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Authors

Sperling, Daniel
Cannon, James S.

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CLIMATE AND TRANSPORTATION SOLUTIONS

*Findings from the 2009 Asilomar Conference
on Transportation and Energy Policy*

**DANIEL SPERLING AND
JAMES S. CANNON (EDITORS)**

ITS UCDAVIS
INSTITUTE OF TRANSPORTATION STUDIES

Climate and Transportation Solutions:

**Findings from the 2009 Asilomar Conference on
Transportation and Energy Policy**

Daniel Sperling
Editor

**Institute of Transportation Studies
University of California, Davis**

James S. Cannon
Editor

Energy Futures, Inc., Boulder, Colorado

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Table of Contents

1 Combating Climate Changes from Transportation	1
Daniel Sperling and James S. Cannon	
2 Scenarios for Cutting Carbon Dioxide in Transport 70 Percent Worldwide by 2050	9
Lew Fulton	
3 U.S. Greenhouse Gas Emissions in the Transportation Sector	24
John Conti, Nicholas Chase, and John Maples	
4 Carbon Dioxide Emissions from Road Transport in Latin America	33
Lee Schipper, Elizabeth Deakin, and Carolyn McAndrews	
5 Role of Low Carbon Fuel Standard in Reducing U.S. Transportation Emissions	48
Sonia Yeh and Daniel Sperling	
6 A Shared Goal: Addressing Climate Change and Energy Security	62
Dave McCurdy and Kathryn Clay	
7 Vehicle Standards in a Climate Policy Framework	75
John M. DeCicco	
8 Accelerating Technology Innovation in Transportation	89
John E. Johnston, Carmen Difulio, Trevor Demayo, Robert Marlay, and David Vincent	
9 Smart Growth and Climate Change: California’s SB 375 and Sacramento’s Blueprint Experience	102
Mike McKeever	
10 The Case for Diesel Cars To Reduce Greenhouse Gas Emissions	111
Johannes-Joerg Rueger	

11 Overview of Light-Duty Vehicle Fuel Economy Technology To 2025 and Policy Implications	120
K.G. Duleep	
12 Technologies and Policies for Improving Truck Fuel Efficiency & Reducing CO₂	133
Anthony Greszler	
13 Improving the Energy Efficiency and Environmental Performance of Goods Movement	145
James J. Winebrake and James J. Corbett	
14 Potential Reductions of Greenhouse Gas Emissions from Light-Duty Vehicles and Electricity Generation	155
Andrew E. Lutz and Jay O. Keller	
Appendix A: Biographies of Editors and Authors	166
Appendix B: 2009 Asilomar Transportation Conference Attendees	171

Preface and Acknowledgements

Climate change has fully entered the public consciousness, but what to do and how fast to do it remains intensely controversial. These and other questions about how to mold transportation policy to help achieve climate goals was the focus of a high level meeting in California in July 2009. Two hundred leaders and experts were assembled from the automotive and energy industries, start-up technology companies, public interest groups, academia, national energy laboratories in the United States, and governments from around the world. Three broad strategies for reducing greenhouse gas emissions were investigated: reducing vehicle travel, improving vehicle efficiency, and reducing the carbon content of fuels. This book is an outgrowth of that conference.

The conference was the latest in a series held roughly every two years on some aspect of transportation and energy policy, always at the Asilomar Conference Center near Monterey on the California coast. The first conference in 1988 addressed alternative transportation fuels; the last three have focused on climate change. The full list appears below:

- I. Alternative Transportation Fuels in the '90s and Beyond (July 1988)
- II. Roads to Alternative Fuels (July 1990)
- III. Global Climate Change (August 1991)
- IV. Strategies for a Sustainable Transportation System (August 1993)
- V. Is Technology Enough? Sustainable Transportation-Energy Strategies (July 1995)
- VI. Policies for Fostering Sustainable Transportation Technologies (August 1997)
- VII. Transportation Energy and Environmental Policies into the 21st Century (August 1999)
- VIII. Managing Transitions in the Transport Sector: How Fast and How Far? (September 2001)
- IX. The Hydrogen Transition (July 2003)
- X. Toward a Policy Agenda for Climate Change (August 2005)
- XI. Transportation and Climate Policy (August 2007)
- XII. Transportation and Climate Policy (July 2009)

The chapters of this book evolved from presentations and discussions at the 12th Biennial Conference on Transportation and Energy Policy.

The Asilomar conference was hosted by the Institute of Transportation Studies at the University of California, Davis (ITS-Davis). The conference was supported by a diverse set of government, foundation and industry sponsors. The premier Cypress Level sponsors for 2009 included the Office of Transportation and Air Quality of the U.S. Environmental

Protection Agency, and the Center for Climate Change and Environmental Forecasting of the U.S. Department of Transportation Research and Innovative Technology Administration. Otter Level Sponsors were the Office of Research and Development of the U.S. Environmental Protection Agency, the U.S. Department of Energy, the William and Flora Hewlett Foundation, the Energy Foundation, the Alliance of Automobile Manufacturers, and Bosch. Others providing important support included the Surdna Foundation, the American Association of State Highway and Transportation Officials (AASHTO), Transport Canada, the California Department of Transportation, the California Energy Commission, and the UC Davis Sustainable Transportation Center.

In addition, companies provided support to conference host ITS-Davis for outreach programs such as the Asilomar Transportation and Energy conference. These sponsors include Aramco, ExxonMobil, Mitsui Power Systems, NetJets, Nissan, Pacific Gas and Electric Company, Royal Dutch Shell, Subaru, and Toyota.

Most of all, we want to acknowledge the many attendees of the conference listed in Appendix B. These invited leaders and experts, coming from many parts of the world and many segments of society, enriched the conference with their deep insights and rich experiences.

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Chapter 1:

Combating Climate Changes from Transportation

by Daniel Sperling and James S. Cannon

Forty thousand political leaders, climate experts, and concerned citizens converged on Copenhagen in December 2009 for a global climate summit. The summit was widely viewed as a failure, with the media using expressions such as “train wreck.” For those troubled by the risk of chaotic climate disruptions and economic turmoil, this failure of leadership is painful.

Was Copenhagen really a train wreck, and is there really an utter failure of leadership? The disturbing story popularized by the mass media is only part of the answer. Real progress is being made, even in the international negotiations that faltered in Copenhagen. Just a few years ago, the president of the United States (U.S.) was denying the reality of climate change and refusing to take serious action to reduce emissions. At the same time, China, the other principal emitter of carbon, was even more insistent that it need not act. Yet in Copenhagen, a new U.S. president personally lobbied other government leaders and promised to put the United States on a path toward dramatic reductions. He was joined by the premier of China, who just one year before was saying that climate change was a scheme of rich countries to suppress the developing countries of the world. In Copenhagen, he committed China to a modest international partnership to tackle climate change.

While the 2.5-page Copenhagen agreement approved by 188 of 192 nations in attendance was undeniably weak and vague, and didn’t even mention transportation, it, too, was an important step forward. The world has rarely seen a larger group of heads-of-state in one place focused on one issue. Their presence indicated that climate change is a top priority around the world. While they were unable to put in place a new treaty to replace the Kyoto Accord of 1997, much good came of the meeting. Thousands of experts and activists—from governments, industries, and non-governmental organizations—sat together and listened to each other. It is not easy to get such a large and diverse group of nations to agree to major financial and institutional commitments for a problem that is still nearly invisible. In many ways, it is remarkable that so many are so committed.

Whether the Copenhagen meeting was a train wreck or a modest step forward, greenhouse gas (GHG) emissions continue to increase and evidence of climate change becomes ever stronger. Global concentrations of carbon dioxide (CO₂) have reached the highest levels recorded since pre-industrial times.

D. Sperling is Director of the Institute of Transportation Studies at the University of California, Davis and J. Cannon is President of Energy Futures, Inc.

In the United States, CO₂ emissions have grown at an average annual rate of 0.8 percent since 1990, according to data from the U.S. Energy Information Administration (EIA 2009). The total increase since 1990 has been 16.3 percent. The transportation sector is the second largest source of CO₂ emissions after electricity generation, accounting for 33.1 percent of total U.S. emissions. Those emissions are principally from the combustion of motor gasoline, diesel fuel, and jet fuel.

The Emerging Policy Paradigm

These grim statistics give way to some optimism when one turns to policy. As discussed in the pages of this book, transportation-related climate policy is progressing rapidly. In recent years, the European Union (EU), United States, Japan, and China all moved forward with aggressive policies to reduce fuel use and carbon emissions from vehicles. Scattered around the world are strong national and regional policies to decarbonize transport fuels. Only in restraining and reducing vehicle use has there been little progress, but even here, some glimmers of light can be seen.

In fact, policy progress, as modest as it is, far exceeds real-world progress in actually reducing emissions, providing some hope for the future. Many governments are putting in place durable and strong policy frameworks to reduce carbon emissions from the transport sector. California is especially notable. Despite, or perhaps because of, its legacy of pioneering car-centric transportation, California has been creative and aggressive at taming motor vehicles. It leads the way in the United States with aggressive vehicle requirements, a far-reaching low carbon fuel standard that could transform the oil industry, and a law to reduce urban sprawl and vehicle use. Most other countries have a much smaller transport-related carbon footprint than California, but California is leading the way in formulating comprehensive durable policy frameworks, and many states and countries are following its lead.

In the United States, the first major effort to rein in greenhouse gas emissions from transportation was California's 2002 law to dramatically reduce emissions from vehicles by 2016. In a sign of the times, that law was blocked every step of the way. The auto industry filed a series of lawsuits to block implementation in California and other states that adopted the California program. When those industry lawsuits were rejected by the courts, the administration of then-president G.W. Bush refused to allow California and the other states to proceed. California responded by suing the national government.

In 2007, the U.S. Congress, after 30 years of inaction on vehicle fuel use, bumped the corporate average fuel economy (CAFE) standards upward 40 percent to 35 miles per gallon (mpg), to be achieved in 2020. Then, at a press conference in May 2009, newly-elected President Barack Obama and the CEOs of the three major U.S. car companies cheerfully embraced the California law as a national standard, in effect agreeing to move the 2020 deadline up to 2016—essentially agreeing to a requirement they had vociferously opposed for seven years.

Other changes were also taking place. As part of the same 2007 energy law when CAFE standards were first raised, the U.S. Congress also dramatically expanded the biofuels requirement, raising it to 36 billion gallons by 2022. California took it one important step further. In 2009, it adopted a low carbon fuel standard, requiring a 10 percent reduction in the carbon content of transport fuels by 2020, measured as lifecycle greenhouse gas emissions per unit of energy. To achieve this new standard would require about 30 percent of gasoline and diesel fuel to be replaced by low-carbon alternative fuels. The European Union also adopted rules requiring a decarbonization of transport fuels, and many U.S. states and Canadian provinces are following California's lead. As with vehicle standards, industry groups that felt disadvantaged—in this case corn ethanol producers—filed a lawsuit in January 2010 trying to block the fuel standards.

In the United States and most other countries, policies to tame cars and fuels are mostly crafted as performance standards. They call for improvements in the technology and fuel, but they usually don't address how much that vehicle and fuel is used. Thus, a law enacted in California in late 2008 is of special importance. It calls for reductions in urban sprawl and vehicle use, couched as reductions in greenhouse

gas (GHG) emissions associated with passenger travel. While that law, known as Senate Bill (SB) 375, has few carrots and sticks associated with it, it provides a framework for reducing vehicle use that can be built upon in the future. For California and the United States, that is revolutionary. This California law was transferred in similar form to the national climate bill passed by the House of Representatives in 2009. While the bill had still not passed into law as this book goes to press, the inclusion of a provision to reduce vehicle use and urban sprawl is notable.

This cluster of transport-related policies represents a coherent and potentially effective policy framework for reducing oil use and GHG emissions. As experience and analyses accumulate, a better sense of which policy instruments are most effective is developing, including what types of changes are possible and likely. Underpinning this new framework is a set of commonly shared observations among transportation experts, which include the following:

- Climate goals are well aligned with energy and urban livability goals. What is good for climate change is almost always good for energy security and healthy, successful cities.
- Major change and major innovation are needed in the transport sector
- Better technology is key, but these technological changes must be complemented with policies and strategies that alter vehicle purchase and use behavior and reduce sprawl
- Transportation transformations are more a question of vision, leadership, and will than cost
- Fuel and vehicle transformations will require unprecedented coordination internationally, but, in the end, it is local and national will and commitment that will be key.

Change will not be easy or quick. Many barriers remain. The fundamental problem is that surface passenger transport is arguably the least innovative sector of the economy. In fundamental ways, the transport system has barely changed since the 1920s. Functional and design attributes of vehicles and roads have been roughly the same for decades. While vehicles today are safer and more reliable, they have about the same size, carrying capacity, weight, and fuel economy as they did 80 years ago. They still have four wheels, drive the same speed, and operate on petroleum. Roads and transit services are also functionally unchanged. While there are many more expressways, almost all vehicles still travel on almost all roads, and almost all are free. Transit service is also largely unchanged. Mass transit vehicles are more comfortable than in earlier times and are air conditioned, but the frequency and distribution of service remains sparse.

There is a tremendous need for innovation in the transportation sector. The need for new low-carbon fuels and advanced and more efficient propulsion systems is clear, but innovation must go much deeper. This means creating new transportation networks and financing systems supported by governmental institutions to manage the huge financial flows that will be involved. It means effective management of land use by local governments. And it means new and better ways of providing mobility and accessibility to people.

Ideas matter, but in this case knowledge matters more. Injecting knowledge into the debate is not easy. Public debates about climate change are frequently framed around ideological and political themes, such as free market versus regulatory approaches, food versus fuel priorities, the needs of haves versus have-nots, and local jobs versus the global marketplace. It is important to engage these big ideas, but ultimately each of them should be firmly grounded in science and data. The challenge for the informed decision maker is to sort through the political slogans to determine those strategies and policies that are most effective and most efficient and equitable. This requires bringing science and data to bear on slogans and concepts. Ignoring these analyses, or leaving them to the imagination of politicians and their staffs, is a recipe for bad policy and bad laws.

The Asilomar Conference Series

The first Biennial Conference on Transportation, Energy and Policy convened in 1988. Oil cost \$15 per barrel then, General Motors still dominated the automotive market, no one had heard of reformulated

gasoline, electric vehicles had not yet reappeared, hybrid electric vehicles were more than a decade from commercialization, plug-in hybrids were an academic pipe dream, and fuel cells could take us to the moon but not the corner store.

On the other hand, some of the weapons wielded today to fight climate change were already in the energy policy portfolio. Biofuel policy had launched ethanol fuels, though it was produced almost exclusively from corn, and the CAFE standards were well established, though they remained stuck at 27.5 mpg for cars for another two decades. Much more obviously needed to be done.

Each Biennial Conference on Transportation, Energy and Policy has been held at the Asilomar Center in a secluded coastal California state park in Pacific Grove. During the first two decades and nine conferences, the themes jumped among a wide range of topics from broad sustainable transport themes to the hydrogen economy. The topic switched in 2005 to climate change, where it has remained fixed for three conferences over six years. Climate change is now widely recognized as the most critical environmental problem facing the planet. Transportation is a major cause of the problem, and it has a key role to play in its solution. Transportation policy experts from around the world that travel to Asilomar remain fixated on climate policy because the challenge is so huge and so important.

Thus, this book, like the two previous books that grew out of discussions at Asilomar, *Driving Climate Change* in 2006 and *Reducing Climate Impacts in the Transportation Sector* in 2008, focuses on innovative strategies to reduce GHG emissions from transportation. It addresses the fundamental question: Is it possible to define a path to a future just 40 years away in which transport-related CO₂ emissions have been reduced 60 to 80 percent?

As in the past, the organizer of the 12th Biennial Conference on Transportation, Energy and Policy in July 2009 was the Institute of Transportation Studies at the University of California, Davis (ITS–Davis) on behalf of three committees of the U.S. Transportation Research Board, a research arm of the National Academies in Washington, DC. They are the Energy, Alternative Fuels, and Sustainable Transportation committees.

ITS–Davis once again lured the most sophisticated and knowledgeable experts and leaders on climate policy and transportation to the conference. This invitation-only, three-day event hosted 200 experts and leaders from five continents. This occurred with the global economy in disarray, automakers going bankrupt, and governments handing out IOUs for their steep debts.

Overview of the Book

Strategies for reducing GHG emissions from the transportation sector can be categorized into three clusters, sometimes referred to as the three legs of the transportation stool: improving the efficiency of the vehicles, reducing the carbon content in the fuel, and reducing vehicle use. The thirteen chapters that follow discuss the effects of energy use in transportation on global GHG emissions and suggest new policies to strengthen one or more legs of the transportation policy stool.

Regional Analyses Setting the Stage

The next three chapters examine climate change and transportation issues in specific regions of the world, and offer examples of innovative actions to reduce climate effects in these areas.

The first chapter is by Lew Fulton, Senior Transport Energy Analyst at the International Energy Agency (IEA) in Paris, France. He notes that transport accounts for about 19 percent of global energy use and 23 percent of energy-related CO₂ emissions. Given current trends, transport energy use and CO₂ emissions are projected to increase nearly 50 percent by 2030 and more than 80 percent by 2050. Without new climate policies, the IEA predicts CO₂ equivalent (CO_{2-eq}) emissions nearly doubling in its baseline scenario

forecast, with the mix of transportation fuels remaining fairly constant. The IEA high baseline scenario foresees an even greater 140 percent growth by 2050.

Either of these IEA baseline scenarios would be catastrophic for the global climate. To avoid the worst impacts from climate change, the United Nations Intergovernmental Panel on Climate Change (IPCC) advises that global CO₂ emissions be cut at least in half by 2050. To achieve this, transport will have to play a significant role. The IEA projects that a 70 percent reduction in transport CO_{2-eq} emissions in 2050 is possible compared to the IEA baseline projection, though it would be highly challenging.

Fulton asserts that it will require both widespread adoption of today's best available technology and longer term development and deployment of a range of new technologies. All transport modes will need to reduce their emissions significantly compared to the baseline trends, in every region of the world.

John Conti, Director of the Office of Integrated Analysis and Forecasting at the U.S. Energy Information Administration (EIA), and his colleagues Nicholas Chase and John Maples note in their chapter that transportation emits more GHGs in the U.S. than the commercial, residential, and industrial end-use sectors. Transport-related GHG emissions more than tripled in the U.S. between 1950 and 2009, but they forecast a leveling off in the future.

The EIA projects U.S. GHG emissions from transportation will remain relatively flat between 2010 and 2030, though this leveling off is a far cry from the 80 percent reductions that may be needed in industrialized countries to counter climate changes. Total liquid fuel consumption in transportation is projected to grow from 164 billion gallons in 2000 to 196 billion gallons by 2030, but nearly all of the increase is forecast to come from biofuels, including ethanol and biodiesel, which generally have fewer net CO₂ emissions than gasoline or diesel refined from petroleum.

The authors report on their EIA analysis of a cap-and-trade program to reduce emissions. They conclude that such a program will produce relatively little reduction in GHG emissions from the transportation sector. This implies that, while transportation is a key to CO₂ emission reductions, a price on CO₂ will have little effect on transportation demand. They suggest four proposals that would be more effective: increasing vehicle fuel economy standards, using low carbon fuel alternatives, reducing passenger vehicle use, and switching from heavy truck freight to rail and marine freight.

Lee Schipper at the Center for Global Metropolitan Studies at the University of California, Berkeley and his colleagues Elizabeth Deakin and Carolyn McAndrews move the geographical focus to Latin America. Their chapter presents some disquieting statistics on rapid increases in CO₂ emissions from transportation in the developing world. In Mexico, for example, the number of passenger vehicles more than doubled in one decade, from 8.3 million in 1996 to 21.5 million in 2006. This was an astounding 9.6 percent annual growth rate, with dire implications for climate change.

In comparison with the world as a whole, the CO₂ emissions in Latin America are more heavily concentrated in transportation, with 35 percent of its total emissions from transportation. These transport emissions are concentrated in road transport, accounting for over 90 percent of the region's transport emissions.

Latin American cities have pioneered one of the most important transportation innovations, Bus Rapid Transit (BRT), first in Curitiba, Brazil, but now in other large cities. Mexico City made a significant investment in dedicated bus lanes and BRT. BRT was devised and championed to reduce traffic congestion, but it has the additional benefit of reducing local air pollution, oil use, and GHG emissions.

New Transportation Policies

The next set of five chapters address new policy approaches to reduce GHG emissions. The first chapter, by Sonia Yeh and Daniel Sperling at University of California Davis, is an in-depth examination of the California low carbon fuel standard (LCFS) adopted by the California Air Resources Board in April 2009

and implemented statewide in January 2010. The LCFS is a performance standard, measured by total GHGs per unit of fuel energy, that aims to reduce the GHG intensities of transportation fuels. The goal is to account for all GHGs emitted in the lifecycle of transportation fuels, from extraction, cultivation, land use conversion, processing, distribution, and fuel use.

California's LCFS applies only to on-road transport fuels, excluding air and maritime transportation, where California has limited authority. The standard is imposed on all transport fuel providers, including refiners, blenders, producers, and importers. Each fuel supplier in California must meet a GHG-intensity standard that becomes increasingly stringent over time, ramping up to the 10 percent reduction in 2020. The LCFS allows for trading and banking of emission credits. An oil refiner could, for instance, buy credits from biofuel producers. Alternatively, it could buy credits from an electric utility that sells power for use in electric vehicles. Those companies that are most innovative and best able to produce low-cost, low-carbon alternative fuels would do best.

The LCFS policy is gaining momentum, with other states and Canadian provinces embracing the California LCFS model as of early 2010. The European Union is also implementing a carbon intensity standard for fuels that is similar to the California LCFS.

Automakers in the United States are committed to a low-carbon future, say Dave McCurdy and Kathryn Clay from the Automotive Manufacturers Association (AMA), the principal trade association for the U.S. auto industry. In their chapter, they note that transportation energy policy in the United States has been dominated by the CAFE standards for over 30 years. They describe the May 2009 landmark agreement between the automakers and President Obama that established a new fuel economy standard of 35.5 mpg for the U.S. motor vehicle fleet by 2016.

Policies directed at transportation sector emissions, such as the new national fuel economy program, are important, the AMA believes. At the same time, sector-based approaches cannot substitute for a more economically efficient, economy-wide program. The overall program should encompass the national economy as completely as possible, they argue, whether the approach is based on a cap-and-trade program or on other measures, such as a carbon tax. The approach should include market measures to the greatest extent possible. Using market mechanisms can provide the pull needed to incentivize the rapid deployment of advanced technologies. This national climate change strategy should clearly delineate appropriate roles for federal, state, and local governments. They note that current legislative efforts in the U.S. Congress reflect many, but not all, of these principles.

They further argue that sustainable mobility should be pursued along four pathways. The first involves development of new vehicle technologies. Second, new low-carbon fuels are needed to power these vehicles. Third, improvements to the national transportation infrastructure, including advanced roadway designs, are needed. Finally, consumers, who are ultimately responsible for the purchase and use of cars and fuels, need appropriate price signals and better information about vehicle and fuel choices.

The following chapter addresses the role of innovation in transforming the transportation and energy systems. Jack Johnston, recently retired from ExxonMobil Research & Engineering, and his co-authors at the U.S. Department of Energy, Chevron Energy Technology Company, and the United Kingdom Carbon Trust argue for a close coupling of science, technology, and policy. "One size fits all" approaches are not consistent with the diversity of demand and supply patterns already existing in developed economies and emerging in developing economies, they say in their chapter. It will be necessary to focus resources on the technologies and policies that achieve the largest emission reductions and to integrate these policies with economy-wide policies to reduce GHG emissions. In particular, it is essential that there be a close linkage between policies to electrify the transportation sector and policies to reduce GHG emissions from the power sector.

They explore examples of how government can encourage innovation, modify transportation demand, and change the character of mobility. Changes in existing policies and measures can also be crucial. Almost any

innovation that requires a significant change in fuel infrastructure, vehicle systems, or consumer behavior will need government support in the early stages because of the magnitude of the existing transportation systems and the relatively slow turnover of technology and evolution of practices.

John DeCicco at the University of Michigan School of Natural Resources and Environment believes vehicle performance standards related to GHG emissions are important because they directly target decision making in the auto market, which is an important determinant of total emissions. U.S. policymakers have decided that vehicle performance standards—based on either fuel economy or GHGs—are an essential tool in the climate policy mix. Neither form of vehicle standard, however, now includes a mechanism for formal coordination with economy-wide climate policy, says DeCicco. Reviewing the history of fuel economy standards and emissions standards for conventional air pollutants suggests that a legal linkage to well-defined environmental goals is important for ongoing progress toward those goals. Such an economy-wide policy could be a cap-and-trade system or other national program that provides well-defined targets and timetables for limiting GHG emissions.

DeCicco proposes to link the administration of vehicle standards to overarching GHG emissions goals by requiring agencies overseeing all elements of the transportation sector, including motor vehicles, to periodically assess the sector's progress in limiting GHG emissions. Agencies would then be obligated to update their policies as needed to ensure that the sector is effectively helping reduce GHG emissions in a manner consistent with the targets and timetable of the national cap. Such an approach places vehicle standards within the framework of an overall climate policy.

Mike McKeever of the Sacramento Area Council of Governments (SACOG) notes that new land use planning efforts are another critical component of future transportation policies to reduce climate impacts. He describes in his chapter how SACOG, representing the governing bodies of 22 cities and six counties in central California, has developed a regional land use plan that has become the model for a statewide smart growth law, SB 375. Known as the Blueprint, the Sacramento plan aims to reduce VMT from new growth by 10 to 30 percent per capita and GHG by 15 to 40 percent per capita.

The Blueprint calls for higher land use densities and more infill development. The reduced development area means less driving and fewer GHG emissions from transportation. In the base case scenario, in 2050 vehicle miles traveled per household increase by 12 percent, while in the Blueprint scenario, they decrease by 17 percent.

New Fuels and Advanced Vehicles

The last five chapters of this book examine the potential role for new fuels and vehicle technologies in combating climate change. Johannes-Joerg Rueger, Senior Vice President for Engineering at Robert Bosch LLC, one of the largest automotive suppliers in the world, addresses opportunities to reduce GHG emissions by improving today's gasoline and diesel engines. He notes that regulatory and industry attention has recently focused on zero emission vehicles, but all are in demonstration or pre-commercialization phases, and none are yet cost competitive with traditional gasoline and diesel vehicles. He focuses on the many enhancements to internal combustion engines that are possible, such as start/stop technologies, gasoline direct injection, and turbocharging. These technologies promise GHG reductions at relatively low costs. Additional hybridization offers even more significant CO₂ reduction potential.

The chapter by K.G. Duleep, Managing Director at ICF International, summarizes recent analyses of new developments in technologies to improve the fuel economy of LDVs, including cars and light trucks. Like Rueger of Bosch, he notes that while the popular press focuses much of its attention on advanced electric vehicles, manufacturer product plans show that improvements to the existing engine and drivetrain will continue to be the major focus of efforts over the next decade. Improvements to conventional technology can reduce GHG emissions by 33 percent in 2016 and by up to 50 percent in 2025.

Hybrid technology will provide even greater reductions, and plug-in electric vehicle technology even more, but it may be premature to judge these technologies. Over the next five to 10 years, understandings of

battery costs and durability will improve, allowing better vehicle design decisions. This could help create cost-effective plug-in hybrid and battery electric models as the next wave of technology improvements takes effect in the post-2025 period.

The focus shifts from LDVs to heavy duty vehicles in the chapter by Anthony Greszler, Vice President of Government and Industry Relations at Volvo Powertrain North America. He focuses on heavy trucks and buses, which account for 21 percent of U.S. transport petroleum consumption. Globally, these vehicles could well surpass light duty passenger vehicles to become the largest users of petroleum and emitters of CO₂ within the transport sector.

The energy efficiency of diesel engines improved approximately 10 percent from 1980 until 1999, but increasingly stringent nitrogen oxide emission requirements have slowed progress in efficiency. Nonetheless, the desire for GHG emission reductions through efficiency improvements is leading toward advancements in fuel injection, air induction, and combustion chamber design for diesel engines. More advanced combustion designs promise even greater reductions.

The chapter by James Winebrake of the Rochester Institute of Technology and his colleague James Corbett of the University of Delaware addresses the use of trucks and other modes to move goods. Winebrake and Corbett explore the potential for mode shifting, but find relatively small opportunities. They suggest that expected benefits from freight mode shifting are often overstated. They argue for a more holistic approach to efficiency improvements in the freight sector, noting that the freight industries are closely tied to economic activity, much more so than passenger transport.

Finally, Andrew Lutz and Jay Keller from Sandia National Laboratories in California argue in their chapter that the best transportation solutions may come from combinations of alternative fuels and advanced vehicle technologies. They focus on vehicle electrification and conduct an extensive analysis of the potential reductions from vehicle and electricity generation improvements. They conclude that incremental improvements to existing vehicle and generation technologies can barely offset continued growth in transport demand, and that the magnitude of the GHG emissions problem requires that research and development be directed toward technologies that both greatly improve end use efficiency and greatly reduce or eliminate carbon from fuels. Energy policy needs to be established today, they argue, to motivate the transition to net-zero carbon technologies.

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Chapter 2:

Scenarios for Cutting Carbon Dioxide in Transport 70 Percent Worldwide by 2050

by Lew Fulton

Worldwide, transport accounted for about 19 percent of global energy use and 23 percent of energy-related carbon dioxide (CO₂) emissions in 2006, and these shares will likely rise in the future. Given current trends, transport energy use and CO₂ emissions are projected to increase nearly 50 percent by 2030 and more than 80 percent by 2050.

This future is not sustainable. The United Nations Intergovernmental Panel on Climate Change (IPCC) advises that, to avoid the worst impacts from climate change, global CO₂ emissions must be cut at least in half by 2050. To achieve this, transport will have to play a significant role. Even with deep cuts from all other energy sectors, if transport does not cut CO₂ emissions well below current levels by 2050, it will be very difficult to meet targets, such as stabilizing the concentration of greenhouse gas (GHG) emissions in the atmosphere at a level of 450 parts per million (ppm) of CO₂ equivalents (CO_{2-eq}).

This paper develops analysis originally published in the International Energy Agency (IEA) *Energy Technology Perspectives 2008* (ETP 2008) and the forthcoming IEA report *Transport, Energy and CO₂: Moving Toward Sustainability* (IEA 2009). It describes how the introduction and widespread adoption of new vehicle technologies and fuels, along with some shifting in passenger and freight transport to more efficient modes, can result in a 70 percent reduction in transport CO_{2-eq} emissions in 2050 compared to the IEA baseline projection, which itself reflects a 40 percent reduction below 2005 levels. As part of a broader effort to cut emissions across the energy economy, this may be sufficient to help stabilize atmospheric CO₂ at average concentrations between 450 and 550 ppm and prevent temperature changes above 2° Celsius (C), according to the IPCC.

But substantially changing transport trends along the lines described here will not be easy. It will require both the widespread adoption of current best available technology and the longer term development and deployment of a range of new technologies. All transport modes will need to reduce their emissions significantly compared to the baseline trends, in every region of the world. Although some technologies and measures appear to be available at low or even negative cost, strong policies will be needed to ensure rapid uptake and full use of these technologies and to encourage sensible changes in travel patterns. It must involve industry, governments, and consumers. In many cases the rate of change that will be needed for the market penetration of new technologies and vehicle types is much faster than has occurred in recent

L. Fulton is Senior Transport Energy Analyst at the International Energy Agency in Paris, France. This chapter is copyrighted as follows: © OECD/IEA, 2010

decades. Large and risky investments will be needed from industry and for the purchases of new types of vehicles by consumers. The challenge to reach the targets described here should not be underestimated.

The Baseline Scenario

Based on recent and expected future trends, in particular population and gross domestic product (GDP) per capita, it is possible to construct a business as usual scenario that suggests a possible future, if there are not strong deviations from the current path. The IEA *World Energy Outlook 2008* provides a reference case scenario that assumes no new policies are implemented and that growth in activity and energy use follows growth in population and GDP roughly as it has in the past, though certain saturation points may be reached, for example, car ownership in wealthy countries (IEA 2008b). The IEA *Energy Technology Perspectives 2008* extends this to 2050 in a baseline scenario (IEA 2008a). For transport, this results in more than a doubling in global transport activity measured by passenger kilometers of travel and a near doubling of energy use. Average transport energy intensity improves somewhat over time, but not nearly enough to offset travel growth and prevent energy use from growing.

For this analysis, a second business-as-usual case was developed that assumes higher growth rates in travel, car ownership, and related indicators. This scenario results in a 130 percent increase in transport energy use by 2050. These and other projections are shown in Figure 2-1. In the baseline and high baseline cases, the mix of fuels remains fairly constant, with petroleum fuels dominant. In the high baseline case, after 2030, biofuels and synthetic gasoline and diesel produced from natural gas and coal grow rapidly as they become competitive with petroleum as oil supplies dwindle.

Figure 2-1: Energy use scenarios

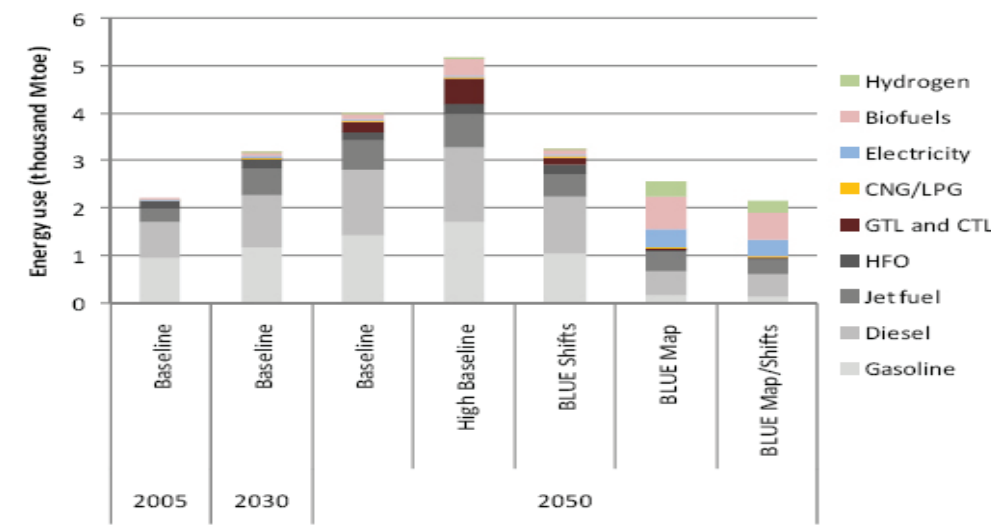
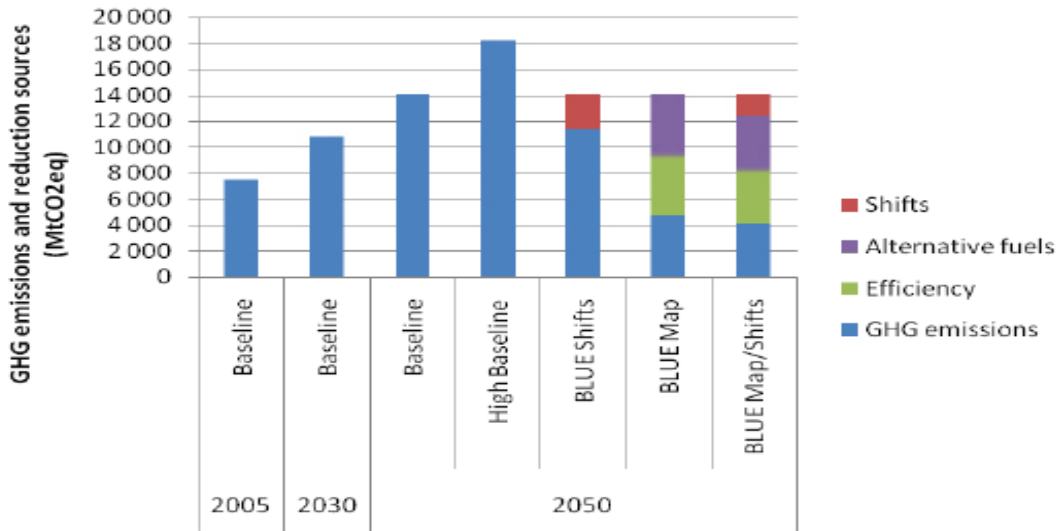


Figure 2-2 shows the CO₂ implications of the baseline and high baseline scenarios. Like energy use, CO_{2-eq} emissions nearly double in the baseline scenario from 7.5 gigatonnes (Gt) in 2005 to 14 GT in 2050 and grow by about 140 percent in the high baseline scenario to about 18 Gt in 2050. In this figure, and throughout this paper except where noted, GHG emissions include CO₂ emissions from vehicles, and CO₂, methane, and nitrogen oxide emissions from fuel production. It does not include other GHGs, such as water from aircraft or sulfur oxides from shipping.

The scenarios shown in Figure 2-2 are clearly unsustainable from both an energy and CO₂ point of view. The remainder of this paper focuses on alternative, low CO₂ scenarios and how these can be achieved.

Figure 2-2: Summary of GHG reductions by scenario



Recent Transport Trends Around the World

The growth in energy use and CO₂ emissions in the baseline and high baseline cases is driven by expected increases in travel that are mostly a function of increasing car ownership and air travel, both in turn driven by rising incomes around the world. While travel data are still scarce for many countries, the IEA has collected enough data to be able to make some initial estimates of total travel worldwide and by region that provide at least order-of-magnitude estimates of where things stand and where they may be headed.

Figure 2-3 shows estimated passenger travel by mode for regions including and excluding nations belonging to the Organization for Economic Cooperation and Development (OECD and non-OECD, respectively) in 2005, and projected in the baseline scenario to 2050. It shows that total passenger travel in non-OECD countries is expected to soar between 2005 and 2050 and to far surpass travel within the OECD region by 2050.

Figure 2-3: Passenger travel by region and mode, 2005 and 2050

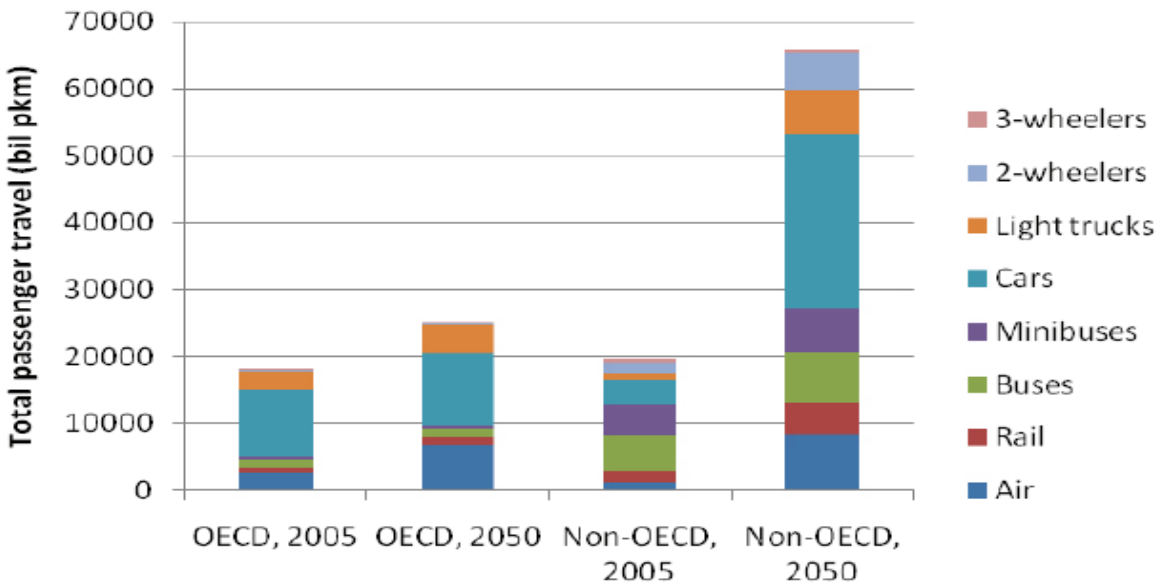
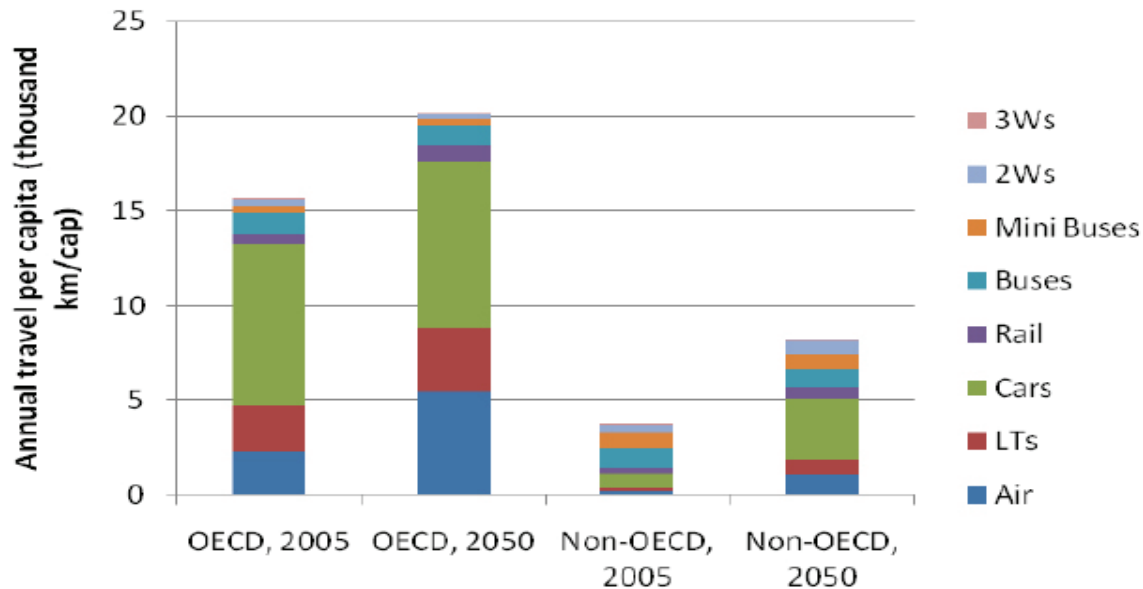


Figure 2-4 shows the same data on a per capita basis. The data show that levels of travel per capita in the developing world are currently far below those in OECD countries, and that travel will grow faster in the developing world than within OECD nations. This is not surprising since population and incomes are expected to grow faster in the developing world, and travel starts from a much smaller base so there is significant potential for a latent demand for travel. However, travel levels per capita in 2050 in non-OECD regions remain well below those in OECD regions, suggesting that even then, travel will not have equalized around the world. Growth may continue to grow rapidly in developing countries for many more decades.

Figure 2-4: Passenger travel per capita by region and mode, 2005 and 2050



In addition, in all regions the growth in travel in the baseline scenario is expected to be mostly by light duty vehicles (LDVs) and air. Rail and bus travel levels are not expected to grow substantially, and as a result, will lose market share fairly dramatically.

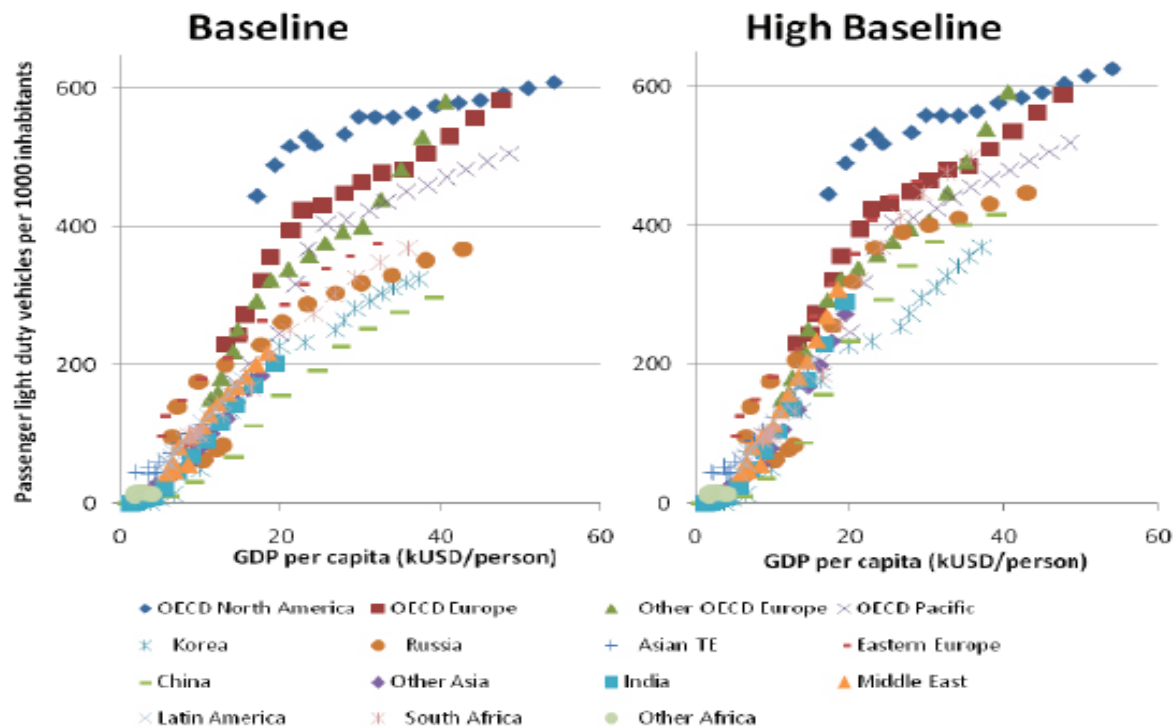
A central driver for the changes in passenger travel in the future is expected to be growth in car ownership. Figure 2-5 shows the IEA projections of car ownership as a function of income growth in countries and regions around the world, through 2050, based on income growth projections and car ownership data in each region. In the baseline scenario, car ownership in most developing countries is assumed to be at a relatively low level for a given income in the future, following the examples of countries like Japan and, especially, South Korea over the past two to three decades. In the high baseline scenario, countries are assumed to have car ownership levels that are closer to European country levels at a given income. The difference in the results for these two types of assumptions is dramatic. In the baseline scenario, car ownership reaches about 2.1 billion passenger LDVs by 2050, compared to about 800 million in 2005. In the high baseline, car ownership approaches 3 billion cars.

The BLUE Map Scenario: A Sustainable Pathway for Transport

In order to change the directions, it will be necessary to radically alter transport activity trends. The IEA has explored several scenarios of low CO₂ futures and their implications for how transport must change and what can help bring about the needed changes.

The BLUE Map scenario is the low-CO₂ scenario developed by the IEA. It forecasts a 70 percent reduction in CO₂ emissions in 2050 compared to the baseline scenario and a 30 percent decrease compared to

Figure 2-5: Car ownership growth in the baseline and high baseline cases



2005 levels. This dramatic reduction can be achieved through the uptake of technologies and alternative fuels across all transport modes that cost up to \$200 (U.S. dollars) per metric ton of CO₂ saved. Under this scenario, improvements in transport energy efficiency offer the largest and least expensive reductions, at least over the next ten years. Adoption of advanced vehicle technologies and new fuels also provides important contributions to this scenario, especially after 2020. The impacts in terms of energy use reductions in 2050 are shown above in Figure 2-1 in terms of CO₂ in Figure 2-2.

Vehicle Efficiency Improvements

A principal finding of the BLUE Map analysis is that the implementation of incremental fuel economy technologies could cost-effectively cut the fuel use and CO₂ emissions per kilometer of new LDVs 30 percent by 2020 and 50 percent by 2030 worldwide. Similar efficiency improvements may be possible for other modes, although the estimation of technology potentials for trucks, ships, and aircraft is not as accurate as it is for LDVs in this analysis. Further, many of the available improvements for these modes are expected to occur in the baseline scenario, which includes stock average improvements of 20 to 25 percent by 2050. The 30 to 50 percent reduction in fuel use per kilometer traveled for trucks, ships, and aircraft by 2050 appears possible, however. For all modes and types of vehicles, the identification and setting of efficiency targets for the 2020 to 2030 time frame would be valuable to help stimulate and coordinate action, particularly if backed by the development of policies around the world to help achieve these targets.

A 30 to 50 percent improvement in new vehicle efficiency across modes by 2030 would help to achieve a stock average improvement of a similar magnitude by 2050. In the BLUE Map scenario, this cuts transport energy use and CO₂ enough to stabilize it at 2005 levels. To go well below 2005 levels, switching to new low-CO₂ fuels and reducing growth in vehicle use will need to play increasingly important roles.

Alternative Fuels

In the baseline scenario, petroleum-based fuels continue to provide over 90 percent of all transport fuel in 2050, while in the high baseline, an increasing share of very high CO₂ fuels, such as coal-to-liquids,

contribute to rapidly increasing CO₂ emissions. By contrast, the share of petroleum and other fossil fuel use falls to below 50 percent in the BLUE Map scenario. They are replaced by a combination of advanced, low CO₂ biofuels, electricity, and hydrogen. Any one of these options has the potential to be sufficient to achieve the targets set in the BLUE Map scenario, but each also has drawbacks and may not reach its full potential. A combination can maximize the chances of overall success, even if it would result in higher investment costs to develop adequate production and distribution infrastructures. Pursuing a combination, at least in the initial stage, appears wise to maximize the potential benefits, while limiting costs.

Ethanol from sugar cane can already provide low cost biofuels today, and increasingly does. Advanced second generation biofuels such as lignocellulosic ethanol and biodiesel derived from biomass appear to have the best long-term potential to provide sustainable, low lifecycle GHG fuels, but more research, development, and demonstration will be needed before commercial scale production is likely to occur. For all biofuels, important sustainability questions must be resolved, such as the impact of production on food security, water supply, and sensitive ecosystems as a result of land use changes. A 20-fold increase in biofuels is needed to achieve the outcomes envisaged in the BLUE Map scenario by 2050. If done wisely, this should be possible using biomass waste straws where possible and only a small share of global agricultural land.

Advanced Vehicle Technologies

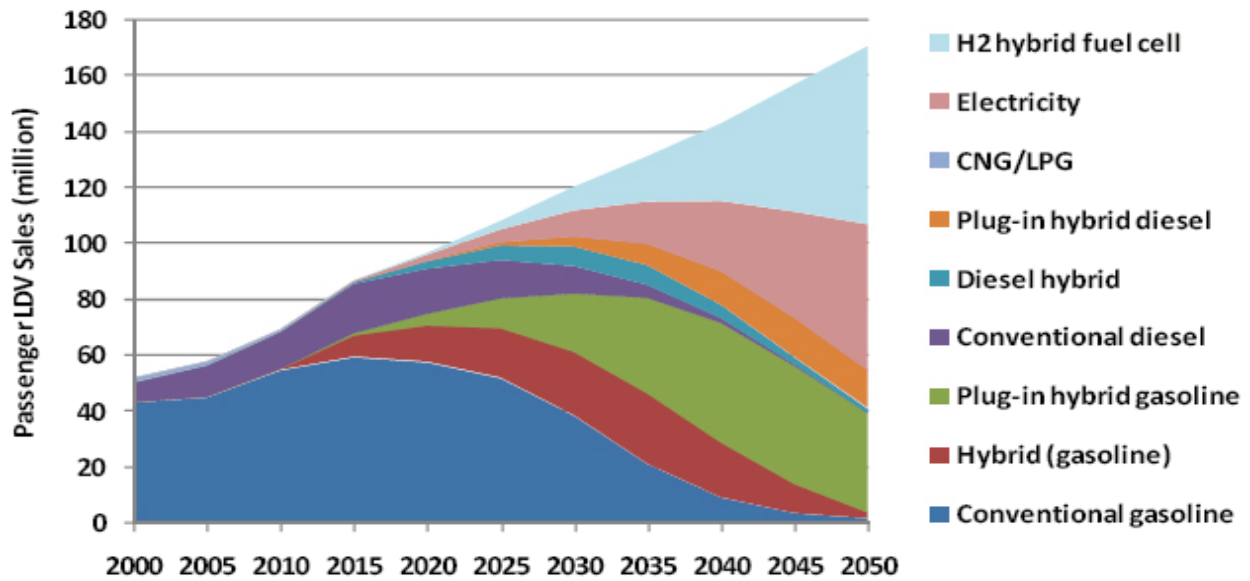
Battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs), and fuel cell electric vehicles (FCVs) play an important role in the BLUE map scenario, especially after 2020. BEVs are rapidly emerging as an important option, especially as lithium ion battery costs decline. It now appears that batteries in high-volume production might cost as little as \$500 per kilowatt hour (kWh) in the near term. This is low enough to bring the battery cost for a BEV with a 150 kilometer (km) driving range down to about \$15,000. This is still very expensive, but with savings from removing the internal combustion engine, relatively low-cost electricity as the fuel, and government incentives, this cost might be low enough to allow BEVs to achieve commercial success over the next five to ten years. Additional policy assistance, such as support for the development of an appropriate recharging infrastructure, will still be needed, however. The cost of oil, the principal competing fuel with electricity, will also be an important factor.

Since the impact of BEVs on CO₂ emissions depends on the CO₂ intensity of electricity generation, it would make sense to deploy BEVs first in those regions with already low CO₂ generation or a firm commitment to move in that direction. This would include Japan, the European Union, California, and parts of North and South America.

A potentially important transition step to BEVs is represented by PHEVs. By increasing the battery storage in HEVs and offering a plug-in option, these vehicles represent an important step toward vehicle electrification that builds incrementally on an emerging hybrid vehicle technology. Like HEVs, PHEVs use both engine and motor, which adds cost. The advantage of PHEVs lies in providing a potentially significant share of driving on electricity with a small, and therefore relatively inexpensive, battery pack. For example, an 8 kWh battery pack might cost \$5,000 to \$6,000 in the near term and provide 40 km of driving range on electricity. For many drivers, this could cut oil use by 50 percent or more. PHEVs also require less new infrastructure than pure BEVs, since the car is not dependent solely on electricity and has a full driving range on liquid fuel.

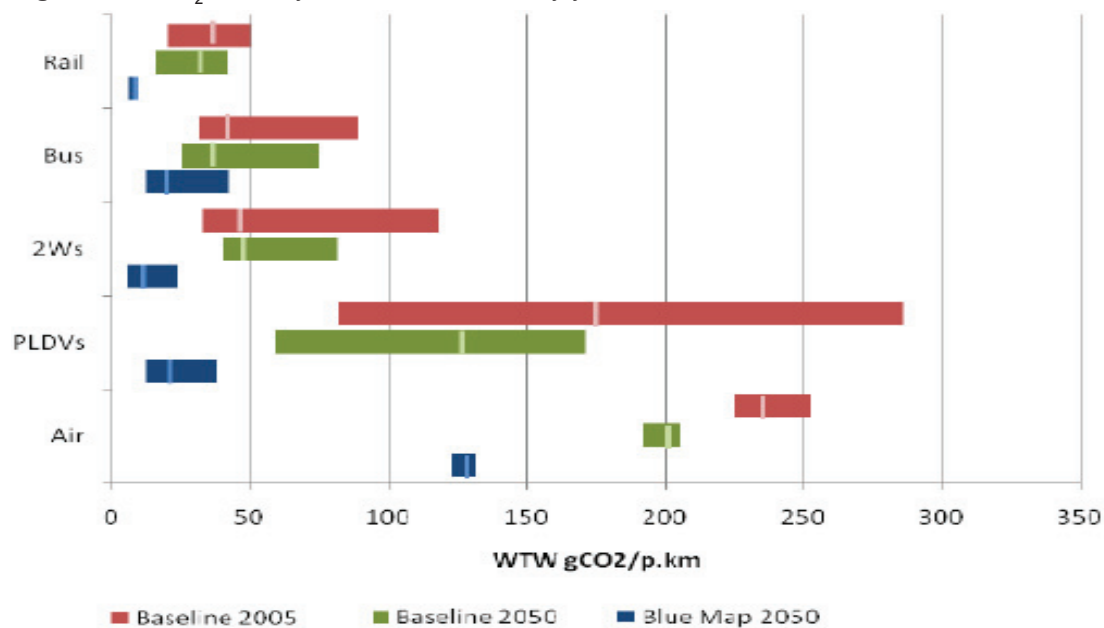
As shown in Figure 2-6, both BEVs and PHEVs are initially deployed in 2010 in the BLUE Map scenario and increase in sales to well over one million vehicles per year by 2020. BEVs and PHEVs experience rapid market penetration around the world, each reaching annual sales of around 50 million by 2050, primarily as passenger LDVs, but also in a small share of trucks. The widespread introduction of BEVs illustrated in the BLUE Map scenario requires adequate investments and coordination among governments and industry for the development of recharging infrastructure. In a separate scenario called BLUE EV Success, in which BEVs almost fully dominate LDV sales by 2050, their sales exceed 100 million vehicles per year.

Figure 2-6: LDV sales and sales shares by vehicle type in BLUE map



Hydrogen FCVs also play a key role in the BLUE Map scenario. FCVs share the market with BEVs and are produced commercially beginning around 2020. They reach a significant sales share by 2030. Sales then rise rapidly to nearly 60 million vehicles by 2050. Recent cost reductions in fuel cell systems for vehicles increase the likelihood that FCVs can eventually become commercialized, although costs and onboard energy storage are still important concerns. As battery costs drop, hybridizing fuel cells appears increasingly attractive, since batteries can help provide peak power to the motor, thereby allowing a smaller fuel cell stack to be used and improving efficiency through regenerative braking. The development of a hydrogen production and distribution infrastructure is necessary and will require substantial new investments. Like electricity, hydrogen must be produced with low CO₂ technologies in order for FCVs to provide significant CO₂ reductions. This will result in higher hydrogen costs than if produced from fossil fuels, for example, by reforming natural gas.

Figure 2-7: CO₂ intensity of different modes by year and scenario



Vehicle efficiency improvements and the shift to lower carbon fuels results in a dramatic decarbonization of all types of transportation by 2050. Figure 2-7 shows that the average CO₂ intensity of different modes will drop dramatically by 2050 in the BLUE Map scenario, reaching well below 50 grams of CO_{2-eq} emissions per km of driving for all modes except air travel. This means that modal shift would provide less CO₂ benefit than it does currently. Since there is no guarantee that such CO₂ intensity reductions will be achieved, however, modal shift options make sense as a complement to vehicle and fuel options to reduce CO₂.

