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COVER: Curbing emissions of greenhouse gases from transportation sources can lead the way in national and international efforts to halt climate change. (Design by Michelle Wandres; earth image courtesy of NASA)

TR NEWS

features articles on innovative and timely research and development activities in all modes of transportation. Brief news items of interest to the transportation community are also included, along with profiles of transportation professionals, meeting announcements, summaries of new publications, and news of Transportation Research Board activities.

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PHOTO: BRIAN DALBALCON, PORT OF TACOMA



International container shipments continue to their destinations via other modes at the Port of Tacoma Road Overpass, Washington.

Transportation and globalization is the theme of the July–August TR News, with feature articles exploring the relationship of international freight transportation to national economic recovery and global sustainability; the effects of globalization on infrastructure and on national security and terrorism; a history of global trade, going back to ancient Rome; an opinion piece on the contributions of seaports to prosperity and employment; a quiz on globalization and international transportation; and a look at lessons learned from the disruption of air traffic by ash from the volcanic eruptions in Iceland.



CLIMATE CHANGE: CURBING TRANSPORTATION'S CONTRIBUTIONS

INTRODUCTION

Transportation and Climate Change

Developing Technologies, Policies, and Strategies

JONATHAN D. RUBIN AND ROBERT B. NOLAND

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The rapid increases in the speed, efficiency, and accessibility of the transportation system over the past century have enabled unprecedented levels of social interaction and economic productivity throughout the world. Transportation for personal mobility and for the movement of freight is integral to the high standard of living in developed nations and to fostering growth in developing nations.

Transportation activity, however, is a major user of the world's carbon-rich fossil fuels and a major source of carbon dioxide (CO₂) and other greenhouse gas (GHG) emissions associated with climate change. In the past 40 years, the developed world has mitigated many of the adverse environmental and public health impacts from transportation emissions—particularly in reducing the tailpipe pollutants from the burning of gasoline and diesel fuels.

Challenging Endeavor

Yet the recent oil release in the Gulf of Mexico starkly and dramatically emphasizes that the environmental impacts of oil use remain a vexing problem. Addressing the transportation sources of climate change, in particular, is a challenging and complicated endeavor—climate change is possibly the greatest environmental and social challenge worldwide. Nonetheless, previous success in mitigating environmental problems instills a confidence that the transportation sector can reduce its significant contributions to climate change.

GHG emissions accumulate in the atmosphere; reducing emissions therefore offers the best strategy for preventing the buildup of GHGs to levels that pose a major risk to human and natural systems. Significantly reducing GHG emissions from transportation will require actions that go beyond increasing vehicle fuel efficiency and that encompass initiatives in all of the major passenger and freight modes.



PHOTO: WIKIMEDIA COMMONS

Traffic near Siam Square in Bangkok, Thailand. Expanding personal transportation networks play a major role in the growth of developing nations.

Transportation GHG emissions consist largely of CO₂ from petroleum combustion (93 percent of emissions) but also include non-CO₂ emissions of methane and nitrous oxide from fuel combustion, as well as hydrofluorocarbons from vehicle air conditioning units—see Table 1, next page (1). Globally, the transportation sector is responsible for 23 percent of energy-related GHG emissions, with approximately three-quarters from road vehicles (2). In the United States, the transportation sector produces 34 percent, reflecting the higher per capita consumption of carbon-based fuels compared with the rest of the world (see Figure 1, next page). Transportation also exerts an indirect effect on climate change by inducing land use changes in agriculture, settlement patterns, housing, and business locations.

TABLE 1 Total U.S. Greenhouse Gas Emissions by the Transportation Sector, 2007

	Million metric tons in CO ₂ -equivalent warming potential
Carbon dioxide	1,902.5
Methane	5.1
Nitrous oxide	56.2
Hydrofluorocarbons	72.7
Total	2,036.5

(Source: *Transportation Energy Data Book*, Edition 28, Table 11.4. www.cta.ornl.gov/data/tedb28/Edition28_Full_Doc.pdf.)

Body of Evidence

This issue of *TR News* brings together leading experts to provide an overview of transportation's role in GHG buildup and in energy use. Several articles highlight recent reports published by the Transportation Research Board and by other units of the National Research Council (NRC). NRC is releasing reports in two series, *America's Energy Future* and *America's Climate Choices*, that present the perspective of all the major energy-consuming sectors.¹

As explained in the NRC reports summarized in this issue (page 6), a strong and credible body of evidence documents that the earth is warming and that this warming is caused largely by human activities, especially through the release of GHGs from the burning of petroleum and other fossil fuels. Many models of emissions trends and climate risks indicate that GHG emissions may need to be reduced worldwide by 50 to 80 percent—perhaps by even more—by the middle of this century. To achieve these deep reductions will require actions that cut across all energy-using sectors to effect a marked departure from the current trajectory of increasing emissions, as one of the new NRC reports makes clear.

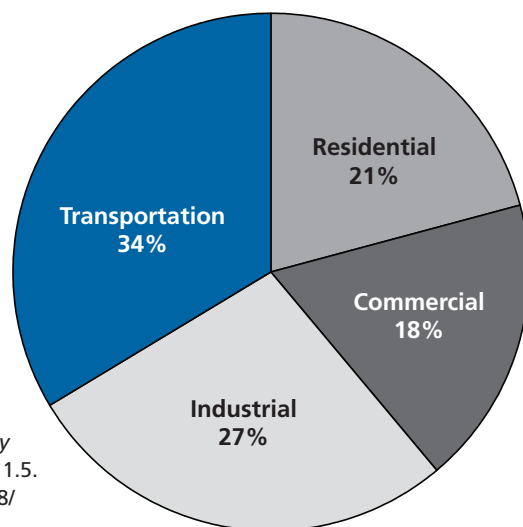


FIGURE 1 U.S. carbon dioxide emissions from fossil fuel consumption by the energy-use sector, 2007. (Source: *Transportation Energy Data Book*, Edition 28, Table 11.5. www.cta.ornl.gov/data/tedb28/Edition28_Full_Doc.pdf.)

Mix of Transportation Strategies

The article by Fulton (page 15) notes that no single transportation technology or policy action offers a promising means of achieving such deep reductions; instead, a mix of different technologies, policies, and strategies is necessary. The mix likely will involve sustained increases in the fuel economy of all kinds of vehicles, switching to fuels with lower GHG emissions per mile, and reducing the demand for energy- and emissions-intensive transport services, with a range of actions from shifting modes to changing urban form.

The spectrum of actions includes the deployment of intelligent transportation systems that improve operational efficiency (see article by Barth and Boriboonsomsin, page 26) and public policies that promote less energy-intensive patterns of land use (see article by Gómez-Ibáñez and Humphrey, page 24). As Frankel and Menzies point out (page 10), these outcomes require many well-informed and complementary policy choices.

Because CO₂ emissions from transportation are roughly proportionate to the amount of petroleum consumed, the price of gasoline, diesel, and alternative fuels can affect emissions through fuel demand and supply. Despite recent spikes in the price of petroleum, however, U.S. transportation fuel costs have been relatively low. The low price, along with rising incomes, has favored heavier and larger personal vehicles that tend to use more fuel and produce greater quantities of GHG emissions.

Regulatory Approaches

To counter this, the U.S. government has taken several actions. For example, federal tax incentives and other policy initiatives are spurring the introduction of vehicles with battery-powered electric drives. As explained by Turrentine (page 32), this poses many challenges, including integration with the electricity infrastructure. In addition, the U.S. Environmental Protection Agency and the National Highway Traffic Safety Administration have promulgated new performance regulations to increase the fuel economy of cars and light trucks and to reduce vehicle emissions of GHGs, including substances besides CO₂ (see article by Noland, page 12).

At the state level, California is pioneering an approach to control GHG emissions by regulating fuels, seeking to spur the development and use of low-carbon fuels such as advanced biofuels. In his article (page 29), Sperling explains California's low-carbon fuel standard, which accounts for the total emissions from fuels, from production to consump-

¹ <http://sites.nationalacademies.org/energy/>; <http://www.americasclimatechoices.org/index.shtml>.



PHOTO: OHIO DEPARTMENT OF TRANSPORTATION

The changes in land use in the areas surrounding roadways and other transportation networks indirectly contribute to climate change.

tion, to achieve net GHG reductions—a critical challenge for all mitigation policies.

Modal Initiatives

Freight activity and its modal distribution also may need to change substantially, depending on progress in boosting energy efficiency and diversifying the energy supply, especially in the trucking sector (see article by Mintz, page 34). The international maritime sector, instrumental in providing cheap transportation for global trade, emits as much CO₂ as some of the world's most prosperous countries—and therefore is becoming a target of policy interventions, as discussed by Corbett, Winebrake, and Wang (page 40).

The aviation sector is becoming a major contributor to transportation emissions globally, and international efforts to control emissions are under way. Aviation depends on liquid fuels with a high energy content, prompting research to develop biofuels for this vital and safety-conscious sector (see article by Anger and Putnam, page 45).

Opportunities for Innovation

The research challenge is beginning, with many issues needing more informed and careful analysis, as Meyer and Godwin point out (page 21). Meeting the challenge of climate change will provide opportunities for innovation—extensive and intensive innovation in technologies, practices, and policies. Although this

issue of *TR News* can cover only a sample of the needs for research and innovation, the articles reflect the importance of a large, varied, and vibrant transportation research community going forward.

Acknowledgments

Members of several TRB committees were instrumental in developing, assembling, and reviewing the articles in this issue of *TR News*, including the TRB Special Task Force on Climate Change and Energy, the Transportation Energy Committee, the Alternative Transportation Fuels and Technology Committee, the Climate Change Joint Subcommittee, and the Transportation and Sustainability Committee. Appreciation is expressed to TRB Senior Program Officer Thomas R. Menzies, Jr., for his work with the committee chairs and authors and with TRB senior staff and the magazine's editorial board in shaping the final content of this issue.

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1. *Emissions of Greenhouse Gases Report*. DOE/EIA-0573, U.S. Energy Information Administration, December 2009.
2. Kahn Ribeiro, S., S. Kobayashi, M. Beuthe, J. Gasca, D. Greene, D. S. Lee, Y. Muromachi, P. J. Newton, S. Plotkin, D. Sperling, R. Wit, and P. J. Zhou. Transport and Its Infrastructure. In *Climate Change 2007: Mitigation—Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [B. Metz, O. R. Davidson, P. R. Bosch, R. Dave, and L. A. Meyer (eds.)], Cambridge University Press, Cambridge, United Kingdom, and New York, 2007.



AMERICA'S CLIMATE CHOICES

The State of Climate Change Science and Options for Limiting Future Climate Change

In May 2010, the National Research Council of the National Academies released reports in the America's Climate Choices suite of studies requested by the U.S. Congress to inform and guide the nation's response to climate change. Experts representing government, the private sector, nongovernmental organizations, and research and academic institutions provided advice in the peer-reviewed reports on limiting the magnitude, adapting to the impacts, and advancing the science of climate change, as well as on informing effective decisions to address the problem. The reports addressing the status of climate change science and the options for limiting the magnitude of climate change are summarized here.

The Science of Climate Change

Science has made enormous progress toward understanding climate change. A strong and credible body of evidence, based on several lines of research, documents that the earth is warming. Strong evidence indicates that this warming is caused largely by human activities, especially from the release of greenhouse gases (GHG) through the burning of fossil fuels.

Global warming is closely associated with other climate changes and impacts, including rising sea levels, increases in intense rainfall events, decreases in snow cover and sea ice, more frequent and intense heat waves, increases in wildfires, longer growing seasons, and ocean acidification. Individually and



PHOTO: SEAN WAUGH, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Certain earth system processes, such as clouds, are not yet fully understood, which leads to complexities and uncertainties in mapping the rate and reach of climate change.

collectively, these changes pose risks for a range of human and environmental systems.

Although much remains to be learned, the core phenomenon, scientific questions, and hypotheses have been examined thoroughly and have proved firm in scientific debate and after careful evaluation of alternative explanations. In the past 100 years, temperatures have risen 1.4°F (0.8°C); projections of climate change anticipate an additional warming of 2.0°F to 11.5°F (1.1°C to 6.4°C) in the 21st century, with even larger temperature increases over land areas and at higher latitudes.

Projected Impacts

The projected impacts of climate change include the following:

- ◆ Decreased availability of water in many drought-prone areas and in areas in which glaciers or snowpack feed into rivers;
- ◆ A higher fraction of rainfall in the form of heavy precipitation, increasing the risk of flooding and—in some regions—the spread of waterborne illness;
- ◆ Rising sea levels, exposing people and ecosystems in coastal zones to storm surges, the intrusion of salt water into freshwater aquifers, and other risks; and
- ◆ Increasing temperatures, rising sea levels, and ocean acidification, with widespread bleaching of coral reefs.

Other projections are less certain—for example, how the combined increases in GHGs, temperature, precipitation changes, and other climate and climate-related changes will affect agricultural crops and natural ecosystems in different regions. Different sectors, populations, and regions will vary in their exposure and sensitivity to the impacts of these changes, but research suggests that climate change will affect poorer nations and communities more harshly.

Scientific research has revealed a great deal about responses to climate change. A growing body of knowledge is identifying technologies and policies to limit emissions and the magnitude of climate change, expanding understanding of the steps for adapting to climate change, and recognizing that climate change will need to be considered in actions and decisions across a range of sectors and interests (see box, this page).

Complexities and Uncertainties

Some earth system processes—such as ice sheet dynamics, cloud processes, and regional climate effects—are incompletely understood or not fully resolved in current climate models, leading to uncer-

What Is Known About Climate Change?

- ◆ Thermometer measurements show that the earth's average surface temperature has risen substantially in the past century and especially in the past three decades.
- ◆ A variety of independent observations also show warming in other parts of the earth system, including the oceans, the lower atmosphere, and ice-covered regions.
- ◆ Most of the recent warming is attributable to fossil fuel burning and to other human activities that release CO₂ and other heat-trapping GHGs into the atmosphere.
- ◆ Human activities also have resulted in an increase in small particles in the atmosphere, which on average tend to have a cooling effect, but this cooling is not strong enough to offset the warming associated with GHG increases.
- ◆ Changes in solar radiation inputs and volcanic activity also can influence climate, but observations show that these changes cannot explain the recent warming trend.
- ◆ Natural climate variability leads to year-to-year and decade-to-decade fluctuations in temperature and other climate variables, as well as to significant regional differences, and these fluctuations will continue under human-caused climate change.
- ◆ Human-caused climate changes and impacts will continue for many decades and in some cases for many centuries. The magnitude of climate change and the severity of its impacts will depend on the actions that human societies take to respond.

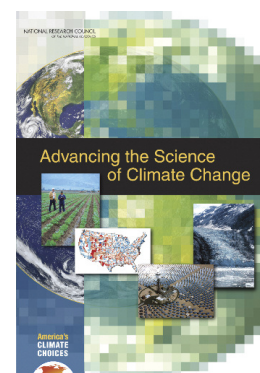
tainties about the magnitude and rate of global climate change and its local and regional manifestations.

Climate change also poses special challenges. For example, many climate change processes have long time lags, so that future generations will have to deal with the consequences of today's decisions. The earth system could cross thresholds that trigger abrupt changes or other unexpected events. The potential consequences could be irreversible and challenging, but the likelihood of such events is not well understood, so that it is difficult to account for these risks in decision making.

The earth's future climate clearly will be unlike the climate that ecosystems and human societies have experienced during the past 10,000 years, leading to significant challenges across a range of human endeavors. Climate change and the severity of its impacts will be greater if actions are not taken to limit its magnitude and to adapt.

Limiting the Magnitude of Climate Change

The burning of fossil fuels is the largest source of GHG emissions. The global atmospheric concentration of carbon dioxide (CO₂), the dominant GHG, is increasing by roughly 2 parts per million



Advancing the Science of Climate Change is one of the foundational volumes in the National Research Council's series, *America's Climate Choices*.

Annual U.S. Emissions

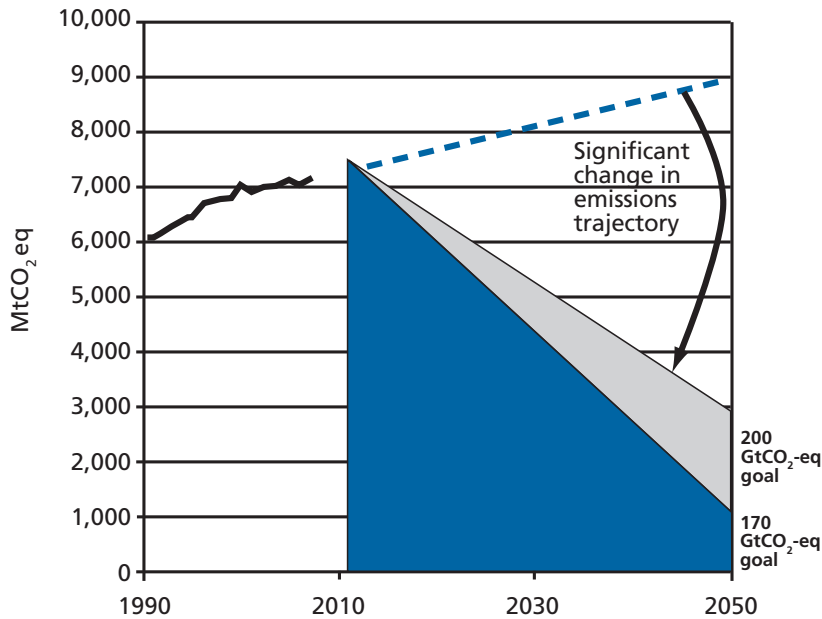


FIGURE 1 Meeting a strict GHG budget for the U.S. would require a significant departure from business as usual. [Note: 1 Gt (gigaton) = 1,000 million metric tons (Mt) of CO₂-equivalent GHG gases normalized by warming potential over a 100-year period. In 2007, the United States emitted about 7.1 billion Mt (7.1 Gt) of CO₂-equivalent GHGs. In burning approximately 200 billion gallons of gasoline, diesel, and jet fuel, U.S. transportation vehicles produced about 1,800 million Mt of CO₂ (1.8 Gt) or about 25 percent of the national total.]

per year; the United States is second to China as a contributor to global CO₂ emissions. U.S. emissions are driven by a growing national economy and a growing population. Even with expected improvements in energy efficiency, U.S. emissions will continue increasing under business as usual.

GHGs currently are emitted without penalty. With no financial incentives or regulatory pressure, the nation will continue to rely on and adopt carbon-intensive technologies and systems.

Setting a GHG Budget

A national policy for reducing emissions will require setting a measurable goal. The NRC report suggests establishing national goals with a quantitative limit on domestic GHG emissions over a specific period of time—in other words, setting an emissions budget.

Because of the scientific uncertainties in identifying a safe level of global GHG emissions, and because of the political and ethical judgments in determining an appropriate U.S. share of global emissions, however, the report does not recommend a specific budget. Using recent studies from the Energy Modeling Forum,¹ the report suggests a representative domestic emissions budget in the range of 170 to 200 gigatons (Gt) of CO₂-equivalent for 2012 through 2050. This corresponds roughly

¹ <http://emf.stanford.edu>.

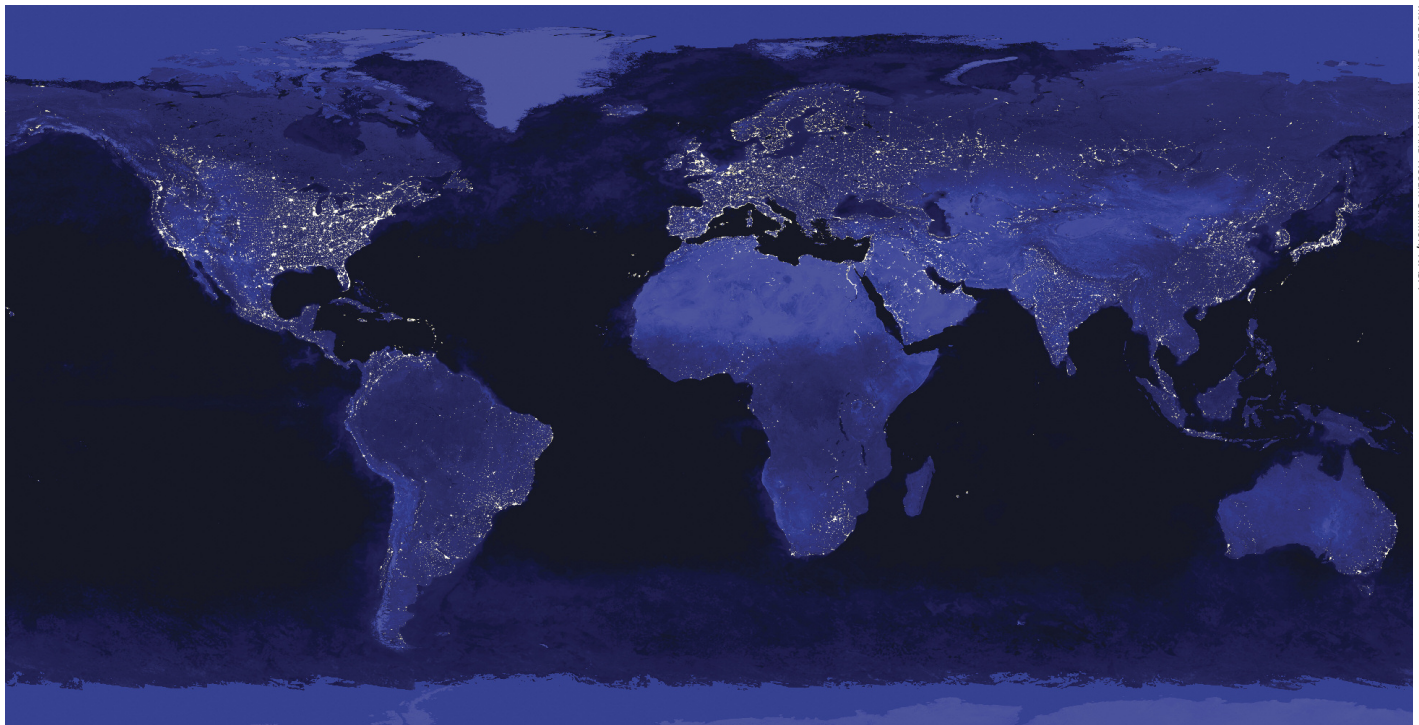


IMAGE: CRAIG MATHEW AND ROBERT SIMMON, NASA

to a reduction of emissions by 80 to 50 percent, respectively, from 1990 levels—a major departure from business-as-usual emission trends (see Figure 1, page 8). At the current rate—roughly 7 Gt of CO₂-equivalent per year—U.S. emissions would exceed the proposed budget well before 2050.

Opportunities for Reducing Emissions

Based on analyses in the Energy Modeling Forum studies and NRC's America's Energy Future studies²—which estimated the technical potential for expanding deployment of key energy technologies—the report concludes that meeting the representative emissions budget will be difficult, but technically possible. Within the electric power and transportation sectors, all available options—for energy efficiency, for low-carbon electricity production, for low-carbon fuels, and more—will need to be deployed at levels near the maximum estimates deemed technically possible by the America's Energy Future studies.

The estimates are based on optimistic assumptions about each technology's cost, performance, and social acceptance. Strong support of research and development, therefore, is needed to make new and improved technological options available. The analyses of potential emissions budget goals, and the degree of action required to meet the goals, underlie the report's conclusion that response efforts on a national scale are urgently needed to reduce GHG emissions.

Need for Policy Actions

The following core strategies are recommended for U.S. policy:

- ◆ Adopt an economywide carbon pricing system that creates incentives for emissions reduction and markets for low-emissions technologies.
- ◆ Complement the carbon pricing system with other sector-based policies aimed at ensuring rapid progress to realize the full potential of energy efficiency and low-emission energy sources.
- ◆ Advance demonstration efforts to establish the technical and economic feasibility of carbon capture and storage and of new-generation nuclear technologies, and accelerate the retirement or retrofit of emissions-intensive infrastructure.
- ◆ Create new technology choices by investing heavily in research and by crafting policies to stimulate innovation.
- ◆ Enable flexibility and experimentation with emissions-reduction policies at regional, state, and local levels.

² http://sites.nationalacademies.org/Energy/Energy_043336.



Photo: NASA

Balancing Durability and Flexibility

The report notes that a policy framework for limiting climate change will need to be durable and remain in place for decades. Nevertheless, the specific policies must be flexible to allow for responses to new developments in climate change science, socioeconomic trends, technological innovation, and understanding of the impacts and effectiveness of climate policy. Striking the right balance between the goals of policy durability and flexibility will be an important, but continuing, challenge.

For more information, contact the Board on Atmospheric Sciences and Climate, 202-334-3426, or visit <http://nationalacademies.org/basc>; or America's Climate Choices, americasclimatechoices.org. Copies of *Limiting the Magnitude of Future Climate Change* are available from the National Academies Press, 500 Fifth Street, NW, Washington, D.C. 20001; 800-624-6242; www.nap.edu.

Satellite image of wildfires in Southern California, October 2007; increases in wildfires and decreased availability of water in drought-prone areas are symptoms of climate change.

The severe storms and floods that hit Tennessee in May 2010 damaged and destroyed many homes and businesses. Increased heavy rainfall is a predicted consequence of climate change.



Photo: David Fine, Federal Emergency Management Agency



Why Focus on Transportation for Emissions Reduction?

EMIL FRANKEL AND THOMAS R. MENZIES, JR.

Frankel is Director of Transportation Policy, Bipartisan Policy Center, Washington, D.C., and Chair of the TRB Committee for a Study of Potential Energy Savings and Greenhouse Gas Reductions from Transportation. Menzies is Senior Program Officer, TRB Studies and Special Programs.

In recent years, much research and modeling have gone into determining the scale and scope of the cuts needed in greenhouse gas (GHG) emissions to stabilize atmospheric buildup and limit the risks of global climate change. As explained in the National Research Council's (NRC's) suite of reports, America's Climate Choices—summarized in this issue (see pages 6–9)—the models suggest that incremental cuts in fossil fuel use cannot meet the challenge. The models indicate that much of the world's energy supply may need to be decarbonized by midcentury, with sizable contributions from the most energy-demanding sectors, such as transportation.

Under the auspices of the Transportation Research Board, an NRC-appointed committee has been studying potential strategies and policies for reducing energy use and the emissions of GHGs by the U.S. transportation sector. The committee's report is scheduled for release later this year; this article reviews some of the context for the study.

