active travel, and more in a changed climate.

Conclusion and Framing Questions

There are several options and a range of policy tools for reducing carbon emissions in metropolitan areas and megaregions by reducing congestion, improving vehicle flow, reducing unnecessary traffic, and creating the momentum for modal shift. However, the ultimate deployment and implementation of a selected right policy mix is a matter for cities and regions to determine. While some best practices (e.g., app-based mobility services, more stringent emission regulations, better charging facilities) have been successful in several metropolitan areas, they are not always transferable. Predicting how things will develop remains challenging, as megaregions increase in complexity.

The following questions may help prioritize policy tools and add to these opportunities while identifying areas for further research during this symposium:

1. What will it take to create an integrated megaregion climate framework for the transportation sector while also considering mitigation and adaptation measures at the same time?
   – What would be the most effective behavior-changing policies?
   – What policy barriers are expected in transferring best practices from one region to another?
   – What would be the phases toward an integrated climate monitoring network?
   – What steps can be taken to make the entire community (government, community, industry) work for an integrated regional solution?

- How can a whole-of-government approach be funded?
- What are the legal barriers that new legislation could address?

– How could this framework meet the United Nations sustainability goals?

2. How may several regions be brought together to work for an integrated, smart, and low-carbon transportation system, given the challenge of multiple differences?

3. Given today's knowledge of the policy mix on decarbonizing urban and regional transportation, what policy mixes should be prepared to respond to the doubling of passengers in traffic (see Appendix A, Figure 27) by 2030? By 2050?

4. What topics should be considered for a joint EU-U.S. program on transportation and climate change?

– Can the Old Dominion University (U.S.) case study be implemented in other regions by using other universities as the convener–trusted agent with applicable research and a firm understanding of the stakeholders in those regions?

– Are there any other novel aspects, in research or practice, to be considered?

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Abbreviations

DfT	Department for Transport, United Kingdom
EC	European Commission
EEA	European Environmental Agency
EOP	Executive Office of the President
ITF	International Transport Forum
ODU	Old Dominion University
RPA	Regional Plan Association
TRB	Transportation Research Board

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APPENDIX E: EXPLORATORY TOPIC 4

Decarbonizing the Logistics and Long-Distance Transportation of Freight

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Simon Edwards, *Ricardo, Shoreham-by-Sea, United Kingdom*

The long-distance transportation of freight and its logistics have been identified as one of the most difficult socioeconomic activities to decarbonize (*1*, *2*). Freight's share of total transportation greenhouse gas (GHG) emissions is predicted to rise from 42% in 2010 to 60% in 2050 (*3*). Yet the Intergovernmental Panel on Climate Change suggests that transportation overall must achieve very significant reductions in GHG emissions to align with the provisions of the 21st Conference of the Parties to the United Nations Framework Convention on Climate Change. (*4*, *5*); for example, the carbon intensity [e.g., grams carbon dioxide equivalent per tonne-kilometer (g CO_2e/tonne-kilometer)] of freight movement in Europe would have to drop to about one-fifth of its 1990 level to meet the European Commission's 2011 target of a 60% cut in CO_2 emissions from passenger and freight transport between 1990 and 2050 (*6*).

The logistics and long-distance transportation of freight include the activities of all the vehicles (trucks, locomotives, aircraft, and harbor craft) and all types of equipment used to move freight at seaports, airports, rail yards, warehouses, and distribution centers. It also includes the use of other modes like oceangoing freight and intercontinental air freight, and the last-mile components of freight. However, these two modes are not the focus of this workshop scoping paper. The logistics and long-distance transportation of freight naturally involve the use of much infrastructure, such as freight hubs, which are considered to be facilities, along with the network of roads, land ports of entry, railways, airports with their airways, and waterways.

This paper aims to provide context to the discussions on the decarbonization of freight in the United States and Europe. There are scenarios and discussion questions toward the end of the paper that are intended to inspire dialogue that ultimately identifies the research needs or knowledge gaps in our efforts to decarbonize freight.

Background

A growing population, increasing demand for goods, sudden changes in commodities and movement patterns (like the emergence of the Bakken oil), the need to remain competitive in an increasingly complex global marketplace, and an aging transportation infrastructure have placed freight systems around the world under serious strain. In some regions, the level of investment in freight-specific transportation needs has not kept pace with a growing economy and thus has added to this strain. Given the inherent importance of having functioning freight logistics and long-distance transportation systems, both globally and regionally, it is important to establish development funding. This funding should be substantial, continuing, multimodal, reliable, and specifically dedicated to freight transportation projects in order to decarbonize the freight system. Freight funding is not just limited to vehicles and equipment; it includes the transportation and energy infrastructure plus workforce development to help workers transition to a decarbonized transportation system. However, funding needs to be structured around future needs and constraints. For example, projected population and economic growth of

U.S. freight movements across all modes are expected to grow by roughly 42% by the year 2040. It is sometimes difficult to plan and implement freight projects because the priorities among global to local governmental and private organizations vary substantially. Publicly owned freight systems (apart from the waterway system) are primarily planned and managed by regional and local governments. At the same time, a local government's control of land use and its dependence on property taxes may challenge broader regional transportation objectives. These effects result in fragmented decision making when it comes to projects of global, regional, and national significance (*7*).