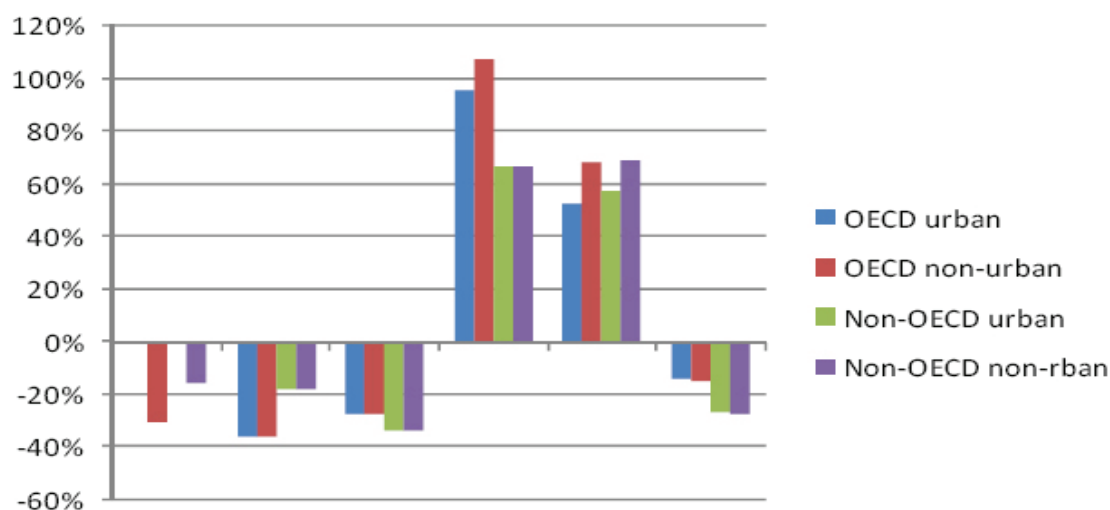
The BLUE Shifts Scenario

Certainly in cities around the world, development that minimizes the need for private motorized travel should be a high priority given the strong cobenefits in terms of reduced traffic congestion, pollutant emissions, and general liveability.

The BLUE Shifts scenario considers one possible future modal mix, in contrast to the one implied in the baseline scenario. This scenario relies on more uncertain information compared to other projections. It has been developed by the IEA to provide a basis for estimating the important potential energy and CO₂ impacts of modal shifts.

As shown in Figure 2-8, the BLUE Shifts scenario envisages an average worldwide reduction in private LDV and aviation passenger travel of 25 percent by 2050 relative to the baseline scenario, and up to a 50 percent reduction compared to the high baseline scenario. In addition, it includes a shift in freight movement to rail transport that reduces long-haul truck transport growth between 2010 and 2050 by half. Shifting travel and goods transport to advanced bus and rail systems, with some outright reductions in travel growth due to better land use planning, improved non-motorized transport infrastructure, and some telecommunications substitution for travel, could yield a 20 percent reduction in energy use by 2050 compared to the baseline, or a 40 percent reduction compared to the high baseline scenario. Even more ambitious mode shifting may be possible, but this will require strong policies and political will.

Figure 2-8: Percentage changes in passenger travel by mode, region, and urban/non-urban, BLUE Shifts scenario compared to baseline in 2050



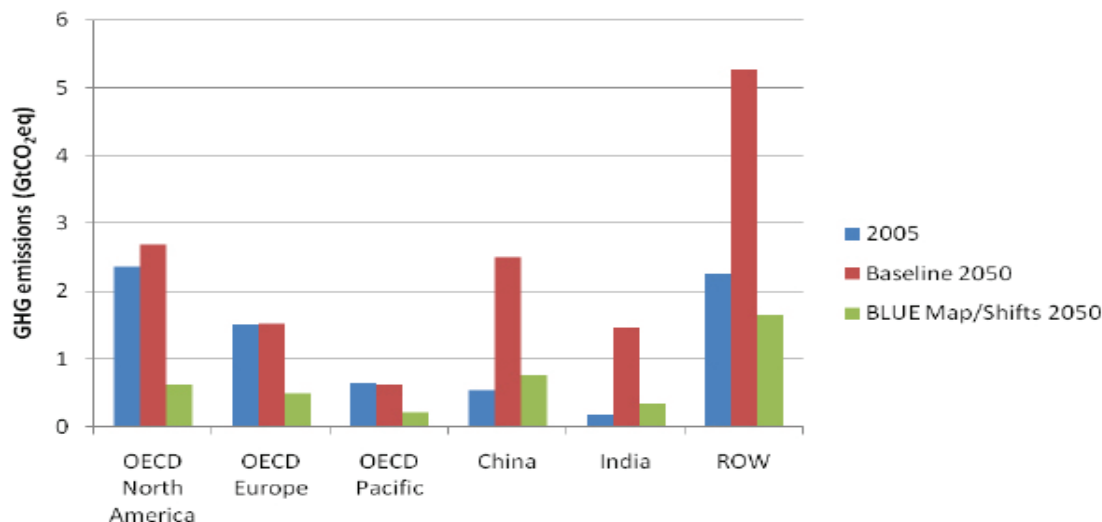
The BLUE Map/Shifts Scenario

When the impacts of improved efficiency, low carbon fuels, and advanced vehicles and modal shift are combined in the BLUE Map/Shifts scenario, CO₂ emissions in transport are cut by 40 percent in 2050

compared to 2005, and by 70 percent compared to the baseline scenario in 2050, as shown earlier in Figure 2-2. This represents a 10 Gt reduction from the 14 Gt that would otherwise be emitted by the transport system in 2050 in the baseline scenario and a 14 Gt reduction compared to the 18 Gt in the high baseline scenario. After 2050, further modal shifting and efficiency improvements, and the deeper penetration of low CO₂ alternative fuels, will be needed to keep transport on a downward CO₂ trend.

As shown in Figure 2-9, the change in CO₂ varies considerably by region, with OECD regions experiencing deep reductions compared to 2005 levels, and most non-OECD regions staying near or slightly above 2005 levels, although far lower than their CO₂ growth in the baseline scenario. All world regions must deeply decarbonize transport by 2050 compared to baseline scenario trends if the overall targets are to be achieved.

Figure 2-9: Transport CO₂ emissions by region, year, and scenario



Modal Findings and Policy Considerations

It will be extremely challenging for transport to achieve the outcomes implicit in the BLUE Map/Shifts scenario. Very strong policies will be needed, both to encourage development and implementation of alternatives and to encourage consumers and businesses to embrace these alternatives. The following sections outline the contribution from the different modes and the policies that will be needed.

The four most important modes, in terms of their expected contribution to CO₂ in the baseline scenario in 2050, are LDVs, which account for 43 percent of the reductions, trucks with 21 percent, aviation with 20 percent, and shipping with 8 percent. In the BLUE Map/Shifts scenario, the role for buses and rail increases significantly and CO₂ reductions from efficiency improvements and alternative fuel use in these modes become increasingly important, though they are already quite efficient.

Light Duty Vehicles

Passenger LDV ownership around the world is expected to rise mainly as a function of income. In the baseline scenario, the total LDV stock increases from about 700 million in 2005 to nearly two billion by 2050. One obvious impact of this growth is a similar increase in the rate of fuel use, unless vehicles become far more efficient than they are today. Modal shifts to mass transit, walking and cycling, and long-distance bus and rail systems could also help reduce fuel use by encouraging people to use alternatives to cars more often.

Based on IEA analysis and various other recent studies (e.g. Cheah *et al* 2007), it seems possible, and is likely to be cost effective even at relatively low oil prices, to achieve a 50 percent reduction in fuel use per kilometer for new LDVs around the world by 2030, relative to 2005 levels, from incremental technology improvements and electric hybridization. Net negative CO₂ reduction costs are achievable at least for much of this improvement, but it will be important to ensure that the efficiency gains are not simply offset by trends toward larger, heavier, and faster cars. Policies will be needed to ensure that maximum uptake of efficiency technologies occurs and that the benefits are translated into fuel economy improvement. Fuel economy standards, perhaps complemented by CO₂-based vehicle registration fees, can play an important role in OECD countries. It is important that non-OECD countries adopt similar policies, and that all countries continue to update these policies in the future, rather than letting policies expire. The Global Fuel Economy Initiative (GFEI 2009) is focused on helping achieve such outcomes.

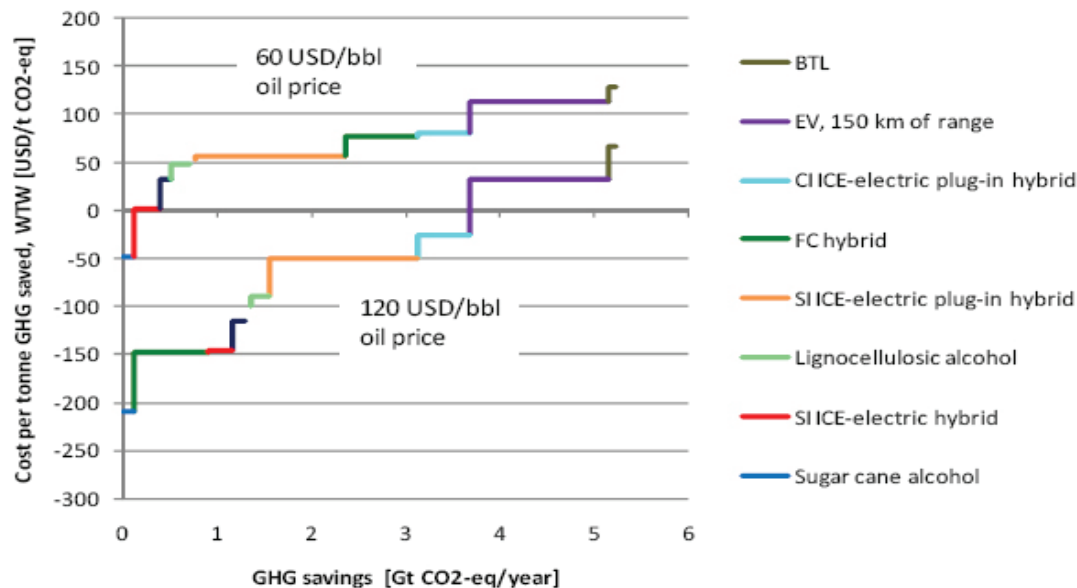
Advanced technology vehicles will need to play an increasingly important role, especially after 2020. Initiatives to promote BEVs and PHEVs, and the continuing development of FCVs, will be important. The BLUE Map scenario includes annual sales of over five million PHEVs and two million BEVs by 2020, rising to around 50 million of each type of vehicle by 2050. It also predicts sales of tens of millions of FCVs by 2050. For governments, undertaking ongoing RD&D programs to cut technology costs, orchestrating the co-development of vehicle and battery production, recharging and hydrogen infrastructure, and providing incentives to ensure sufficient consumer demand to support market growth will be important near-term activities. Selecting certain regions or metropolitan areas that are keen to be early adopters of new vehicle types may be an effective approach.

Biofuels for LDVs and other transportation modes could play an important role, but their use may be limited by the availability of sustainable and truly low-CO₂ feedstocks. Second generation biofuels from lignocellulosic and other non-food feedstocks reach about 25 percent of LDV transport fuel by 2050 in the BLUE Map scenario, nearly 20 times 2008 levels worldwide. Fuel compatibility with vehicles is not likely to be a significant problem, needing only minor modifications to new vehicles in the future. A transition is needed to much more sustainable feedstocks and approaches to biofuels production, however. As sustainability criteria and rating systems emerge, policies need to shift toward incentivizing the most sustainable, low-CO₂, and cost-efficient biofuels, while minimizing impacts from land use changes. CO₂ differentiation through the low carbon fuel standard now in effect in California (CARB 2009) represents an important step. A transition to second generation production techniques is particularly needed in OECD countries, since their current biofuels production is dominated by ethanol from grain crops and biodiesel from oil-seed crops. These compete with food and animal feed supplies and are costly in terms of CO₂ cost-per-tonne or land use efficiency.

Shifting passenger travel to more efficient modes, such as urban rail and advanced bus systems, can play an important role in cutting CO₂, and they often provide other important benefits, including reduced traffic congestion, lower pollutant emissions, and more liveable cities. Policies need to focus on better urban design to cut the need for motorized travel, improving transit systems to make them much more attractive, and improving infrastructure to make it easier to walk and cycle for short trips. Rapidly growing cities in developing countries have the opportunity to move toward far less car-oriented development than has occurred in many cities in OECD countries, but it will take strong measures and political will and support for alternative investment paradigms.

Figure 2-10 shows the role and estimated marginal cost of different technologies and fuels in contributing to CO₂ reductions from LDVs in the BLUE Map scenario in 2050, under \$60 and \$120 per barrel oil price assumptions. These curves are uncertain, and sensitive to small changes in assumptions. Modal shifts and non-LDV modes are not included due to cost uncertainties. Costs for 2050 for technologies and fuels shown in the figure are partly dependent on earlier deployment, which triggers learning and cost reductions. The curves show the particular combination of technology and fuels options that are deployed in the BLUE Map scenario, but other combinations could also achieve the same or similar outcomes in terms of CO₂ reductions.

Figure 2-10: GHG reductions in BLUE Map for light-duty vehicles and fuels: contribution and estimated cost per tonne by vehicle and fuel type in 2050



Notes: SI = spark ignition, gasoline vehicle; CI = compression ignition diesel vehicle; ICE = internal combustion engine vehicle; hybrid refers to hybrid electric vehicle; BTL = biomass-to-liquids biodiesel.

Despite the uncertainties, the results are revealing. By 2050, deep reductions in CO_{2-eq} GHG emissions from LDVs on the order of 5 Gt appear possible at a marginal cost of about \$210 per metric ton with oil at \$60 per barrel. A second case, assuming a higher oil price of \$120 per barrel, is also shown. At this higher oil price, the emissions reductions are achieved at a marginal cost of about \$130 per metric ton. Most of the emissions reduction is achieved at costs far below this. In earlier years, particularly up to 2030, most cost reductions come from incremental improvements to conventional vehicles and hybridization at very low average cost.

Trucks and Freight Movement

Trucking has been one of the fastest growing transport modes over the past few decades. This growth is likely to continue, although possibly with some decoupling from GDP as an increasing share of economic growth comes from information and other non-material sectors. Trucks have also become more efficient. Even so, there remain major opportunities to improve efficiency through technical measures, operational changes such as driver training, and implementation of logistical systems to improve efficiency in the handling and routing of goods.

Better technologies, including improved engines, light-weighting, better aerodynamics, and better tires, can probably make vehicles 30 to 40 percent more efficient by 2030. Many of the improvements appear likely to be cost effective, although significant market failures are evident in terms of truck operators failing to adopt cost-effective technologies. In addition, using a societal cost basis for analysis of options increases cost effectiveness well beyond private cost analysis. Logistic systems to ensure better use of trucks and shifts to larger trucks can provide additional efficiency gains system-wide, and may also be quite cost effective. To maximize the gains, governments will need to work with trucking companies, for example, by supporting driver training programs, and to create incentives or requirements for improved efficiency. Japan's Top Runner efficiency requirements for trucks are the first of their kind in the world (JFS 2009).

For many trucks, shifting to electricity or hydrogen as a main fuel will be difficult due to driving range requirements and energy storage limitations. Thus, the development of second generation biofuels may

be the only way to substantially decarbonize trucking fuel. Trucks can be easily adapted to burn biodiesel, especially the very high quality biodiesel that is produced by biomass gasification and liquefaction. In the BLUE Map scenario, trucks achieve a 40 percent reduction in energy intensity per metric ton-km, and shift 30 percent of their remaining fuel demand to advanced biofuels by 2050.

Shifting some freight from truck to rail can be an attractive option to save energy and cut CO₂ emissions, due to the high energy efficiency of rail movement. Many countries move only a small share of goods by rail, but to achieve shifts, very large investments in rail and intermodal systems will be necessary.

Aviation

Air travel is expected to be the fastest growing transport mode in the future. Air passenger kilometers increase by a factor of four between 2005 and 2050 in the baseline scenario, and by a factor of five in the high baseline scenario. It is expected to grow even faster than income during normal economic cycles. Aviation also benefits from steady efficiency improvements in each generation of aircraft, which is likely to continue.

Given the expected very high rate of growth, aviation energy use and CO₂ emissions are expected to triple in the baseline scenario and quadruple in the high baseline scenario. An increase in the rate of efficiency improvements beyond baseline rates may be possible, for example, by encouraging aircraft manufacturers to make bigger gains with each generation of aircraft and by improving air traffic control systems. A wide range of fuel efficiency technologies for aircraft remain unexploited, including aerodynamic improvements, weight reduction, and engine efficiency. The estimated potential for improvement suggests that the average aircraft may be nearly twice as efficient in 2050 as it is today.

Table 2.1: Fuel savings and costs from new generation planes

<i>Parameter</i>	<i>B767</i>	<i>B787</i>	<i>B747-400</i>	<i>B747-800</i>
Seat Capacity	250	250	460	467
Load factor	80	80	80	80
Energy intensity (MJ/seat-km)	1.9	1.3	1.8	1.4
Fuel use L per plane km	10.8	7.4	18.6	14.7
Annual plane-kilometres of travel per year (million)	2	2	2	2
Annual fuel consumption (million l)	22	15	38	30
Annual savings (million USD, @ USD 120/bbl or about USD 0.90/L)	6.4		8.6	
Savings over 30 years, 10% discount rate, USD millions	60		81	
Savings over 30 years, 3% discount rate, USD millions	125		169	
Approximate aircraft purchase costs (USD millions)	150	190	230	280
Purchase Cost Difference (USD millions)	40		50	

Sources: IEA estimates based on aircraft data from Boeing's website (Boeing 2009) and previous reports. Airplane cost data from Air Guide Online, 2009

Improved air traffic control can also improve the overall fuel efficiency of aviation by between 5 and 10 percent. More work is needed to better understand the cost effectiveness of various options, although available estimates suggest that some available options may be quite attractive. One significant factor in assessing technology cost/benefit for aircraft is that aircraft burn large quantities of fuel over their lifetimes. Up to one billion liters of jet fuel can be burned in a large airplane over its lifetime. Cutting fuel use can provide enormous fuel cost savings. Thus, major investments to improve aircraft efficiency may be cost effective.

The fuel savings associated with two recent aircraft replacements are shown in Table 2-1. A host of new upgrades and features may justify much of the higher cost. Even so, fuel savings alone over 30 years, assuming a 10 percent discount rate and fuel costs of \$ 0.90 per liter, fully offset the higher plane cost. Using a 3 percent societal discount rate, fuel savings are far greater than the higher plane cost. This also reveals the fact that, over the 30-year minimum equipment life for aircraft, using a 3 percent discount rate instead of a 10 percent rate doubles the value of fuel savings, in turn indicating that far greater investments in aircraft efficiency are justifiable from a societal point of view than a private or corporate point of view.

Measures such as CO₂ taxes to encourage faster introduction of new technologies reflecting very high societal benefits on successive generations of aircraft can help. International agreements can place a price on or limit aviation GHG emissions. However, GHG reduction is complicated by the fact that CO₂ is just one of several aircraft emissions that have radiative forcing, or warming, effects. Others include nitrogen oxides, methane, and water vapor. More work is needed to better understand the net effects and optimal strategies for reducing overall aviation GHG emissions.

Even more than trucks, aircraft are restricted in the types of fuels they can use. The energy density of fuels is critical for providing adequate aircraft flying range. Shifting from energy dense liquid fuels to gaseous fuels or electricity appears impractical. Liquefied hydrogen may be a viable option, but its use would require major compromises in other airplane design features. High energy-dense biodiesel fuels, therefore, are of great interest to the airline industry, including aircraft manufacturers, as they may hold the best hope of providing low-CO₂ fuels.

In the BLUE Map scenario, 30 percent of aircraft fuel is second generation biofuel by 2050. The BLUE Map/Shifts scenario predicts a cut in air travel growth by 25 percent, resulting in a tripling by 2050 rather than quadrupling. This will occur naturally if alternatives such as high-speed rail systems are provided, but it must also be encouraged by policies that help ensure the availability and cost-competitiveness of rail travel. Substituting telematics, such as teleconferencing, for some long-distance trips could also play an important role.

Shipping

International water-borne shipping has grown very rapidly in recent years, in particular as a function of the growth in Asian manufacturing and exports to other countries. Transoceanic shipping now represents about 90 percent of all shipping energy use. The remainder is river and coastal shipping. Container shipping fuel use has risen faster than any other ship category, and it may continue to rise rapidly in the future. The average size of ships is also rising, such that shipping is becoming steadily more efficient per metric ton-km moved.

Ship efficiency has not been improving significantly in recent years. The structure of the shipping industry, with fragmented and very different systems of ownership, operation, and registration, often involving several different countries for a single ship, may serve to limit the market incentives to optimize ship efficiency.

The IEA has identified about 50 efficiency improvement measures for shipping (IEA 2009). If most were adopted, a 50 percent or greater reduction in energy use per metric ton-km could be achieved. More economic research is needed, but recent studies suggest that many options for retrofitting existing ships could achieve substantial energy and CO₂ savings at very low or net negative cost.

As for aircraft, biofuels are likely to be important for the decarbonization of shipping fuel. Ship engines are capable of using a wide range of fuels, and may be able to use relatively low quality, low cost biofuels. In the BLUE Map scenario, 30 percent of shipping fuel is low GHG biofuel by 2050.

Policies to promote improved international shipping efficiency and CO₂ reduction may have to come from international agreements. Shipping could be included in a CO₂ cap-and-trade system. Another proposal has been to develop a ship efficiency index and score all new and existing ships using the index. This could be coupled with international incentives or regulations on new ship efficiency and used to encourage modifications to existing ships, given that many efficiency retrofit opportunities for existing ships are available. More work is needed to develop such an index, and in particular to estimate the efficiency benefits and costs for various types of improvements. The UN International Maritime Organisation is playing a lead role in such efforts.

Conclusions

It appears that, by 2050, it should be possible to cut transport energy use and CO₂ emissions nearly in half compared to baseline projections through efficiency improvements, and by nearly half again by substitution of very low-CO₂ alternative fuels, mainly electricity, hydrogen, and biofuels. Modal shifting can also help, particularly in the 2010 to 2030 time frame, before private modes, such as LDVs, have become significantly decarbonized.

While CO₂ reduction costs are uncertain, the efficiency improvements should be, on average, cost effective, with an average cost per metric ton for LDVs near zero using a societal discount rate. The costs of many options available for trucks, ships, and aircraft appear near zero on a cost per metric ton basis, but costs are uncertain at the margin. The biggest uncertainty, however, is the cost for producing large numbers of BEVs or FCVs. If targeted cost reductions are achieved, these technologies should provide CO₂ reductions by 2050 at net costs below \$200 per metric ton, and perhaps below \$100 per metric ton. However, in a more pessimistic scenario, with fewer cost reductions, the costs of these technologies may well exceed \$200 per metric ton.

International cooperation to move things in the right direction will be critical. A significant reduction in CO₂ emissions in transport will be possible only if all world regions contribute. Although transport emissions per capita are far higher today in OECD than in non-OECD countries, nearly 90 percent of all the future CO₂ growth is expected to come from non-OECD countries. In the IEA BLUE scenarios, all regions cut transport CO₂ dramatically compared to the baseline in 2050. Vehicles can be made more efficient in all regions of the world, generating large fuel savings worldwide. Changes in travel can also occur, although in many countries the main priority is to preserve current low-energy travel modes. Alternative fuels, if their costs can eventually approach those for oil-based fuels, will also contribute to CO₂ reductions worldwide.

Governments need to work together and with key stakeholders to ensure that markets around the world send similar signals to consumers and manufacturers, in part to maximize efficiency and limit the cost of future changes. Common medium- and long-term targets in terms of fuel economy, alternative fuels use, and modal shares would send clear signals to key players and help them plan for the future. For those producing efficient products, knowing that a wide range of markets will be eager for those products will help plan production and, eventually, to cut costs. The Global Fuel Economy Initiative represents an important example of moving toward greater international co-operation in developing targets and standards.

National governments need to develop and deploy new types of very low GHG vehicles and fuels. Technologies such as BEVs and FCVs can only be introduced into markets where there is adequate refueling infrastructure, and consumers willing and ready to purchase both the vehicles and the fuels. Markets alone will have difficulty achieving such outcomes. Governments around the world must orchestrate such transitions and help overcome the risks involved.

To put transport on a sustainable pathway over the coming 40 years, current trends must be changed substantially within the next five to ten years. Strong policies are needed to begin to shift long-term trajectories and to meet interim targets. Strong measures are also needed in terms of investments in infrastructure and incentives that can influence how people choose to travel.

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Chapter 3:

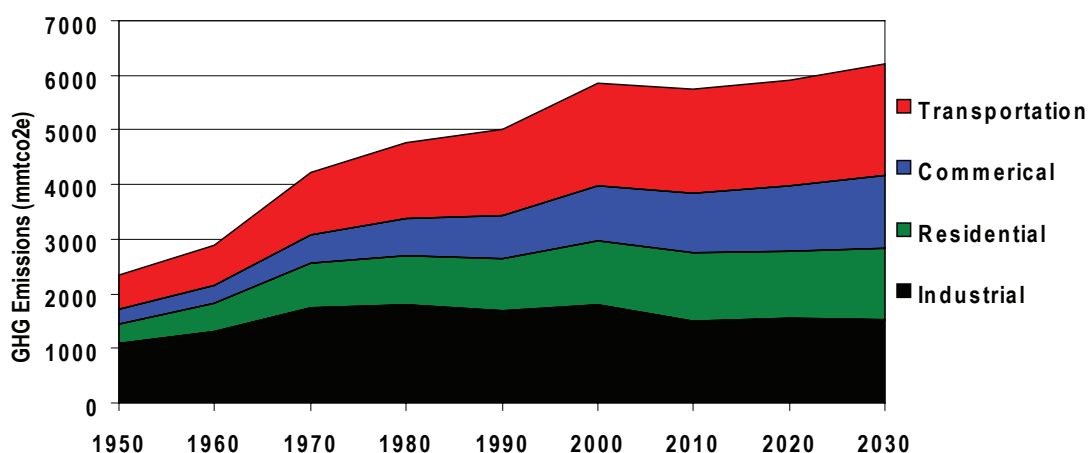
U.S. Greenhouse Gas Emissions in the Transportation Sector

by John Conti, Nicholas Chase, and John Maples

Transportation is the single largest emitter of greenhouse gases (GHG) in the United States (U.S.) among the four end use sectors, which also include commercial, residential, and industrial end use sectors, with emissions associated with electricity generation distributed to the sectors where electricity is consumed. According to data collected by the U.S. Energy Information Administration (EIA) and projected through its National Energy Modeling System (NEMS), GHG emissions in the transportation sector grew from 630 million metric tons of carbon dioxide equivalent (mmtCO_{2e}) in 1950, representing 27 percent of the total U.S. emissions, to 1,882 mmtCO_{2e} in 2009, representing 33 percent of the U.S. total (EIA 2008).

GHG emissions in the transportation sector in the U.S. more than tripled between 1950 and 2009, but are projected to remain relatively flat between 2010 and 2030. Figure 3-1 shows the trends in GHG emissions

Figure 3-1: Historical and projected U.S. GHG emissions by end use sector, 1950-2030



Source: EIA National Energy Modeling System Emissions Data

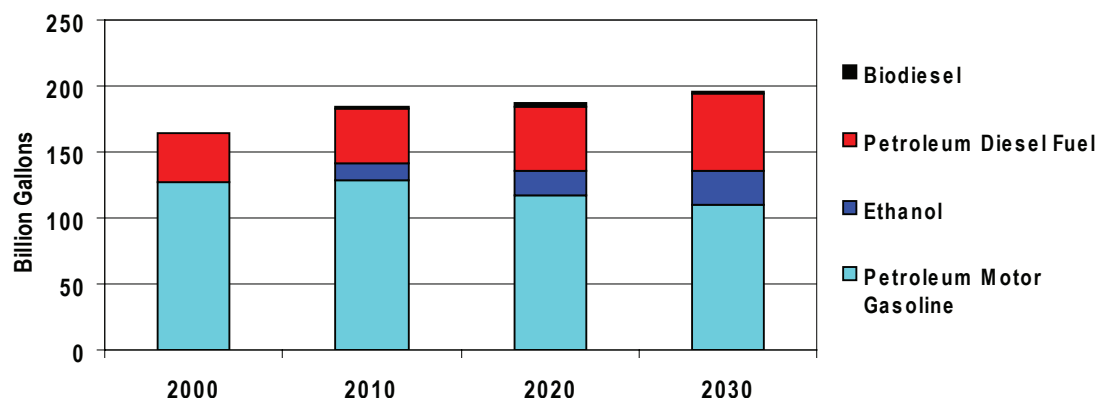
J. Conti is Director of the Office of Integrated Analysis and Forecasting, Nicholas Chase is an industry economist, and J. Maples is an Operations Research Analyst with the U.S. Energy Information Administration in Washington, DC

by energy sector from 1950 to projected emissions in 2030. In the 1980s, transportation overtook the industrial sector to become the largest emitting end use sector, driven by increased personal mobility as rising income and low fuel prices stimulated motorization and the suburbanization during the era after the end of World War II in what became the greatest migration in American history.

The EIA *Annual Energy Outlook 2009* updated reference case projects that the transportation sector's GHG emissions will increase from 1,905 mmtCO_{2e} in 2010 to 2,045 mmtCO_{2e} by 2030 (EIA 2009a). Transportation's overall share of emissions is projected to remain at 33 percent throughout the forecast period, continuing its distinction as the largest source of GHG emissions among U.S. end use sectors.

Total liquid fuel consumption in transportation, including petroleum motor gasoline and diesel, ethanol, and biodiesel, is projected to grow from 164 billion gallons in 2000 to 196 billion gallons by 2030, as shown in Figure 3-2. Ethanol and biodiesel consumption is projected to grow from nearly zero in 2000 to 28 billion gallons in 2030, with ethanol accounting for 26 billion gallons of the increase. Because emissions from ethanol feedstock production and conversion are counted in the industrial end use sector, GHG emissions from liquid fuel consumption reported for the transportation sector will remain almost flat between 2000 and 2030. The sidebar discusses the accounting of GHG emissions from biofuel production and use in the

Figure 3-2: Total liquid fuel consumption in transportation



Source: EIA National Energy Modeling System Emissions Data

NEMS.

GHG Emissions in Transportation Modes

Between the years 1950 and 2000, the U.S. economy underwent a rapid expansion, growing from \$293.7 billion in 1950 to \$9.52 trillion by 2000, corresponding to a real disposable personal income increase from \$1,401 billion in 1950 to \$8,161 billion by 2000.

This quintupling of real personal income drove a corresponding increase in the amount of vehicle miles traveled. While these trends affected primarily the light duty vehicle (LDV) sector, similar trends occurred in other transportation sectors as the U.S. economy grew and wealth increased. Consumer demand increased for a vast array of goods, which required the movement of large quantities of materials and industrial output and increased the emissions from heavy duty vehicles. Similarly, the air travel mode became a major form of travel as wealthier consumers demanded more air travel.

Figure 3-3 shows the growth in transportation GHG emissions by transport mode from 1970 to 2005, followed by a leveling off predicted to continue through 2030. Almost all the GHG emissions that resulted from transportation demand over the past few decades have been derived from the combustion of petroleum products.

Since 2005, GHG emissions from the transportation sector have remained relatively flat and are projected to remain relatively flat through 2030, rising from 1,872 mmtCO_{2e} in 2000 to 1,904 mmtCO_{2e} in 2010, and 1,929 mmtCO_{2e} in 2020, before moving slightly upward to 2,045 mmtCO_{2e} in 2030. Petroleum products will remain the overwhelming source of GHG emissions in the transportation sector, but biofuels will also begin to play an important role. Because of the accounting method used by the EIA, the growing use of ethanol and the less significant growth in the use of biodiesel across the projection period explain in large part, but not entirely, why GHG emissions in transportation have remained and are projected to remain relatively flat between 2000 and 2030.

Light duty vehicles (LDVs) represent the single largest source of GHG emissions in the transportation sector by a wide margin, accounting for around 59 percent of total transportation emissions today. Throughout the EIA projection period, LDV GHG emissions will continue to represent the single largest emission source, although emissions are projected to decline four percent as a result of higher fuel economy standards and the increasing use of biofuels. Heavy duty truck GHG emissions are projected to increase 31 percent, growing from 17 percent of total transportation GHG emissions in 2009 to 23 percent by 2030, furthering the heavy duty truck mode's place as the second largest overall GHG emitter in the transportation sector. GHG emissions from air travel are projected to increase 36 percent, the highest rate of increase in the forecast. Marine and rail are projected to grow, but remain relatively minor sources of energy use and GHG emissions in the U.S.

Light Duty Vehicle GHG Emissions

In 2009, LDVs, vehicles with a gross vehicle weight rating up to 10,000 pounds accounted for 1,104 mmtCO_{2e} out of a total of 1,882 mmtCO_{2e}. Emissions are projected to decline to 1,062 mmtCO_{2e} in 2030, a decrease of 42 mmtCO_{2e}. This decline will lower the LDV mode's overall share of transportation GHG emissions from 59 percent to 54 percent in 2030. Biofuels consumption in LDVs is projected to increase to 28 billion gallons by 2030, which will offset almost all of the growth in liquid fuel demand in the LDV fleet.

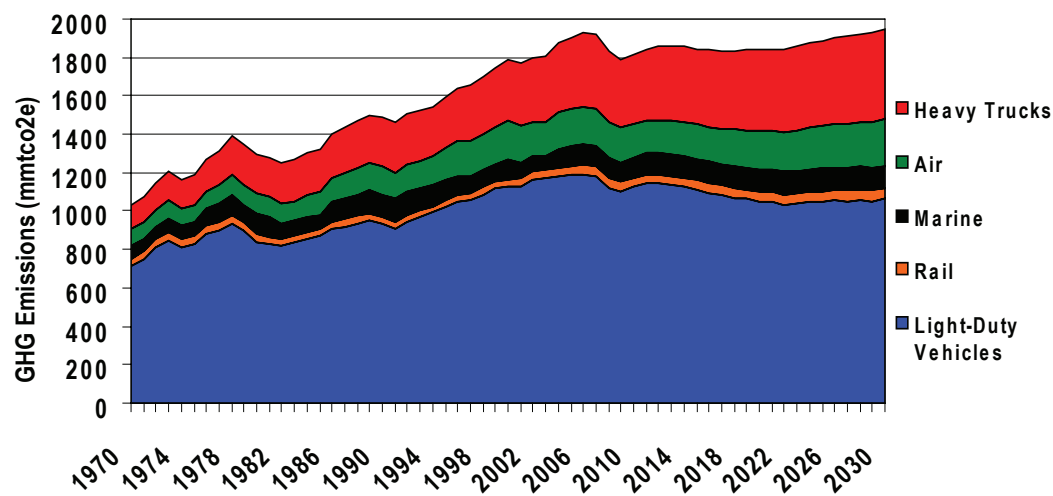
Higher proposed fuel economy standards mandated by the Energy Independence and Security Act of 2007, which require new LDVs to reach a fuel economy of 35 miles per gallon (mpg) by 2020, also contribute to the decline in projected GHG emissions (EISA 2007). As new vehicles enter the LDV fleet, the stock average fuel economy for those vehicles is projected to increase from 20.5 mpg in 2009 to 24.6 mpg in 2020 and 28.9 mpg in 2030. While the stock average fuel economy is projected to increase, the impact on emissions is forecast to be strongest in the early part of the projection period because of the continuing growth in overall LDV miles traveled (VMT). Total light duty VMT is forecast to increase from 2,856 billion miles in 2010 to 3,221 billion miles in 2020 and 3,936 billion miles in 2030. Between 2010 and 2020, the stock average fuel economy increases at a rate of 20 percent, while VMT increases at a rate of only 13 percent; thus, GHG emissions are driven downward. Combined with the increasing use of ethanol, emissions decline between 2010 and 2020.

GHG Emissions and Biofuels

Consumption of biofuels produces varying amounts of GHG emissions, depending on the accounting for and allocation of life cycle emissions, including feedstocks used, fuels consumed, and land use emissions. In the NEMS, GHG emissions from biofuels, including both ethanol and biodiesel, are calculated using a field-to-tailpipe accounting method, with land use emissions currently excluded and emissions distributed across various energy sectors. Due to this accounting, full GHG emissions are not accounted for in the transportation end use sector.

In transportation, vehicle GHG emissions from biofuels are assumed to be zero as they are completely offset by the growing of the feedstock. Biofuel process emissions are counted in the industrial end use sector based on the energy used in agriculture for the production of crops and in the production process of turning the biofuel feedstock into a transportation fuel. GHG effects of direct or indirect changes in land use are not tracked in the NEMS.

The fact that GHG emissions from biofuels feedstock production and conversion processes, excluding changes in land use, are accounted for in the NEMS outside of the transportation end use sector has significant implications for projecting emissions for transportation because of the projected growth of biofuel used as a liquid transportation fuel.

Figure 3-3: GHG emissions by transport mode, 1970-2030

Source: DOE 2009; EIA 2008

Between 2020 and 2030, stock average fuel economy increases at a rate of only 17 percent, while VMT grows at a rate of 22 percent, which, when combined with a growing use of biofuels, still leaves total LDV GHG emissions lower in 2030 than 2010, but higher than 2020. If, beyond 2030, VMT continues to grow and biofuels use and fuel economy do not continue to increase, LDV GHG emissions will begin to increase again.

Heavy Duty Vehicle GHG Emissions

While LDV GHG emissions are projected to decline, heavy duty truck GHG emissions are projected to increase 31 percent between 2009 and 2030, representing the largest absolute increase and the second largest percentage increase in GHG emissions in the transportation sector during the forecast period. Heavy duty truck GHG emissions are projected to grow from 17 percent of total transportation GHG emissions in 2009 to 23 percent by 2030, continuing to place heavy duty trucks as the second largest overall GHG emitter in the transportation sector.

The driving force behind this increase is the growth in heavy duty VMT from 226 billion miles in 2009 to 347 billion miles in 2030, which is itself driven by a corresponding growth in industrial output from \$4,927 billion 2000 dollars to \$7,391 billion by 2030. While heavy duty vehicle fuel economy is projected to increase, the increase is not significant enough to offset the growth in VMT.

Air GHG Emissions

GHG emissions from air travel are the third largest source of emissions in the transportation sector and represent the fastest growing mode. Aircraft accounted for 179 mmtCO_{2e} of emissions in 2009, 10 percent of total transportation emissions. GHG emissions in the air mode are projected to increase 65 mmtCO_{2e} by 2030, the second largest absolute increase among transportation modes. By 2020 aircraft emissions reach 200 mmtCO_{2e} and by 2030 reach 244 mmtCO_{2e}, or 12 percent of transportation total.

GHG emissions from air transportation increase because aircraft travel demand as measured in air seat miles available is predicted to increase from 995 billion miles in 2009 to 1,465 billion miles in 2030, a growth of 47 percent. Air travel demand stems from rising real disposable personal income per capita, which increases from \$29,157 (in 2000 dollars) in 2009 to \$42,741 by 2030, also a growth of 47 percent. Aircraft fuel economy measured in aircraft seat miles per gallon of jet fuel is projected to increase 15 percent from 63.6 to 73.4, partially offsetting increased aircraft travel demand.

Marine and Rail GHG Emissions

The remaining non-highway transportation modes also are forecast to experience growth in GHG emissions. Marine and rail are the fourth and fifth largest sources of GHG emissions in the transportation sector, respectively. In 2009, marine traffic accounted for five percent of total transportation emissions, while rail accounted for two percent of total transportation emissions.

Marine emissions are projected to increase from 102 mmtCO_{2e} in 2009 to 118 mmtCO_{2e} by 2030, or six percent of total transportation emissions after a 16 percent growth. Rail emissions are forecast to grow from 46 mmtCO_{2e} in 2009 to 56 mmtCO_{2e} in 2030, remaining around three percent of total emissions despite a 22 percent growth. Marine and rail emissions are driven by an increase in ton miles traveled in each mode while fuel efficiency in both is projected to remain relatively constant in terms of ton miles per Btu.

Impacts of ACESA

GHG emissions are unregulated in the United States, but continue to garner significant attention because of concerns about anthropogenic climate change. Since transportation accounts for one-third of total U.S. GHG emissions by end use, great focus and attention has been devoted to developing policies that could substantially reduce its emissions. One way to reduce GHG emissions that has drawn the support of many U.S. lawmakers is through a cap-and-trade program. This system functions by using market-based methods to reduce GHG emissions by essentially making it more costly to emit GHGs. A cap-and-trade system sets an overall level of allowable GHG emissions for the entire economy, minus exempted sources. Allowable emissions are then allocated to various emissions sources that are required to maintain emissions at levels below the caps.

Compliance is enforced through a requirement for entities subject to the cap to report GHG emission allowances, which are bankable, sufficient to cover their emissions. For those unable to do so, allowances can be purchased from other owners of emissions sources that successfully reduced emissions below the amount they were allotted. This effectively places a price on GHG emissions and creates a market price on allowances as an incremental cost to emitting GHGs. A final, but critical, element of a cap-and-trade system is that the GHG emission caps are reduced over time with the expectation that the market price to emit a given unit of GHG emissions will increase and encourage efforts to reduce emissions.

On June 26, 2009, the U.S. House of Representatives passed H.R. 2454, the American Clean Energy and Security Act of 2009 (ACESA), a complex bill that uses a cap-and-trade market-based mechanism to reduce the emission of GHG emissions, along with efficiency programs and other economic incentives (ACESA, 2009). The Title III cap-and-trade program for GHG emissions, which covers roughly 84 percent of total U.S. GHG emissions by 2016, is in many respects the centerpiece of the bill. The program subjects covered emissions to a cap that declines steadily between 2012 and 2050. The cap requires a 17 percent reduction in covered emissions by 2020 and an 83 percent reduction by 2050, relative to a 2005 baseline with targets that decline steadily for intermediate years.

EIA Analysis of ACESA

The EIA analyzed ACESA by considering the energy-related provisions in the proposed legislation that can be analyzed using the National Energy Modeling System (EIA 2009b). The starting point for the analysis was the updated reference case of the *Annual Energy Outlook 2009* (EIA 2009a), which includes the American Recovery and Reinvestment Act (ARRA 2009) and other updates capturing recent changes in the U.S. economy. While this analysis is as comprehensive as possible, it does not address all provisions of ACESA, such as the authority provided to establish efficiency standards for transportation equipment other than LDVs and the effects of increased investment in energy research and development. Thus, results are

presented with the important caveat that the lone effect on the transportation sector from ACESA analyzed by the EIA is the impact of a cap-and-trade system on fuel prices.

Furthermore, the analysis of ACESA separates demand sectors by transportation, industrial, buildings, and electric power for analysis. This differs from the method used in the first section of this chapter. The analysis in the first section divided emissions between industrial, commercial, residential, and transportation, with electricity usage attributed to the various end users. For its analysis of H.R. 2454, GHG emissions from electric power generation were aggregated and compared to emissions from the transportation, residential and commercial buildings, and industry sectors.

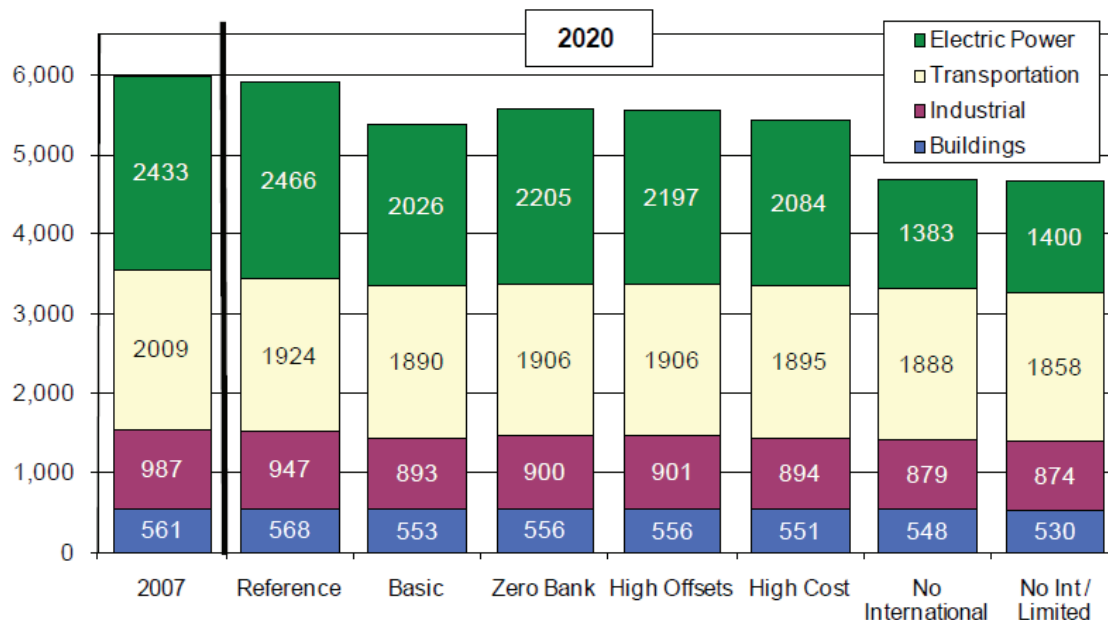
Allowance prices in the ACESA cases varied from between \$20 and \$93 per metric ton of CO_{2eq} in 2020 to between \$41 and \$191 per metric ton of CO_{2eq} in 2030, depending on the various allowance scenarios evaluated in the report. The EIA prepared a range of analysis cases for this report. The six main scenarios focus on two key areas of uncertainty--namely, the role of offsets and the energy system and economic impacts of ACESA on the timing, cost, and public acceptance of low carbon and no carbon technologies. The ACESA basic case projects a price of \$32 per metric ton in 2020 and \$65 in 2030.

Analysis Results

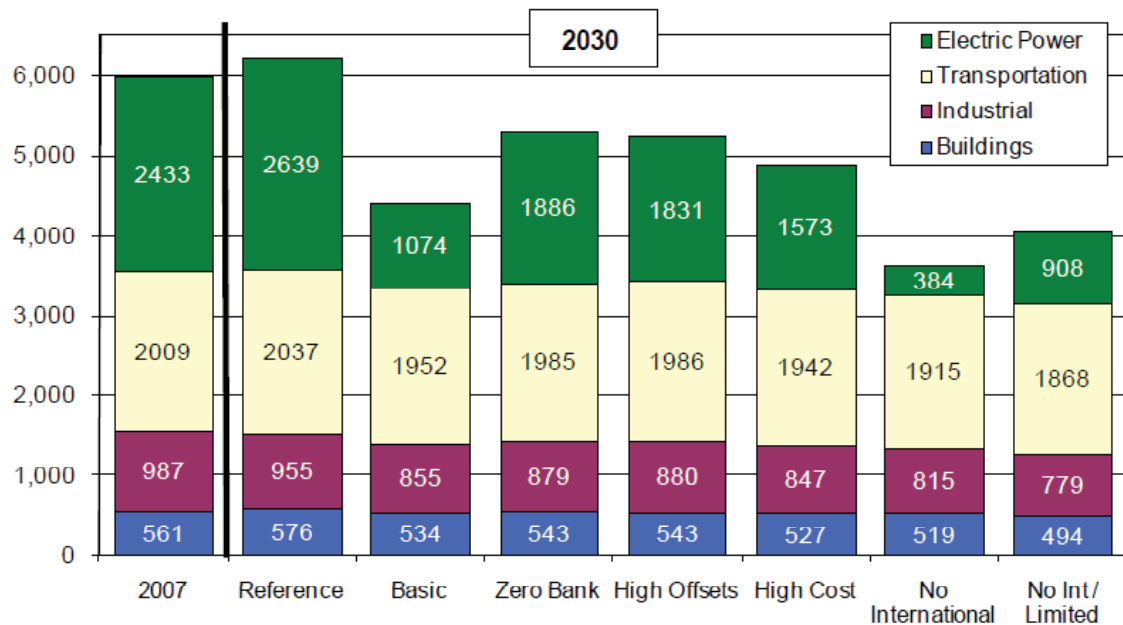
Figure 3-4 summarizes the EIA analysis of GHG emissions in 2020 from all energy sectors under each of the main scenarios examined. According to the EIA analysis, implementation of ACESA will reduce carbon dioxide (CO₂) emissions between 338 and 1,243 million metric tons (mmt) in 2020 depending on the various allowance cases. Emissions fall from 5,905 mmt in the updated reference case to between 4,662 and 5,567 mmt, a decline of between 6 and 21 percent. Emissions projected for 2030 under each scenario are summarized in Figure 3-5. GHG emissions decline from 6,207 mmt in the updated reference case to between 3,633 and 5,293 mmt in the ACESA scenarios, a drop of between 13 and 41 percent.

Transportation is projected to account for relatively little of the total GHG emission reductions due to ACESA. In 2020, transportation CO₂ emissions decline only between 18 and 66 mmt across cases, from 1,924 mmt to

Figure 3-4: Energy related CO₂ emissions by sector in ACESA main cases, 2020 (mmt CO₂)



Source: National Energy Modeling System Data

Figure 3-5: Energy related CO₂ emissions by sector in ACESA main cases, 2030 (mmt)

Source: National Energy Modeling System Data

between 1,858 and 1,906 mmt, a reduction of only one to three percent. By 2030, transportation emissions will decrease from 2,037 mmt to between 1,915 and 1,985 mmt, a reduction of just 2.5 to 6 percent.

Since emissions from electric power are not included as transportation emissions in the EIA analysis of H.R. 2454, electricity consumption by electric vehicles or plug-in hybrid electric vehicles, while counted towards transportation emissions in the first section of this chapter, are now attributed to the electric power sector. Transportation GHG emissions associated with electricity are predicted to be about 5 mmtCO_{2e} in 2020 and 8 mmtCO_{2e} in 2030. This explains the difference in total transportation emissions between the H.R. 2454 analysis updated reference case and the updated reference case of the *Annual Energy Outlook 2009*.

As a result of the relatively small decline in transportation GHG emissions as a result of ACESA, transportation's overall share of energy-related end-use emissions increases from 33 percent in 2020 in the updated reference case to between 34 and 40 percent in the ACESA scenarios and from 33 percent in 2030 to between 38 and 53 percent.

The EIA projects that the vast majority of GHG emission reductions will take place in other sectors affected by ACESA. Specifically, between 80 and 88 percent of reductions in energy-related emissions by 2030 are expected to occur in electric power generation, reflecting both a change in the electric generation mix and reduction in electricity consumption in the residential, commercial, and industrial end use sectors. Reductions are primarily achieved by reducing the role of conventional coal-fired generation, which in 2007 provided 50 percent of total U.S. generation, and increasing the use of no carbon or low carbon generation technologies that either exist today, in the case of renewable resources and nuclear power, or are under development, for example, carbon capture and sequestration from coal burning.

The relatively small changes in transportation are driven by the modest changes in fuel prices. For example, gasoline price is expected to increase just \$0.12 to \$0.67 above the \$3.62 per gallon projected in the updated EIA reference case in 2020 and between \$0.20 and \$1.28 above the \$3.82 per gallon price in 2030.

EIA's analysis of ACESA also includes a sensitivity case that incorporates President Obama's plan for tougher CAFE standards. The new CAFE standards require passenger cars to reach a fleet average of 39

mpg and light trucks to reach a fleet average of 30 mpg in model year 2016. In the sensitivity case, these new fuel economy standards are slightly exceeded for model year 2016, reaching 39.3 mpg for passenger cars, 30.4 mpg for light trucks, and a combined 34.8 mpg given the mix of cars and trucks projected for that year, compared to the 38.0, 27.9, and 32.9 miles per gallon projected in the *Annual Energy Outlook 2009* updated reference case, respectively. The difference in achieved fuel economy for light-duty vehicles narrows subsequently, with fuel economy reaching 36.4 mpg in 2020 in the CAFE sensitivity case compared to 35.6 mpg in the reference case and 38.7 mpg in 2030 versus 38.1 mpg. The revised standards do not start until 2012, as fuel economy standards for model year 2011 have already been promulgated by the National Highway Traffic Safety Administration. Standards are assumed to remain the same after model year 2016.

Light-duty vehicle GHG emissions in the CAFE sensitivity case decline from 1036.5 mmtCO_{2e} in 2016 to 982.5 mmtCO_{2e} in 2020 and 952.2 mmtCO_{2e} in 2030, compared to 1055.5 mmtCO_{2e}, 1011.8 mmtCO_{2e}, and 1021.3 mmtCO_{2e} in the updated reference case, respectively. As a percent, the proposed CAFE standards reduce LDV emissions by 2 percent in 2016, 3 percent in 2020, and 7 percent in 2030 compared to the reference case. As a total percent of transportation, the new CAFE standards reduce GHG emissions by 1.5 percent in 2016, 2.2 percent in 2020, and 5 percent in 2030.

Conclusions

The EIA has concluded that a cap-and-trade system that effectively places a price on GHG emissions will produce relatively little reduction in GHG emissions from the transportation sector. This implies that, for a given price on GHG emissions, the transportation sector is not the most cost effective sector to reduce emissions. Also, recently proposed CAFE standards offer reductions in transportation GHG emissions. However, even these reductions are moderate and would require much higher standards to more significantly reduce emissions relative to the updated reference case.

This implies that the transportation sector does not initially offer many opportunities for emission reduction that are as cost effective as those available in other sectors, such as changes in the electricity generation mix. The transportation sector is, however, the largest end-use GHG emitter, and the second largest demand-based source of emissions if electric power is counted separately. Thus, efforts to significantly reduce U.S. GHG emissions will eventually need to address transportation sector emissions.

While a price on carbon does not yield significant reductions in transportation emissions, at least four major proposals have been put forth and advocated as ways to reduce GHG emissions in transportation:

- Increasing vehicle fuel economy standards
- Using low carbon fuel alternatives
- Reducing vehicle miles traveled by mode switching from LDVs into rail and from heavy truck freight into rail and marine freight
- Changing land use patterns

There are many challenges and uncertainties facing the implementation of any of these proposals, but they merit careful analysis and consideration, if energy security considerations, equity concerns, or the need to prepare for deeper GHG emissions reductions in the future are deemed to require greater near-term reductions in fossil fuel use in the transportation sector than the ACESA market-based cap-and-trade system is expected to provide.

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Chapter 4:

Carbon Dioxide Emissions from Road Transport in Latin America

by Lee Schipper, Elizabeth Deakin, and Carolyn McAndrews

Today, Latin America is a small contributor to the world's emissions of greenhouse gases (GHG). However, the region's car ownership, use and emissions are higher than would be predicted on the basis of population or gross domestic product (GDP), and car traffic clogs the streets and pollutes the air of many Latin American cities. Furthermore, Latin American carbon emissions from transport, mostly from cars, are predicted to grow threefold by 2030 as both automobile ownership and vehicle use expand. The total emissions will still be small compared to those of developed countries, but they will not be trivial.

As a heavily motorized and urbanized part of the developing world, Latin American cities suffer from notorious congestion and air pollution. Yet, Latin America has also become one of the birthplaces of Bus Rapid Transit (BRT), first in Curitiba Brazil, but now in an increasing number of large cities. Reducing carbon dioxide (CO₂) emissions from urban transport in Latin America as population and incomes in urban areas grow is a challenging goal, but it is one that many cities are already pursuing. Substantial additional gains seem achievable. This chapter reviews the challenges these cities face.

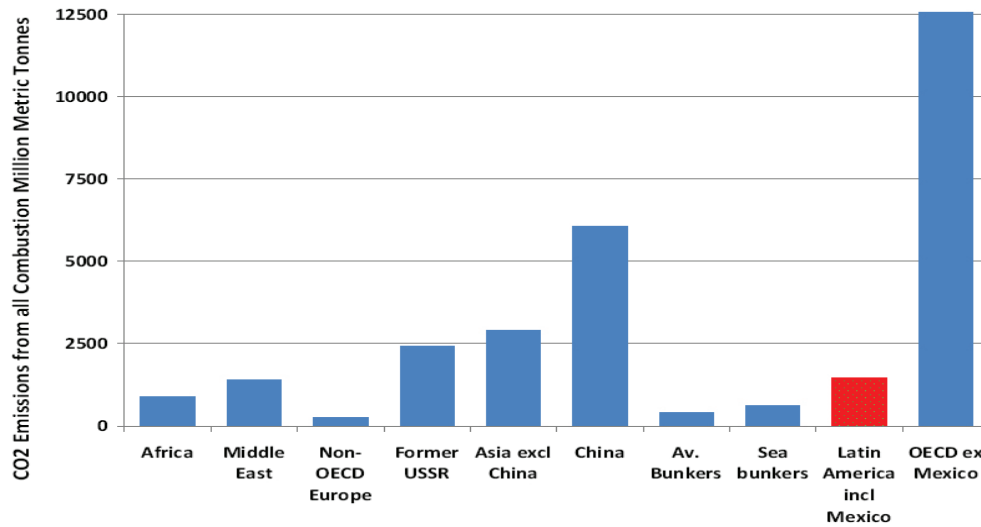
Global GHG and CO₂ Trends—Where Is Latin America?

There is broad consensus that GHGs are warming the planet (IPCC 2007). Many human activities produce GHG emissions, but roughly two-thirds of the total anthropogenic emissions comes from fossil fuel combustion for transportation, buildings, and industry. Anthropogenic GHGs, including methane, CO₂ and small quantities of other potent gases, also come from agriculture, mining, natural gas production, landfills, and industrial processes. Land use changes that remove plants that absorb CO₂ contribute to the problem.

Figure 4-1 shows the origin of CO₂ emissions from all fossil fuel combustion by region of the world. About half of the total emissions comes from Organization of Economic Cooperation and Development (OECD) countries, excluding Mexico, and about 20 percent are emitted in China, but only seven percent are from Latin America. On a per capita basis, the world average was 4.3 metric tonnes of CO₂ per capita, while that from Latin America was only 2.5 tonnes per capita.

L. Schipper is Project Scientist at the Center for Global Metropolitan Studies at the University of California, Berkeley. E. Deakin is Professor of City and Regional Planning and Design and C. McAndrews, is a PhD candidate at the University of California, Berkeley

Figure 4-1: CO₂ emissions from all fossil fuel combustion by country or region in 2006 (million metric tonnes)

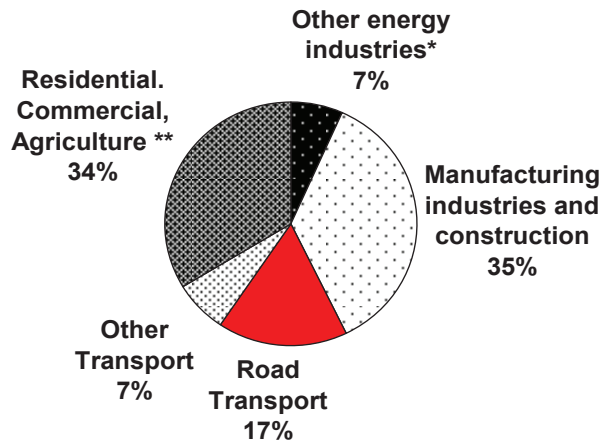


Source: International Energy Agency (IEA 2008)

Figure 4-2 shows global CO₂ emissions among major energy consuming sectors in 2006. Figure 4-3 shows the pattern just for Latin America, including Mexico, in the same year. Interestingly, road transport represents a full one-third of the total CO₂ emissions in Latin America, higher than the world average share.

In explaining differences in CO₂ emissions among regions or countries, the most obvious factors are population and level of development, as measured by per capita income. A host of additional factors share in explaining differences, including geography and local climate, degree of urbanization, land uses, fuel mix, and the efficiency of energy use (IEA 1997). Differences in policies, available technologies, and fuel prices shape the latter factors.