Targeting Sectors

Why policy makers may want to target individual sectors is not self-evident—stabilizing GHG concentrations will require emissions reductions across all economic sectors and all regions of the world. Although accounting for approximately 25 percent of the carbon dioxide emitted in the United States, the U.S. transportation sector contributes only an estimated 5 percent of the emissions globally. Policy actions targeting U.S. transportation, therefore, can have significant effects on national GHG emissions but only marginal effects on global GHG emissions and buildup.

Many government policies, however, have aimed at reducing GHG emissions from U.S. transportation. Federal fuel economy standards for passenger cars and light trucks have increased substantially after years without change. In addition, national energy policies now include measures to diversify the mix of transportation fuels and vehicle technologies through mandates for the supply of advanced biofu-



Parking area at a Northern Virginia Metrorail station, adjacent to Route 66; measures to mitigate greenhouse gas emissions from transportation include diversifying the transportation infrastructure to reduce dependence on fossil fuels.



PHOTO: ARGONNE NATIONAL LABORATORY

A researcher at Argonne National Laboratory checks a plug-in hybrid electric vehicle battery. As the technologies develop and become more available, national energy policies can create incentives to purchase electric vehicles.

els, research into new energy sources, and tax incentives for developing and purchasing vehicles powered by electricity. Some of these policies may have other motives—for example, to reduce the U.S. economy's dependence on foreign oil—but can have a significant effect in cutting GHG emissions from transportation.

New policies are being adopted with the explicit goal of reducing GHGs. In 2007, the U.S. Supreme Court ruled that GHG emissions are candidates for regulation under the Clean Air Act (CAA); the ruling has opened a large avenue for policy action. Through this CAA authority, the U.S. Environmental Protection Agency (EPA) is introducing GHG performance standards for new cars and light trucks. These standards represent the first concerted federal effort to regulate transportation for GHG abatement and are likely to be followed by similar actions targeting other transportation modes, as well as stationary sources of GHGs.

Economywide or Sector-Based Measures?

Targeting transportation or any other sector of the economy for GHG mitigation remains a topic of debate. Even as EPA proceeded with GHG performance standards for passenger cars in 2009, Congress has been working on legislation to create broader, market-oriented means for reducing GHG emissions that include economywide carbon pricing

(see sidebar on legislative activities, page 12).

Most of the economic models that project the impacts of economywide carbon pricing assume that transportation users would be fairly unresponsive to higher carbon prices, at least in comparison with other sectors, such as electric power generation. For example, EPA's analysis of the carbon pricing program proposed in the American Clean Energy and Security Act of 2009 estimated that only 5 percent of the reductions in GHGs would come from transportation (1). The analysis noted that emissions reductions in the transportation sector are likely to be more expensive than in the electricity sector, which can substitute natural gas for coal in power plants.

Although the fleet of cars and trucks can be replaced in 8 to 10 years, far more time is required to change the physical infrastructure used for transportation and connected by transportation services. This infrastructure consists of the transportation network and of the vast built environment of homes, businesses, and other establishments often situated in relatively low-density urban areas designed to be served by personal vehicles and trucks (see article by Gómez-Ibáñez and Humphrey, page 24). Moreover, the nation's metropolitan areas have few practical means of connection, except by motor vehicle and air travel. As transportation fuel prices rise with carbon pricing, the adjustments by people and businesses to fundamental changes in travel patterns and means will take time.

The expected slow response by transportation to carbon pricing often is used to justify additional mea-

A U.S. Coast Guard port security specialist patrols the Mina al Bakr Oil Terminal in Iraq, 2003. A reliance on foreign oil supplies is at the root of many national security concerns.

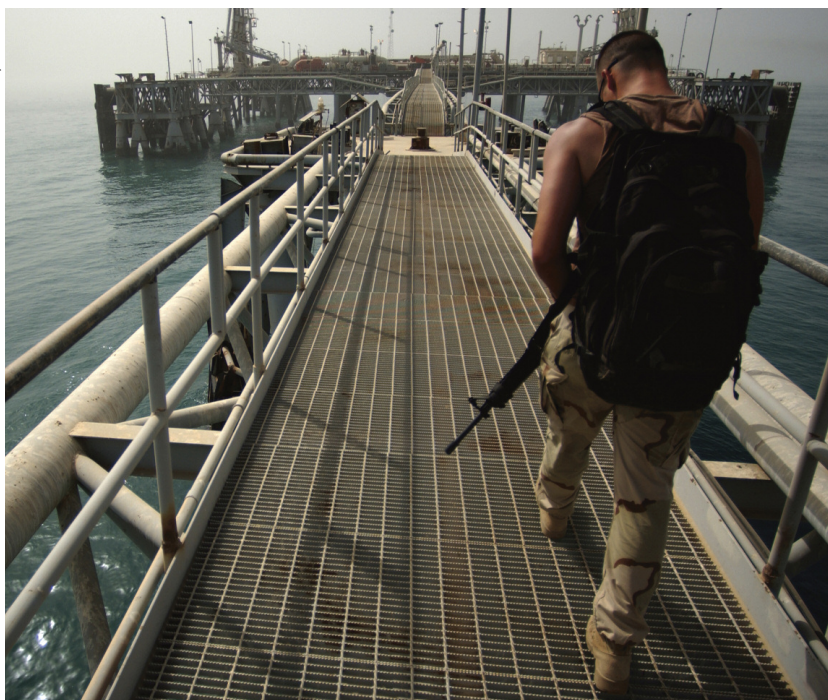


PHOTO: SHANE T. MCCOY, U.S. NAVY

Legislative and Regulatory Moves to Reduce Transportation's Greenhouse Gas Emissions

ROBERT B. NOLAND

The 111th Congress now in session has devoted much time and effort to addressing climate change. In June 2009, the House of Representatives passed the American Clean Energy and Security Act of 2009 (HR 2454). The full Senate has not considered comprehensive climate change legislation, although its Energy and Natural Resources Committee approved comprehensive clean energy legislation (S 1462) in July 2009. Both the House and Senate bills include market-based economic incentives, known as cap and trade, for reducing greenhouse gas (GHG) emissions, and both incorporate provisions for the deployment of transportation technology.

The ultimate prospect for these bills is uncertain, however; in the meantime, the Environmental Protection Agency (EPA) and the U.S. Department of Transportation (DOT) are drawing on current laws to mandate reduced GHG emissions per mile traveled by passenger vehicles and to sharpen the definitions and criteria for renewable fuels and feedstocks. Regulations and policies under active development and consideration include the revised Renewable Fuel Standard (RFS2) required by the Energy Independence and Security Act of 2007 (EISA); mandated national GHG emissions standards for mobile sources, authorized by the Clean Air Act; and updated Corporate Average Fuel Economy (CAFE) standards, required by EISA.

EPA recently released the RFS2 volumetric requirements for 2010, calling for approximately 8 percent of the total gasoline and diesel pool to consist of renewable content, mostly from corn-based ethanol. The life-cycle greenhouse gas emission reduction threshold for new corn-based ethanol production is 20 percent below that for petroleum gasoline. The emission reduction thresholds are greater for advanced biofuels, biomass-based diesel, and cellulosic biofuels: 50 percent, 50 percent, and 60 percent, respectively.

According to the requirements, a larger percentage of renewable fuels will consist of these second- and third-generation biofuels—such as algal diesel and cellulosic ethanol. By 2022, advanced biofuels will comprise almost 60 percent of the renewable fuel mandate. In this way, the move to renewable fuels will contribute a greater share to a drop in transportation's GHG emissions.

EPA and U.S. DOT are tightening fuel efficiency standards for passenger vehicles, building on rules issued by U.S. DOT in 2009. In March 2010, the two agencies released a combined GHG emissions and CAFE standard that will increase the fuel economy of the fleet substantially by 2016. The rule goes into effect with model year 2012. By model year 2016, the combined car and truck standard will be 250 grams of CO₂ emissions per mile.

The actual fuel economy of the combined fleet of cars and light trucks manufactured in 2016 will be 34.1 miles per gallon (mpg). Additional GHG standards to improve air conditioning systems in vehicles will achieve the fuel economy equivalent of 35.5 mpg. The new program allows flexibility—manufacturers

can trade credits with each other and can gain credits for earlier compliance with the standards.

In late May 2010, President Barack Obama issued a memorandum directing EPA and U.S. DOT to begin the rule-making process for further reductions for model years 2017 through 2025. The memorandum also directed both EPA and NHTSA to establish fuel efficiency and GHG standards for commercial medium- and heavy-duty trucks, starting with model year 2014, in accordance with the Clean Air Act and EISA.

Conventional wisdom now discounts the likelihood that climate legislation will emerge from the 111th Congress, and how much progress will be made is uncertain. An energy-only bill could have important implications for climate, especially by funding programs to advance the electrification of transport, the commercialization of carbon capture and storage, and—perhaps—the establishment of clean power requirements in the power sector. Regardless of what occurs on the legislative front, the Clean Air Act requires EPA to regulate GHG emissions—although many policy makers would prefer this to proceed under new legislation establishing a cap-and-trade system for the nation.

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Tesoro Refinery in Anacortes, Washington, was the site of a fire in April; the facility processes 120,000 barrels a day. Proposed national regulations call for renewable content and reduced GHG emissions.

PHOTO: AQUASENSE LLC

asures targeting this sector, in part to make it more responsive to pricing. But the United States may not institute carbon pricing or any other economywide mitigation measures anytime soon. The federal government's ability to adopt vehicle efficiency standards for GHG emissions, however, indicates the advantage of a sector-oriented approach to policymaking.

Efficiency standards are not the only sector-based options available. Transportation fuel taxes, vehicle registration fees, and various forms of vehicle and fuel tax incentives have been used in transportation for decades and present opportunities for GHG mitigation. Moreover, public entities own and operate much of the transportation infrastructure. Investments in these facilities and restrictions on their use can further the nation's climate and energy goals. Public policies also influence land use patterns and the built environment, which in turn affect the volume of transportation activity and energy consumption. These present many potential avenues for policymaking.

Addressing Other Impacts

Transportation's consumption of energy—and particularly its dependence on oil—offer many other compelling reasons besides GHG emissions for controlling energy use. The cost of securing global oil supplies is one reason (2). Protecting world oil supplies has created geopolitical and national security concerns that have been daunting issues for decades. A Rand Corporation study estimates that the United States could have saved between 12 and 15 percent of its defense budget for fiscal year 2008 if all concerns about securing oil from the Persian Gulf had disappeared (3).

Oil price volatility is another reason for taking action. In the past dozen years, crude oil prices have soared as high as \$140 and dropped as low as \$20 per barrel. This volatility creates a host of challenges for energy users and suppliers, for manufacturers of vehicles and other products that use oil, and for investors in other energy sources. By discouraging capital-intensive investments in energy production that require long payoff periods, oil price volatility can have pernicious effects on attempts to diversify transportation energy sources and technologies. Paradoxically, energy diversification, in the long run, can be instrumental in dampening oil price volatility and its adverse effects on transportation and the economy at large.

Transportation's use of oil contributes to many other vexing environmental impacts. The products and byproducts of gasoline and diesel fuel consumption—such as emissions of oxides of nitrogen, carbon monoxide, volatile organic compounds, and



Photo: BP

aerosols—are important sources of metropolitan and regional air pollution, harmful to humans and the environment. In the past 40 years, significant progress has been made in controlling the impacts on public health and the environment, but at considerable financial expense.

Scrutiny of the public health and environmental impacts of oil use intensified with the catastrophic oil release in the Gulf of Mexico, starting April 30. Yet the environmental disturbances from oil exploration, extraction, and refining have been controversial for decades. Oil leaks and spills have caused chronic and acute environmental disturbances—infesting groundwater, sullyng shorelines, and causing eco-

Workers clean the beach at Grand Isle, Louisiana, in the wake of the Deepwater Horizon–BP oil spill that began April 20.

The oil spill in the Gulf of Mexico highlighted the concerns that have surrounded oil production for many years.



Photo: BP

Vehicle fuel and GHG performance standards are having an impact on cars and light trucks and are likely to be extended to trucking.



PHOTO: SHERI ARMSTRONG, DREAMSTIME.COM

logical damages to water resources. The recent incident in the Gulf amplifies these concerns and will play a prominent role in future energy and environmental policymaking.

A Strategic Policy Response

Decisions about the best ways to reduce transportation's use of energy and its emissions of GHGs will occur over decades, in the context of a larger national and international effort to manage the risks of climate change. Policymaking will need to be flexible and adaptable, capable of responding to new information—such as scientific understanding of climate risks—and to changes in technology.

At the same time, policy options should be pursued in the context of a response strategy, underpinned by realistic assessments of how different policies can reduce transportation emissions. Policy approaches that can be adopted early, even if they promise modest emissions impacts, deserve attention but cannot be the sole focus. Policies that have the potential for large but longer-term impacts on emissions must be central to the strategy. In such instances, the best approach may be to confront the challenges to implementation and to explore ways to overcome them.

Vehicle fuel and GHG performance standards have proved acceptable largely by association with reducing transportation's dependence on foreign oil. The standards already are having an impact on energy use and emissions by cars and light trucks. In the next several years, vehicle efficiency standards are likely to be extended to other modes, such as trucking. These policies are highly implementable and

promise important near- and medium-term reductions in transportation emissions.

Policies that address more than vehicle efficiency—such as the amount of travel and the types of fuels used—also will be necessary to achieve deep cuts in emissions during the next half century. Fuel taxes, carbon pricing, and other market-oriented policies frequently are advocated because they can generate a broad-based response and complement other policy initiatives. Such policies present implementation challenges, however, and face public and political resistance. The immediate challenge, therefore, is to improve understanding of these policies and to find ways to overcome the barriers.

In the longer term, the actions taken in transportation must be part of a national, economywide strategy. Economywide policy choices will have important implications on transportation and on the other sectors. Until then, transportation may be an important precursor and testing ground for economywide action.

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Curbing Carbon Dioxide Emissions from Transportation

Scenarios for Meeting the Global Challenge

LEW FULTON

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Transportation accounted for approximately 19 percent of global energy use and 23 percent of energy-related carbon dioxide (CO₂) emissions worldwide in 2006; these shares are likely to rise. Without marked changes in current trends, transportation energy use and CO₂ emissions are projected to increase by nearly 50 percent by 2030 and by more than 80 percent by 2050.

This growth in CO₂ emissions is not compatible with the goal of controlling the risks of climate change. The United Nations Intergovernmental Panel on Climate Change (IPCC) advises that global CO₂ emissions must be cut by at least 50 percent by 2050 from current emissions levels, to avoid the severest impacts of climate change.

Transportation must play a significant role in achieving these deep cuts. Even with deep cuts in emissions from all other energy-using sectors, transportation will need to reduce emissions significantly to stabilize atmospheric concentrations of greenhouse gases (GHGs) in the range of 450 parts per million (ppm) to 550 ppm of CO₂ equivalent (CO₂-eq) by mid-century.¹

Changing the Trends

An analysis completed for the International Energy Agency (IEA) BLUE Map futures scenario shows how the introduction and widespread adoption of new vehicle technologies and fuels, along with some shifts in passenger and freight transportation to more energy-efficient modes, can yield a reduction of 30 percent in transportation CO₂-eq emissions in 2050 from 2005 levels, and a reduction of 70 percent from baseline trends in 2050 (1, 2). Accompanied by other actions to cut CO₂ emissions from all energy-using sectors, a 70 percent reduction from transportation

¹ CO₂-eq includes CO₂, methane (CH₄), and nitrous oxide (N₂O). Except for upstream emissions during fuel production, particularly for biofuels and natural gas, however, CO₂ has the most impact on climate.



PHOTO: ENVIRONMENTAL PROTECTION AGENCY

If action is not taken to mitigate their effects, transportation emissions of greenhouse gases are predicted to increase by more than 80 percent by 2050.

can make an important contribution to stabilizing atmospheric concentrations of CO₂ within the targeted range.

But changing transportation trends to achieve this reduction will not be easy. Industry, government, and users of transportation services must be involved. The task is to combine the widespread adoption of the best available technology with longer-term development and deployment of many new technologies and to encourage a willingness among consumers to adopt the technologies and make changes in their travel behavior. Transport modes in every region of the world will need to reduce emissions significantly from the baseline trends (1).

Although some energy-saving technologies and measures appear to be available at low or even neg-

Oil wells along I-20 in Midland, Texas. Consumer demand can provide the incentive for industry to invest in new, low-emissions fuel technologies.



PHOTO: WIKIMEDIA COMMONS

ative cost—based on the value of the fuel savings—aggressive and concerted policies will be needed to spur rapid adoption and extensive use of the technologies, as well as to encourage travel shifts to more efficient modes. In many cases—for example, the penetration of new vehicle types—the pace of change will need to occur at a faster rate than it has in recent decades.

Industry will need incentives and encouragement to make large, often risky investments in technology, and consumers will have to demand these technologies—for example, by buying new types of vehicles. The challenge of reaching the 70 percent target should not be underestimated.

Baseline Emissions Trends

From recent and projected economic and demographic trends—particularly growth in population

and in the gross domestic product (GDP) per capita—business-as-usual scenarios can be constructed for global transportation energy use into the future. The IEA World Energy Outlook (WEO) provides a reference-case scenario to 2030, assuming that no significant new energy or climate policies will be implemented and that growth in transportation activity and energy use will accompany growth in population and GDP (3). The IEA *Energy Technology Perspectives* report extends the WEO projection to 2050 (1).

With these projections as the baseline scenario, global passenger and freight transport activity will double by 2050, and associated energy use will nearly double, compared with 2005 levels. Under the baseline scenario, average transport energy intensity declines but does not offset growth in travel or prevent growth in energy use. In comparison,

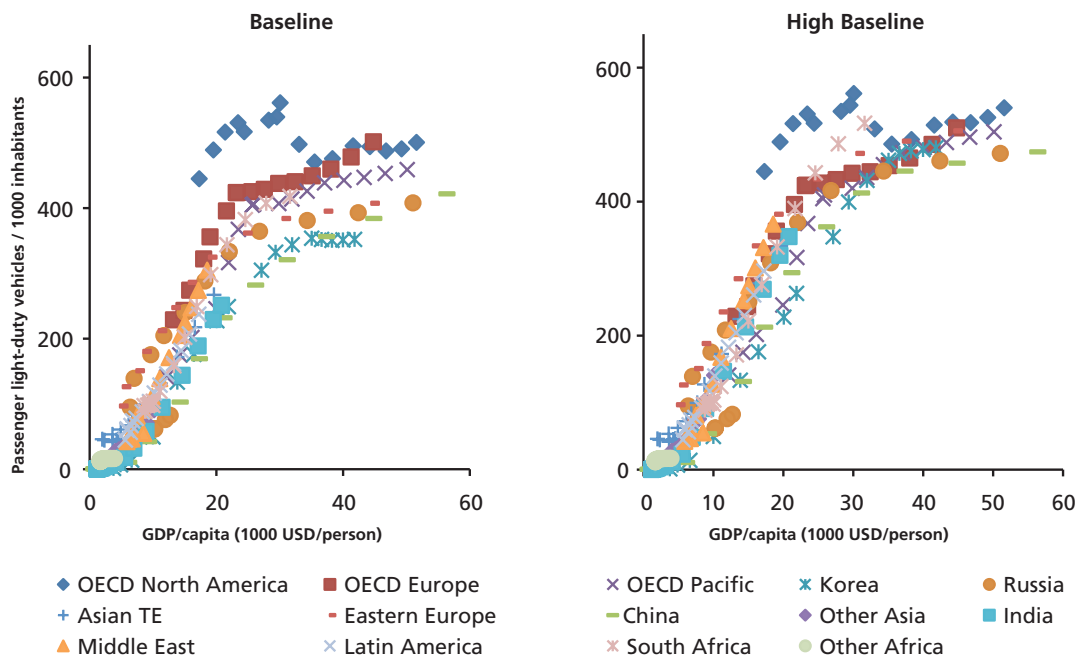


FIGURE 1 Passenger car ownership projections. (GDP = gross domestic product; USD = U.S. dollars; OECD = Organisation for Economic Co-operation and Development; TE = transitional economies.)

according to a high-growth scenario that accounts for higher growth rates in car ownership and in other activity indicators across the transport modes, transportation energy use would increase by 130 percent by 2050.

Continued growth in car ownership is changing passenger travel worldwide. Figure 1 (facing page) shows the IEA projections of car ownership as a function of income in countries and regions around the world through 2050. The baseline scenario assumes that car ownership in most developing countries will remain at low levels according to income, as was the case in Japan and South Korea during the past 2 to 3 decades. In the high baseline scenario, developing countries are assumed to have levels of car ownership closer to those of European countries at given levels of income.

The difference in the projections is dramatic. In the baseline scenario, the number of cars owned reaches an estimated 2.1 billion by 2050, compared with approximately 800 million in 2005. In the high baseline scenario, car ownership approaches 3 billion.

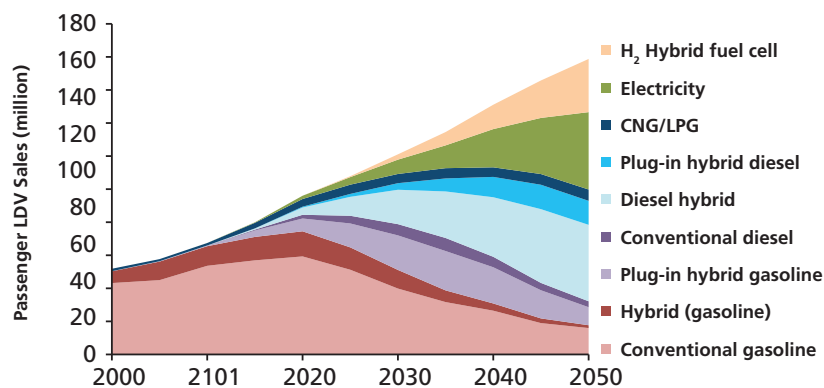
Because of the increased energy use, both the baseline and high baseline scenarios produce marked growth in transportation emissions of GHG. On a well-to-wheels basis, CO₂-eq emissions grow by nearly 100 percent in the baseline scenario and by approximately 140 percent in the high baseline scenario. These CO₂ growth rates are not compatible with the sharp reductions needed to stabilize GHG concentration during this period. Nonetheless, alternative scenarios for CO₂ emissions trends may be achievable.

Technology Paths

Changing the direction of transportation energy use and CO₂ emissions will require a radical departure from recent transportation trends. IEA has explored several scenarios for low CO₂ futures and has traced out the necessary changes in vehicles, energy sources, and activity, as well as the actions that can help bring about the changes.

IEA has developed a foundational low-CO₂ scenario to 2050, called BLUE Map. According to this scenario, a combination of changes in technologies and fuels can achieve a 70 percent reduction in the level of CO₂ emissions compared with the baseline scenario by 2050 and a 30 percent reduction compared with 2005 levels.

With oil priced at US\$60 per barrel and with reasonably successful technology development and cost reductions, the marginal cost of CO₂ reduction would approximate US\$200 per metric ton by 2050. With higher oil prices, the marginal costs would be lower. Furthermore, the average costs for 2010 to 2040 could be low or negative, taking into account



the value of fuel savings, which increases over time.

Fuel-Efficiency Technologies

BLUE Map implies that more aggressive deployment of currently available fuel-saving technologies for passenger cars and light trucks could be cost-effective in cutting vehicle fuel consumption and CO₂ emissions per mile by 30 percent by 2020 and by 50 percent by 2030. Comparable gains in vehicle fuel economy may be possible for other transportation modes. The baseline scenario projects 20 to 25 percent increases in energy efficiency for other modes by 2050; in contrast, BLUE Map assumes that the improvements reach 35 percent to 50 percent.

Alternative Fuels

In both the baseline and high baseline scenarios, the mix of fuels remains fairly constant up to 2030, with petroleum fuels dominant. In the high baseline scenario, biofuels, synthetic gasoline, and diesel made from natural gas and coal-to-liquids processes grow

FIGURE 2 Light-duty vehicle (LDV) sales and sales shares by vehicle type in BLUE Map. (CNG = compressed natural gas; LPG = liquefied petroleum gas.)

Issues such as sustainability, agricultural and food supply impacts, and sensitive ecosystems must be considered in biofuel development. Lignocellulosic ethanol is being examined for use as a biofuel.

PHOTO: NATIONAL RENEWABLE ENERGY LABORATORY (NREL)



Electric vehicle charging station at the Camarillo Outlet Center in California is a prototype for the development of a recharging infrastructure.



PHOTO: SEAN H. MCELHENON

rapidly after 2030, becoming more price-competitive with petroleum as oil supplies dwindle.

In BLUE Map, the share of conventional gasoline and other fossil fuels used by light-duty vehicles falls to below 50 percent of total supply by 2050 (Figure 2, page 17), replaced by a combination of advanced, low-CO₂ biofuels, electricity, and hydrogen. If produced from low-CO₂ feedstocks, any one of these fuel options might achieve the CO₂ emissions target, but each has drawbacks that limit this possibility. Using these alternative fuels in combination, therefore, can maximize the chances of success, although higher investment costs may be required to develop the infrastructures for production and distribution.

Ethanol made from sugar cane can provide a low-GHG, low-cost biofuel. Second-generation biofuels, such as lignocellulosic ethanol and biodiesel, have a long-term potential for low GHG emissions over their life cycles, but more research, development, and demonstration are needed before commercial-scale production.

Several issues must be addressed for biofuel production, such as ensuring that the cultivation of land does not adversely affect food supplies or harm sen-

sitive ecosystems. Achieving the energy and CO₂-eq outcomes envisioned in the BLUE Map scenario by 2050 requires a 20-fold increase in biofuel production from current levels.

Electric Vehicles

Electric vehicles (EVs), plug-in hybrid electric vehicles (PHEVs), and fuel-cell vehicles (FCVs) play an important role in BLUE Map, especially after 2020. EVs are rapidly emerging as the cost of lithium-ion batteries declines. The cost of batteries for an electric-only vehicle in high-volume production might drop to US\$500 per kilowatt-hour (kWh) in the near term; this would bring the battery cost to \$15,000 for a vehicle with a 100-mile range. But savings from the removal of the internal combustion engine and from the relatively low cost of electricity could enable EVs to achieve commercial success in the next 5 to 10 years. Policy assistance will be required, however, such as public planning and support for the development of a recharging infrastructure.

The market price of oil, the principal competing fuel, and the CO₂ emissions characteristics of the electric grid will influence the rate of adoption of EVs. Early deployment of EVs in regions that already emit low levels of CO₂ or that are committed to decreasing CO₂ emissions may be a good strategy.