It is clear that decisions related to the future decarbonization of long-distance freight transportation will be complex and need to include many stakeholders (see Figure 1). Future advances in technology and changes in supply chains could reduce the intensity of freight transportation in the global economy. It is also not enough to limit the discussion to the GHG emissions from the movement of freight; the focus includes particulate matter (PM) and NO_x emissions, which are detrimental to air quality and human health. Often GHGs and PM have an inverse relationship; therefore, focusing on one and ignoring the other can lead to a situation in which one problem is solved while another is created.

The reshoring of manufacturing activity (i.e., the bringing of manufacturing to consuming countries), the relocalization of food supplies, and changes in trade restrictions may reduce long-distance freight transportation and its carbon footprint. However, as the global population continues to grow, more freight movement is expected. Additionally, technologies such as miniaturization (the trend to manufacture ever smaller mechanical, optical, and electronic products and devices), digitization (the conversion of text, pictures, or sound into a digital form that can be processed by a computer), and localized additive manufacturing (technology processes that

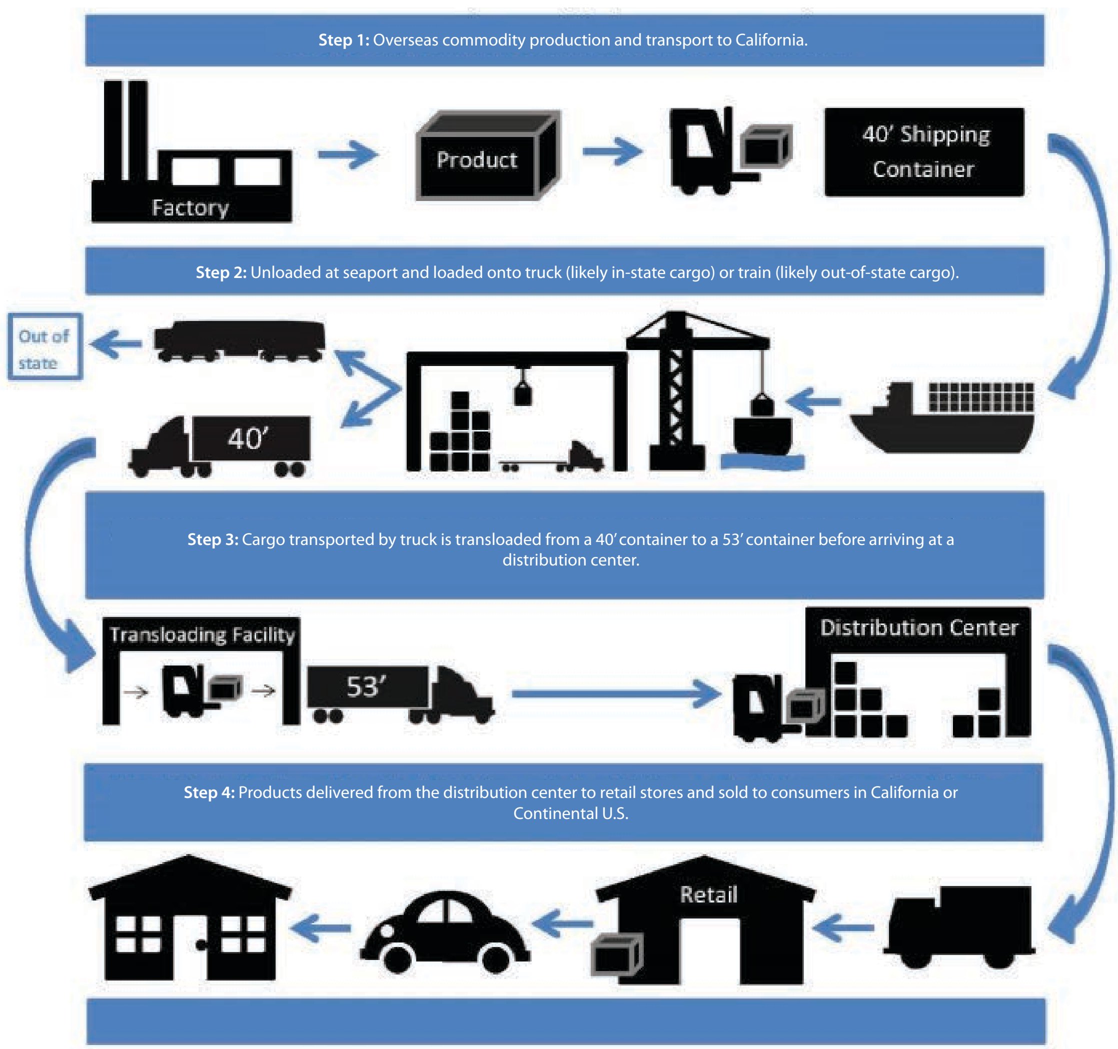


FIGURE 1 Complexity of logistics: import supply chain example (*8*).

build three-dimensional objects by adding layer upon layer of material) could remove the need for some local and global trade (*9*). However, political commitment to economic development is likely to mean that the growth in the global transportation of freight will be maintained. There is evidence to suggest that some of these factors, such as relocalization, may actually increase the carbon footprint of some products (*10*). A net reduction in the total ton-kilometers of freight seems almost impossible; for further sustainability and societal benefits to be realized, efforts should focus on driving down the average carbon intensity of freight logistics and transportation (*2*). These benefits may include reductions in other (toxic) emissions and related health effects.