Figure 4-2: CO₂ emissions for the entire world by sector, including electricity losses allocated to end-us sectors, 2006

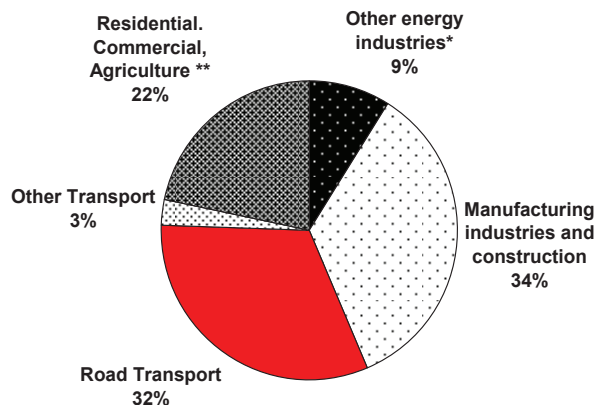


Source: IEA

In comparison with the world as a whole, the CO₂ emissions in Latin America are more heavily concentrated in transportation, which produces 35 percent of its total emissions, compared to a 24 percent transport share throughout the world. Furthermore, transport emissions are concentrated in road transport, which accounts for over 90 percent of the region's transport emissions.

Figure 4-3: CO₂ emissions for Latin America including electricity losses allocated to end-use sectors, 2006.

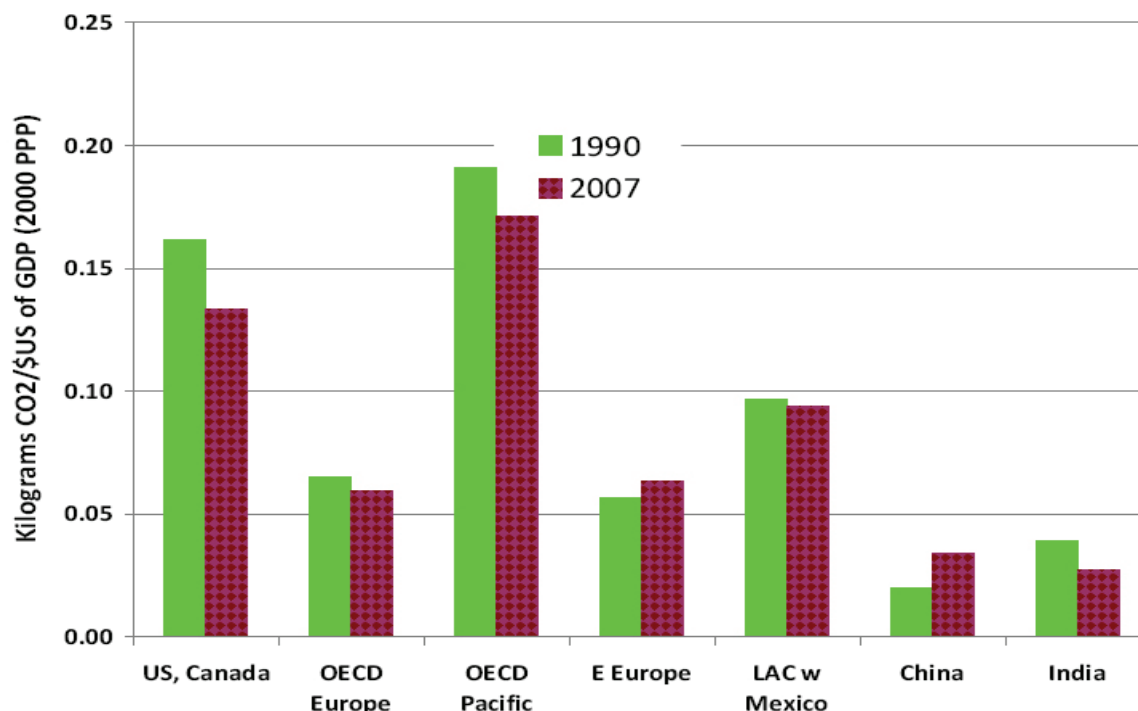
Total 2.5 metric tonnes CO₂/capita



Source: IEA

For the world as a whole, the transport emissions/GDP ratio has declined by about 20 percent since 1990 (IEA 2008). As shown in Figure 4-4, however, regional differences are large, with some regions showing increases in the ratio, while others have achieved substantial decreases. For Latin America, the ratio of road transport CO₂ emissions to GDP has declined slightly, by less than 0.5 percent per year. In other words, transport emissions in Latin America have increased at almost the same rate as GDP has grown.

Figure 4-4: Ratio of road transport CO₂ emissions to GDP for regions, 1990 and 2007



Source: IEA. Note the data for India are 1996 and 2007 as there are no road-transport diesel data before 1996.

Data from the International Energy Agency (IEA) indicate that direct emission increases from tailpipes have been driven in large part by the rising importance of fossil fuels for transport, especially in populous Brazil,

where use of ethanol from sugar cane did not keep pace with the demand for automobile fuels after 1990. Tailpipe emissions from ethanol produced from sugar cane are significantly lower than those of gasoline. Emissions from other sectors in Latin America grew less rapidly than those from road transport. Thus the importance of road transport in the Latin America emissions story has increased over time.

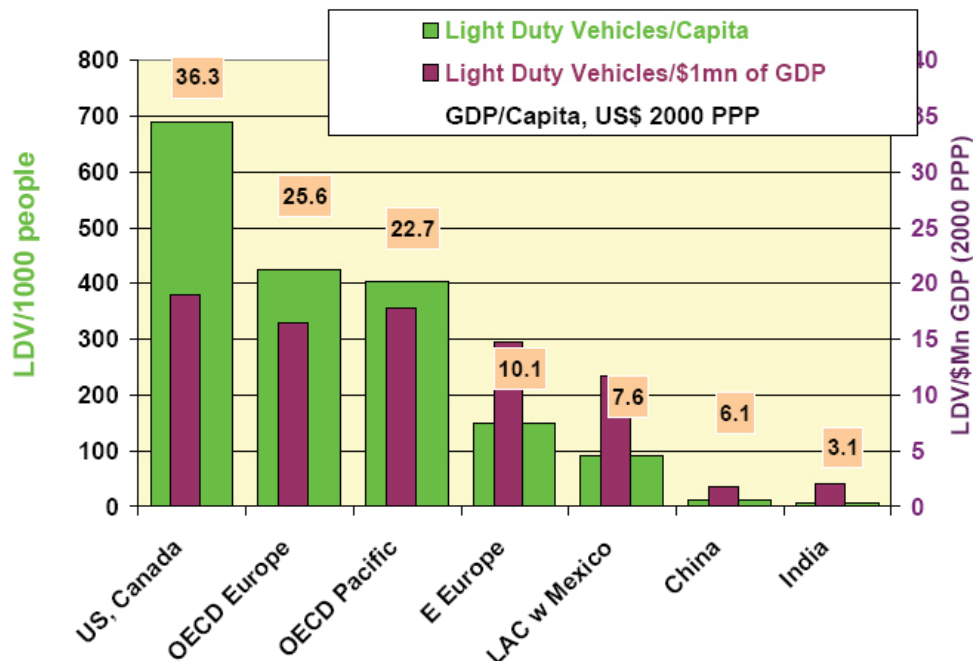
Road Transport in Latin America

An understanding of CO₂ emissions from road transport in the region requires a clear picture of the vehicle fleet and vehicle use, usually measured in vehicle-kilometers (km) of driving. Data on vehicle ownership and yearly usage have been developed by the International Energy Agency and the World Business Council for Sustainable Development (WBCSD 2004) and are used here, with some modifications.

Vehicle Ownership

Figure 4-5 shows light duty vehicle (LDV) ownership in different regions of the world, relative to both population and GDP, in 2005. Among the developing regions shown, Latin America had a per capita ownership of light duty vehicles of 86 vehicles per 1,000 people, mostly private cars, SUVs, and light trucks.

Figure 4-5: Light duty vehicle ownership vs. income and population, 2005, selected regions



Source: IEA MoMo Database (IEA 2009)

Notes: 10 to 20 percent of these light duty vehicles are commercial vans or pickups. GDP per capita in USD \$1,000 (2000 PPP) shown above each region. 1990 data are from 1996, as previous years contain diesel used in stationary sectors.

The high level of motorization in Eastern Europe is explained in large part by a rapid increase in cars bought used after 1990 and the stronger presence of Western European automobile manufacturing in Eastern Europe after that time. Even though China and India have much larger populations, the per capita auto ownership is very low and even the absolute numbers of LDVs in those two giants were still well below the number in Latin America in 2005.

Vehicle Use and Emissions in Latin America

Data estimated by the WBCSD's Sustainable Mobility Project (WBCSD 2004) and more recently refined by the International Energy Agency (Fulton et al. 2009) provide information on vehicle types, their energy intensities, and the average km driven each year for Latin American countries. CO₂ emissions by vehicle type can be calculated from these data. The total fuel use for each particular fuel and vehicle type is calculated using the estimated numbers of vehicles, distance/vehicle, and fuel/distance, with national road fuel use as tabulated by the IEA used as the control total. Table 4-1 presents the results.

Table 4-1: Road transport emissions in Latin America in 2000 by vehicle type: The role of light duty vehicles

Vehicle Type	Vehicles (100,000)	Km / year	Energy, EJ	Emissions Mtonnes CO ₂	Share of total CO ₂ Emissions
LDV Pass.	40,127	13,000	2.11	155.4	41.70%
Motorcycles	6,948	7,500	0.05	3	0.80%
Minibuses	930	40,000	0.21	14.1	3.80%
Buses	511	40,000	0.2	14.5	3.90%
LDV freight	4,459	13,000	0.23	16.2	4.40%
Med Trucks	5,385	22,000	1.15	77.6	20.80%
Heavy Trucks	2,314	50,000	1.38	92.2	24.70%
Total	-	-	5.33	372.9	-

Note: 1 EJ (exajoule=10¹⁸ joules) = 24 MTOE (million tonnes of oil). Data adjusted to include Mexico. Emissions for rail were included in the original Sustainable Mobility Project spreadsheets but are omitted here.

Source: WBCSD Sustainable Mobility Project and IEA.

For the region as a whole, about half of road transport emissions are for passenger traffic, the other half for freight travel. The dominant vehicles are LDVs, most of which are passenger cars. The urban share of traffic (VKT), emissions and the number of passenger kilometers traveled were estimated. The results are shown in Table 4-2.

Table 4-2 shows that about 60 percent of all road transport emissions in Latin America appear to be associated with urban areas, with LDVs responsible for well over half of the urban emissions. Further

Table 4-2: Estimated urban share of traffic and emissions by vehicle type, Latin America 2000

Vehicle Type	Urban Share of VKT	Urban VKT (billion)	Vehicle Occupancy (people)	Passenger km (billion)	Emissions MTonnes CO ₂	Share of Urban CO ₂
LDV and Motorcycles	80%	453	2	907	127	61.50%
Mini Buses	80%	30	20	595	11	5.50%
Buses	50%	10	50	511	7	3.50%
Light Trucks	80%	46	-	-	13	6.30%
Medium Trucks	50%	59	-	-	39	18.80%
Heavy Trucks	10%	12	-	-	9	4.50%
Total	-	510	-	2013	208	100%

assuming that LDVs in urban regions have an average occupancy of two people, motorcycles one person, minibuses 20 people, and large buses 50 people, it appears that two trillion passenger km of driving occurred in these motorized modes in Latin American urban areas in 2000.

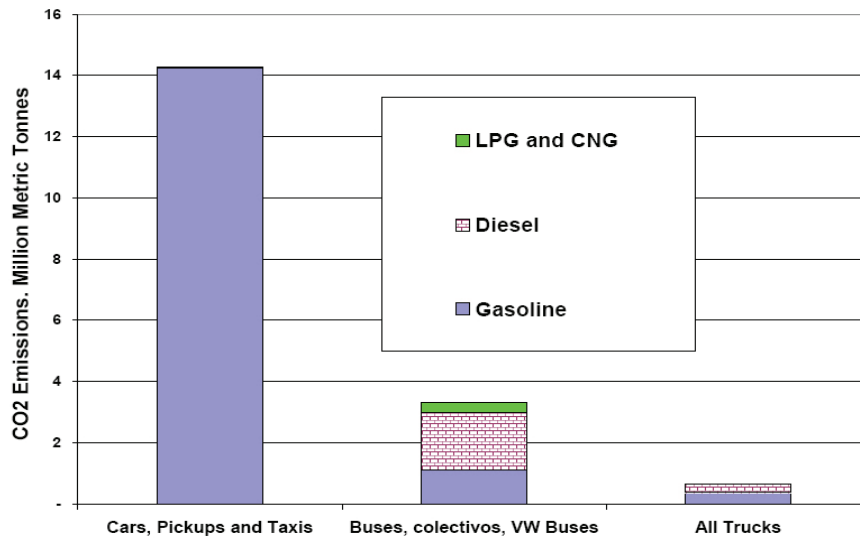
Table 4-3: CO₂ emissions, vehicles and traffic, Mexico City, 2006

Vehicle Type	Mtonnes CO ₂	Vehicles (100,000)	Billion VKT
Cars	10.49	3,395.80	46.31
Taxis	2.6	155.1	10.38
VW Bus Colectivos	0.7	39.7	2.64
Other Colectivos	0.74	36.1	2.54
Pick Up	0.83	133.4	3.48
Other Vehicles < 3 t	0.63	81.6	1.8
Truck Tractors	1.63	60.9	1.38
Autobuses	1.87	43.1	1.79
Other Vehicles < 3 t	0.54	100.8	2.2
Motorcycles	0.37	180.7	4.47
Totals	20.4	4,227.30	76.98

Source: Mexico City Emissions Inventory (SMA, 2006)

Data from major metropolitan regions of Latin America are consistent with the estimates of urban traffic and emissions generated from national and regional data for specific cases. Table 4-3 and Figure 4-6 show the results for Mexico City in 2006. The data come from the region's emissions inventory, which is updated every other year.

Figure 4-6: CO₂ emissions from the main classes of transport emitters in the Mexico City Metropolitan Area, 2006



Source: Mexico City SMA emissions inventory estimated by vehicle, distance, and fuel intensity.

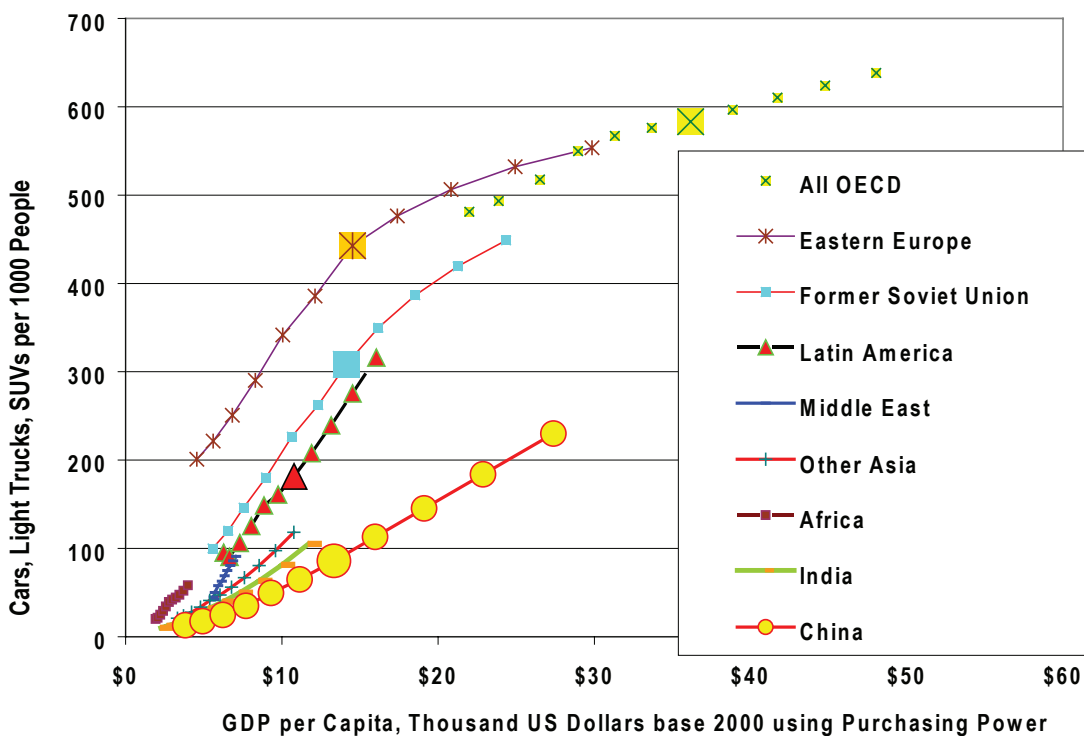
The results show that individual cars, pickup trucks, taxicabs, and motorcycles account for 68 percent of the CO₂ emissions from all transportation sources in Mexico City (SMA 2006). Traffic is also dominated by small individual vehicles, which account for almost 83 percent of the VKT. Interestingly, Mexico City car ownership is lower than that in many other large Mexican cities, so the share of emissions in LDVs may be even higher in other Mexican urban areas, where there are more cars per capita. This also implies that the light duty personal vehicle fleet in other Mexican cities is an even greater contributor to CO₂ emissions than it is in Mexico City.

Patterns for Santiago de Chile (Escobar 2007), Bogotá (Giralto 2005), and Sao Paulo (Vasconcellos personal communication 2008; Melor de Alvares personal communication 2008) are similar. LDVs account for less than 25 percent of travel, but more than 60 percent of VKT and CO₂ emissions in these urban areas.

Present trends in the Latin America region point to increasing automobile ownership and use. Latin America will probably approach Europe's level of motorization in the 1960s by 2030, but with far more urban regions of over five million people than Europe has even now. Between 2004 and 2006, Latin America had four urban agglomerations with 10 million people or more—Mexico City, Sao Paulo, Buenos Aires and Rio de Janeiro. Europe had just one, Paris. Lima, Bogotá, Santiago and Bel Horizonte in Latin America each had between five and 10 million people, while Europe had just London and Madrid. Latin America had eight more cities among the world's 100 largest urban areas (UN 2007). Traffic in these largest cities tends to be the most congested. Thus the prospects for future traffic problems in the face of growing motorization in all these large Latin American cities are daunting.

Figure 4-7 shows forecasts of LDV ownership in 2030 versus per capita GDP for Latin America, China, OECD nations, the Former Soviet Union, and Eastern Europe. According to this projection, per capita income in Latin America will almost double by 2030, with per capita LDV ownership, predominately cars,

Figure 4-7: Sustainable Mobility Project projections of future LDV ownership by region



Source: WBCSD 2004

rising to 200 per 1,000 when Mexico is included. This means that, relative to GDP, growth in CO₂ emissions could continue to rise faster in Latin America than in other developing countries, where fuel efficient motor scooters and e-bikes are a major portion of motorization.

The Sustainable Mobility Project foresees a more than tripling of total LDV VKT in Latin America by 2030 and a sixfold increase by 2050. The VKT growth is pushed up by growth in population, and LDV ownership increases are supported by rising affluence. The estimates are consistent with historical evidence from Europe and North America (Schipper and Marie-Lilliu 1999; U.S. BTS 2009). However, the Sustainable Mobility Project did not foresee any major changes to transportation policy that could slow the rise in LDV use. Thus, the projections are not inevitable, but illustrative of where present trends lead.

Table 4-4 shows the WBCSD data for 2000 and projections for 2030 for LDV ownership per 1,000 population, VKT per vehicle and per capita VKT. VKT per vehicle is treated as constant, which is approximately the OECD experience from the 1970s and 1980s, except for periods of very high oil prices.

Table 4-4: Global projections of LDV and use

Region	LDVs/1000		VKT/LDV		VKT/Capita 2030	
	2000	2030	2000	2030	2000	2030
OECD North America	779.7	825	17,600	17,600	13,723	14,080
OECD Europe	390.2	511	12,500	12,500	4,877	6,388
OECD Pacific	438	546.1	10,000	10,000	4,380	5,461
FSU	100	308.4	13,000	13,000	1,300	4,009
Eastern Europe	201	442.6	11,000	11,000	2,211	4,869
China	13	86	10,000	10,000	130	860
Other Asia	21	56.1	10,000	10,000	210	561
India	10	39.8	8,000	8,000	80	318
Middle East	42	68.9	13,000	13,000	546	896
Latin America	95.2	181.5	12,000	12,000	1,142	2,178
Africa	20	41.9	10,000	10,000	200	419

Source: WBCSD 2004

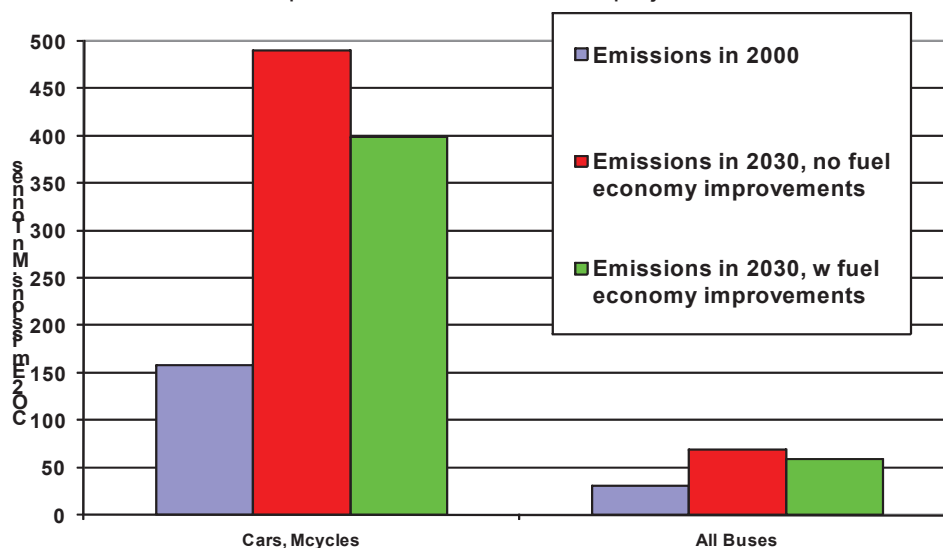
On-road fuel economy in Latin America is projected to improve from an estimated 11.8 liters per 100 km in 2000 to about 9.4 liters per 100 km by 2030 and to 8.3 liters per 100 km over 50 years. The improvement is a drop of about 20 percent in terms of fuel use per km. For comparison, the European Union hopes that by 2030 its fleet will use less than 6.5 liters per 100 km on the road, below the present value of 7.8 liters per 100 km, also a 20 percent improvement (Schipper 2009).

Since cars in Latin America are smaller and less powerful than those in the European Union, the high fuel intensity for LDVs in Latin America may seem odd. The explanation appears to be poor traffic conditions, as suggested by the relatively high in-use fuel intensities of small cars in the Mexico City, Sao Paulo, Bogotá, and Santiago emissions inventories.

Models used to simulate fuel use in traffic in Latin America, like MODEC (Goicoechea 2007; Osses et al. 2000) or Mobile 6 Mexico and COPERT (COPERT 2009; Rogers 2006) show rising fuel use per km with greater congestion. If congestion continues to worsen in Latin American cities, this gap between vehicle potential fuel economy and real-world performance will increase, erasing some of the benefits of improved vehicles. Conversely, measures that reduce congestion lead to improvements in in-use fuel economy (Skabardonis 2004).

When the Sustainable Mobility Project projections for vehicles, VKT, and fuel economy for each mode are combined without further mitigation, emissions from passenger vehicles in Latin America are forecast to more than double by 2030, despite improvements in vehicle fuel economy. This is shown in Figure 4-8. By 2050, emissions are expected to increase to four times their current value. Emissions from trucks grow less rapidly than those for cars, while emissions from buses are not seen as growing much at all. Indeed, while opportunities to reduce emissions per vehicle-km or passenger-km in buses should not be ignored, those reductions would be minor compared to the growth in emissions from LDVs.

Figure 4-8: Sustainable Mobility Project estimates of CO₂ emissions from Latin American road transport, 2000 actual and 2030 projected.



Source: Sustainable Mobility Project, 2004

A business as usual forecast prepared for the Sustainable Mobility Project shows that emissions growth in Latin America is expected to be substantial, but will still be outpaced by that of other regions or countries. Some of the other countries start with lower individual motorization and are catching up over the forecast period. Others have higher overall incomes or rates of economic growth. Although these projections suggest that Latin America will remain a relatively modest contributor to total world CO₂ emissions, it would still be a relatively high emitter from road transport compared to population and GDP.

Projected GHG emissions could change substantially if the basic factors driving them, primarily incomes and vehicle fuel economy, change unexpectedly. For example, a number of analysts believe that the vehicle fuel economies could be much higher. To illustrate how this might change emissions, Table 4-5 shows the effect of a global achievement of 6.4 liters per 100 km by 2030. Such fuel economy, consistent with current projections for the EU in 2030, would mean that Canada and the United States would see a decline in CO₂ production from LDVs, rather than the increase estimated by the WBCSD. Latin America would still see an increase in emissions, but a smaller one.

The Transport CO₂ Challenge for Latin America

Present levels of CO₂ emissions from road transport in Latin America are high by developing world standards. Not coincidentally, per capita ownership and use of LDVs in Latin America are also high. In urban regions, around 70 percent of CO₂ emissions from road transport arise from the use of LDVs, which are by far the most common vehicle on the streets and in general the greatest contributors to both congestion and pollution. The high CO₂ emissions from road transport in Latin America can be seen as a symptom of transport problems caused by high car ownership and use. Addressing these transport problems likely would reduce car use and fuel consumption, which, in turn, would reduce CO₂ emissions.

Table 4-5: Effects of a global fuel standard of 6.4 liters per 100 km achieved in actual traffic

Region	I	II	III	IV	V
	Base Case: 2030 emissions w/ WBCSD Fuel Economies	2030 Emissions w/ Global 6.4 l/100 km Fuel Economy	6.4 l/100 km Emissions as % of Base Case Emissions	Emissions Change 2000- 2030 w. Base Case Fuel Economies	Emissions Change 2000- 2030 Using 6.4 l/100 km Fuel Economy
OECD North America	1623	952	58.70%	132.40%	77.60%
OECD Europe	535	532	99.50%	109.60%	109.10%
OECD Pacific	219	171	77.70%	99.70%	77.50%
Former Soviet Union	229	153	66.70%	272.40%	181.80%
Eastern Europe	82	63	76.50%	166.30%	127.20%
China	303	198	65.20%	664.10%	433.00%
Other Asia	174	116	66.60%	322.60%	214.90%
India	103	70	68.00%	459.10%	312.30%
Middle East	67	45	67.50%	253.60%	171.20%
Latin America	29	198	67.20%	266.80%	179.20%
Africa	168	97	57.90%	313.30%	181.30%

Source: Columns I and IV WBCSD 2004. Columns, II, III and VI, this study.

The data and trends-extended forecasts for vehicle ownership and use, fuel economy improvements, and predicted emissions present serious challenges for transport policymakers in Latin America and elsewhere. Without additional interventions, emissions will grow substantially during a period in which combating global warming would necessitate their substantial reduction. The large forecasts of increased VKT in Latin America also would increase traffic in urban regions, which implies worsening congestion and other transport problems unless increases in road capacity keep pace with or exceed traffic growth.

Strategies that improve the fuel economy of LDVs and bus fleets are likely to reduce emissions per kilometer by 20 percent by 2030, according to the SMP projections used above. This still leaves emissions from road transport in Latin America more than doubling over the same period. Even a major increase in fuel efficiency over and above the projected levels would result in significantly increased emissions in Latin America. This means that there is a need to consider additional interventions.

If reductions in transport emissions are to be achieved, many analysts now conclude that the growth in individual vehicle use must be moderated and transit vehicle use and non-motorized travel must increase in relative importance. Further reductions in CO₂ emissions can be accomplished through changes in urban development and transport paths, not just in Latin America but around the world. Such changes could reduce growth in vehicle ownership or vehicle use, or both.

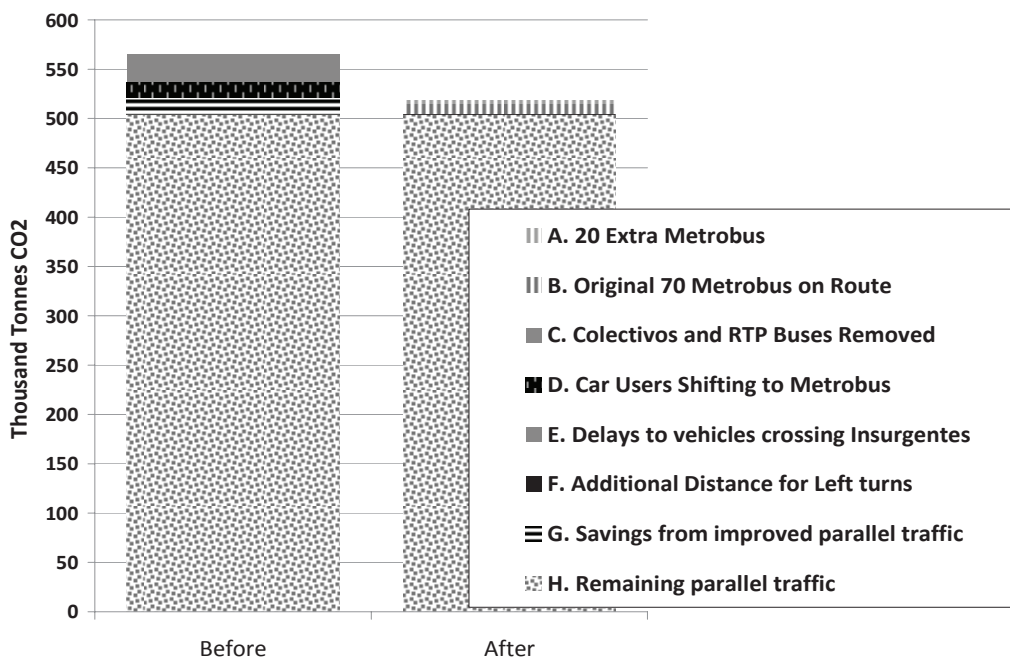
Additional CO₂ reduction can be attained through well planned urban transport investments. Many Latin American cities are already steering transport growth in more carbon efficient directions by investing in high quality public transportation and new facilities for bikes and pedestrians. These travel choices improve accessibility for a large portion of the population while managing traffic, cutting pollution and moderating CO₂ emissions.

Latin American leadership in implementing new travel options is creating models from which others can learn. Cities such as Curitiba and Bogotá are already widely emulated for their creative investments in urban planning and BRT. These activities provide good transport, while reducing carbon emissions, and their success puts pressure for change on countries slower to reduce carbon emissions.

The progress of bus rapid transit is one of many important transportation measures spreading in cities around the world, a measure that most consider originating in Latin America. A recent update for Mexico by the Fonadin, the national fund for infrastructure, projects more than 2.2 million new trips per day on BRT and over 1.2 million trips per day on rail lines in Mexico's major cities (Mier y Tieran 2009). Such changes must of necessity take road space and other resources from cars. The experience from Metrobús suggests the good outcome there gives political momentum to this refocusing of transport planning and infrastructure development.

The challenge for Latin America is that CO₂ per se is not a driving factor compared with other externalities or transport variables. Still, it is clear there are substantial CO₂ savings from BRT. Figure 4-9 illustrates this for a specific bus rapid transit (BRT) project in Mexico City, Metrobús (Schipper et al. 2009). It shows the components of reductions in CO₂ emissions from introduction of a BRT corridor along one of Mexico City's busiest routes (Rogers and Schipper 2005; Rogers 2006). Included are the CO₂ emissions of all vehicles in the corridor before the BRT lanes were created and after. Rogers' original estimates (2006), subsequently updated by him in 2009, show that this project reduced emissions in the corridor from all traffic by 10 percent. Of those reductions, about one-third came from the direct substitution of 90 large articulated buses for over 300 small buses, one-third came from bus riders who used to take cars for the same journeys, and one-third came from smoother resulting traffic in the corridor. No special steps were taken to use low-carbon fuels, hybrid electric buses or other technological options aimed specifically at fuel saving or CO₂. It is encouraging that these reductions occurred without any special effort to save CO₂.

Figure 4-9: Emissions in Insurgentes corridor before and after Metrobús



Sources: Rogers, 2006 and Rogers, 2009

Legend explanations: A and B are the emission from Metrobús after; C is the emissions of the transit vehicles removed; D is the emissions imputed before drivers switched to Metrobús; E and F are the extra emissions from delays and circuitry imposed by Metrobús; G, shown as emissions before reductions due to smoother traffic on Insurgentes after Metrobús was put in place. H gives the remaining emissions from all parallel traffic on Insurgentes.

How important are the savings of CO₂ emissions in comparison with other changes brought about by this project? The question can best be answered by monetizing the results using information about the damages from air pollution, the value of CO₂, the value of time, and other variables, even if the valuations

of externalities and transport benefits is uncertain (Maddison et al. 1996). If the results of the Metrobús BRT program were monetized, however, the role of CO₂ savings is seen to be small compared with other benefits of this program.

Table 4-6: Annual benefits of Metrobús Project

<i>Nature of annual benefit or savings</i>	<i>Low CO₂ value (USD \$5/tonne)</i>	<i>High CO₂ value (USD \$85/tonne)</i>
Time savings of bus riders	\$1.32	\$1.32
VKT external costs -- reduction in traffic	\$2.19	\$2.19
Air Pollution Reduction /Health Benefits	\$3.00	\$3.00
Fuel savings from bus switch	\$3.68	\$3.68
Fuel saving, mode switch car to bus	\$3.66	\$3.66
Fuel savings to parallel traffic	\$1.56	\$1.56
CO ₂ reduction from bus switch	\$0.09	\$1.75
CO ₂ reduction, mode shift car to bus	\$0.13	\$2.58
CO ₂ reduction in parallel traffic	\$0.05	\$0.87
CO ₂ Reduction, total value	\$0.27	\$5.20
Reduction in accidents/death (not estimated)		
Total first year annual value US\$ Million (2005)	\$15.69	\$20.62

Source: CO₂ and fuel calculations made in this study, based on Rogers 2006; Other savings taken from INE 2006.

Table 4-6 shows the results. INE (2006) used a value of time of approximately \$0.60 (U.S. dollars) per hour multiplied by the number of hours saved. They estimated the value of reduced road wear and the value of health benefits of lower air pollution. Excluded were values derived from fewer accidents and lower loss of life, important variables unfortunately not addressed in the INE study. Added to the INE valuations, we estimated fuel cost savings by buses, parallel traffic and consumers who left their cars at home. The CO₂ savings from Figure 4-9 were also factored in at a value of \$5.00 per metric tonne of CO₂ and at \$85.00 per tonne. The former value is what Mexico City received for savings from a carbon fund. The latter is the much higher estimate developed by the Stern Report (Stern 2006). It is notable that even when CO₂ is valued at the high end, it only comprises about 20 percent of the total benefits shown. At the lower end, its value almost vanishes. In either case the estimate of other benefits was low because INE did not count reductions in traffic accidents and fatalities. With CO₂ valued so low compared with other transport benefits, CO₂ saved from improved traffic and transport can be seen as an important co-benefit of good transport strategies. Interestingly, Mexico City could have chosen hybrid buses that were tested before the Metrobús project was finished (Schipper et al. 2007). This choice would have increased the savings of CO₂ by only around 3,000 tonnes/year, yet the hybrid drivetrains would have cost at least \$100,000/bus more than the buses actually chosen (Schipper et al. 2009).

Conclusions

Additional investments in transportation facilities and services that increase access and quality of life, while also cutting carbon, would benefit cities in Latin America and around the world. Transit, pedestrian and bicycle facilities, improved traffic management, and coordinated transport and land use are important low-carbon access and mobility strategies. Most cities could also gain by strategically coordinating transport investments, creating networks of transit operating on traffic-managed streets and arterials conveniently

reached by bikeways and pedestrian ways and serving mixed-use neighborhood and commercial district centers. In addition, most cities could benefit from pricing policies for fuels, parking, and other transport services that better reflects marginal social and economic costs. Such pricing is not only efficient, but can generate revenue that can be used for further transport improvements.

Thus there are many options open to Latin American authorities to restrain CO₂ emissions from urban transport. Improvements to vehicle technology that keep fuel use per kilometer low are important, but longer-term changes in transport policy and infrastructure that also improve the quality of mobile life, however complex to implement, may have an even greater impact on CO₂ by restraining its growth in the first place.

The challenge for authorities in Latin America and other regions is to make the transport changes for their own value and reap the co-benefits of lower CO₂ emissions. Currently, the rewards of a third party paying for the CO₂ savings would be small compared to the rewards from saved fuel and time. Can authorities make these changes, if the rewards from carbon reduction are so small?

The answer may be yes if the focus is kept on improvements in transport and quality of life. The CO₂ savings from Metrobús helped boost the project's popularity in the planning phases, particularly when the city's full endorsement was politically important. The fact that the initial success of this line led to both its extension (the implementation of a new line, the Eje 4) and planning of at least a half dozen more lines gives weight to the argument that changes in transport policy that have obvious transport benefits can set off chain reactions. A recent World Bank Urban Transport Strategy makes the case for strong measures to make individual vehicle users face the externalities they cause other travelers, who are the majority in Latin American and other developing cities (World Bank 2008). Following their advice may provide larger carbon restraint as a co-benefit than any other group of measures.

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Chapter 5:

Role of Low Carbon Fuel Standard in Reducing U.S. Transportation Emissions

by Sonia Yeh and Daniel Sperling

The transportation sector in the United States (U.S.) relies almost exclusively on petroleum fuels, which accounted for over 96 percent of transport greenhouse gas (GHG) emissions in 2009. Policies aimed to reduce transportation emissions have made some progress. These policies include the new Corporate Average Fuel Economy (CAFE) standards and the Renewable Fuel Standards (RFS) established by the Energy Independence and Security Act (EISA). Despite these important policies, future U.S. transportation emissions are projected to continue to rise, although at a slower rate, in the next 20 years (EIA 2009).

To gain large reductions in transport-related GHG emissions, more actions are needed. These actions include improving vehicle technology efficiency, reducing vehicle miles traveled and lowering the GHG intensity of transportation fuels. Many policies have already been adopted to introduce alternative fuels into the transportation sector, with the goals of reducing energy dependence on foreign oil and improving local and regional air quality. These policies have largely failed (McNutt and Rodgers 2004, Sperling and Gordon 2009). The Low Carbon Fuel Standard (LCFS) is a promising approach to reduce GHG emissions by decarbonizing transportation fuels. An LCFS has the following features:

- Is technology neutral
- Uses a lifecycle GHG intensity standard
- Targets a range of transport fuels
- Incorporates market mechanisms by allowing credit trading

This chapter reviews the LCFS standard adopted in California and the European Union (EU) and compares the LCFS policy instrument to other measures. It explores the possibility of a national LCFS in the United States, including key shortcomings and challenges.

The Need for Effective and Performance-Based Policy

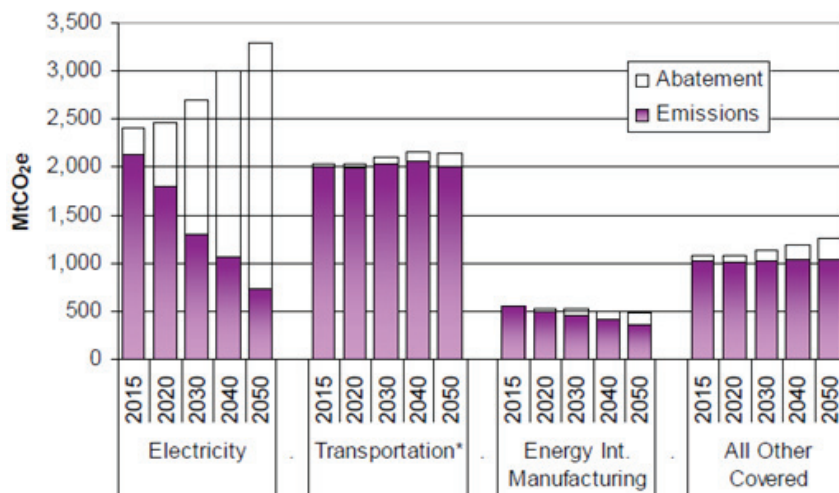
Several new policy approaches have been adopted or considered in the past few years to improve energy security and reduce GHG emissions from transportation fuels. These include fuel-specific policies that

S. Yeh, Research Scientist, and D. Sperling, Professor and Director,
Institute of Transportation Studies, University of California, Davis

have already been adopted, such as volumetric biofuel mandates (RFS) and fuel subsidies and tax credits for corn ethanol and biodiesels. Market-based policies that have not yet been adopted include carbon taxes, carbon cap and trade, and fuel “feebates.” The RFS, biofuel fuel subsidies, and tax credits have increased domestic U.S. corn ethanol production and biodiesel exports. The actual greenhouse benefits of these policies, however, may be small based on several recent studies (Gibbs et al. 2008; Hertel et al. 2008; Searchinger et al. 2008; Hertel et al. 2010).

Carbon cap-and-trade programs and carbon taxes, at politically acceptable levels, will have little effect on transport emissions. Analyses of proposed cap-and-trade programs suggest that only a very small fraction (less than five percent) of emission reduction will come from the transport sector (EIA 2008; U.S. EPA 2009a). Figure 5-1, for example, shows the limited projected emission reductions in the transportation sector under the cap-and-trade program proposed in 2009 in the federal Waxman-Markey Bill (H.R. 2454). A study by the U.S. Environmental Protection Agency (EPA) estimated that the Waxman-Markey Bill would raise gasoline prices by \$0.13 in 2015, \$0.25 in 2030 and \$0.69 in 2050 (U.S. EPA 2009a). This modest price signal is not likely to be strong enough to induce significant change in consumer behavior in reducing vehicles miles traveled or purchasing low-GHG vehicles or fuels.

Figure 5-1: Projected emission reductions by sector under the proposed cap and trade program: H.R. 2454



Source: U.S. EPA 2009a

More direct policies are likely to be far more effective in reducing transportation fuel use and GHG emissions. The rationales for more direct policy instruments, such as the low carbon fuel standard, are as follows. First, there are significant market barriers that are unique to the transportation sector, including the chicken-and-egg challenge of simultaneously introducing alternative fuels and alternative-fueled vehicles (McNutt and Rodgers 2004), consumers’ inelastic demand for gasoline (Hughes et al. 2008), and the failure of transport fuel prices to incorporate large externalities such as air pollution and energy security in fuel use and vehicle purchase decisions (Delucchi 2008; Lave and Griffin 2008). Second, the cost of doing nothing now and fixing it later will result in very high future costs since the liquid fuel mix is becoming increasingly more GHG intensive as a result of greater use of heavier crude oils and oil sands—with the prospect of even more carbon-intensive oil shale and coal-to-liquid fuels being used in the future (EIA 2009). Additional measures beyond cap-and-trade will be necessary to achieve long term reductions in oil use and GHG emissions.

What is the Low Carbon Fuel Standard?

The LCFS is a performance standard that aims to reduce the GHG intensities of transportation fuels. The metric around which the LCFS is designed is total GHGs per unit of fuel energy. The GHGs are measured

as carbon-equivalents based on their global warming potential, abbreviated as “carbon” throughout this chapter. The goal is to account for all GHGs emitted in the lifecycle of the fuel, from extraction, cultivation, land use conversion, processing, distribution, and fuel use. Although upstream emissions account for only about 20 percent of total GHG emissions from petroleum, they represent almost the total lifecycle emissions for biofuels, electricity and hydrogen. Upstream emissions from extraction, production and refining also comprise a large percentage of total emissions for the very heavy oils and oil sands that oil companies are increasingly embracing to supplement limited supplies of conventional crude oil. The LCFS is the first major public initiative to codify lifecycle concepts into law, an innovation that will become more widespread as climate policies are pursued more aggressively.

Several countries and states have adopted or are considering adoption of an LCFS. The California LCFS was adopted in April 2009, and took effect in January 2010 (CARB 2009). California’s LCFS applies to onroad transport fuels, but credits can be generated from low-carbon fuels used in off-road vehicles. It excludes the air and maritime transportation activities, where California has limited authority. The standard is imposed on all transport fuel providers, including refiners, blenders, producers and importers. It requires a 10 percent reduction in the GHG intensity in transport fuels by 2020.

To implement the LCFS, each fuel supplier in California must meet a GHG-intensity standard that becomes increasingly stringent over time, ramping up to the 10 percent reduction in 2020. To maximize flexibility and innovation throughout low-carbon technologies, the LCFS allows for trading and banking of emission credits. An oil refiner could, for instance, buy credits, or the fuels themselves from biofuel producers. Alternatively, it could buy credits from an electric utility that sells power for use in electric vehicles. Those companies that are most innovative and best able to produce low-cost, low-carbon alternative fuels would do best. The combination of regulatory and market mechanisms makes the LCFS more robust and durable than a pure regulatory approach and more effective than a pure market approach, given that aggressive carbon caps and taxes are politically unacceptable in the United States and elsewhere.

The European Union first unveiled an LCFS proposal at about the same time as California in early 2007. In December 2008, the European Parliament adopted a revised Fuel Quality Directive (FQD) that incorporated a low carbon fuel standard (EC 2008a). The FQD requires fuel suppliers to reduce lifecycle GHG emissions by up to 10 percent by 2020. The scheme is broader than the California LCFS because it allows credit for upstream reductions in gas flaring and venting and for the use of carbon capture and storage (CCS) technologies. It also allows the purchase of credits under the Clean Development Mechanism (CDM) established by the Kyoto Protocol. Upstream emission reductions, CCS, and the CDM can be used to meet up to four percent of the 10 percent requirement.

Eleven Northeast and Mid-Atlantic states have announced a regional initiative to develop a regional LCFS (NESCCAF 2009). The conceptual construction of the plan is largely based on California’s model, with a major difference being the proposed inclusion of heating fuels for home heating, a significant source of diesel fuel consumption in the Northeast. A national version of the LCFS was considered in the early version of the Waxman-Markey Energy Bill, which required a five percent reduction by 2023 and a 10 percent cut by 2030. The LCFS provision was later dropped from the bill that was passed by the U.S. House of Representatives.

Scenarios to Meet California’s LCFS

California’s LCFS will achieve GHG reductions between 20 and 25 million metric tons (tonnes) of carbon dioxide equivalents (CO₂e) on a lifecycle basis per year by 2020 (CARB 2009; Yeh et al. 2009a). Depending on the particular feedstock and production pathways and the carbon intensity of the fuels used by the regulated parties to meet the standard, it will require between 1.5 and 3.0 billion gallons of ethanol, 0.6 to 0.8 billion gallons of biodiesel or renewable diesel, an additional 1,200 to 16,000 gigawatt hours (GWh) of electricity and from zero to 33 thousand tonnes of hydrogen per year by 2020 (CARB 2009; Yeh et al. 2009a).

California has the potential to supply roughly half of the biofuels needed to meet its LCFS (Yeh et al. 2009a). Biofuels produced in other states to meet the federal U.S. volumetric requirement for renewable fuels will be further incentivized by the prospect of earning LCFS credits when being supplied to the California fuel market. Fuels from other states or countries, such as sugarcane ethanol from Brazil, can also contribute to California’s LCFS program.

Figure 5-2: Fuel use change (million gge) between the business-as-usual (BAU) and the portfolio scenario

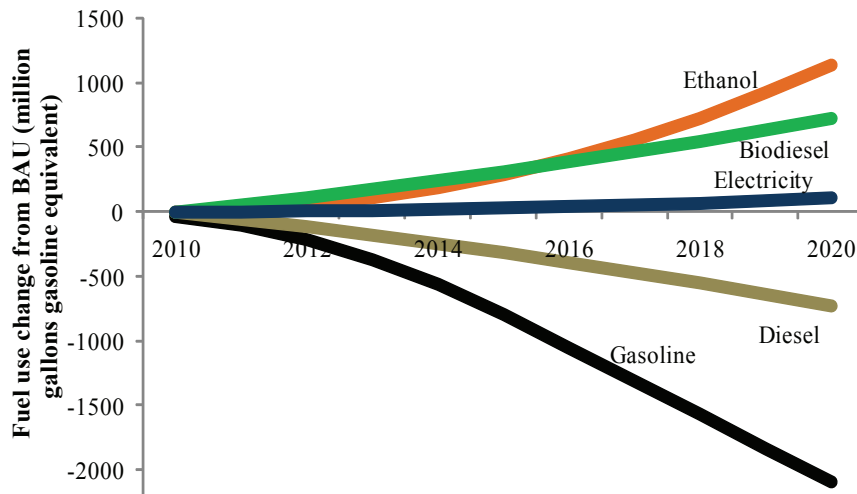
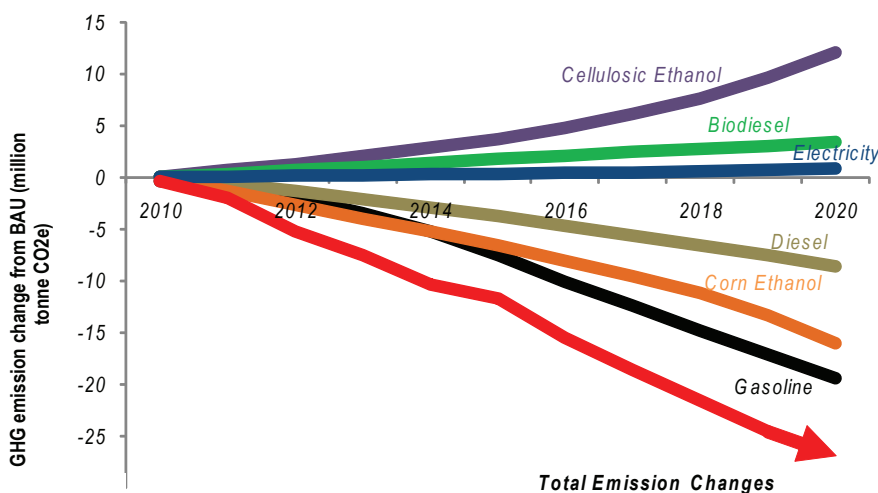


Figure 5-2 shows the fuel use change, measured in million gallons gasoline equivalent (gge), achieved by a portfolio of GHG reduction strategies that achieves the 10 percent reduction target. Figure 5-3 shows the corresponding GHG reduction from the portfolio of GHG reduction strategies relative to the BAU scenario. The portfolio scenario assumes that a mix of second-generation biofuels and advanced electric-vehicle technologies, primarily hybrid electric vehicles, flexible-fuel vehicles capable of burning up to 85 percent ethanol in gasoline, and plug-in hybrid electric vehicles, will be needed by 2020.

Figure 5-3: Greenhouse gas emission reductions (million tonnes CO_{2e}) from BAU in the portfolio scenario



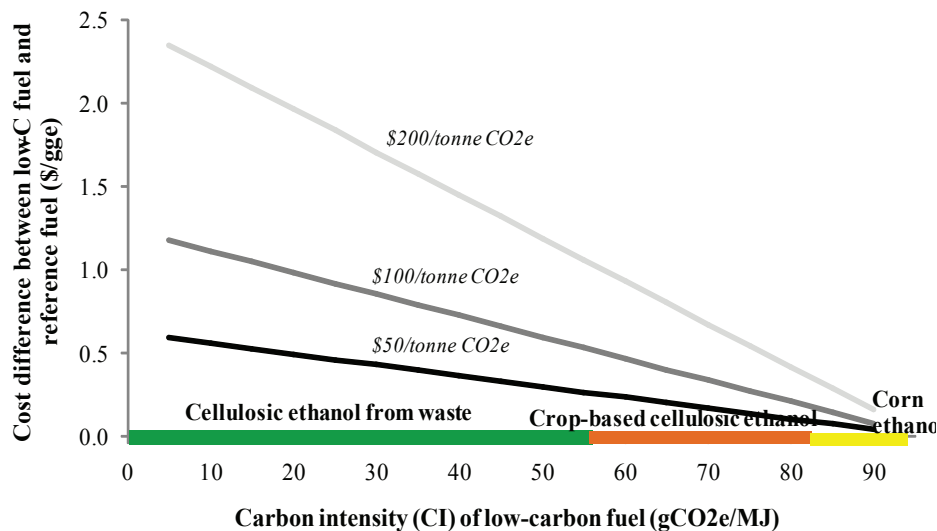
The portfolio scenario estimates that 2.5 billion gge of ethanol, or 3.70 billion gallons, and 0.73 billion gge of biodiesel, or 0.65 billion gallons, will be needed per year by the year 2020 to meet California’s LCFS. This is roughly equal to 14 percent of the total biofuels needed to meet the federal RFS of 30 billion gallons

in 2020, a ratio slightly higher than California’s total transportation fuel demand, which accounted for 11 percent of the U.S. total.

Growth of PHEVs from 2010 to 2020 would be slightly higher than the sales growth of HEVs in California from 2000 to 2010, which was twice the national average, reaching 7.3 percent of new vehicle sales and a total of 0.7 million PHEVs on the road by 2020. The total electric vehicle population would reach 60,000 by 2020. The combined electricity use from PHEVs and electric vehicles would reach 2,280 GWh per year by 2020. These PHEV and electric-vehicle penetration rates represent an optimistic technology deployment scenario. Other policies, such as California’s zero emission vehicle program, may provide additional incentives for adoption. In addition to PHEVs and electric vehicles, off-road applications such as forklifts, electrification of truck stops, and marine ports electrification also offer relatively high potential GHG reductions.

Projected low-GHG fuel use will vary because the performance-based LCFS does not specify a minimum amount of fuel volume or energy content for the alternative fuels. The lower the average GHG intensity of the fuels used, the smaller quantity of alternative fuels that would be needed to meet the GHG reduction target. Thus, use of lower carbon fuels will generate more LCFS credits than the same volume of fuel with higher carbon intensity. The price premium can be much higher for low-GHG fuels at a given compliance cost target, as shown in Figure 5-4. In other words, low-GHG fuels incurring higher relative costs of production may still be competitive in the LCFS credit system.

Figure 5-4: Breakeven cost difference between low-carbon fuels and the reference fuel at various levels of compliance cost targets



Note: Color bars shows the range of California default carbon intensity values, including indirect land use changes, for the three major types of biofuel categories: corn ethanol, crop-based cellulosic ethanol and cellulosic ethanol from waste.

Key Challenges of an Expanded LCFS

A national LCFS could be adopted in parallel with, or in place of, the RFS. The RFS mandates 36 billion gallons of biofuels by 2022, of which 21 billion gallons must be advanced biofuel with a minimum GHG reduction of 50 percent compared to 2005 baseline gasoline. Sixteen of the 21 billion gallons must be cellulosic biofuel with a minimum GHG reduction of 60 percent. A national LCFS avoids clumsy categorization of GHG emission accounting, provides additional flexibilities to companies by incorporating market mechanisms, and stimulates innovation and investment in low-carbon fuels.

Some of the challenges associated with the implementation of a national LCFS include the leakage and shuffling of emissions to sources outside the United States, energy security concerns, measurement of indirect land use changes, and sustainability issues. The first two issues are common to carbon policies such as the cap-and-trade program and the LCFS, while the latter two issues are also not LCFS specific, but rather issues associated with biofuels.

Leakage and Shuffling

One potential consequence of the LCFS performance standard is the issue of leakage. In the case of LCFS and cap-and-trade, regulated parties will have incentives to export high-carbon fuels to non-LCFS countries or not import high-carbon fuels (Stavins 2008, Burtraw et al. 2005, and Reilly et al. 2007). Thus, improvement would appear to be made in the United States, but there would still be no net environmental benefit globally. In fact, leakage resulting from a U.S. LCFS may result in higher overall global emissions, due to the added emissions from transportation.

The specific concern in the U.S. is that a national LCFS will limit flow of oil sands to the U.S., but only marginally reduce overall oil sands production, since the majority of the oil sands exports will be diverted to the Pacific market via the Enbridge pipeline to Kitimat (Difiglio 2009). This concern is premised on an assumption that the national LCFS would be implemented in the absence of a national cap-and-trade system or broader global actions to reduce GHG emissions.

More robust assumptions and alternative scenarios will be needed to give a better picture of the impacts of a national LCFS on global oil markets. It is entirely possible, for instance, even likely, that other states and provinces will follow California's lead with the LCFS. A U.S. LCFS must be analyzed in the context of a national cap-and-trade system and a global climate policy regime likely to emerge after 2020. It is unlikely that Canada will do nothing about reducing its emissions from high-carbon oil sands if the United States adopts a national LCFS. If Canada includes oil sands upstream emissions under a cap-and-trade program, then Canadian oil sands would be treated as conventional crude oil under California's LCFS program, since the high-carbon part is only associated with energy-intensive extraction and upgrading (Charpentier et al. 2009). Indeed, a national LCFS may be feasible only if there are well-functioning cap-and-trade programs in both countries (Levi and Rubenstein 2009).

It is important to note that the LCFS does not ban high-carbon fuel, but provides fuel providers with maximum flexibility to use high-carbon fuels as long as carbon liability is managed through improvement in refinery efficiencies, CCS, cogeneration (Jacobs 2009; TIAX 2009), advanced technologies (Ordorica-Garcia et al. 2008), or other low-carbon energy sources, such as nuclear or renewable energy sources. After paying for these offsets, however, it is unclear if Canadian oil sands would still be competitive relative to convention petroleum, especially when oil price could be lowered due to lower demand caused by carbon policies and biofuel programs in the future.

Energy Security

The LCFS helps to achieve climate goals by reducing GHGs, but there are debates about the impacts of the LCFS on energy security. On the one hand, the LCFS encourages the use of alternative fuels and reduces oil consumption. This will lower oil imports and increase energy security. The U.S. Department of Energy's Annual Energy Outlook projects that growth in biofuels for the RFS will lower the prices of transportation fuels and reduce net oil imports from 58 percent of total oil supply in 2007 to 41 percent in 2030 in the reference case (EIA 2009). The increased use of low-carbon fuels, such as biofuels, electricity, landfill gas, and hydrogen, under an LCFS would further decrease imports and strengthen oil independence.

On the other hand, the LCFS discourages production of fuels from oil sands, heavy oil, oil shale and coal. Critics argue that such disincentives would increase the risk of energy dependence on Middle East oil, which is typically less carbon intensive than unconventional oil. This concern is real, but may be overstated

according to EIA analyses. Canadian oil sands production currently contributes 1.4 percent of global oil supply. The EIA projects that this figure will increase steadily to 3.5 percent by 2030 (EIA 2009).

There are many ways to define energy security, and a variety of strategies, including reducing imports and diversifying energy type and geographical sources; increasing the portfolio of supplying countries from politically stable regions; and reducing energy prices, can effectively improve energy security (Krutz 2009). Similarly, to achieve oil independence, the United States must reduce the oil intensity of its economy, increase the economy's ability to substitute energy efficiency and alternative energy sources for oil, and increase domestic production of oil from conventional and unconventional resources (Greene 2010). The LCFS and other policies, such as the CAFE standard, the ZEV mandate and the subsidies for batteries, will directly encourage the first two objectives—reducing oil imports and increasing the economy's ability to substitute energy efficiency and alternative energy sources. A more rigorous analysis of energy security will be needed to compare different carbon policies to reduce transportation emissions.

Indirect Land Use Change

Recent studies have shown that massive consumption of biofuels in the United States could lead to expansion of farm lands throughout the world, at the expense of other crop lands and non-crop lands such as forest and grass lands (Koh and Wilcove 2008; Laurance 2007; Searchinger et al. 2008). When lands with rich soil and biomass carbon deposits are initially converted to agricultural production, a large amount of carbon is emitted. This initial "carbon debt" can take years or even decades of cultivation to pay back (Delucchi 2004; Fargione et al. 2008; Gibbs et al. 2008).