Plug-In Hybrid Electric Vehicles

PHEVs can assist in the transition to EVs. PHEVs use both an engine and an electric motor, which adds to the production cost. The driving electricity for PHEVs, however, is stored in a small and relatively inexpensive battery pack. For example, an 8-kWh battery pack might cost \$5,000 to \$6,000 in the near term and provide a driving range of 20 to 25 miles. For many drivers, running most of the first 25 miles per day on electricity could cut petroleum use by 50 percent or more. Because PHEVs can drive long distances on liquid fuel, they may not require as much new recharging infrastructure as EVs.

In BLUE Map, both EVs and PHEVs are initially deployed in 2010 and increase in sales to more than 5 million per year worldwide by 2020 (Figure 2, page 17). Both vehicle types experience rapid market penetration worldwide, reaching annual sales of approximately 50 million each by 2050, primarily as passenger light-duty vehicles but also including a small share of trucks.

This rate of growth, however, is faster than has occurred in transport systems in the past 40 years. For example, hybrid electric vehicles were introduced in the mid-1990s but as of 2009 had achieved global sales of approximately 1 million per year—less than 2 percent of the market share. The market pen-

High-powered lithium-ion batteries for use in hybrid electric vehicles. To meet BLUE Map targets, electric and plug-in hybrid electric vehicles would need to increase market shares.

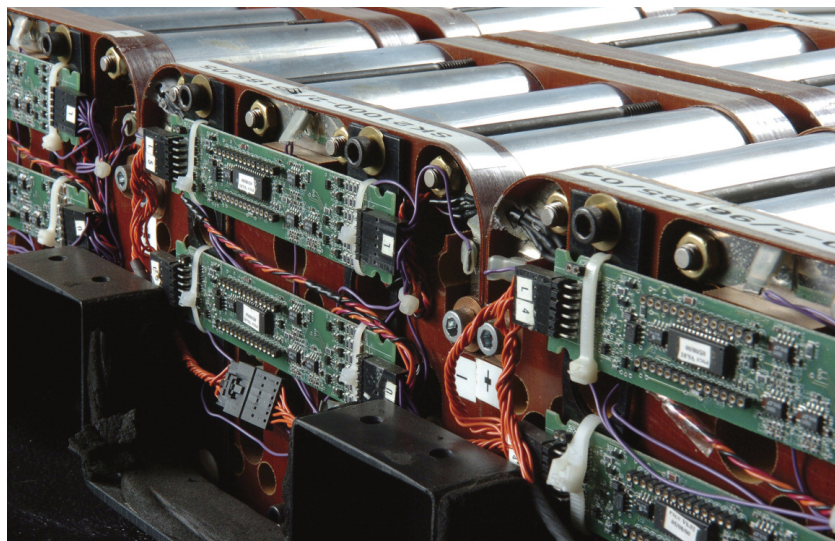


PHOTO: ARGONNE NATIONAL LABORATORY



Photo: NREL

Central production for fuel-cell vehicles can come from low-CO₂ technologies, such as wind power.

etration of EVs and PHEVs will need to move at a much faster pace to achieve the targets in BLUE Map. Strong policy support will be necessary.

Fuel-Cell Vehicles

FCVs also play a key role in BLUE Map, with commercial-scale production beginning around 2020. FCVs will coexist with EVs and PHEVs but are expected to achieve a higher market share among

vehicles with a longer driving range, but a lower share among urban vehicles. FCVs should gain significant market penetration by 2030, with sales rising rapidly afterward, to nearly 60 million vehicles per year by 2050.

Recent cost reductions in fuel-cell systems suggest an increased likelihood of FCV commercialization, although hydrogen infrastructure and on-board energy storage remain barriers. As battery costs drop, hybridizing fuel cells appears to be an attractive strategy, because batteries can provide peak power to the motor, allow for a smaller fuel cell stack, and improve efficiency through regenerative braking.

As with the electricity used to power EVs, the hydrogen fuel must be produced with low-CO₂ technologies for FCVs to achieve significant CO₂ reductions. Central production is likely using biomass, heat from nuclear sources, or electrolysis from off-shore wind power.

Improvements in vehicle efficiency and the shift to lower carbon fuels can decarbonize vehicle types and modes dramatically by 2050. Figure 3 (below) shows that the average CO₂ intensity of different modes drops to lower levels by 2050 in BLUE Map—well below 50 grams of CO₂-eq per kilometer for all modes except air travel.

Implications for Mode Shifts

Because of the large differences in the energy requirements of different modes today, shifting travel to the most efficient modes could reduce CO₂ emissions. In many countries, improved transit systems could avoid or slow the shifts to cars, resulting in major reductions in the GHG emissions projected in the baseline scenario. The BLUE Map scenario, however, indicates that after 2030, vehicle efficiency improvements and low-carbon fuels would reduce CO₂ intensity, so that shifting transportation activity from

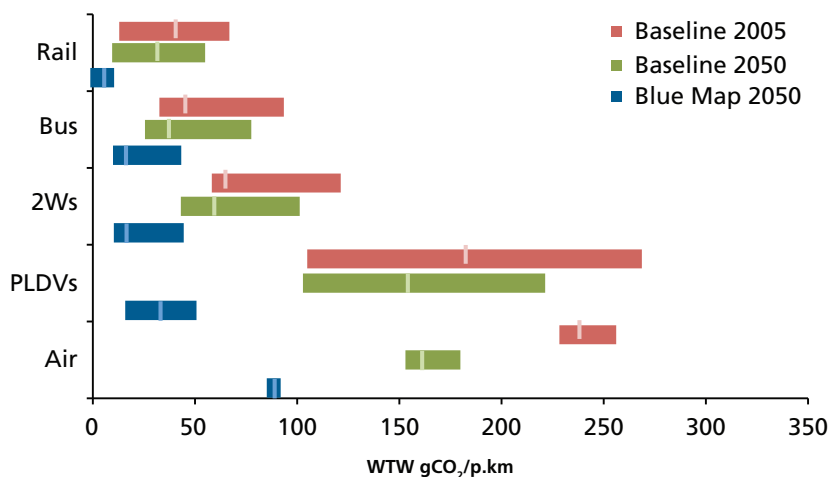


FIGURE 3 CO₂ intensity of different modes by year and scenario. (PLDV = passenger light-duty vehicle; WTW = well to wheel; p.km = passenger kilometers; 2Ws = two-wheelers.)



Photo: World Shipping Council and Hanjin Shipping

The BLUE Shifts scenario envisions a shift in freight movement to rail transportation.

GHG-intensive modes to less intensive modes would provide less CO₂ benefit.

But achieving these CO₂ intensity reductions is not guaranteed. Therefore modal shift options should be considered as an important complement to vehicle and fuel improvements, to speed near-term CO₂ reduction and to provide other benefits, such as reduced traffic congestion, reduced pollutant emissions, and general livability.

The BLUE Shifts scenario incorporates a dramatic change in modal mix and levels of transportation activity. The scenario assumes an average worldwide reduction of 25 percent in private light-duty vehicle and aviation passenger travel by 2050 compared with the baseline scenario and close to a 50 percent reduction compared with the high baseline scenario. The travel is diverted mainly to advanced bus and rail systems.

The scenario also assumes a radical shift in freight movement to rail transport, which cuts the growth in long-haul truck transport by half between 2010 and 2050. A reduction is projected in the rate of travel growth because of changes in land use and improvements in nonmotorized transport infrastructure, along with the replacement of some travel by telecommuting. Although these mechanisms can

provide the underpinnings for modal shifts, the focus of the IEA analysis is on the energy and CO₂ impacts, not on the policies required to bring about the modal shifts.

Combining these assumptions, the BLUE Shifts scenario projects a 20 percent reduction in energy use and CO₂ emissions by 2050 compared with the baseline scenario or a 40 percent reduction compared with the high baseline scenario. The cost of BLUE Shifts is uncertain, depending on the costs of a range of investments in sustainable transport, such as bus and rail systems. IEA will explore these costs in future studies.

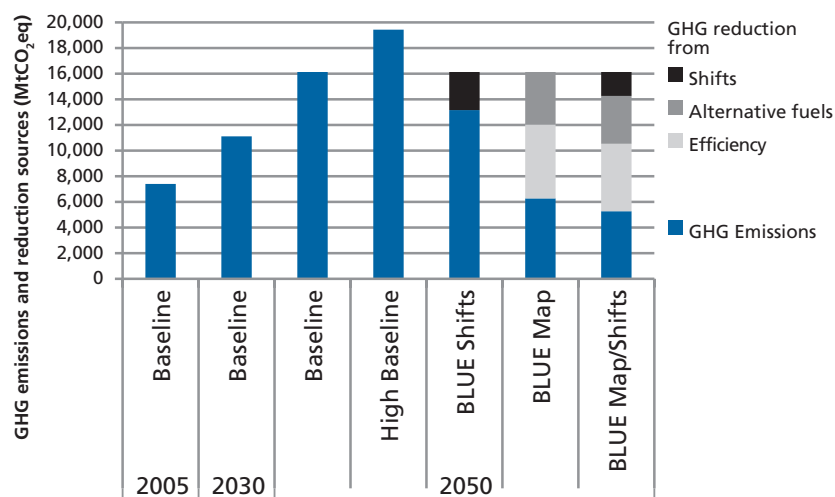
Insights from the Analyses

As shown in Figure 4 (below, left), the BLUE Shifts scenario yields a 20 percent reduction in CO₂ emissions compared with the baseline in 2050; the BLUE Map scenario yields a 65 percent reduction. Combining the BLUE Map and BLUE Shifts scenarios—gaining the effects of low-carbon fuels, advanced vehicles, and modal shifts—can reduce CO₂ emissions from transportation worldwide by 40 percent by 2050 compared with 2005 levels and by 70 percent compared with the baseline projections for 2050.

By 2050, cutting transport energy use and CO₂ emissions by nearly half should be technically possible through improvements in vehicle energy efficiency, and by nearly half again by substituting low-CO₂ alternative fuels—mainly electricity, hydrogen, and biofuels. Shifting traffic to GHG-efficient modes may be helpful and complementary, particularly early on, before the vehicle technologies and fuels are heavily deployed.

The changes posited in the BLUE Map and BLUE Shifts scenarios will require strong policy actions and a willingness to embrace change. Pricing carbon through an international carbon market will help, but even a price of US\$50 per metric ton of CO₂, for example, would raise average fuel prices only modestly—in the United States, gasoline prices would increase by US\$0.40 per gallon. Strong sectoral measures will be needed around the world—such as fuel economy standards across the transport modes, low carbon fuel standards, and measures to encourage a new paradigm for investing in transport infrastructure.

FIGURE 4 Comparison of baseline and BLUE scenarios. (Mt = million tonnes.)



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A Transportation Research Program for Mitigating and Adapting to Climate Change and Conserving Energy

MICHAEL D. MEYER AND STEPHEN R. GODWIN

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Buildings and roads in Harris County, Texas, were destroyed by the flooding that followed Hurricane Ike in 2008. The transportation system still needs to adapt to changes in storm surges, precipitation, wind loadings, and flooding.

The risks posed by climate change and the dependence on imported petroleum are among the most challenging problems facing the United States. Many state and national policy makers are embracing proposals to reduce total greenhouse gas (GHG) emissions by 50 to 80 percent below current levels by 2050 and to reduce energy consumption by the transportation sector.

Transportation depends on petroleum for 97 percent of its fuel and is a major contributor to climate change and to energy dependence. Transportation accounts for 28 percent of U.S. GHG emissions and consumes twice as much petroleum as the nation produces annually. Passenger and freight vehicles using surface transportation modes account for approximately 88 percent of carbon dioxide emissions from transportation and for a comparable share of energy consumption.

Seeking Additional Reductions

Projections of the impact of policies already in place to improve fuel economy and introduce alternative fuels suggest that by 2030 total transportation GHG emissions would be about the same as today. Sub-



PHOTO: OREGON DOT

Mileage charging is an option—but a controversial one—to increase transportation revenue. A mileage counting computer underwent trials in Oregon.

stantial improvements in vehicle fuel economy, along with other improvements, will offset the demands of expected growth in population and economic activities. For this reason, proposed legislation has targeted additional reductions from the transportation sector through policies that would reduce demand for the most fuel-intensive modes.

Transportation contributes significantly to total GHG emissions and to energy dependence, but it also contributes to economic and social well-being. Careful selection of policies to reduce or shift demand will help to avoid or minimize losses to the economy and society. Yet the effectiveness, costs, feasibility, and acceptability of various policies to mitigate transportation's GHG emissions and energy consumption are not well understood.

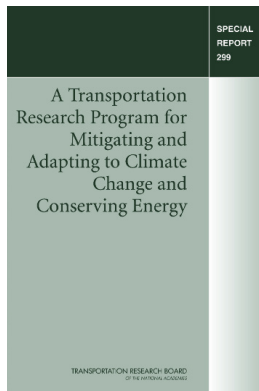
Also not well understood are policies and practices that should be considered for adapting the transportation system to changes in precipitation, flooding, storm surges, and wind loadings that are likely to occur with climate change. The cost of adapting infrastructure is high, as is the uncertainty about the timing, magnitude, and location of the risks.

Developing Guidance

Federal, state, and local policy makers need informed



PHOTO: FEDERAL EMERGENCY MANAGEMENT AGENCY



Special Report 299, *A Transportation Research Program for Mitigating and Adapting to Climate Change and Conserving Energy*, is available from the TRB online bookstore, www.trb.org/bookstore; to view the book online, go to <http://onlinepubs.trb.org/onlinepubs/sr/sr299.pdf>.

guidance about the effectiveness, costs, feasibility, and acceptability of transportation mitigation and adaptation strategies. The committee that prepared Special Report 299, *A Transportation Research Program for Mitigating and Adapting to Climate Change and Conserving Energy*, recommends making a modest investment of \$40 million to \$45 million annually to develop the best guidance quickly, working from available information, and then to improve the guidance as new research is completed (Table 1, right).

The investment represents approximately 9 percent of current U.S. Department of Transportation research spending on surface modes. Yet because of the importance of making policy choices that produce the most benefit for the least harm, the investment could pay substantial long-term dividends.

The committee's research cost estimate is an approximation, to give the U.S. Congress a sense of the level of investment needed. The topics suggested for research in the report are preliminary and should be refined by convening expert and practitioner stakeholders early on to develop more detailed plans and more refined estimates of investment needs.

To be most effective, the research should be guided by the following principles:

- ◆ The topics should relate directly to the needs of federal, state, and local transportation policy makers;
- ◆ Funding should be awarded through open competition, with a merit review of the proposals by peers; and
- ◆ Results should be evaluated by expert and practitioner stakeholders.

Program managers should have the flexibility to shift areas of investment as knowledge is developed. An independent group reporting directly to Congress should evaluate the program regularly.

Effective Strategies

One of the most effective mitigation strategies would

TABLE 1 Estimated Cost of Mitigation and Adaptation Research Programs (\$ millions)

Program	6-Year Total	Annual Average
Mitigation^a		
Guidance and outreach	60.0	10
Fundamental research	130.0	21.7
Subtotal	190.0	31.7
Adaptation		
Research	60.0	10
Total	250.0	41.7

^a The mitigation research cost estimate does not include the cost of collecting travel data for research and improved modeling or the cost of a mileage-charging demonstration program.

be to tax or charge for use of the system in ways that more closely reflect economic, social, and environmental costs. Charging for mileage traveled on all roads could make this possible and could supplement or replace taxes on fuels that currently generate revenues for highway and transit infrastructure.

Fuel taxes have become unreliable revenue generators, and this unreliability will grow as vehicle fuel economy improves. Although mileage charging shows promise, it is controversial because of concerns about privacy, equity, and administrative costs. The committee joins other groups—including two congressional commissions—that have called for investing in an aggressive demonstration program to test alternative concepts and address concerns. The total cost probably would be \$70 million to \$100 million for a multiyear project.

Researching and analyzing cost-effective strategies for reducing GHG emissions will depend on the quality of the data. The data available for national-level estimates of passenger and freight travel are useful but are too crude to guide the detailed analysis and planning to inform decisions about the best strategies at the state and local levels.

Much of the data also could be used for statewide and metropolitan area planning, could improve compliance with other environmental policy goals, and would be essential if the next surface transportation reauthorization includes performance standards. The committee recommends that Congress authorize funding to collect data adequate to meet the needs of federal, state, and local governments for analyzing options and planning for mitigation strategies.

Climate change and energy dependence will remain major problems for decades. Transportation's contributions to these problems must be addressed, but the wrong policies could impose significant costs without gaining the intended effects. The research programs identified in this report represent the topics of greatest importance for informing the best choices in coming years.

Committee for Study on Transportation Research Programs to Address Energy and Climate Change

Michael D. Meyer, Georgia Institute of Technology, Atlanta, Chair
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TRB Special Task Force Produces Climate Change Primer and Research Needs Statements

MARK R. NORMAN

The TRB Special Task Force (STF) on Climate Change and Energy has prepared two new reports, available online as e-circulars:

◆ The *Modal Primer on Greenhouse Gas and Energy Issues for Transportation*, written by volunteer teams from throughout the transportation industry and edited by Peter Bryn, Sea-River Maritime, Inc., contains brief but informative overviews of climate change and energy issues for the primary transportation modes.^a

◆ *Research Needs Statements for Climate Change and Transportation* assembles approximately 40 research needs statements to assist universities, students, research organizations, government agencies, and other interested parties in selecting, conducting, and funding projects.^b

The authoring teams for the chapters of the modal primer come from a variety of backgrounds. Each team produced an educational discussion of the status and future of a mode in relation to greenhouse gas emissions and energy use; the goal was to provide an inclusive, informed, and objective overview. The chapters are not position papers or advocacy documents—each presents a spectrum of viewpoints, from academics and researchers to practitioners and policy makers.

Several TRB groups were involved in assembling the e-circular of research needs statements:

- ◆ The STF, which took the lead;
- ◆ The Transportation Energy Committee, the Alternative Transportation Fuels and Technology Committee, and their Climate Change Joint Subcommittee; and
- ◆ The Transportation and Sustainability Committee.

Face-to-face meetings, conference calls, a workshop, and a collaborative website provided opportunities to propose, develop, critique, and revise the research needs statements. The participants drew from work that has identified research themes for the mitigation of transportation's impact on climate change and the adaptation of transportation to climate change.

The statements constitute a robust supplement to the

The author is TRB Director, Technical Activities.



PHOTO: CARLE RISSON, TRB

Members of the Special Task Force for Climate Change at the 2009 TRB Annual Meeting.

topics that already had been posted in the area of transportation and climate change in the TRB Research Needs Statements database.^c The new statements also provide more specifics for the themes identified in

Special Report 299, *A Transportation Research Program for Mitigating and Adapting to Climate Change and Conserving Energy*.^d A key area not discussed in either e-circular is climate change adaptation, to avoid redundancy with the adaptation-focused TRB Special Report 290, *The Potential Impacts of Climate Change on U.S. Transportation*.^e

Established in January 2008, the STF coordinates activities related to climate change and energy and facilitates communications among TRB standing committees. The STF augments the work of committees on climate change and energy and maintains a road map for ongoing and potential TRB initiatives. The STF reports directly to the TRB Technical Activities Council; Marcy Schwartz, CH2M Hill, was the initial chair during the first 2 years of the STF, succeeded in April by Cochairs Robert Noland, Rutgers University, and James M. Sime, Connecticut Department of Transportation. Membership is drawn from TRB committees with strong interest in climate change and energy issues, supplemented by members-at-large, including subject matter specialists from constituencies outside TRB.

^a Circular E-C 143, <http://onlinepubs.trb.org/onlinepubs/circulars/ec143.pdf>.

^b Circular E-C 144, <http://onlinepubs.trb.org/onlinepubs/circulars/ec144.pdf>.

^c <http://rns.trb.org/>.

^d <http://onlinepubs.trb.org/onlinepubs/sr/sr299.pdf>.

^e <http://onlinepubs.trb.org/onlinepubs/sr/sr290.pdf>.



Driving and the Built Environment

The Effects of Compact Development on Motorized Travel, Energy Use, and CO₂ Emissions

JOSÉ A. GÓMEZ-IBÁÑEZ AND NANCY HUMPHREY

Gómez-Ibáñez is Professor of Urban Planning and Public Policy, John F. Kennedy School of Government, Harvard University, Cambridge, Massachusetts; he chaired the study committee for this project. Humphrey, Senior Staff Officer, TRB Division of Studies and Special Programs, served as study director.

Suburbanization is a longstanding trend reflecting the preference of many Americans for living in detached single-family homes. The automobile and an extensive highway network have provided the mobility to make this possible. Yet dispersed, automobile-dependent development patterns have come at a cost, consuming vast quantities of undeveloped land; increasing the nation's dependence on imported petroleum; and increasing greenhouse gas emissions that contribute to global warming.

Study Charge and Overview

Requested by Congress and funded by the U.S. Department of Energy, TRB Special Report 298, *Driving and the Built Environment: The Effects of Compact Development on Motorized Travel, Energy Use, and CO₂ Emissions*, examines the relationship between land development patterns—often referred to as the built

environment—and motor vehicle travel in the United States. The study assesses whether petroleum use—and by extension, emissions of the primary greenhouse gas, carbon dioxide (CO₂)—could be reduced by more compact, mixed-use development—that is, development at higher densities with a variety of land uses.

The committee that produced the report estimates that the reduction in vehicle miles traveled (VMT), energy use, and CO₂ emissions resulting from more compact, mixed-use development would range from less than 1 percent to 11 percent by 2050. All of the committee members did not agree, however, that the changes in development patterns and public policies necessary to achieve the high end of the estimates were plausible. The study committee was appointed by National Research Council of the National Academies under the auspices of TRB and the Board on Energy and Environmental Systems (see box, page 28).



PHOTO: ARLINGTON COUNTY, VIRGINIA

Findings

More compact development patterns are likely to reduce VMT.

Both logic and empirical evidence suggest that development at higher population and employment densities results in trip origins and destinations that are closer to each other, on average; therefore average trip lengths are shorter. Although theory suggests that reduced trip lengths can increase trip frequencies, empirical evidence indicates that the increase is not enough to offset the reduction in VMT that comes from reduced trip length alone. Shorter trips also may reduce VMT by making walking and bicycling more competitive alternatives to the automobile; in addition, higher densities are well-suited for public transit. Mixing land uses to bring housing closer to jobs and shopping can reduce trip lengths as well.

The effects of compact, mixed-use development on VMT can be enhanced with other policy measures that make the alternatives to driving more convenient and affordable. Examples include a street network that provides good connectivity and accommodates nonvehicular travel; well-located transit stops; and good neighborhood design. Demand management measures, such as reducing the supply and increasing the cost of parking, also can complement efforts to reduce VMT.

The most reliable studies estimate that doubling residential density across a metropolitan area may lower household VMT by 5 to 12 percent, and perhaps by as much as 25 percent, if coupled with higher employment concentrations, significant public transit improvements, mixed uses, and other supportive demand management measures.

Many of the studies reviewed by the committee failed to distinguish between different types of density changes—for example, decreasing lot size versus increasing multifamily housing—or to examine the location of these changes in a region. Relatively few accounted for self-selection—people's tendency to locate in areas consistent with their housing and travel preferences. Finally, most studies are cross-sectional, that is, they find an association between higher density and lower VMT at a single point in time but cannot be used to infer cause and effect.

More compact, mixed-use development can reduce energy consumption and CO₂ emissions directly and indirectly.

To the extent that more compact development reduces VMT, it will directly reduce fuel use and CO₂ emissions. The VMT savings will be slow to develop, however, because the existing building stock is

Exploring the Effects of Compact Development

Approximately 80 percent of the U.S. population lives in metropolitan areas, but population and employment continue to decentralize within regions, and population density continues to decline at the urban fringe.

The adverse effects of suburbanization and automobile dependence have long been evident but now are particular concerns for several reasons. First, after decades of low energy prices, the cost of oil rose to record highs in 2008, reflecting the growth of China and India and the instability of many key suppliers in the Middle East and other oil-producing areas, and underscoring U.S. dependence on imported fuels. The transportation sector accounts for more than 28 percent of annual U.S. energy consumption; cars and light trucks, mostly used for personal transportation, represent approximately 17 percent of annual U.S. energy consumption, and the share is rising.

Second, concern about climate change has grown domestically and internationally, and transportation is a major contributor to the problem. Gasoline consumption, largely by personal vehicles, accounts for about 20 percent of annual U.S. CO₂ emissions.

At the same time, changing demographics—an aging population and continued immigration—and the possibility of sustained higher energy prices could lead to more opportunities for the kinds of development patterns that could reduce vehicular travel, saving energy and reducing CO₂ emissions.

A key question is to what extent developing more compactly would reduce vehicle miles traveled and make alternative modes of travel—such as transit and walking—more feasible. Special Report 298, *Driving and the Built Environment: The Effects of Compact Development on Motorized Travel, Energy Use, and CO₂ Emissions*, focuses on metropolitan areas and on personal travel, the primary vectors through which policy changes encouraging more compact development should have the greatest effect.

enduring, limiting opportunities to build more compactly; new housing may be built to accommodate a growing population and to replace the small percentage of units that are scrapped each year.

Additional indirect savings in energy consumption and CO₂ emissions from more compact, mixed-use development can accrue from higher ownership of smaller, more fuel-efficient vehicles; from longer vehicle lifetimes, through less driving; from smaller homes and more multifamily units, which are more energy-efficient than the average single-family dwelling; and from more efficient urban truck travel and delivery patterns. To the extent that higher energy prices or other public policies and regulations increase vehicle fuel efficiency or the energy efficiency of residential heating and cooling, however, the absolute savings in energy use and CO₂ emissions from developing more compactly will be reduced, all else being equal.

(*Photograph, facing page:*) High-density residential and business development—as along the Ballston–Rosslyn Metrorail corridor in Arlington County, Virginia—tends to result in shorter trip lengths, since origins and destinations are closer to each other and public transportation is readily accessible.

Traffic Congestion and Greenhouse Gases

MATTHEW BARTH AND KANOK BORIBOONSOMSIN

Fuel consumption and carbon dioxide (CO₂) emissions are sensitive to many factors, including individual driving behavior, vehicle and roadway types, and traffic conditions. Therefore estimating CO₂ emissions from a single variable, such as trip distance or average speed, cannot provide a reliable measure. A comprehensive methodology has been developed to take advantage of the latest vehicle activity measurements and detailed vehicle emission factors to create a more accurate emissions inventory for different types of vehicles and different levels of traffic congestion (1, 2). This methodology produces better estimates of CO₂ reductions from improvements in traffic operations, including

- ◆ Congestion mitigation strategies—such as ramp metering and incident management—that achieve higher average traffic speeds;
- ◆ Speed management techniques—such as better enforcement and active speed governors—that can reduce excessive speeds to more moderate speeds of approximately 55 miles per hour; and
- ◆ Traffic-flow smoothing techniques—such as variable speed limits and intelligent speed adaptation—that can suppress shock waves, reducing the number of acceleration and deceleration events.