The carbon intensity of logistics and the transportation of freight is determined by at least five parameters: the structure of the logistics chain, the modalities of the freight, the utilization of the facilities and vehicles, the energy efficiency of these facilities and vehicles, and the carbon basis of the energy consumed. Each of these parameters is considered below along with possible related needs for research.

Structure of the Logistics Chain

The structure of the logistics chain determines the amount of freight movement per unit of delivery. Vertical integration of process (the combination in one company of two or more stages of production normally operated by separate companies) reduces the number of links in the logistics chain. While this might have occurred in developed economies within the retail sector—chain stores, for example—it is not true in the manufacturing sector, where supply lines have usually lengthened. Larger single-market regions have tended to centralize distribution, increasing transportation-related emissions while reducing inventories in a just-in-time world. The balance of carbon intensity across the logistics supply chain versus the cost needs to be reinvestigated and future-proofed in relation to the circular economy if the climate change mitigation targets are to be approached.

Freight Modalities

The average carbon intensity of freight transportation modes varies enormously (*2*), as shown in Figure 2. Around the world there are opposing trends in changes between modalities for a wide variety of reasons (Figure 3). For example, the European Commission has set ambitious targets to change from road to rail or water modes (*11*). The carbon cost of the investment and maintenance needed to achieve these modal shifts and the net societal (economic) costs, such as for sustainability, are not always well understood. It is also important to note that rail is efficient in terms of GHGs per unit of freight moved but tends to emit more PM and NO_x, which affects air quality and undermines other sustainability goals.

Utilization of Facilities and Vehicles

Improving utilization in all aspects normally results in a carbon intensity reduction with relatively few downsides.

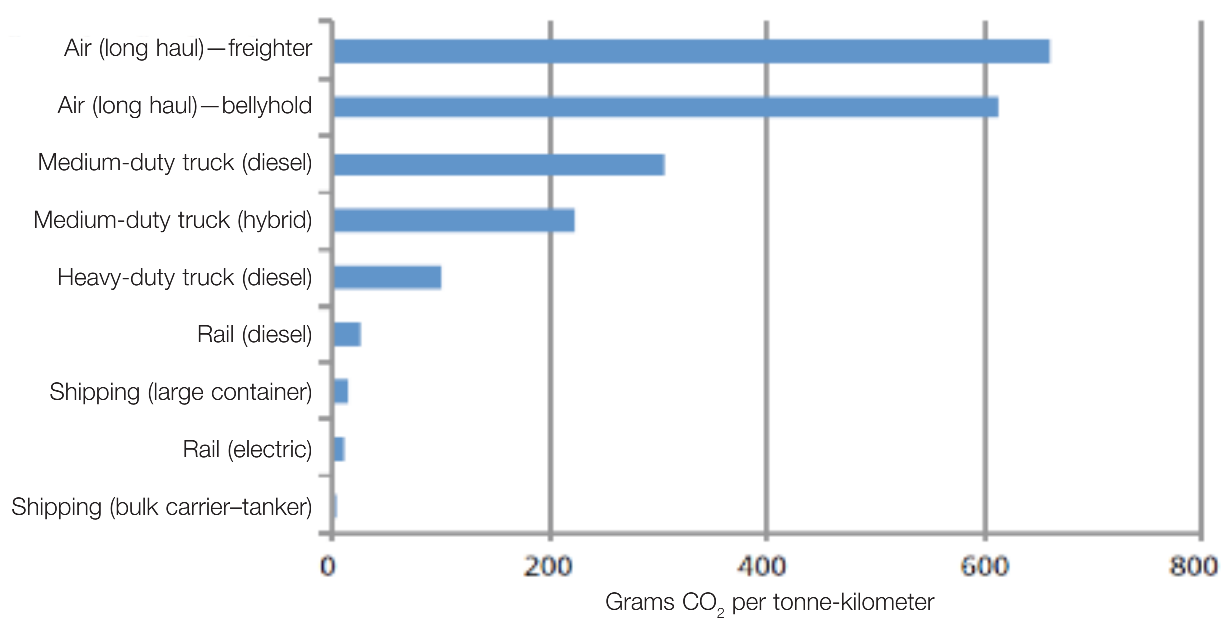
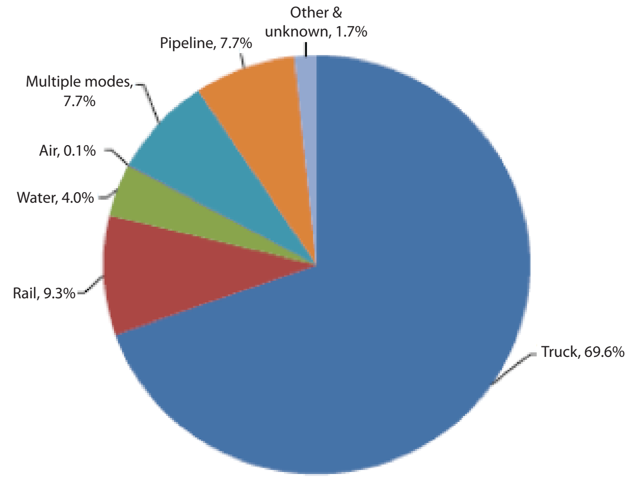
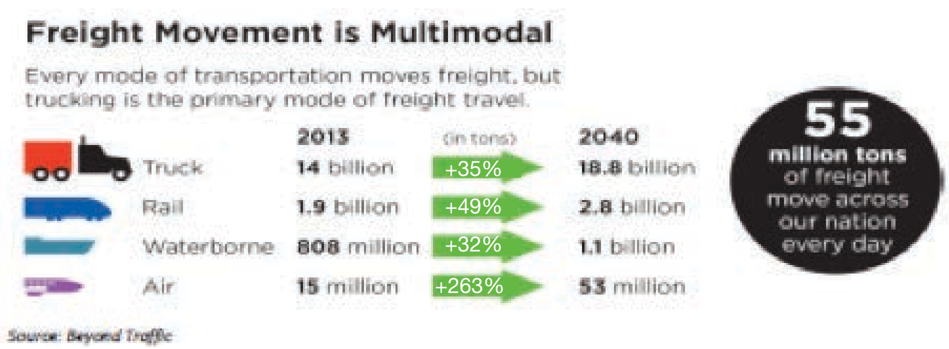