The conversion of land, induced by market-mediated effects, can be direct or indirect. The indirect effect, or indirect land use change (iLUC), represents the overall impact from an increased demand for crop-based biofuel production, leading both to expansion of cultivated land area, called extensification, and increased land inputs to increase yields of agriculture that would not occur in the absence of biofuels production. Extensification modifies the use of global farmland and forests, marginal lands, and their carbon stocks. The iLUC effects cannot be directly observed or easily measured.

A host of models have been applied to estimate the magnitude of indirect land use change. These models include computational general equilibrium (CGE) models, such as the GTAP model (Hertel et al. 2008, 2010) and the miniCAM model (Wise et al. 2009), and partial equilibrium models such as the FASOM and FAPRI models (U.S. EPA 2009b). Reviews of recent model development and model comparison can be found in Chakravorty et al. (2009), Dehue (2009) and Searchinger (2009). The principal building blocks for estimating GHG emissions from indirect land use change and the major uncertainties associated with these steps are shown in Table 5-1.

The LCFS encourages the use of low-GHG biofuels from organic waste or other biomass and cellulosic biofuels from energy crops, crop residues and forest wastes. These biofuels are considered to have substantially lower risk of indirect land use, compete less with food production (FAO 2008; Gibbs et al. 2008; OECD 2008; Searchinger 2009; Tilman et al. 2009), provide higher yields and lower intensity of agricultural inputs including land, fertilizer, irrigation and pesticides, and incur less environmental impacts on soil erosion and loss of biodiversity (Robertson et al. 2008; Tilman et al. 2006). A recent analysis suggests that large quantities of biofuels can be produced in the U.S. from perennials grown on degraded formerly agricultural land, municipal and industrial solid waste, crop and forestry residues, and double or mixed crops produced annually (NAS 2009).

An LCFS without a cap on high-carbon fuels and indirect land use change, as some have proposed, will not be effective in reducing global GHG emissions, but could result in significant leakage, as illustrated in Wise et al. (2009) and Gillingham et al. (2008). An LCFS that covers emissions of high-carbon fuels and direct and indirect emissions will be a more robust and economically efficient policy (Wise et al. 2009, Holland 2009).

Table 5.1 Key components of estimating GHG emissions from ILUC and major uncertainties

<i>Key Component</i>	<i>Key Uncertainties</i>
Energy Demand from Biomass	Price of biofuels compared to oil; technology development in biofuel conversion technology
Feedstock Demand	Fuel yield; co-product markets; price elasticity of yield
Trade Balance	Tariffs and trade barriers
Area of Lands Converted	Assumed annual increases in crop yields; productivity of new land; bioenergy-induced additional productivity increase; availability of idle/marginal/degraded/abandoned/underutilised land; methodology of allocating converted land (e.g. conversion of grassland vs. forests)
Impacts/GHG Emissions	Biofuel cultivation period; carbon stock data; discount rate; Albedo changes (eg, snow on former boreal/temperate forest land); nitrogen cycle; Other greenhouse gases (eg, cattle, rice methane)

Environmental and Social Sustainability

In addition to GHG emissions, concerns for the environmental and social impacts of large-scale biofuel production have also increased (Donner and Kucharik 2008; FAO 2008; Miller et al. 2007; National Research Council 2007; Robertson et al. 2008). As a result, sustainability goals or requirements for biofuel production have been adopted by The Netherlands (Cramer et al. 2007; Cramer et al. 2006; NEN 2009), the United Kingdom (Department for Transport 2008), Germany (BioNachV 2007; WWF 2006), the European Union (EC 2008b), and California (CEC 2008). International organizations, including the United Nations (UN) Food and Agriculture Organization and Environment Programme and the G8's Global Bioenergy Partnership, have led the research, modeling and negotiation efforts among stakeholders at the country level.

There are also more private and public efforts in promoting certifications, facilitating information sharing and sustainability management. Many new commodity-based, biofuel-targeted certifications have recently been or are being established, including by the Roundtable on Sustainable Palm Oil, Roundtable on Responsible Soy, Better Sugarcane Initiative, Council on Sustainable Biomass Production, and Roundtable for Sustainable Biofuels (RSB).

These biofuel schemes often include requirements for sustainable management of agricultural production and seek to avoid environmental damage and long term degradation and improve the socio-economic principles of welfare of local communities, land rights issues and labor welfare. Procedures for certification or verification and requirements to monitor or report progress are key elements of a sustainability scheme. Detailed reviews of these recent sustainability schemes and key challenges can be found elsewhere (Endres 2009; Winrock International 2009; Yeh et al. 2009b).

The most important sustainability criteria for a national LCFS will be to ensure that there are significant GHG reduction benefits from using biofuels. This will be dependent on a credible and consistent carbon accounting scheme that is compatible with international efforts. It is widely accepted that any further expansion of biofuel use should minimize competition between food and fuel (FAO 2008). Using largely non-agricultural land to expand dedicated energy crops would reduce the pressure on food prices and clearing of land, compared to the impacts of first-generation biofuels such as corn ethanol and soybean, but there must be efforts to ensure that unmanaged negative environmental impacts on sensitive areas and biodiversity losses do not occur (OECD 2008). Perennials grown on degraded formerly agricultural land, municipal and industrial solid waste, crop and forestry residues, and double or mixed crops offer great potential for providing significant alternative energy resources, while reducing GHG emissions and with minimal harm to the environment (Tilman et al. 2009).

UC Davis researchers have published a comprehensive review of recent efforts in sustainability standards (Yeh et al. 2009b) and conclude that an LCFS sustainability requirement may be the most effective if it adopts the following principles:

- Stakeholders should collaborate to establish a performance-based sustainability framework that sets reasonable expectations, clear measures of compliance and methods of enforcement; encourages innovation; and rewards practices exceeding a minimum standard.
- The sustainability framework should adopt a lifecycle approach and apply to all fuels, feedstocks, and production and conversion technologies. In the short term, however, the standards may apply only to non-baseline LCFS participating fuels, to address acute concerns for new fuels, reduce administrative burden and recognize existing regulations on baseline fuels.
- Careful coordination and integration among diverse international initiatives is required to improve coherence and efficiency of sustainability standards between countries. Table 5-2 summarizes principles of the RSB sustainability standard.

Table 5-2: Summary of RSB sustainability standard

<i>Category</i>	<i>Direct</i>	<i>Indirect</i>
National Law (especially concerning land, labor, water rights)	✓	
Community Consultation (especially to determine land rights, social and environmental impact, and idle land and to resolve grievances)	✓	
Social – biofuels should benefit rural communities and workers	✓	
Social – biofuels should not contribute to food insecurity	✓	✓
GHG (biofuels should have significantly positive balance over lifecycle)	✓	✓
Environmental – biofuels should conserve and protect soil, water, air	✓	
Environmental – biofuels should conserve and protect high conservation value areas	✓	✓
Technology and Efficiency – technologies (especially biotech) should be used responsibly and transparently and be economically efficient	✓	

Source: RSB 2009b

Harmonizing LCFS with Cap-and-Trade Programs

LCFS is clearly superior to RFS as a structure to promote the full range of low carbon fuels and to reduce the carbon intensity of fuels in the most cost-effective manner. It is technology neutral and performance based, and accounts for full fuel cycle GHG emissions. A national LCFS should keep these key elements, but need not be identical to the current program designs in California, the Northeast or the European Union. The design details, including compliance schedules; regulated fuel pools that may or may not include jet

fuel, maritime fuel and home heating oil; efficiency adjustment factors for diesel and electric fuels; and either a single target or separated gasoline and diesel targets, need to be examined within a national context.

If the LCFS is adopted along with a cap-and-trade program, as would likely be the case in the United States, it would be critical to ensure minimum conflicts with or overlaps between the two programs. In California, the LCFS credits will be allowed to be exported to the cap-and-trade program, but not the other way around. The rationale for this is that the LCFS credits are expected to be of higher value than the cap-and-trade program, at least during the Phase I period from 2010 to 2020. Thus, limiting the flow of the cap-and-trade credits to the LCFS will ensure that the projected reductions under the LCFS program will be achieved.

As the transportation and electricity energy sectors become increasingly coupled due to the development of plug-in hybrid vehicles, battery electric vehicles and off-road electrification applications, issues of double crediting and double counting will become more important. For example, if an independent producer puts up a wind turbine and generates electricity to power a vehicle fleet, there is a possibility to earn credits under both the cap-and-trade program and the LCFS program. Alternatively, if a biorefinery generates electricity that goes into an off-road application, the biorefinery may claim the electricity credits under California's Renewable Portfolio Standard program as well as the LCFS. In these situations, the possibility of double crediting without double counting illustrates the potential overlap between the programs.

In the long term, when costs for low carbon fuels subside and initial market barriers are overcome, it will likely be desirable to phase out the LCFS and allow a full economy-wide credit market to operate under a cap-and-trade program. But that time is far in the future.

Conclusions

The LCFS adopted in California and the EU provide a promising opportunity to drastically reduce fossil fuel use and long-term GHG emissions from the transportation sector that is otherwise unresponsive to other moderate carbon policy initiatives. The LCFS is superior to other alternative fuel policies such as the RFS since it provides additional flexibility, encourages innovation in low-carbon fuels and incorporates market mechanisms. However, as with other policies, the implementation of the LCFS faces several challenges that may reduce its effectiveness. Further understanding of these issues, improvements of the policy design and the adoption of other complementary policies may be needed to overcome these challenges.

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Chapter 6:

A Shared Goal: Addressing Climate Change and Energy Security

by Dave McCurdy and Kathryn Clay

Energy security and environmental protection have converged at the center of the national political agenda in the United States (U.S.). The colliding realities of continued dependence on imported oil, two costly wars in the Persian Gulf region, wildly fluctuating energy costs, and deep economic recession have focused public attention and calls for action. Combined with the emerging international consensus on the science and challenges of global warming, support for a new approach on energy and climate policy in the U.S. is needed. Recognizing that energy and global climate change solutions will not be achieved without strong leadership from the United States, President Barack Obama has made energy security and global climate change a signature issue for his administration.

Meanwhile, the auto industry is facing unprecedented economic challenges. The national economy has been in recession, and the auto industry was among the first to be hit by the downturn. The swiftness and the extent of the impact on the auto industry surprised even the most seasoned industry analysts. Annual sales in North America contracted from 16 million in 2007 to 13 million units in 2008. Sales figures for 2009 will continue this downward trend still further to less than 11 million units (Ward's Automotive Group 2007, 2008, 2009).

In the midst of this turbulence, auto industry chief executives joined the Obama administration to forge a single national standard for fuel economy and greenhouse gas (GHG) emissions. On May 19, 2009, President Obama announced the culmination of this effort in a Rose Garden ceremony. The centerpiece of this landmark agreement was a new fuel economy standard for the overall U.S. motor vehicle fleet of 35.5 miles per gallon (mpg) by 2016. Between 2012 and 2016, efforts to implement this standard will reduce U.S. oil consumption by 1.8 billion barrels over the 4-year period, and will lower national emissions of GHGs by over 950 million metric tons over the same period (White House Press Office 2009).

Prior to the 2009 presidential announcement, automakers supported provisions in the Energy Independence and Security Act (EISA) in 2007 to raise fuel economy standards to at least 35 mpg by 2020, an increase of 40 percent. Before EISA, the industry had resisted efforts to change automobile fuel efficiency standards, which were unchanged since 1990.

D. McCurdy is President of the Alliance of Automobile Manufacturers in Washington, DC, and K. Clay is the Director of Research

Automakers support moving to a low-carbon future. Other stakeholders, including fuel providers and consumers, will also need to take on commitments and be accountable. Government can contribute most by creating the conditions that promote private sector investment and innovation, and that incentivize consumer adoption of advanced, low-carbon technologies.

Developing a Comprehensive Energy and Climate Strategy

Policies addressing the transportation sector are essential, but by themselves will not be sufficient to meet overall national goals. New federal legislation is needed to create a national, economy-wide program to replace the current patchwork of conflicting standards. Existing legislative authority is not adequate to accommodate the fundamentally different approach required for GHG emissions compared to other types of pollutants. The legislative framework of the federal Clean Air Act, developed in the 1960s and 1970s, did not envision GHG emissions and was not designed to address them. Even the emissions trading provisions for pollutants related to acid rain, included in the 1990 amendments, are inadequate as a model for a GHG abatement program. The acid rain program addresses pollutants for which local, rather than global, concentrations are the predominant concern. Moreover, the acid rain program addresses a comparatively small number of emissions sources within one sector of the economy, and so has limited utility to inform the design of an economy-wide GHG program regulating literally hundreds of millions of emission sources.

A number of key principles should be incorporated into a national program to reduce GHG emissions. Most importantly, the overall program should encompass the national economy as completely as possible, whether the approach is based on a cap-and-trade program or on other measures, such as a carbon tax. If cap-and-trade is the preferred framework, the program should be designed to achieve the greatest emissions reductions, while minimizing economic disruption. This will require taking equitable carbon reductions across all sectors of the economy. Policies directed at transportation sector emissions, such as the new national fuel economy program, are an important element. At the same time, sector-based approaches cannot substitute for a more economically efficient, economy-wide program.

Additionally, the national approach should include market measures to the greatest extent possible. Market measures will lend advantages to the most economically feasible actions. Using market mechanisms can provide the pull needed to incentivize the rapid deployment of advanced technologies. Such measures will work to maximum effect if policies are also adopted to increase public and private investment in the research and development (R&D) needed to produce new, clean energy technologies. Finally, a national climate change strategy should clearly delineate appropriate roles for federal, state, and local governments.

In the United States, energy security is closely tied to oil security. Any discussion of oil security necessarily centers on the transportation sector, because transportation accounts for 71 percent of U.S. petroleum consumption. Today's transportation sector relies on petroleum for 94 percent of its primary energy (Davis *et al.* 2009). At the same time, the transportation sector accounts for 30 percent of national GHG emissions. Automobiles and light duty trucks account for slightly less than two-thirds of this total, or 17 percent (EPA 2009).

For over thirty years, energy policy has been dominated by the Corporate Average Fuel Economy (CAFE) standards. The Energy Policy Conservation Act, enacted into law by Congress in 1975, established CAFE standards for passenger cars and light trucks in response to the Arab oil embargo of 1973 and 1974. Historically, CAFE has made an important contribution to lessening our dependence on foreign oil. The National Academy of Science concluded in 2002 that, in the absence of CAFE, motor vehicle fuel consumption would have been approximately 14 percent higher than it actually was at that time (NRC 2002).

The national experience with CAFE standards illustrates the importance of developing a more comprehensive, integrated approach to energy security and climate change policy going forward. Past vehicle efficiency

gains under CAFE have been offset by increases in total vehicle miles traveled (VMT) in the U.S. Between 1980 and 2007, VMT nationally nearly doubled, a growth rate three times faster than the growth in population (BTS 2009). CAFE, while it drives progress on vehicle technologies, is insufficient on its own to guarantee reductions in GHG emissions or oil consumption. Addressing one dimension of the transportation sector, while neglecting other aspects, profoundly limits what is ultimately achievable.

Another limit on the absolute utility of CAFE is that it affects only a subset of a single sector of the U.S. economy. A better approach would integrate transportation energy policy with the rest of the economy by attaching a price on carbon, and perhaps imposing an energy security surcharge on imported fuel. While the Obama national program creates a process for coordinating fuel economy and GHG tailpipe emissions standards, a need for an additional level of harmonization still remains if transportation emissions are included under an economy-wide energy and climate program.

Achieving sustainable mobility will require an integrated approach that considers the four main dimensions of transportation energy use and GHG emissions: vehicle technologies, transportation fuels and alternative fuels infrastructure, conventional transportation infrastructure investments, and consumer behavior.

Advancing Vehicle Technologies

The automobile industry is a leading sector in R&D, investing in a diverse array of vehicle technologies. Major automobile manufacturers typically invest four to five percent of their gross revenue in R&D each year. Total global R&D investment by automakers in 2008 was over \$86 billion.

Many new advanced technology vehicles under development today are likely to fail in the marketplace. The market responds to many variables, such as cost, quality, reliability, and risk, and should be allowed to operate freely in the pursuit of sustainable mobility. Market competition between the technology options that emerge is also needed. The best policies are based on performance metrics rather than technology mandates, allowing markets to find optimal, least-cost solutions, while maximizing public goods.

Delivering any new vehicle technology to the market requires years of product planning. Policies that provide automakers with regulatory certainty and adequate lead time are essential. The development of a new drivetrain typically requires five to seven years and an investment on the order of \$1 billion. Even after a new technology is introduced, it can take years before it achieves a significant market penetration. One of the first and the most successful hybrid electric vehicle models to date took eleven years from its first commercial introduction to selling its one-millionth unit worldwide.

Because technology development is inherently unpredictable, technology neutrality in policies should be maintained to the greatest extent possible. A broad-based approach that promotes a wide range of vehicle technologies has the best overall chance of producing market success. This principle of technology neutrality should guide government vehicle technology programs that span the range from basic and applied research to manufacturing R&D, and through deployment and commercialization activities.

Tax policy is a powerful tool to encourage the deployment of advanced technology vehicles, and should also be technology neutral overall. Many new technologies have upfront cost premiums that deter consumers, despite the expectation of lower fuel costs over the lifetime of the vehicle. Consumer tax incentives can compensate early adopters for these cost premiums, accelerating the acceptance of new technologies by the market. These incentives can help promote early market penetration, achieving greater scales of manufacturing more quickly and hence driving down cost curves more rapidly. This, in turn, supports the more rapid development and deployment of second generation technologies.

While it is impossible to predict with certainty what the automobiles of the future will look like, in the coming decades the vehicle fleet will likely become much more diverse technologically, with growing proportions of vehicles powered by biofuels, clean diesel, hydrogen, fuel cells, and battery-electric drivetrains. Continued

advancements to gasoline powered internal combustion engines will also play a role in increasing the overall fuel economy of the vehicle fleet for decades to come.

Providing Cleaner Fuels

Vehicles and fuels form a system. A full discussion of fuel quality should address both the need for new low-carbon alternatives and the need for stricter standards for the quality of gasoline and diesel fuel. Stricter quality standards would enable further improvements in gasoline and diesel engines, yielding fuel economy and environmental gains. The auto industry's best efforts to develop and deploy new, alternative fuel vehicles will succeed only if consumers have access to the fuels to support these vehicles. Policies to promote the production and distribution of these new fuels will be critical to their success in the market.

Low Carbon Fuels

Automakers support efforts to reduce the carbon content of fuels. Well-designed low carbon fuel standards (LCFSs) can help achieve that goal. Efforts to develop low carbon fuel standards are underway at the state and regional level, and federal legislation has proposed a national LCFS. Standards currently under discussion would include fuels derived from biomass, as well as electricity generated using renewable sources, such as solar, wind, or biomass.

Multiple LCFS systems may emerge, requiring careful coordination between state, regional, and national programs. On the biofuel side, calculating the carbon content for purposes of these standards will likely include indirect effects, such as the consequences of bringing additional land into agricultural production. Since fuels produced in one state or region may be transported great distances before reaching their final point of use, adopting common methodologies to calculate life cycle carbon content will facilitate smoother implementation of these programs.

Developing standards that use carbon content as a single, common denominator for comparisons between fuels will lead to the greatest transparency and efficacy in achieving transportation carbon reductions. In practice, adhering to this principle will require considerable political will. Potentially, these standards could be used to advance other environmental and local economic goals unrelated to carbon abatement. For example, regions experiencing pressure on local water supplies could choose to weight their standard to encourage biofuel production that is less water intensive, even beyond accounting for carbon associated with energy use due to irrigation or water consumption at the biorefinery.

Producers of local agricultural crops might similarly press for favorable weighting within the standard to recognize their contributions to regional rural development. While such objectives are laudable, using an LCFS as a vehicle for their advancement would dilute the standard's effectiveness as a carbon reduction strategy and should be resisted.

Automakers support the inclusion of electricity generated by renewable sources in low carbon fuel standards. Again, coordination between state, regional, and national standards that may emerge will maximize effectiveness and facilitate program implementation. Including electricity produced from renewable sources in a state-administered LCFS will require policy makers to decide whether to look at the electrical generating mix within their borders or to look more broadly at the generation mix in their regional power pool. If the latter course is taken, questions of double counting of renewable electricity credits may emerge if neighboring states adopt similar but independent standards. The question is further complicated by the fact that the definition of sources that qualify as renewable electricity generation varies between states.

For states that also have adopted renewable electricity standards, policy makers must also decide whether credits for renewably generated electricity should be included in an LCFS calculation. Allowing credits for renewable electricity generation under both programs could be viewed as mutually reinforcing, or as duplicative. Similar questions will need to be addressed if the federal government enacts a national renewable electricity standard.

Fuel Quality

Gasoline. The vehicle technologies automakers can offer in a given market may be limited by the characteristics of the transportation fuel they burn. In some developing countries, the presence of lead in gasoline is still a limiting factor to the introduction of catalytic converters that could yield huge benefits to local health. In the United States, the introduction of ultra-low sulfur diesel allowed the successful introduction of technologically advanced emissions control equipment that enabled light duty diesel vehicles to meet stringent emission standards.

Adopting stricter standards for the sulfur content of gasoline would open the U.S. market to gasoline lean burn engines capable of providing 10 to 20 percent improvements in fuel economy. Other markets have adopted lower gasoline sulfur standards, including the European Union and Japan (AIR 2009). A national clean gasoline standard with lower gasoline sulfur and other quality improvements could achieve significant benefits.

Biofuels. As the nation strives to replace more petroleum-based fuels with biofuel components to reduce GHG emissions and improve energy security, policies directed at ensuring the quality of these new fuels are needed. The Renewable Fuel Standard established under the Energy Independence and Security Act of 2007 encouraged the rapid expansion of a national biofuels industry and created legal requirements to absorb greater quantities of bio-based fuels into the national transportation fuel mix. The United States needs to act to ensure that standards keep pace with the new types of fuels that will increasingly reach consumers.

Mid-level Ethanol Blends. Today's fleet of gasoline-powered vehicles can safely accommodate blends of up to ten percent ethanol. Higher blends of ethanol can damage polymer-based materials that are used in fuel lines, seals, and other vehicle components. Flexible fuel vehicles, which are designed to run on blends of up to 85 percent ethanol, use materials chosen to withstand the effects of exposure to higher ethanol blends. Fueling a conventional, non-flexible fuel vehicle with ethanol blends exceeding ten percent can void the vehicle's warranty.

A joint research effort, conducted by the U.S. Department of Energy (DOE) and Environmental Protection Agency (EPA), is considering the effects of higher-level blends of ethanol on the existing light duty vehicle fleet. One challenging aspect to this research is that it must assess the long-term durability of vehicles under higher ethanol exposure. The EPA is considering whether to approve blends of ethanol of up to fifteen percent with gasoline. The automobile industry supports efforts by the EPA and DOE to ensure that the eventual regulatory decision is based on sound and thorough research on vehicle and fuel compatibility.

Biodiesel. Biodiesel can be compatible with diesel engines when blended in low proportions with conventional diesel fuel. However, biodiesel has different properties from conventional diesel, and further variations occur depending on the fuel stock used to produce the biodiesel. These variations include viscosity changes at different ambient temperatures and susceptibility to microbial contamination. Coordinated efforts between fuel providers, standard-setting bodies, and government agencies responsible for enforcement are needed to ensure that biodiesel entering the fuel mix is safe and reliable for diesel engines.

Emerging Biofuels. Research efforts are underway for new classes of second, third, and even fourth generation biofuels. Some of the biofuels under discussion are chemically distinct from conventional gasoline and diesel. Further research will be critical to ensure that these emerging fuels can meet appropriate standards for safe and reliable use.

Alternative Fuels Infrastructure. Government has traditionally played a role in financing infrastructure projects. Alternative fuel and electric vehicle charging infrastructures will require a significant new public investment. It is not yet clear which alternative fuels will make the most headway in the market, so acting too quickly on new fueling infrastructures risks locking in on technology choices too soon. Moreover, regional solutions may emerge. Establishing a biofuels infrastructure may be less costly in rural areas that

are closer to biofuels feedstock production and biorefineries. Urban areas, where many residents drive relatively fewer miles per day, may be better suited to grid-charged vehicles, at least until battery technology matures further.

President Obama's commitment to plug-in hybrid electric vehicles must be accompanied by greater efforts to understand consumer preferences for recharging, and initiatives to accelerate investments in a recharging infrastructure. Other alternative fuel vehicle technologies have not presented the same scope of challenges that face the electric recharging paradigm. Natural gas, methanol, diesel, ethanol, and hydrogen could adopt a fueling infrastructure model that closely parallels that of gasoline because each of these alternative fuels allows vehicles comparable in size and performance to conventional gasoline vehicles to achieve ranges consistent with consumer expectations for all-purpose driving.

Current battery technologies provide only limited ranges for battery, plug-in hybrid, or extended range electric vehicles. Some automakers have announced plans to introduce grid-charged electric vehicles capable of 40 miles of electrically powered driving between charges of the battery pack. This range would be sufficient for nearly 80 percent of trips taken by Americans (FHWA 2002). Still, it is not clear whether consumers will come to view electric drive vehicles as commuter cars suitable for most daily driving or whether they will demand an electric refueling infrastructure that enables them to use these vehicles for less frequent, but significantly longer, trips. If consumer acceptance relies on a ubiquitous charging infrastructure, a strong government role will be needed to support its establishment.

Estimates of the costs of building an adequate charging infrastructure for electric drive vehicles vary depending on the assumed vehicle ranges provided by the onboard battery pack and on the vehicle use and charging patterns assumed for consumers. These factors will also determine whether utilities will need to provide additional electrical generating capacity. The Pacific Northwest National Laboratory estimates that, if vehicle charging is conducted during off-peak periods, existing electrical generation capacity could support the energy requirements of 73 percent of the U.S. light duty vehicle fleet (Kinter-Meyer *et al.* 2007). Off-peak charging fits well with utilities' business models because it allows for load leveling, or greater use of currently underutilized generating capacity during nighttime hours.

Consumers will likely demand some level of daytime charging; this could mean significant costs for both the additional generating capacity and for a network of non-residential charging stations on a national scale. This type of charging pattern is not necessarily in alignment with electric utility business interests. Policies to encourage the inclusion of recharging infrastructure investments into utility rate bases will be essential to enlisting the participation of utilities at significant scale. The federal government could also show leadership by developing model building codes for residential and commercial retrofits to accommodate vehicle recharging stations, helping localities overcome regulatory barriers. Standardization of vehicle-charger interfaces will be an important part of this effort.

In summary, encouraging the adoption of plug-in hybrid vehicles can best be achieved through a better understanding of consumer expectations for vehicle recharging, government policies to facilitate the establishment of a recharging infrastructure in synch with consumer expectations, and increased investment in research and development of next generation battery technologies.

Investing in Transportation Infrastructure

The safe and efficient movement of people and goods is intrinsic to commerce and a cornerstone of a strong economy. Yet the nation's transportation infrastructure is aging and in urgent need of revitalization. Failing to invest sufficiently in transportation infrastructure will exacerbate traffic congestion that afflicts urban areas across the nation and create a system that is less efficient, consumes more fuel, produces more pollution, and detracts from quality of life. Achieving sustainable mobility will also require the establishment of infrastructures to support the next generation of alternative fueled vehicles, including electric drive vehicles.

Transportation challenges, and in particular traffic congestion, are among the top issues that city officials believe most urgently require federal action. In a national survey of municipal and city leaders, transportation issues ranked second only to healthcare, and ahead of education as their most important concern (McFarland 2008). In 2007, congestion caused urban Americans to spend an additional 4.2 billion hours traveling and to purchase 2.8 billion gallons of fuel. This amounts to an effective “congestion tax” imposed on the economy of \$87 billion, an increase of more than 50 percent than the previous decade (Schrank and Lomax 2008). Slower speeds and unproductive idling time in heavy traffic have also meant increased emissions of GHGs and smog-related pollutants. High gasoline prices and the recession have recently combined to slow the trend toward greater traffic congestion, but as the economy recovers, previous growth rates in VMT and traffic congestion are likely to resume.

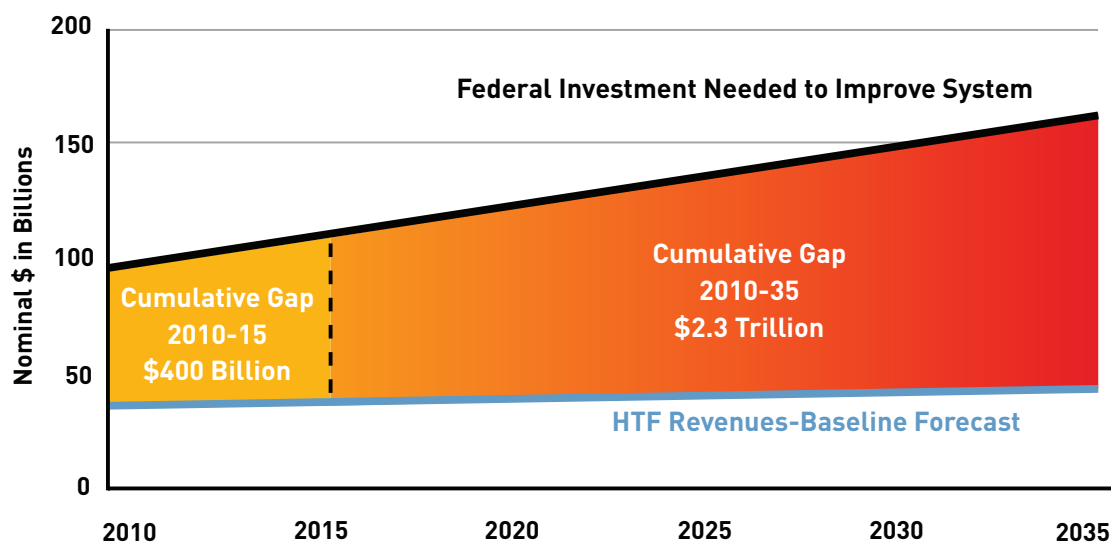
Alleviating congestion requires a balanced approach of policies, including adding roadway capacity and public transit in the most affected areas. Other important strategies include promoting ridesharing and flexible work schedules to reduce rush hour demand. A longer term solution involves diversified land development patterns that are more conducive to walking, biking, and mass transit.

Ensuring adequate roads and highways is a necessary element of the infrastructure component of sustainable mobility. The existing transportation infrastructure needs to be augmented to support the alternative fuel vehicles that will increasingly populate the roadways. Market deployment of alternative fuel vehicles is impeded by fueling anxiety among consumers. Consumers will not adopt alternative fuel vehicles unless they have confidence that an adequate refueling infrastructure is in place or will be established within an acceptable timeframe. At the same time, investors may be unwilling to commit sufficiently to an alternative fuel infrastructure until a significant number of compatible vehicles have entered the fleet. Successful policies to promote alternative fuel use need to address both sides of this issue.

Addressing Financing Challenges

The surface transportation infrastructure in the United States will require substantially more funding over the next few decades to deal with physical deterioration, congestion, and future demand for both passenger and freight travel. Over 13,000 Americans die each year on the nation’s roadways due to inadequate highway maintenance (CSIS 2006). The Department of Transportation (DOT) estimates that the nation will

Figure 6-1: A large and widening gap between federal revenues and investment needs in nominal dollars



Source: NSTIFC 2009

need to increase highway capital spending by 12 percent and transit capital spending by 25 percent from 2005 through 2024 to maintain the current condition and performance of the system (FHWA 2007).

Recommended improvements would require even greater investments. Under current policies, revenues raised by all levels of government will total only one-third of the approximately \$200 billion needed annually to provide needed improvements in the nation's highway and transit systems. The cumulative investment gap at the federal level alone is projected by the National Surface Transportation Infrastructure Financing Commission to be \$400 billion between 2010 and 2015. As shown in Figure 6-1, the gap is projected to rise to \$2.3 trillion when summed over the next 25 years (NSTIFC 2009).

The issue has taken on new urgency recently due to funding challenges at the federal and state levels. The main revenue mechanism for the federal Highway Trust Fund, the transportation fuels tax, is faltering. Real highway spending per mile traveled has fallen by nearly 50 percent since the Federal Highway Trust Fund was established in 1956. Total combined highway and transit spending as a share of GDP has fallen about 25 percent in the same period, to 1.5 percent today (NSTIFC 2009). The trust fund provides almost all federal highway funds and approximately 80 percent of federal transit funds.

Funding shortfalls in the Highway Trust Fund are related to a few key underlying factors, particularly the erosion of the real per gallon value of the fuels tax. Because it is not adjusted for inflation, the federal gas tax has dropped in terms of purchasing power by 33 percent since 1993, the last time it was increased (NSTIFC 2009). Adjusting further for increases in the price of highway construction materials, the federal gasoline tax had only 49 percent of the purchasing power in 2006 that it did on 1993 (Slone 2008). Meanwhile, construction inflation rose by a cumulative 40 percent in just three years from 2005 to 2008 (Florian 2008).

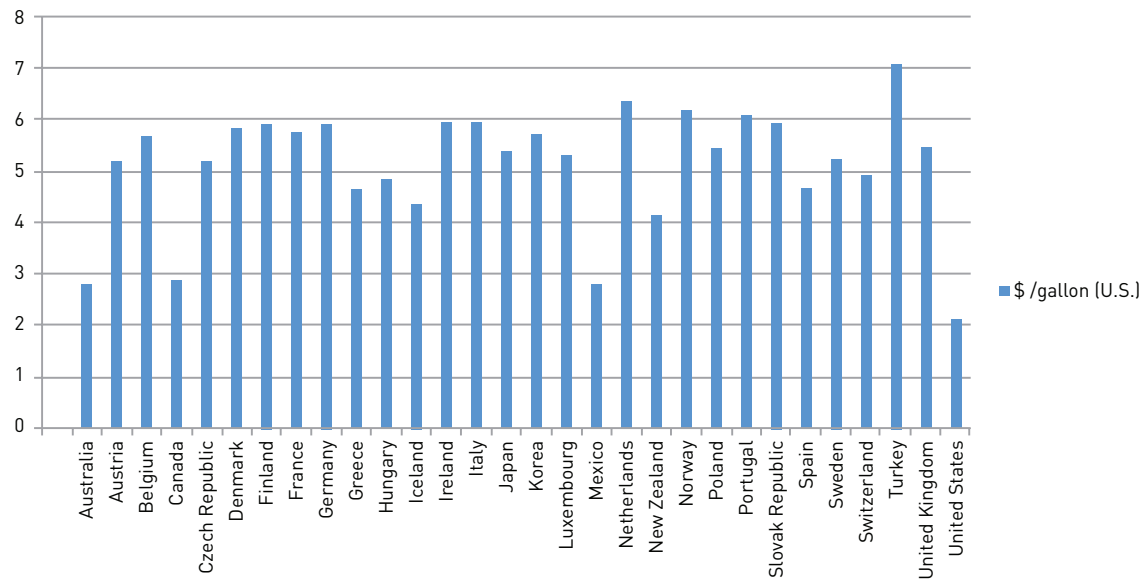
The problem has become even more acute because the recent economic downturn has significantly depressed gasoline and diesel consumption, thereby decreasing federal fuel tax revenues. Providing the funding to improve and expand the transportation system is also a significant challenge for state governments. Lower rates of gasoline consumption have meant diminishing funds for beleaguered state governments that also depend on fuel taxes for revenue.

The precarious situation of transportation infrastructure finance has significant implications for emission mitigation in the transportation sector. First, transportation funding is needed for traffic congestion mitigation projects. Urban congestion means slower traffic speeds and increased vehicle idling, and both of these factors contribute to higher vehicle emissions per mile. Second, greater investment for public transit is essential. Greater access to public transit means more options for consumers, and well planned public transit can achieve fewer GHG emissions per passenger-mile, for its ridership, while simultaneously alleviating pressure on congested urban roadways.

There are increasing calls for a dedicated fuel tax to address the staggering costs that state and federal governments face in rebuilding the decaying transportation infrastructure. Increased fuel prices could also be structured to attach a price on carbon in transportation fuels. As shown in Figure 6-2, current national transportation policies in the United States support gasoline prices that are significantly lower than those seen in the rest of the developed world. A national debate is needed to assess whether this is the best way to price transportation fuels in the future.

Engaging Consumers

Success in implementing sustainable mobility hinges on consumers and their purchasing decisions. The current national energy policy as it pertains to vehicle fuel economy sends consumers conflicting signals. Automakers are mandated to manufacture more fuel efficient vehicles. At the same time, the government promotes policies supporting inexpensive gasoline, and in doing so undermines demand for more efficient vehicles. This contradiction should be corrected by new public policies that send consumers consistent market signals promoting fuel efficiency and GHG reductions.

Figure 6-2: Retail gasoline prices among developed nations (U.S.\$)

Source: German Technical Cooperation 2009

Consumer choice involves several elements that relate to sustainable mobility, including VMT, vehicle fleet composition, the rate of adoption of new vehicle technologies, and consumer behaviors affecting real-world fuel economy, such as driving styles and commitments to proper vehicle maintenance. Too often, they are approached as distinct challenges requiring separate, and often complicated, policy solutions when the simple fact is that appropriate fuel price signals would address all of these elements of consumer behavior.

Policies to reduce VMT can lessen dependence on foreign oil and also reduce GHG emissions. Historically, growth rates for VMT and gross domestic product (GDP) have been strongly correlated (OHPI 2000). Policies to decouple VMT and GDP growth are possible, but efforts to reduce VMT demand careful analysis and planning to anticipate and avoid inadvertent impacts on the economy. In the future, as the vehicle fleet becomes more diverse and depends more on electricity and alternative fuels, VMT will not be the direct proxy for oil consumption it largely is today.

Eco-driving is another example of a powerful effect that consumer choices can have on real world fuel economy. The term refers to driving practices that maximize the fuel economy consumers obtain in real world driving. These practices include avoiding rapid stops and starts, maintaining a steady rate of speed while anticipating traffic flow, and consistently using the highest gear possible.

Experience in Europe demonstrates that eco-driving education campaigns can achieve results. The Netherlands and Sweden each launched eco-driving training programs in the late 1990s. The Dutch Ministry of Transport, Public Works and Water Management estimates that their eco-driving program resulted in a 600,000 ton reduction in carbon dioxide emissions in 2006 at an overall cost of only seven euros per ton of carbon dioxide emission avoidance. The Swedish eco-driving effort began with courses for drivers of passenger cars in 1999. Sweden has educated 27,000 drivers of light duty vehicles since the program's inception and projects an annual reduction in fuel consumption of 10 million gallons. This equates to a reduction of carbon dioxide emissions of 95,000 tons per year and an annual cost savings of 38.7 million euros (Cambridge Systematic 2009).

Consumer education on eco-driving has the potential to deliver significant improvements in fuel efficiency. In one U.S. study, 48 volunteers trained in eco-driving techniques showed an average 24 percent improvement in fuel economy as a result of the training. The results ranged from a six percent fuel economy improvement

to more than 50 percent, depending on driving style and the ability to master eco-driving behaviors (Ford 2008). Automakers support public-private efforts to educate drivers on eco-driving techniques. In 2008, Alliance members launched an online initiative to promote eco-driving awareness. To date, governors of 18 U.S. states and more than 20 organizations have announced their endorsement of the Alliance EcoDriving Initiative. To further these efforts, automakers support incorporating eco-driving techniques in student driver education programs administered by states, and the inclusion of eco-driving content in state and privately administered driving examinations.

The CAFE program requires automakers to produce vehicles that meet fleet-wide average fuel economy standards, with these standards becoming more stringent over time. Simply manufacturing these vehicles is not sufficient for automakers to fulfill their obligation under this form of regulation. More to the point, the public policy objectives of sustainable mobility are not met by simply producing these vehicles. The success of a CAFE approach ultimately depends upon deployment of these vehicles into the national fleet, and this rests in turn on purchasing decisions made by consumers.

Events during the summer of 2008 show how gasoline price signals can affect vehicle purchasing decisions. When gasoline prices surged to levels near \$4.00 per gallon in May 2008, there was a dramatic shift in consumer preference towards cars over less fuel efficient trucks and sport utility vehicles, although this consumer preference lasted only as long as the high fuel prices persisted. By February 2009, with the national average price of gasoline once again below \$2.00 per gallon, the U.S. market returned to favoring light trucks and sport utility vehicles over cars.

Feebate programs are designed to incentivize the purchase of more fuel efficient vehicles by issuing a rebate for vehicles exceeding a set fuel economy standard and imposing a fee on the sale of vehicles that fall below that standard. A feebate program is typically intended to be revenue neutral, with the rebate and fee portions offsetting one another. Predicting changes to consumer buying behavior under a feebate structure is difficult, and as a result it is hard to anticipate the revenue that will be generated by the fees and the amount required to fund the rebates. Experiences with the French and Canadian feebate programs, which have involved large government subsidies of their programs, illustrate the challenge of achieving revenue neutrality in practice.

Feebate programs present challenges to automakers by introducing uncertainty into their product planning. To keep the program revenue neutral, government must continually rebalance the rebate and fee halves, changing vehicle eligibility requirements each time. This is fundamentally at odds with the timescales for product planning needed by automakers. A feebate approach also suffers from the limitations inherent in the CAFE program. Both are narrow approaches that cannot address VMT growth or the carbon content of fuels. Like CAFE programs, feebates may succeed in increasing the fuel economy of the vehicle fleet while failing to deliver decreases in emissions from the fleet overall. Alternatively, appropriate fuel price signals can influence consumer choices along all of the relevant dimensions, including vehicle purchase decisions, VMT, and fuel economy enhancement behaviors, including eco-driving and proper vehicle maintenance.

A gasoline price floor is one policy option that would send a steady price signal to consumers, encouraging the sale of more fuel efficient automobiles. Under this approach, the government would impose a variable gasoline surcharge that would move inversely with the price of oil to maintain the retail price of gasoline at or above a selected level. Proponents have used a number of different terms to describe such a pricing mechanism, including a variable oil security charge, a fuel price stabilization program, or a gasoline price floor (Bordoff and Metcalf 2009; Lee 2009).

In setting the level of the floor, policy makers would first determine the amount of desired reductions in gasoline consumption and tailpipe emissions, and then select a price level that would deliver those reductions. If the price floor were set at \$4.00 per gallon of gasoline and the market price would otherwise have been \$3.00 per gallon, the government would assess a surcharge of \$1.00 per gallon sold to bring the price seen by consumers to the \$4.00 mark. If the price of oil increased, the surcharge would automatically

decline so that gas prices would stay about constant. If the market price for gasoline met or exceeded \$4.00 per gallon, the surcharge would disappear.

The U.S. government has historically been much more resistant to imposing fuel taxes than is the case in most other countries. Fuel tax policies have empirically proved to be a powerful means to achieving national goals in other countries. European tax policies, for example, have encouraged diesel fuel over gasoline since the 1940s. Diesel vehicles are 20 to 40 percent more efficient than conventional gasoline vehicles. In the United States, diesel is taxed at a slightly higher rate than gasoline, discouraging its use. In Europe, diesel is taxed 12 percent less than gasoline (*Diesel Fuel News* 2003). In the United States, federal taxes for diesel are 25 percent more than those for gasoline (API 2009). In the European Union, clean diesel accounted for over 50 percent of new vehicle sales in 2008, while in the United States the figure is only three percent (U.S. DOE 2009; Ward's 2009). Thus, the United States is in the curious position of imposing higher taxes on a fuel that supports a more fuel efficient vehicle technology.

2012-2016 and Beyond

The auto industry is committed to achieving the goals of the new paradigm outlined in President Obama's May 2009 program. Policies for 2012 and beyond will need to build on the success achieved early in the implementation of the new CAFE standards. While CAFE has made significant contributions to driving more fuel efficient vehicle technologies to date, its potential is limited. A more comprehensive set of policies is needed that also addresses transportation fuels and the ways consumers buy and drive vehicles. A new transportation strategy also needs to be anchored to a comprehensive, economy-wide effort to address energy and climate challenges.

State governments should be actively engaged in the development of a new transportation strategy, although, ultimately, federal leadership is required. Inconsistent or contradictory state policies can cause regulatory burdens and can stifle innovation. Pursuing national, economy-wide programs will maximize the chances of success.

A portfolio approach is needed to achieve sustainable mobility. Progress must occur in all four pathways—improved vehicle technology, cleaner conventional and alternative fuels, improved transportation infrastructure, and greater consumer engagement. Contributions by many stakeholders, including automakers, will be essential.

As part of a technology neutral approach, policies that promote long-term vehicle technologies must be combined with those that can achieve near-term, incremental progress. Emission-free miles are part of a powerful long-term vision. Work towards the development of vehicles that can deliver that vision, including both hydrogen and battery powered vehicles, should continue. At the same time, other technologies, including continued improvements to internal combustion engines, will play a significant role in greater vehicle efficiency for many years to come.

Consumers in particular will play a key role in the years ahead. Past efforts have failed to engage consumers adequately, in large measure because of the absence of adequate price signals. Policies should be created that will motivate all Americans to make choices that will limit GHG emissions and petroleum consumption. While some of these measures may be politically challenging, they deserve due consideration in a serious, honest discussion about how best to achieve sustainable mobility.

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Chapter 7:

Vehicle Standards in a Climate Policy Framework

by John M. DeCicco

Policy makers have long turned to vehicle regulation for addressing public concerns about transportation's energy and environmental impacts. This paradigm is ratified in recent action to raise Corporate Average Fuel Economy (CAFE) standards and issue vehicle greenhouse gas (GHG) emissions standards both in California and federally. At the same time, United States (U.S.) policy makers are moving toward a national program to limit GHG emissions economy wide. The most robust strategy entails capping emissions from all major sectors including transportation. Such a policy would place a broader constraint on the dominant, carbon dioxide (CO₂) portion of vehicle GHG emissions, which are also regulated by vehicle standards. This overlap raises questions of how vehicle-specific regulations should relate to the broader policy and what metric vehicle standards should use in such a context.

Answers can be found by reviewing the strengths and weaknesses of past policies and drawing on recent discussions regarding the design of national climate policy. One conclusion is that climate policy should require agencies to administer vehicle standards as part of an overall transportation sector GHG management plan that explicitly considers the costs and benefits of the standards relative to other measures that affect emissions. Another is that vehicle standards should be based on an energy metric rather than on GHG emissions rates, which depend on the fuel supply system and not just the vehicle itself. In general, vehicle standards should be promulgated as part of a policy structure that provides appropriate incentives for all actors in the sector: fuel suppliers, transportation infrastructure and land-use planners, consumers and vehicle manufacturers. Such an approach will ensure a balanced and ongoing progress in limiting transportation emissions in a manner reasonably commensurate with national climate protection goals, such as those defined by a declining cap on GHG emissions economy wide.

Introduction

Regulations have been a mainstay of public policy for addressing societal impacts affected by vehicle design since the first automotive air pollution standards were authorized by California's Motor Vehicle Pollution Control Act in 1960. Safety standards were instituted with the passage of major road safety legislation in 1966. The Clean Air Act required nationwide limits on tailpipe pollution starting in 1975 (CAA 1970). Following the 1973 oil embargo, the Energy Policy and Conservation Act established Corporate Average

J. DeCicco is a senior lecturer at the School of Natural Resources and Environment, University of Michigan

Fuel Economy (CAFE) standards as a way to control oil demand (EPCA 1975). Taking effect for cars in 1978 and light trucks in 1979, CAFE standards required a roughly 63 percent improvement by 1985 for the overall light duty fleet relative to its 1975 level of 15.3 miles per gallon (mpg), or an average improvement rate of 5 percent per year (EPA 2008).

Many policy makers see vehicle fuel economy and GHG emissions standards as crucial for addressing the transportation portion of the global warming problem. For the auto industry and many economists, however, vehicle regulation is not an obvious tool for controlling GHG emissions. Their preferred solutions are taxing carbon or using a cap-and-trade system to put a price on carbon throughout the economy. From an environmental perspective, a cap-and-trade approach has the advantage of constraining emissions while maximizing flexibility and cost-effectiveness (Stavins 2008). If vehicle standards remain in place, economic efficiency gains can be realized if the regulations are integrated into the cap-and-trade regime (Ellerman et al. 2006).

Transportation Emissions and Regulation

Transportation accounts for 28 percent of the total GHG inventory in the United States and is, after industrial energy use, the second-largest end-use source (EPA 2007). Therefore, it is essential to include transportation in any comprehensive national climate program. A cap-based design confronts the dispersed nature of transportation emissions, which come from millions of individual vehicle tailpipes. Directly regulating GHG emissions from consumers' vehicles is not workable (House E&C 2007).

Some analysts suggest using a "sectoral hybrid" strategy (Nordhaus and Danish 2003). In this case, cap-and-trade covers major stationary sources and transportation is handled with vehicle efficiency standards. Similarly, the European Union's Emissions Trading System (EU-ETS) addresses power generation and industrial sources. The EU addresses transportation through a combination of voluntary vehicle CO₂ standards and pricing policies, including high fuel and vehicle taxes. Without transportation under the cap, however, this strategy does not assure the integrity of economy-wide emissions limits.

Most U.S. cap-and-trade proposals require that transportation fuel suppliers submit allowances to cover the CO₂ emitted from the use of fossil-derived fuels that they sell. Transportation emissions are therefore covered indirectly based on fuel chemical characteristics, which are readily measured. This approach is seen in bills dating from the McCain-Lieberman proposal of 2003 through the Waxman-Markey bill that passed the House in June 2009 (ACESA 2009) and Senate bills under discussion as of this writing. California authorized a cap-and-trade system in its Global Warming Solutions Act (AB 32 2006). The state's draft regulation proposes to place transportation fuels under the cap starting in 2015 (CARB 2009). All of these policies assume that vehicle standards are already in place.

The tailpipe CO₂ emissions covered by cap-and-trade are the same as those addressed by vehicle regulations, including both CAFE standards and GHG emissions standards such as California's Pavley rules (AB 1493 2002) and newly proposed federal rules (EPA and DOT 2009). Environmental advocates believe that vehicle standards leverage the technology change needed for reducing emissions (ASE et al. 2002; Sierra Club 1991, 2005). Others believe that if the objective is to reduce total fuel use and emissions, fuel and carbon taxes or a carbon cap are more cost effective (Portney et al. 2003).

At this point vehicle standards are a fait accompli. For light duty vehicles, the single national program announced by the Obama Administration on May 19, 2009, is in place for model years 2012 to 2016 (White House 2009a). This program entails a ramp-up of stringency similar to that called for by California's Pavley standards. For fuel economy, it amounts to a four-year advance approaching the 35 mpg combined fleet target that EISA (2007) had required by 2020. Moreover, authority for direct regulation of motor vehicles is unlikely to be superseded by climate policy. Pending climate legislation is either silent on the matter or extends authority to vehicle classes not regulated historically. California policymakers are starting to plan for post-2016 Pavley standards, identifying hypothetical levels for analytic purposes (CARB 2009).

Regulatory Coordination Questions

To date, vehicle standards have been developed independently of GHG targets, being set instead through engineering and economic studies of how much fuel economy gain can be accomplished over a given time frame (Greene and DeCicco 2000; NRC 1992, 2002). Such studies use a technology assessment rather than an economic efficiency framework, and are not quantitatively tied to the emissions limitations needed to meet climate targets. Neither have fuel economy rules been formally driven by quantitative energy conservation or petroleum reduction goals, even for the original CAFE standards that required a near doubling of automobile fuel economy over ten years (DOT and EPA 1974). Interestingly, however, an aspirational goal of saving two million barrels per day figured prominently in the Congressional deliberations that led to the original CAFE standards (Nivola 1986).

Going forward, the issue is whether future motor vehicle standards, promulgated after a national climate policy is in place, should be coordinated relative to economy-wide GHG targets. Questions include how the effort required by vehicle regulation relates to that for other parts of the transportation system, such as fuels, travel demand and other modes; how it relates to the level of effort in other sectors of the economy; and what metric is best for administering vehicle standards within a broader climate policy.

A Climate Policy Framework

To successfully confront a problem as vast as global warming, it is necessary to evaluate numerous GHG reduction measures in terms of how well they collectively limit emissions to climate protective targets. As stated by the U.S. House of Representatives Energy and Commerce Committee:

The climate change program must be an economy-wide program that accounts for all greenhouse gas emissions in the United States because (1) dramatic emissions reductions are required, (2) many economic sectors contribute to greenhouse gas emissions, and (3) everyone must fairly share responsibility for reductions. An economy-wide climate change program does not mean, however, that all sectors contribute their fair share in the same way. (House E&C 2007)

As climate strategy advances, policy makers increasingly see merit in setting GHG emissions caps at national or regional levels and using emissions trading as a way to balance environmental effectiveness with economic efficiency.

Cap-and-trade enables the creation of an international system for tracking GHG emissions allowances. It minimizes costs through trading within and among capped nations and the use of emissions credits earned by uncapped countries or sectors (Jorgenson et al. 2008). Incentives to reduce emissions are thereby extended to sources that otherwise would be unregulated. Only cap-and-trade moves economies toward a uniform, cross-jurisdictional price on carbon, because markets linked through emissions trade will gravitate toward a common price if the trading rules are transparent (Rühl 2009).

For domestic policy, a cap-and-trade system ties together the elements of what is otherwise a piecemeal strategy. The cap establishes a well-defined limit on the GHG emissions inventory, providing an anchor for other parts of the policy and linking economic sectors together in a legally enforceable manner. Through such a framework, policy makers can have reasonable confidence that the GHG inventory will stay within the bounds necessary for climate protection (EDF 2007).

Pros and Cons of Cap-and-Trade for Transportation

As a leading transportation energy analyst notes, creating an economy-wide price signal is considered, “the essential cornerstone of a meaningful climate change strategy” (Greene 2007). However, a cap alone

is not sufficient for transportation. Greene also states, “[O]ther policies will be needed in addition to a cap-and-trade system in order to make the reductions in GHG emissions that are likely to be necessary” for addressing the sector (Greene 2007). This view builds on the rationale for vehicle efficiency regulation that exists apart from climate concerns. Technologies that increase fuel economy face market barriers that a carbon price signal is unlikely to overcome because consumers do not fully value fuel savings over a vehicle’s lifetime (Greene and Shafer 2003; Greene et al. 2009). One reason is that fuel represents a relatively small share of total vehicle ownership costs (von Hippel and Levi 1983).

Some analysts conclude that cap-and-trade is not useful for the sector (German 2007; Yeh and Sperling 2009). Indeed, it has been called a “nonsolution” for transportation, the argument being that “until biofuels and electric and hydrogen vehicles become commercially viable ... it is better to focus on more direct forcing mechanisms, such as a low-carbon fuel standard for refiners, coupled with fuel and greenhouse gas standards for vehicle makers and incentives and rules to reduce driving” (Sperling and Gordon 2009). Nordhaus and Danish (2003) conclude that cap-and-trade is the best design overall, but because it poorly handles transportation, they propose an approach that omits transportation fuels from the cap and relies instead on vehicle efficiency standards to control GHG emissions from the sector.

Other analysts view vehicle standards as a complement to, rather than replacement for, including transportation within a cap-and-trade system. The Energy and Commerce Committee (2007) wrote:

If refiners and importers are designated as the “point of regulation” for the transportation sector in the cap-and-trade program, a comprehensive climate change program will also regulate motor vehicle manufacturers through efficiency or other performance standards for vehicles.

In addition, that paper said that climate policy should involve all parties that contribute to emissions from the sector, with a design that treats vehicles and fuels as a system and addresses consumer demand.

Structure of Transportation Markets

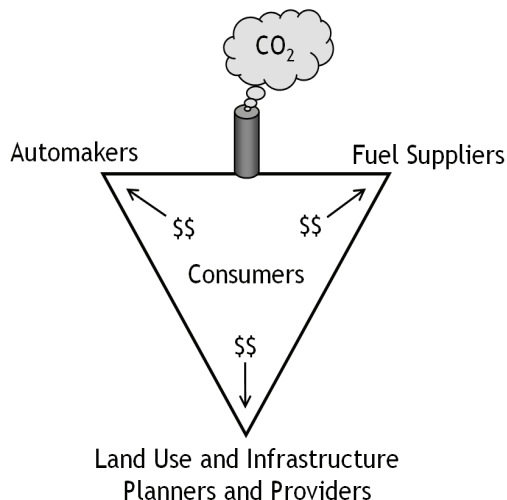
The insufficiency of simply putting fuels under the cap can be understood by a close look at the markets comprising the sector. It is not just the fuels market that underpins transportation GHG emissions. The “three-legged stool” analogy reflects how emissions are a product of factors, rather than a sum of terms. These three factors are vehicle usage, vehicle fuel consumption rate and fuel carbon intensity. The result is a “factorization dilemma,” meaning that the GHG inventory for each major mode of transportation cannot be subdivided in a manner that assigns unique shares of emissions to the sector’s key actors.

Figure 7-1 shows the market structure for the automotive subsector. The emissions come from vehicles operated by consumers, shown in the middle of the triangle. The points of the triangle correspond to the sector’s other major actors, whose financial transactions with consumers define the distinct but interlinked markets that influence emissions:

- Consumers purchase vehicles from automakers.
- Consumers buy motor fuel from fuel suppliers, now mainly the petroleum industry.
- Consumers purchase roads, parking, land and its associated uses and land-use patterns through taxes, user fees and in the price of many bundled services of the built environment from the array of public and private entities that provide transportation infrastructures, plus urban and regional plans that underpin travel demand.

The distinct markets that influence transportation emissions can be seen as cash flows from consumers or other system users who are the source of demand to the suppliers of transportation-related products and services. Analogous structures exist for other transportation subsectors.

Figure 7-1: Actors in the interlinked markets that determine automotive sector CO₂ emissions



No one price-quantity relationship captures the decision making that determines transportation emissions. Neither can a simple, single market model adequately inform policy design for integrating the sector into a carbon market. A complex set of different but interlinked markets defines the way actual decisions are made. It is not reducible to the market for motor fuel, although fuel suppliers are the actors best suited to serve as the point of regulation for cap-and-trade.

A complete market-based policy must reckon with all of these relationships. Focusing on only one, such as the fuel market price/quantity response, will lead to an imbalanced and ineffective policy. Because the vehicle, fuel and travel demand markets are so different, one cannot expect to easily level the costs of carbon reduction among them, let alone among transportation markets and other sectors.

USCAP Recommendations

The above concepts buttress recommendations made by the U.S. Climate Action Partnership (USCAP), a coalition of corporations that includes diversified industrial firms, automakers, oil companies, utilities and other businesses as well as several environmental groups. A Blueprint for Legislative Action outlines a framework that entails a cap-and-trade program plus cost-containment measures and complementary policies (USCAP 2009). For transportation, it recommends a systematic approach in which responsibility for limiting emissions is shared among fuel suppliers, vehicle manufacturers, consumers and public officials who plan and manage infrastructure and land use, as shown in Table 7-1.

Although fuel suppliers are the point of regulation, the principle of shared responsibility implies that they serve in an accounting capacity on behalf of all actors in the sector. Vehicle standards are a mechanism by which automakers do their share, but as for other measures in a capped sector, efficiency standards are not expected to significantly decrease CO₂ emissions below the level set by the cap. As Table 7-1 indicates, other measures needed to control transportation energy use and thereby limit demand for allowances include policies to reduce GHG-intensive travel and improve system efficiency.