Figure 1 (below) shows an example of a speed-based CO₂ emissions curve for a typical vehicle traveling on a highway section

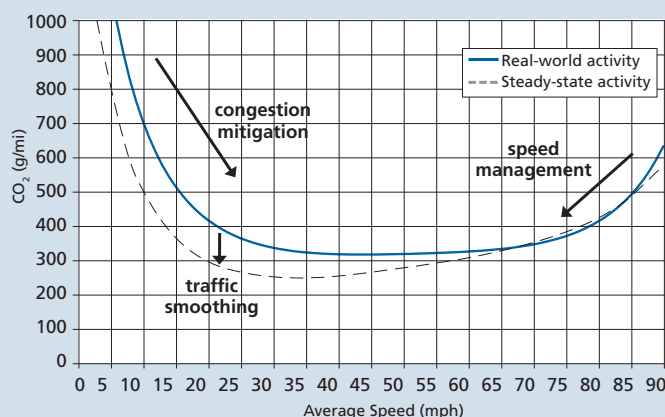


FIGURE 1 Possible use of traffic operation strategies in reducing on-road CO₂ emissions.

The authors are with the University of California, Riverside—Barth is Professor of Electrical Engineering and Director of the Center for Environmental Research and Technology, and Boriboonsomsin is a member of the research faculty at the Center for Environmental Research and Technology.



Speed management techniques, such as this dynamic message sign in Phoenix, Arizona, can help reduce vehicle emissions.

(solid line). The curve indicates how different traffic management techniques would affect CO₂ emissions:

- ◆ Congestion mitigation increases average traffic speeds from those under heavily congested conditions;
- ◆ Speed management reduces excessively high speeds to safer speeds; and
- ◆ Traffic smoothing reduces the number and intensity of accelerations and decelerations.

The dashed line in Figure 1 represents the approximate lower bound of CO₂ emissions for vehicles traveling at constant steady-state speeds.

Under typical traffic conditions in Southern California, each of these methods could lower CO₂ emissions by an estimated 7 percent to 12 percent as long as travel demand does not increase because of the improved traffic flow. Although the individual effects of single methods may not be that large, combining methods could have a synergistic effect, adding up to a greater amount. Because of the potential demand for additional driving in heavily congested areas such as Southern California, other demand management techniques also could be employed to realize these synergistic effects.

References

1. Barth, M., and K. Boriboonsomsin. Real-World Carbon Dioxide Impacts of Traffic Congestion. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 2058, Transportation Research Board of the National Academies, Washington, D.C., 2008, pp. 163–171.
2. Barth, M., and K. Boriboonsomsin. Traffic Congestion and Greenhouse Gases. *ACCESS Magazine*, University of California Transportation Center, Fall 2009. www.uctc.net.

Significant increases in more compact, mixed-use development result in only modest short-term reductions in energy consumption and CO₂ emissions, but these reductions will deepen.

The committee assembled illustrative scenarios with housing forecasts prepared especially for the study and with estimates of VMT reduction from the literature to quantify the potential effects of developing more compactly, looking forward to 2030 and to 2050. The scenarios assume that compact development is focused on new and replacement housing, because of the difficulty of converting existing housing to higher densities.

As many as 57 million new housing units will be needed to accommodate population growth and as replacement housing by 2030, growing to between 62 million and 105 million units by 2050—a substantial net addition to the housing stock of 105.2 million in 2000. In the scenarios, developing more compactly is defined as doubling the density of new residential development, mainly at the urban fringe, where most new development takes place, but also through some strategic infill.

The results depend on assumptions about the percentage of new housing developments to be built compactly and on how much less the residents of these more compact developments will drive. The base case assumes continued low-density development and that household VMT remains constant, an assumption tested in sensitivity analyses.

In an upper-bound scenario—a significant departure from current conditions—the committee estimates that 75 percent of new and replacement housing units are located in more compact developments, and that residents of compact communities would drive 25 percent less. The VMT and associated fuel use and CO₂ emissions of households would decrease by 7 to 8 percent by 2030, compared with base case conditions, and would widen to between 8 and 11 percent by 2050.

A more moderate scenario assumes that 25 percent of new and replacement housing units will be built in more compact development and that residents will drive 12 percent less. This would reduce fuel use and CO₂ emissions by approximately 1 percent in 2030, compared with base case conditions, and would grow to between 1.3 and 1.7 percent below the base case in 2050. If the residents of compact developments drive only 5 percent less—the lower bound of available estimates—the savings in fuel use and CO₂ emissions would be less than 1 percent compared with the base case, even in 2050.

The committee disagreed about the feasibility of achieving the target density in the upper-bound scenario—doubling the density of 75 percent of new

development—even by 2050. The members who believed the scenario is feasible questioned whether densities on the urban fringe will continue to decline and noted that macroeconomic trends—the likelihood of higher energy prices and carbon taxes—in combination with growing public support for strategic infill, investments in transit, and higher densities along rail corridors, could produce considerably higher densities by 2050.

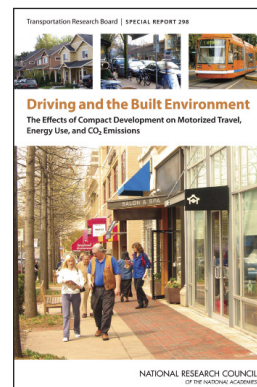
Other members pointed out that the upper-bound scenario required too significant a departure from current housing trends, land use policies of jurisdictions at the urban fringe, and public preferences. They maintained that curbing large-lot development and achieving substantial infill would be unrealistic unless states or regions took a strong role in growth management.

Promoting more compact, mixed-use development on a large scale will require overcoming many obstacles.

Local zoning regulations—particularly suburban zoning that restricts density levels and the mixing of land uses—represent one of the most significant barriers to more compact development. Highly regulated land use markets also limit the supply of compact developments, despite evidence of increased interest in such communities.

Land use control is largely a local government function and is sensitive to legitimate local concerns—for example, congestion, local taxes, and home values—which are sometimes at odds with other regional or national concerns, such as housing affordability or climate change. Land use policies aimed at achieving sweeping changes in development patterns therefore are likely to meet political resistance from homeowners and local governments. This may explain in part why metropolitanwide or state policies aimed at controlling land use and steering development and infrastructure investments are not widespread.

In the near term, the biggest opportunities for more compact, mixed-use development are likely to arise in new housing construction and replacement units in areas already experiencing increases in density—such as the inner suburbs and developments near transit stops and along major highway corridors or interchanges. Coordinated public infrastructure investments and development incentives can encourage more compact development in these locations, and zoning regulations can be relaxed to steer development to areas that can support transit and nonmotorized travel modes. Market-based strategies, such as congestion pricing and market-based parking fees, along with zoning requirements for maximum parking, can complement higher-density development pat-



Special Report 298, *Driving and the Built Environment: The Effects of Compact Development on Motorized Travel, Energy Use, and CO₂ Emissions*, is available from the TRB online bookstore, www.trb.org/bookstore; to view the book online, go to <http://onlinepubs.trb.org/Onlinepubs/sr/sr298.pdf>. Background papers commissioned by the committee are posted at <http://onlinepubs.trb.org/Onlinepubs/sr/sr298appendixb.pdf>.

PHOTO: METRO



Compact, high-density development in Portland, Oregon.

terns that encourage transit use and pedestrian travel.

In the longer term, if housing preferences and travel patterns change, and compact, mixed-use developments become more commonplace, a greater political consensus may emerge in support of stronger state and regional measures to control land use. Policy instruments may include setting urban growth or greenbelt boundaries to steer growth to areas already developed.

Changes in development patterns entail other benefits and costs that have not been quantified in this study.

More compact, mixed-use development should reduce some infrastructure costs, increase the feasibility and cost-effectiveness of public transit, and expand housing choices where compact developments are undersupplied. Other benefits include less conversion of agricultural and other environmentally fragile areas and greater opportunities for physical activity by facilitating nonmotorized modes, such as walking and bicycling.

On the cost side, the savings in highway infrastructure will be offset, at least in part, by increased expenditures for public transit—particularly for rail transit—to support high-density development. Moreover, many Americans apparently prefer detached single-family homes in low-density suburbs offering more privacy, greater access to open space and recreation, and less noise than many urban neighborhoods. Nonetheless, housing preferences may change with changes in the demographic and socioeconomic characteristics of the population.

Committee for the Study on the Relationships Among Development Patterns, Vehicle Miles Traveled, and Energy Consumption

José A. Gómez-Ibáñez, Harvard University, Cambridge, Massachusetts, *Chair*

Marlon G. Boarnet, University of California, Irvine

Dianne R. Brake, PlanSmart NJ, Trenton

Robert B. Cervero, University of California, Berkeley

Andrew Cotugno, Metro, Portland, Oregon

Anthony Downs, Brookings Institution, Washington, D.C.

Susan Hanson, Clark University, Worcester, Massachusetts

Kara M. Kockelman, University of Texas at Austin

Patricia L. Mokhtarian, University of California, Davis

Rolf J. Pendall, Cornell University, Ithaca, New York; The Urban Institute, Washington, D.C.

Danilo J. Santini, Argonne National Laboratory, Argonne, Illinois

Frank Southworth, Oak Ridge National Laboratory, Tennessee, and Georgia Institute of Technology, Atlanta

Recommendations

Policies that support more compact, mixed-use development and that reinforce its ability to reduce VMT, energy use, and CO₂ emissions should be encouraged.

The committee recognizes the lack of verifiable scientific evidence to support this recommendation. The committee's scenarios suggest that compact, mixed-use development will generate only modest reductions in energy use and carbon emissions in the near term. Moreover, the committee did not examine the other benefits and costs of compact, mixed-use development.

Nevertheless, climate change is a problem more easily dealt with sooner than later, and more energy-efficient land use patterns may become part of the strategy if the nation sets ambitious goals for energy efficiency and the reduction of greenhouse gas emissions. Implemented carefully, compact development also may reduce housing costs while increasing housing choices. Because the full energy and emissions benefits of changes in land use may take decades to realize, and development patterns take years to reverse, implementation of these policies should start soon.

Given the incomplete understanding of the benefits and costs of different policies for compact, mixed-use development, however, these policies should be implemented carefully and the effects monitored.

More carefully designed studies examining the effects of land use patterns and the form and location of more compact, mixed-use development on VMT, energy use, and CO₂ emissions are needed to implement compact development more effectively.

The committee identified five areas for more research:

- ◆ Federally funded longitudinal studies based on panel data to help isolate the effects of different types of development patterns on travel behavior;
- ◆ Studies of changes in metropolitan areas at finer levels of spatial detail to help inform the needs and opportunities for policy intervention;
- ◆ Careful before-and-after studies of policy interventions to promote more compact, mixed-used development to help determine what works;
- ◆ Studies of threshold population and employment densities to support rail and bus transit, walking, and bicycling, which would bring old references up to date and help guide infrastructure investments, as well as zoning and land use plans; and
- ◆ Studies of the changing housing preferences and travel patterns of an aging population, new immigrant groups, and young adults to help determine whether future trends will differ from those of the past.



Policies to Promote Low-Carbon Transportation Fuels

What Works?

DANIEL SPERLING

The author, a member of the TRB Executive Committee, is Founding Director, Institute of Transportation Studies, and Professor of Engineering and Environmental Science and Policy, University of California, Davis.

Three basic approaches are available to reduce transportation's greenhouse gas (GHG) emissions from petroleum-based fuels:

- ◆ Improve vehicle and engine efficiency;
- ◆ Reduce the amount of vehicle or engine use—that is, the vehicle miles traveled; and
- ◆ Reduce the carbon content of the energy used for transportation.

The three options are interrelated, but the focus here is on reducing the carbon content of fuels and on the policies that are needed.

In the United States, two newly implemented programs are promoting the replacement of petroleum-based fuels with biomass-based and other alternative fuels that tend to yield lower GHG emissions. California has adopted a low-carbon fuel standard, which requires a reduction in GHG emissions from transportation fuels by gradually introducing lower-carbon fuels, including biofuels, electricity, natural gas, and hydrogen. The U.S. Environmental Protection Agency (EPA) has established the more limited renewable fuel standard (RFS), which requires replacing petroleum-based fuel with biofuels made from renewable materials.

The Energy Independence and Security Act of 2007 increased the RFS fuel requirements and set GHG performance thresholds—the first time that GHG emissions performance has been applied in a regulatory context for a nationwide program. Both the California and EPA programs apply mainly to cars and trucks.

Fundamentals of Effective Programs

Policies and programs that aim to motivate industry to pursue innovations are more likely to be successful if they are flexible, performance-based, and inclusive. Federal fuel economy standards for cars and

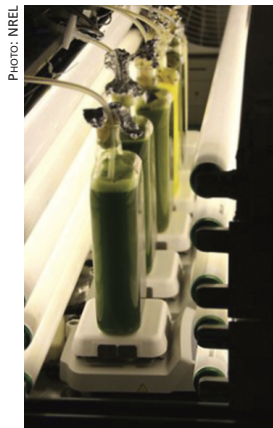


All emissions associated with the production of a biofuel should be counted in determining its greenhouse gas output—the energy expended in acquiring, growing, harvesting, and processing the material.

light trucks, for example, allow industry to determine the best way to achieve the targets, which stimulates innovation. Experiences with fuel economy standards and other programs suggest several principles for policies that promote low-carbon transportation fuels.

Don't try to pick winners.

Programs are more successful if they focus on the goal and not on the specific means to achieve it. If the goal is to lower GHG emissions from fuels, then setting GHG performance standards for transportation fuels motivates companies to find the best approach. Although mandating the use of specific fuels such as natural gas or ethanol may reduce GHG emissions, the market generally will achieve that goal at lower cost if allowed the flexibility to choose from the mix of possible fuels. The market can adapt quickly to changes in technology, allowing the introduction of new fuel pathways with greater emissions reduction or lower cost or both.



California's low-carbon fuel standard calls for the gradual introduction of lower-carbon fuels, such as fuel made from biomass such as algae.

PHOTO: NREL



The use of feedstock like corn for ethanol production affects the agriculture market and food prices. The promotion of low-emissions fuels must take these and other related consequences into account.

A hand-operated petroleum fuel pump in Leo, Burkina Faso. Reduced consumption in the United States may reduce prices worldwide, leading to greater consumption overseas.



PHOTO: STEFAN DRESSLER

Assess the full GHG life cycle.

To reduce GHG emissions, all emissions associated with the production, distribution, and use of the fuel must be considered. This well-to-wheel or source-to-wheel life-cycle assessment would include all direct emissions, such as those associated with acquiring, growing, and harvesting the feedstock for biofuels; transporting the feedstock to the fuel processing facility; turning the feedstock into an acceptable fuel; delivering the fuel to the point of retail sale; and burning the fuel.

The life-cycle analyses also should consider the indirect impacts, which can be large. For biomass-based fuels, for example, indirect emissions are associated with diverting land from food and other uses to energy production; in the case of corn ethanol, additional land is drawn into production to replace the corn diverted to energy use. These effects are controversial, because they never have been included in policies or regulations, and because the underlying science is still evolving.

The indirect land use effects can be large for food-based feedstocks, which are land-intensive, but small for cellulosic materials, and zero for waste materials. California's low-carbon fuel standard and EPA's RFS regulation both take indirect land use changes into account.

Be aware of positive and negative side effects.

Policies and programs promoting fuels with lower GHG emissions may have other consequences, beneficial or harmful. For example, how are food prices affected by the diversion of food and animal feed, such as corn and soybeans, to biofuel production?

How much does greater reliance on biofuels from feedstock grown in the United States reduce expenditures on imported oil and increase farm incomes and jobs? Some so-called side effects—for example, the energy security benefits of reducing dependence on petroleum—may be chief reasons for implementing the policies.

Don't be naïve about real-world responses.

Responses may occur outside the jurisdiction of the entity that establishes a low-carbon fuel program. One response, termed “leakage,” occurs when fuel suppliers shift their fuels to avoid compliance with the low-carbon fuel standards in California or the federal biofuel mandate. For instance, a high-carbon source of transportation fuel, made from oil sands or liquefied coal, can be shipped to states or countries with no regulations to reduce the carbon content of fuels. Because GHG buildup is a global problem, the benefits of reduction will be lost if the leakage response becomes rampant. The leakage problem would diminish as more states and nations adopt low-carbon fuel policies.

Because reduced consumption in California or the United States may reduce world oil prices, another response could be increased consumption of gasoline and diesel fuels in places without low-carbon fuel policies and biofuel mandates. This “rebound” effect may be small, but nonetheless could offset some of the GHG emissions reductions that the program achieves.

Recognize infrastructure and economic barriers.

Infrastructure can be slow to change and thus act as a barrier to the widespread introduction of new fuels. For example, ethanol is now used as a blend stock with gasoline. With ethanol use increasing, gasoline in the United States is likely to reach the 10 percent blending limit for vehicles by 2015.

Two options could expand the use of ethanol. One is to increase the blending limit—but manufacturers of cars and light trucks and of off-road equipment, such as lawnmowers, oppose this, because of concerns about damage to the engines. The second option is to expand the use of flexible-fueled vehicles, which can use ethanol in concentrations of up to 85 percent in gasoline (E85). Yet the number of filling stations now offering E85 is limited; the cost of adding a pump and storage tank for E85 can run \$100,000 and more.

EPA estimates that the number of E85 retail facilities may need to expand from approximately 2,000 to between 12,000 and 24,000 nationwide by 2022, if most of the required 36 billion gallons of biofuel are sold as ethanol, and the blend limit is not raised.

PHOTO: WIKIMEDIA COMMONS



A gas station along the Tarim Desert Highway in China. As more nations adopt low-carbon fuel policies, the problem of fuel suppliers turning to markets with lower emissions standards will decrease.

The number of flexible-fueled vehicles on the road capable of using E85 also would need to expand dramatically.

Performance Standard or Mandate?

Both the California low-carbon fuel standard and EPA's RFS regulation are designed to accelerate the use of lower-carbon fuels, but the two programs pursue the goal in different ways.

California's regulations require a gradual reduction in the carbon intensity of the fuel marketed in the state. The regulations lower the average GHG emissions per unit of energy consumed, by establishing a GHG life-cycle emission performance for transportation fuels—not only for biofuels but for alternatives such as natural gas. Fuel suppliers can market any mix of fuel types, as long as the mix meets the GHG performance standard set by California.

In comparison, the national RFS program requires that certain volumes of certain types of biofuels meet specific GHG performance thresholds. The program mandates increased volumes of cellulosic biofuel; of the 36 billion gallons required in 2022, 16 billion gallons must be produced from cellulosic feedstock. The cellulosic fuels, moreover, must reduce GHG emissions by at least 60 percent compared with gasoline or diesel.

The RFS mandate provides an incentive for developing cellulosic biofuels, even if these may not be the lowest-cost transportation fuels in the near term. Yet treating all cellulosic biofuels the same, as long as the 60 percent performance threshold is met, gives producers less incentive to continue improving the GHG performance. Biofuels from waste materials, for example, can have near-zero life-cycle emissions, but the EPA program gives them no special advantage.

How do the two measures address infrastructure needs? Both count on the fuel industry to assemble the necessary fuel supply infrastructure in a timely way. For biofuels, this is not a great problem—ethanol can be transported readily by rail; petroleum-like biofuels by pipeline; and both can be sold at fuel stations with few additional costs—with the exception of E85.

Electricity, natural gas, and hydrogen raise greater infrastructure problems. Expensive new retail fueling stations are needed for each, and electric vehicles require expensive retrofitting of most houses. California is exploring incentives for energy suppliers to overcome this energy infrastructure challenge.

Neither program attempts to implement measures to control the potentially important impacts of leakage and rebound, except to encourage others to adopt similar programs. Studies are under way to estimate the magnitude of the leakage and rebound effects and determine how to mitigate them.

Challenges for the Transition

How and when low-carbon energy alternatives such as cellulosic biofuels and electric and fuel-cell vehicles will succeed in the marketplace remain unclear, even under aggressive low-carbon fuel policies. The adoption of the low-carbon fuel standard, the RFS, and any other policy approach to introduce low-carbon fuels faces many political, administrative, and scientific challenges.

Scientific uncertainty about the indirect effects of changes in land use encourages lawsuits from those who are placed at a disadvantage by the rules; this creates uncertainty for fuel suppliers who are trying to decide whether and when to make the large investments for low-carbon fuels. The difficulty of addressing other environmental and resource impacts of fuels, from biodiversity to water use, creates additional challenges.

Finally, regulators and policymakers face exceptional challenges in responding to the uncertain and potentially high cost of compliance and to the variety of impacts across regions, companies, and population areas. Embedded in these challenges are the broader questions of avoiding climate change and improving energy security—and the relative importance assigned to each.

The low-carbon fuel standard and RFS programs are important steps forward. Continued progress will require the concerted efforts of scientists, investors, producers, and elected officials to ensure that wise choices are made in the transition to a different transportation energy future.



Hemicellulose fibers undergoing biofuel conversion pretreatment. The California renewable fuel standards provide incentives for the production of cellulosic biofuels.

PHOTO: NREL



Plug-In Hybrid and Electric Vehicles

Recent Developments and Prospects

TOM TURRENTINE

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Plug-in, electric-drive vehicles (PEVs) are an alternative to internal combustion engine vehicles (ICEVs). PEVs offer ways to diversify fuels for personal vehicles, to reduce tailpipe criteria pollutants, and—if the source of electricity has followed a low-carbon pathway—to reduce greenhouse gas emissions.

PEV technology comprises three primary categories:

- ◆ Electric vehicles (EVs);
- ◆ Plug-in hybrid electric vehicles (PHEVs); and
- ◆ Extended-range electric vehicles (EREVs), a major subcategory of PHEVs.

Fuel-cell hybrids, which use electric motors and—in most designs—hydrogen for fuel, are not discussed in this article.

Vehicle Categories

Electric Vehicles

EVs use electric motors to power and brake the vehicle, with chemical batteries for onboard energy storage; the batteries are recharged by plugging into the electric grid. This design is the simplest of the three types of PEVs. EVs are energy-efficient, but

their limited onboard energy storage makes them extrasensitive to range, aerodynamics, vehicle weight, heating and air conditioning, and cargo and passenger loads.

Most of the EV designs coming into the market are micro and compact sizes and can store 20 to 50 kilowatt-hours (kWh) of electricity—enough for traveling 100 to 200 kilometers. The Nissan Leaf, to be sold in a few regional markets in the United States in late 2010, is an example—a five-seat compact with a range of approximately 150 kilometers. Ford, Tesla, Volkswagen, and BMW also are manufacturing EVs.

Plug-In Hybrids

PHEVs use the grid and liquid fuels. The models incorporate a battery with a capacity of 4 to 10 kWh to store electricity from plugging into the grid and to increase the time the vehicle can be driven in all-electric mode—in comparison, non-plug-in hybrid batteries store 0.5 to 3 kWh. The PHEV batteries are smaller than those for EVs, and therefore much less expensive.

PHEVs face higher costs because of the complexity of the design. The most well-known PHEV design and the closest to market is the Toyota Prius PHEV. Toyota will demonstrate 500 of the models worldwide this year.

Extended-Range Electric Vehicles

EREVs are a subcategory of PHEVs but use a supplemental internal combustion engine to power the vehicle when the batteries are exhausted. The primary example is the GM Chevy Volt, expected to enter the market this year. The Volt's battery can store at least 16 kWh of charge, which will power the vehicle up to 40 miles. Like EVs, EREVs face high battery costs but place greater demands on the batteries.

Battery Charging

Three levels of charging are available for PEV designs:

Level 1: 110 volt, 15 to 20 amp—Charging a fully depleted battery takes many hours; this level is

Most electric vehicle designs can store enough electricity to travel 100 to 200 kilometers.

Depending on the voltage and amp capacity of the battery-charging mechanism, recharging can take place overnight or in less than 1 hour.



PHOTO: ARKONNE NATIONAL LABORATORY

appropriate for PHEVs; small, low-speed EVs with small batteries; and emergency charging.

Level 2: 220 volt, 30 to 60 amp—Charging a fully depleted battery takes hours but can be done overnight or while the vehicle is parked.

Level 3: 440 volt, 80 to 100 amp—Charging takes less than 1 hour, sometimes only minutes for partial charges.

EVs dropped out of the market in the 1920s with the rise of ICEVs and then were deployed experimentally during the 1990s in a few locations, such as California. The models failed to go commercial, largely because of the batteries—the poor reliability of lead acid and the high cost of the nickel hydride batteries.

Challenges and Prospects

The primary challenges for all types of PEVs remain the cost, energy density, safety, and durability of the batteries. Costs are measured in dollars per kWh. The current costs for limited-production volumes are \$1,000/kWh. Low-volume goals are \$700/kWh, and mass-produced goals are \$300/kWh. The costs of EV battery packs run in the thousands of dollars, and are expected to continue at those levels (1, 2).

But interest in PEVs has renewed through such developments as the success of hybrid vehicles; advances in high-power, electric-drive trains; steady improvements in lithium batteries and in electric-drive control systems; the volatility of crude oil prices, caused by increased demand coupled with uncertainty about supply; and increased concern about greenhouse gas emissions.

Several nations, regions, and cities have announced new deployments of EVs, often with regulatory support. At least a dozen nations, including the United States, the United Kingdom, Germany, France, Spain, the Netherlands, Denmark, and Italy, have specified tax credits and other incentives—in some cases as high as €5000 per vehicle in Europe and \$7,500 per vehicle in the United States. Additional state and provincial incentives also may be applicable.

Most automobile manufacturing nations have set aside financial support to help industry commercialize PEVs, particularly for battery manufacturing. Almost every major automotive maker has announced plans to develop and commercialize PEVs by 2014.

Israel and Denmark and the cities of London and San Diego, for example, are engaging in multifaceted deployments, with expansive rollouts of public charging systems and offers of consumer incentives—such as parking privileges and charging system installations at homes, special electricity rates, high-occupancy vehicle lane privileges, and special tax savings. In Israel and Denmark, the savings on the



Photo: ANL

Argonne National Laboratory tests a Tesla electric vehicle. Plug-in electric and hybrid electric vehicles and extended-range electric vehicles offer ways to reduce consumption of fuels for personal vehicles.

taxes for sales and registration can offset the cost of batteries.

Expected Developments

EVs offer consumers such benefits as an expected lower cost of fuel, the ability to fuel the vehicle while it is parked, environmental sensitivities, and the promise of fun in operating the vehicle—electric motors are easier to control, and many designs achieve fast speeds. Several car makers—such as BMW, Tesla, and Audi—are designing luxury sports car EVs with reportedly better acceleration and handling than their gasoline-fueled counterparts.