FIGURE 2 Average carbon intensity of freight transport modes (2, 4).



(Source: Bureau of Transportation Statistics and Federal Highway Administration, U.S. Department of Transportation, Freight Analysis Framework, Version 3.6, 2015)

(a)



(b)

FIGURE 3 Current and future projections for freight modality: (*a*) tonnage of U.S. shipments by mode and (*b*) multimodal nature of freight movement (*7*).

Freight infrastructure and facilities are complex, with public and private players involved in their development and operation. There are often good practice guidelines on ways to increase utilization, however. For example, in the United States, practice suggests siting freight projects to avoid greenfield development by enhancing existing freight infrastructure or targeting infill development near compatible land uses. Other good practices are supporting local and regional efforts to improve trade facilities and corridors that achieve environmental goals and investing strategically to improve travel time reliability and achieve sustainable reduction in congestion at key bottlenecks on primary trade corridors. Expanding freight transport operating hours, to effectively reduce congestion during peak hours by rescheduling freight movement to off-peak hours, as done at the Port of Los Angeles and Long Beach, is another example of good practice.

Business practices also have a positive role to play in improving utilization. A positive correlation between economic and carbon costs is often driven by commercial considerations, so that practices such as just-in-time delivery or facility collaboration have a net benefit on carbon intensity. Nevertheless, there is a need for these aspects to be better measured.

There is always opportunity to improve vehicle utilization, which naturally reduces carbon intensity (*12*). However, quantifying underutilized capacity is difficult, as needed data are often not available. Here the possible benefits through improved information systems seem significant but remain to be determined and realized. Vehicle utilization may be improved not just through removing unused capacity but also by changing capacity discretization, that is, changing the size or shape of vehicles like trucks (*13*). Such changes can have many positive effects on carbon intensity, but the constraints on infrastructure or logistics potential and the interactions across modalities, including emerging modes, need to be comprehensively understood.

Energy Efficiency of Facilities and Vehicles

While improvements in vehicle technology have significantly improved energy efficiency over the last decades, compromises with other emissions-related technologies have not necessarily been made. Going forward, significant improvements in vehicle efficiency are still possible, even at ultralow emissions levels [see, for example, Dörr et al. (*14*)]. This is true particularly for on-road transportation as well as across other modes. The challenge is to encourage the commercial application of these fuel-saving technologies. The operation of these vehicles is becoming more fuel efficient; in the future, digital technologies like electronic horizons that improve information in the vehicle (*15*), or automation that allows more efficient operation (*16*), will play an increasingly important role in improvements to vehicle fuel efficiency. Less headline grabbing, but similarly important, are the improvements in the energy efficiency of logistic hubs (*17*). It is unclear whether emphasis for future research should be placed on further specific improvements in vehicle technology, or whether existing knowledge would be better transferred across modes and facilities to realize the most effective reductions in GHG emissions.

Carbon Basis of Energy Consumed

Freight transportation is a fossil fuel–intensive operation, and the repowering of logistics operations with low-carbon energy is at an early stage. The possibility of electrifying freight transport is mode dependent. The mass and volume energy density requirements at the vehicle level are the key determinants influenced by the local electrical energy supply mix. In the short term, the decarbonization of liquid fuels for long-distance transportation is the main option for aircraft, ships, freight trains, and heavy-duty commercial vehicles. The electrification of the highway road network, together with increasing levels of vehicle hybridization (electric), is one possible medium-term option.

With each of these options, the carbon consequences of the infrastructure investment and the balance with other societal needs, such as for biofuels, need to be comprehensively understood. The move to non-carbon-based (liquid) fuels remains a possibility, especially in less energy-dense applications, but the balance of the optimal rate of change compared with the societal costs versus benefits must be determined.