USCAP also recommends fuel-related performance standards in addition to including fuels in the cap. A low-carbon fuel standard (LCFS) has been proposed for this purpose (Hwang 2009; Yeh and Sperling 2009). Such an approach is used in California, with the state's LCFS designed to mesh with its vehicle GHG emissions standards. A purely market-based approach for addressing uncapped emissions and motivating fuel technology change has also been proposed (DeCicco 2009).

The item most pertinent to the question of how to coordinate vehicle standards with the broader climate program is USCAP's recommendation for an overall transportation sector GHG management policy. Such a provision would require the Environmental Protection Agency (EPA), Department of Transportation (DOT) and other federal agencies to assess progress in controlling GHG emissions from the sector, examining contributions from vehicle efficiency, fuels, consumer demand, infrastructure and other transportation systems, and update their policies as needed to keep the sector on track.

Table 7-1: Elements of the USCAP approach for transportation climate policy

<i>Transportation Fuels in the Cap</i>	<i>Complementary Measures</i>
Fuel suppliers submit allowances to cover fossil-based CO ₂ emitted from transportation fuel use by consumers and other end users	Fuel-related GHG performance standards
Point of regulation at the refinery gate and importers of refined products	Vehicle-related GHG performance standards
Transparency of the carbon price signal to end users	Policies to reduce carbon-intensive travel, educate consumers and improve system efficiency
Fair and equitable allocation of allowance value for addressing carbon price impacts on transportation fuel consumers	Overall transportation sector GHG management policy
	Technology transformation programs for the sector, including RD&D for advanced low-carbon vehicles and fuels

A cross-cutting recommendation is that local, state, regional and federal programs should be complementary, aiming to achieve compatibility and avoiding conflicts that might drive up compliance costs and make it more difficult to achieve environmental goals.

Source: USCAP (2009), pp. 6-7, 12-13, 16, 21-23

Tying Targets to Societal Needs

This last recommendation suggests a formal public process for tying vehicle standards to national GHG mitigation goals specified by cap-and-trade legislation. Even without a legislated cap, standard setting could be guided by administrative goals, such as the Obama Administration's targets of 17 percent below 2005 levels by 2020, ramping down to 83 percent below by 2050 (White House 2009b). Note that this linkage does not imply that vehicle standards have the same targets as an economy-wide program; it only means that the national targets should be formally factored into the standard setting process.

Exactly how such a linkage can be made has not been determined to date. California's Pavley standards were set before the statewide climate policy was enacted. Those targets, plus the EISA-dictated CAFE levels, defined the negotiating space in which the White House compromise was struck in May 2009, without any formal tie to national GHG targets.

The Need of the Nation to Conserve Energy

EPCA requires CAFE standards to be set at the maximum feasible level based on four considerations: technological feasibility, economic practicability, the effect of other standards of the government on fuel

economy, and the need of the nation to conserve energy (EPA and DOT 2009). Program administration has, however, varied greatly, from the Carter Administration's rapid increase in light truck standards to the Reagan Administration's rollbacks of car standards. It is difficult to see how purely objective assessments of the first three statutory considerations could result in such widely different outcomes unless their application was itself guided by differing subjective views of the need to conserve energy.

Aside from the initial near doubling of passenger car fuel economy mandated by EPCA, Congress has not made a firm commitment on limiting U.S. transportation energy use. The many failed attempts to move stronger standards through Congress and the appropriations riders that prevented the National Highway Traffic Safety Administration (NHTSA) from raising CAFE standards demonstrate this reluctance. Legally, the recent CAFE increases can be seen as just another transient response to political pressures of the time, in contrast to a well-defined, long-term commitment such as a carbon cap might provide.

EPCA and EISA do not provide rigorous guidance for determining societal need, even though EISA strengthened some economic analysis requirements. The CAFE program lacks "any statutorily prescribed formula for balancing the factors" that go into standard setting (EPA and DOT, 2009). NHTSA has broad discretion in how to interpret the law when determining the "maximum feasible" fuel economy levels required for a future model year. Challenges to CAFE rules were rarely upheld by the courts until the notable Ninth Circuit Court decision in 2007, which remanded the model year 2008-11 light truck rule to NHTSA for reconsideration. Among the reasons cited was the agency's failure to monetize CO₂ emissions when setting the standards (Ninth Circuit, 2007).

Clean Air Act Lessons

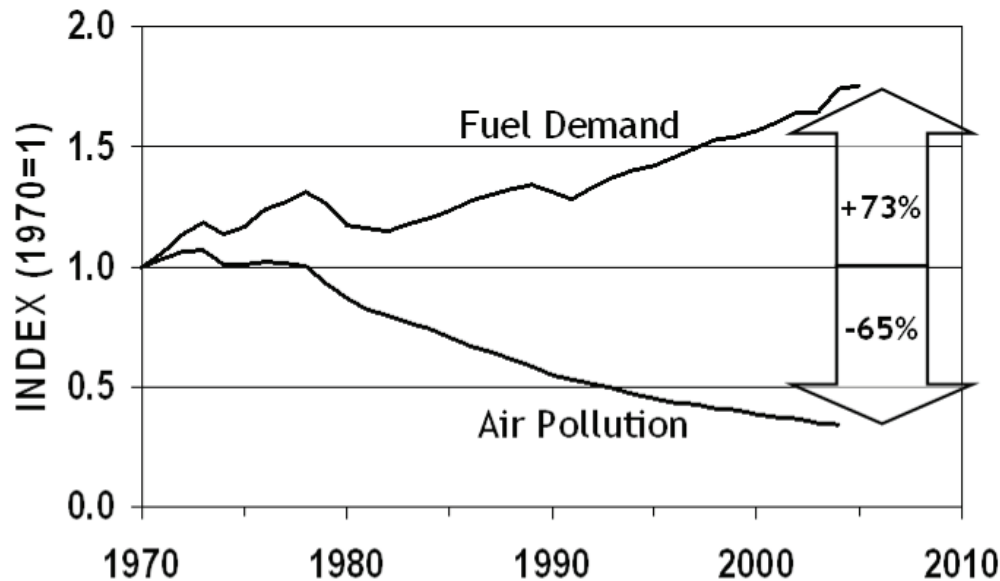
EPCA's lack of specificity for evaluating the need of the nation to conserve energy when setting CAFE standards contrasts with the administrative approach in the CAA. The act requires attainment of National Ambient Air Quality Standards (NAAQS), which are in turn scientifically determined based on the impacts of air pollution on public health and welfare. This formal linkage is essential because the long, ongoing quest for clean air has driven successive rounds of emissions standards for all major sources of air pollution, including motor vehicles. The results can be seen in Figure 7-2, which compares the reduction of total conventional pollutants from U.S. light duty vehicles with the lack of progress in reducing fuel use over the past 35 years.

Bottom-up engineering assessments are a major part of the regulatory process for developing vehicle emissions standards. Questions of technological feasibility and cost loom large, involving lively debates regarding what is possible over a given time frame and at what cost. Regulated industrial firms, such as automakers, are understandably cautious about environmental investments because they are rewarded poorly in the private market. Conversely, environmental advocates and officials representing regions with strong support for clean air, such as California, are optimistic about the ability to improve technology at an acceptable cost. Ongoing "clean air wars" have reflected this dynamic (Doyle 2000).

The CAA legal foundation has been critical for achieving the absolute reductions in environmental impact seen in Figure 7-2. As long as areas were not in attainment, public officials were obligated to cut emissions further, leading to tighter inventory targets for criteria pollutants and their precursors. Specific regulatory requirements for meeting these targets were then apportioned among major sources based on technical and economic considerations.

This process balances the concerns and capabilities of different industrial and regional stakeholders. An instructive example is the EPA-led effort to help the Northeast with ozone attainment in the face of interstate nitrogen oxide (NO_x) transport. The resulting recommendations by the Ozone Transport Assessment Group (OTAG) led to stricter standards for vehicles and fuels, power plants, industrial boilers and other sources (OTAG 1997). This process of basing on scientifically determined inventory targets is seen in the EPA-mandated revisions to State Implementation Plans in the so-called NO_x SIP call and the Tier 2 and heavy-duty diesel programs and related regulations, the health benefits of which are still accruing today.

Figure 7-2: Trends in total fuel consumption and conventional air pollution for U.S. cars and light trucks, 1970-2005



Source: Derived by author using total nationwide fuel use and emissions levels (not per-mile rates) from U.S. DOT and EPA data; the air pollution index is based on a health damage cost weighting of tailpipe nitrogen oxides (NO_x), volatile organic compounds (VOC), particulate matter (PM₁₀), carbon monoxide (CO) and sulfur dioxide (SO₂).

Seen in this light, it is not the simple analogy of vehicle GHG emissions standards to emissions standards for controlling criteria pollutants that is most relevant for climate policy, even though that analogy has had tactical value for leveraging climate action broadly and vehicle regulation in particular. Rather, it is the core CAA paradigm of attainment and the administrative process it entails. Such a requirement is a missing link in the energy policy embodied in EPCA's guidelines for the CAFE program and the way those guidelines are mimicked in California's AB 1493 law. Technology and economic assessments can be argued to greater or lesser levels of stringency, but by themselves lack a legal link to quantitative environmental requirements.

As administered to date, vehicle efficiency and GHG emissions standards answer only the question of "How much can we do?" rather than the more critical question of "How much must we do?" to meet a societal goal. The Clean Air Act works because it compels an ongoing effort to do what must be done to protect public health and welfare. Recognizing the importance of this foundation, most climate legislation is crafted to build on the CAA, preserving its core enforceability provisions, while specifying a sequence of GHG emission limits through the cap, which plays the role for climate protection that the NAAQS do for air quality.

Toward Carbon Management for Transportation

The national climate policy proposals of 2009 do not ensure that the authorities affecting transportation limit GHG emissions to levels low enough to meet the cap. ACESA does not address light duty CAFE and GHG emissions standards, providing for no coordination with the bill's cap-and-trade program. Most new measures authorized, such as GHG standards for heavy vehicles and alternative fuel promotions, are given in Titles I and II of the bill without a link to Title III, which sets the cap. The energy efficiency and clean energy provisions for other sectors are similarly disconnected from the cap. In California, although the first round of AB 1493 standards was promulgated before the statewide climate policy established by AB 32, the goals of latter legislation are being applied as the state develops additional policies and updated measures

under its scoping plan (CARB 2008). Thus, that state is moving toward a cross-sectoral GHG management framework that will presumably include future rounds of GHG standards.

The closest connection federally is ACESA's system efficiency provision requiring DOT to "establish national transportation-related greenhouse gas emissions reduction goals," plus procedures for evaluating targets for achieving those goals, which are to be set at levels "commensurate with the emissions reductions goals" given by the bill's global warming provisions (ACESA 2009). It also requires DOT to assess progress in reducing transportation GHG emissions at least every six years. It does not, however, require an administrative process to modify the programs if the sector fails to make adequate progress. The proposed GHG policy differs from CAA transportation conformity provisions, which require state and local transportation plans to demonstrate consistency with air quality goals before federal project funding is approved (FHWA 2005).

Some might argue that weak administration of complementary measures does not matter if a cap is in place because the carbon price will rise enough to bring emissions into line. However, real-world complexities dictate that climate policy include carefully crafted sets of measures addressing sector-specific concerns and many other issues. If lack of progress in a major sector such as transportation causes very high carbon prices, the overall program could be jeopardized. It might trigger provisions that allow emissions to exceed the cap or provoke a political backlash that eviscerates the policy. Therefore, measures to limit transportation energy demand must be administered to ensure adequate progress relative to other measures both within and across sectors.

The transportation sector GHG management policy suggested by the USCAP Blueprint provides such a coordination mechanism:

Congress should require EPA, in collaboration with the Department of Transportation and other federal and state and local agencies, to carry out a periodic in-depth assessment of current and projected progress in transportation sector GHG emissions reductions.... This assessment should examine the contributions ... attributable to improvements in vehicle efficiency and GHG performance of transportation fuels, increased efficiency in utilizing the transportation infrastructure, as well as changes in consumer demand and use of transportation systems, and any other GHG-related transportation policies enacted by Congress. (USCAP 2009)

The results of this assessment should be applied to modify policies as needed to ensure sufficient progress, without a need to go back to Congress:

On the basis of such assessments EPA, DOT and other agencies with authorities and responsibilities for elements of the transportation sector should be required to promulgate updated programs and rules—including revisions to any authorized market incentives, performance standards, and other policies and measures—as needed to ensure that the transportation sector is making a reasonably commensurate contribution to the achievement of national GHG emissions targets. (USCAP 2009)

The resulting linkage between complementary measures such as vehicle standards and economy-wide goals provides a coordination mechanism now absent from climate policy as proposed to date.

This approach offers protections for regulated parties such as automakers. It does not create a new expectation for increasingly more stringent vehicle standards; the authority to raise standards already exists under EISA and the Clean Air Act. What it means instead is that standards would no longer be developed in isolation from other measures. Agencies could use an OTAG-like process, with stakeholders able to air their concerns and guide the analysis used to update not only vehicle standards, but all sector policies affecting GHG emissions. If the cap itself—perhaps amplified by incentives that reward measured

as opposed to projected realization of low net carbon vehicle-fuel systems—begins to accelerate progress in limiting transportation emissions, then further increases in vehicle standards may become unnecessary.

What Metric for Vehicle Standards?

Two metrics are now in use: 1) fuel economy measured in miles per gallon as used for CAFE standards; and 2) GHG emissions rate measured in grams of CO₂-equivalent emissions per mile as used by CARB and proposed by EPA. The EPA and DOT (2009) proposed rule notes that the vast majority of CO₂ emissions from vehicles are related to fuel economy because they are proportional to fuel consumption. Most reductions under vehicle GHG standards come from fuel-related CO₂, the exceptions being halocarbons from air-conditioning systems and small amounts of methane and nitrous oxide. These trace gases, which comprise about five percent of total vehicle GHG emissions, would need to be specially handled in any case.

In considering the metric for vehicle regulation, the actors diagram of Figure 7-1 is a useful point of reference. A policy should motivate parties according to aspects they most directly control. Vehicle standards target automakers, but automakers do not control the processes associated with producing fuel. Automakers can develop vehicles that use any given fuel more efficiently. Therefore, a metric for energy rather than emissions, such as fuel efficiency or consumption rate, makes the most sense. This view is corroborated in the USCAP Blueprint, which, in reference to CAFE, states:

These vehicle fuel economy programs have a scope and structure that are consistent with the need for complementary measures for on-road vehicles, as stated in the Call for Action, and can serve as the basis for such measures going forward. (USCAP 2009)

Thus, fuel economy standards are now supported by a wide range of stakeholders.

Problems with GHG emissions rates for vehicle standards

Vehicle GHG emissions rates can be evaluated on an end-use, or tailpipe, basis or on a lifecycle, or well-to-wheels, basis. An end-use basis misses the emissions associated with supplying fuel. For zero emissions vehicles (ZEV), such as battery electric or hydrogen fuel cell cars, essentially all impacts occur upstream during fuel production and distribution. Rating such vehicles as having zero GHG emissions is misleading and provides no incentive for efficiency. A direct basis is also problematic for biofuels, if the “renewability shortcut,” which excludes CO₂ emissions from biogenic carbon, is used (DeCicco 2009).

For these reasons, GHG standards are commonly defined on a lifecycle basis. Compliance relies on CO₂-equivalent gram-per-mile (gCO₂e/mi) results from lifecycle analysis (LCA) models that account for vehicle use-phase emissions, and, therefore, fuel economy, plus fuel supply-phase emissions. Notably, vehicle supply-phase manufacturing emissions are not included in vehicle GHG standards as proposed to date, even though the regulated automakers arguably have more control over emissions from the production of their product than they do over the emissions associated with the production of fuel.

A vehicle’s GHG emissions rate is not a well-defined attribute of the vehicle itself. Although it has taken on great familiarity from the voluminous well-to-wheels analyses over the years, the gCO₂e/mi metric is an abstraction based on the joint characteristics of an assumed vehicle-fuel system. Unlike fuel economy or vehicle emissions as traditionally regulated, it cannot be measured using repeatable, objective tests of a given vehicle. Fuel lifecycle assumptions must be introduced, and these assumptions have a very large impact on the results.

Another rationale for GHG emissions standards is that they provide a technology-forcing mechanism for the vehicle/fuel system. The belief that alternative fuels will solve transportation energy problems motivates policies to promote alternative fuel vehicles (AFVs), which fuel cycle analyses suggest are capable of

deep reductions in GHG emissions. Although numerous federal and state AFV and ZEV mandates and programs have been pursued over the years, none have had a measurably transformative impact (McNutt and Rodgers 2004). Nevertheless, hope springs eternal for policies that seek to change the car in order to change the fuel, as seen in the current enthusiasm for plug-in hybrids like the Chevy Volt. Vehicle GHG standards expand this paradigm, embedding assumptions about the promise of alternative fuels, whether liquid, gaseous or electricity, in standards that regulate vehicles.

Vehicle focused-policies cannot affect fuel availability or infrastructure (Viera 2009). Neither do they affect the fuel supply system and the upstream processes that dominate the impacts of many alternative fuels. Moreover, it is not clear that reducing fuel GHG intensity requires changing fuel chemistry. Attempting to use vehicle policies to force changes in transportation energy supply may turn out to be as ill-advised over the decades ahead as it has been ineffectual over the decades past.

An Energy-Based Metric

A vehicle regulatory metric based on energy entails the fewest assumptions and avoids confounding attributes of the vehicle with those of the fuel supply system. Energy-related impacts, such as demand for GHG emissions allowances, scale with fuel consumption as opposed to its inverse of fuel economy, and so vehicle energy use rate, measured, for example, in BTUs per mile, is an ideal metric. It can be directly measured for any vehicle, including dual-fuel vehicles or plug-in hybrids, based on defined tests.

While fuel consumption rate might be ideal, a fuel economy metric could be reformed to avoid its existing distortions based on assumptions about particular fuels. CAFE has used regulatory parameters related to petroleum use and other special assumptions, such as those for dual-fuel vehicle credits. The planned phase-out of those credits is helpful in moving to a well-specified metric that will stand the test of time. An energy-based metric maintains a clean division of labor between the regulated parties on the demand side of the market, such as automakers, and transportation fuel providers on the supply side.

Much recent effort by CARB and EPA has gone into defining GHG emissions standards for vehicles. The Supreme Court (2007) found no conflict in having both GHG and CAFE standards in place. Although complicated, the overlapping regulation is administratively workable, as discussed by the EPA and DOT (2009). This does not mean, however, that dual regulation of vehicles for both fuel economy and GHG emissions is the best long-term approach for policy.

Compared with an energy-based metric, a GHG metric introduces numerous problems and no clear benefits. GHG emissions standards were advanced for tactical reasons to overcome automakers' strong objections to raising CAFE standards. It may well be that it is politically important to preserve such leverage. However, if a mechanism, such as the overall sector GHG management policy described above, is put in place to ensure coordination of standards with national GHG reduction goals, then these tactical considerations may become less important.

Conclusions

Vehicle standards are an essential part of climate policy because they target decisions in the auto market, an important determinant of transportation GHG emissions. Although standards have been based on fuel economy or GHG emissions rates, neither approach now includes a mechanism that ties vehicle standards to a broader climate policy, such as cap-and-trade.

A lesson from the success of the CAA is that a formal linkage to a well-defined national goal is crucial for ongoing progress. This legal framework is more important than the resemblance of GHG emissions standards to conventional emissions standards. Linkage can be achieved through an overall transportation GHG management policy that ties the administration of vehicle standards and other sector programs to

national climate protection goals. It would entail requiring agencies that oversee aspects of the transportation system to assess the sector's progress in reducing emissions and to update their programs and policies as needed to ensure that the sector progresses along a path that is reasonably consistent with the economy-wide GHG targets and timetable.

For specifying vehicle standards as part of a broader climate policy, an energy-based metric makes the most sense. This conclusion is reached for several reasons: vehicle efficiency is a factor that automakers can influence; automakers have little influence on fuel supply or the fuel production processes that determine fuel GHG intensity; the fact that energy consumption rate and fuel economy can be measured unambiguously; and because efficiency-based reductions of fuel demand are important for limiting GHG emissions under a cap.

Further analysis and discussion are needed regarding how to implement such a policy, which would need to consider the structure of the multiple markets that affect transportation emissions. Nevertheless, the challenges involved are similar to those of conventional air quality management, if not indeed technically more straightforward. The success that federal and state agencies have had in balancing the costs and benefits of various air pollution control strategies serves as a good model for an effective transportation sector GHG management policy. Such a policy would enable more stable and evenhanded administration of vehicle standards than seen historically as stringency varied with the politics of the day. It would harmonize the level of effort on vehicle regulation with that on fuels and travel demand as well as other sectors of the economy. The resulting framework would create a stronger and more equitable climate strategy for both transportation and the economy overall.

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Chapter 8:

Accelerating Technology Innovation in Transportation

**by John E. Johnston, Carmen Difiglio, Trevor Demayo, Robert Marlay,
and David Vincent**

Worldwide policy actions are required to avoid dangerous concentrations of greenhouse gases (GHGs). If the transportation sector is to achieve large reductions in its GHG emissions, major changes will be needed over the next four decades. It will be necessary to reduce the demand for transportation services and to supply those services with as few GHG emissions as is possible. Success will require close coupling of science, technology, and policy.

The scale of the transportation system and its energy consumption complicate the innovation process. “One size fits all” approaches are not consistent with the diversity of demand and supply patterns already existing in developed economies and emerging in developing economies. It will be necessary to focus resources on the technologies and practices that achieve the largest emission reductions and to integrate them with economy-wide policies. In particular, a close linkage between policies to electrify the transportation sector and policies to reduce GHG emissions from the power sector are essential. Technology impact will be limited by diffusion, which depends on market readiness, capital availability, vehicle fleet turnover rates, and public and private institutional capacity. Accelerated innovation depends on greater inputs from the social sciences as well as the traditional physical sciences and engineering.

This chapter begins to answer several critical questions that link transportation technology development and commercial success. Are the existing fuel, vehicle, and transportation technologies capable of achieving large reductions in oil use and GHG emissions? What is the government’s role in bringing new technologies to the market? What might be some new approaches for government and industry to stimulate innovation, from research and development (R&D) to commercialization and international technology transfer opportunities? Should government policy begin to back particular transportation technologies or attempt to be technology neutral? Finally, if no single approach is likely to be sufficient, what is the best decision-making strategy to undertake in a resource-constrained environment?

Creating and sustaining portfolios of technology and policy options is an important strategic element. However, if corporations and entrepreneurs want and need government financial and policy assistance to support innovation, then they and the government will have to come to terms with the concept of “picking

J. Johnston is a retired Planning Executive and Senior Scientific Advisor at ExxonMobil Research & Engineering, C. Difiglio is Deputy Assistant Secretary for Policy Analysis at the U.S. DOE, T. Demayo is a Senior Planning Engineer at Chevron Energy Technology Co. and leads the Low Carbon Energy Team, R. Marlay is Acting Director of the Office of Climate Change Policy and Technology at the U.S. DOE and D. Vincent is Director, Projects at the Carbon Trust in the United Kingdom.

winners.” Portfolio development, technical and economic risk assessment, and scenario planning are potentially powerful tools used to address this challenge. Equally important, the various stakeholders must appreciate that successful innovation depends on rapid learning from failure as well as success, and design, investment and commercialization processes accordingly.

The Scope of the Problem

The U.S. Energy Information Administration (EIA 2009) and the International Energy Agency (2008) project increasing demand for transportation energy between now and 2030. The EIA reference case shows liquids made from petroleum and biomass used in transportation increasing from 51 percent of total liquid fuel consumption in 2006 to 56 percent in 2030. This increasing share is largely the result of industrial, electric power, and residential and commercial sectors shifting away from liquid fuels. The net effect is liquid fuel use for transport increasing from 41 million barrels of oil equivalent production per day (MBOE/day) in 2006 to about 57 MBOE/day in 2030. The IEA projections show a somewhat smaller increase in demand for conventional liquid fuels in 2030, but increases in the demand for unconventional liquid fuels, biofuels, natural gas, and electricity to meet a transportation sector demand of about 63 MBOE/day in 2030. In summary, both reports project a significant increase in both transportation energy demand and fossil fuel use in the business-as-usual reference cases.

Because the reference cases assume no major changes in the carbon intensity of energy globally, the projected rise of carbon dioxide (CO₂) emissions will tend to track increases in energy consumption. Achieving significant reductions in CO₂ emissions in order to stabilize atmospheric concentrations would require reductions of over 50 percent from the 2030 reference case. This is a significant challenge and requires changes in all sectors, including transportation.

Wigley *et al.* point out that the timing of technology implementation is critical for determining emission trajectories and more importantly the longer term CO₂ concentration trajectories (Wigley *et al.* 1996). These trajectories define a window between 2005 and 2040 during which planning and initial implementation need to take place.

Fuels and Vehicles

Traditional providers of fuel and vehicle technology face an increasingly complex set of requirements and market conditions. Global energy demand is growing, especially in China, India, and Latin America. This has led to increased industry competition for, and investment in, resource discovery and production. Uncertainty about the balance between supply and demand has resulted in increased price volatility, which complicates investment decisions, particularly those with large scale and longer term payout.

Energy companies, particularly transportation fuel producers, are attempting to respond to increasing expectations about the need to address climate change, as well as the environmental, social, and health impacts of our transportation system. Specific examples include constraints on energy development arising from the potential negative impacts on air quality, the availability of land, and water quality.

At the same time, these companies are actively engaged in developing technologies to improve the energy efficiency of their own operations, for example through increased use of cogeneration of steam and electricity in refining and enhanced oil recovery. Technology is also required to support the diversification of the energy supply, including developing and integrating sustainable energy resources and clean fuel technologies. A typical energy company R&D portfolio will contain project and program elements directed toward all of these areas. The portfolio is designed to respond to the short term demands for innovation and investment in sustaining the business and transportation energy sector. There will also be medium and longer term portfolio elements intended to support a rapidly changing view of the future.

Vehicle manufacturers face a similarly complex set of challenges. Creating a market for alternative fuel and other advanced vehicles requires them to respond to customer demands for tangible environmental benefits, including improved fuel economy. These must be coupled with equal or improved performance, safety, reliability, utility, and comfort, with an equal or lower cost of ownership, including fuel costs. The EIA projects that unconventional light duty vehicles (LDVs) could make up 63 percent of the 2030 annual sales of 20 million vehicles in the United States. Of these almost five million are projected to be hybrid electric vehicles, including plug-in hybrids.

Table 8-1: Key technical issues and challenges – fuels

<i>Fuel</i>	<i>Key Technical Issues and Challenges</i>
Gasoline and Diesel	Crude oil supplies, producing cleaner higher performing fuels, WTW GHGs
Biofuels	WTW GHGs, water and land use, impact on fuels, feedstock selection, biomass growth strategy, conversion processes, fueling infrastructure compatibility
CNG, LNG, LPG	Supply, WTW GHGs, cost, distribution logistics
GTL	Plant efficiency and cost, WTW GHGs, competition from LNG
Hydrogen	WTT GHGs, forecourt storage volume, cost, infrastructure requirements, distribution logistics, codes and standards
Electricity	GHGs, cost, charging infrastructure, energy storage

The carbon constrained scenario includes significant contributions from energy reduction in transportation, as well as the use of a mix of fuels very different from those assumed in the reference case. Actualizing this scenario implies major changes in fuels, vehicles, and transportation systems. Specific challenges for the fuel system include availability, cost, safety, and well-to-wheels (WTW) GHG emissions. These are described in more detail in Table 8-1. Equally important are the required improvements to the vehicle technologies capable of utilizing these fuels. These are identified in Table 8-2.

Table 8-2: Key technical issues and challenges – vehicles

<i>Engine Technology</i>	<i>Key Technical Issues and Challenges</i>
Internal Combustion Engine Vehicles	Improved fuel economy at affordable cost and at scale, new combustion regimes such as HCCI
Natural Gas Vehicles	Onboard storage weight and volume, cost and range
Plug-in and Battery Electric Vehicles	Battery materials, power, energy density, reliability, lifespan, charge time, cost and production scale-up
Fuel Cell Vehicles	Fuel cell cost, reliability, and lifespan, hydrogen storage weight and volume, materials, packaging, water management, safety

The U.S. Department of Energy (DOE) and Department of Transportation (DOT) also recognize that meeting significant GHG emission reduction requirements will mean changes in the transportation system within which the fuels and vehicles are used. They have identified a set of transformational transportation

strategies, which are the major strategic components of government support for research and development in transportation (Cambridge Systematics 2009). These strategies are summarized in Table 8-3.

Table 8.3: Transformational transportation strategies

<i>Strategy</i>	<i>Elements</i>
A Vehicle Energy Efficiency	Highway vehicle technology, anti-idling, CAFE, feebates, maintenance, rail, marine and aviation
B Alternative Fuel Solutions	Ethanol, GTL, CNG, LNG, biofuels, hydrogen fuel cells, alternative jet fuels, electricity, hydrogenated fuels, dimethyl ether
C Transportation System Efficiency	Operations, anti-idling, LCVs, weight limits, information and information technology, bottleneck relief, infrastructure, construction and maintenance, regulation and education, congestion pricing, carbon pricing, reduced speed limits, interactions with VMT strategies
D Transportation Demand Management	VMT/travel behavior, intercity tolls, VMY fees, PAYD Insurance, demand management, PI-cost of flying, telework, compressed work week, flexible work schedules, urban freight consolidation centers, market regulation and education, mode choice, demand management, transit expansion, promotion, service, ride matching car and van pools, nonmotorized transport, modal freight diversion intercity passenger rebound effects, land use planning, infrastructure development, technical assistance
E Economy-wide Market Incentives	Cap and trade, carbon taxes, motor fuel taxes
F Infrastructure Planning and Investment	Changes to state and metropolitan planning, emission budget mechanisms, structure of government spending on transportation

As these three tables indicate, a successful approach to reducing the GHG emissions associated with transportation is going to require significant innovation. It is unlikely that all of the technologies listed in these tables will play a key role in the decarbonization of transport. In particular, the DOE will likely focus on just a few alternative transportation fuels even though there are many current candidates. Traditionally, improvements in transportation efficiency have centered on fuel and vehicle technology, with an emphasis on modifying the internal combustion engine (ICE) system through changes in areas such as fuel quality, ignition control, and the introduction of hybridized drivetrains. A wider and more intensive approach to technologies is needed.

Attempts to introduce alternative fuel engine systems, such as compressed natural gas (CNG) use in natural gas vehicles (NGVs) and hydrogen use in fuel cell electric vehicles (FCEV), have had little success to date. The motivation to introduce alternative fuels has evolved over the years. In the 1970s, alternative fuels were offered as a solution to oil dependency. In the 1980s and 1990s, they were offered as a path towards reduced urban pollution. More recently they are being promoted to reduce GHG emissions. Certain alternative fuels, such as CNG, offer a limited GHG reduction potential but are promoted as a way to reduce oil dependence. Hydrogen and electricity may offer GHG benefits if economically produced and distributed from a renewable energy source, or if produced from natural gas or other fossil fuels coupled with carbon capture and sequestration (CCS). Regardless of the potential benefits of CNG, hydrogen, or electricity, the

problem of building the refueling infrastructure and introducing large numbers of vehicles that operate on those fuels may be so great that the investments happen slowly or not at all.

Biofuels, such as ethanol and renewable biodiesel, based on vegetable and algal oils, are also a key element of a GHG reduction strategy. Challenges to widespread biofuel use include land and water use, life cycle GHG emissions, conversion efficiency, integration into the existing fuel distribution system, compatibility with the existing vehicle fleet, and cost. While U.S. policy is still evolving, national climate and energy legislation proposed during 2009 appeared to focus on reduction of power sector emissions and programs to encourage the electrification of private motor vehicle transport. The previous Congress, in 2007, enacted strong policies to promote low-carbon biofuels, although there may be opportunities to improve upon these policies using a low carbon fuel standard approach based on the full fuel cycle emissions of each biofuel.

Second and third generation biofuels are also a key element of a GHG reduction strategy since, if successfully developed, they directly displace petroleum in conventional vehicles. Nonetheless, advanced biofuels face a number of sustainability issues including land use, water requirements, and increased GHG emissions caused by indirect land use effects. While there are strong biofuel mandates and incentives in many countries, they are unlikely to be successful without lower-cost production technologies.

Increasing electrification of vehicles, in the form of plug-in hybrid electric vehicles (PHEVs) and battery electric vehicles (BEVs), could provide increased efficiency and lower GHG emissions, depending on the source of the electricity, and with the advantage of a largely existing infrastructure. Combined with policies to reduce power sector GHG emissions, PHEVs and BEVs appear to be highly promising technologies to dramatically reduce GHG emissions in private motor vehicles. Nonetheless, challenges remain in the development of battery systems, vehicle performance and reliability, and cost. Even so, rapid technological progress and initial commercialization are underway.

Despite the historical emphasis on vehicles and fuels, making significant reductions in GHG emissions associated with transportation will also require major changes in the patterns of demand for transportation energy. Specifically, vehicle use needs to be reduced. This involves changing individual patterns of behavior, adopting land use practices that discourage the use of private transport, and increasing the availability and attractiveness of public transport in urban and suburban areas. Finally, there is a need to shift the cultural context of personal transportation to that of a privilege with inherent social and environmental responsibilities.

Much of the basic research needed to support these efforts at transforming vehicles and fuels has been done. In many cases significant development work is underway, both in the private and public sectors. In some cases, there have been limited demonstrations of the technologies and systems. Progress has been slow, in part due to the sheer size of the transportation system, but also due to inadequate attention to the complexities of processes to successfully take ideas from development and demonstration into the market. This issue needs urgent attention in order to transform transportation to reduce its GHG emissions.

Thus, it appears that there are sufficient fuel, vehicle, and transportation technologies to gain large reductions in oil use and GHG emissions, but a much more comprehensive approach to the amount and pace of innovation in the transport sector is still needed. This includes innovations in fuel and vehicle technologies and innovations to modify the patterns of demand and use in the private and commercial sectors.

The Role of Government

Governments have several traditional mechanisms for encouraging innovations, including direct funding of R&D, financial incentives and tax credits, and policies that help create a more predictable environment for investment and risk taking. In addition, there are at least two more progressive strategies that can be employed: 1) identifying and removing barriers to innovation, and 2) actively participating in the innovation process by providing both financial support and innovation process expertise.

U.S. DOE Activities

An example of a more progressive strategy is DOE's identification of the major categories of barriers to innovation. They include cost effectiveness, fiscal barriers, regulatory and statutory barriers, and intellectual property barriers. Other obstacles include infrastructure limitations, industry structure, and policy uncertainty. Beyond identifying the categories and more specific barriers, the DOE has developed a portfolio of activities designed to reduce or eliminate these barriers for transportation technologies (DOE 2009b). The programs involve the DOE, the Environmental Protection Agency, the Department of Transportation, the Department of the Interior, and other federal government agencies. A summary is shown in Table 8-4. The strategies reflect some of the complexity in innovation systems, including incomplete and inaccurate information, risks of both technical failure and market failure, the criticality of infrastructure, and the sometimes conflicting requirements of regulatory bodies and statutes. Effectively implementing these strategies will also require innovative approaches to policy development and intra-governmental cooperation.

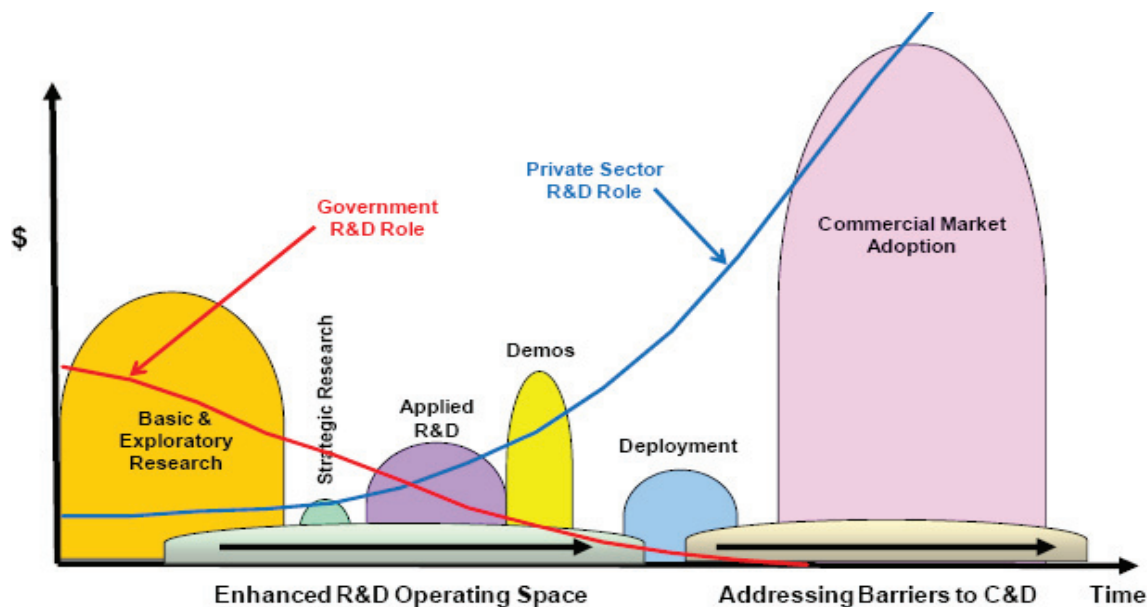
Table 8-4: Select federal activities addressing technology deployment barriers in transportation

<i>Technology Deployment Barriers</i>	<i>Major Programs, Policies or Initiatives</i>	<i>Illustrative Deployment Activities</i>
Incomplete and Imperfect Information	43	Clean Cities (DOE), Green Vehicle Guide (EPA), climate friendly parks (DOI), commuter choice (DOT, EPA)
High Costs	23	Alternative motor vehicle credit, Voluntary Airport Low Emission Program (DOT), Clean Fuels Grant Program, (DOE) Clean School Bus USA (EPA)
Market Risks	17	Fuel use for federal vehicles, Hybrid Truck Users Program (DOD), SmartWay Transport Partnership (EPA)
Technical Risks	16	FreedomCAR and Fuel Partnership (DOE), Advanced Vehicle Testing Activity (DOE), 21st Century Truck Partnership (DOE)
External Benefits and Costs	15	Federal workforce transportation benefit, gas guzzler tax
Infrastructure Limitations	13	Transit Capital Investment Grant Program (DOT), alternative fuel infrastructure tax credit
Competing Regulatory Priorities	7	Alternative fuel infrastructure tax credit
Lack of Specialized Knowledge	12	Arterial Management Program (DOT)
Competing Statutory Priorities	1	Hydrogen Codes and Standards Program (DOE)

In addition, there are a number of new approaches to supporting innovation that are underway. These include use of Energy Frontier Research Centers to bring scientists from the national laboratories, universities, and non-profit and for-profit enterprises together for a period of five years to "... harness the most basic and advanced discovery research in a concerted effort to establish the scientific foundation for a fundamentally new U.S. energy economy" (DOE 2009a). Also underway is the development of Energy Innovation Hubs to support cross-disciplinary research addressing barriers to transforming the U.S. energy system. This was originally envisioned as a group of eight hubs, hosted by the DOE's offices of Science, Energy Efficiency and Renewable Energy, Nuclear Energy, and Basic Energy Sciences, and will focus on solar electricity, fuels from sunlight, batteries and energy storage, carbon capture and storage, grid technologies, energy efficient buildings, extreme materials, and modeling and simulation. Success in these areas will inevitably impact the transportation sector.

These activities and initiatives reflect a view of government's role in the innovation process as a provider of direct support for basic R&D, strategic research efforts and some applied R&D, all of which are coupled to private industry R&D. In addition to the direct R&D support, the types of activities mentioned above are designed to enhance the effectiveness of all parties in the R&D operating space as well as eliminate barriers to commercial deployment, as visualized in Figure 8-1.

Figure 8-1: Government and private sector roles in innovation



The Carbon Trust Model

The United Kingdom (UK) Carbon Trust was created in 2001 following a proposal from members of the business community. It provides an example of government directly engaging with the private sector to stimulate technological innovation. The trust was founded to overcome challenges of:

- National or regional economies not making the transition to a low carbon economy in a timely fashion
- Markets alone not undertaking this transition, calling for government intervention
- Current bodies and systems not able by themselves to catalyze this transition

The Carbon Trust's mission is to "accelerate the move to a low carbon economy by working with organizations to reduce their carbon emissions and develop commercial low carbon technologies" (Carbon Trust 2009). In response to business, it was established by the UK government as an independent company, funded by the government.

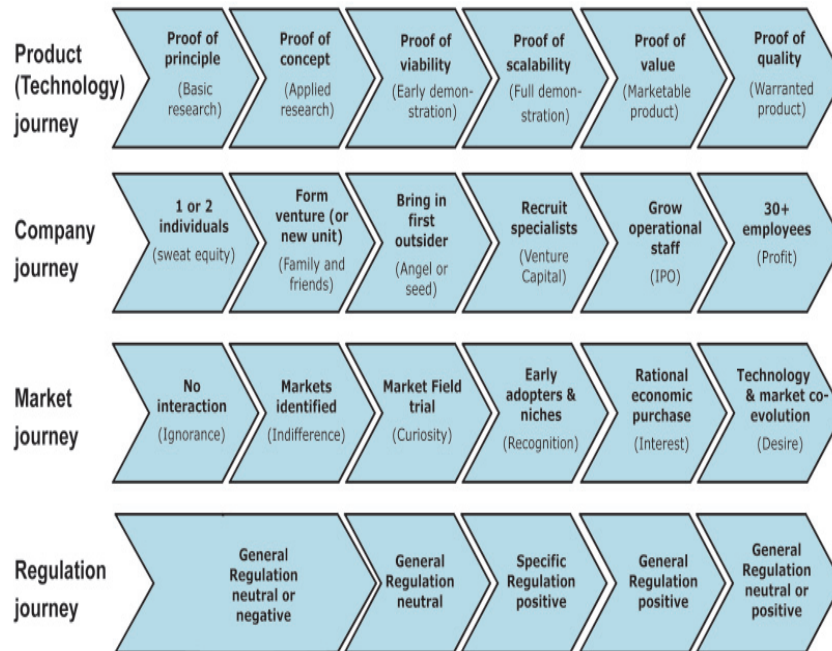
Each year, the board approves and oversees the business plan, and determines the allocation of funding to the programs, without reference to the government. The use of the funds is overseen by the National Audit Office. The Trust focuses on five low-carbon business areas:

- Insights: explaining the opportunities and challenges surrounding climate change
- Solutions: delivering carbon and monetary savings through energy efficiency
- Innovations: developing low carbon technologies for future carbon savings
- Enterprises: creating low carbon businesses for a low carbon economy
- Investments: financing clean energy businesses for a green growth economy

The following generic characteristics of the Carbon Trust are probably desirable for almost all countries in almost all settings: independence, transparent governance, business focus, well-informed technology teams, and the ability to analyze the operating environment in order to inform its development.

The Carbon Trust relies on two main strategies to accelerate innovation: informed intervention and active engagement with the innovators throughout the process, from R&D to incubators to early stage investment. This engagement reflects a view of the innovation process that goes beyond a focus on the development and deployment of a technology. The process model, summarized in Figure 8-2, recognizes the importance of developing organizational capacity and of assuring market conditions favorable to product acceptance and a regulatory environment that supports rather than impedes commercial success.

Figure 8-2: Low-carbon innovation journeys



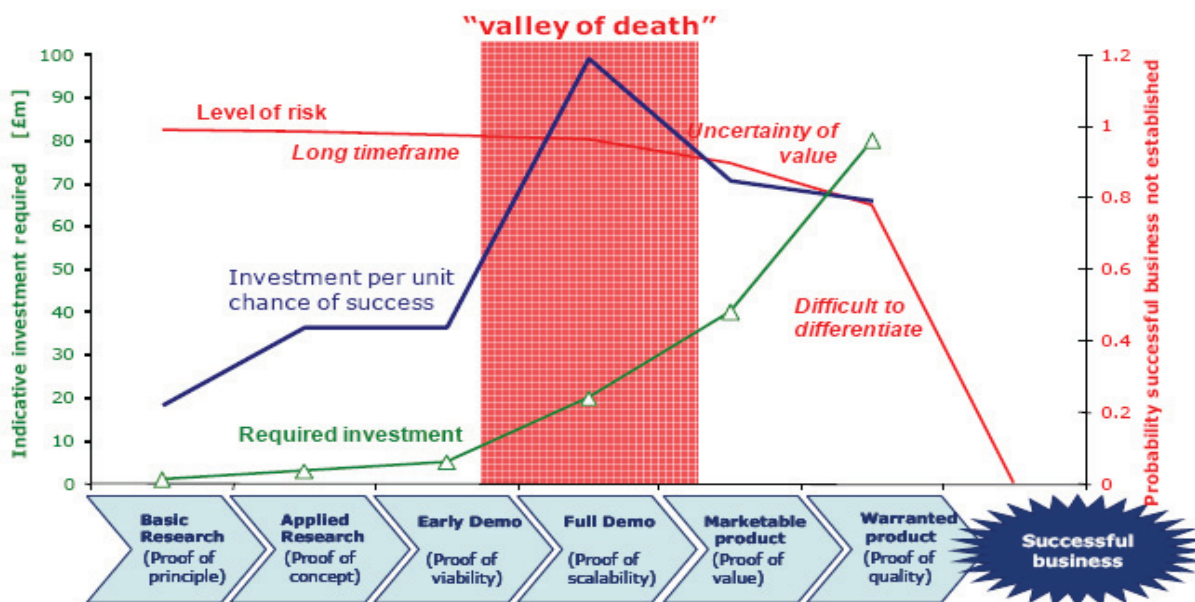
R&D investment in low-carbon technologies represents somewhat unique circumstances compared with more conventional technology investments. They include uncertainty of value, long time frames, and difficult product differentiation. It can be quite difficult to differentiate the product of a low-carbon production chain sufficiently to support a higher end-user price. Value depends on governmental and societal priorities and pricing mechanisms, such as carbon cap and trade systems, that are new or untested. Replacing existing technology, for example in transportation, may require fleet turnover, the installation and integration of new production facilities, and possibly even new logistical infrastructure, all of which typically require long times before a major impact is seen.

What that means for low-carbon technology innovation is that the investment risk can be substantial, particularly at the critical proof of viability and scalability stage, the so-called “valley of death,” shown graphically in Figure 8-3.

The challenge is to create commercially focused projects, at scale, which attract research and commercial partners and address the barriers to market. Since its inception the Carbon Trust has developed a number of insights about navigating this terrain. The amount of money committed by the Trust appears to be less important than the knowledge, breadth of experience, and commitment of its staff. Public funding can be highly leveraged with private capital and capital from the various consortia that the Trust organizes to help bring partners and investors together. For example, over 180 applied R&D projects have been funded and

over 65 percent of completed projects are in the process of generating new patents, making commercial sales, or receiving further private sector investment for the development of the technology.

Figure 8-3: Risk and investment in low-carbon innovation



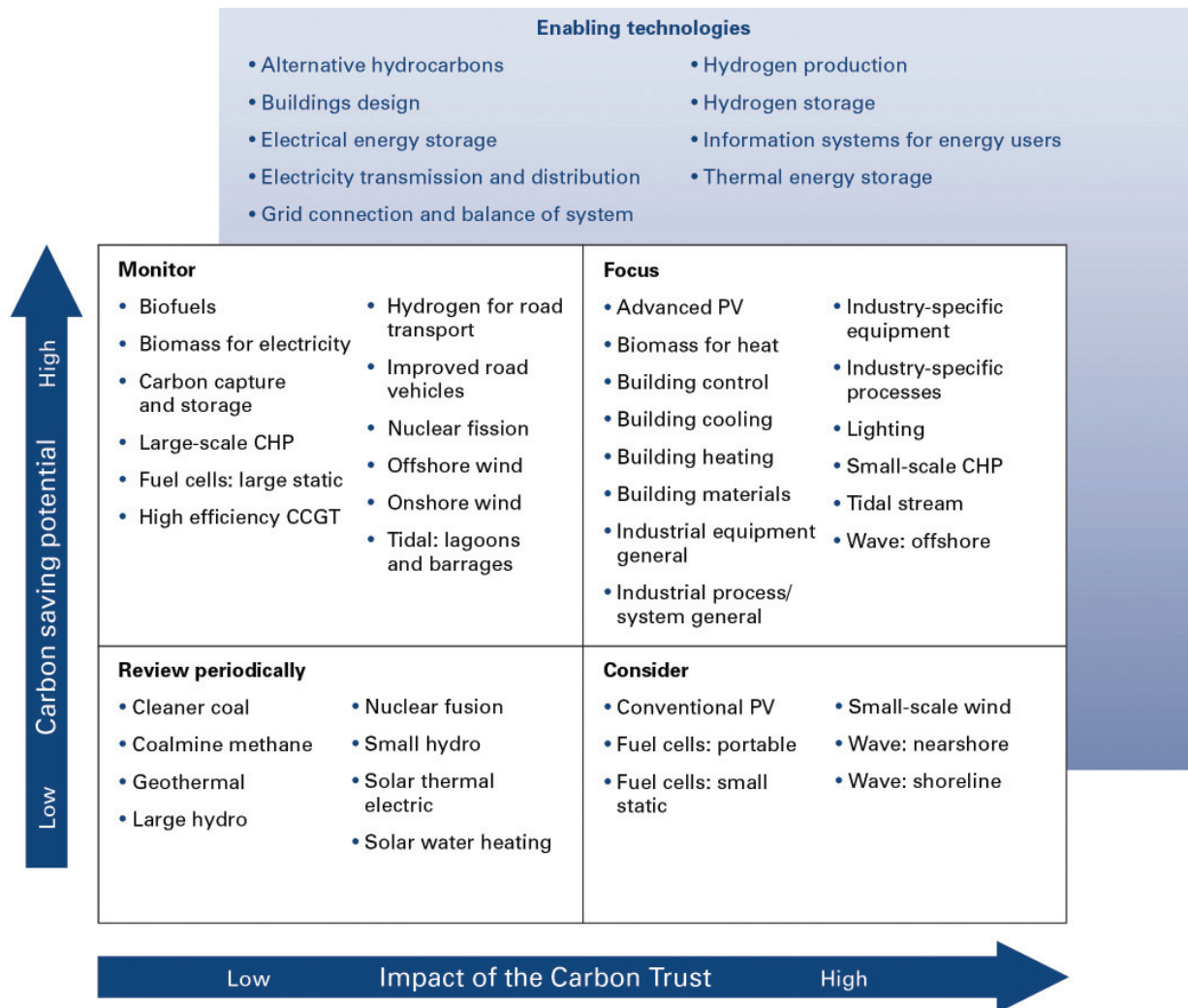
In addition to finance, it is also necessary to remove barriers to the adoption of low carbon technologies. This area is the focus of technology accelerators, which are projects specifically designed to direct Carbon Trust funds and resources at specific commercialization barriers. In a typical example featuring micro combined heat and power units, a lack of independent information on performance and carbon savings was preventing appropriate deployment in the market for new or replacement boilers. In the case of the Offshore Wind Accelerator, a major barrier to accelerated deployment was the absence of engineering information essential to the design and development of lower-cost solutions essential to greater deployment.

Portfolio management plays a central role in helping to focus the efforts of the Trust. The opportunities may be characterized by their impact on carbon emissions and also by the impact that the Trust might have if it were to engage. An example of this type of analysis is shown in Figure 8-4; it presents a broad range of projects that are periodically reviewed, monitored, and analyzed. It also helps to identify enabling technology areas for special attention.

A central tenet of the Carbon Trust's approach is the use of partnerships of various types. One of these is in directed research. These are relatively large investments, averaging a few million British pounds per project as a minority contribution, led by the Carbon Trust. They are designed to overcome specific technical barriers and capitalize on research breakthroughs. Partners are identified through public competitions that assemble world-class teams. The results of the work are intended to generate equity investments to form commercial outlets such as special purpose vehicles (SPV) or spin-off companies. Current examples include directed research projects in advanced photovoltaics, advanced biofuels pyrolysis, development of algal biofuels, and breakthrough polymer fuel cell research.

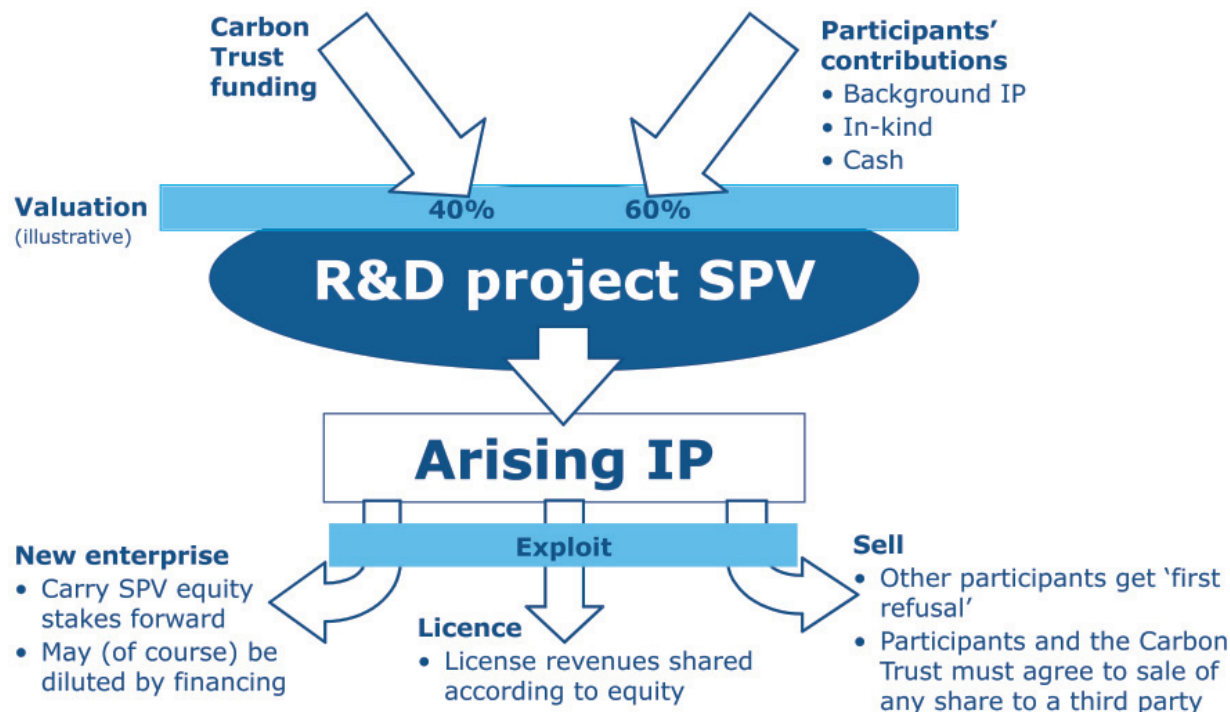
SPVs can accelerate the introduction of low carbon innovation technologies through processes shown schematically in Figure 8-5. Their development creates new intellectual property and is a means to conduct the R&D needed to ensure commercial success. They enable partners, including the Trust, to achieve a return from investments.

Figure 8-4: Technology Focus Makes Better Use of Resources



Another partnership approach used by the Carbon Trust is to support incubators—early stage university spinoffs and business start-ups with viable clean energy concepts. The Carbon Trust currently has six low carbon incubators providing specialized assistance on company formation, business plan preparation, capacity building, intellectual property protection, and marketing strategy. Up to 70,000 British pounds, or about \$110,000 (U.S. dollars), of service can be provided per incubatee. The aim of the incubation support is to bring incubatees to the next level of commercial maturity so that they become ready for investor capital. Incubator mentors provide the necessary strategic and commercial thinking to prepare these start-ups for investment. Eighty-two companies have been supported since the inception of the Trust. Twenty-five raised private investment, three have listed on the UK Alternative Investment Market with over 84 million pounds (\$130 million) of private funding raised, and three launched license agreements.

A non-financial contribution made by the Carbon Trust is the knowledge it shares and the insights gained in its exploration for opportunities. This contribution includes teams of experts who can explain the opportunities and challenges surrounding clean energy and carbon reduction technologies. Analysis teams work with innovation teams to explore how to develop the policy-market environment for low- carbon technologies and businesses. Published independent insights are also available to inform government policy, and to help businesses take advantage of the opportunities presented by a low-carbon economy.

Figure 8-5: Special purpose vehicle model for shared risk and reward

Summarizing the Role of Government

These examples from the U.S. DOE and the UK illustrate a diverse set of ways in which government can play a role in encouraging technological innovation to combat climate change through the deployment of low carbon technologies. Both governments have a portfolio of technologies and models for innovation that identify when, where, and what types of government involvement might be most effective. Both are actively engaged in trying to identify and remove both technical and nontechnical barriers to innovation. While the amount of funding varies, both governments recognize that funding alone is not the answer and they see that institutional and organizational capacity needs to be developed to successfully deal with the unique challenges of low-carbon technologies.

Government's role in bringing new technologies to market includes providing funding, insight, and information; the creation and encouragement of partnerships among universities, national laboratories, and the private sector; identification and removal of barriers; and risk mitigation in early-stage commercialization.

Specific Issues Related to Transportation

There are both industry and government perspectives related to specific issues appropriate to the transportation sector. Additional R&D funding and support to the fuel and vehicle industries from the public sector are needed.

Fuels development R&D funding and support is needed for each step of the well-to-tank lifecycle. Specific research areas include the following:

- Identifying and growing sustainable renewable feedstocks, including the selection of viable biomass conversion pathways
- Generating low carbon hydrogen and steam

- Further integrating efficiency upgrades into refineries and oil fields
- Demonstrating and deploying carbon capture and sequestration technologies

Development of new vehicles with low-carbon tank-to-wheels GHG emissions will require research in the following areas:

- Better understanding of real-world performance and fuel economy of new vehicles, including use of PHEVs in a wide range of applications
- The study of better pathways to help deploy leading edge technologies, such as advanced batteries and homogenous charge compression ignition engines
- Focusing R&D to help bridge technology gaps, such as systems to improve exhaust waste heat recovery
- Continuing support for near-commercial technologies, including advanced ICEs, with priority on those with clear potential for wide customer use

In addition to providing funding, governments can help by taking stock of existing policies and measures directed at the transportation sector. The challenge is to look at the impact these have on innovation, speed to market, and economies of scale. This implies identifying gaps and formulating complementary policy designs. It may also mean recognizing that “one size fits all” may not be the best approach. There may be significant regional and modal differences that favor the use of one set of policy instruments over another. The problems associated with low carbon transportation are not unique to the U.S. or the UK, and neither are the potential responses. This means that international engagement and cooperation are important.

Almost any innovation that requires a significant change in fuel infrastructure, vehicle systems, or consumer behavior will need government support in the early stages because of the magnitude of the existing transportation systems and the relatively slow turnover of technology and practices associated with that size. Overall, accelerating low carbon innovation requires commercially focused, independent and well-informed support for early-stage R&D activities to reduce technology risks, attract private investors, and create compelling consumer products. The R&D must be conducted by impartial and credible entities to bring business and researchers together to address the barriers.

The transportation sector embodies some unique challenges in reducing its GHG emissions. It is a significant contributor to overall GHG emissions and energy use, but is composed of hundreds of millions of individual sources and many individual decision makers. Simply improving technology will not provide a route to timely reductions in GHG emissions. Changes in the behavior of the individual vehicle users and decision makers are required, and can be supported and encouraged by government policies. There are already examples of how government can encourage innovation. These types of approaches need to be extended to the modification of demand and changes in the character of supply.