EVs also may benefit the power sector by plugging into excess nighttime power capacity. This would entail the development of a system of prices and convenient nighttime charging locations, to encourage the recharging of PEVs during off-peak times, primarily at night, while the vehicle is parked.

Crossing the Threshold

The assumption is that 100 miles of charge will suffice for most of the driving of most vehicles. If this pattern holds as the market develops, several studies indicate that the system capacity is adequate for many millions of PEVs (3, 4).

Nevertheless, the cost of batteries, consumer inexperience, lack of an established manufacturing base, and limited driving range will slow the rollout of PEVs until the markets are proven, costs come down, and the prices of the main competition—ICEVs and fossil fuels—cross a threshold.

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Photo: BMW Group

The ActiveE concept from BMW. High-end car manufacturers are developing luxury electric vehicles.



Reducing Greenhouse Gas Emissions from Freight Trucking

Challenges and Opportunities

MARIANNE MINTZ

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Freight is ubiquitous, moving raw materials and intermediate products between factories, farms, and service providers, and bringing finished goods to warehouses, retailers, and consumers. Freight is transported by truck, train, ship, and aircraft, typically in multiple moves from origin to final destination. Excluding the vast quantities of petroleum products transmitted by pipeline, trucks moved 75 percent of freight tonnage in 2007, and various intermodal combinations moved another 7 percent.¹ Rail accounted for 12 percent of tonnage, and water transportation for 4 percent (1).

The freight system is diverse, having evolved to serve a range of transport needs with an array of modes, infrastructures, and vehicles. This diversity complicates efforts to regulate energy use and associated emissions of carbon dioxide (CO₂) and other greenhouse gases (GHGs). Rail, truck, and domestic air and waterborne shipping account for approximately 30 percent

¹ Rail and waterborne freight typically include longer hauls and are likely to account for larger shares of ton-miles; however, consistent data on modal ton-miles are not available.

of the energy consumed and CO₂ emitted by all transportation vehicles in the United States (2).

In the next two decades, these shares are expected to grow as the fuel efficiency of cars and light trucks improves in response to stricter federal fuel economy and GHG performance standards (2). Unlike the cars and light trucks used for personal travel, however, freight modes are not yet subject to fuel efficiency regulation—although the federal government has begun moving in that direction (see sidebar, page 36).

Truck Freight GHGs

Heavy-duty trucks dominate U.S. freight energy use and GHG emissions, accounting for approximately one-fifth of the GHGs emitted from the transportation sector and for 80 percent of the GHGs associated with the movement of all freight (3). Although all modes can become more energy efficient, strategies to reduce total freight emissions must center on trucking. Major strategies include reducing truck movements by increasing the payload efficiency and capacity and by shifting freight to more energy-efficient modes; improving the energy efficiency of operations; and reducing the carbon content of fuels.



Photo: Virginia Port Authority

The freight system uses an array of modes, infrastructures, and vehicles to serve the nation's transportation needs.

Payload Efficiency

In passenger travel, consumers may defer discretionary trips; in contrast, shippers must move their goods to market. This leaves less scope for reducing travel.

Nonetheless, shippers can cut the weight of their products or packaging; vehicle manufacturers can cut cab and chassis weight to increase payload capacity; and carriers can shorten travel distances through improvements in load-matching and by optimizing the locations of warehousing and consolidation facilities. In many cases—for example, automobile parts and consumer electronics—efforts to reduce manufacturing costs are producing lighter-weight products and thereby reducing ton-miles.

Truck cab and chassis manufacturers are using more lightweight materials to reduce tare weight, increasing the payload capacity for heavier commodities. For hauls that are weight-limited, lighter-weight vehicles and loadings permit shippers to increase the number of units placed on each vehicle, reducing vehicle trips and increasing fuel efficiency or ton-miles per gallon. Yet for the majority of truck hauls that are volume-limited—or that cube out—this kind of weight reduction will have little impact.

Longer combination vehicles offer another option for increasing payload and reducing total truck trips. For example, Sweden and Finland allow truck combinations up to 25.25 meters (82.8 feet) in length, compared with 18.75 meters (61.5 feet) elsewhere in Europe; the longer combinations reportedly consume 14 percent to 20 percent less fuel per ton-kilometer (4).

In the United States, longer combination vehicles, like those shown in Figure 1 (below, right), are estimated to improve energy efficiency by 11 percent to 30 percent, depending on gross vehicle weight, payload, and engine size, compared with standard 5-axle tractor-semitrailer combinations (4). Concerns about the impact on traffic safety and on pavement wear, however, have raised obstacles to their widespread use.

Shifting Modes

Because rail and waterborne freight modes are 2 to 5 times more energy efficient than line-haul trucking, shifting more truck hauls to these modes is another potential strategy for reducing energy consumption and CO₂ emissions (5–7). The scope for mode shifts, however, is limited. Rail lines and navigable waterways are not ubiquitous; some shipments are too small, move too short a distance, or require special handling not available by rail or ship; and shippers of high-value products, perishables, or inputs to just-in-time production schedules are often too time-constrained to consider intermodal options.



PHOTO: AAA FOUNDATION FOR TRAFFIC SAFETY

Packaged foods, chemicals, wood products, and other industrial products generally are considered most amenable to truck-to-rail mode shifts (5). In corridors where rail is an option, energy efficiency varies widely, from 156 to 512 ton-miles per gallon, depending on train configuration, rail-car type, payload weight and type, haul length, and the grade and circuitry of the route (see Table 1, next page).

Although trucks are less variable, with an energy efficiency ranging from 68 to 133 ton-miles per gallon, estimating the energy savings from truck-to-rail shifts is difficult (5). Most rail shipments require a truck movement at one or both ends of the journey, so that the savings tend to be less than shown in Table 1. Recent, detailed studies by commodity and by corridor estimate that approximately 5 percent of truck ton-miles could shift to rail, reducing energy use by approximately 4 percent (6).

Longer truck combinations—as opposed to the standard 5-axle tractor-semitrailer—have improved energy efficiency and can reduce total truck trips.

Energy Efficiency

If the freight system continues to evolve as it has in the recent past, modest improvements can be expected in the energy efficiency of trucking and other freight modes. The U.S. Department of Energy projects

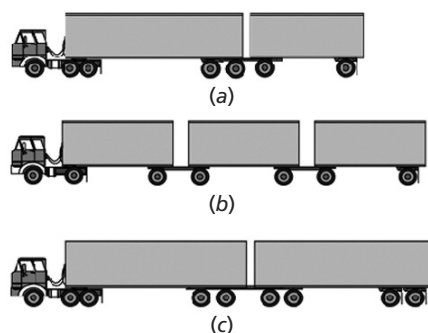


FIGURE 1 Longer combination vehicles—(a) Rocky Mountain double, (b) triple trailer, and (c) turnpike double—can improve energy efficiency by 11 percent to 30 percent over standard tractor-semitrailer combinations.

TABLE 1 Truck and Rail Energy Efficiency by Trailer or Train Type (ton-mi/gal) (5, 8)

Trailer or Train Type	Truck	Rail
Container	68–100	226–512
Auto hauler	74–81	156–164
Other ^a	70–133	278–487
Average ^b	NA	420 ^c

NA = not available.

^a Rail = mixed train; truck = dry van, tank, dump, or flatbed with sides.

^b Across all traffic and equipment types, 2006.

^c As compared with approximately 270 ton-mi/gal for domestic waterborne commerce, averaged across all traffic and equipment types.

annual improvements in energy efficiency of 0.8 percent for heavy trucks and 0.1 percent to 0.2 percent for rail and domestic shipping for the next 25 years (2).

Carriers have a strong incentive to economize on fuel in freight operations, particularly for truck freight. Fuel expenses average \$70,000 to \$125,000 per vehicle per year, the single largest expense for Class 8 long-haul truck fleets, which often operate on

small profit margins (3). Many large common and private carriers are purchasing more fuel-efficient new trucks, training operators to drive more efficiently and to reduce engine idling, and improving load and route planning to save on fuel.

Driver training may reduce fuel consumption by 2 percent to 17 percent and may reduce idling by 6 percent to 15 percent, depending on the engine load, body type, vehicle utilization, and the duty cycle (4, 9, 10). Some carriers, however, are concerned about the reliability of speed governors and other equipment and about the impact on driver retention and therefore are reluctant to invest in energy-saving technologies and techniques (3).

Promising Technologies

Large gains in the energy efficiency of heavy-duty trucks are likely to require the widespread adoption of technologies deployed in light-duty vehicles, such as hybrid powertrains; improved tires, transmissions, and engines; and weight reduction. In addition, truck tractors and trailers will need to reduce aerodynamic

Reducing Fuel Consumption by Medium- and Heavy-Duty Vehicles

Study Evaluates Technologies and Approaches

A new congressionally mandated report from the National Research Council (NRC) of the National Academies evaluates various technologies and methods to improve the fuel economy of medium- and heavy-duty vehicles, such as tractor-trailers, transit buses, and work trucks. The report, *Technologies and Approaches to Reducing the Fuel Consumption of Medium and Heavy-Duty Vehicles*, also recommends approaches for federal regulation.

No fuel economy standards currently apply to trucks, buses, and other large motor vehicles, which account for approximately

26 percent of the transportation fuel used in the United States. In 2007, however, Congress passed legislation requiring the National Highway Traffic Safety Administration (NHTSA) to establish fuel economy standards for medium- and heavy-duty vehicles.

Estimating the Savings

The NRC study—jointly produced through the Division on Engineering and Physical Sciences' Board on Energy and Environmental Systems and the Transportation Research Board—estimates the fuel-saving improvements that various vehicle technologies could achieve in the next decade for seven vehicle types. For example, with advanced diesel engines, tractor-trailers could lower their fuel consumption by up to 20 percent by 2020, and improved aerodynamics could yield an additional reduction of 11 percent. Hybrid powertrains could lower the fuel consumption of vehicles that stop frequently, such as garbage trucks and transit buses, by as much as 35 percent. Although the cost of these improvements would be passed on to vehicle purchasers, many of these technologies would pay for themselves even at today's energy prices, according to the report.

The report also estimates the cost and fuel savings by 2020 with the technologies for each type of vehicle combined. The best cost-benefit ratio was for tractor-trailers, which could cut fuel use by an estimated 50 percent for approximately \$84,600 per truck; the improvements would be cost-effective over 10 years if diesel fuel prices are at least \$1.10 per gallon. Motor coaches could lower fuel use by 32 percent, for an estimated \$36,350 per bus,

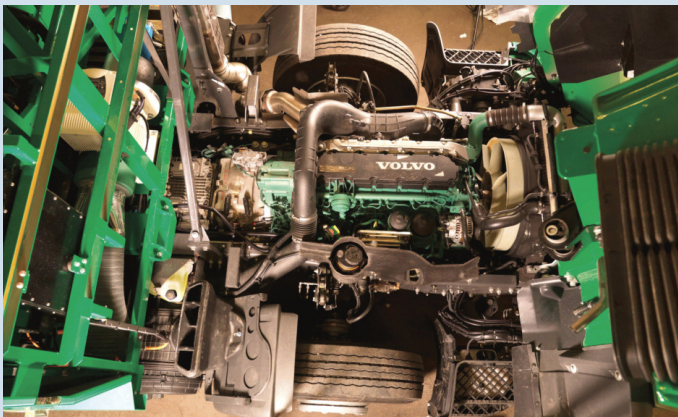


Photo: Volvo Group

The engine of a Volvo hybrid diesel test vehicle. The new NRC report examines ways to improve fuel economy for medium- and heavy-duty trucks.

drag with integrated designs incorporating such features as fairings, undercarriage flow control, boat tails, and gap seals. As shown in Table 2 (next page), widespread application of these technologies, coupled with improved energy management strategies, could yield a 30 percent reduction in gallons per ton-mile for tractor-trailers entering the fleet in the next 5 years; in 2015 to 2020, these technologies could reduce the gallons per ton-mile of new vehicles by approximately 50 percent (9).

The 21st Century Truck Partnership, a combined effort of the U.S. Departments of Energy, Transportation, and Defense with the Environmental Protection Agency and 16 industrial partners, is working to develop many of the energy-saving truck technologies examined in a National Research Council study (9). Research under the partnership focuses on reducing losses from aerodynamic drag, rolling resistance, auxiliary loads, and drivetrain inefficiencies; decreasing idling; and developing heavy-duty hybrid propulsion technology. As shown in Figure 2 (page 39), these losses currently limit the average fuel



economy of a typical Class 8 combination vehicle to 3.5 miles per gallon in urban conditions and to 6.7 miles per gallon in Interstate operation (3).

Aerodynamics

Trailers present a special fuel efficiency challenge. Aerodynamic features are now common in long-haul

Swedish truck manufacturer Scania runs a training course in fuel-efficient driving. Driver training can reduce fuel consumption up to 17 percent.

which would be cost-effective with the price of fuel at \$1.70 per gallon or higher. For other vehicle classes, the financial investments for improvements would be cost-effective only at higher fuel prices.

Load-Specific Standards

The NRC study committee urged regulators setting standards to use a fuel consumption measure that accounts for the freight or passengers carried. The miles-per-gallon measure for regulating the fuel economy of passenger cars, or light-duty vehicles, is not appropriate for medium- and heavy-duty vehicles, which are designed to carry loads efficiently. For example, a partly loaded tractor-trailer could travel more miles per gallon than a fully loaded one—miles per gallon therefore would be a poor measure of the fuel efficiency of moving goods. Instead, metrics for regulating medium- and heavy-duty vehicles should reflect the effi-

ciency with which a vehicle moves goods or passengers, such as gallons per ton-mile—the amount of fuel a vehicle would use to carry 1 ton of goods 1 mile.

The report therefore recommends that NHTSA establish load-specific fuel consumption standards, tied to the task associated with a particular type of vehicle; for instance, garbage trucks might be held to a different standard from transit buses or long-haul tractor-trailers. The regulations should reflect national data on the average payload carried by each type of vehicle. Moreover, the regulations should apply not to the vehicle component makers but to the final-stage vehicle manufacturers, who have the greatest control over the vehicle's configuration and design.

Regulatory Approaches

Regulating medium- and heavy-duty vehicles will be more complicated than regulating passenger cars, the report notes, because of the variety of vehicles and their differing tasks and terrains. Models are available—Japan regulates the fuel economy of medium- and heavy-duty vehicles, and the European Union and the state of California are developing standards.

According to the NRC report, however, one way to avoid the complexity of regulating different types of vehicles would be to impose a fuel tax, which would induce firms to optimize the fuel efficiency of their operations. The report urges Congress to consider this and other pricing approaches. In addition, the report recommends that NHTSA apply nontechnical methods to lower fuel consumption, including incentives to train vehicle operators in efficient driving techniques, which can produce fuel savings of 2 percent to 17 percent. One approach could be to establish a process to train drivers in these techniques as part of commercial driver license certification.



A hybrid garbage truck manufactured by Volvo. For vehicles that stop frequently, hybrid powertrains can lower fuel consumption by as much as 35 percent.

PHOTO: AAA FOUNDATION FOR TRAFFIC SAFETY



Truck weight reduction can lead to increased energy efficiency.

tractors, but trailer aerodynamics has changed little; when the equipment is owned by shippers, not by carriers, the purchase decision often focuses on low purchase or maintenance cost for the shipper, instead of on fuel economy for the carrier.

As shown in Table 2, aerodynamic tractors coupled with three aerodynamic trailers could improve fuel efficiency by more than 11 percent by 2020 (9). As a practical matter, however, such configurations face many barriers, including the distribution of the costs and benefits among the parties; uncertainties about driver and community acceptance; concerns about equipment maintenance and durability; and the safety implications of the mass differences between light and heavy vehicles in mixed traffic.

Low-Carbon Fuels

Almost all freight moves on diesel vehicles, which can operate on neat or blended biofuels. Substituting biodiesel from soybean methyl esters for petroleum diesel can reduce GHG emissions by 60 percent to 75 percent, depending on how emissions are allocated among biodiesel, animal feed, and electricity coproducts (11).

For many biofuel feedstocks, however, the potential for reducing GHG emissions is uncertain. The full life-cycle of the fuels may include GHG emissions associated with more intense land cultivation, as well as indirect or second-order effects from shifting the cultivation of food crops from a continuously farmed location to a previously uncultivated one.

Liquefied natural gas (LNG) and synthetic Fischer-Tropsch diesel are other potential lower-carbon diesel substitutes for petroleum diesel. Growing supplies of domestic natural gas from deep shale formations have spurred interest in these options. These fuels are unlikely to achieve large GHG reductions, however, without improvements in the energy efficiency of heavy-duty natural gas engines—which are 10 percent less efficient than comparable diesels—and reductions in the exhaust emissions of methane, a potent GHG (11). The exception is LNG from biomethane, which may reduce GHG emissions by 77 percent to 97 percent, depending on the carbon content of the fuel that was used to produce electricity for the process (11).

TABLE 2 Potential Near-Term and Midterm Reductions in Fuel Consumption from Technologies and Operating Changes to Tractor-Trailer Trucks (9)

Technology or Operating Change	Description	Near-Term Increase in ton-mi/gal (%)	Midterm Increase in ton-mi/gal (%)
Aerodynamics	Lower drag tractor plus three aerodynamic trailers	5.5	11.5
Engine	Advanced 11- to 15-liter diesel engine with bottoming cycle	10.5	20
Weight reduction	Materials substitution	0.8	1.25
Tires	Improved wide bias single tires on tractor and trailers	4.5	11
Transmission and driveline	Advanced manual transmission, reduced driveline friction	5.0	7
Hybridization	Mild parallel hybrid with idle reduction	–	10
Speed management and coaching	60-mph speed limit; predictive cruise control with telematics; driver training	3.0	6
Idle reduction	Included in hybrid system	6.0	–
Total added weight	Added components	1,530 lb	2,030 lb
TOTAL	Fuel efficiency improvement of entire package (% reduction in gal/ton-mi)	30.0	50.5

Outlook

Energy use and GHG emissions are expected to grow faster from freight trucks than from passenger cars in the next decades. Achieving large reductions in the GHG emissions from U.S. transportation therefore will require a focus on freight trucks. Large trucks and their operations must become more fuel-efficient.

According to estimates, various technologies can reduce the fuel consumption of new heavy-duty trucks by 50 percent by 2020—but when or if these gains can be achieved fleetwide remains unclear. Shifting some freight to more energy-efficient modes, improving driver skills, reducing engine idling, and increasing the use of lower-carbon fuels also can contribute to emissions reductions. The more that energy use and GHG emissions must be reduced, the more important it will be to achieve reductions through a variety of means.

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Freight rail movement often involves motor carriers at one or both ends of the route, complicating estimates of emissions reductions from mode shifts.

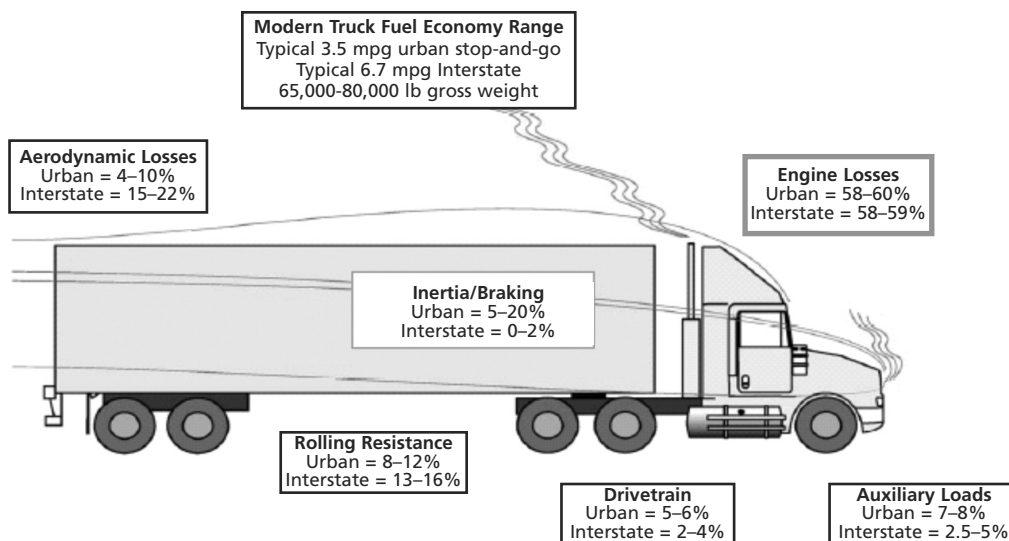


FIGURE 2 Engine, drive train, and other losses reduce truck fuel economy.



International Shipping and Greenhouse Gas Emissions

From Assessment to Mitigation

JAMES J. CORBETT, JAMES J. WINEBRAKE, AND HAIFENG WANG

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The burning of carbon-rich fossil fuels to power marine vessels and other transportation modes contributes worldwide to the risk of climate change from the atmospheric buildup of carbon dioxide (CO₂) and other greenhouse gases (GHG). According to a study for the International Maritime Organization (IMO), international marine shipping emitted approximately 1,050 million metric tons (Mmt) of CO₂ in 2007, accounting for approximately 3 percent of CO₂ emissions globally. Shipping industry emissions of CO₂ exceed those of Germany, which ranks sixth among the nations, according to the United Nations (U.N.) Millennium Development Goals Indicators¹ (Figure 1, next page).

The international movement of goods relies on the massive system of transoceanic, coastal, and inland water routes. The maritime industry has become a pillar of global trade, providing inexpen-

sive and reliable long-distance transportation service. Data from the U.N. Conference on Trade and Development show that sea-based transport accounts for approximately 90 percent of freight ton-miles. Because of this volume, shipping produces twice as much CO₂ emissions as air cargo, even though shipping emissions are 40 times lower per ton of freight. With growth in international trade (Figure 2, next page), maritime emissions also will rise, and the rate of growth in shipping may increase faster than in nontransport energy-using sectors of similar size.

Controlling the emissions from shipping will require novel policy and technology approaches. International shipping comprises a complex mix of ownership by companies in large trading nations, registry by flags from developed and developing countries, and services connecting suppliers and customers all over the globe. In contrast, most activity for passenger vehicles, trucks, and locomotives occurs within national jurisdictions, and the emissions impacts of these modes are seldom modeled globally.

¹ <http://mdgs.un.org>.



PHOTO: PORT OF LOS ANGELES

Emissions Types and Effects

In addition to GHGs, shipping emits other substances that have detrimental impacts on the atmosphere, coastal environments, and human health. According to the *Second IMO Greenhouse Gas Study 2009*, GHGs from ships include CO₂, volatile organic compounds (VOC), methane (CH₄), black carbon (BC), organic carbon particles (OC), nitrogen oxides (NO_x), nitrous oxide (N₂O), sulfur oxides (SO_x), and carbon monoxide (CO) (see Table 1, page 42).

The total mass of those emissions is small, but most are much more potent than CO₂ as potential causes of global warming. For example, 1 kilogram of BC is 460 times more potent on a global average than an equivalent amount of CO₂ over a 100-year period and 1,600 times more potent over a 20-year period. BC emitted in the Arctic or near ice and snow may have an even greater effect.

Global Cooling

At the same time, shipping contributes to global cooling through the emission of aerosols. Although emissions in the global transport sector are expected to account for approximately 15 percent of warming caused by humans in the coming decades, shipping is unique for what is termed the negative forcing associated with aerosol emissions.

The Intergovernmental Panel on Climate Change has defined radiative forcing as the influence a factor has in altering the balance of incoming and outgoing energy in the earth-atmosphere system; radiative forcing is an index of the factor as a potential mechanism for climate change. A positive forcing, which signifies more captured energy, tends to warm the system; a negative forcing generates more reflected energy and tends to cool the system.

Ships that burn high sulfur residual fuel with a sulfur content averaging 2.7 percent, or 27,000 parts per million, generate short-lived sulfate aerosols from the SO₂ emissions. These sulfate aerosols prevent sunlight from reaching the earth's surface, creating a cooling effect or negative forcing.

Even with the large quantities of CO₂ emissions from international shipping, scientists estimate that the net global mean radiative forcing by ships is negative. This creates a conundrum for regulators intent on addressing the adverse effects on human health by reducing the aerosol emissions from shipping.

Arctic Routes

Other types of emissions from ships can have regional impacts, affecting sensitive ecosystems and potentially contributing to the risks of climate change. For example, shipping emissions of small BC particles may accelerate ice melt, notably in the Arc-

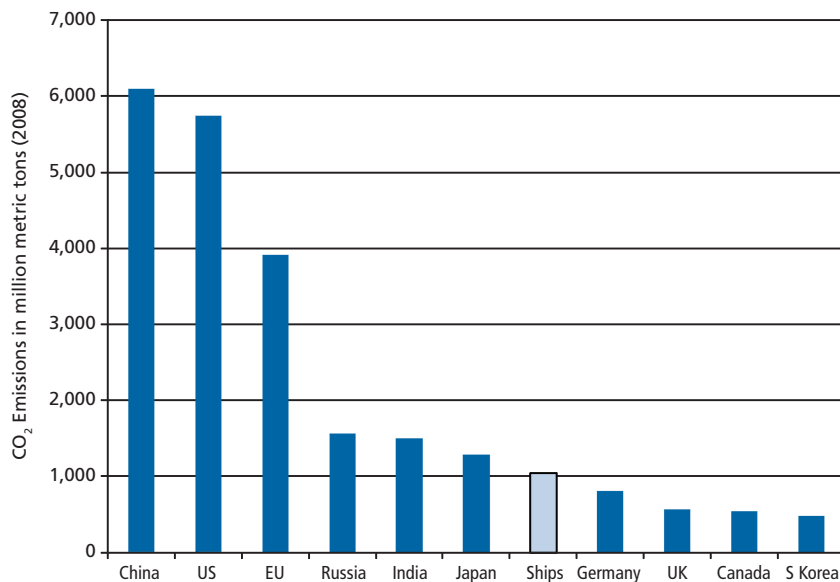


FIGURE 1 CO₂ emissions by nation compared with international shipping, 2008. (Sources: *Second IMO Greenhouse Gas Study 2009*; World Resource Institute 2009.)

tic. As Arctic sea-ice melts, maritime transportation to the region may increase. Many envision new navigable trading routes opening in the Arctic Ocean, thousands of kilometers shorter than current routes, possibly rivaling the Suez and Panama Canals.

Although the shorter routes may change global CO₂ emissions from ships by cutting energy consumption, the increased regional exposure to short-lived forcing emissions like BC may have a greater effect on climate change. Policies to reduce short-lived forcing emissions, therefore, may help slow the effects of global warming in sensitive regions like the Arctic.