Scenarios

Scenario 1

A consumer orders five pairs of shoes online and requests delivery within a 2-hour window. The shoes arrive on time. The consumer keeps one pair of shoes and returns the others to the store. The following are the steps involved in the process (Figure 4):

Step 1. Five pairs of shoes are produced and packaged at a factory in China and the shoes are loaded onto a shipping container with a forklift.

Step 2. The container is transported to the nearest port (assume within 100 miles from the factory) by a large truck and placed on a container vessel by means of a variety of cargo-handling equipment (likely a crane, top handler, and yard truck).

Step 3. The vessel transports the container to a port in California.

Step 4. The container is unloaded from the vessel and placed on a large truck by means of a variety of cargo-handling equipment (likely a crane, top handler, and yard truck).

Step 5. The large truck takes the container to a transloading facility (assume within 10 miles of the California port), where a forklift transfers the shoes into a large truck with a 53-foot trailer.

Step 6. The large truck drives to a distribution center (assume within 100 miles of the transloading facility), and the shoes are unloaded with a forklift.

Step 7. The shoes are placed into a medium-sized truck and the truck delivers the five pairs of shoes to the consumer (assume within 50 miles of the distribution center) within a 2-hour window. (Note: Step 7 occurs once the customer orders the shoes.)

Step 8. The consumer drives, bikes, or walks the unselected four pairs to a local package delivery store (assume within 10 miles of the consumer's home).

Step 9. The four pairs of shoes are placed onto a medium-sized truck and taken to a distribution center (assume within 50 miles of the package delivery store).

Step 10. The four pairs of shoes are unloaded and stored until ordered again.

Scenario 2

The operation of the world's 700 million vehicles together with their manufacturing process contributes to about 5% to 6% of global GHG emissions. The production and sales of passenger vehicles are forecast to grow in most regional markets over the next two decades, with approximately 40% of the emissions associated with the supply chain of vehicle parts moving across an international border (Figure 5). While the life-cycle emissions per

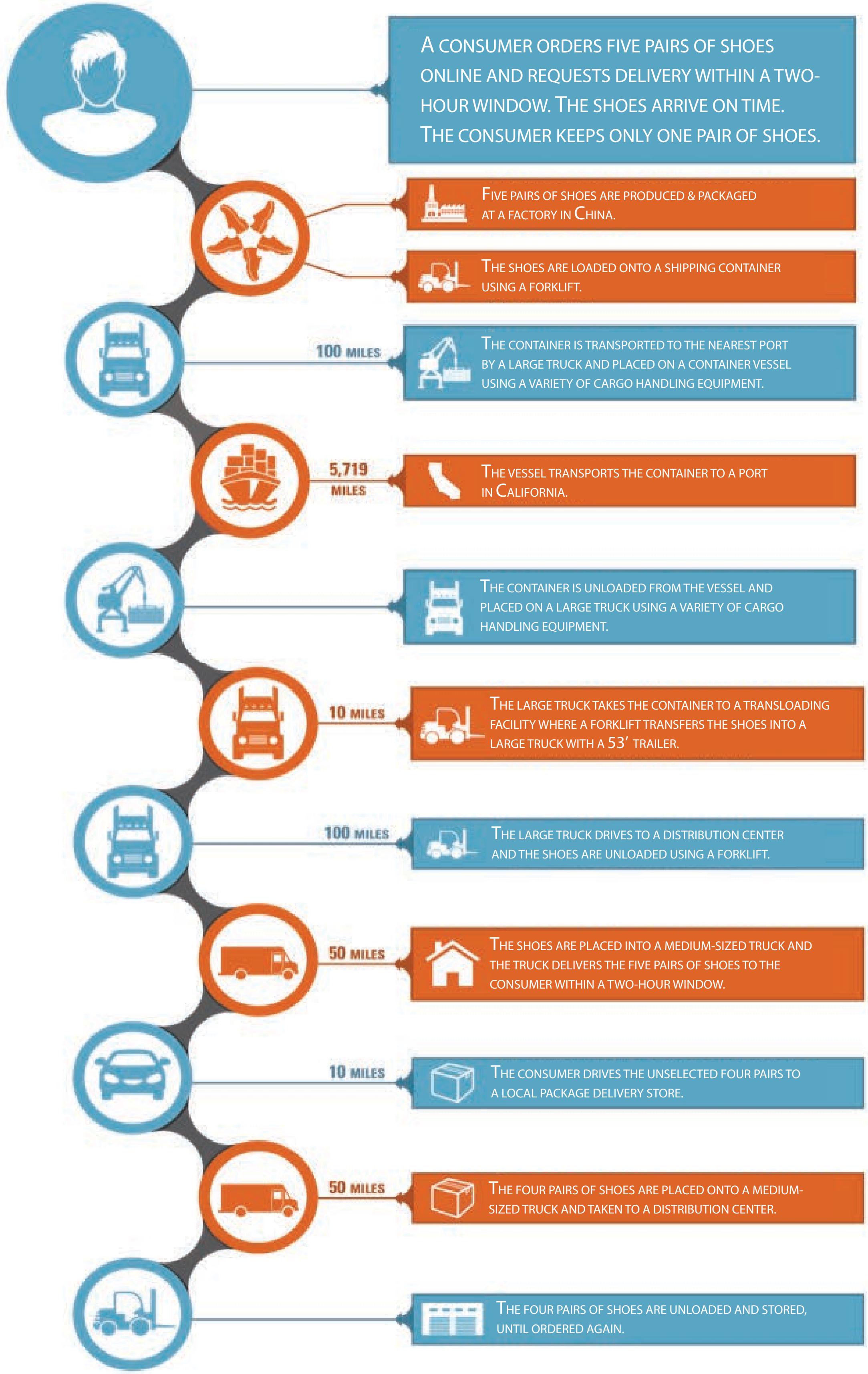
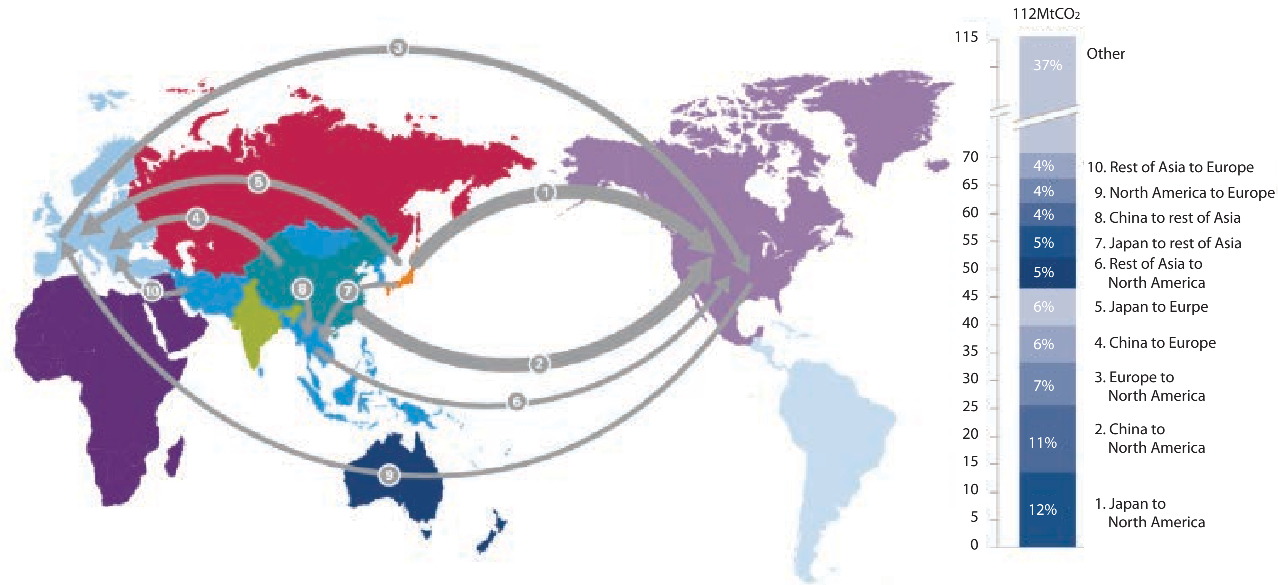