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Chapter 9:

Smart Growth and Climate Change: California's SB 375 and Sacramento's Blueprint Experience

by Mike McKeever

Strategies and policies to reduce greenhouse gas (GHG) emissions from transportation have mostly focused on vehicle technology and fuels. The use of those vehicles and fuels has received much less attention. This chapter describes innovative efforts in Sacramento, California, to reduce vehicle use and sprawl. While the initial motivation for this initiative had little to do with climate change, the Sacramento experience soon became a model and inspiration for a 2008 California law to reduce GHGs by reducing land use sprawl and vehicle use. The 2008 law is now being used as a model for national legislation. Thus, the Sacramento experience provides insight and background for policies and processes targeted at vehicle use and urban land use—whether to reduce GHGs or simply manage urban growth.

The Sacramento Area Council of Governments (SACOG) represents the governing bodies of 22 cities and 6 counties—Sacramento, Placer, El Dorado, Yolo, Yuba and Sutter—in central California that work collaboratively to plan future transportation and land use patterns for the region. Under federal law, SACOG is the designated Metropolitan Planning Organization (MPO) for the region. Every four years, it prepares a long-range Metropolitan Transportation Plan that must comply with the federal Clean Air Act. SACOG is also responsible under state law for planning to meet the region's housing needs and, since 2008, to oversee reductions in GHG emissions from passenger travel. The organization is a voluntary association with responsibilities to address the needs of its member cities and counties. SACOG's 31-member governing board includes at least one elected representative from each of its 28 member governments.

While SACOG carries out integrated land use, transportation and housing planning for the entire region, it does not mandate compliance with its regional land use vision, known as the Blueprint. Instead, the Blueprint represents a consensus among its members based on their recognition that they share common challenges and will succeed through common strategies. This chapter describes SACOG's Blueprint growth strategy; the land use planning principles that underpin it; land use, transportation and air quality metrics that measure the plan's performance; and SACOG's new responsibilities to reduce GHGs.

The Blueprint Process

The Blueprint is a strategy to guide growth through the year 2050 adopted in December 2004. Its development followed adoption of a Metropolitan Transportation Plan in 2002 to determine whether traffic conges-

M. McKeever is Executive Director of the Sacramento Area Council of Governments

tion, air quality and overall quality of life could be improved in the Sacramento region through changing the current pattern of development. The process was designed to combine the best technical information with a comprehensive citizen and stakeholder participation to determine the region's preferred future growth pattern. SACOG designed the process to produce a vision for the region that had sufficient technical grounding and political support to serve as the basis for SACOG's next Metropolitan Transportation Plan and, more broadly, to shape the region's future.

Over the last 15 years the Sacramento region has grown very rapidly. Until the last few years, much of the growth had been in a pattern typical of most metropolitan areas in the country characterized by low population density and an imbalance between jobs and houses within the major sub-areas of the region. Larger lot subdivisions farther away from the region's employment centers dominated the housing market. Growth in primary, or base sector, jobs has been dominated by government and other service sector employment.

The adopted Blueprint is comprised of seven growth principles through 2050:

- Housing choice and diversity
- Use of existing assets
- Compact development
- Natural resources conservation
- Quality design
- Mixed use development
- Providing transportation choices

The map and growth principles set out a strategy for managing a projected increase of nearly two million people, one million jobs and 840,000 housing units. The long-term 2050 time frame was selected purposely to stretch beyond the typical 20- to 25-year planning horizons of existing land use and transportation plans. The Blueprint tested these principles at three geographic scales: neighborhood, county and regional.

Neighborhoods

A series of thirty neighborhood level workshops were held throughout the region. To help reach out to communities across a large region, SACOG turned to Valley Vision, who was a full partner in executing the project. Valley Vision recruited and involved citizens and stakeholders in the workshops, and they formed advisory committees of key opinion leaders within each county to further recruit workshop participants. The goal, realized at most workshops, was to seat individuals from five to seven diverse interests at each small group table, including developers; local property owners and businesses; citizens; activists from the environmental, housing and other issue specific communities; and public agency representatives.

Project staff designed a series of interactive planning exercises for participants. In their small groups, participants used context maps, pictures and data, along with a map of the study area, and a menu of land use options to make decisions that were recorded by placing stickers on parcels to represent the land uses they wanted in their plan. Roving land use and transportation experts answered questions, and a trained facilitator guided the discussion.

A laptop computer and operator, running the new web-based Planning for Community Economic, Environmental and Energy Sustainability (I-PLACE3S) software through a cell phone connection, were available at each table to enter the plan as the citizens created it and, at various junctures, to tell them how it was performing on key metrics like the balance between jobs and housing, housing diversity, vehicle miles traveled, air emissions per household, and mode choice, including the percent of trips by car, transit, walking and biking. I-PLACE3S is designed to achieve two primary objectives. First, it provides sophisticated, objective technical information to illustrate the complex interrelationships between land use, transportation and air quality issues. Second, it provides information in an easily understood and accessible format that all stakeholders can use to develop informed opinions. This system enabled SACOG to use interactive planning technology in dozens of community meetings to provide parcel-specific land use planning accu-

racy at a regional scale and at real-time response speeds. An economic reality test included in I-PLACE3S conducts a planning level pro forma analysis on the proposed development ideas for every parcel. This return on investment function was used to test the profit performance and, thus, investment feasibility for private developers.

The Counties

SACOG convened committees of senior land use planners within each of the counties and built three alternative county level planning scenarios for growth through 2050 to compare to the base case scenario. The planners started with the citizen input from the neighborhood workshops. They examined the results of a housing market preference survey and the long-range demographic forecast to develop realistic targets for what portion of future housing construction should be planned for eight low, medium and high density housing products. Current general plans and zoning codes were assessed to determine to what extent built densities were at or below allowed densities. The planner committees discussed ways it may be possible to change local policies and codes over the next five decades. Each county prepared three scenarios, all designed to use smart growth principles, but in different ways and to different degrees. The four scenarios, including the base case, were labeled A, B, C and D to avoid biasing people's opinions about their merits. The overall growth rate within the county typically varied between the three scenarios. This method of building the county scenarios was designed to blend visionary planning with real-world policies and market conditions, with the goal of ultimately finding a preferred scenario that would perform well and could actually be implemented.

The county-level round of workshops were conducted with a minimum of one workshop in each county and several in Sacramento County. Maps, charts and stickers used in the earlier neighborhood workshops were used, but this time the participants were asked to choose the county-wide scenario they liked best, either the base case or one of the three alternatives.

Laptop computers and operators were at each table to enter the changes and give immediate feedback on how their changes would alter the performance of the scenario for travel behavior, air quality impacts, jobs-housing balance, total growth, and other impacts measured by I-PLACE3S. This time, the computers were connected to the server using high speed Internet, not cell phones, to transfer much larger data sets resulting from more parcels in a county compared to a neighborhood.

Region

Three alternative regional scenarios were created with the regional planners committee to compare to the base case future. The three scenarios were similar or identical for about 80 percent of the growth through 2050. In one scenario, the final 20 percent was located in small towns, including one new town, around the periphery of the region. In another scenario, the final 20 percent was located in inner-ring suburban locations adjacent to existing urbanization. In the final scenario, the last 20 percent growth was placed into inner infill and revitalization areas.

The four regional scenarios were also labeled A, B, C and D and discussed at a large day-long regional forum attended by 1,500 people in downtown Sacramento. Facilitators for each table were recruited, drawing from local elected officials, senior local government staff, and staff from related state agencies, transit agencies and air districts. The facilitators were required to take a training course, and their direct participation in the event was an important element in building understanding of and support for what became the final preferred scenario.

After the small group work, participants used individual keypad clickers to record both their personal preferences and the consensus preference of their small group. No tables voted for the base case scenario and very few selected the scenario that placed the final 20 percent growth in the cities the farthest away from the urban core of the region. The consensus votes of the tables favored the scenario that placed the final 20 percent in the inner suburban areas, while the individual votes favored the scenario that placed the final

20 percent of the growth in inner infill areas, an interesting divergence that turned out not to be particularly difficult to resolve. After analyzing each of the maps, SACOG staff prepared a draft preferred scenario that was a balance of the two most popular scenarios from the regional workshop.

Board Approval

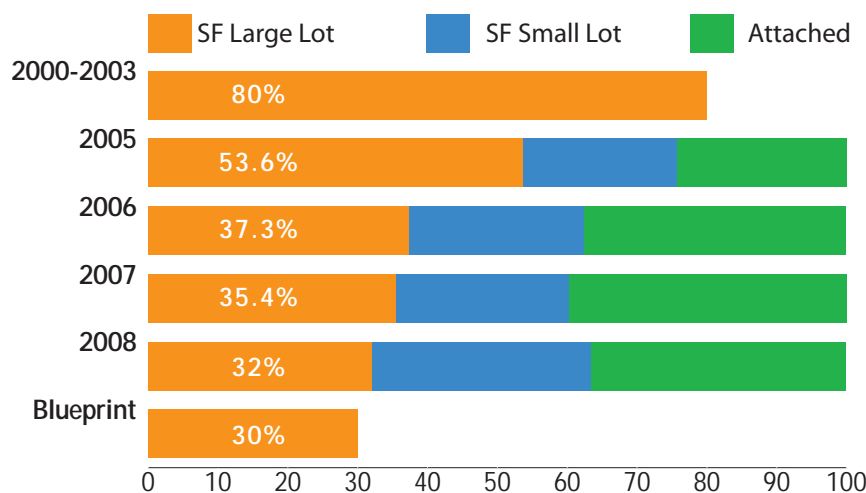
Throughout the entire workshop process, SACOG board members were briefed and provided opportunities to give input and guidance on project progress at least monthly, both at committee meetings and at full board meetings. The input from the elected officials peaked with the last big event of the Blueprint development process, a regional summit of all city and county elected officials. The elected officials used electronic keypads to identify what aspects of the draft preferred Blueprint alternative they liked and disliked. The draft alternative was very popular with the participants, and the few areas of concern gave SACOG staff fairly clear direction about the types of final refinements needed before taking the plan to the board for final action.

By the time the workshops and two regional forums had been conducted in April 2004, more than 5,000 individuals had used the modeling software and given input into the future vision of land use in the Sacramento region.

Major Features of the Blueprint Growth Strategy

The Blueprint changes the mix of future housing products significantly compared to base case trends in the region. In 2004, detached single family (SF) properties from 5,500 square feet to several acres in size represented 68 percent of the existing housing stock and 80 percent of the new housing being constructed. The Blueprint calls for only 31 percent of the new residential units to be built in this larger lot, with nearly seven out of ten in an attached format, such as townhouses, rowhouses, condominiums or apartments, or small 3,000 to 4,000 square foot lots in detached formats.

Figure 9-1: Recent trends in the Sacramento area housing mix 2005-2006



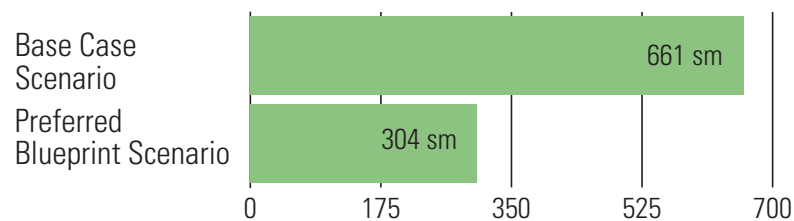
The project conducted market research on homebuyer and renter preferences that showed a strong interest in the higher density products, particularly when placed in a setting that reduced driving distances to jobs and services. The market interest was particularly strong among households with residents aged 55 years and older, with two-thirds of people in this category stating a preference for small lots or attached

products for their next residential move. This is important because the project's demographic research projected that two-thirds of the growth in households in the region through 2050 would be people in this age category, within only 21 percent of the growth in households with children. As shown in Figure 9-1, by 2008, the fourth year of Blueprint implementation, 68 percent of new housing starts were small lot single family or attached, a dramatic change from the trend line in 2004.

In 2004, virtually no growth was occurring through redevelopment of parcels with existing buildings that were either in disrepair or had a market value below the value of the land. SACOG used the simplified economic feature of the I-PLACE3S software to estimate the redevelopment potential for downtowns and transportation corridors throughout the region. The analysis showed there is a great deal of land appropriate for redevelopment. The Blueprint scenario relies on redevelopment of existing built parcels for 13 percent of the housing growth, or 109,000 units, and 10 percent of the employment growth, or 100,000 jobs. The Blueprint also relies on infill with new buildings on existing, vacant lots for a substantial portion of future growth. Approximately four out of ten of the 400,000 new jobs and 320,000 envisioned by the Blueprint will occur within walking distance of transit service at least every 15 minutes during the peak afternoon and evening commute hours.

The result of the higher density housing products and aggressive use of redevelopment and infill opportunities is a growth pattern that uses land much more efficiently. As shown in Figure 9-2, the base case scenario requires 661 square miles of land for new urban development through 2050, while the Blueprint requires only 304 square miles for the same amount of growth in population, housing and jobs. This is a reduction of 357 square miles needed for future urbanization.

Figure 9-2: Land requirements for new urbanization, in square miles through 2050



The Blueprint's more compact future urban footprint creates the potential to preserve significant amounts of agricultural and natural resource lands in the future. While the Blueprint does not constitute a detailed open space, farmland or natural resources management plan for the region, it could require 64 fewer square miles of agricultural land converted to urbanization; 31,300 fewer acres of disturbed resource lands, such as wetlands, vernal pool complexes and hardwood stands; and 36,000 fewer acres of development in floodplains.

The detailed design features of development determine its overall quality and some aspects of travel behavior. Variables, such as the relationship of buildings to streets, setbacks, the placement of garages, sidewalks and parking, landscaping, the aesthetics of building design, and the design of the public right-of-way, including block lengths, grid street patterns and connectivity, increase walking, biking and transit use and reduce the length of auto trips. In 2050, only 34 percent of the people in the base case scenario would live in neighborhoods with good or excellent pedestrian features. Twice that many, or 69 percent, would live in neighborhoods with these features in 2050 in the Blueprint scenario.

The concept of mixing rather than segregating land uses has many manifestations, including locating jobs with housing nearby. The Sacramento region has three major employment centers, downtown Sacramento and two suburban centers. All three have many more jobs than nearby housing, an imbalance that the Blueprint strives to remedy with more aggressive housing growth in these areas in the future. By 2008, 25,000 of the 40,000 new housing units projected by the Blueprint near the Sacramento jobs center were already either built, under construction, approved for development, or in the application stage.

Mixing land uses means more than the location of jobs and housing. Multiple worker households and other considerations mean that it will never be possible to have all workers living close to their jobs. Moreover, only 15 percent of all auto trips are commuter trips. Short connections to schools, shopping, services, parks and other amenities are also important. The Blueprint focuses on the neighborhood scale by encouraging a mix of uses in infill settings and in new, larger master planned communities. In the 2050 base case scenario, 26 percent of the people would live in areas with a good mix of housing, jobs and other amenities, while in the Blueprint over twice that many people, or 53 percent, would live in these circumstances.

SACOG designed a transportation network to serve the Blueprint and base case growth patterns in 2050. The difference in travel performance was substantial. Congestion was significantly reduced. In the base case scenario, in 2050 vehicle miles traveled per household increased by 12 percent, while in the Blueprint scenario, they decreased by 17 percent. Average daily travel time per household increased by 27 percent by 2050 in the base case and increased by only 5 percent in the Blueprint. The percentage of trips using transit was more than four times as high in the Blueprint, roughly 3.3 percent, compared to the 0.8 percent in the base case. The percentage of walking or bike trips was more than twice as high in the Blueprint than the Base Case, 12.9 compared to 5.5 percent, respectively.

Other performance metrics were also favorable. Emissions of small particulates and greenhouse gases are estimated to be 15 percent less in the Blueprint compared to the base case. Residential water demand is projected to be 33 percent less per household, largely due to smaller yards. The total cost of constructing infrastructure for water, transportation, sewer, flood control, drainage and resource mitigation is \$14 billion less through 2050 in the Blueprint scenario compared to the base case scenario.

Integrating the Blueprint

In 2008, the SACOG board adopted a new Metropolitan Transportation Plan (MTP), which prioritized \$42 billion in transportation investments for the region through 2035. It was SACOG's first MTP based on a future land use pattern that was significantly influenced by the Blueprint growth principles. It reflects a transportation investment portfolio purposely designed to serve a growth pattern that is more compact and has a stronger mix of land uses within the various neighborhoods and cities of the region.

SACOG staff included a number of enhancements to its data and modeling capabilities in developing the new MTP. Most notably, they developed parcel-level GIS data, including general plan and zoning designations, lot size, and ownership for all 800,000 parcels throughout the six-county region. For the first time, SACOG used an integrated forecasting model, called MEPLAN. This model uses economic costs, development policies, travel time and household demographics to allocate future growth. The regional travel model, called SACMET, was upgraded most importantly by the addition of a post-processing capacity called 4Ds, standing for density, diversity, design and destination. The 4Ds are land use characteristics that influence travel behavior and are added to travel models to better understand the effects of smart growth land use design options on travel. The analysis uses elasticities, or percent changes, to modify vehicle trips, vehicle miles traveled, and mode choices based on changes in land use characteristics.

In the transition period between the end of the Blueprint process and the beginning of the new MTP development, SACOG committed to another round of enhancements to its data and models. Workshop capabilities were improved by embedding a somewhat simplified version of SACMET, the 2002 MTP regional travel model, into the I-PLACE3S software so that it could be used interactively to produce travel and land use information in minutes. This upgrade included the 4Ds to better capture smart growth details. SACOG's overall analytical capacity was improved by shifting from the SACMET 4-step model to a new, activity-based regional travel model, called SACSIM.

This SACMET and SACSIM models analyze travel patterns in a fundamentally different manner than traditional 4-step models. The 4-step model segments travel into individual trips by purpose. Activity-based

models link trips into tours that begin and end at home or work, depending on the list of activities associated with the tour. With this new approach, the number and sequence of trips, the modes chosen, the time of day, and the total amount of travel time are internally consistent, which is not possible with 4-step models.

In addition to the Blueprint growth pattern, the 2035 MTP has a different portfolio of transportation investments compared to previous plans. Leading the change is a 56 percent increase in bicycle and pedestrian investments and a 35 percent increase in smart growth programs. These new investments are made possible by reducing the demand for investment in options that serve only single occupant vehicles and allocating a larger share of flexible revenues to alternatives that meet the future set of mobility demands. The 2035 MTP also includes a 21 percent increase in transit funding and a 17 percent increase in road operations and maintenance funding to better optimize the existing system.

Increases in road capacity are also part of the 2008 MTP. Strategic road expansions include several car-pool and bus lanes, largely in the inner areas of the region, and complete street grids that better serve local transit, bike, pedestrian and auto travel. Through matching MTP investments with supportive Blueprint land uses and focusing on critical bottlenecks, congested vehicle miles traveled per household increase a modest 12 percent versus 60 percent projected in the earlier plan. By 2035, the projected vehicle miles traveled per household and air emissions are substantially lower than the prior MTP, while walking, bicycling and mass transit trips are substantially higher.

A few examples of SACOG's MTP2035 investments that are targeted at creating synergies with the Blueprint growth strategy follow.

- **Bridges:** Downtown Sacramento, the employment center for the region, is surrounded by the American and Sacramento rivers. The Blueprint encourages more growth in the downtown area, particularly housing, and in areas immediately across the rivers, but otherwise adjacent to downtown. Two multi-modal bridges, one over each river, will provide added connections and mobility to encourage this inward growth.
- **Streetcars:** Rail transit stimulates compact urban development by providing a viable option to replace the car and sending a signal to the private markets that the government is making long-term investments to promote growth in a particular area. Light rail transit is an important part of the 2035 MTP, but lighter weight rail, commonly called streetcars, will be reintroduced to provide shorter-distance service. A starter streetcar line will be built to link inner West Sacramento and Sacramento across the Sacramento River, and a streetcar loop will be built to tie the region's second largest employment center in Rancho Cordova into the existing light rail line.
- **Expanded bus service:** While the plan expands the light rail system and reintroduces the streetcar, the largest increases in transit service miles come from enhanced local bus service and a significant expansion in the use of neighborhood shuttles.
- **Complete streets.** The plan focuses on multi-modal road designs that promote transit, walking, biking and smart growth land development along with auto mobility. The goal is not to eliminate the automobile from the equation, but to ensure that all modes function well in the right-of-way.
- **Targeted highway investments:** While highways receive a declining share of funds, there are still important investments that improve traffic flow and reduce greenhouse gas emissions, including auxiliary lanes, which are particularly helpful in keeping delivery trucks off of local streets, interchange improvements and expansion of the incomplete carpool and bus lanes.
- **Transportation funds for Blueprint growth:** The 2035 MTP includes nearly \$750 million in transportation funds to support Blueprint style growth through 2035. A competition will be held every 18 months to solicit the best projects in the region that can leverage these funds for transportation infrastructure improvements like new parking garages and projects to promote street connectivity.

Senate Bill 375 and GHG Reduction

In 2006, California passed the Global Warming Solution Act, the toughest law in the nation for reducing GHG emissions. That law provides overall targets for the state but not specific rules and policies. In late 2008, a new law was passed, Senate bill 375 (SB375), that specifically targeted GHG reduction from vehicle use in metropolitan areas. It was patterned after the planning process used at SACOG and the other major MPOs in California, all of which had also conducted sophisticated regional scenario planning exercises over the last decade. The SB375 law requires the California Air Resources Board (CARB) to assign targets for reducing greenhouse gas emissions in 2020 and 2035 to each of the state's 18 MPOs.

The new law also makes major changes to the California Environmental Quality Act (CEQA) to encourage the construction of smart growth housing and mixed use projects. It includes a Regional Housing Needs Assessment (RHNA) statute that requires the location of new housing to be consistent with the land use components of regional transportation plans. Furthermore, SB375 requires local governments to rezone land consistent with those plans, and to integrate the state's goals for reducing greenhouse gas emissions under a previous law, known as AB32, with regional transportation plans. SB375, two years in the making, was supported by a unique coalition of the California Building Industry Association, several environmental groups, the California League of Cities, the County Supervisors Association of California and various housing advocacy groups.

The three main components of the bill are the sustainable communities strategies (SCS) and regional transportation plans (RTP), CEQA reform, and affordable housing planning through the RHNA. They are summarized below.

Sustainable Communities Strategies and Regional Transportation Plans

By July 1, 2010, SB375 requires the CARB, after considering the recommendations from a broadly based Regional Targets Advisory Committee, to provide targets to MPOs, including the SACOG, for greenhouse gas emissions for cars and light duty truck trips from regional land use and the transportation system. The MPOs will prepare a SCS as a component of their RTP, or MTP in the case of the Sacramento region that meets the target, if feasible.

If the SCS does not meet the target, the MPO must adopt an alternative planning strategy (APS) that does. However, the MPO is not required to implement the APS if it requires funds that exceed available transportation funding or if the changes to land use patterns go beyond what federal law allows. Several safeguards in the law are included to preserve local government land use authority.

California Environmental Quality Act Reform

The CEQA reforms require some changes to residential and residential-oriented mixed use projects to meet the greenhouse gas targets. For example:

- Such projects no longer have to analyze their growth-inducing impacts or their impacts on climate change or on the regional transportation network.
- A limited set of projects that meet a very stringent series of environmental and other criteria are now exempt from CEQA analysis.
- A substantially more limited CEQA review than normal is now available for projects with a density of 20 dwelling units per acre that are within 0.5 miles of current or planned high quality transit service for any impacts that are sufficiently analyzed in the RTP environmental impact report and provide adequate mitigation.
- Local governments can now establish their own mitigation standards for local traffic impacts.

Affordable Housing Planning through the RHNA

Each MPO's process for updating its RHNA will occur every eight years instead of every five years to improve coordination with updates to RTPs, which occur under federal law in four year increments. The California Department of Housing and Community Development process for setting the regional housing allocations for the MPOs will be amended to encourage providing sufficient housing to match the projected employment growth in a region, and the way the MPOs allocate the housing to each of the cities and counties must be consistent with the SCS.

Local governments will be required to rezone their properties to be consistent with their updated RHNA within three years, or within four years if the local government has completed 75 percent of its rezoning by the third year and meets one of three conditions—circumstances out of its control, lack of infrastructure to serve the sites or need for a major update to its general plan to meet its RHNA allocation. If a local government does not update its housing element within 120 days of the statutory deadlines, then it will have a four-year RHNA update cycle instead of an eight-year cycle.

The CARB will establish the targets for the regions by September 30, 2010, and the first round of RTPs to comply with the new law will occur between 2011 and 2013, depending on the regular update schedule for each region.

Conclusions

The experience of SACOG in grappling with urban planning issues has broad implications for the development of climate change policies. Already the SACOG Blueprint has served to guide the development of state urban planning legislation, and it is serving as a model for incorporation into state GHG reduction strategies. While GHG reduction may not be the principal benefit of better urban planning and management, the increasing public support for GHG reduction and the enthusiasm of lawmakers to institute a legal process to reduce GHGs from transportation provide the opportunity to do better planning. They could also provide the legal mandate and the financial incentives to accelerate and strengthen efforts at smart growth. The challenge in California now is to improve the SB375 process so that it creates real incentives for local and regional governments and accelerates good policy and planning.

Chapter 10:

The Case for Diesel Cars To Reduce Greenhouse Gas Emissions

by Johannes-Joerg Rueger

Governments worldwide are adopting rules, laws, and incentives aimed at reducing greenhouse gas (GHG) emissions and petroleum fuel consumption of vehicles. All of them also have aggressive rules to reduce conventional pollutants. Europe has the most aggressive GHG rules, while California has the most aggressive rules for local conventional pollution.

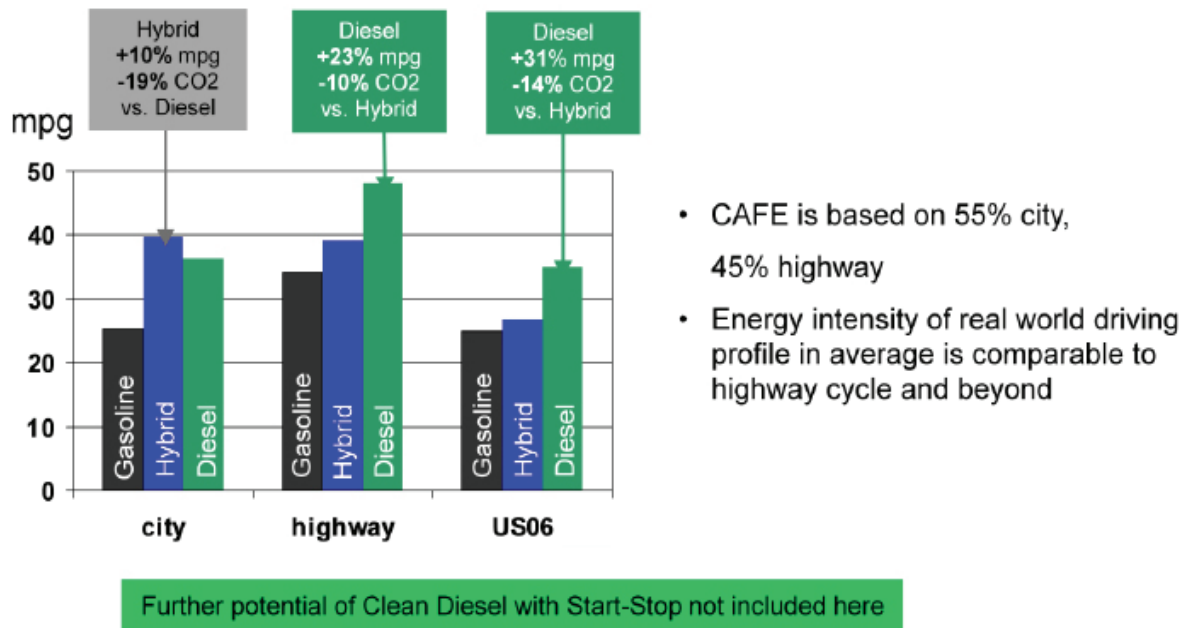
While these goals are challenging for the auto industry, many technologies are available to help attain them. However, these goals can often conflict since some of the technologies to achieve the largest GHG reductions may slow reductions in tailpipe criteria emissions. Thus, the state of California's continuing focus on reduction of criteria emissions may make it more difficult for automotive engineers to craft maximum reductions in GHG emissions, in particular emissions of carbon dioxide (CO₂).

In addition, California is planning to take into account well-to-wheel GHG emissions for fuels in order to account for the full spectrum of the impact of the use of different fuels, while at the same time reducing the carbon intensity of these fuels. These regulations have been codified in the Low Carbon Fuel Standard, adopted by the California Air Resources Board and expected to be implemented beginning in 2011 (CARB 2009b). This adds another layer of complexity for the auto industry by requiring it to adapt to new liquid fuels, while also seeking to meet increasingly stringent GHG and criteria emission regulations.

While the regulations aim at reducing tailpipe emissions based on defined test cycles, it is important to keep an eye on the real-world behavior of the different technologies as well, as illustrated in Figures 10-1 and 10-2.

One concern is that some of the test cycles do not always reflect the real world attributes of the various technologies. A Bosch test lab simulation compared conventional gasoline and diesel vehicles and a full Prius-style hybrid electric vehicle (HEV) version of otherwise identical cars. The base car was a 1,700 kilogram (kg) Mercedes E-Class. For this simulation, the hybrid version was assumed to be equipped with a 110 kilowatt (kW) internal combustion engine, a 31 kW electric motor, a lithium-ion battery pack and a 6-speed automatic transmission. The tests found that the HEV had 10 percent better fuel economy than the diesel in a city driving cycle, while the diesel outperformed the HEV by 23 percent on the highway cycle.

J.Rueger is Senior Vice President for Engineering, Diesel Systems at Robert Bosch LLC

Figure 10-1: Driving tests favor clean diesel

Note: Simulation based on Mercedes E-class, 1,700 kg combustion, 110 kw electrical, 31 kWh lithium ion battery, 6-speed automatic transmission

But in the US06 test cycle, which is used by the United States (U.S.) Environmental Protection Agency (EPA) to show emissions and fuel economy at high speeds and with rapid acceleration simulating typical freeway driving, the diesel had 31 percent higher fuel economy than the HEV. These results are even more impressive as they were calculated without applying additional technology like start/stop, which is standard with the HEV, to the diesel vehicle. As noted in the comparative miles per gallon (mpg) and carbon dioxide (CO₂) numbers, the CO₂ reductions are not equivalent to the fuel economy gains of diesel compared to gasoline hybrids because of the difference in the carbon content of the fuels.

Similarly, a test by *Popular Mechanics* magazine, echoing a similar one in the European magazine *Auto Motor und Sport* illustrated in Figure 10-2, examined the measured real world highway fuel consumption of a 2009 Toyota Prius and a 2009 VW Jetta TDI and found the Jetta superior, achieving an overall fuel economy of 45.4 mpg compared to 44.8 mpg by the Prius. The Prius surpassed the diesel fuel economy on city roads, but the magazine concluded that:

When it comes down to which of these two popular efficient cars is more fun and more comfortable to drive every day, it's an easy pick: We like the Jetta TDI, and the fuel economy numbers in the real world for VW's new player make it ... a legit Prius fighter. (Stewart 2008)

The two cars are both five-passenger models. The Prius has a larger interior volume, 96 compared to 91 cubic feet, but a smaller cargo area, 14.4 versus 16 cubic feet. Similarly, the Prius has a longer wheelbase, 106.3 inches compared to 101.5 inches for the Jetta, but is shorter overall, narrower and slightly taller. The Prius weighs 350 pounds less than the Jetta with an automatic transmission and a little less than 300 pounds less compared to the Jetta with a manual transmission. Performance numbers from the manufacturers indicate the Prius accelerates zero to 60 miles per hour (mph) in about 10 seconds, while the Jetta accomplished the same feat in 8.2 seconds with a manual transmission and 8.5 seconds with an automatic.

What is clear from this and other observations of real world fuel economy is that there are multiple technology pathways to achieve improved fuel economy and lower CO₂ emissions, keeping in mind that the two are not

Figure 10-2: Real-world driving favors clean diesel

In a real world test by automotive magazine editors the fuel consumption and CO₂ Emissions of the Prius were compared to a similar-size VW Jetta. Auto Motor und Sport magazine averaged 35.1 mpg in the Prius and 40.6 mpg in the Jetta with similar CO₂ numbers



interchangeable. Because of diesel's higher carbon content, CO₂ reductions are not as dramatic as fuel consumption reductions. For instance, while a typical diesel vehicle has approximately 35 percent better fuel economy than a comparable gasoline vehicle, it would have about 25 percent lower CO₂ emissions, as is seen in Figure 10-1. The key is the ability to match automotive technologies to the needs of the customer.

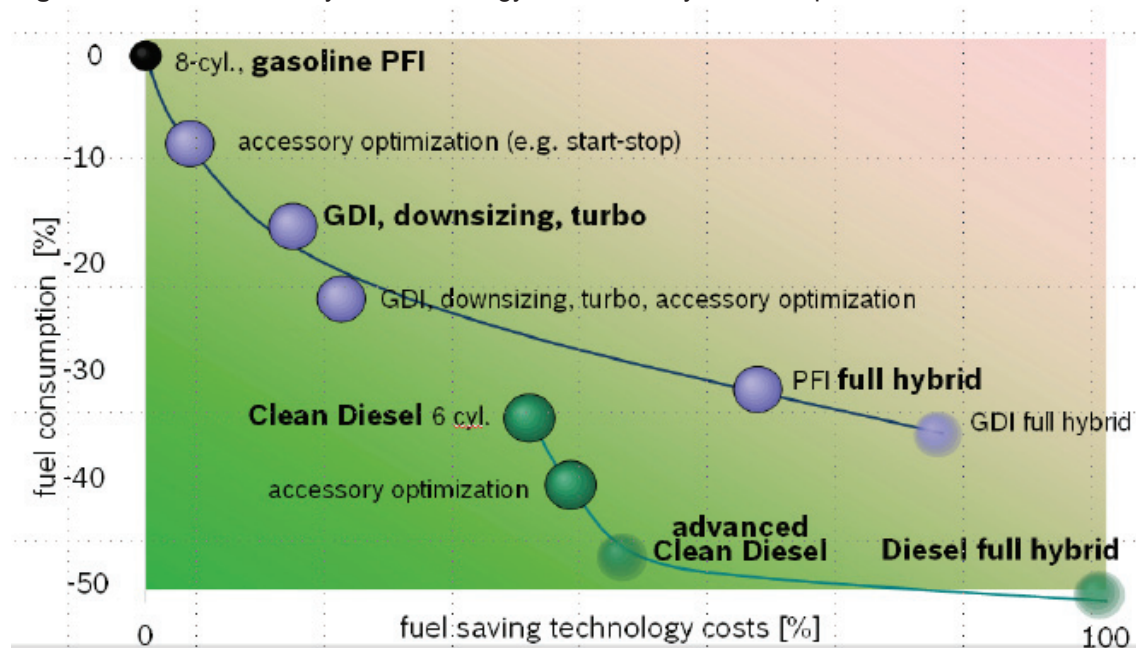
Technology Today

While the automotive sales market in the United States is in flux, having shrunk substantially in size during 2008 and 2009 and shifted in model mix toward smaller vehicles, it still retains a broad spectrum of vehicles ranging from small, highly fuel efficient models to ones that offer lower fuel economy, but feature capabilities such as towing or hauling capacity deemed essential for a significant segment of the consumer market. What is clear is that consumers appear to prefer a variety of different size vehicles with different performance characteristics as opposed to ones solely focused on fuel efficiency. While all sizes of vehicles can be made more fuel efficient, the laws of physics dictate that larger, heavier vehicles will inherently be less fuel efficient than smaller, lighter ones.

The first technology path toward reduced greenhouse gas emissions for the auto industry, as shown in Figure 10-3, is to bring improvements to the basic gasoline engine by adding technologies such as start/stop, which automatically shuts down and restarts the internal combustion engine to reduce the amount of time the engine spends idling, and other accessory optimization technologies including high efficiency generators, friction reduction, thermal management, and electrified accessories. Eventually, industry could shift to gasoline direct injection in combination with downsizing and turbocharging. These technologies promise GHG reductions between 5 and 20 percent at relatively low costs based on Bosch engineers' estimates, which are comparable to those found by K.G. Duleep of ICF International and those of the committee of the National Research Council that assessed technologies for the improvement of fuel economy in 2008. Estimates on the fuel consumption and CO₂ reduction vary in different studies because of a variety of factors. Sometimes different components are employed in similar technologies by different companies. Other studies may reflect that the reported numbers may be obtained from real-world testing, laboratory testing, or simply computer simulation, all of which can yield different results, even when discussing the same components.

Additional hybridization offers a significant CO₂ reduction potential, but is associated with a far less attractive cost/benefit ratio. Hybridization has achieved significant market recognition since the launch of the Toyota Prius. As an alternative, today's modern clean diesel shows a large CO₂ reduction and has significant additional future potential with the aforementioned accessory optimization technologies and downsizing. Hybridization is an option for this technology, too.

Figure 10-3: Fuel economy and technology costs in today's landscape



Acronyms used: PFI = port fuel-injected engine, the typical current gasoline engine; GDI = gasoline direct injection

A Gasoline Vehicle Example

To examine what can be accomplished to move automotive vehicles toward California's environmental goals with current technology, consider a basic 8-cylinder port fuel-injected (PFI) gasoline engine, which is standard technology in many larger U.S. passenger cars, light duty trucks, and sport utility vehicles (SUVs). The same principles also apply to other configurations of PFI engines, including 6- and 4-cylinder configurations. With accessory optimization using start/stop systems, high efficiency generators, friction reduction, thermal management, and electrified accessories, a fuel economy improvement of 10 to 15 percent can be achieved with relatively low cost, while reducing CO₂, criteria emissions, and fuel consumption with no change in the performance characteristics of the base engine.

The next stage of reductions, collectively contributing another 5 percent efficiency gains, could be obtained through the use of gasoline direct injection (GDI) technology and turbocharging, which will allow for the downsizing of the engine. In some cases, this might mean an 8-cylinder engine could be downsized to a 6-cylinder engine or a 6-cylinder model downsized to a 4-cylinder version, keeping the original performance, but adding efficiency. This stage would produce an approximate 15 percent reduction in fuel consumption compared to the base engine at a cost more than double that of accessory optimization.

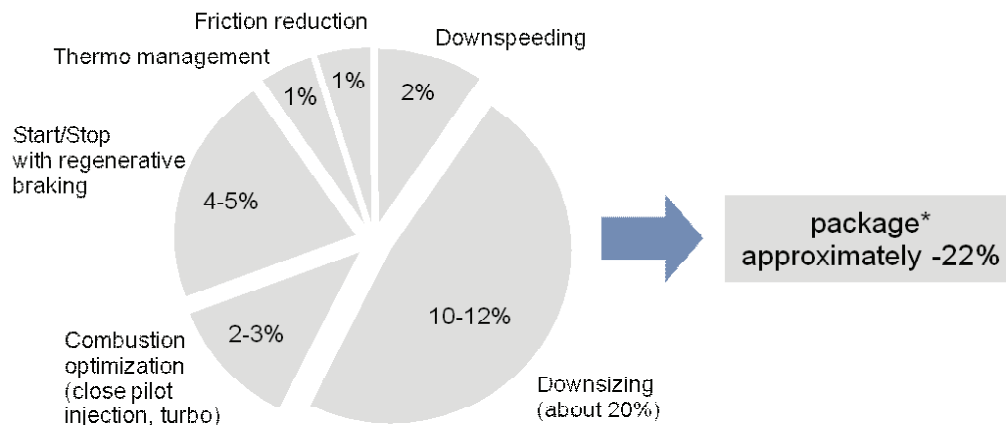
A next step would be full accessory optimization with new GDI technology, which would boost efficiency to more than 20 percent compared to the original engine, but also raise costs. A further level of efficiency could be gained through applying a full hybrid electric drivetrain to the basic PFI engine. This would result

in about 30 percent efficiency improvement compared to the original engine, but with a far less favorable cost/benefit ratio compared to the GDI technology. Finally, a full hybrid electric system could be applied to a GDI engine, resulting in a gain of about 5 percent compared to the PFI hybrid, but again with significant incremental costs.

A Diesel Vehicle Example

A similar scenario can be explored with today's clean diesel technology. Figure 10-4 describes the technological options to reduce CO₂ emissions from advanced diesel vehicles. One difference between gasoline and diesel vehicles is that a 6-cylinder diesel engine could be used to compare to the 8-cylinder gasoline PFI engine since they would have similar torque, horsepower, and acceleration characteristics. The diesel engine would start with an average of 30 percent less fuel consumption compared to the 8-cylinder gasoline engine, but at a cost incrementally more than a fully optimized GDI engine. Accessory optimization could be applied to the diesel to gain an approximately 5 percent improvement in fuel consumption at relatively low cost.

Figure 10-4: CO₂ potential of advanced clean diesel compared to current diesel



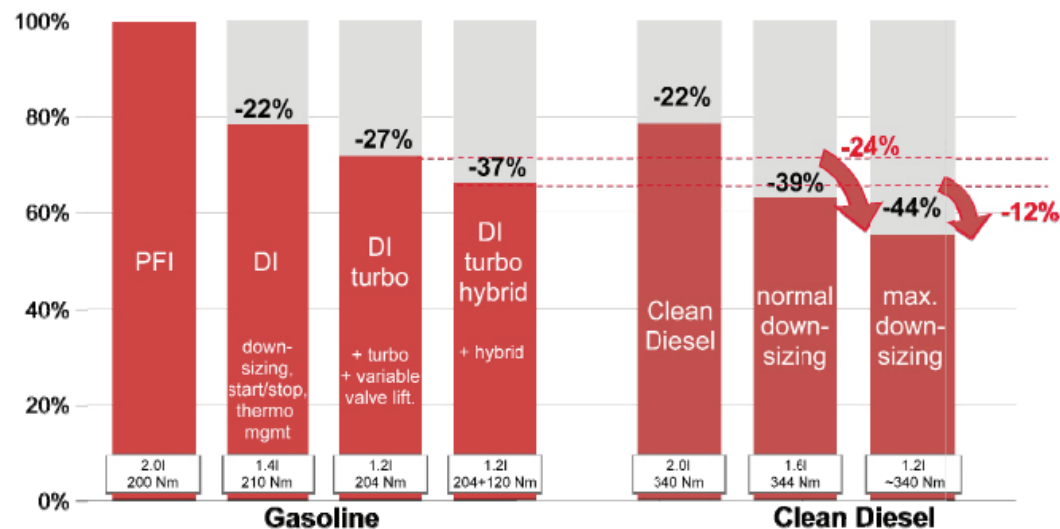
The Clean Diesel has high potential for consumption and CO₂ emission reduction

* Package is Optimized conventional combustion system. All data is approximate from Bosch internal investigation

A next step would be to move to advanced clean diesel technology, including start/stop with regenerative braking, combustion optimization, friction reduction, thermal management, additional downsizing, and downspeeding through the application of a longer gear ratio. This would reduce fuel consumption, compared to the base gasoline engine, by almost 50 percent. A further step for diesel vehicles would be to develop a full hybrid electric drivetrain that would deliver more than 50 percent improvement in fuel consumption, but would be the most expensive variant on this technology landscape. More details about the impact of technology changes on CO₂ reduction are detailed in Figure 10-5.

Dieselization

It is well documented that a modern, clean diesel engine offers 20 to 25 percent CO₂ reduction compared to a similar gasoline engine (Stewart 2008; see also Figure 10-6). At the same time as modern diesels have increased efficiency, they also have drastically reduced criteria pollutants, including particulate matter, hydrocarbons, and nitrogen oxides. These advances have resulted in recent launches of new clean diesel

Figure 10-5: CO₂ reductions in diesel and gasoline concepts

Note: Additional clean diesel mild hybrid potential is about 10 percent

vehicles in the United States, all of them meeting EPA Tier 2 Bin 5 and low emission vehicle (LEV) emission limits for all 50 states, the same emission level that most gasoline vehicles achieve. This is a technology available immediately and offers significant further improvement potential, making it an even more attractive choice for the consumer in the future.

The European Experience

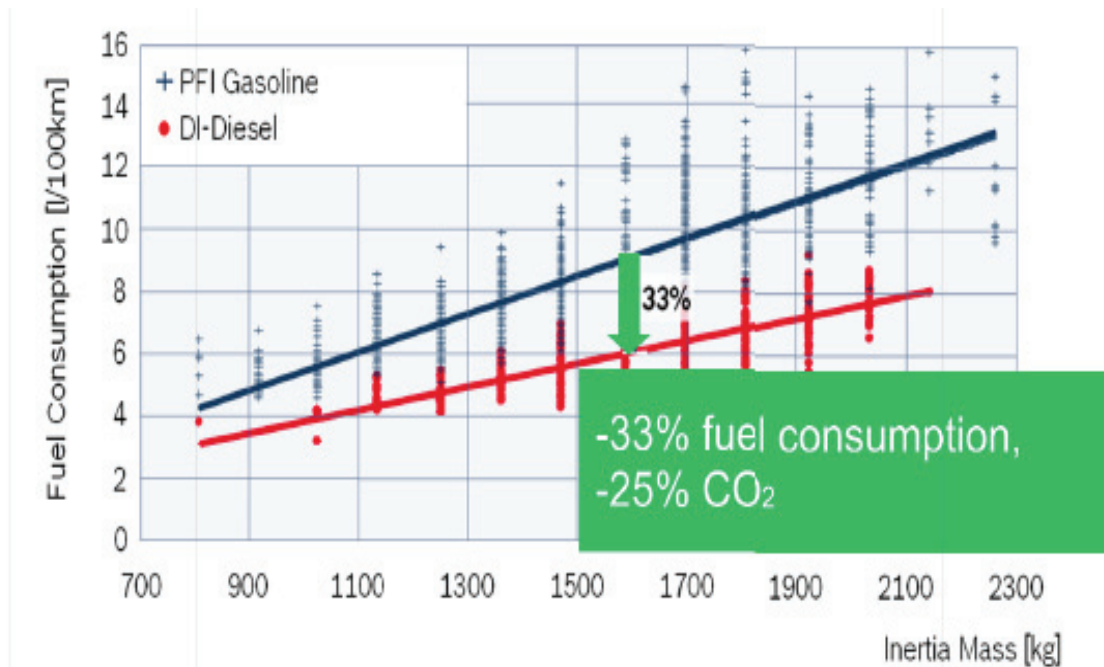
After the signing of the Kyoto Treaty in 1997 (Global Warming Glossary 2008), the European Union (EU) took a different route than the United States to reduce CO₂ from the transportation sector. While the United States continued to focus primarily on the reduction of criteria pollutants, Europe shifted its attention to CO₂ reduction as well. Clean diesel technology has been playing a major role in this strategy supported by the early introduction of low sulfur diesel fuel and a structured fuel taxation system that favored diesel in most countries. The generally high fuel prices motivated many EU consumers to focus on fuel efficiency as a key purchase requirement for their vehicles. The European Union also had less stringent criteria pollutant standards than the United States.

In 1997, automakers employed the newly developed common rail fuel injection system, enabling improved combustion systems and resulting in reduced criteria and CO₂ emissions, higher fuel economy, and increased engine power. Since then, the common rail system has continued to be developed, enabling automakers to offer vehicles that continued to improve performance and reduce GHG and criteria emissions.

The new vehicle market in Europe shifted rapidly to diesel vehicles in the latter half of the 1990s and first half of the last decade, reaching 50 percent of the market in the European Union by 2008 (*Green Car Congress* 2009). This change in basic engines resulted in the reduction of petroleum use and CO₂ reductions in new vehicles. The European Environmental Agency reported that from 1995 to 2004 the GHG emission rates of new passenger cars dropped 12 percent, although overall sector emissions increased due to higher vehicle miles traveled, a larger consumer vehicle fleet, and other factors (EEA 2006).

Zero Emission Vehicles and Life Cycle Emissions

Regulatory and industry attention has recently focused on zero emission vehicles (ZEVs), which eliminate GHG emissions at the vehicle level. A variety of ZEVs are in demonstration or pre-commercialization

Figure 10-6: The CO₂ reduction potential of diesel vehicles today

Note: Additional clean diesel mild hybrid potential is about 10 percent

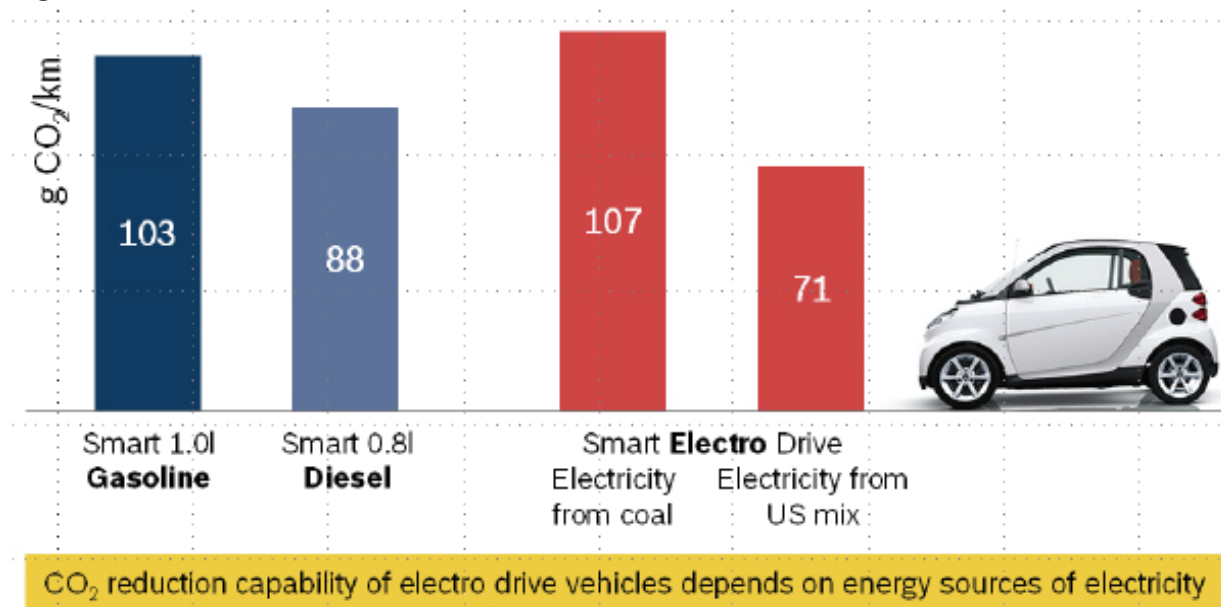
phases, presenting regulators and early adopters with concrete examples of the potential of the technology. However, these vehicles are by far not yet cost competitive with traditional gasoline or diesel vehicles on the market.

Another shift during recent years has been to take a broader view of these vehicles' emissions, encompassing the well-to-wheel emissions of the energy used as fuel rather than merely focusing on the emissions directly from a vehicle tailpipe. The impact of this approach can be seen from a comparison of the European versions of the Smart Fortwo car in gasoline and diesel engine modes and in a battery electric configuration, as shown in Figure 10-7. The full well-to-wheel GHG emissions of the gasoline Smart were calculated to be 103 grams of CO₂ per kilometer (km). Well-to-wheel emissions from the diesel car were found to be 88 grams of CO₂ per km. The well-to-wheel emissions from the battery electric Smart were even higher, 107 grams of CO₂ per km, when coal was the source for electricity generation, although they dropped to 71 grams of CO₂ per km if the average mix of the U.S. electricity generation was applied, and would be even lower based on California's electricity mix (ADAC 2008).

The conclusion from this exercise is that the energy source for electricity generation determines in large part the potential CO₂ reduction of a battery electric vehicle, while emissions from traditional gasoline and diesel vehicles are relatively fixed. Therefore, the expectations of CO₂ reduction from the deployment of electric vehicles must be analyzed along with the expected source of electricity to power the vehicles. California's Low Carbon Fuel Standard is a step toward establishing values for these upstream impacts. Another issue to note is that the CO₂ reduction gained shifting from one technology to another, whether it is gasoline to gasoline-electric hybrid or gasoline to diesel, will vary depending on the vehicle platform and powertrain.

Policy Conclusions

The examples cited in this chapter suggest that policies that promote a technology without considering elements such as the full well-to-wheel impact of emissions or real-world driving results can potentially fall short of their goal to reduce GHG emissions. Due to this and because of different driving needs

Figure 10-7: Zero emission is different from no emissions

Source: ADAC *Motorwelt* November 2008

of consumers, it is important to use all available technologies that contribute to GHG reduction now. Furthermore, a new technology can take a decade or more to reach market maturity and mass production, which is usually considered to be more than 100,000 vehicles.

The Toyota Prius HEV is a good example of this phenomenon. It was initially introduced in Japan in 1997, and brought to the U.S. in 2000 and to selected other countries shortly thereafter. It was not until the 2004 model year, however, that its annual sales passed the 100,000 unit mark on a worldwide basis. Sales in the U.S., its largest market, reached the 100,000 mark in 2005. Worldwide sales hit more than 280,000 in 2007, a decade after the vehicle's introduction.

Another factor to be considered is the behavior changes required by new technology. The Prius did not require significant changes for consumers in terms of refueling or driving habits to obtain its higher level of fuel economy. Behavioral changes will be required for many of the newer technologies expected to be introduced commercially during the coming decade, particularly electric vehicles. This presents a challenge to industry and should be taken into consideration by policymakers and regulators.

Automotive engineers are making rapid progress in developing and commercializing technologies to reduce GHG emissions. Further development and commercialization of diesel technology is one of the near-term opportunities. In the future, advanced gasoline and diesel technologies, possibly integrated into homogeneous charge compression ignition engines, allied with hybrid electric drivetrains, show even greater potential to reduce GHG emissions. These new technologies will take time to develop and will increase the cost of vehicles, thereby limiting their market penetration.

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Chapter 11:

Overview of Light-Duty Vehicle Fuel Economy Technology To 2025 and Policy Implications

by K.G. Duleep

The transport sector is a major contributor to greenhouse gas (GHG) emissions in the United States (U.S.), but the traditional methods of control, such as carbon taxes, do not apply to the sector, especially to the personal transport sector. This is because consumers are relatively insensitive to fuel prices and require very large increases in fuel price to change their buying preferences significantly. More direct methods using command-and-control regulations have been successful in the past, and the corporate average fuel economy (CAFE) regulations were widely viewed as a success in bringing more fuel efficient vehicles into the marketplace. As a result, fuel economy has become a focus of legislative activity in response to concerns about GHG-related emissions and high fuel prices. In 2008, the administration of U.S. President Barack Obama announced a plan to improve fuel economy (FE) by 40 percent over the next decade relative to the standards set for vehicles in that year, which implied a fuel economy standard for the combined car and light truck fleet of about 35 miles per gallon (mpg). More recently, the U.S. Environmental Protection Agency (EPA) and Department of Transportation (DOT) jointly announced standards approximately equivalent to 35.5 mpg for model year (MY) 2016 motor vehicles (NHTSA 2009).

Typically, FE standards are set by cost benefit analyses that equate the cost of technological improvements to vehicles to the benefits realized from fuel consumption reduction and allied benefits of reduced GHG emissions and improved energy security. Hence, good information on technology attributes to improve FE is essential to the regulatory process. Technology continues to develop at a rapid pace and periodic analyses are required to maintain an up-to-date list of technologies and their costs and benefits. ICF has provided the Department of Energy (DOE) with such periodic analyses based on interviews with the technical staff of major automotive manufacturers and Tier I suppliers of new technology around the world.

This chapter summarizes recent analyses of new developments in technologies to improve the FE of light duty vehicles (LDVs), including cars and light trucks, which will be available in the 2010 to 2025 time frame. Two specific points are relevant in the discussion. First, all technology benefits are referenced to the U.S. official test procedure for FE. Second, technology “cost” is defined as the cost to the consumer and more correctly referred to as “retail price equivalent” (RPE). This value represents the fully burdened cost with normal profit margins if a technology is produced at high volumes and the benefits of learning and scale are accounted for. Initial costs of introducing a technology at low production volume can be 40 to 80 percent higher than the RPE values referenced in this chapter.

K.G. Duleep is a Managing Director at ICF, Inc.

Engine Technology

While the popular press focuses much of its attention on battery and hybrid electric vehicles, manufacturer product plans show that improvements to the existing engine and drivetrain will continue to be a major focus of effort over the next decade. Both suppliers and automakers have shown new technologies capable of substantial improvements to vehicle FE, while continuing to use the basic spark ignition cycle.

In the conventional spark ignition engine, most driving conditions use only 5 to 15 percent of the maximum power capability of the engine, but maximum power is required under certain infrequently occurring situations, such as during hard accelerations or mountain climbing with full loads. As a result, the engine is usually operating at a highly throttled condition, and throttling loss and mechanical friction each use 17 to 20 percent of the energy generated by fuel combustion. The energy generated by fuel combustion is itself subject to the thermodynamic limitations of the Otto cycle. Hypothetically, reducing throttling loss and mechanical friction loss to zero would improve the fuel economy by as much as 40 percent, but this is not possible in real life.

Manufacturers are looking into two major types of technologies to reduce these losses. First, throttling loss can be avoided by being able to vary valve lift and timing. Variable valve timing (VVT) changes the times when the intake and exhaust valves open and close by camshaft phasing, and is already in widespread use. Variable valve lift (VVL) is used only by some automakers, notably BMW and Honda. BMW started its combined VVL and VVT system, called Valvetronic, on its higher end models, but now the technology is available on most engines. BMW has claimed that the system achieves a FE improvement of about 12 percent, but this includes the benefit of dual cam phasers and reduced friction (Kreuter *et al.* 2003). Subtracting these benefits, the VVL system is expected to yield about 8 percent FE improvement in high performance cars but only 6 to 7 percent improvement in average performance vehicles. This comparison is relative to a port fuel injected (PFI) engine with fixed valve timing and compression ratio. In addition, friction losses can be reduced by 10 to 15 percent, which can yield a 22 to 33 percent improvement in fuel economy.

A similar approach is used on larger engines where both exhaust and intake valves are disabled on some cylinders so that four of eight cylinders in a V8 engine run at a much higher load with reduced throttling loss (Albertson *et al.* 2003). The system is used in many General Motors (GM) and Chrysler V8 engines, but its use in six or four cylinder engines is more problematic, due to noise and vibration when running on two or three cylinders. Hence, VVLT and friction reduction may be the preferred approach for smaller engines in the future.

While VVL and VVT technologies have been around for some time, new attention has focused on using small turbocharged gasoline engines to replace larger engines. Turbocharged gasoline engines were introduced over 30 years ago to tepid market response since the small engines performed poorly at low speeds. A new technology, direct injection, is changing the performance map to make these engines more competitive.