International policy to reduce criteria pollutants to protect human health and the environment will

FIGURE 2 U.S. gross domestic product (GDP) and container traffic, 1980–2005. (TEUs = 20-ft equivalent units.)

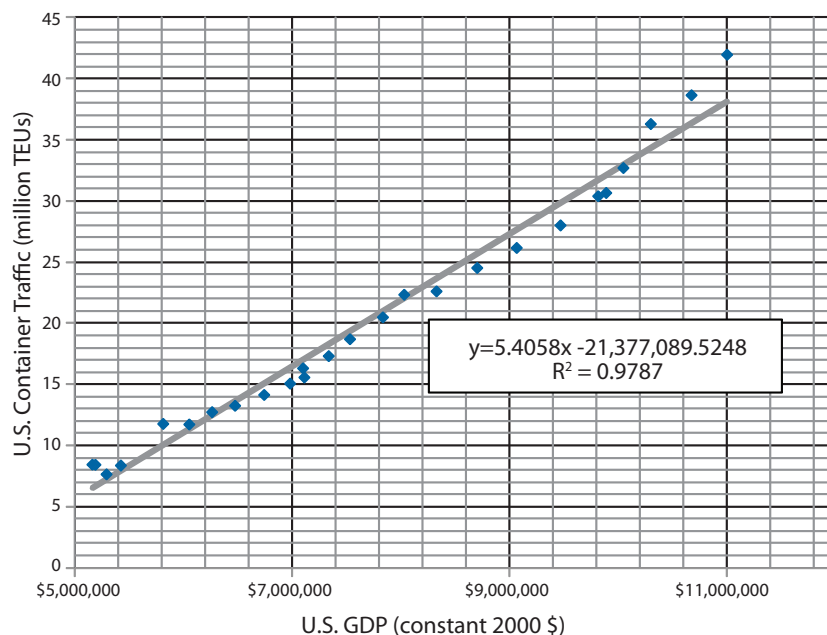


TABLE 1 GHGs and Other Emissions from International Ships in 2007 (million metric tons)

CO ₂	VOC*	CH ₄ *	BC	POM	N ₂ O	CO	NO _x	SO _x
1050	0.8	0.1	0.12	0.29	0.027	1.8	24.5	14.6

* Not including tanker loading.

(CO₂ = carbon dioxide; VOC = volatile organic compounds; CH₄ = methane; BC = black carbon; POM = particulate organic matter; N₂O = nitrous oxide; CO = carbon monoxide; NO_x = nitrogen oxides; SO_x = sulfur oxides.)

Source: *Second IMO Greenhouse Gas Study 2009*.

affect the emissions of SO_x and NO_x from shipping; prospective policy actions on trends in CO₂ emissions are less clear and still uncertain. Figure 3 (facing page) summarizes the emissions trends projected in IMO's GHG study, which assumes a range of scenarios involving alternative rates of economic and population growth, mixes of fuel types, levels of international trade, and technological advancement. These scenarios indicate the potential for a range of emissions outcomes, without including the climate policy actions now in development. All produce marked growth in emissions of CO₂ and NO_x, but

relatively smaller increases in the emission of SO_x, which produces sulfate aerosols.

Policy and Pricing Signals

IMO and the U.N. Framework Convention on Climate Change are exploring the use of regulatory and pricing signals to control shipping emissions. Mitigation policies under discussion range from new vessel design and operation metrics to carbon taxes and emissions trading schemes.² The European Commission is considering interventions if IMO's multilateral initiative proves unsatisfactory and may add the shipping industry to the European Union's emission trading system or may include ships in emission-related harbor dues and binding CO₂ index limits.

Regulatory actions are under way at the regional level. California's Global Warming Act of 2006, for

² For a detailed discussion on issues related to the implementation and enforceability of international regulations aimed at the shipping sector, see Corbett and Winebrake 2010 in the list of further reading.

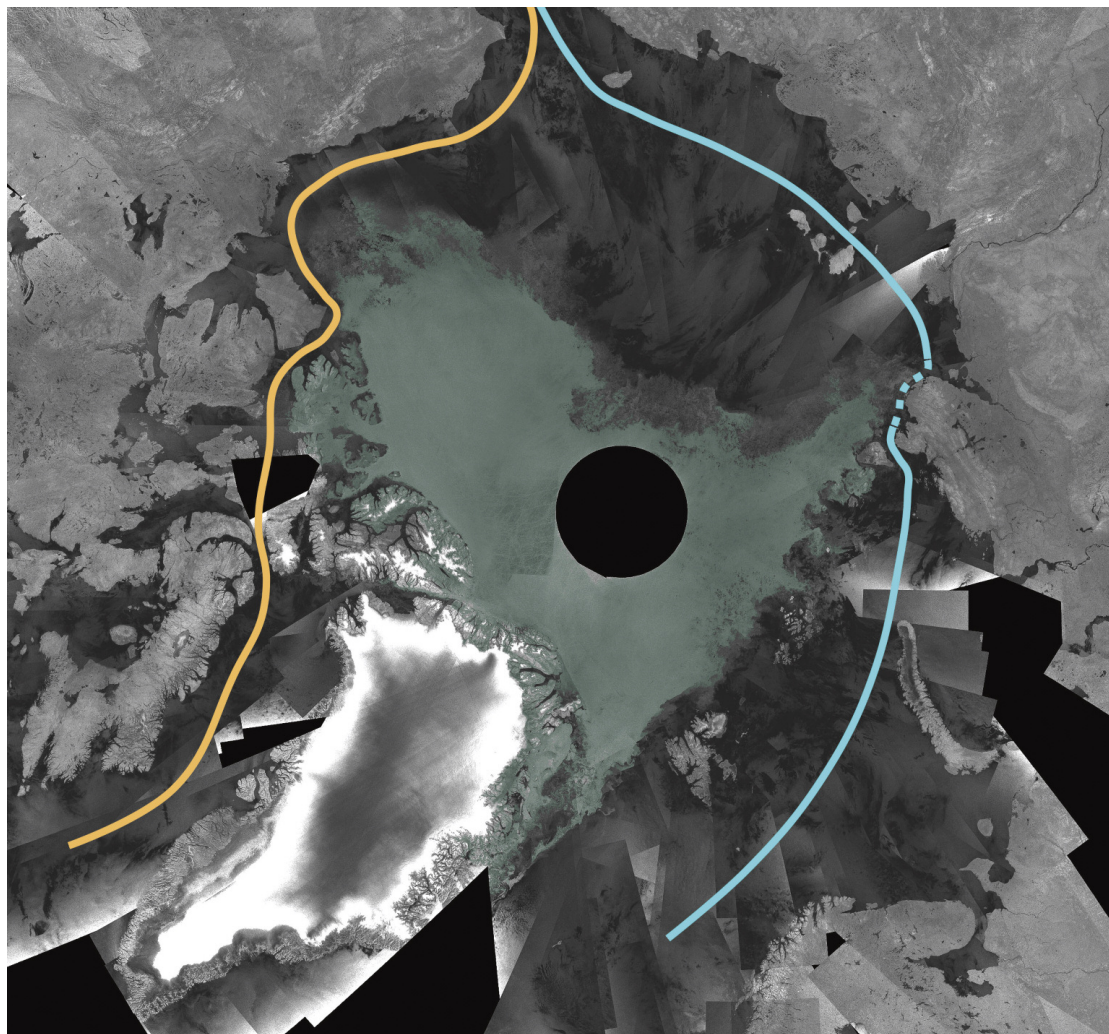


PHOTO: EUROPEAN SPACE AGENCY

Paths of the northwest and northeast passages through the Arctic, as of September 2007. New navigable trading routes will open as the polar ice cap melts.



Photo: IPCC

Rajendra K. Pachauri, Intergovernmental Panel on Climate Change (IPCC), speaks at the United Nations Summit on Climate Change in 2009. The IPCC identified radiative forcing as an index of a potential mechanism for climate change.

example, requires the reduction of GHG emissions from all economic sectors, including ships in port. Some regional port authorities are participating in environmental mitigation programs that address energy use and emissions. The Port of Virginia has established an environmental management system to improve air and water quality and energy efficiency at Newport News Marine Terminal, Norfolk International Terminals, and Portsmouth Marine Terminal.

Because shipping services are highly sensitive to energy prices, pricing instruments hold promise as a mitigation option. The size and speeds of vessels have been optimized to provide reliable goods movement at an expected fuel price, which was stable until recently. Energy pricing will motivate changes in ship design speeds, as well as recapitalization with more efficient vessel designs. Other expected effects include fuel switching, advanced retrofits for energy efficiency and emissions control, slow-speed operations, new logistics routing plans, and improved matching of container payloads and warehouse inventory needs in the supply chain.

Energy pricing signals will create new opportunities and challenges for the industry, affecting operational behavior and modifying fleet design requirements for recapitalization. Yet even without fuel levies, emissions trading, or other policies such as mandates for energy-efficient vessel designs, shipping companies face demands and costs that should have the side effect of reducing energy use and carbon emissions.

Recent increases in marine fuel prices and international environmental agreements requiring ships to switch to higher-priced, lower-sulfur fuels in the next decade already are providing economic and regulatory signals to increase the energy efficiency of shipping. Infrastructure renewal and new investments in vessels and port terminals to accommodate

the expected growth in goods movement will provide further opportunities for increasing the efficiency of shipping operations.

Complex Strategies

Controlling the GHG emissions from shipping in international waters will require a complex set of strategies; many countries are setting ambitious targets for emissions reductions. The reduction of sulfate emissions, which damage human health but cool the atmosphere, adds to the complexity of international policymaking.

Because it transcends national boundaries, shipping may take a leadership role in implementing innovations for goods movement under IMO agreements, or the industry may be compelled to take part in the regulatory and market-based measures being developed by international policy bodies. Either way, expected increases in global trade will provide opportunities for enhancing efficiency. Policies that exploit these opportunities will ensure that the maritime sector maintains a vital role in goods movement in ways that are compatible with world energy and climate goals.

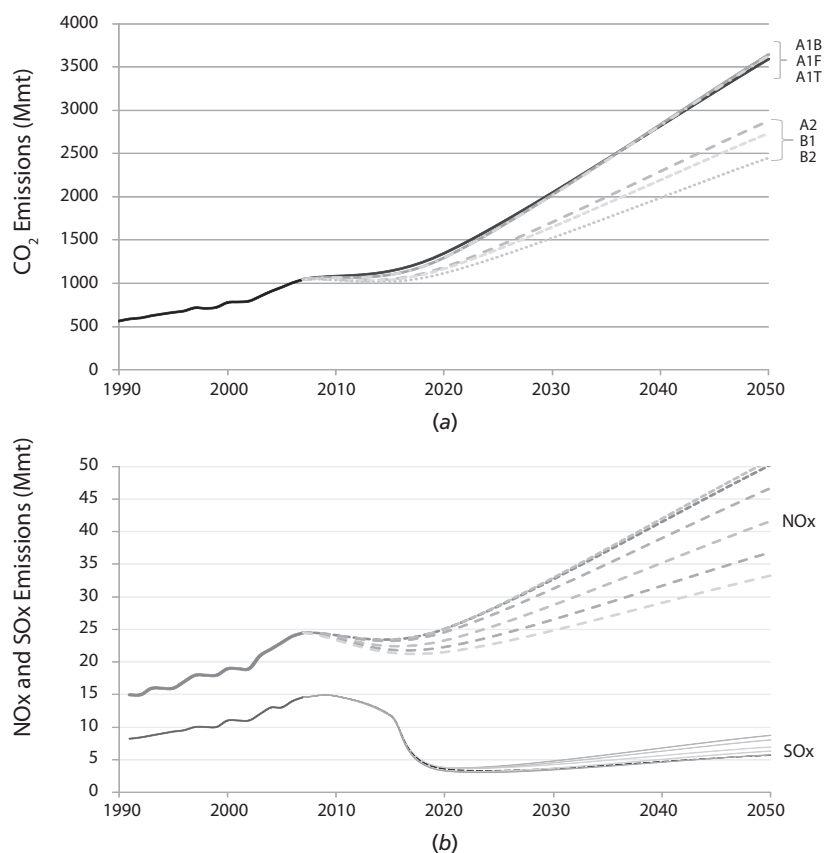


FIGURE 3 Trends and projections for international shipping emissions of (a) CO₂ and (b) NO_x and SO_x. (Note: Forecast trends conform to scenarios in the *Second IMO Greenhouse Gas Study 2009*. Mmt = million metric tons.)

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PHOTO: WORLD SHIPPING COUNCIL AND OOCL

International marine shipping accounted for approximately 3 percent of global CO₂ emissions in 2007.

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Preparing Inventories of Airport Greenhouse Gas Emissions

No national or state legislation requires U.S. airport operators to prepare inventories of greenhouse gas (GHG) emissions. A few airports have generated inventories either voluntarily or at the request of municipalities, often in conjunction with state and local initiatives to mitigate climate change. Sacramento International

Airport and San Diego International Airport, for example, prepared inventories to assist with the analysis of proposed airport improvements under the California Environmental Quality Act. With no national legislative mandates, however, no clear guidance is available for developing airport-specific inventories.

To fill this need, TRB's Airport Cooperative Research Program (ACRP) has developed the *Guidebook on Preparing Airport Greenhouse Gas Emissions Inventories*.^a The publication presents guidance for airports developing inventories of GHG emissions. Methodical instructions and diagrams specify the procedures and explain the metrics.

Because scientific understanding is evolving, along with policies to address the causes of climate change, ACRP plans to update elements of the guidebook regularly to incorporate new information about the impacts of emissions on climate and about improved methods to measure emissions. The guidebook is available online,^a or in print from the TRB online bookstore.^b

^a ACRP Report 11, http://onlinepubs.trb.org/onlinepubs/acrp/acrp_rpt_011.pdf.

^b www.trb.org/bookstore.



PHOTO: VIRGINIA PORT AUTHORITY

Many regional port authorities have established environmental management systems (EMS). Above, the Virginia Port Authority employs EMS at its terminals, including the Norfolk International Terminal (above).

Recent Developments in Aviation Climate Policy

ANNELA ANGER AND JOHN E. PUTNAM

The Kyoto Protocol of the United Nations (U.N.) Framework Convention on Climate Change delegates authority for controlling the greenhouse gas (GHG) emissions from international aviation sources to the International Civil Aviation Organization (ICAO). Concerned about a lack of progress in establishing controls, however, the European Union (EU) has decided to include carbon dioxide (CO₂) emissions from all domestic and international flights within the EU Emissions Trading Scheme (ETS) starting in 2012. The ETS includes all flights to and from the 27 EU countries, plus Iceland, Norway, and Liechtenstein. The monitoring and reporting of emissions and tonne-kilometer activity data for aircraft operators affected by the ETS began this year; the data for 2010 will be used to calculate the ETS benchmark for aviation.

The applicability of the ETS to non-EU airlines has been controversial. Airlines based in countries outside the European Union will not need to comply if their home countries have established equivalent CO₂ reduction measures.

Working Toward Agreements

Aviation's impacts on global climate go beyond those associated with the emission of CO₂ from fossil fuel combustion. For example, nitrogen oxide emissions from aircraft at high altitudes, as well as persistent contrails or vapor trails, can form heat-trapping cirrus clouds. During the debate about including the aviation industry in the ETS, the use of a multiplier was proposed to account for the additional warming effects from aviation. The multiplier, however, was not included in the final plan, partly because the nature and scale of these impacts remain uncertain.

At the U.N. Climate Change Conference in Copenhagen in December 2009, national representatives attempted to reach agreement on how to regulate GHG emissions from aircraft, as well as from ships. The European Union proposed that the 2020 targets for reducing GHG emissions from the fuel burn of international aviation be set at 10 percent below the levels in 2005. Although no agreement was reached in Copenhagen, talks continue in preparation for follow-on meetings in Cancun, Mexico, in November. If an international agreement is reached, the European Union probably will exclude aviation from the ETS.



PHOTO: FLUGHAFEN MÜNCHEN GABRIEL

Emissions data for domestic and international flights in Europe have been collected for the first time this year.

Introducing Biofuels

Aviation biofuels offer a potential means of complying with EU's ETS or with any future international emissions controls—including voluntary commitments by airlines. Research on biofuels has advanced rapidly through the Commercial Aviation Alternative Fuels Initiative (CAAFI), a partnership of the Federal Aviation Administration, the Air Transport Association, the Aerospace Industries Association, and the Airports Council International–North America. A critical issue is safety and assuring

that any biofuel or biofuel blend meets the high standards for certifying a fuel for use in commercial aviation.

The certification of biofuels by the standards organization ASTM International is pivotal in ensuring the safety of biofuels for use in commercial aircraft. In September 2009 ASTM certified for commercial use a blend of up to 50 percent synthetic jet fuel derived from fossil fuels or biomass using the Fischer-Tropsch (FT) process.

At the same time, CAAFI is working to secure ASTM certification for a blend of up to 50 percent hydrotreated renewable jet (HRJ) fuels from oils such as jatropha, camelina, or algae. CAAFI also is working toward certification for 100 percent FT or HRJ fuels by 2013.

CAAFI established life-cycle emissions guidelines for aviation biofuel in late 2009, recognizing that the GHG emissions of fuels can differ significantly, depending on feedstock. Airlines have been working to introduce biofuels; many have flown test flights with different fuels during the past 2 years.

Aviation represents one of the most promising applications of biofuels and other alternative fuels, because use is concentrated at relatively few locations, limiting the need for new infrastructure. Nonetheless, securing capital for the development of commercial-scale biorefineries is a significant immediate challenge under current economic and industry conditions. Addressing this challenge will be an important focus for the industry in the next few years.



PHOTO: NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION/NATIONAL WEATHER SERVICE

Vapor trails from aircraft at high altitudes can form heat-trapping cirrus clouds.

Anger is a researcher with the Cambridge Centre for Climate Change Mitigation Research, University of Cambridge, United Kingdom; Putnam is Partner, Kaplan Kirsch & Rockwell, LLP, Denver, Colorado.

CALENDAR

TRB Meetings
2010**July**

- 11–14 TRB Joint Summer Meeting
Minneapolis, Minnesota
- 11–14 49th Annual Workshop on
Transportation Law
Newport, Rhode Island
- 11–15 5th International Conference
on Bridge Maintenance,
Safety, and Management*
Philadelphia, Pennsylvania
- 13–14 SHRP 2 5th Safety Research
Symposium
Washington, D.C.

August

- 23 Asset Management in a
World of Dirt
Oklahoma City, Oklahoma
G. P. Jayaprakash
- 25–26 Towards Zero Deaths: A
National Strategy for Highway
Safety (*by invitation*)*
Washington, D.C.

September

- 4 Pavement Performance
Data Analysis Forum
São Paulo, Brazil
A. Robert Raab
- 15–17 International Conference on
Sustainable Concrete Pave-
ment Technologies: Practice,
Challenges, and Directions*
Sacramento, California
- 20–23 Workshop on Research Needs
for IntelliDriveSM Applications
for the Public Sector
Irvine, California

- 22–24 10th National Conference on
Transportation Planning for
Small- and Medium-Sized
Communities: Tools
of the Trade
Williamsburg, Virginia
- 22–24 Symposium on Mineral
Aggregates in Transportation
Charleston, South Carolina
- 23 Workshop on Rail Network
Capacity Issues*
Jacksonville, Florida

October

- 10–13 9th National Conference on
Access Management*
Natchez, Mississippi
- 11–13 European Transport
Conference*
Glasgow, Scotland
- 18–19 Transportation Systems for
Livable Communities
Conference
Washington, D.C.
- 24–27 19th National Rural Public and
Intercity Bus Transportation
Conference
Burlington, Vermont
- 24–29 Pavement Evaluation 2010*
Roanoke, Virginia
- 25–27 Sustainable Transport and
Quality of Life in the City*
Buenos Aires, Argentina

November

- 8–10 International Conference on
Commercial Driver Health and
Wellness
Baltimore, Maryland

- 16 Commodity Flow Survey
Workshop
Washington, D.C.

December

- 1–3 7th International Bridge
Engineering Conference:
Improving Reliability and
Safety—Restoration, Renewal,
and Replacement
San Antonio, Texas

2011

January

- 23–27 TRB 90th Annual Meeting
Washington, D.C.
www.TRB.org/AnnualMeeting

March

- 13–16 Geo-Frontiers 2011*
Dallas, Texas

April

- TBD Visualization in
Transportation: Expanding
Uses and Technologies
Madison, Wisconsin

May

- 1–4 International Transportation
Economic Development
Conference: Economic Impact
of Connecting People, Goods,
Markets, Employment,
Services, and Production*
Charleston, West Virginia

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RESEARCH PAYS OFF



Creating Environmentally Sound Specifications for Culvert Rehabilitation

Virginia Applies Findings for Cured-in-Place Pipe Repair

BRIDGET DONALDSON AND EDWARD D. WALLINGFORD

Donaldson is a Research Scientist with the Virginia Transportation Research Council, Charlottesville. Wallingford is an Environmental Program Manager with the Virginia Department of Transportation, Richmond, and Chair of the TRB Waste Management and Resource Efficiency in Transportation Committee.

A CIPP repair project during the steam cure.



Photo: VTRC

Repair or replacement of damaged or worn culverts and pipes is a major maintenance concern for U.S. transportation agencies. Cured-in-place pipe (CIPP) rehabilitation allows users to repair underground pipes in place, instead of unearthing and replacing damaged pipe sections.

Problem

CIPP repair has become a common way to preserve transportation infrastructure efficiently and at a reasonable cost. Typically, a liner saturated with a styrene-based thermosetting resin is inserted into the damaged pipe and polymerized—or cured—through the introduction of steam or heated water.

Although styrene can be toxic to aquatic species and is classified as a potential carcinogen by the Environmental Protection Agency (EPA), the potential environmental impacts of CIPP repair have been little investigated. Of particular concern are the potential impacts of the release of the styrene-

contaminated water or steam condensate and the leaching effects of styrene from the cured pipe.

Research

The Virginia Department of Transportation (DOT) tasked the Virginia Transportation Research Council (VTRC) to evaluate the impacts of styrene-based CIPP repair on water quality. During the 1-year study, VTRC evaluated seven steam-cured CIPP installations in Virginia by three different companies.

Researchers collected water samples from each project site before, during, and after installations and analyzed the samples for styrene. The results were evaluated against established regulatory standards and toxicity criteria for several aquatic indicator species found in freshwater habitats throughout the United States.

Observations

At two of the installations, researchers observed that effluent—steam condensate—from the curing process was discharged directly downstream. At three installations, uncured resin residue waste extruded during the lining process and either washed downstream or remained on the dry stream bed immediately outside the pipe outlet or inlet. At three sites, algal blooms—which can indicate pollution—were apparent within 1 week after installation and remained visible for up to 3 months.

Water and Waste Samples

Water sampling results were compared with EPA's maximum contaminant level (MCL) of 0.1 parts per million (ppm) for styrene in drinking water and with the lethal concentrations of styrene for five different species that indicate water quality—water flea, fat-head minnow, rainbow trout, amphipod, and fresh-



Photo: VTRC

An uncured extruded resin with algal blooms 1 week after CIPP installation.

water green algae—which range from 0.7 ppm to 10.0 ppm.

Water sampling results were as follows:

- ◆ Styrene was detected in water samples from six of the seven sites and up to 88 days after CIPP installation.

- ◆ The highest concentration of styrene, 77 ppm, was found in water samples taken during the downstream release of effluent from the curing process.

- ◆ Although the sites were not directly linked to sources of drinking water, styrene concentrations reached up to two orders of magnitude—more than 700 times—greater than the MCL for drinking water. Styrene concentrations at five of the seven sites exceeded the MCL for drinking water for 5 to 71 days after the CIPP installation.

- ◆ Styrene concentrations at five sites exceeded the toxicity criteria for aquatic species for up to 24 days after the installation.

In addition to the water samples, a sample of the uncured resin waste in a stream bed was collected 1 day after installation and had a styrene concentration of 580 ppm.

Study Implications

The findings suggest that the elevated styrene levels

could have resulted from any one or more of the following: (a) installation practices that did not capture effluent containing styrene; (b) uncured resin that escaped from the liner during installation; (c) insufficient curing—that is, incomplete polymerization—of the resin; and (d) some degree of permeability in the liner material. In addition, if the curing was incomplete in the finished product, the maximum structural strength likely was not achieved, although destructive testing was not performed to confirm this. The research report is available online.¹

Application

The research findings led Virginia DOT to place a stop-work order on all contracts for styrene-based CIPP repair. Virginia DOT formed a task group, led by staff in the Environmental Division, to evaluate further the use of the technology and to provide recommendations about continuing use. The task group asked the state environmental quality agency for input; performed additional testing at CIPP sites; solicited input from CIPP industry representatives; and developed new construction specifications to minimize environmental risks and ensure maximum structural performance of the finished product.

With the release of the new specifications, Virginia DOT reinstated CIPP installations.² The specifications require the following:

- ◆ Both an inner and an outer impervious film to envelop the resin-liner system and promote complete polymerization, prevent resin loss, and prevent styrene contamination of the interior portion of the finished pipe;
- ◆ Use of a semirigid plastic slip sheet over significant voids and pipe intrusions that could damage the liner during insertion;
- ◆ Installation oversight by a trained inspector;
- ◆ Time-temperature monitoring, with data logging, at points throughout the length of the pipe for the curing of the lining material;
- ◆ Thorough rinsing of the finished product;
- ◆ Proper containment and disposal of effluent cure water and rinseate;
- ◆ Water and soil testing for styrene before and after installation; and
- ◆ Corrective actions to remediate the accidental release of styrene.

Further research by VTRC will determine if the

¹ www.virginiadot.org/vtrc/main/online_reports/pdf/08-r16.pdf.

² The complete list of specifications is posted at www.virginiadot.org/business/resources/const/cdmemo-0811.pdf.

application of these specifications ensures strict control of styrene at new installations.

Benefits

The research confirmed that discharges of styrene into the environment were occurring during styrene-based CIPP installations. The findings highlighted the need for more stringent controls of the installation process to prevent impacts to aquatic species and associated violations of water quality. The research findings also served as a foundation for candid discussions with industry representatives in the search for achievable process modifications that would satisfy environmental requirements.

Follow-up research revealed that lack of control over cure variables increased the chances of inadequate liner cure, potentially jeopardizing the structural strength and durability of the finished product. The research and the actions taken by Virginia DOT have generated attention from other states with similar concerns about styrene-based CIPP and other pipe repair technologies and have prompted several transportation agencies to review their pipe repair specifications more closely.