FIGURE 4 Scenario 1: Online shopping.



Note 1: Includes Scope 1 emissions (direct), Scope 2 emissions (allocated electricity) and Scope 3 emissions (inputs to automotive manufacture).
Note 2: Includes Scope 1–Scope 3 emissions generated within the country of automotive production only (i.e., excludes flows between countries of inputs to automotive manufacture).
Note 3: Exludes intra-regional flows.
Source: Carbon Trust Analysis; CICERO/SEI/CMU GTAP7 EEBT (2004) model.

FIGURE 5 Major flows of emissions between the European Union and the United States that are embodied in the global auto sector (*18*).

car are projected to fall by around 50% in the medium term as a result of technology innovation, embodied emissions (rather than tailpipe emissions) will become the dominant source of life-cycle emissions within the next decade. These emissions drive significant differences between production and consumption emissions in the automotive sector in many countries. The transportation associated with the supply chain of vehicle parts in the vehicle manufacturing process contributes to CO_2 emissions. Whereas significant reductions in embodied emissions (up to 50% of CO_2e) may be possible through the optimization of current production processes, the benefit of improved transportation and logistics within the supply chain and production process has probably yet to be quantified (*18*). Examples of the supply chain for the primary components of a Tesla Electric Sedan for delivery in the continental United States are as follows (Figure 6):

Step 1. Aluminum sheet for chassis and body panels is shipped from Japan to a south coast port.

Step 2. Rolls are loaded onto trucks by crane for transfer to off-dock rail (~15 miles).

Step 3. Rolls are transported by rail and truck to the Fremont, California, facility (~400 miles).

Step 4. Multiple materials and interior components arrive by ship at Oakland, California, and are transported by truck to the Freemont facility (~20 miles).

Step 5. Battery and cathode materials are shipped from a proprietary location in Asia to a south coast port.

Step 6. Battery cathode and materials are loaded onto a train and shipped to a battery manufacturing facility in Nevada (~500 miles).

Step 7. Batteries manufactured in Nevada are shipped by truck to Fremont (240 miles).

Step 8. Assembled vehicles are loaded onto trucks for direct delivery, including east coast destinations (distance varies).