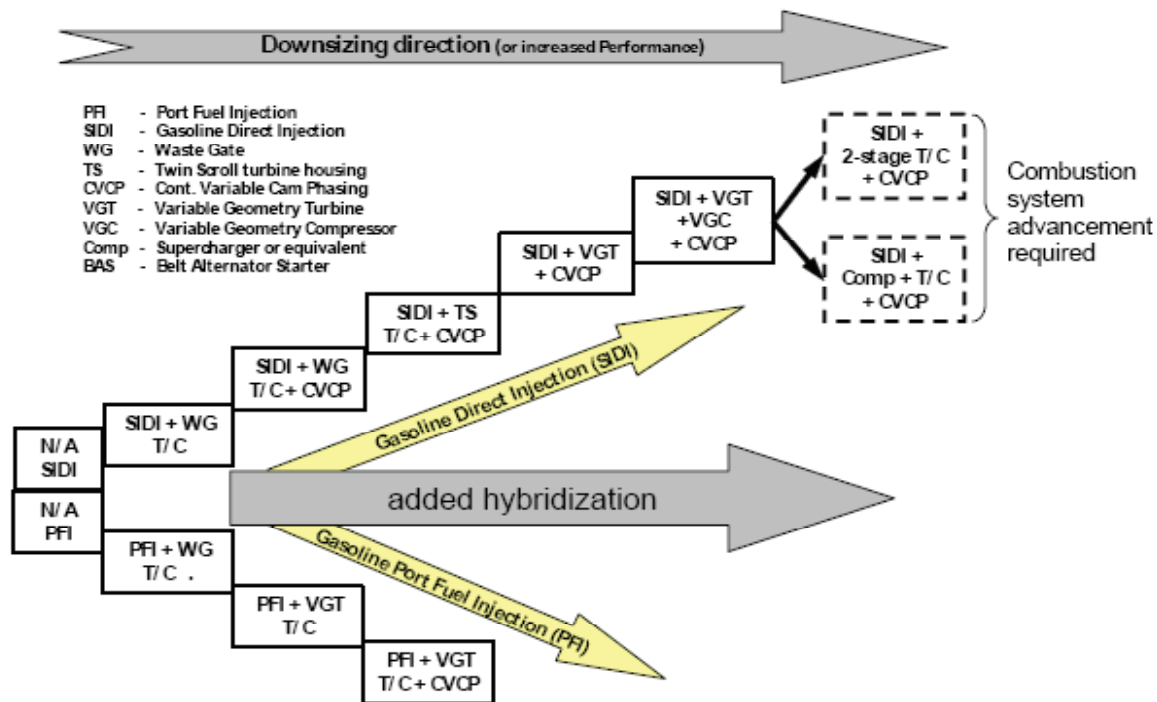
Direct injection spark ignition (DISI) engines can be differentiated into the stoichiometric homogeneous combustion and lean stratified mixture combustion types. The stoichiometric DISI process forms a homogenous mixture by injecting fuel into the cylinder during the intake stroke and controls the fuel/air ratio in the same way as conventional PFI engines. These types of engines typically achieve fuel consumption improvements, among other effects, due to intake air cooling caused by fuel vaporization directly in the cylinder and the resulting opportunity to increase compression ratio, thereby increasing the thermodynamic efficiency of the cycle. The emissions are controlled by a conventional 3-way catalyst, and FE gains of 3.0 to 3.5 percent can be realized with a compression ratio increase of two points.

The latest generation lean-burn DISI systems control air/fuel mixture stratification in the cylinder by the spray formation of a centrally mounted injector, and therefore, are called spray guided. The air/fuel mixture formation takes place independently of gas flow and piston movement, and lean burn can increase the fuel economy of gasoline engines by 10 to 12 percent (Bosch). Stratified lean combustion has high costs due to

the complexity of aftertreatment catalysts to meet stringent U.S. emissions standards. In the U.S. market, shifting spray-guided operation toward stoichiometric combustion over some parts of the driving cycle may offer a solution to the emissions issues.

Most auto manufacturers agree that DISI combined with turbocharging and VVT offers an attractive path for the future. Figure 11-1 provides a pictorial illustration of the downsized, or enhanced performance, and turbocharged engine pathways from GM's perspective (Grebe and Larsson 2007). The company has demonstrated that turbocharging and downsizing can be executed in numerous configurations and can be used for both PFI and DISI engines. The package with the most promising fuel economy improvement potential is DISI with variable geometry turbocharging and VVT. GM further argues that all downsizing and DISI turbo packages would work well with hybridization, since the turbo lag issue can be minimized with the electric motor power assist.

Figure 11-1: Pathways for future turbocharged engine evolution

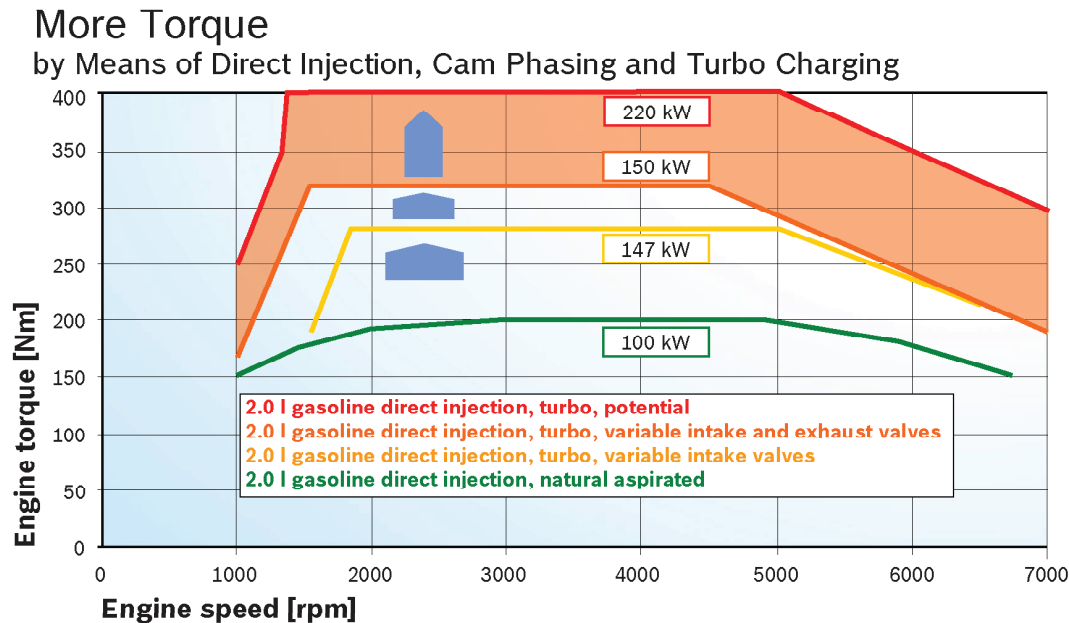


The ability to downsize the engine by one-third makes the turbo DI package particularly appealing from a cost viewpoint. A typical 3.5 liter V-6 can be replaced by a 2.4 liter 4-cylinder turbo DI engine, with the cost reduction from the engine downsizing offsetting much of the cost of the DI system and the turbocharger package. Similarly, a 5.2 liter, V8 engine can be replaced by a 3.5 liter V6 turbo DI engine with similar savings. The U.S., with its high concentration of V8 and V6 engines, is a good market for this strategy. The smaller engine also has lower levels of mechanical friction due to the reduced cylinder count. This strategy can provide roughly a 13 percent improvement in FE with the level of downsizing implied. The strategy is more difficult to execute starting from a smaller cylinder engine because of the noise and vibration issues with 3-cylinder and 2-cylinder engines, but this may become acceptable eventually.

Additional developments are likely to occur in the post-2016 period with the use of technologies such as twin sequential turbochargers and advanced combustion control with piezo-injectors for direct injection. As shown in Figure 11-2, current concepts (the orange line) have 1.5 times the output of naturally aspirated engines (the green line), while future concepts (the red line) can have 2.2 times the output, implying the potential to downsize engines by more than 50 percent with no loss in peak performance (Bosch).

Additional improvements in the post-2015 time frame are being shown in prototype form by automakers and suppliers. Engine developers have long been interested in camless valve actuation (CVA), since it promises as much as 20 percent improved FE over an engine with conventional mechanically operated valves. There is less assembly complexity, engine friction, and weight with camless design because mechanical camshafts and related parts are eliminated.

Figure 11-2: Engine and motronic system concepts

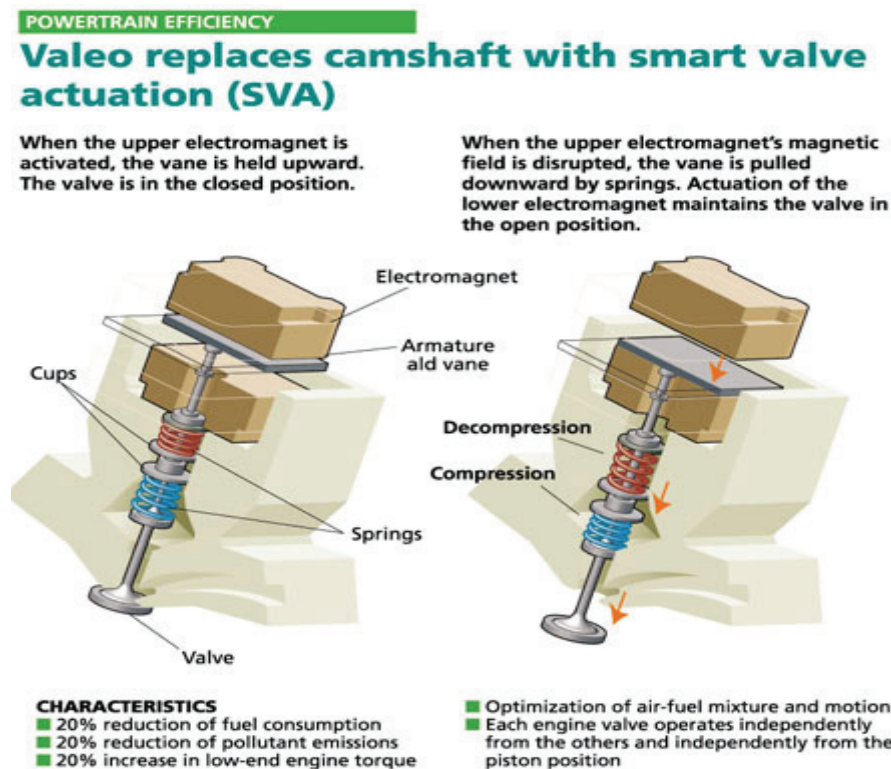


Camless valves could eliminate the conventional throttle and, as a result, reduce pumping losses. An example of such a system has been shown by a French supplier, Valeo. In Valeo's electromagnetic camless engine design, shown schematically in Figure 11-3, each valve is operated individually by an actuator that is placed on the upper surface of the cylinder head, directly above the valve guides (Durrieu *et al.* 2007). The individual actuators are linked to an engine-mounted valve control unit (VCU) that performs the power drive function. Each actuator is linked to an engine-mounted valve control unit (VCU) that performs the power drive function.

Valeo is developing two different systems, each one including actuators, the VCU, the wiring rail, and the electronic control unit (ECU) with the specific strategies dedicated to these new concepts. The first one is called full camless, since it manages the valves on both the intake and exhaust side of the engine. The second one is called half camless because it manages the inlet valves only. Valeo claims that the half camless engine would improve fuel consumption by about 12 percent, implying a 14 percent FE improvement, and provide 15 to 20 percent more low end torque than a conventional gasoline fixed valve timing engine. When cylinder deactivation benefit is included, implying that the exhaust valves must have a separate deactivation mechanism, the FE gain can be as high as 20 percent.

Another exciting development is a new form of combustion called homogenous charge compression ignition (HCCI). This type of combustion permits ultra-lean mixtures to be used without combustion stability problems and is sometimes described as bridging the gap between diesel-type droplet compression ignition and homogenous mixture spark ignition. Its appeal lies in the potential to attain diesel-like efficiency with very low emissions, but combustion control has proved difficult. Recent announcements by several automakers suggest that commercialization by 2020 is a good possibility (Yun *et al.* 2009). It is quite possible that direct injection of fuel and camless valve control will be enabling technologies to achieve the

Figure 11-3: Valeo electromagnetic CVA design



desired level of combustion control. HCCI in combination with these technologies and friction reduction could ultimately provide a total gain of up to 28 percent in FE by 2025.

Table 11-1 provides a summary of mid-term and longer term engine improvement prospects in percent changes to fuel economy as well as the RPE in 2009 U.S. dollars for a four cylinder engine. As can be seen by the data in the table, the mid-term technologies offer gains that typically cost less than \$40 per percent improvement in FE, but the longer term improvements are likely to be more expensive at \$50 to \$60 per percent improvement.

Table 11-1: Mid-term and longer term engine improvement prospects

Technology	Near Term FE Benefit	RPE (2009 \$)	Long Term FE Benefit	RPE (2009 \$)
Variable Valve Timing	1.5 to 2%	50 to 100	2 to 2.5 %	80 to 100
Variable Valve Lift	5 to 6%	150 to 250	6 to 7%	150 to 200
Camless Valves	11 to 13 %	400 to 500	15 to 17%	600 to 700
Direct Injection (DI)	2.5 to 3%	180 to 230	3 to 4%	160 to 200
DI – Turbo/ Downsize	11 to 15%	100* to 600	13 to 17%	100* to 600
DI Lean Burn	-	-	12 to 15%	900 to 1200
HCCI	-	-	18 to 20%	~1500
Friction Reduction	1.5 to 2%	20 to 40	3 to 4%	40 to 60

* with reduced cylinder count

Driveline Technology

While the engine improvements described above will be a major contributor to near-term fuel economy improvement, there is substantial scope for improvements in all other aspects of the vehicle that contribute to energy losses.

Transmission improvements include both the addition of more gears and the reduction of internal losses within the transmission. Adding more gears allows improved matching of engine operation to the vehicle power demand. While the majority of transmissions in the 2000 time frame were four-speed units, there is a major changeover to six-speed units that has already started. Technology breakthroughs in transmission design have allowed packaging a 6-speed transmission in the same general package size as a 4-speed unit with relatively low marginal cost, while providing a 4.0 to 4.5 percent gain in fuel economy, and the 6-speed unit is expected to be standard equipment in a majority of vehicles by 2012 (Schener 2003). Seven- and eight-speed units have appeared in luxury cars, but their marginal benefit over a 6-speed unit is small—in the range of 1.0 to 1.5 percent—so the 6-speed unit is likely to be the transmission of choice in mass market vehicles for the next decade (Konda *et al.* 2007).

The continuously variable transmission (CVT) is the logical extension to the increasing number of gears, but it has more internal losses than conventional gear-based automatic transmissions, so many manufacturers have not opted to deploy the technology. Others, notably the Japanese manufacturers, are more optimistic about the prospects for the CVT, especially in small cars, so increased penetration in the subcompact and compact segments appears likely (Vaughan 2007).

A notable competitor is the new double clutch transmission (DCT), which is the equivalent of having two manual transmissions in parallel. The manual transmission offers much lower internal losses relative to an automatic, largely due to the elimination of the fluid torque converter, but a problem results from torque interruption, due to clutch disengagement when the gears are shifted. The 6-speed DCT solves this problem by having one of the two parallel units engaged at all times, and is 33 to 44 percent more fuel efficient than the six-speed automatic (Matthes 2003). DCT units have become more popular in Europe, where the manual transmission enjoys high levels of market penetration.

Reductions in other driveline losses, such as axle friction and brake drag, are also likely through design improvements and better axle lubricants. The net benefits from these actions are small at 0.5 to 1.0 percent improvement in FE.

Weight, Drag, and Rolling Resistance

A reduction in power required to move a vehicle can be achieved by reducing the inertial and frictional components resisting motion. Smaller vehicles have better fuel economy because they have less weight, lower aerodynamic drag, and lower tire rolling resistance, but these reductions can also be achieved with improved technology.

Weight can be reduced without size reduction through the use of alternative materials, improved packaging, and weight conscious design. Although the industry has, over the last 25 years, shown very lightweight prototype vehicle bodies using aluminum or composite materials, very few concepts have actually made it into production. This is because of the high cost of alternatives relative to steel, and the need to develop new production processes to handle such materials. In addition, steel continues to improve, and new ultra-high strength steels have closed the gap in weight reduction potential so that marginal costs of alternatives per unit weight saving have increased.

Manufacturers expect that with intensive use of high strength and ultra-high strength steel and advanced design techniques most vehicles can have 5 to 10 percent weight reduction at relatively low costs of less

than \$1 per pound saved (EEA 2007). Aluminum has already achieved high penetration in the market for castings, such as engine blocks and transmission cases, and in applications, such as suspension members, where weight reduction brings additional benefits in ride and handling. Advanced composite materials are widely used in interior components, such as the dashboard, seats, trim, and in selected engine components like intake manifolds and valve covers, but have seen only limited use in exterior components or in load bearing structures. ICF does not anticipate weight reduction beyond the 5 to 10 percent forecast for most vehicles, although some vehicles like luxury cars may showcase more high-cost approaches with alternative materials.

Aerodynamic drag reduction can be achieved through design and styling changes, but, contrary to popular belief, does not require all vehicles to look like sports cars. Low-speed aerodynamic drag reduction requires attention to details like the airflow around the bumper and hood of the car and the wheel arches and controlling flow separation towards the rear of the vehicle. There are limits to drag reduction as measured by the drag coefficient, which is a non-dimensional measure of drag force. Car bodies may be limited to a coefficient of 0.22 to 0.24 without seriously impacting desirable attributes. This represents a 20 to 25 percent reduction from the current average levels of 0.30 to 0.32, although some models such as the Mercedes S-class are already at 0.25. Trucks are limited to even higher levels due to their boxy shape and higher ground clearance, but the percentage reductions possible from current levels are believed to be similar to that for cars (*Automotive Engineering* 2008).

Rolling friction is measured by the tire rolling resistance coefficient (RRC), which is also a non-dimensional measure of tire energy loss. The rolling resistance can be improved by changes to tire tread and shoulder design and changing the materials used in the tire belts and traction surfaces. The tire size and sidewall height also affect the rolling resistance of the tire, with larger diameter tires and shorter sidewalls reducing the rolling resistance (NAS 2006). The RRC for typical family cars is in the 0.007 to 0.009 range, but performance tires with high speed ratings and off-road tires have higher RRC values. While tires with RRC values as low as 0.005 are commercially available, such as the ones used in the GM EV1 battery electric vehicle a decade ago, the main issue has always been the tradeoff with other tire parameters that are desired by the customer. Tires are selected for vehicles based on a complex set of properties of which rolling resistance is one. The properties also include wear, noise, ride comfort, traction, and wet and dry braking. For a given tire size, the properties are interrelated and improving one results in some other property becoming worse.

Technological improvements to tires can simultaneously increase all desirable properties at some increase in cost. Tire manufacturers indicate that evolutionary design improvements and material technology improvements will continue to drive down average RRC by 5 to 7 percent per decade. Market trends to larger diameter tires with low aspect ratios may assist in lowering RRC further, especially if the trends towards higher speed ratings and better traction performance slow in the future.

The FE effect of these changes depends on whether the vehicle is re-optimized for constant performance. For example, reducing weight by 10 percent will improve FE by 4.0 to 4.5 percent, if nothing else is changed. If the engine size is reduced so that the vehicle still has similar performance, the benefit can be 6.0 to 6.5 percent. In the long run, the engine and drivetrain will be re-optimized for the new weight, drag, and rolling resistance to obtain maximum FE benefits.

Vehicle Electrification and Hybrid Technology

Accessories use 8 to 10 percent of engine output on the federal test procedure (FTP), but several technologies are available to reduce this demand. In the past, accessories were generally designed for low cost and good durability, and efficiency was only a secondary concern. For example, the typical claw-pole alternator is used in vehicles because of its low cost and good durability, but it has an efficiency of about 60 percent in converting shaft power to electrical power compared to other alternator types that can provide up to 90 percent efficiency.

Power steering pumps are somewhat different in that they operate continuously, but are needed infrequently. Electrical, as opposed to hydraulic, systems can save relatively large quantities of energy by eliminating continuous operation that wastes energy. Water and oil pumps also operate continuously independent of cooling or lubrication requirements, and moving to an electric drivetrain can save energy by providing the service on demand. Increasing the level of electrification can be part of a strategy to employ and store electricity onboard the vehicle to improve efficiency.

Engine stop/start technology, the first step in the hybridization process, is used to shut the engine off during idle and deceleration, which can provide a 3 to 4 percent FE gain (Bosch). While this seems to be a simple process, it is not easy to implement, especially in vehicles with air conditioning and automatic transmissions. The frequent restarts require a significantly upgraded starter, and the stress on the electrical system requires that the battery be upgraded to withstand frequent high current demand. The automatic transmission needs to be shifted to neutral and torque converter fluid pressure maintained to permit quick launch at restart, while a hill-holder clutch is required to prevent the vehicle slipping backwards with the engine off. Maintaining air conditioner operation with the engine stopped is difficult due to large power demand, but ingenious solutions like storing cold coolant can overcome short engine stoppage periods. As a result, such systems are more popular in Europe, where neither the automatic transmission nor air-conditioning has high market penetration.

The belt alternator starter (BAS) is the next step up the hybridization ladder. Here, the alternator also operates in reverse as a motor to restart the engine using the accessory belt drive. The alternator is more powerful than a starter motor, thereby permitting smoother restarts. It also allows capture of some braking energy (Itagaki *et al.* 2002). GM has introduced this system in several models, but market response has been tepid since its FE benefit is less than 8 percent. The availability of more electrical energy does permit the easier electrification of accessories discussed above.

Increasing electrical machine power output from the 3 to 4 kW of the BAS system to 10 to 15 kW or higher gives rise to the hybrid electric technology now employed in most hybrid electric vehicles (HEVs) marketed in the US. The Honda IMA system is one such design. It uses a single electric motor sandwiched between the engine and transmission (Hanada *et al.* 2005). The motor provides the start/stop function and also assists the engine during periods of high power demand, while recovering more braking energy. Operating solely with electricity is challenging, however, since the electric motor must also restart the engine when more power is demanded.

More sophisticated systems using two electric motors that provide all of the functions, including low to mid-speed electric drive, are represented by the Toyota hybrid synergy drive system and the GM two-mode hybrid design that typically feature electric motors with a combined output of over 60 kW (Nitz *et al.* 2006). The RPE of the Toyota system is estimated at \$4,500 for a mid-size car in high volume production, while the Honda system is about half this price. However, the hybrid system includes a significant downsizing of the engine and the system can provide an additional 28 to 30 percent FE benefit for the Honda system and a 40 to 44 percent benefit for the Toyota system in comparison to a conventional vehicle of equal size and performance, with additional benefits from accessory electrification.

The Toyota Prius, for example, achieves almost 60 percent improvement in FE over a Corolla of equal performance, but it has numerous other technology improvements over and above hybridization. Some have argued that the IMA system provides a better cost-benefit than the 2-motor type system since it provides about 70 percent of the benefits for half the cost, but others believe that the drivability and feel of the IMA system is inferior to that of the 2-motor system.

The benefits of hybridization relative to conventional vehicle technology will not be degraded by 2020. Although some of the technology improvements for conventional vehicles are not applicable to HEVs, such as the improvements to transmissions or throttling at the intake valve, most others are. In addition, the electrical system efficiency will increase in the future, and increased battery capacity with reduced internal

resistance will permit more of the operating modes to be all-electric. As a result, incremental FE benefits may actually increase in the short term, but stay at current levels even in the long term (Oba *et al.* 2004).

While the hybrid electric systems have demonstrated significant benefits in fuel economy, their high cost has limited market appeal to date. The Toyota system costs over \$100 per percent improvement in FE, which is more than twice that of conventional technology improvements. Cost reduction of 25 to 30 percent per design cycle of seven to eight years appears possible and likely for both the Honda and Toyota type HEVs, which would make them cost competitive with conventional vehicles in the 2020 to 2025 time frame.

Plug-in Hybrids and Electric Vehicles

Plug-in hybrid electric vehicles (PHEVs) have received much attention over the last few years, and this technology is seen as one step on the path towards U.S. energy independence. Pure battery electric vehicles (BEV) have also enjoyed a renaissance, with several manufacturers announcing their intent to introduce a BEV model by 2012. Both these vehicle types have been made possible largely because of the development of the lithium ion battery, which now appears to be on the verge of commercial introduction as an automotive power and energy storage device.

The lithium ion battery actually refers to a number of different chemistries. In such batteries, the anode is typically made of graphite, while the cathode can be lithium alloyed with manganese, iron phosphate, nickel-cobalt, or other alloys. Each particular chemistry offers a different trade-off between energy density, safety, durability, and cost, but so far, no consensus has emerged on an optimum chemistry for automotive applications. Batteries maximizing energy storage or balancing power versus energy capacity currently have a cost of about \$700 to \$750 per kilowatt hour (kWh) of energy storage capability if manufactured in volume. This cost refers to the cost of individual battery cells, not the retail price. Individual cells are combined into a battery that features thermal and electrical management of the cells and ensures safety from both internal short circuits and external forces, such as a crash. The RPE of an entire battery is currently over \$1,300 per kWh. Battery manufacturers seem confident of reducing cell costs to under \$500 per kWh by 2015 and aim to cut costs by another 30 percent by 2020, which would reduce the battery RPE to about \$600 per kWh.

A second major area of uncertainty in automotive use is battery life. There is little experience with lithium ion batteries under on-road conditions, and manufacturers appear confident of only an average seven-year life. By 2020, battery manufacturers hope to extend the life to 12 years or more to match the typical lifetime of a conventional car, but this is also not assured.

Converting a 2-motor, Prius-type HEV into a PHEV requires a considerable expansion of the energy storage capability. The current Prius model stores only a maximum of 1.3 kWh of energy, but the system does not allow extended all-electric operation. If the Prius were to have an all-electric range of 20 miles, it would require about 5 kWh of usable energy. Since battery life deteriorates by discharging toward empty or charging to 100 percent of capacity, five kWh of usable energy requires a battery of about 7.5 to 8.0 kWh capacity, which adds about \$10,000 to the HEV retail price. In addition, cabin heating and ventilation systems must be redesigned to accommodate all-electric operation, which adds another \$1,500 in RPE. Turning on the heat or air conditioning also has a large effect on all-electric range. The RPE increment could be reduced to about \$5,000 by 2020. Such high RPE increments have been a matter of great concern to automakers. The energy efficiency of the PHEV would be similar to that of an HEV when the batteries are low, but it would be much more energy efficient as a BEV.

The two-motor PHEV operates in electric-only mode up to moderate speeds and acceleration rates. The engine is turned on during periods of high power demand or at freeway speeds. GM has developed another type of PHEV termed an extended range electric vehicle (EREV), which is similar to a BEV with a small battery and an onboard engine/generator combination to recharge the battery. The GM EREV has a 16

kWh battery and a claimed 40 mile all-electric range, and is capable of electric operation at all speeds and loads. Costs of such a vehicle are even higher than the PHEV. ICF estimates an RPE increment of \$23,000 for a compact car assuming normal overhead and profit margins, or about \$18,500 more than an HEV.

The pure BEV with a 100-mile range is technically possible, but still an expensive proposition. To achieve a 100-mile range in a compact car a battery capacity of about 24 kWh is required, and the 100-mile range is possible only without turning on the heating and air conditioning systems. On a cold rainy day, use of the defroster and heat and headlights along with reduced battery capacity may cut actual range to 50 miles.

The pure BEV battery is a little cheaper per kWh compared to a PHEV battery, but, even so, the RPE increase is quite large. With normal profit margins, a 100-mile range compact BEV would have an RPE of about \$30,000 more than a conventional car, but this could decrease to about \$20,000 by 2015, if planned cost reductions are achieved and volume production occurs. Recent comments by manufacturers about the 2012 models suggest that they will be pricing BEVs at expected 2015 levels rather than actual 2012 costs and lose money initially to ramp up sales volume quickly.

The BEV would have an energy efficiency of about 0.25 to 0.28 kWh per mile when calculated from the plug to the wheels. For larger vehicles, energy efficiency scales approximately inversely with vehicle weight. Typically, recharging at home with a 110 Volt outlet will take 8 hours or more, but this time can be halved when charging through a 230 Volt outlet. Specialized recharging equipment is now available to recharge the batteries in 0.5 hours or less, but the effect of such fast recharging on battery life is not clear.

Diesel Engines

The diesel engine is not new, but many new technological improvements to this engine could offer significant increases in FE. Diesel engines provide a 33 percent increase in FE at similar performance levels to gasoline engines (Schmidt 2006), and proponents point to its 50 percent penetration of the European market as a proven path to fuel efficiency. The diesel car in Europe has been helped both by the high absolute price of fuel and the lower cost of diesel fuel relative to gasoline, conditions that do not exist in the United States. In addition, more stringent emissions standards in the United States impose high aftertreatment costs, and the RPE of a four-cylinder diesel engine suitable for compact cars is around \$2,300, while a V6 diesel engine has an RPE of about \$3,300. This makes the diesel very similar in terms of cost and cost effectiveness to the IMA hybrid electric drivetrain.

The diesel engine has two issues to contend with in the U.S. that are not faced by the IMA hybrid or other gasoline-fueled hybrid electric drivetrains. First, the GHG reduction is much smaller than that for an IMA hybrid due to the fact that diesel has 12 percent more carbon content than gasoline per gallon. Second, diesels have struggled to meet the current California emissions standard and have only recently demonstrated compliance with existing regulations. Meanwhile, California has announced its intention to further tighten emission standards. The continuing uncertainty about future emissions compliance and cost, and the emergence of GHG emission standards as a constraint have affected manufacturer interest. Only the German car manufacturers offering diesel engine options now include them in U.S. product plans for the future. Diesels may yet emerge in larger trucks where the low-end torque and the durability of the engine are valued, but the prospect of high market penetration in the United States as in Europe seems unlikely now.

Forecast and Policy Implications of Technology

Table 11-2 provides a summary of the improvements possible to 2016 and 2025 from the technologies discussed when applied in a midsize car, starting from a 2008 baseline. These levels can be considered as the maximum that can be done in that time frame, since every make and model would have to be redesigned to include all available technology. The table shows that improvements to conventional technology can

provide a gain of 33 percent by 2016 and up to 50 percent by 2025, and going beyond these levels will require increasing levels of hybridization. In reality, even these levels will require moderate increases in hybridization, since the pace of technological change is also a limiting factor, and not all products can include all technology by 2016.

Table 11-2: Midsize car technology improvements possible by 2016 or 2025

<i>Technology</i>	<i>Near Term FE Benefit</i>	<i>RPE 2009\$</i>	<i>Long Term FE Benefit</i>	<i>RPE 2009\$</i>
Engines	14 to 17 %	200* to 800	25 to 28%	\$1,100* to \$1,700
Transmissions	5 to 7%	200 to 350	6 to 8%	\$240 to \$400
Weight, Drag & RRC Reduction	5 to 6 %	180 to 250	10 to 12%	\$400 to \$500
Electric Accessory Power	2 to 3 %	70 to 100	3 to 4%	\$100 to \$130
Idle Stop	3 to 4%	300 to 400	2 to 3%	\$200 to \$300
Total Conventional	33 ± 3%	1,200* ± 100	50 ± 3%	\$2,300* ± 150
IMA Hybrid*	28 to 30%	\$2,300 ± 100	30 to 33%	\$1,600 ± 100
Two Motor Hybrid*	40 to 45%	\$4,500 ± 200	44 to 48%	\$3,100 ± 200
Diesel Engine* (mpg)	32 to 35%	\$1,800 ± 100	32 to 35 %	\$1,800 ± 100

* includes credit for engine cylinder count reduction. Baseline is a 2008 midsize car with a 3L V-6 and 5-speed automatic. All values are increments to baseline.

Other analyses, such as the one by Kasseris and Heywood (2007) at MIT, have come to broadly similar conclusions, although there are differences in assumptions about individual technology improvements by 2030. They estimate that conventional technologies alone can increase fuel economy by 75 to 80 percent by 2035, partly because of a higher level of weight reduction and performance reduction assumed. Their analysis also points to a narrowing of the diesel benefit over gasoline engines by 2035, while they find incremental hybrid benefits to continue at current levels. The RPE for conventional technology estimated in a companion paper from Cheah *et al.* (2007) from MIT are similar to the ones in this chapter, at \$2,650 for a midsize car compared to the ICF estimate of \$2,300, although their estimate also includes costs for more aggressive weight reduction. Hybrid and diesel technology RPE are also quite similar, at about \$2,500 and \$1,700, respectively.

Economic considerations can determine how much and how far technology can be pushed, but the vehicle market presents some unique challenges. Even though vehicle life is about 14 years, manufacturers state that consumers do not purchase fuel saving technology unless the fuel saving offsets increases in vehicle first cost in about three years or less. On average a consumer drives about 40,000 miles in three years, and a midsize car with an on-road FE of 25 mpg will use 1,600 gallons of fuel. At \$3 per gallon, fuel costs are \$4,800. Hence, each 1 percent reduction in fuel consumption is worth about \$48 to the consumer, and it appears that most of the conventional technology improvements to 2016 are within this cost/benefit ratio. Not coincidentally, the 2016 standards require about this level of improvement relative to 2008, so it does appear that the standards will be quite cost effective even from the consumer's perspective.

The two-motor type hybrid midsize vehicle will have an on-road FE of about 40 mpg and use \$3,000 of fuel in three years for a saving of \$1,800 relative to a conventional vehicle, but incremental vehicle costs are much higher. This explains the relatively low market penetration of HEVs to date. On a discounted lifetime net present value analysis with a 7 percent social discount rate, the HEV is cost effective as fuel savings are about \$4,500, matching first cost increases. However, as conventional vehicles become more efficient, alternatives such as HEVs can be less cost effective, even if their costs are falling. For example, if the FE of the example conventional vehicles is improved by 40 percent to 35 mpg by 2020, fuel costs decrease to \$3,400 and each additional percent reduction in fuel consumption is worth only \$34 instead of \$48, a

reduction of 28.6 percent. If HEV costs decrease more than 30 percent over the next decade, as expected, its competitive position barely improves against the backdrop of improving conventional vehicles, making this level of cost reduction almost a requirement. Higher fuel costs and longer consumer valuations of fuel efficiency benefits will be required to change the market dynamics to expand HEV penetration without resorting to subsidies.

PHEV and BEV costs are so high in the near term that absent large subsidies, it is difficult to see any financial benefit to the consumer. The incremental price of a PHEV over an HEV in a compact car is about \$10,000, and no amount of fuel saving can justify this amount to the consumer. Even with a subsidy of \$5,000, the marginal benefit of the PHEV does not approach the increased price. The implication is that PHEV and BEV markets will be very small in the near term to 2015, and real market expansion must wait until 2020 or later, when battery costs have declined significantly and fuel prices could rise significantly. The BEV may succeed in niche markets, like urban commuter vehicles that are small with a range of about 50 miles, but previous attempts to sell these types of cars in the United States have not been successful.

Greenhouse Gas Reductions

In general, GHG emissions and fuel economy have an inverse relationship, so that the 40 percent increase in fuel economy planned for the 2016 period will result in a net reduction of GHG emissions by 28.6 percent, and reductions of approximately this magnitude from new light duty vehicles by 2016 seem assured with technology that is very cost effective to the consumer for the most part. GHG emissions from light duty vehicles will also be reduced by air conditioner improvements, and by the use of lower carbon content fuels.

The ICF analysis also points to difficulties in setting more aggressive GHG standards in the post-2016 time frame. Technologies become more expensive per 1 percent fuel savings, while lifetime absolute fuel savings become smaller as new cars become increasingly efficient. Hybrid electric technology appears to be cost effective on a lifecycle basis at \$3 per gallon of fuel and could modestly improve its position to 2020 with anticipated cost reductions even with increasingly efficient cars.

Hybrid technology will likely be the focus of the next round of more stringent GHG standards for the 2016 to 2025 period, and could spur innovative ways of marketing or pricing HEVs to allow consumers to recognize lifecycle benefits instead of short-term benefits. Widespread use of hybrid technology with conventional technology improvements suggests GHG emissions from new light vehicles can ultimately be halved over the next two decades, while continuing to be cost effective to the consumer on a vehicle lifetime basis.

PHEV and BEV technology could allow further progress as economics improve, but it may be premature to judge these technologies. Over the next five to 10 years, understanding of battery costs and durability will improve, allowing better vehicle design decisions. This could help create cost-effective PHEV and BEV models as the next wave of technology improvements takes effect in the post-2025 period.

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Chapter 12:

Technologies and Policies for Improving Truck Fuel Efficiency & Reducing CO₂

by Anthony Greszler

Most of the focus on transportation efficiency and carbon dioxide (CO₂) mitigation has been on light duty cars and trucks used primarily for personal transport. This segment has a 66 percent share of transport petroleum consumption in the United States (U.S.) and a proportional share of CO₂ emissions. Nonetheless, the 21 percent share of U.S. transport petroleum consumption by heavy trucks and buses is significant and growing. Furthermore, when transport is viewed globally or if trends are projected out to mid-century, commercial road transport could well become the largest user of petroleum and emitter of CO₂ within the transport sector. Hence, increased focus, particularly on road freight transport, is essential for an effective program for mitigating transport CO₂ and petroleum consumption.

This chapter investigates the reasons for the increasing petroleum consumption, potential technologies for improved efficiency and greenhouse gas (GHG) mitigation, and policy options to promote these technologies. It will look at both vehicle and freight systems, since each offers significant potential for improvement.

Freight Segment Projections

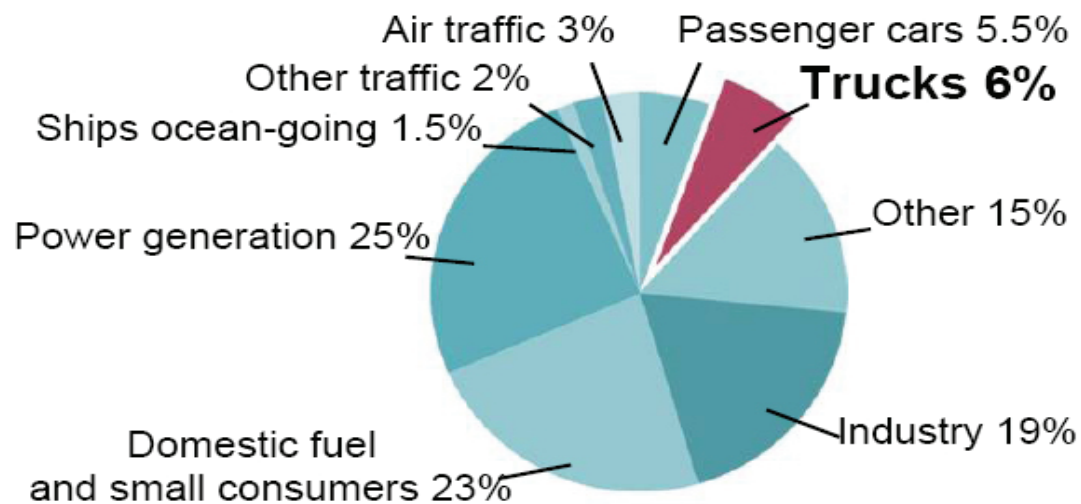
Freight movement, measured in ton-miles, is closely correlated with economic activity in the U.S. The *Annual Energy Outlook 2009 (AEO)*, published by the Energy Information Administration projects annual truck vehicle miles traveled (VMT) to grow by 2.5 percent per year over the next 20 years (EIA 2009), while the Federal Highway Administration pegs the growth rate for tons hauled at 2.0 percent annually (FHWA 2009). This difference is primarily due to AEO's projection that the average length of haul will increase, in addition to a growth in tonnage moved.

The impact is that, by 2030, truck VMT is projected to increase by 62 percent, barring improvement in freight transport, distribution, manufacturing, or other systems that drive freight demand. Interestingly, many "green" developments can also increase freight demand. For example, reduction in sulfur dioxide output from coal-fired power plants has greatly driven up coal transport from the Powder River Basin to eastern power plants, although primarily by rail. Moreover, mandates for renewable fuels, particularly ethanol and biodiesel, drive up transport of feedstock and finished product, since neither of these can be transported through existing oil pipelines.

A. Greszler is Vice President of Government and Industry Relations at Volvo Powertrain North America

When the freight projections are combined with the historical rate of truck efficiency improvement of around 0.6 percent per year, the result is a dramatic growth in diesel consumption and CO₂ emissions by 44 percent by 2030, barring significant availability of lower carbon fuel alternatives. A recent U.S. Department of Energy (DOE) projection showed truck petroleum consumption exceeding light duty car and truck consumption by 2040, assuming a variety of aggressive policies to reduce light duty fuel consumption and VMT (DOE 2009). On a global basis, the impact of trucks is even greater, since developing countries have much lower reliance on personal cars (although use may now be increasing rapidly), but still depend heavily on road freight transport. As shown in Figure 12-1, data from the United Nations Environment Program show that truck CO₂ emissions exceeded emissions from the much more numerous cars on the road in 2002 (UNEP 2002).

Figure 12-1: Global anthropogenic carbon dioxide



Source: UNEP 2002

The demands for road freight have accumulated over time as primary modes have shifted from animal-drawn carts, to rivers and canals, to rail, and finally to roads. This last transition has been driven by dramatic improvements in highways, trucks, and logistic systems. According to the American Trucking Association (ATA), “Economic deregulation of the trucking industry, with its resulting low cost and high service levels, combined with the completion of the interstate highway system, gave rise to what is known as just-in-time delivery, allowing manufacturers to shift inventories from the warehouse to the highway” (ATA 2008). U.S. manufacturing and distribution systems are now critically dependent on the cost-effective delivery precision that trucks provide. Improvement in freight movement efficiency will do nothing to lower the demand for goods movement and may even tend to increase demand if efficiency translates into lower freight cost.

In dealing with light duty vehicle CO₂ mitigation, it has long been recognized that we need a “three-legged stool” approach combining actions to improve vehicle efficiency, to de-carbonize fuel, and to reduce VMT. The same approach needs to be applied to freight transport, but very little public sector attention has gone into this area. In fact, public policy related to freight has been almost entirely focused on safety or mitigation of criteria emissions, primarily nitrogen oxides and particulate matter, from diesel combustion. With the final phase-in of the 2007 and 2010 on-highway diesel emissions regulations, even the U.S. Environmental Protection Agency (EPA) refers to trucks as “clean diesel” (EPA 2001). Further reductions in criteria emission levels are not envisioned. Except for the introduction of low sulfur fuel, criteria emissions improvements have otherwise been accomplished almost entirely through vehicle technology improvements. These emission cuts have also reduced engine efficiency below what it might otherwise be, primarily due to combustion modifications to reduce nitrogen oxide emissions. Concerns are now shifting to global warming impact, which considerably broadens the scope of potential improvement, encompassing the entire freight and distribution system.

Truck Fuel Efficiency

Trucks haul a wide variety of goods in urban, regional, and long-haul operations. They also perform a broad range of vocational work such as garbage collection, concrete mixing, and utility repair. Commercial trucks cover a broad size range, rated by gross weight capacity, and generally include class 3 trucks weighing up to 10,000 pounds to class 8 trucks weighing as much as 80,000 pounds. Eighty-three percent of fuel burned in medium to heavy duty trucks is in the heavy truck segment, and most of this is in combination tractor-trailer trucks (ORNL 2009).

For light duty vehicles, fuel efficiency is usually measured in miles per gallon (mpg), but this is not an appropriate measure for heavy trucks. In the broadest sense, truck fuel efficiency could be defined as work performed per amount of fuel burned, an easy concept to envision, but nearly impossible to measure unless the scope is confined to a subset of the many functions trucks perform. If the vocational functions of trucks are ignored, attention focuses on freight delivery. Here, fuel efficiency can be measured in terms of freight-miles per gallon of fuel. Figure 12-2 below helps to show the big differences between mpg, ton-mpg, and volume-mpg. It shows why an mpg measure, which would be maximized by use of very small trucks, is a poor measure for efficient freight transport.

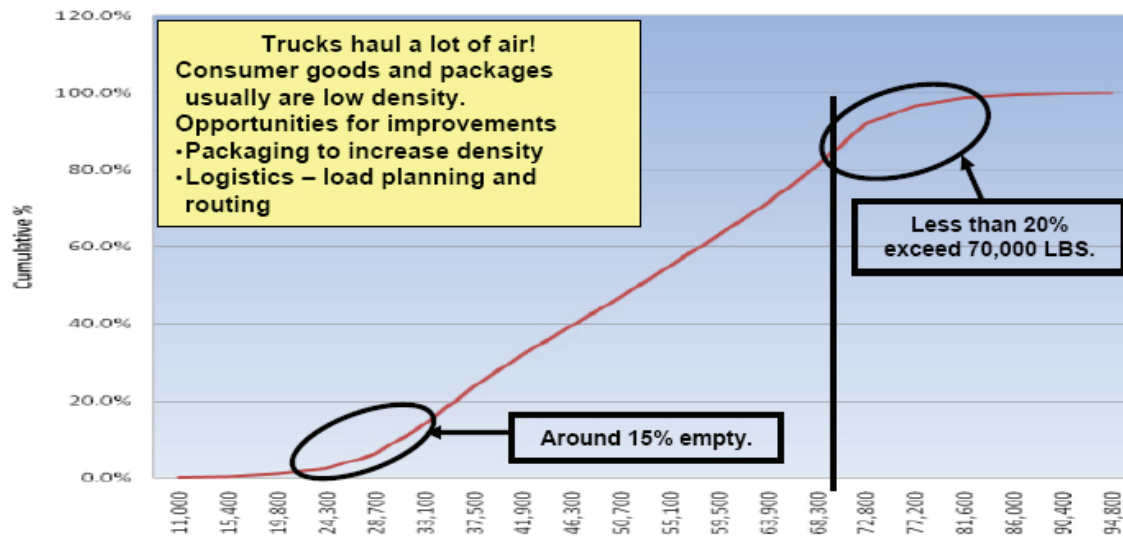
Figure 12-2: MPG is not an appropriate efficiency measure of global anthropogenic carbon dioxide



Source: Volvo Powertrain Division of AB Volvo

The majority of combination trucks in the United States are hauling 53-foot long box vans, simply because this is the longest trailer permitted in most states. There is no data on how often these vans are filled to capacity, but anecdotal data from carriers indicates that most loads are volume limited to well below the maximum gross combination weight (GCW) of 80,000 pounds, the limit set by federal regulation. Weigh station data, noted below in Figure 12-3, show that the 50th percentile load is around 53,000 pounds, and less than 20 percent of trucks carry over 70,000 pounds (US DOT VTRIS 2008). The major reason for this is that trucks usually haul high value, but lower density consumer goods, while heavier bulk and liquid commodities usually go by train, especially over longer distances. Regardless of the reasons, being aware of what trucks haul is important in driving technologies and establishing policies to improve truck freight efficiency and freight system efficiency. From a vehicle design standpoint, the goal is to haul the greatest volume of freight with the least fuel. From an operation standpoint, the goal is to maximize the amount of freight in each load, while minimizing VMT and fuel consumed. From a total system standpoint, the goal should be to minimize fuel burned by minimizing the amount and cost of freight movement required to support economic activity and by moving to lower carbon fuels.

Figure 12-3: Cumulative percentage weights of 5-axle truck combinations in 15 U.S. states in 2008



Source: U.S. Department of Transportation, Vehicle Travel Information System, 2008

Until recently, heavy truck design and manufacturing in the U.S. has been primarily a process of purchasing and assembling major components developed somewhat independently by the component manufacturers. Most engines, transmissions, axles, drivelines, and other systems were supplied by nonintegrated manufacturers. Customers were given wide latitude in specifying their desired components. Original equipment manufacturers (OEMs) of trucks focused on frame and cab features and also developed modeling tools to help integrate the components to meet the expected service requirements, including efficiency. This system drove a focus within the industry on component efficiency, but not necessarily on complete vehicle efficiency. Even government research funding tended to be funneled into specific component areas, particularly diesel engines. While this has reduced criteria emissions and improved fuel efficiency, it has also resulted in designs that could demonstrate very high efficiency in laboratory testing, but could not be reasonably deployed on a working truck due to packaging, weight, cooling requirements, or excessive in-use criteria emissions (NAS 2008).

During the past decade, largely driven by very demanding criteria emissions requirements, there has been a need for much closer integration of major truck components, particularly diesel engines. Of the three former non-integrated engine suppliers, only Cummins remains independent, with Caterpillar dropping out of the on-road diesel engine market and Detroit Diesel fully owned by Daimler. Meanwhile, all of the major U.S. heavy truck manufacturers (Daimler/Freightliner, Navistar, Paccar, Volvo/Mack) now have integrated diesel engine design and manufacturing capacity. These developments reflect the need for vehicle design integration while continuing efforts at component improvement, as noted in Congressional testimony by the industry members of the 21st Century Truck Partnership (HSTC 2009). The U.S. DOE has recognized this need as well and made funding available through the SuperTruck program to demonstrate a long-haul combination truck with a target of 50 percent freight efficiency improvement, including 20 percent improvement in engine efficiency at average road load.

Diesel Engine Efficiency

Diesel engine efficiency has long been driven by competitive demands in the trucking industry. From 1980 until 1999, diesel engines reduced fuel consumption by approximately 10 percent, but since then much of this improvement has been given up as increasingly stringent nitrogen oxide (NO_x) emission requirements

led to combustion optimization for least NO_x emissions, rather than maximum efficiency. With most engine manufacturers adding selective catalytic reduction NO_x exhaust aftertreatment in 2010, efficiency will start to improve again. Trucks have seen steady improvements in available fuel efficiency features, particularly for long-haul tractors. The high fuel prices of 2008 forced many operators of “classic” shaped trucks with large frontal area and external air cleaner and mufflers out of business since they could not compete with more fuel-efficient trucks. Even as fuel prices have dropped, most fleets are now purchasing only aero-shaped trucks. It is very difficult to extract truck fleet fuel efficiency from available public data, but what data are available indicate very little change in combination truck mpg since 1980 (US DOT VTRIS 2008). Confounding issues are increasing speed limits since the gradual repeal of the federal 55 mph limit between 1987 and 1995 and truck load factors.

A major focus continues on diesel engine in-cylinder efficiency, including fuel injection, air induction, and combustion chamber design. New fuel system designs allow for injection pressures over 35,000 pounds per square inch with multiple injections per combustion event and rate shaping during each carefully timed injection event. Air induction is accomplished with variable geometry turbochargers and exhaust gas recirculation. Unfortunately, all this technology has been required to achieve nitrogen oxide and particulate matter reductions, while minimizing efficiency losses, rather than making efficiency gains, which would translate to GHG emission reductions. In fact, the most efficient truck engines were produced in 1998, before increasingly tight nitrogen oxide emissions requirements resulted in an approximately 10 percent loss in engine efficiency.

A recent development in diesel combustion is premixing fuel and air prior to start of combustion, commonly referred to as homogenous charge compression ignition (HCCI) or partial HCCI (PHCCI). Conventional diesel diffusion combustion relies on injection of fuel to time the start of combustion. Fuel is injected when the heat and pressure of compression are sufficient to initiate combustion as the atomized fuel spray plume evaporates and mixes with air. This process results in relatively slow combustion and generates nitrogen oxides and particulate matter. In premixed combustion, fuel is injected prior to achieving sufficient in-cylinder conditions to promote combustion, allowing for the fuel and air to be better mixed when combustion begins, eliminating most criteria emissions and increasing the rate of combustion. If in-cylinder conditions can be managed to perfectly time the start of combustion, the result is both very clean and very efficient combustion. Unfortunately, it is very difficult to control the variables that impact start of combustion, which include temperature, pressure, oxygen concentration, and fuel properties. An early start of combustion (SOC) reduces efficiency and can cause major damage, due to high cylinder pressure. Late combustion reduces efficiency and could also cause misfire. To date, PHCCI has been successfully deployed only at light loads, primarily for criteria emissions control. Deployment at higher loads will require systems to sense SOC and real-time management of in-cylinder conditions. This remains an elusive goal.

A requirement to meet recent on-highway diesel engine criteria emission levels has been the addition of exhaust aftertreatment systems (EATS). In 2007, all manufacturers added diesel particulate filters (DPF). In 2010, most will add selective catalytic reduction (SCR) to remove nitrogen oxides from the exhaust. Both these systems raise exhaust back pressure, which reduces engine efficiency. The DPF may also require active regeneration, accomplished by combusting fuel in the exhaust system to raise the temperature high enough to burn carbon accumulated in the DPF. Conversely, EATS allows for higher in-cylinder nitrogen oxide formation. As a result, manufacturers using SCR are expected to deliver a fuel efficiency improvement of around 4 percent. Fuel cost savings are partially offset by the need to use diesel exhaust fluid (DEF) to facilitate nitrogen oxide catalysis, but most of the CO₂ benefit is retained since DEF has very low net CO₂ impact. Further efficiency gains can be expected as better combustion optimization is facilitated by increased EATS effectiveness.

Engine efficiencies are also improving through efforts to reduce parasitic losses from pumping coolant, oil, and fuel and from friction. Efforts include reducing fluid pressure requirements, electrical or mechanical variable displacement pumps, low friction oil, active management of oil and coolant temperature, reduced friction power cylinder units, and reduced friction bearings.

Probably the single biggest engine efficiency gain could potentially come from waste heat recovery. Current diesel trucks average about 42 percent thermal efficiency, due to limits of the diesel cycle, emissions, and materials. The majority of the remaining 58 percent of fuel energy is rejected to coolant or exhaust heat. There are multiple approaches to convert some of this wasted heat energy into usable mechanical or electrical energy. The three primary methods are:

- Turbo-compounding, which uses a power turbine in the exhaust stream to drive power back into the crankshaft or to generate electricity
- Thermo-electricity, which uses thermo-electric materials capable of generating an electric current from a thermal gradient
- Rankine bottoming cycles, which involves boiling a fluid using the waste heat and driving a turbine or rotary expander to generate mechanical power or electricity

Turbo-compounding has seen limited deployment in production application, but has already been shown to deliver around 3 percent better fuel economy in a highly loaded application. However, at light load, it may harm fuel efficiency. Thermo-electricity, with current materials, can deliver an efficiency improvement of only 1 percent, due to very low conversion efficiency. Rankine bottoming cycles offer the greatest potential, with estimates of efficiency improvement of up to 10 percent in a highly loaded application. Rankine systems require multiple heat exchangers, an expander to generate the power with near-zero leakage of working fluid, low temperature heat rejection in the condenser, and a working fluid that can survive high exhaust temperatures, provide appropriate thermodynamic properties, and avoid freezing. All this has to be done with minimal additional weight and space claim and without adding aerodynamic drag for cooling.

All of these engine technologies combined might deliver a 15 to 20 percent improvement in efficiency, considering that not all can be combined and some are only applicable to highly loaded applications. A tremendous amount of development and expense is required to bring the best technologies into production. Given this, diesel engine efficiency might be expected to improve at a rate of about 1 percent per year over the next 20 years.

Heavy Truck Efficiency

Key areas for truck efficiency gain, beyond the fuel and engine, involve changes to the powertrain, hybridization, wheel and tires, aerodynamics, weight reduction, auxiliary systems, idle managements, driver management, and navigational aids.

In the powertrain, small losses occur in the transmission and axles. Although some friction reduction is possible, the biggest gains are available by deploying smart, advanced transmissions carefully matched to the engine and truck. A growing number of current trucks are sold with automated manual transmissions (AMT) that use a conventional gearbox and clutch, but deploy mechatronic controls to automate the clutching and shifting. This retains the very high mechanical efficiency of a conventional gearbox, while providing the convenience of fully automatic operation. More importantly, a computer controls the shift schedule to maintain the optimal gearing for efficiency. The most advanced AMT's have the ability to sense load and grade to optimize the shifting based on the engine efficiency map. Future transmissions may offer power-shifting capability that can avoid transient torque loss during each shift due to turbocharger lag and improve the acceleration capability from a smaller engine. In turn, use of a smaller engine will drive the average engine load into a more efficient zone, enhancing engine cycle efficiency.

Most long-haul trucks use tandem drive axles, due to the need for traction in slippery conditions or on uneven surfaces. Since each drive axle requires a differential and drive shafts, using only one drive axle reduces friction and lowers weight. This can be accomplished with minimal loss of traction by transferring

weight to the drive axle when wheel slip is detected, although this system may temporarily exceed allowable axle weight limits.

Hybridization offers huge potential for efficiency gains in certain vocational applications, most notably urban refuse collection, due to stop-and-go operation, and utility trucks where engine idling can be avoided during extensive periods when the vehicle is parked, but power is needed for utility functions. In these applications, 30 percent or greater efficiency improvements are possible. However, in long-haul operations, where most truck fuel is burned, there are few braking cycles, and braking energy recovery, possible with hybridized drivetrains, is not a major source of energy. Long-haul hybrid systems can be effective in rolling hills or to avoid idling and light load diesel operation, however, and they can provide electrical power for auxiliary functions. A long-haul hybrid system is estimated to provide between 6 and 8 percent improved efficiency, but much of this is due to elimination of idling during sleeper truck hotel mode, which can be achieved with lower-cost systems. It remains unclear if the fuel and GHG savings of a long-haul hybrid system are adequate to cover the extra weight and cost of the system for typical long-haul applications.

Significant progress has been made recently in advancing low rolling resistance and single-wide truck tires. Since about 30 percent of a truck's energy demand is due to rolling resistance, every 3 percent reduction in rolling resistance translates into 1 percent vehicle fuel savings. The lowest rolling resistance is accomplished by replacing dual wheels on the rear tractor axles and trailer axles with wide single wheels and tires. This can reduce fuel consumption by approximately 3 percent compared to a typical dual wheel and tire system. Further gains are expected, but care must be taken to avoid loss of tire safety, durability, and traction.

Aerodynamic losses are the biggest power demand in a long-haul truck, typically accounting for about half of all losses at 65 miles per hour (mph). Truck manufacturers all offer aerodynamic cabs, which now comprise the vast majority of tractors sold. Still there are small aerodynamic improvements in tractor design that offer about 2 percent vehicle efficiency gain, but the biggest gains are possible by matching the tractor to the trailer and in streamlining the trailer. Significant trailer improvements have been demonstrated, including side skirts, bogie covers, and rear aerodynamic devices known as boat tails, that offer a total fuel efficiency gain of around 10 percent, but very few trailers are so equipped. A primary reason for this is that there are more than three trailers for every tractor, tripling the cost side of the cost/benefit ratio. Also, these devices may be subject to damage on uneven surfaces or may interfere with loading and unloading operations. Greater standardization of trailers could allow for better airflow design between tractor and trailer.

Since aerodynamic losses increase dramatically with speed, the simplest efficiency gain is to slow down. All modern long-haul trucks come with road speed governors that are used by most fleets to restrict maximum speed. In most countries, a maximum governed road speed is legally mandated and restricted by factory engine settings. Europe, for example, sets the maximum governed speed at 90 kilometers per hour, or 56 mph, which is programmed into the truck control system at the factory. The ATA is in favor of setting a road speed governor limit at 65 mph to increase fuel efficiency and safety (ATA 2009).

Heavy trucks are much less sensitive to weight impact on fuel efficiency than light duty vehicles. Fuel efficiency improves around 0.5 percent per 1,000 pounds of weight reduction, so the cost of weight reduction is hard to recover in fuel savings. However, weight is particularly important in the 20 percent or so of trucks that are hauling maximum weight, since less weight means increased freight capacity and fewer trucks to haul the same freight.