As pipes that convey stormwater and streams age, deteriorate, and require repair, new products are developed to provide quick and affordable rehabili-

tation. Although the literature on the performance and durability of a variety of pipe repair products is readily available, research into the environmental implications during and after installation is lacking.

Many transportation agencies are facing budget restrictions, making the affordability of maintenance technologies more important than ever before. The Virginia DOT-VTRC investigation underscores the importance of maintaining a commitment to environmental protection by testing these products for potential environmental impacts during and after installation in the field.

For more information, contact Bridget Donaldson, Research Scientist, Virginia Transportation Research Council, 530 Edgemont Road, Charlottesville, VA 22903; phone 434-293-1922; fax 434-293-1990; e-mail: Bridget.Donaldson@VDOT.Virginia.gov.

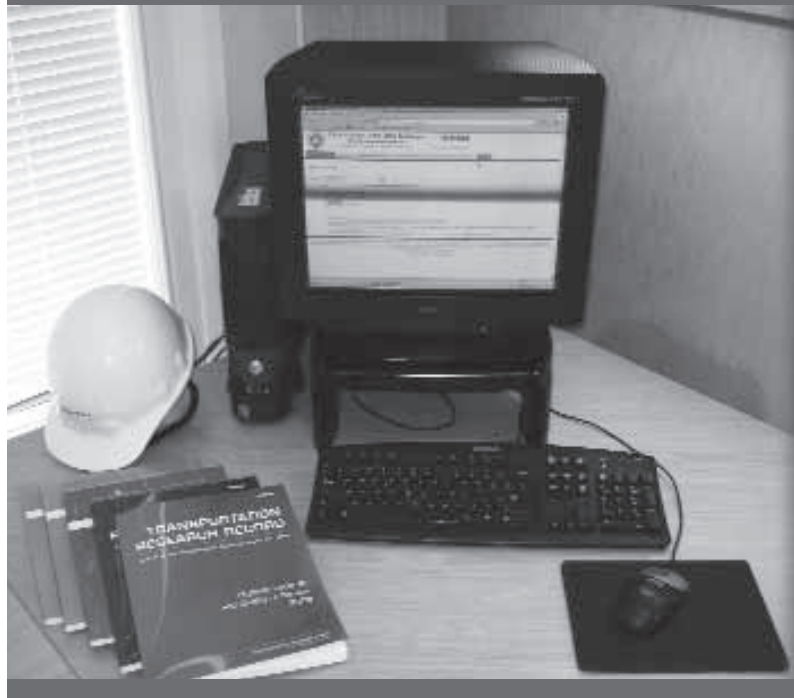
EDITOR'S NOTE: Appreciation is expressed to Waseem Dekelbab and G. P. Jayaprakash, Transportation Research Board, for their efforts in developing this article.

Suggestions for "Research Pays Off" topics are welcome. Contact G. P. Jayaprakash, Transportation Research Board, Keck 488, 500 Fifth Street, NW, Washington, DC 20001 (202-334-2952; gjayaprakash@nas.edu).



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TRANSPORTATION RESEARCH BOARD
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James M. Sime

Connecticut Department of Transportation

James M. Sime describes his job in the Division of Research at the Connecticut Department of Transportation (DOT) as similar to that of a broker: “I work continually to be aware of new developments, to bring pertinent improvements to the attention of the appropriate researchers and departmental personnel, to act as an intermediary between research needs and programs, to investigate specific problem areas, and to offer suitable solutions.” He notes that Connecticut DOT’s focus on the preservation, management, and development of the state’s transportation system requires a guide who can match research needs with resources and research partners.

Sime oversees the planning and management of Connecticut DOT’s research and implementation activities, highway



“It helps to be persistent in any kind of research and development activity, to keep your eye on the goal and be flexible and responsive to changes in technology.”

photolog, new product evaluations, and pavement network evaluation programs. Since 2008, he also has represented Connecticut Commissioner of Transportation Joseph Marie on the Connecticut Energy Advisory Board, which participates in regional energy planning and electric load forecasting and reviews the state procurement plan submitted by electric distribution companies.

At Connecticut DOT, Sime is chair of the Research Liaison Committee, secretary of the Joint Highway Research Advisory Council, and signatory authority for departmental research agreements with organizations such as the New England Transportation Consortium, TRB, the Federal Highway Administration (FHWA), and the University of Connecticut (UConn). He oversees the highway photolog, a ground-based, automated high-definition image inventory for Connecticut’s entire roadway network, which provides information to more than 500 state personnel about roads’ geometric data; pavement curvature, cross-slope, roughness, and rutting; overhead obstruction measurement; and automated pavement distress analysis.

Sime has been with Connecticut DOT since 1978, when he started as a research engineer with the Bureau of Highways (now the Bureau of Highway Operations and Bureau of Engineering and Construction). A 1977 graduate of UConn with a

bachelor’s degree in civil engineering, Sime also earned a master’s degree in business administration from UConn with a specialty in finance. He is a licensed professional engineer in Connecticut. In 1986, Sime joined the Office of the Commissioner and in 1987, began work as Transportation Assistant Director of Research in the Bureau of Highways.

Sime’s career highlights include a role in developing TRB’s Transportation Research Information Services (TRIS) publications database and the Research in Progress (RiP) online system. As chair of the National Cooperative Highway Research Program (NCHRP) Project Panel on Improved User Access to TRIS Through the American Association of State Highway and Transportation Officials’ Value-Added Network (AASHTO VAN), Sime helped implement and reengineer TRIS, first through AASHTO VAN and, later, via a web-based system. He then worked on the start-up of the RiP online database.

“It helps to be persistent in any kind of research and development activity, to keep your eye on the goal and be flexible and responsive to changes in technology that can be adapted to your needs and purposes,” Sime comments.

Starting in 1999, Sime was involved with FHWA in its business-process reengineering of the Transportation Pooled Fund Program. He credits early panel member Larry Scofield, then at Arizona DOT, with the idea of an eBay-like functionality tailored to the needs

of transportation research, which guided the initial design and development of the program’s website, www.pooledfund.org.

Sime became active in TRB in 1985, when he attended the Annual Meeting to demonstrate new developments in highway photologging. He has served on the TRB Information Services Committee for several periods since 1993, notably as chair from 1998 to 2000, and he has been the TRB state representative from Connecticut since 1997. Sime has participated in several NCHRP panels; current memberships include the TRIS access panel; the NCHRP Project Panel on Innovations Deserving Exploratory Analysis; the NCHRP Project Panel on Next-Generation Transportation Pooled Fund Website; and the NCHRP Project Panel on Wind, Solar, and Ground-Source Energy for Maintenance Area Facilities, which he chairs. He recently was named cochair of the Special Task Force on Climate Change and Energy and is a member of the Committee for Alternative Transportation Fuels and Technologies. Sime represents Connecticut DOT on the AASHTO Research Advisory Committee.

Since 1998, Sime has taken part in federally mandated transportation peer exchange teams in nearly a dozen states. As a generation of state transportation research managers retires, he notes, peer exchanges have become essential for new managers.

Stephen Stark

MTA Capital Construction Company

After more than 30 years working in public transit management, Stephen Stark holds to the simple philosophy that to solve a problem, one needs first to experience it. “If you can’t, then you need to partner with the people who do,” Stark observes. “As a manager, your job is to solve problems. Unfortunately, you rarely get a chance to pick the problems you need to solve.”

After graduating from Northeastern University, Stark started his first field position with the Chicago Transit Authority (CTA). In the job interview, he recalls, the director of service told him: “We know that you just got out of school, and we know that you know everything, but if you come here as a planner, you will need to learn how to drive a bus.” Stark not only learned how to operate a bus, but also went on to train and



“The challenge is in overcoming the fact that about 70 percent of all new initiatives fail to realize the intended benefits.”

qualify as a conductor and then as motorman on the rapid transit system before working as a project manager in the operations planning unit. He credits those experiences—and CTA’s philosophy—with the direction his career has taken: “You have no idea of what operating people go through until you actually do what they do. To this day, operating people have my respect.”

When he left CTA in 1983, Stark took an assignment as the general manager of a small city bus system in Bloomington, Indiana. With a fleet of 22 small buses—and six needed for regular service—one of the first things he put in place was a service contingency plan, in case one of the vehicles was not available.

Stark then went on to what he considers to be one of the best assignments of his career—working for urban transportation expert George Smerk at Indiana University’s Institute for Urban Transportation (IUT). “That was a once-in-a-lifetime opportunity, as it is the perfect environment to take a step back, do some research, and apply lessons learned,” Stark recalls. IUT offered many transit management training programs; Stark worked in the bus fleet management program with the late Tom Maze, who initiated the Iowa Transportation Center at Iowa State University (now the Center for Transportation Research).

Maze’s work in vehicle reliability corresponded well with the subject of Stark’s master’s thesis, and the two went on to implement fleet maintenance staff training programs across the country. Stark remembers Maze’s uncanny ability to explain complex topics clearly to anyone dealing with transit fleet maintenance.

In 1990, Stark became deputy director for systems data and research in the operations planning department at the New York City Transit Authority. He transferred into the capital program management department in 1993 and currently serves as senior director for program support at MTA (Metropolitan Transit Authority) Capital Construction Company in New York, for the extension of the No. 7 subway line to Manhattan’s West Side. His work includes the development and implementation of a variety of business processes supporting the management of the \$2.1 billion construction project.

Stark recently completed his 22nd year of involvement with TRB’s Transit Fleet Maintenance Committee, which he chaired from 1998 to 2004 and again from 2007 to 2010. With the help of member Mike Wehr, Milwaukee County Transit, the committee sponsored a web board, allowing transit agencies to post fleet maintenance issues for peer review.

“Mike’s input made all the difference, as he was living with the day-to-day issues that were of so much interest to the committee,” notes Stark. Through the online community, now supported by a program at the University of South Florida, the committee has developed successfully funded problem and synthesis statements on such subjects as compressed natural gas fire protocols, the development and dissemination of bus fleet maintenance practices, and bus fleet maintenance intervals.

An area of focus that lately has caught Stark’s attention is the study of change management. “It’s one thing to define a problem, seek consensus, and develop a solution, but it’s quite another thing to implement that solution. It’s hard to argue against the value of research and the findings it produces. The challenge is in overcoming the fact that about 70 percent of all new initiatives fail to realize the intended benefits,” he emphasizes.

Through the study of managing change, Stark comments, firms are employing simple, common-sense approaches that produce sustainable solutions: “This critical skill is a must for seasoned managers as well as for young people entering any mode of transportation management today.”

In 2002, Stark won an award for his role as a member of a critical incident stress debriefing team that worked with employees directly affected by the September 11, 2001, attacks on the World Trade Center.

NEWS BRIEFS

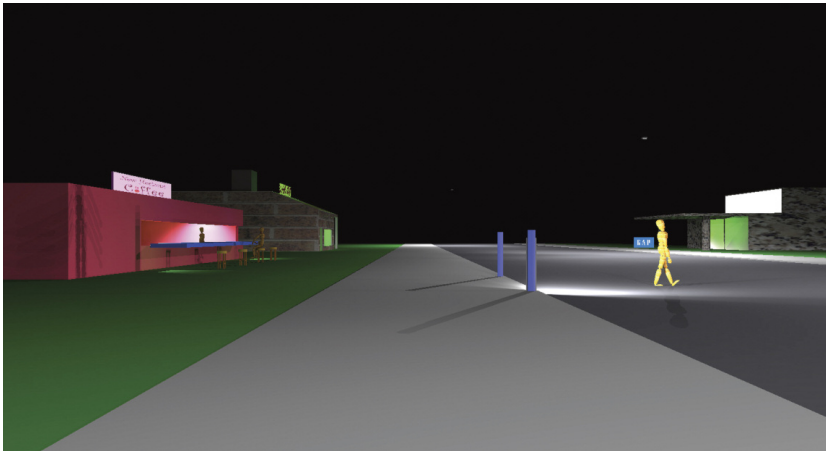


PHOTO: LIGHTING RESEARCH CENTER

The beams from the Lighting Research Center's bollard-based lighting system highlight the pedestrian crossing the street while still providing contrast with the background, making the pedestrian easier to see.

Lighting Innovation Increases Pedestrian Safety

Scientists at the Rensselaer Polytechnic Institute's Lighting Research Center (LRC) are developing a lighting system to increase the safety of pedestrians crossing the street at nighttime. Led by John Bullough, the researchers evaluated different crosswalk lighting systems to determine which would best illuminate the pedestrian and provide enough background contrast to increase visibility. The study was supported by the New Jersey Department of Transportation and the Federal Highway Administration through the University Transportation Research Center at the City University of New York.

Most intersections are lighted by pole-mounted luminaires, which illuminate the crosswalk, pedestrian, and surrounding areas but often do not provide enough contrast between the pedestrian and the background. Researchers devised a lighting system using bollards—short, vertical posts—with linear light sources inside that provided sufficient contrast between the pedestrian and the surroundings. Economic analyses indicated that the installation, maintenance, and operation of the bollard-based system were less expensive than the typical crosswalk lighting system.

A temporary, prototype fluorescent bollard lighting system was installed at a crosswalk along U.S. Route 9 in Middlesex County, New Jersey. Local police and state transportation officials evaluated the prototype and determined that it was likely to increase pedestrian safety but suggested improvements such as louvers to reduce glare, dimming the lights when no pedestrians were present, and installing LEDs on the bollards.

The LRC study is accessible at www.utrc2.org/research/assets/152/FHWA-NJ-2009-0031.pdf.



ROADS ACROSS AMERICA—*Asphalt* magazine has established www.FavoriteRoad.com, a website that allows people to post photos of their favorite roads online, along with information about the road's location, composition, or personal anecdotes. Photos on the site include the Jones Nursery Road in Winchester, Kentucky (*left*) and Route 112 in North Woodstock, New Hampshire (*right*). The site is updated regularly with new and featured photos, reader contests, and information on roads nationwide.



PHOTO: WIKIMEDIA COMMONS

Safest Year for U.S. Freight Railroads

In 2009, U.S. freight railroads completed their safest year on record, according to data released by the Association of American Railroads (AAR). The report noted that the railroad industry invested more than \$9 billion in capital improvements—track maintenance and improvements, signaling systems, and freight cars and locomotives. Collision rates in the freight rail industry dropped to a record low of 0.23 collisions per million train miles; since 1980, the rate has dropped by 85 percent, and since 2000, by 35 percent.

Preliminary 2009 data from the Federal Railroad Administration show a decline of 26 percent in total train accidents involving freight railroads; the number of employee casualties on freight railroads fell by 14 percent. Grade-crossing collisions on freight railroads in 2009 fell to 1,670, the first time under 2,000. Of the record-low 497 rail-related fatalities last year, 93 percent involved either grade-crossing collisions or trespassers.

For more information, visit www.aar.org/NewsAndEvents/PressReleases/2010/03/031110_SafestYear.aspx.

Projecting Transportation Trends in Megacities

In a February report, researchers at the University of Michigan Transportation Research Institute analyzed 15 cities across the globe to determine the implications of increased urban population for transportation. Data on population, wealth, public transportation, the level of motorization, and modal split were gathered for megacities—cities with more than 10 million inhabitants—such as New York; London; Moscow; Paris; Hong Kong; Buenos Aires, Argentina; Mexico City; Rio de Janeiro and São Paulo, Brazil; Bangalore, Calcutta, Delhi, and Mumbai, India; Chicago, Illinois; and Shanghai, China.

For each of these areas, authors made projections through 2025 for factors such as the ownership of personal vehicles, the distance traveled by personal vehicle within the inner core, and the number of road fatalities. Although the projections treated each transportation mode as exclusive to the others, authors noted that more people are using integrated transportation networks that provide connected, technology-enhanced mobility for users from door to door.

Overall, the authors do not expect a substantial decrease in the reliance on personal vehicles in the next 15 years; instead, they project that the use of personal vehicles will increase in the megacities of India, China, and Brazil. The largest increases in vehicle ownership, use of personal vehicles for leisure travel, and road fatalities will occur in Shanghai, Bangalore, Calcutta, Delhi, and Mumbai, according to estimates in the report.

To see the full report, visit <http://deepblue.lib.umich.edu/handle/2027.42/65001>.

INTERNATIONAL

Flight Demonstrations Promise Greener AIRE

An initiative of the Single European Sky Air Traffic Management Research (SESAR) Joint Undertaking has shown that improvements in operating procedures can lead to better fuel efficiency and lower carbon dioxide (CO₂) emissions. In 2009, the Atlantic Interoperability Initiative to Reduce Emissions (AIRE) performed 1,152 “green” flight trials in Stockholm, Sweden; Madrid, Spain; Santa Maria, Portugal; Reykjavik, Iceland; and Paris.

Researchers studied environmentally friendly surface, terminal, and oceanic procedures. At Paris’ Charles De Gaulle airport, ground movement trials

tested a collaborative decision support system designed to minimize taxi time and allow for reduced engine taxi operation. Fuel-saving approaches, climbing procedures, and continuous descents were studied in Stockholm, Madrid, and Paris. Researchers also completed oceanic flight optimization trials on various routes between Europe, North and Central America, and the Caribbean. Data collected from the trials showed a 400-tonne reduction of CO₂ emissions—the equivalent of the annual CO₂ emissions of 100 cars.

Eighteen organizations from around the world participated in the AIRE initiative. SESAR’s goal is to reduce the environmental impact of aircraft by 10 percent per flight.

For more information, see www.sesarju.eu.

TRB HIGHLIGHTS

Transportation and Ecology Intersect at Movie Screening

Members of the TRB Transportation and Ecology Committee fielded audience questions at the Washington, D.C., premiere of the documentary film *Division Street*, on March 26 at the National Academies' Keck Center. The film, examining the future of transportation and the environment, marked the National Academies' first entry into the D.C. Environmental Film Festival. The festival ran March 16–28 and included films from 31 countries, 67 filmmakers, and appearances from 94 speakers and guests.

Directed by Eric Bendick and produced by Frogpondia Films, *Division Street* chronicles a quest to find the most remote spot from any road in the lower 48 states. Deep within Yellowstone National Park, the location is still only 22 miles from the nearest byway—a testament to the pervasiveness of America's car culture. Interviews with ecologists, engineers, and city planners, along with footage of Yellowstone, the Everglades, Glacier National Park, and Banff National Park, examine the effect of automotive transportation on the environment. The documentary explores the concept of wildlife corridors, ways to make the highway system more environment-friendly, and the intersection of engineering and environmental research.

A discussion with panel members Tricia White, Defenders of Wildlife; Joe Burns, USDA Forest Service; Bill Branch, Maryland State Highway Administration (SHA); and moderator Christine Gerencher,



TRB's Transportation and Ecology Committee members Tricia White, Joe Burns, and Bill Branch discussed transportation planning and environmental concerns at a D.C. Environmental Film Festival screening March 26.

TRB, followed the screening. The panelists emphasized the incorporation of environmental considerations into the earliest stages of transportation planning. When the majority of the U.S. highway system was designed in the mid-20th century, White noted, these considerations were not in place.

Burns pointed out that road building in the past 50 years has focused on expanding the reach of the automobile. "The next 50 years are going to be very different," he predicted, emphasizing that strategic planning must start at the first stages and citing the Mary-

Cooperative Research Program News

Predicting Bridge Scour: Risk-Based Approach

Bridge scour depths are predicted with empirical equations from laboratory-scale studies, supplemented by limited field-measurement data. Empirical and deterministic relationships are used in contraction scour equations, but statistical analysis of the data can lead to conservative results. Engineering judgment is vital to the development of an estimate of confidence in the estimated scour magnitude.

Practitioners also must examine the level of confidence associated with results of hydrologic analysis, such as design discharges and flow duration; results of hydraulic analysis, such as depths, velocities, and flow direction; and scour estimates of pier, abutment, contraction, and long-term channel changes. Scour reliability analysis quantifies the uncertainties in each of these steps, then combines them to gain an estimate of the confidence for the final scour prediction.

Ayres Associates has been awarded a \$500,000, 30-month contract [National

Cooperative Highway Research Program (NCHRP) Project 24-34, FY 2010] to develop a risk-based methodology to calculate bridge pier, abutment, and contraction scour at waterway crossings so that scour estimates can be linked to a probability. The probabilistic procedures developed should be consistent with the load and resistance factor design approaches used by structural and geotechnical engineers.

For further information, contact Waseem Dekelbab, TRB, 202-334-1409, wdekelbab@nas.edu.

Quantifying Bridge System Reliability for Redundancy

Although engineers can factor for redundancy in bridge design by using load modifiers from the American Association of State Highway and Transportation Officials (AASHTO) *LRFD Bridge Design Specifications*, the quantification of redundancy is not fully formulated. The values of these load modifiers—design factors on the load side of the LRFD equation that reflect the structure's ductility, redundancy, and oper-

ational importance—were determined by judgment, not by calibration.

NCHRP Reports 406 and 408 proposed system factors calibrated based on structural reliability theory to ensure uniform system performance for different bridge configurations, geometrical arrangements, and types of material and structure. Quantifying redundancy in highway bridge structures is necessary for developing system criteria to allow the bridge to resist extreme events. Past efforts have developed superstructure and substructure redundancy independently of one another; a new approach combining a system of superstructure and substructure interaction is required.

City College of New York has been awarded a \$325,000, 27-month contract (NCHRP Project 12-86, FY 2010) to develop a methodology that quantifies bridge system reliability for redundancy; to recommend revisions to AASHTO's *LRFD Bridge Design Specifications* and to the *Guide Manual for Condition Evaluation and Load and Resistance Factor Rating of Highway*

land Department of Natural Resources' (DNR) Green Infrastructure Assessment as an example. Partnerships are necessary for states and regions to have a successful environmental plan, Branch added. Partnerships between DNR, SHA, citizens, and garden clubs made the preservation of 200 acres of wetlands and 1 million trees possible, he commented.

The cost-effectiveness of wildlife underpasses and other environmental measures must be assessed and designed into a project to avoid adding to the cost, Burns observed. Citing a 2005 Virginia Transportation Research Council report by Bridget Donaldson, White commented that if a wildlife underpass prevents 2.5 wildlife-vehicle collisions per year, it pays for itself.

For more information on Cultural Programs of the National Academy of Sciences, e-mail cpnas@nas.edu or call 202-334-2436.

Conference Explores Nanotechnology in Cement and Concrete

Concrete research on a small scale was the focus of TRB's First International Conference in North America on Nanotechnology in Cement and Concrete, May 5–7, 2010, at the Beckman Center in Irvine, California. The conference explored the science and engineering of nanotechnology in modifying and monitoring the behavior and performance of cement and concrete at the nanoscale—techniques that dramatically can improve concrete's tensile strength, toughness,

ductility, and durability.

More than 100 people from 17 countries attended the conference, sponsored by the Nanotechnology-Based Concrete Materials Task Force and cosponsored by the Basic Research and Emerging Technologies Related to Concrete Committee and the Properties of Concrete Committee. Participants included engineers, scientists, and graduate students from federal, state, and local governments; universities; and industry. Topics included improvement through nanosilica, the use of nanotechnology to achieve sustainability, nanocharacterization, nanomodification, modeling and calcium silicate hydrates, carbon nanofibers, and the future of nanotechnology in cement and concrete. Papers were published in the *Transportation Research Record: Journal of the Transportation Research Board*, No. 2141 and No. 2142.

Financial supporters included the Federal Highway Administration; the Royal Institute of Technology, Sweden; the U.S. Army Corps of Engineers; and the Center for Nanotechnology in Cementitious Systems, Iowa State University. The National Institute of Standards and Technology, the American Concrete Institute, the International Society for Concrete Pavements, the Engineering Mechanics Institute, the American Society of Civil Engineers, the National Ready Mixed Concrete Association, the Portland Cement Association, and RILEM were participating supporters.

To purchase *Transportation Research Records 2141 and 2142*, visit the TRB online bookstore at www.trb.org/Finance/Public/Bookstore.aspx.

Bridges; and to provide illustrative applications based on the recommended revisions.

For further information, contact Waseem Dekelbab, TRB, 202-334-1409, wdekelbab@nas.edu.

Conducting Forensic Investigations of Highway Pavements

Forensic investigations of highway pavements allow highway agencies and researchers to determine the underlying causes of premature pavement failures, to understand the factors in exceptional pavement performance and longevity, and to collect data for the development and calibration of performance prediction models. These investigations often follow different practices and have focused on specific issues, so that the resulting data are difficult to use in other studies. Widely accepted guidelines must be developed to facilitate implementation and to consider relevant factors such as functional and structural performance, material-related distress, pavement type, sampling and testing requirements, and sequence of activities.

Fugro Consultants, Inc., Austin, Texas, has been awarded a \$449,999, 27-month contract (NCHRP Project 1-49, FY 2010) to develop guidelines for forensic investigations of highway pavements. These guidelines will address the various purposes of forensic investigation.

For further information, contact Amir N. Hanna, TRB, 202-334-1432, ahanna@nas.edu.

Dry Ice Limits on Aircraft

Dry ice is used as a refrigerant for perishable commodities transported by air—food products, biomedical supplies, biological samples, and industrial products—but the excess carbon dioxide (CO₂) gas produced by dry ice sublimation may be dangerous in confined spaces with little or no ventilation.

The Federal Aviation Administration (FAA) states that the concentration of CO₂ in the aircraft cabin cannot exceed 0.5 percent, but for many reasons, the air carrier industry has had difficulty calculating dry ice capacity on aircraft. Questions remain about the FAA's calculated sublimation rate for dry ice (2 percent per hour), because

the packaging, insulation, initial temperature, and the form of the dry ice can influence sublimation.

Ventilation rates vary by aircraft type and age and can be influenced by the number of air conditioning packs used during flight. Also, the configuration of the aircraft influences cabin air quality—some older-generation aircraft have no ventilation between the cargo and passenger decks, but newer-generation aircraft recirculate air through the cargo deck compartments. Research is needed to clarify how to use dry ice as a refrigerant, to enable the safe transportation of goods on aircraft.

Battelle Memorial Institute has been awarded a \$250,000, 16-month contract [Hazardous Materials Cooperative Research Program (HMCRRP) Project HM-09, FY 2009] to develop process flow maps and decision-making tools to assist passenger and cargo-only aircraft operators in determining the maximum quantity of dry ice that can be carried safely as cargo.

For further information, contact Joseph D. Navarrete, TRB, 202-334-1649, jnavarrete@nas.edu.

IN MEMORIAM

Kenneth Blackburn (K. B.) Johns, 1925–2010

Former TRB Technical Activities Director Kenneth Blackburn (K. B.) Johns died March 1 at his home in Boone, North Carolina. He was 84.