Conclusion and Framing Questions

The logistics and freight transportation share of global GHGs is likely to rise substantially in the coming decades, and the level of decarbonization needed for this mode to reach its global climate change mitigation targets seems almost impossible. However, mutually reinforcing opportunities to cut the carbon intensity of long-distance freight transportation are appearing; the realization of these opportunities should set governments and businesses on a path to low-carbon logistics by 2050.

The following questions may help prioritize and add to these opportunities during conversation within the Fifth EU-U.S. Transportation Research Symposium, Decarbonizing Transport for a Sustainable Future: Mitigating Impacts of the Changing Climate:

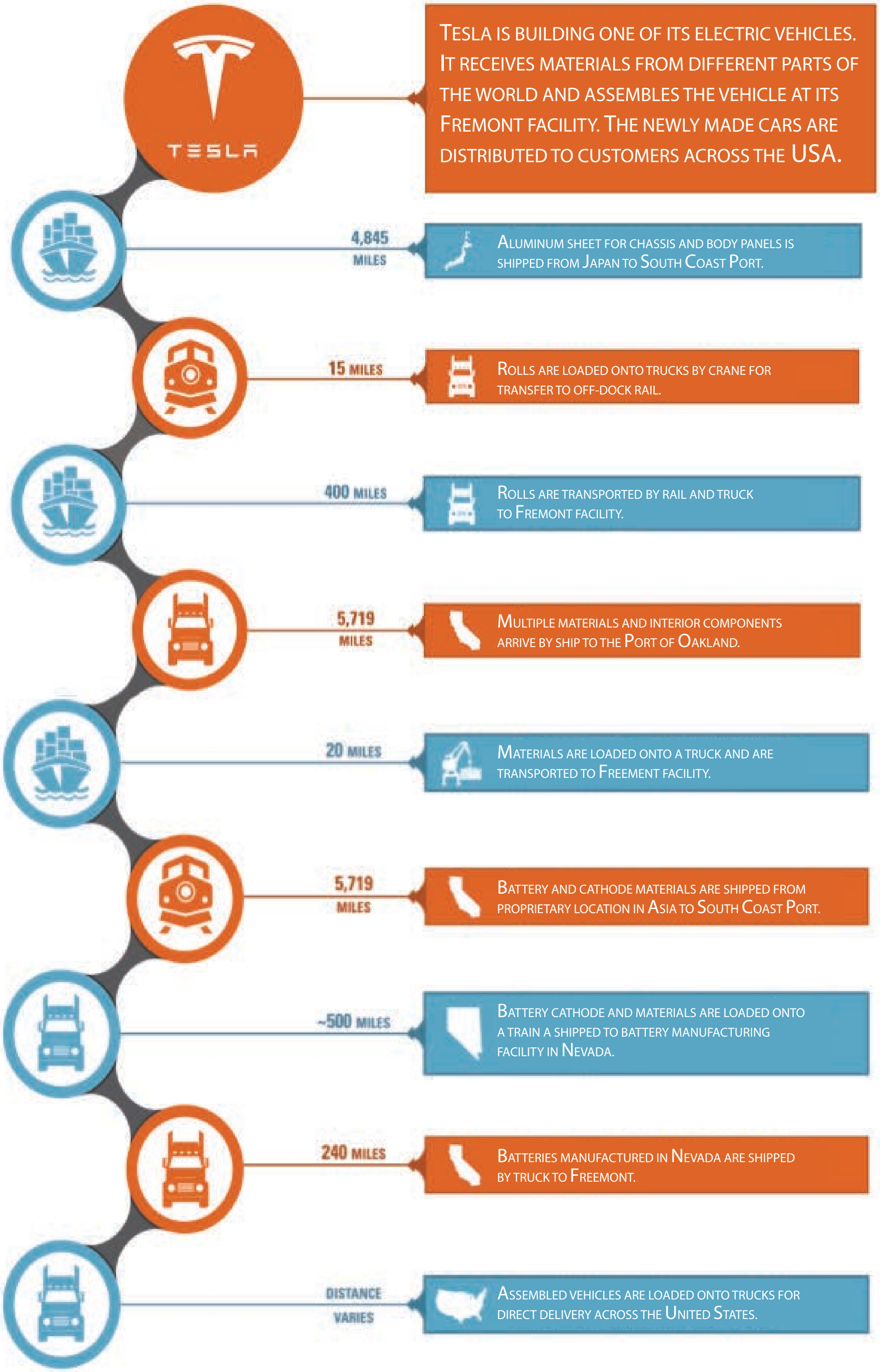


FIGURE 6 Scenario 2: Manufacturing of Tesla electric vehicles.

1. Are there any additional trends in the decarbonization of freight transportation that will affect the reduction of emissions to 80% below 1990 levels by 2050?

– How do other global trends (migration, settlement, technology) interact with the trends in the decarbonization of freight transportation?

– Are there opportunities when these trends converge? For example, will it be more difficult to decarbonize freight if more people shop online?

– What possible disrupters might there be within this time frame?

2. Are there any additional policy options to address challenges or foster opportunities to decarbonize freight transportation over the coming years? What opportunities to decarbonize freight have been missed in the past, and what policy options could have been adopted to avoid that?

3. What other ideas should be considered in the strategic planning framework for decarbonization pathways that will advance the freight transportation system over the next 30 years? What other factors have hindered the decarbonization of the freight system?

4. What are the correct measures for evaluating the decarbonization of the logistics and long-distance transportation of freight, and what further research is needed to enable these measures to be used successfully across the complex stakeholder landscape?

5. Given that infrastructure has a lead time, how can freight infrastructure solutions be developed that do not use technology that will be obsolete by the time construction is completed?

6. What are possible social or political problems that could arise from decarbonizing freight?

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APPENDIX F

PROGRAM

DECARBONIZING TRANSPORT FOR A SUSTAINABLE FUTURE: MITIGATING IMPACTS OF THE CHANGING CLIMATE

Fifth EU-U.S. Transportation Research Symposium

Organized by the
European Commission
Transportation Research Board

May 17–18, 2017
National Academies of Sciences, Engineering, and Medicine Building
Washington, D.C.

WEDNESDAY, MAY 17, 2017

7:30 a.m. Registration and Breakfast

8:30 a.m. **Welcome and Opening Remarks**
Neil J. Pedersen, Transportation Research Board
Robert Missen, Directorate-General for Mobility and Transport, European Commission

Purpose and Scope for the Fifth EU-U.S. Symposium: Decarbonizing Transport for a Sustainable Future
Kate White, California State Transportation Agency (standing in for Steven S. Cliff, California Air Resources Board)
Simon Edwards, Ricardo

9:00 a.m. **Opening Keynote Address**
Transport Emissions After the 21st Conference of the Parties
Axel Friedrich, International Council on Clean Transportation

9:30 a.m. **Presentation: White Paper**
Decarbonizing Transport for a Sustainable Future: Mitigating Impacts of the Changing Climate
David L. Greene, University of Tennessee, Knoxville
Graham Parkhurst, University of the West of England, Bristol

10:30 a.m. Morning Refreshment Break

10:45 a.m. **Setting the Scene: Why We Cannot Wait!**
Seleta Reynolds, City of Los Angeles Department of Transportation
Helle Søholt, Gehl

11:30 a.m. **Review of the Two Exploratory Topics for Day 1**

Exploratory Topic 1
Breaking Silos and Human Cocreation on Multiple Levels: The Key to Transforming the Current Sociotechnical Transport System Regime?
Daniel Kreeger, Association of Climate Change Officers
Malin Andersson, Urban Transport Administration, City of Gothenburg

Exploratory Topic 2
The Influence of Policy Environment Factors on Climate Change Mitigation Strategies in the Transport Sector
Timothy Sexton, Minnesota Department of Transportation
Oliver Lah, Wuppertal Institute for Climate, Environment, and Energy

12:30 p.m. Networking Lunch

1:30 p.m. **Working Group Discussion on Exploratory Topic 1**
Breaking Silos and Human Cocreation on Multiple Levels: The Key to Transforming the Current Sociotechnical Transport System Regime?

3:00 p.m. Afternoon Refreshment Break

3:30 p.m. **Working Group Discussion on Exploratory Topic 2**
The Influence of Policy Environment Factors on Climate Change Mitigation Strategies in the Transport Sector

5:00 p.m. **Wrap-up for Day 1 and Adjourn**

5:30 p.m. Mix and Mingle: Networking Reception

Thursday, May 18, 2017

7:30 a.m. Breakfast

8:00 a.m. **Review of the Two Exploratory Topics for Day 2**

Exploratory Topic 3
Megaregions: Policy, Research, and Practice
Ray F. Toll, U.S. Navy (ret.), and Old Dominion University
Delia Dimitriu, Manchester Metropolitan University

Exploratory Topic 4
Decarbonizing the Logistics and Long-Distance Transportation of Freight
Kate White, California State Transportation Agency
Simon Edwards, Ricardo

8:45 a.m. **Working Group Discussion on Exploratory Topic 3**
Megaregions: Policy, Research, and Practice

10:30 a.m. Morning Refreshment Break

11:00 a.m. **Working Group Discussion of Exploratory Topic 4**
Decarbonizing the Logistics and Long-Distance Transportation of Freight

12:30 p.m. Networking Lunch

1:30 p.m. **Report-Out on the Working Group Discussions**
Simon Edwards, Ricardo, Facilitator

2:30 p.m. **Concluding Keynote Presentation**
Decarbonizing Transport: To Life in a Sustainable World—
What Did We Learn, What Can We Do?
José Viegas, International Transport Forum

3:15 p.m. **Last-Chance Assertions**
Timothy Sexton, Minnesota Department of Transportation, Facilitator

4:00 p.m. **Adjourn**

APPENDIX G

Symposium Attendees

Michele Acciaro
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Washington, D.C., USA

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U.S. Department of Transportation
Washington, D.C., USA

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U.S. Department of Transportation
Washington, D.C., USA

Peter Chipman
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Madrid, Spain

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Manchester Metropolitan University
Manchester, U.K.

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Tesla
Brussels, Belgium

Mario Dogliani
SEA Europe
Brussels, Belgium

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Shoreham-by-Sea, UK

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Brussels, Belgium

Heather Hamje
CONCAWE
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Harvard University
Cambridge, Massachusetts, USA

Allie Kelly
Ray C. Anderson Foundation
Atlanta, Georgia, USA

Malgorzata Kirchner
Institute of Logistics and Warehousing
Pozna, Poland

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