Johns joined TRB—then known as the Highway Research Board (HRB)—in 1969 as Engineer of Safety in the Technical Activities Division. His title changed to Engineer of Traffic and Operations in 1971. Promoted to Technical Activities Director in 1979, Johns oversaw the work of the Board's standing committees and supervised the division's staff in developing and conducting the Annual Meeting, special conferences and workshops, and other core programs. He retired in 1987.

Former TRB Executive Director Thomas B. Deen remembers Johns as a dedicated professional whose service to TRB included the annual survey of state activities, the Annual Meeting, publications, and conferences. "He was of great help to me when I arrived at TRB and he will be missed by professionals across the country interested in transportation," Deen notes.

Born in 1925 in Versailles, Kentucky, Johns graduated from the University of Kentucky with a bachelor's degree in electrical engineering, following a tour in the Pacific with the U.S. Marine Corps



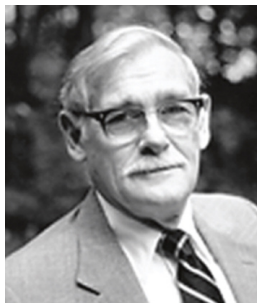
during World War II. In 1950, Johns began working for the Kentucky Department of Highways. He held engineering positions at all levels before being promoted to Director of the Division of Traffic in 1960. He was Assistant

Engineer from 1964 to 1966, and from 1966 to 1968 served as Operations Management Engineer.

Before joining TRB staff, Johns was active in HRB and the American Association of State Highway Officials (AASHO, now the American Association of State Highway and Transportation Officials). He chaired the HRB Special Committee to Review Safety Activities from 1967 to 1969, and was a member of the committee on Maintenance of Devices for Safety and Traffic Services from 1966 to 1969. For AASHO, Johns chaired the Subcommittee on Safety for Maintenance Operations and served on several other traffic, maintenance, and equipment committees. Johns also was a member of the first *TR News* Editorial Board.

Ross DeWitt Netherton, 1918–2010

Ross DeWitt Netherton, 91, died April 30 at his home in Arlington, Virginia. Netherton was a major contributor to the National Cooperative Highway Research Program (NCHRP) Project Panel on Legal Problems Arising Out of Highway Programs and a founding father of *Selected Studies in Transportation Law*, an eight-volume publication issued by a continuing NCHRP project.



The Chicago native earned a bachelor's degree, a master's degree in social science, and a law degree from the University of Chicago. Netherton also received a master's degree in law from the University of Michigan in 1950 and a PhD in law from the University of Wisconsin, and he taught law at the Chicago–Kent School of Law and at American University in Washington, D.C.

After serving in the U.S. Army during World War II, Netherton spent 27 years in the Army Reserve. His

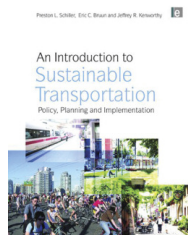
career of more than 40 years focused on transportation law, land use planning law, environmental law, and historic preservation. He was legal research counsel for TRB (then the Highway Research Board) in the 1960s. Before joining the Federal Highway Administration's office of research in 1974, Netherton worked for the U.S. Department of the Interior and for the Highway Beautification Commission.

Netherton briefly returned to TRB as legal counsel in the early 1990s. His involvement with TRB committees began in the late 1960s. Throughout the next decade, he was a member of several task forces, committees, and groups focusing on transportation law, research, land use, and legal resources. He chaired the Environmental Issues in Transportation Law Committee from 1970 to 1976, was an ex officio member of the Technical Activities Council from 1990 to 1992, and in 1999 was elected an emeritus member of the Eminent Domain and Land Use Committee.

After retirement in the 1980s, Netherton wrote books on Northern Virginia's neighborhoods, historic sites, and local landmarks that remain definitive works on the region's history.

An Introduction to Sustainable Transportation: Policy, Planning, and Implementation

Eric C. Bruun, Jeffrey R. Kenworthy, and Preston L. Schiller. *Earthscan*, 2010; 368 pp.; \$39.95; 978-1-84407-665-9.



Sustainable transportation planning requires the integration of environmental, social, and economic factors to develop solutions to such challenges as reducing carbon emissions and preventing climate change. Outlining a new sustainable transportation planning paradigm, this book explores the concepts of development and transportation, describes practical techniques for comprehensive evaluation, provides tools for multimodal transportation planning, and presents mobility management solutions to transportation problems. Authors focus on accessibility rather than mobility and emphasize the need to expand the range of options and to provide practical tools for planners, policy makers, and the public.

Each mode of transportation—from human-powered to motorized modes—is analyzed according to criteria such as infrastructure demands, resource consumption, land use considerations, pollution, and costs. With comprehensive examples from across the globe, case studies, graphics, lists of recommended reading, and more, the authors draw on their teaching and research to assemble a comprehensive text on sustainable transportation.

Development of Regional Airports: Theoretical Analyses and Case Studies

M. N. Postorino, Editor. *WIT Press*, 2010; 192 pp.; \$146; 978-1-84564-385-0.

Regional airports often are proposed as ways to improve congestion at the main air travel hubs and to

promote the economic development of decentralized areas, especially in Europe. Studies suggest that the role of established regional airports should be considered before new airports are built. Drawing on this research and examples of regional airports worldwide, this volume provides an overview of the issues involved in regional airport development, such as economics, the role of low-cost air carriers, demand modeling, the relationships between hub capacity constraints and regional airport growth, and more.



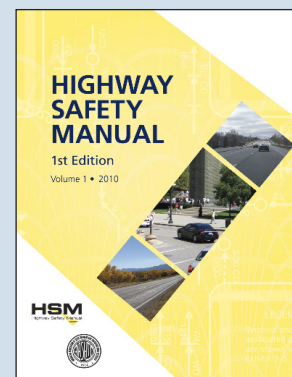
The books in this section are not TRB publications. To order, contact the publisher listed.

Highway Safety Manual, First Edition

American Association of State Highway and Transportation Officials (AASHTO), 2010; 1,500 pp.; \$390; 1-56051-477-0.

Developed through efforts and research administered by TRB committees and National Cooperative Highway Research Program panels, AASHTO's *Highway Safety Manual* (HSM) provides an array of tools for the consideration of safety in transportation project development, with the goal of reducing the frequency and severity of crashes on American roadways. The HSM allows planning, design, construction, maintenance, and operations practitioners to select countermeasures and prioritize projects, compare alternatives, and quantify and predict the safety performance of roadway elements. The three-volume HSM comprises a synthesis of validated highway research, procedures for including safety in project decisions, and analytical tools for predicting a project's impact on road safety.

Note: The *Highway Safety Manual* can be ordered through TRB's online bookstore: www.trb.org/bookstore.



TRB PUBLICATIONS

Concrete Materials 2009

Transportation Research Record 2113

The 18 papers in this volume explore a moisture transport model, pervious concrete pavement, soy methyl esters used to reduce fluid transport in concrete, ultra-fine fly ash and silica fume in concrete, the chloride ion permeability of latex-modified concrete, the recycled concrete aggregate coefficient of thermal expansion, bond stresses of bridge deck overlays, the effect of relative humidity on the thermal expansion of concrete, rigid pavements containing recycled concrete aggregate, the effect of clinker chemistry on the resistance of concrete to salt scaling, a simulation of concrete materials' fracture resistance, and more.

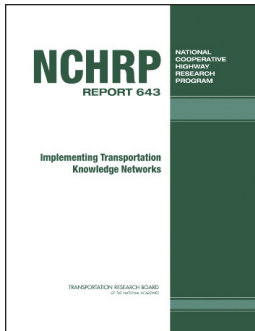
2009; 155 pp.; TRB affiliates, \$49.50; nonaffiliates, \$66. *Subscriber category: materials and construction (IIIB)*.

Developing Countries 2009

Transportation Research Record 2114

Ways to increase the efficiency of aid for road development; bus rapid transit systems in India; citywide transit integration in São Paulo, Brazil; transportation greenhouse gas mitigation in Nanchang, China; a safety assessment of taxi drivers in Singapore; an evaluation of road safety actions promoted by a non-governmental organization; safety performance of rural signalized intersections in South Korea; and





TRB PUBLICATIONS (continued)

pedestrian levels of service at signalized intersections in China are examined in this volume.

2009; 89 pp.; TRB affiliates, \$42; nonaffiliates, \$56. Subscriber category: safety and human performance (IVB).

Finance, Pricing, Economics, and Economic Development

Transportation Research Record 2115

Authors present findings on catastrophe bonds for transportation assets, the private funding of intermodal exchange stations in urban areas, value-for-money analysis in public-private partnerships, revenues from a statewide congestion pricing program, road pricing as an impetus for environmentally friendly travel behavior, the effect of transit on mileage responses to road pricing, the impact of congestion pricing on retail trade, policy options for truck user charging, the effect of a two-part pricing scheme on social welfare for congested networks, a benefit analysis of travel-time reliability from automated detection, and more.

2009; 137 pp.; TRB affiliates, \$46.50; nonaffiliates, \$62. Subscriber category: planning and administration (IA).

Soil Mechanics 2009

Transportation Research Record 2116

The papers in this volume cover topics such as vibratory roller-measured soil stiffness and resilient modulus testing, the automation of pavement sublayer moisture content determination, a stiffness-based assessment of pavement foundation materials, horizontal drains for clay landslide stabilization, a geotechnical perspective on design-build contracts, high-capacity composite spun piles, the deformation factors of buried corrugated structures, geogrid base reinforcement, geosynthetic-reinforced aggregate roads, and porous asphalt composites with carbon fiber-reinforcement polymer grids.

2009; 117 pp.; TRB affiliates, \$42.75; nonaffiliates, \$57. Subscriber category: soils, geology, and foundations (IIIA).

The TRR Journal Online website provides electronic access to the full text of more than 10,000 peer-reviewed papers that have been published as part of the Transportation Research Record: Journal of the Transportation Research Board (TRR Journal) series since 1996. The site includes the latest in search technologies and is updated as new TRR Journal papers become available. To explore the TRR Online service, visit www.TRB.org/TRROnline.

Railways 2009

Transportation Research Record 2117

Examined are methods to increase rail demand by improving multimodal information and ticketing; the effect of delays on passenger train services; regional locomotive emission modeling; a railway capacity evaluation tool, a spectral analysis of ground acceleration-based testing; railroad asphalt trackbed performance; a railway track maintenance management model; noncontact, ultrasonic, guided wave detection of rail defects; epoxy debonding in bonded, insulated rail joints; fouled railroad ballast behavior; and more.

2009; 101 pp.; TRB affiliates, \$42; nonaffiliates, \$56. Subscriber category: rail (VII).

Behavioral and Social Factors

Transportation Research Record 2118

The papers in this volume explore a voluntary program to reduce car use, actual and perceived car dependence, the response to paid parking at a regional shopping center, the impacts of residential off-street parking, carpool formation and use, the social network and dwelling characteristics that influence seniors' ridesharing behavior, a transportation demand management benchmark, and travel demand management strategies.

2009; 74 pp.; TRB affiliates, \$39; nonaffiliates, \$52. Subscriber category: planning and administration (IA).

Planning 2009

Transportation Research Record 2119

Authors present research findings on the integration of climate change concerns into transportation plans; a visualization of the long-range health of rural corridors; cap and trade; the application of transportation, economic, and land use model software; traffic patterns at national parks; the silent group in neighborhood traffic-calming surveys; the effect of performance management on transportation planning organizations; collaboration between transportation agencies and Native American tribes; downtown street management; and land use change prediction.

2009; 136 pp.; TRB affiliates, \$42.75; nonaffiliates, \$57. Subscriber category: planning and administration (IA).

Implementing Transportation Knowledge Networks

NCHRP Report 643

A business plan is outlined for the development of transportation knowledge networks in the United States to assist transportation practitioners, managers, and executives in navigating the available informa-

TRB PUBLICATIONS (continued)

tion resources. If successfully implemented, a decentralized, managed network of information centers will help link users to the information they need, when they need it.

2009; 74 pp.; TRB affiliates, \$34.50; nonaffiliates, \$46. *Subscriber category: planning and administration (IA).*

Guidelines for Conducting a Disparity and Availability Study for the Federal DBE Program

NCHRP Report 644

Designed for state departments of transportation (DOTs), this report explores guidelines for conducting effective and legally defensible disparity and availability studies to meet the Disadvantaged Business Enterprise program requirements. The report offers assistance to DOTs in determining when and if a disparity or availability study should be undertaken; a model scope of work for use in a request for proposals; and detailed recommendations on designing and implementing disparity and availability studies.

2010; 103 pp.; TRB affiliates, \$38.25; nonaffiliates, \$51. *Subscriber category: transportation law (IC).*

Blast-Resistant Highway Bridges: Design and Detailing Guidelines

NCHRP Report 645

This report explores code-ready language containing general design guidance and a simplified design procedure for blast-resistant reinforced concrete bridge columns. Also examined are the results of experimental blast tests and analytical research on reinforced concrete bridge columns that investigates the effectiveness of many different design techniques.

2010; 142 pp.; TRB affiliates, \$42.75; nonaffiliates, \$57. *Subscriber categories: bridges, other structures, and hydraulics and hydrology (IIC); security (X).*

Monitoring Scour Critical Bridges

NCHRP Synthesis 396

This synthesis gathers survey responses from transportation agencies and other bridge owners to investigate the current state of the practice for fixed scour bridge monitoring. Of the thousands of scour critical bridges in the United States, some have been monitored by fixed instrumentation for more than 10 years and have provided valuable field data. Exploring the data and associated evaluations available will be useful for improving bridge scour prediction and scour monitoring technologies.

2009; 158 pp.; TRB affiliates, \$45; nonaffiliates, \$60. *Subscriber categories: bridges, other structures, and hydraulics and hydrology (IIC); maintenance (IIIC).*

Quality Management of Pavement Condition Data Collection

NCHRP Synthesis 401

This synthesis explores the quality management practices employed by public highway agencies for automated, semiautomated, and manual pavement data collection and delivery. Information gathered through a literature review, surveys of public agencies and private contractors in the United States and Canada, and selected interviews provides practical insights into transportation agencies' procedures for pavement data quality management.

2009; 144 pp.; TRB affiliates, \$42.75; nonaffiliates, \$57. *Subscriber category: pavement design, management, and performance (IIB).*

Construction Manager-at-Risk Project Delivery for Highway Programs

NCHRP Synthesis 402

This synthesis presents methods applied by state DOTs and other public engineering agencies in implementing construction manager-at-risk (CMR) project delivery in construction projects. CMR project delivery is an integrated team approach to highway project planning, design, and construction, engaging at-risk construction expertise early in the design process to enhance constructability, manage risk, and facilitate concurrent execution of design and construction.

2010; 127 pp.; TRB affiliates, \$44.25; nonaffiliates, \$59. *Subscriber categories: planning and administration; materials and construction.*

Guidelines for Guard-Restraining Rail Installation

TCRP Report 71, Volume 7

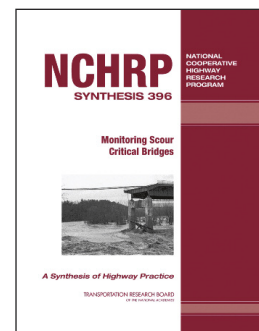
Examined in this report are two guardrail installation philosophies and the effects of vehicle types, wheel flange angle, wheel-rail friction coefficient, curve radius, cant deficiency, and track perturbation on flange climb derailments. The report offers guidance for transit agencies implementing wheel-rail maintenance practices, both for transit rail cars and light rail vehicles.

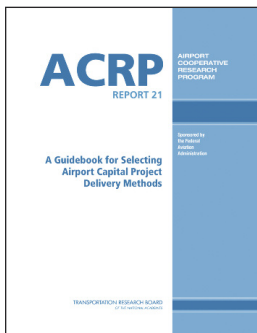
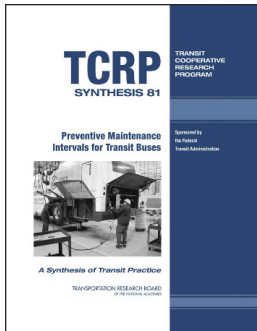
2010; 26 pp.; TRB affiliates, \$27; nonaffiliates, \$36. *Subscriber categories: public transit; rail.*

Improving Pedestrian and Motorist Safety Along Light Rail Alignments

TCRP Report 137

Research on the pedestrian and motorist behaviors that contribute to light rail transit (LRT) safety is presented, along with an investigation of measures to improve safety along LRT alignments. Ways to facili-





TRB PUBLICATIONS (continued)

tate the coordinated and homogeneous compilation of accident data across LRT systems are discussed; also included is a catalog of new and currently used safety devices, treatments, and practices along LRT alignments.

2009; 147 pp.; TRB affiliates, \$45; nonaffiliates, \$60. Subscriber category: public transit (VI).

Preventive Maintenance Intervals for Transit Buses

TCRP Synthesis 81

This report investigates preventive maintenance measures taken by a sampling of transit agencies to ensure that buses are on time, to protect taxpayer investments, and to promote passenger satisfaction and public safety. Based on the results of a survey of U.S. and Canadian transit agencies, a literature review, and telephone survey interviews, the findings can help in avoiding inconvenience to passengers and can prevent safety-related incidents. The study reveals how agencies establish different preventive maintenance intervals and activities according to their fleet makeups, operating environments, and maintenance philosophies.

2010; 71 pp.; TRB affiliates, \$35.25; nonaffiliates, \$47. Subscriber categories: maintenance and preservation; public transit; vehicles and equipment.

A Guidebook for Selecting Airport Capital Project Delivery Methods

ACRP Report 21

Authors examine the impacts, advantages, and disadvantages of various project delivery methods—design-bid-build, construction manager-at-risk, and design-build—for major airport capital projects. The guidebook presents a two-tiered project delivery selection framework: an analytical delivery decision approach that helps the user to understand the attributes of each project delivery method, and a weighted-matrix delivery decision approach that allows users to prioritize their objectives and select the best delivery method. ACRP Web-Only Document 6, *Evaluation and Selection of Airport Capital Project Delivery Methods*, is a companion publication to this report.

2009; 91 pp.; TRB affiliates, \$42; nonaffiliates, \$56. Subscriber category: aviation (V).

Helping Airport and Air Carrier Employees Cope with Traumatic Events

ACRP Report 22

This report provides insight and practical guidance to address the difficult emotional and psychological implications in response and exposure to traumatic

events—human-made accidents, acts of terrorism, or natural disasters—that have occurred at or near air carriers or airports.

2009; 74 pp.; TRB affiliates, \$34.50; nonaffiliates, \$46. Subscriber categories: planning and administration (IA); safety and human performance (IVB); aviation (V).

Airport Passenger-Related Processing Rates Guidebook

ACRP Report 23

Facility requirements for planning airline passenger terminals rely on data on airline passenger volumes, the rates at which passengers can be served at ticket counters, baggage check-in, passenger security screening, and other processing points. Passenger processing rates are influenced by the type of airline service, type of travel, amount of baggage, and party size. Recent developments—the growth of low-cost carriers, increased security, and the increased use of Internet and self-service devices—have raised doubts about the validity of previous data. This report provides guidance on how to collect accurate passenger-related processing data for evaluating facility requirements to promote efficient and cost-effective airport terminal design.

2009; 117 pp.; TRB affiliates, \$40.50; nonaffiliates, \$54. Subscriber categories: planning and administration (IA); aviation (V).

Airport Passenger Terminal Planning and Design, Volume 1: Guidebook

ACRP Report 25

Airport planners and designers face a challenge in designing passenger terminals that provide good value and efficiency in services while meeting necessary criteria—from security requirements and procedures to the needs of low-cost carriers and concessionaires. In a single reference document, this report explores the passenger terminal planning process and provides important criteria and requirements needed to address emerging trends and to develop solutions for airport passenger terminal planning and design. Addressed in Volume 1 are the airside, terminal building, and landside components of the terminal complex.

2010; 409 pp.; TRB affiliates, \$62.25; TRB nonaffiliates, \$83. Subscriber category: aviation; planning and forecasting; terminals and facilities.

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INFORMATION FOR CONTRIBUTORS TO

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FEATURES are timely articles of interest to transportation professionals, including administrators, planners, researchers, and practitioners in government, academia, and industry. Articles are encouraged on innovations and state-of-the-art practices pertaining to transportation research and development in all modes (highways and bridges, public transit, aviation, rail, and others, such as pipelines, bicycles, pedestrians, etc.) and in all subject areas (planning and administration, design, materials and construction, facility maintenance, traffic control, safety, geology, law, environmental concerns, energy, etc.). Manuscripts should be no longer than 3,000 to 4,000 words (12 to 16 double-spaced, typed pages). Authors also should provide appropriate and professionally drawn line drawings, charts, or tables, and glossy, black-and-white, high-quality photographs with corresponding captions. Prospective authors are encouraged to submit a summary or outline of a proposed article for preliminary review.

RESEARCH PAYS OFF highlights research projects, studies, demonstrations, and improved methods or processes that provide innovative, cost-effective solutions to important transportation-related problems in all modes, whether they pertain to improved transport of people and goods or provision of better facilities and equipment that permits such transport. Articles should describe cases in which the application of project findings has resulted in benefits to transportation agencies or to the public, or in which substantial benefits are expected. Articles (approximately 750 to 1,000 words) should delineate the problem, research, and benefits, and be accompanied by one or two illustrations that may improve a reader's understanding of the article.

NEWS BRIEFS are short (100- to 750-word) items of interest and usually are not attributed to an author. They may be either text or photographs or a combination of both. Line drawings, charts, or tables may be used where appropriate. Articles may be related to construction, administration, planning, design, operations, maintenance, research, legal matters, or applications of special interest. Articles involving brand names or names of manufacturers may be determined to be inappropriate; however, no endorsement by TRB is implied when such information appears. Foreign news articles should describe projects or methods that have universal instead of local application.

POINT OF VIEW is an occasional series of authored opinions on current transportation issues. Articles (1,000 to 2,000 words) may be submitted with appropriate, high-quality illustrations, and are subject to review and editing. Readers are also invited to submit comments on published points of view.

CALENDAR covers (a) TRB-sponsored conferences, workshops, and symposia, and (b) functions sponsored by other agencies of interest to readers. Notices of meetings should be submitted at least 4 to 6 months before the event.

BOOKSHELF announces publications in the transportation field. Abstracts (100 to 200 words) should include title, author, publisher, address at which publication may be obtained, number of pages, price, and ISBN. Publishers are invited to submit copies of new publications for announcement.

LETTERS provide readers with the opportunity to comment on the information and views expressed in published articles, TRB activities, or transportation matters in general. All letters must be signed and contain constructive comments. Letters may be edited for style and space considerations.

SUBMISSION REQUIREMENTS: Manuscripts submitted for possible publication in *TR News* and any correspondence on editorial matters should be sent to the Director, Publications Office, Transportation Research Board, 500 Fifth Street, NW, Washington, DC 20001, telephone 202-334-2972, or e-mail jawan@nas.edu.

- ◆ All manuscripts should be supplied in 12-point type, double-spaced, in Microsoft Word 6.0 or higher versions, on a CD or as an e-mail attachment.

- ◆ Submit original artwork if possible. Glossy, high-quality black-and-white photographs, color photographs, and slides are acceptable. Digital continuous-tone images must be submitted as TIFF or JPEG files and must be at least 3 in. by 5 in. with a resolution of 300 dpi or greater. A caption should be supplied for each graphic element.

- ◆ Use the units of measurement from the research described and provide conversions in parentheses, as appropriate. The International System of Units (SI), the updated version of the metric system, is preferred. In the text, the SI units should be followed, when appropriate, by the U.S. customary equivalent units in parentheses. In figures and tables, the base unit conversions should be provided in a footnote.

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Transportation, Energy, and Climate Change

Energy and climate change are two of today's most significant public policy issues. Developing and sharing knowledge and experiences on ways to mitigate the adverse impacts of transportation on energy resources and global climate is critical, as is adapting transportation to the effects of climate change and to new energy requirements.

- ◆ **Modal Primer on Greenhouse Gas and Energy Issues for the Transportation Industry**
Circular E-C143, 78 pages, 8.5 x 11 electronic, 2010,
<http://www.trb.org/Main/Blurbs/163289.aspx>
- ◆ **Adapting to the Impacts of Climate Change**
National Academies Press, 325 pages, 7 x 10 paperback, 2010,
ISBN 978-0-309-15455-0, \$56.95
- ◆ **Limiting the Magnitude of Future Climate Change**
National Academies Press, 258 pages, 7 x 10 paperback, 2010,
ISBN 978-0-309-15445-1, \$56.95
- ◆ **Advancing the Science of Climate Change**
National Academies Press, 506 pages, 7 x 10 paperback, 2010,
ISBN 978-0-309-15460-4, \$56.95
- ◆ **Real Prospects for Energy Efficiency in the United States**
National Academies Press, 352 pages, 7 x 10 paperback, 2010,
ISBN 978-0-309-14801-6, \$56.95
- ◆ **Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use**
National Academies Press, 506 pages, 6 x 9 paperback, 2010,
ISBN 978-0-309-14640-1, \$47.00
- ◆ **Energy and Global Climate Change 2009**
Transportation Research Record 2139, 188 pages, 8.5 x 11
paperback, 2009, ISBN 978-0-309-14269-4, \$70.00

In addition to a website that highlights activities addressing climate change (<http://www.TRB.org/climatechange>), TRB has assembled resources to inform transportation professionals, decision makers, and the general public. Here are some of the latest titles produced by TRB and other parts of the National Academies.

- ◆ **A Transportation Research Program for Mitigating and Adapting to Climate Change and Conserving Energy**
TRB Special Report 299, 120 pages, 6 x 9 paperback, 2009,
ISBN 978-0-309-14275-5, \$35.00
- ◆ **Driving and the Built Environment: The Effects of Compact Development on Motorized Travel, Energy Use, and CO₂ Emissions**
TRB Special Report 298, 239 pages, 6 x 9 paperback, 2009,
ISBN 978-0-309-14255-7, \$37.00
- ◆ **Guidebook on Preparing Airport Greenhouse Gas Emissions Inventories**
Airport Cooperative Research Program Report 11, 53 pages,
8.5 x 11 paperback, 2009, ISBN 978-0-309-11774-6, \$41.00
- ◆ **America's Energy Future: Technical and Transformation: Summary Edition**
National Academies Press, 184 pages, 8 x 10 paperback, 2009,
ISBN 978-0-309-14145-1, \$24.95
- ◆ **Potential Impacts of Climate Change on U.S. Transportation**
TRB Special Report 290, 280 pages, 6 x 9 paperback, 2008,
ISBN 978-0-309-11306-9, \$37.00



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