Truck auxiliary systems include the air compressor, air conditioner compressor, power steering pump, electrical alternator, cooling fan, engine oil pump, and engine coolant pump. Collectively, these can account for around 8 percent of the total vehicle power demand. All except the oil and coolant pump are typically operated either as an on/off function or modulated by demand, although most incur frictional losses even in the off mode. By converting these from mechanically driven to electrically driven, it is possible to eliminate the friction when off and to fully modulate the operation to meet demand. If the electricity is generated by an engine-powered alternator, much of the benefit is lost due to inefficiencies incurred in converting mechanical

energy to electric and then back again. However, if the electricity can be generated by a hybrid motor using braking energy or by a waste heat recovery system, total system efficiency can be improved. Furthermore, an electric air conditioning system could be deployed while the truck is parked either by plugging in at an electrified truck stop or by using battery power to eliminate engine idling for cab cooling demand.

Truck idling while parked can account for a significant portion of fuel burned. Drivers are required by federal rules to rest for at least 10 consecutive hours. Drivers may not drive more than 11 hours per day. These rules mean a long-haul truck with a single driver must spend 13 hours per day stopped, much of it with the driver in the vehicle. If the diesel engine is idled to maintain cab comfort and electric supply, it consumes approximately 0.7 gallons per hour or 6 to 10 gallons in a day, depending on the total amount of idle time. The same truck might consume 100 gallons while driving, assuming 600 miles per day and 6 mpg. In this mode, 6 to 9 percent of fuel consumed is due to idling. There are many idle reduction systems on the market, for example diesel fired heaters, diesel auxiliary power units, battery powered systems, diesel start/stop systems that monitor cab temperature and battery, and truck stops with air conditioning, heating, and electricity supply. None of these is fully optimum, but all offer improvement over continuous idle and more improvement is possible.

The most important influence on the fuel economy of trucks is the driver. Unfortunately, there is a huge annual turnover of long-haul drivers, typically exceeding 100 percent in most fleets. Driver training is expensive, so fleets need to balance training against expected turnover. Fleets also must compete vigorously to attract and retain drivers. This might pressure them to acquire higher-power, less-efficient trucks because drivers generally like these trucks. Significant vehicle technology is available to help manage drivers, including road speed governors with maximum speed set by the fleet, reduced power in lower gears to encourage early up-shifting for better efficiency, smart transmissions to control gearing, driver feedback, and driver efficiency rewards. Future systems might deploy GPS with terrain and route maps to advise or even control vehicle speed when cresting hills to minimize brake application on the downhill segment or to adjust the road speed governor based on posted speed limits. The objective is to control the truck in the most fuel efficient way.

Additional navigational aid can be providing via intelligent transportation systems that rely on vehicle-to-vehicle communication and infrastructure communication to convey information on congestion, truck stop availability, or other data to help drivers adjust speed, schedule breaks and stops, and to modify routes to minimize time, distance, and fuel consumption.

Freight System Efficiency

Freight is moved by road, rail, pipeline, water, and air. Quite often, multiple modes are deployed. For example, an overseas shipment usually arrives by water. From the port, it may go by truck to a rail terminal, be transported some distance by rail, be moved to a warehouse by truck, and then be distributed to a retail store by truck, transported to a home by a consumer's automobile, and ultimately transported to a landfill or recycled by truck, maybe even being shipped back overseas for reuse. Typically, a domestically-manufactured product moves by truck six times during production and distribution, while imported products move four times after landing at a port (ATA 2009).

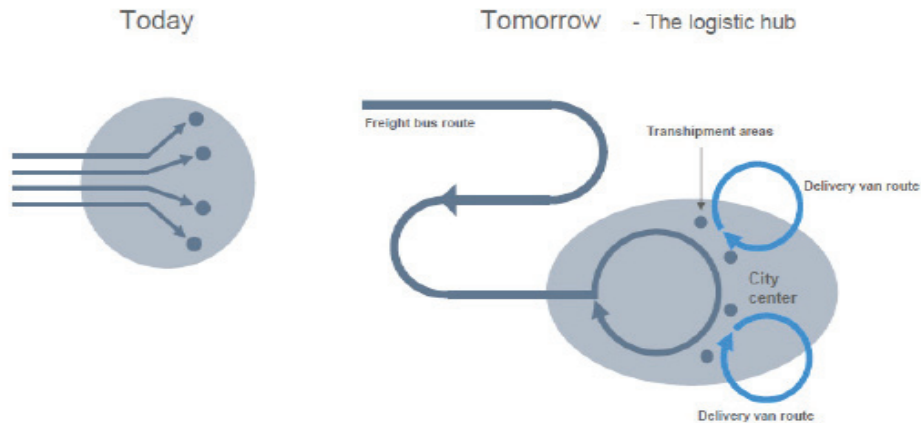
Carriers control truck specifications, the purchase of trailers, and the matching of trailers to tractors. Maximum road speed settings are also controlled by carriers and all long-haul trucks are equipped with programmable road speed governors. Fuel efficiency improves between 1.5 and 2.0 percent for every mph speed decrease between 70 and 55 mph. Therefore, a decrease from 68 to 63 mph can deliver a fuel savings of about 7 percent. Carriers can also use increasingly sophisticated logistics tools to increase the average load per truck, decrease the distance traveled, and optimize routes for fuel efficiency. Many carriers also work with railroads to provide intermodal service when it best meets customer needs. However, in reality, logistics demands and shipper expectations include delivery timing precision, total operating cost, driver satisfaction, and many other concerns that may not be compatible with maximum fuel efficiency.

Shippers can contribute by establishing manufacturing, warehousing, and distribution systems to minimize transport demand. This could include less reliance on just-in-time delivery, which often requires a truck to move before a full load is available and often precludes transport by rail or even forces air transport. Shippers could also reduce packaging that takes up valuable space while adding to the refuse transportation demand. Manufacturing facilities can be located to minimize distance for transport of incoming materials and finished products. Once again, however, there are many factors beyond freight transport efficiency that factor into the decisions made by shippers.

It is not feasible to regulate most of the potential efficiencies possible by carriers and shippers. The related factors are far too numerous and the trade-offs are too complex. Nonetheless, transportation costs are a factor in these decisions. If fuel and carbon emissions costs are increased, the choices will become more biased toward reducing these costs with resulting efficiency gains. Of course, many of these adjustments will take years to implement, since the system infrastructure includes buildings, highways, railroads, terminals, and other components.

Another key element in the road freight system is the public highway system and related facilities and regulations. As highways become increasingly congested, more fuel is burned to travel the same distance. Also, insufficient truck stops for parking during driver rest periods with electrification forces more trucks to seek alternate places to stop with more engine idle time. Regulations on truck weight, trailer length, and permissible combinations, which vary by state, preclude some of the available fuel efficiency upgrades that require more weight, for example, for idle reduction, or more length, such as for trailer boat tails. Even in cases where federal provision is intended to provide for such features, it may not be accepted or understood by state enforcement agencies and truckers will not take the chance of being ticketed. Ideally, trucks would be provided with unique lanes that avoid congestion and allow for low speed on grades without interfering with car traffic.

Figure 12-4: Freight truck movement patterns today and tomorrow



As urban areas grow, there is a need to design better systems for freight and package delivery into urban centers. One proposal is to use a structure similar to bus rapid transit (BRT) systems or even to use the same routes as BRT. This would have large trucks run a circular route, dropping off freight at terminals where smaller trucks would make local deliveries. Figure 12-4 compares the freight delivery pattern of today's system with a proposal for the future modeled after BRT systems.

Public Policy Issues

Given the complexities of the freight system and the fact that freight delivery is a highly competitive business, an effective policy to improve the overall system efficiency and reduce CO₂ emissions is to increase the cost of carbon emissions. Ultimately, this cost will impact all private aspects of the system:

vehicle technology, carrier purchase decisions, logistics, warehousing and distribution, shipper demands, and even manufacturing strategies. Some of the impacts occur quickly, as was evidenced during the 2008 fuel price spike, when carriers placed a great emphasis on fuel savings and many inefficient trucks were taken out of long-haul service. However, many of the impacts require long-term infrastructure changes or technology development that can only occur with sustained carbon pricing policy at sufficient level to offset other factors. Furthermore, these longer-term decisions require confidence by decision-makers and investors that policies will stay in place long enough to provide return on the investments.

Major fluctuations in the price of oil reduce confidence in investment in fuel savings. Hence, policies that contribute to a predictable, increasing cost in petroleum diesel fuel will have the greatest impact. However, the relationship between cost for fossil fuel or CO₂ emissions and the resulting short and long term reduction in emissions is not well established and needs further study.

The federal 12 percent excise tax on new trucks has a negative impact on truck fuel efficiency, since it taxes the value of fuel efficiency and increases the cost to replace older, less efficient equipment. Elimination of this tax and recouping the revenue by increasing the fuel tax would both lower the purchase cost and increase the value of fuel efficiency features.

Increasing the length of trailer combinations to allow twin 48-foot trailers has been shown to offer up to 28 percent improvement in ton-mpg for volume limited freight. Increasing the weight allowance for this combination, while maintaining current axle weight limits, can improve ton-mpg up to 39 percent (ATRI 2008). Although studies have shown that such combinations can actually improve safety, if done with proper equipment and trained drivers, there are still many concerns about safety for cars passing such long trucks and for road or bridge damage in the case of increased weight. There is also concern that such allowances might shift freight from rail to truck, with loss of efficiency, although the same argument could be made against any improvement in truck efficiency. Even if length and weight limits are not generally increased, it would be helpful to at least establish consistent limits rather than the current system where states set inconsistent limits that require trucks to load for the most restrictive state they must cross. Also, weight and length limits should allow for increases to accommodate fuel saving features such as anti-idling systems, tractor and trailer skirts, or trailer boat-tails.

Incentivizing a shift from road freight to rail is another viable policy, since rail can decrease fuel required by approximately 50 percent. Incentives could include provisions for intermodal terminals and assuring adequate bridge clearance for double stacked containers on rail cars. However, the amount of freight that can be moved to rail is limited by a variety of factors.

Significant fuel savings can also be realized while increasing safety by restricting maximum truck speeds. The ATA supports a mandatory road speed limiter set at 65 mph. Even lower limits could be considered.

There is currently a federal mandate created in the Energy Independence and Security Act of 2008 for the Department of Transportation to establish fuel efficiency regulations for trucks. The EPA is also working to establish GHG emission limits that will essentially be fuel efficiency standards, in the absence of significant availability of low carbon fuels. Such standards will be difficult to develop because of the great variety of trucks with varying duty cycles, sizes, and load factors. Effective regulation needs to account for the work performed. For example, an mpg standard would tend to drive down the size of trucks, to the detriment of freight efficiency, which improves with larger trucks. For freight trucks, ton-mpg and volume-mpg are more appropriate measures, but their implementation would complicate the efficiency measurement process.

For vocational and work trucks, such as refuse or utility, efficiency measurement is further complicated by the energy demands of the work function. Furthermore, the areas for potential improvement in freight efficiency are only partially impacted by vehicle technology, and even these areas are split between manufacturers of truck chassis, tractors, trailers, and body builders. So, there is no single manufacturer in control of most finished trucks. Still, there are good reasons to promulgate efficiency regulations. The trucking industry

is very reluctant to accept new, unproven technology, since on-road breakdowns are expensive and result in failures to meet customer delivery demands. Fleets look for short payback time for any technology investment, typically about two years. Establishing firm requirements that force technology by a set date means that improvements are forced into the marketplace even when carriers may not yet freely accept them. The advantage, however, is that it forces manufacturers to allocate engineering and capital to the improvements and limits the risk that customers will not accept the new technology. It would be helpful if federal standards were established for trailers both to require efficiency improvements and to promote a streamlined design profile between tractor and trailer.

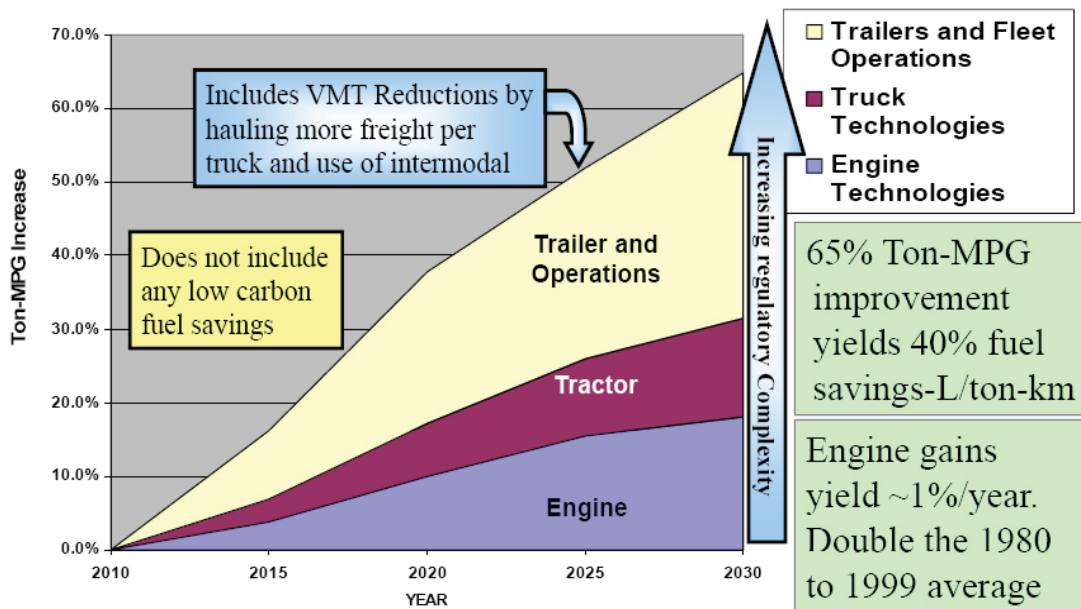
Many states, lead by California, have adopted anti-idling regulations to limit the time trucks spend idling. As noted earlier, idling can consume 6 to 9 percent of fuel in long haul truck operation. Anti-idling regulations force drivers to shut off their engine when it is not needed and can force owners to install systems for sleeper cab hotel function that do not require engine operation, saving most of the fuel otherwise consumed.

There is a great need for long-term planning for the U.S. freight delivery infrastructure. This should include plans for trucks to avoid congestion, adequate truck stops with electrification facilities to avoid idling, consideration for truck-only lanes to allow for slower trucks in busy areas, intelligent highway systems, and urban delivery systems.

Another key policy issue is the development of low carbon fuels for the freight sector. Due to much higher average power requirements, it is far more difficult to provide significant vehicle driving range on battery power in trucks than with passenger cars. There are currently no serious alternatives to fossil diesel, except for limited amounts of biodiesel, with questionable GHG benefits. There are many proposals to develop fuel alternatives, including biomass gasification, algae, natural gas, and dimethyl ether. All of these have major cost, efficiency, infrastructure, and scaling issues that will require federal support and policies to resolve.

There is a need for significant investment in technology development before many efficiency improvements can be realized. Additional focus and funding for this effort can help to demonstrate what is feasible and accelerate the rate of improvement. If these are provided by the federal government, significant gains are possible.

Figure 12-5: A Prospective Scenario for Vehicle Efficiency Gains and VMT Reductions for a Class 8 Truck



Summary

This has been an overview of potential efficiency gains in the very complex but critical U.S. freight transport system. Significant gains are possible in truck technology, trailers, fleet operations, logistics, and public policy. An estimate of potential gains for new vehicles is presented in Figure 12-5.

The figure shows over 60 percent improvement in ton-mpg by 2030 through technology improvements. If low carbon fuels are introduced, even more gains are possible. All this will require a major focus in government policy and huge investments by industry. This means a shift in focus to expand beyond light duty vehicles to include the important and growing freight transportation sector.

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Chapter 13:

Improving the Energy Efficiency and Environmental Performance of Goods Movement

by James J. Winebrake and James J. Corbett

In the United States (U.S.), light duty vehicles (LDVs) have traditionally been the focus of regulatory action aimed at improving the fuel economy and environmental performance of transportation. The first LDV tailpipe emissions standards were promulgated in the mid-1960s, and corporate average fuel economy (CAFE) standards for LDVs were instituted a decade later and recently revised in May 2009. By contrast, heavy duty vehicles (HDVs), trains, and ships have only recently been affected by emissions standards, and currently do not face any restrictions affecting their fuel efficiency. Yet, it is clear that all opportunities for improving efficiency in all sectors of our economy must be exploited in order to avoid the calamitous consequences posed by climate change (Liu, J. *et al.* 2007a and 2007b). For the transportation sector, this includes improving the efficiency of our freight transportation systems through a variety of options.

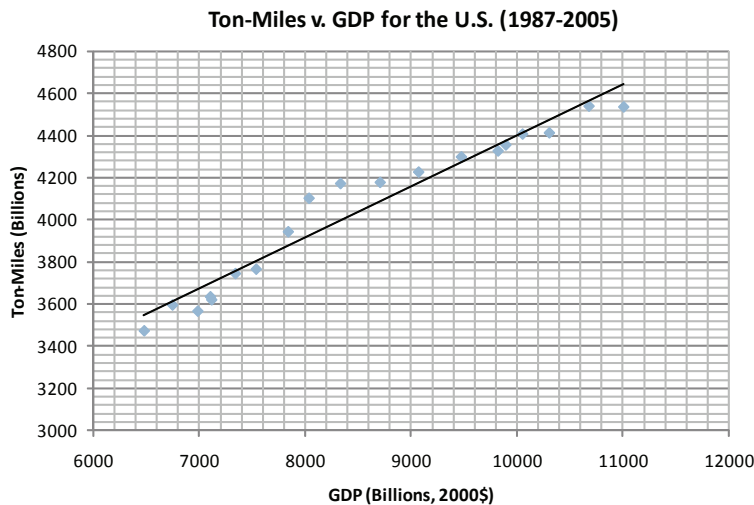
This chapter discusses the role of freight transportation as an important contributor to greenhouse gas (GHG) emissions. It presents a new context for discussing interrelated technology and policy options for reducing these emissions through an “IF-TOLD” analytical framework. In particular, the IF-TOLD framework is applied to evaluate opportunities for mode shifting, a credible method for reducing energy consumption and emissions in the freight sector. Based on this framework, a potential appears to exist for mode-shifting to help achieve energy and environmental goals, but expected benefits are likely overstated. Mode-shifting can have only limited impacts given the existing goods movement infrastructure in the United States. This argues for a more holistic approach to efficiency improvements in the freight sector. The chapter concludes with a discussion of the importance of technology policy mechanisms that encourage freight performance improvements across a range of long and near-term goals.

Overview of Goods Movement

The relationship between goods movement and economic activity in the United States is displayed in Figure 13-1, which depicts ton-miles of freight movement as a function of gross domestic product (GDP) over a 20-year period. In the consumer-based economy, the relationship is intuitive: the more economic activity there is, the greater the use of freight transportation services.

J. Winebrake is a professor in the Department of STS/Public Policy at the Rochester Institute of Technology. J. Corbett is a professor in the College of Earth Ocean and Environment at the University of Delaware.

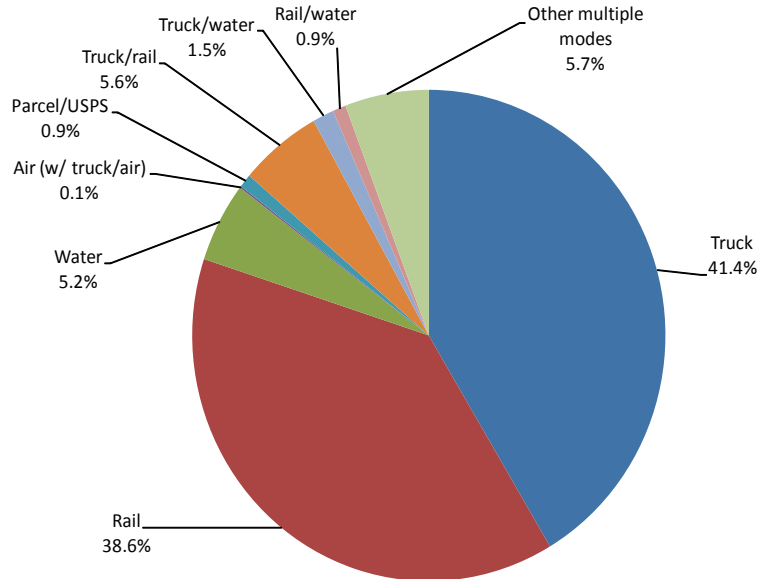
Figure 13-1: Relationship between freight transportation services and GDP for the U.S., 1987-2005



Source: Derived from BTS 2007a and BEA 2009

About 80 percent of this freight service is provided by truck and rail service, with other modes, including intermodal service, constituting the difference. The full breakdown of ton-miles by mode is shown in Figure 13-2.

Figure 13-2: Ton-miles by mode (single and intermodal) for the U.S. in 2007



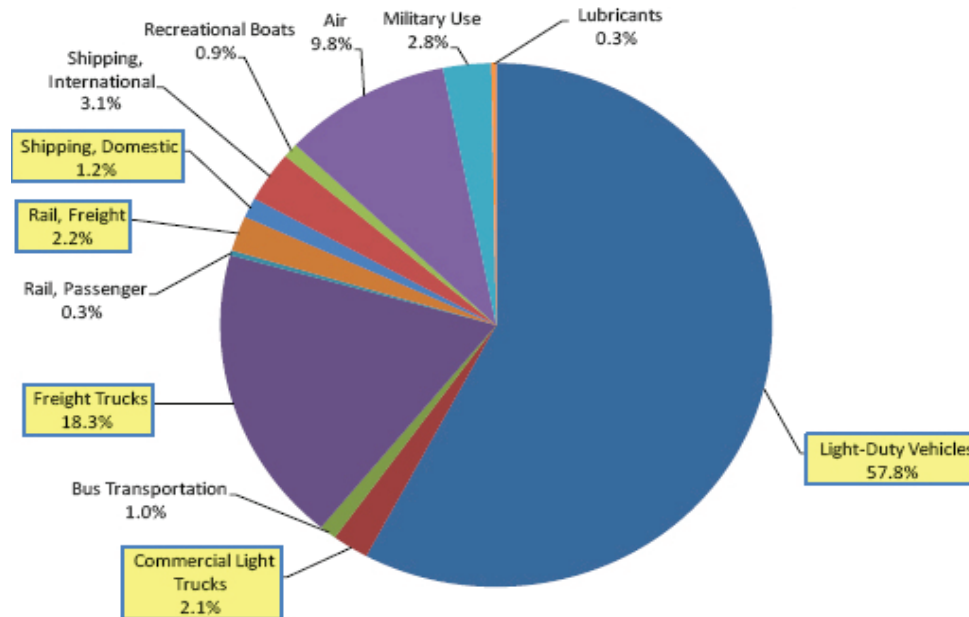
Ton-Miles by Mode (Single and Intermodal) for the U.S. (2007)

Source: Derived from BTS 2007b

Energy is required to move these goods, and most of this energy is derived from fossil fuels that power the fleets of trucks, trains, and ships employed in freight operations. This fuel consumption has had a large impact on GHG emissions in the United States. Driven almost entirely by petroleum, the freight sector represents about 25 percent of the GHG emissions from the transportation sector, as shown in Figure 13-3. Since the transportation sector represents about 30 percent of the total U.S. GHG inventory, freight

transportation accounted for about 9 percent of total GHG emissions. This is significant, especially given its rate of growth has generally exceeded the overall growth in economic activity. The increasing importance of this sector makes it important to identify ways that allow this sector to serve economic needs most efficiently.

Figure 13-3: Transportation-related carbon dioxide emissions by mode for the U.S. in 2008



Source: Derived from EIA 2009

Modal Comparisons

Different modes of transportation are used for different types of freight services, and the energy-to-work relationships are asymmetric across modes. Domestic ships and trains are often used for long-distance travel greater than 300 miles and for bulk cargo transport services, often when cargo is not time sensitive. These modes are capable of moving the greatest volumes with the least energy per unit work. Trucks are used for shorter trips, time sensitive cargo, and delivery to locations where ship and rail infrastructure is not available. Independently routed trucks, higher speeds, and smaller package densities increase energy required by trucks per unit work relative to bulk transport. Rail can perform similarly to either water modes or trucking, depending on payload densities, distances, and backhaul usage. Airplanes are used typically for time-sensitive shipments where transportation costs are a small percentage of overall cargo value. The additional energy for flight compared to Archimedes principles of floatation or rolling friction make work done by this mode the most energy intensive.

These freight modes have different characteristics dictated by a number of factors, including:

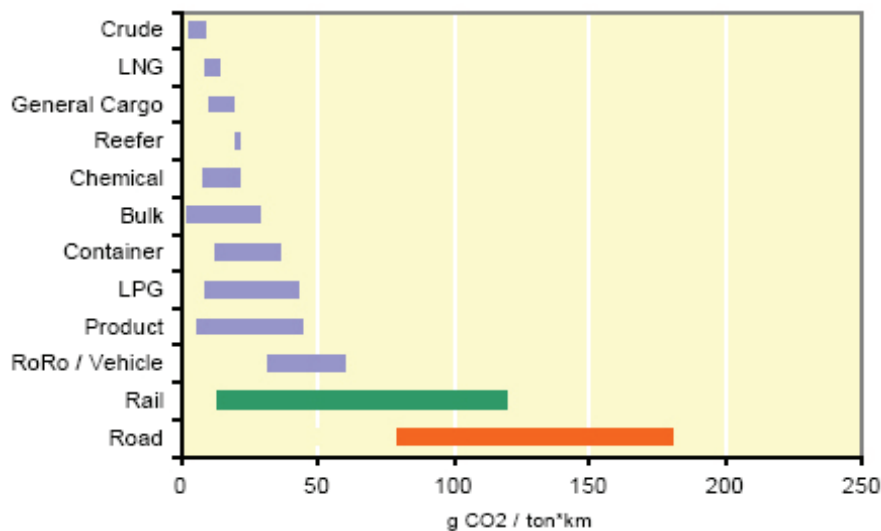
- Technology, for example, types of engines used and emissions control systems
- Fuel quality, including the sulfur, carbon, and energy content of fuel
- Transportation routes, such as gradients and distance
- Transport speed
- Operator behavior, including idling patterns and driving behavior
- Logistics, for example, dwell times and intermodal cargo transfer emissions

National statistics implicitly combine these characteristics, contributing to freight performance comparisons, often ranking trucks highest in surface transportation energy intensity. Using top-down calculations, which

is the total annual energy use in a sector divided by total freight services performed, one can derive energy intensities on the order of 3,500 to 4,000 BTU/ton-mile for trucks, and only 350 to 500 BTU/ton-mile for trains and ships (EIA 2009). Air freight energy intensities are an order of magnitude greater than trucking statistics.

These composite comparisons allow for useful generalizations about different transport modes, but there are at least two dangers in using them for conducting modal comparisons for specific shipping events. First, top-down calculations include energy used in moving empty containers, repositioning equipment, and providing services that do not necessarily involve cargo movement. When comparing modes for a specific shipping service, an activity-based approach is recommended that accounts for cargo, logistics and technology characteristics. Figure 13-4 presents carbon dioxide intensities for ships, trains, and trucks derived using a range of activity-based parameters. The ranges show the variability that exists depending on modal, route, and operating characteristics. Figure 13-4 also implies an opportunity for reducing energy consumption and emissions by shifting from high energy intensity modes to lower energy intensity modes.

Figure 13-4: Range of carbon dioxide intensities for various cargo carriers



Source: Buhaug et al. 2008

Second, modal comparisons ignore the inherent complementarities among the modes, mistakenly posing them as simple substitutes. Where the origin/destination pairs do not offer multiple unimodal connectivity, the modes must be combined in an intermodal network. In other words, route-specific barriers and asymmetries may apply to any of the modal efficiencies in Figure 13-4 that result in re-ranking the best-to-least efficiencies by mode.

Route-specific modal comparisons have been explored and illustrated by a team of researchers at the University of Delaware (UD) and the Rochester Institute of Technology (RIT). The Geospatial Intermodal Freight Transportation (GIFT) model is a model jointly developed by the UD/RIT team with support from the U.S. Maritime Administration, the Great Lakes Maritime Research Institute, and the California Air Resources Board, among others. The model connects multiple road, rail, and waterway transportation networks at intermodal transfer facilities using a “hub-and-spoke” concept. Activity-based calculations are embedded in the model, adjustable by the user. Within this intermodal network, the model assigns various economic, time-of-delivery, energy, and environmental attributes to real-world goods movement routes. In this way, network optimization algorithms can be run to determine optimal routing for achieving different objectives, such as least cost, least carbon, and least time (Winebrake *et al.* 2008; Comer *et al.* 2009).

With such a model, the measures of performance improvement to one characteristic, for example, fuel economies, increased transit times, or payload densities, are presented along with coupled changes in

emissions, delay, or energy intensity. The GIFT tool is currently being applied to study several dimensions of goods movement performance and is enabling a new context in which to explore freight technology/policy pathways to meet energy, environmental, and economic goals.

Opportunities for Mode-Shifting

There are three-dimensional interactions among fuels, technology, and vehicle miles traveled (VMT) and demand within the LDV sector. This has been a convenient framework for LDVs and has allowed for a simple, yet effective, way of communicating efficiency options to policy makers and the public.

Two key limitations are implicit in this three-dimensional context, however. First, individual driving patterns of citizens are treated as conditionally independent of the infrastructure, and second, routing choices are considered to be somewhat inelastic, for example, mostly ad hoc, discretionary, or commute-related. This has allowed economists and policy makers to identify technology providers as exercising greater influence on LDV fleet performance than drivers, except in regions where modal substitutes exist and where strong price signals are possible. This framework suggests that emissions can be addressed by a combination of fuel improvements, such as low carbon fuels; technology advancements, including more efficient technologies; or VTM reductions through demand management policies.

The freight sector is much different than the LDV sector, and a three-dimensional foundation fails to provide insights into the greater range of options that strong economic coupling makes available for freight sector emissions reductions. Moreover, informing good policy decisions requires that the long- and near-term planning activities by the public and private sectors be reconciled by considering dynamic response among decision drivers.

The IF-TOLD model is a better framework for considering freight options. The letters of this acronym represent the following:

- Intermodalism/infrastructure: employing different transportation modes and infrastructure to improve freight services
- Fuels: burning low carbon or clean fuels
- Technology: applying efficient technologies within each mode
- Operations: using of best practices in operator behavior
- Logistics: improving supply chain management
- Demand: reducing the amount of goods that are shipped, measured in ton-miles

Using the IF-TOLD model, a greater range of opportunities can be identified for improving the efficiency of goods movement. Intermodalism and mode-shifting are often looked upon as providing significant opportunities for emissions reduction in the freight transportation sector (Winebrake *et al.* 2008; NPWI 2004; Janic 2007; Komor, P. 1995; Kreutzberger *et al.* 2003; Patterson, Z. *et al.* 2008; Racunica and Wynter 2005).

Given the lower energy intensity of modes such as rail or ship, conventional wisdom holds that movement of goods from truck to these other modes will greatly enhance the environmental performance of the freight sector. However, although ships and trains tend to be less energy intensive than trucks when measured per unit payload basis, the actual opportunities for system-wide mode-shifting with today's intermodal infrastructure must be evaluated.

The following equation describes the overall energy impacts associated with shifting a set of commodities (k) from one mode (i) to another mode (j):

$$\Delta E_j = \sum_k [W_k \cdot c_{ijk} \cdot f_{ijk} \cdot p_{ijk} (E_i - E_j)] \quad (1)$$

Where,

ΔE_j = energy savings due to modal shift from mode i to mode j

W_{ik} = work done by mode i for commodity k (ton-miles)

c_{ijk} = shipment compatibility fraction of i to j for k (cargo)

f_{ijk} = shipment feasibility fraction of i to j for k (infrastructure)

p_{ijk} = shipment practicality fraction of i to j for k (economic)

E_i = energy intensity factor for mode i (Btu/ton-mile)

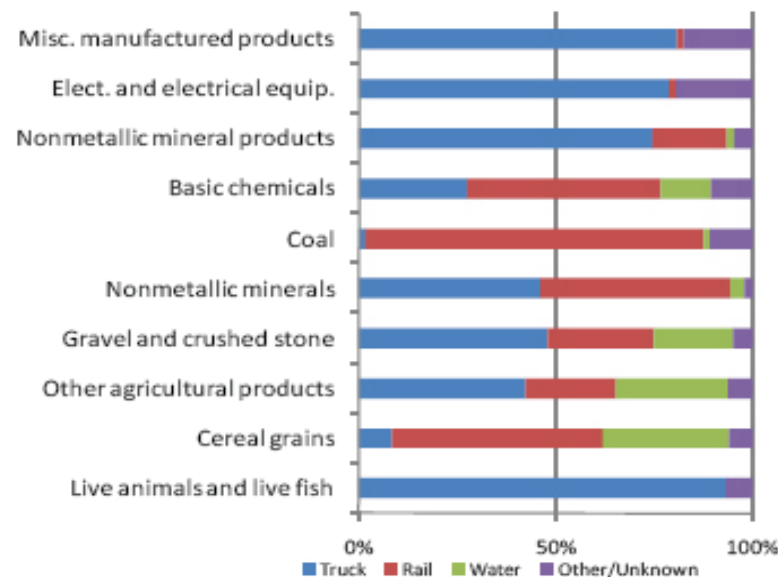
E_j = energy intensity factor for mode j (Btu/ton-mile)

The Compatibility, Feasibility, and Practicality Fractions

This equation introduces three new parameters that are important: compatibility fraction, feasibility fraction, and practicality fraction. Each represents the fraction of the total goods to be shipped that are affected by cargo compatibility, infrastructure feasibility, and economic practicality.

The cargo compatibility fraction is a reflection of how compatible a given cargo is with a different transportation mode, and whether there are options for consolidation, containerization, and facility location. For example, some commodities are shipped by truck for logistical considerations, such as time-of-delivery requirements associated with livestock transportation, while others must be shipped by train or ship due to the nature of the cargo, for example the shipment of chemicals. Figure 13-5 depicts a sample of commodities and the percentage of ton-miles of those commodities moved by different modes.

Figure 13-5: Percentage of goods movement in the U.S. by commodity and mode in 2002



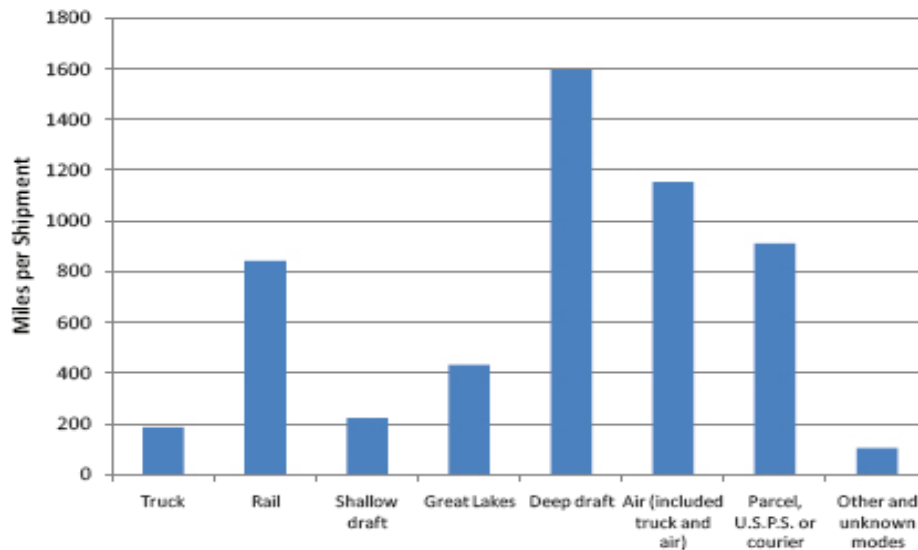
Source: Derived from BTS 2007b

In addition to whether a commodity is compatible with a given mode, the infrastructure must be available to support transport and delivery by one or more modes. Intermodal or multimodal routes are not always available, as some parts of the country do not have adequate rail infrastructure, waterways, or port or railyard transfer facilities that would allow effective mode-shifting. While mostly considered to be a long

term and semi-public investment choice, reconfiguration and improvement of transportation nodes and segments can greatly affect the feasibility of intermodal transportation efficiencies.

Lastly, the economics of freight transportation play a significant role in determining whether mode-shifting opportunities exist. To understand the potential role for mode-shifting, consider Figure 13-6, which presents the average miles per shipment for U.S. freight transportation in 2007 by mode. This chart demonstrates that on average, truck transportation is used for shipments of less than 200 miles, while rail is used for shipments greater than 800 miles. These distances are a function of compatibility, infrastructure, and the economics of freight transportation. Of course, operational choices can involve more cost-minimization measures than mode choice. Freight transportation consists of both marginal costs, such as fuel costs associated with moving goods over network segments, and fixed costs, including transfer costs associated with moving cargo from one mode to another mode. Typically, ships and trains have much lower marginal costs than trucks, but vehicle fixed costs for ships and locomotives are higher because of fewer unit sales and larger size. Moreover, the freight-only network embedded fixed costs are much higher because rails and waterways rarely share infrastructure with passenger use. For long-distance transport, the marginal cost advantages of trains and ships offset higher fixed costs and lead to lower average costs compared to trucks. For shorter distances, however, the opposite is true.

Figure 13-6: Average miles per shipment by mode for the U.S. in 2007

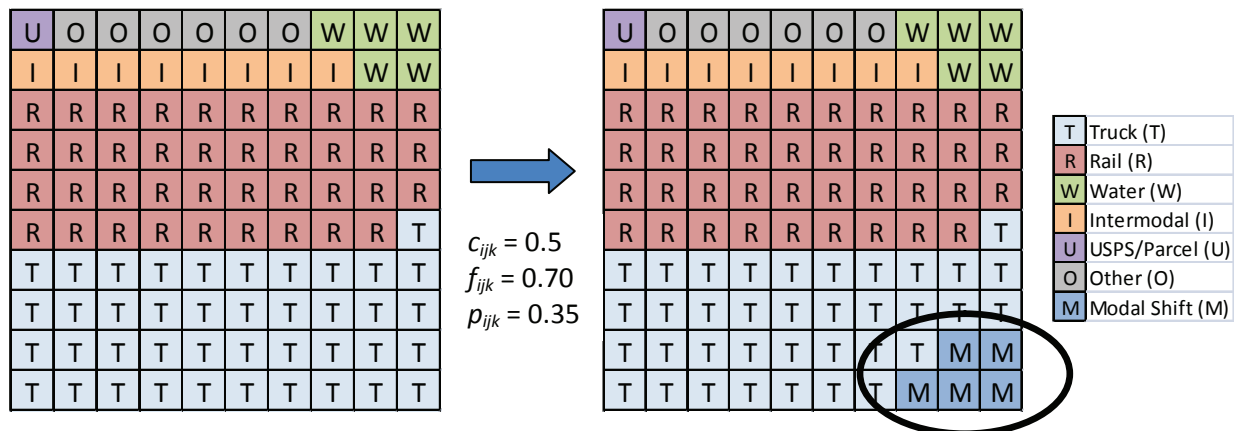


Source: Derived from BTS 2007b

The Potential of Mode-Shifting

Application of Equation 1 demonstrates conceptually the overall opportunity for mode-shifting in the United States. Figure 13-7 depicts a box of 100 cells, each representing 1 percent of ton-miles service in the U.S. freight sector and divided by mode from 2007 data. The lightest shade at the bottom in the figure represents the trucking mode and is the target of the analysis, which is to move freight from truck to some other mode, such as rail or ship. Assuming values for c_{ijk} , f_{ijk} , and p_{ijk} of 0.50, 0.70, and 0.35, respectively, the figure shows how the potential opportunity for truck beginning at 41 percent of the total ton-miles is reduced to a situation where only about 5 percent of the total ton-miles representing 12 percent of truck ton-miles can be moved from truck to rail or ship. If energy intensity of truck is five times greater than rail or ship, then this implies an 8 percent reduction in total energy consumption, certainly not negligible, but much less than would be expected without the compatibility, infrastructure and practicality constraints on the system.

Figure 13-7: Estimation of mode-shifting potential for the U.S.



Policies for Promoting Efficiency

The opportunities for mode shifting identified above cannot be achieved without creating different signals to industry. These can be “invisible hand” signals as fuel prices rise, the cost of inventory falls, and consumption changes result from recession or boom years. More relevant may be the policy choices to commit to energy and environmental goals not currently priced in the market, through policy instruments.

A wide variety of policy mechanisms are available to provide incentives or disincentives within the IF-TOLD context, as shown in Table 13-1. This table provides each element of IF-TOLD in columns, and a set of common policy instruments in rows. Cells are identified where a particular policy instrument may directly influence the behavior within an IF-TOLD element. For example, emissions or efficiency standards may improve modal performance of the most polluting or energy-intensive modes to achieve targets without mode-shift through the application of control devices; economic instruments, including taxes, may

Table 13.1: Cross matrix of policy instruments and IF-TOLD framework elements

<i>Transportation Policies</i>	<i>Intermodalism</i>	<i>Fuel</i>	<i>Technology</i>	<i>Operations</i>	<i>Logistics</i>	<i>Demand</i>
Policy Instruments	I	F	T	O	L	D
Performance standards	•	•	•			
Taxes	•	•	•	•	•	•
Subsidies	•	•	•			
Technology mandates			•			
Infrastructure Investment	•				•	
R&D investment		•	•			
Alternative/low-carbon fuels		•	•			
Size/weight restrictions	•			•	•	
Operator training/education				•		
Demand management					•	•

have greater potential to influence all decisions within the IF-TOLD context, offering choice in meeting performance goals through multi-attribute optimization. More research to evaluate the effectiveness of different policy instruments on the freight transport system could access the IF-TOLD rubric for how to structure those analyses.

Conclusion

The goods movement sector in the United States is highly correlated with economic activity. As such, it is expected that freight transportation will continue to grow with the economy. With this growth comes the responsibility for an increasing energy and environmental burden, mostly due to the high energy intensity of certain modes, especially trucks, and system characteristics. Options exist to reduce this energy consumption, and this chapter presented some ideas on the potential of mode-shifting as one possible approach. However, the freight system benefits of mode-shifting are limited by factors not considered previously and will vary depending on vessel, vehicle, locomotive, and route characteristics.

In addition to mode-shifting, there are other ways to improve the environmental performance of freight transport, captured in the IF-TOLD framework discussed above. Importantly, achieving energy and environmental goals will require policy makers to look at the freight sector as a system of different modes operating under asymmetric constraints even where there may be common objectives. The IF-TOLD framework is one useful way to explore policy options, enabling better application of research designs, such as wedge analyses, to describe the role new policy decisions might play.

Acknowledgements

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Chapter 14:

Potential Reductions of Greenhouse Gas Emissions from Light-Duty Vehicles and Electricity Generation

by Andrew E. Lutz and Jay O. Keller

The objective of this chapter is to consider the potential for reductions in greenhouse gas (GHG) emissions in light of projected growth by mid-century. The analysis focuses on two major energy sectors, light-duty vehicles (LDVs) and electricity generation. These two sectors combine to produce more than half of the total GHG emissions in the United States (U.S.). They are also the sectors of the U.S. energy economy with the fastest growing GHG emissions. While the transportation sector relies almost exclusively on petroleum, new vehicle technologies that move toward eliminating this dependence will involve some degree of coupling to the electricity sector.

The chapter examines the potential for reducing GHG emissions by technological improvements, under the assumption that end-use activity continues to grow at the present rate. A simple linear projection to 2050 suggests that yearly GHG emissions in the U.S. will increase to 60 percent above 1990 emissions without a concerted effort to reduce them. Relatively incremental policy improvements, such as increasing the U.S. Corporate Average Fuel Economy (CAFE) standard to 35 miles per gallon (mpg), are a good start for reducing emissions, but much greater efficiency improvements are needed to have a significant impact. The analysis presented in this chapter shows that after a transition to an LDV fleet at 35 mpg and replacement of coal-fired electricity generation with more efficient natural gas generation, GHG emissions will return to 1990 levels.

The magnitude of the GHG emissions problem requires that research and development be directed toward technologies that both greatly improve end use efficiency and greatly reduce or eliminate carbon from fuels. Policies that incentivize only incremental improvements to efficiency and fuel carbon content will be insufficient to meet GHG reduction targets of 80 percent below 1990 levels. Energy policy needs to be established today to motivate the transition to net-zero carbon technologies.

Background

Calls for more efficient transportation and alternatives to petroleum as a transportation fuel accelerated after the oil crisis of the 1970s. The combination of a peak in domestic U.S. oil production and politically

A. Lutz is an engineering analyst and J. Keller is department manager of Hydrogen and Combustion Technologies at Sandia National Laboratories in Livermore, California

motivated restrictions in oil production by the Organization of Petroleum Exporting Countries (OPEC) created sharply rising prices. The initial attempt at controlling prices created the gasoline lines that became the visual image of the decade.

The second problem with transportation was the smog in certain metropolitan regions. The 1970s saw the introduction of catalytic converters on gasoline vehicles to reduce emissions of pollutants, such as carbon monoxide and nitrogen oxides, which are detrimental to local air quality. This required a significant change to the refueling infrastructure. Previously, lead was added to gasoline to prevent engines from knocking at high compression ratios, but lead proved to be a poison to the catalyst. For a period of years, refueling stations provided separate pumps for leaded and unleaded gasoline. The unleaded pump had a smaller nozzle diameter to prevent drivers from accidentally filling the new vehicles with leaded gasoline.

The two problems of the 1970s—limited oil supply and regional smog—motivated regulations that led to the design of cleaner, more efficient vehicles. More stringent regulations and gradually rising oil prices motivated research that resulted in new technologies, such as the hybrid electric drivetrain and advanced diesel technology. The California Zero Emission Vehicle mandate of 1990 attempted to require the introduction of battery electric vehicles, but was ineffective at eliciting a large number of such vehicles because of the limited range and high cost of the initial vehicles. During this brief introduction, there was an attempt to develop a recharging infrastructure. In addition to home recharging, some public parking lots installed recharging facilities. Auto manufacturers also introduced natural gas vehicles, but the refueling infrastructure did not develop beyond a scattered network of sites at government facilities, utilities, and corporate fleets. Research considered hydrogen as a fuel for either internal combustion engines or fuel cells. Problems with pre-ignition—at least for stoichiometric mixtures—limited the use of hydrogen in engines at first, but contemporary engines avoid this problem with either dilution or direct injection. Fuel cells were limited to aerospace applications until the mid-1990s, when breakthroughs in material science made possible the polymer electrolyte membrane (PEM) fuel cells that are now being proven in vehicle demonstrations.

The Greenhouse Gas Problem

Today, concerns about climate change have created a third problem, one that is uniquely global. Carbon dioxide (CO₂) emitted from fossil fuel combustion remains in the atmosphere for decades. Reduction of GHG emissions from the transportation sector requires reducing CO₂ emissions from the fleet of LDVs, either by societal changes to reduce miles traveled or technological changes to the vehicles. Leaving the issue of societal change to social scientists, this chapter considers the potential of technological improvements, under the assumption that end-use activity continues to grow.

CO₂ emissions from LDVs can be reduced technologically by lowering the carbon content of the fuel, increasing the fuel economy of the vehicles, or some combination of the two. Increasing fuel economy is the logical first step, since it does not require changes to the fueling infrastructure. However, vehicle efficiency improvements alone cannot meet GHG reduction targets.

Considering the carbon content of the fuel, biofuels offer the potential of reduced net CO₂ emissions over the entire fuel cycle. Biofuels provide energy storage densities similar to gasoline and diesel. As liquid fuels, their use requires relatively minor changes to the refueling infrastructure, and when produced with attributes similar to gasoline and diesel, they require no change at all to the distribution infrastructure. While corn ethanol may offer only marginal CO₂ reductions, cellulosic ethanol and biodiesel may provide significant reductions. However, even optimistic estimates of biofuel production do not suggest that all of America's current and future transportation needs can be met (Perlack et al 2005; West et al 2010).

Other low-carbon fuel alternatives are electricity, hydrogen, and natural gas. Natural gas contains about 25 percent less carbon per unit of chemical energy than gasoline. While electricity and hydrogen carry

no carbon, they are energy carriers that must be produced from other sources, so their life-cycle carbon content depends on the source.

The best solutions may come from combinations of alternative fuels and advanced vehicle technologies. For example, the use of some alternative fuels enables vehicle technologies that allow for better efficiency in converting stored energy to motion. Electric propulsion, supplied either by batteries or fuel cells, offers improved efficiency, in addition to the potential of a fuel that can be produced from noncarbon sources. However, providing refueling facilities for either battery or hydrogen vehicles will require far more extensive investment in the infrastructure than the transition to a separate liquid fuel, such as ethanol or unleaded gasoline.

Vehicle electrification will have impacts on the markets for electricity and natural gas. About 20 percent of the electricity in the U.S. is generated from natural gas. Larger fractions are contributed by natural gas in some regions, and recent installations of new generating capacity are dominated by natural gas. If hydrogen vehicles are adopted anytime soon, the hydrogen will most likely be produced by reforming natural gas. So these three low-carbon fuel options couple the LDV fleet to the electricity market.

Renewable pathways, such as wind and solar, produce electricity with very low carbon intensities. Hydrogen from these sources requires the extra step of electrolyzing water at the expense of system efficiency, but add little to the carbon intensity of the process. Nuclear power is also a source of noncarbon electricity. A new generation of nuclear power plants may in the future produce hydrogen by a thermochemical cycle that splits water, thereby skipping the electricity as an intermediate to hydrogen and improving efficiency. Existing nuclear plants do not operate at sufficiently high temperatures to produce hydrogen, however, so electrolysis is necessary.

Other potentially large sources of noncarbon hydrogen involve fossil fuels coupled to carbon capture and sequestration (CCS) technologies. Steam methane reforming at large, centralized plants could facilitate carbon sequestration. Coal can be used to produce both hydrogen and electricity from oxygen-blown integrated gasification-combined cycle (IGCC) plants. The air separation up front yields an exhaust mixture without nitrogen, eliminating the need for separation prior to sequestration. Such plants may be demonstrated in the near future, providing combined production of electricity and hydrogen with near-zero carbon emissions. In all these cases, near-zero carbon and noncarbon pathways to hydrogen involve electricity, either as an intermediate step or a co-product.

Recognition of the coupling of hydrogen, electricity, and natural gas suggests the approach in this chapter of considering the potential GHG emissions reductions from the transportation and electricity sectors together. The transportation and electricity sectors will likely interact in a variety of ways in the future (Yang 2008). The two sectors are two of the “wedges” of the growth triangle that Pacala and Socolow (2004) suggested could be part of a carbon-stabilization strategy. These two sectors are natural targets for new CO₂ emission regulations. They are already regulated for many local pollutants, including carbon monoxide and nitrogen oxides. The LDV sector is also already regulated with respect to fuel economy, via the CAFE standards, which affect the CO₂ emissions per mile driven.

The following analysis starts by establishing a baseline for the total future GHG emissions, based on the data for U.S. emissions over the past couple decades. The next two sections estimate the potential reductions of CO₂ emissions from LDVs and electricity separately, but casting the reductions in reference to the total emissions. The combined reductions are then estimated by superposition of the individual contributions. This approach ignores the possible interactions between the sectors, because the intent is to examine limiting cases.

The scope of the analysis is limited to the United States. While the United States did not ratify the Kyoto treaty, which intended to limit emissions to 5 percent below 1990 levels, the U.S. government is working on legislation for a cap-and-trade system to regulate future GHG emissions. In addition, individual states are acting to reduce emissions. California, for example, has enacted a low carbon fuel standard (LCFS)

for vehicles and an aggressive renewable portfolio standard for electricity generation. Beyond these regulatory actions, California's Governor A. Schwarzenegger has issued an executive order calling for GHG reductions to 80 percent below 1990 levels by 2050, and President Obama endorsed this target in his campaign. Research is studying the so-called "80 in 50" target for both California (Yang et al 2009) and the nation as a whole (McCollum and Yang 2009).

Baseline Emissions Projection

The analysis starts with the most recent data for the contributions of the various sectors to the national emissions of GHG (EPA 2009). Table 14-1 shows the breakdown of U.S. GHG emissions by sector. The LDV and electricity sectors combined account for one-half of the total GHG emissions. Most of the growth in the past two decades has occurred in these two sectors. Emissions from the LDV and electricity sectors grew at average rates of 1.2 and 1.6 percent per year, respectively. In contrast, the other sectors grew at an average of only 0.4 percent per year. These observations suggest that technological improvements in the LDV and electricity sectors would go far towards combating future growth in GHG emissions.

Table 14.1: U.S. GHG emissions in metric gigatonnes of CO_{2eq} per year

<i>Year</i>	<i>Electric Generation</i>	<i>LDV</i>	<i>Other</i>	<i>Total</i>
1990	1.86	0.95	3.29	6.1
2000	2.33	1.11	3.55	7.01
2005	2.43	1.16	3.52	7.11
2007	2.45	1.15	3.55	7.15

Source: EPA 2009

To project a baseline into the future, the emissions data are linearly extrapolated, as shown by the solid line in Figure 14-1. The data appear to follow a linear fit between 1990 and 2007. Extrapolation to 2050 suggests the GHG emissions will reach nearly 10 gigatonnes of CO₂ equivalents per year, which is 60 percent larger than the emissions in 1990. In order to apply a business-as-usual policy, the analysis defines three sectors—LDV, electricity, and other—and assumes that the sectors grow linearly. This simplification allows the analysis to project the impact of various strategies for reducing emissions onto the overall picture for GHG emissions to mid-century.

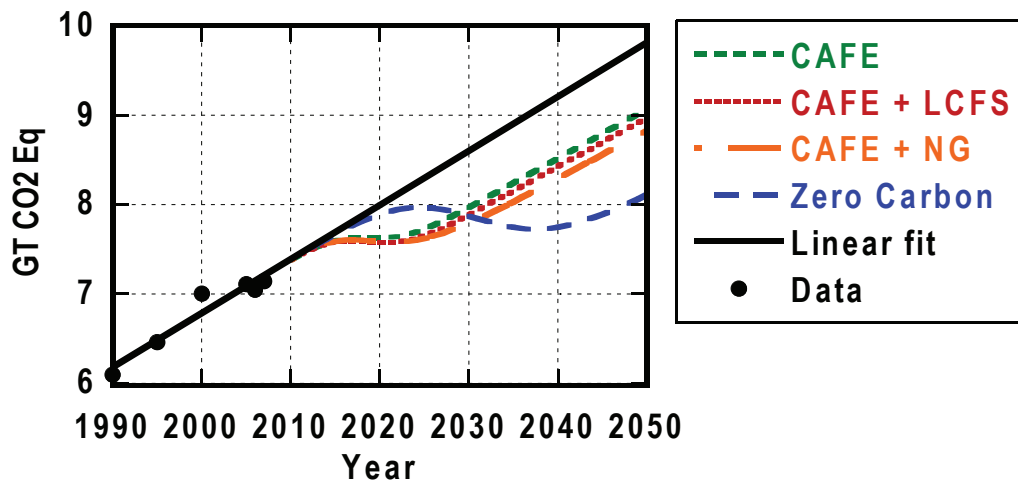
The following sections present estimations of the reduced CO₂ emissions from the LDV and electricity sectors, considering one at a time, and then combining the effects of both sectors.

Reduction Potential of the LDV Fleet

The LDV fleet currently accounts for 16 percent of total U.S. GHG emissions, and its high growth rate means that its contribution is increasing. At present trends, projected LDV emissions are expected to grow to 18 percent of total emissions by 2050.

Except for the recession year of 2009, sales of new vehicles have averaged about 15 million per year (EPA 2007), or about seven percent of the roughly 230 million LDVs in the U.S. fleet (Polk 2009). The average age of vehicles has been growing, due to the fact that the scrap rate is only about 5 percent (Polk 2009). For these sales and scrap rates, a simple uniform replacement of the existing LDV fleet would take about 17 years. The analysis in this chapter captures this replacement period by simulating the transition of the average fuel economy of the vehicles on the road from the existing vehicles to a more efficient fleet. Rather than use dynamic simulation methods to track the vehicle fleet as it evolves with the introduction of new

Figure 14-1: Scenarios of U.S. GHG emissions from LDV fleet



vehicles (Lutz and Reichmuth 2009; Struben and Sterman 2008), we use a simple s-shaped function of time, which can be adjusted by centering the transition at a given year and setting the width of the transition. The s-shaped function varies from zero to one and serves as an adjustment factor in the decomposition of the CO₂ emissions. The convenience of an analytical function means the details of the transition are not captured and the duration of the transition period is not an outcome of the analysis, but an input to be specified. Nevertheless, for the purposes of the study, specification of the transition period provides a picture of the emissions reductions in light of the projected growth.

The first scenario is the proposed new CAFE standard of 35.5 mpg, applied for the combined fleet of cars and trucks, which is to take full effect by 2016 (White House Press Release 2009) and assumed to be held constant to 2050. The projected emissions are scaled from the existing fleet average of 20 mpg (EPA 2007) to the proposed more stringent CAFE value. Actual mpg in 2016 will be lower because the regulations are based on tested fuel economy, not real world fuel economy.

To approximate the new CAFE legislation taking effect in 2016, the transition function is centered at 2020, with a transition from the old, 20 mpg vehicles to the new, 35.5 mpg vehicles that is completed over a period of 16 years. Centering the transition at 2020—not 2016 when the regulation takes effect—puts the halfway mark for the vehicles on the road four years after the regulation. This means that at 2020, half the vehicles on the road are new vehicles that meet the 35.5 mpg CAFE regulation on average, while the remaining vehicles still have an average fuel economy of 20 mpg. The value of the transition function at 2016 is 0.16, meaning that 16 percent of the on-road fleet has been replaced by the newer vehicles. This effectively assumes that manufacturers will be selling a significant number of the more efficient vehicles a couple years early. In fact, the CAFE regulation will require improved mileage in years prior to 2016, but this analysis does not attempt to capture the details of the time schedule in the regulation.

Compared to the black extrapolation line in Figure 14-1, the CAFE proposal, shown in the short dashed line (green), creates a shift to lower emissions. However, after the initial shift downward, the emissions grow in parallel with the extrapolated growth after 2030. The reduction by 2050 is eight percent below the projected GHG emissions.

A modification of this CAFE scenario combines improved mileage with changes to the fuel. Coincident with the new CAFE regulation, California will implement its LCFS that reduces the carbon emissions from the fuel 10 percent by 2020 (Farrell and Sperling 2007). The combined reductions of the CAFE regulation and the extension of the LCFS to the entire U.S., a 10 percent reduction in fuel carbon, is depicted in the dotted line (red) in Figure 14-1.

As another scenario, the long-dashed line in orange in Figure 14-1 shows the influence of switching from gasoline to natural gas, in addition to the vehicles meeting the new CAFE standard. The transition for this scenario is centered at 2025, with a width of approximately 20 years, so it is assumed to occur a bit later than the CAFE scenario and take a little longer to accomplish. These adjustments account for the extra time required to develop the natural gas refueling infrastructure.

Using natural gas instead of gasoline reduces the CO₂ emissions by 25 percent simply because of the lower carbon content per unit of chemical energy. This assumes the vehicle burning natural gas will have the same fuel economy in energy space, which is justified by the comparison of vehicle mileage in Table 14-2. The Honda Civic model is chosen for comparison because it is available as a conventional gasoline vehicle, a hybrid electric vehicle, or a natural gas vehicle. The mileage ratings show that the natural gas vehicle and the conventional gasoline vehicle achieve the same fuel economy rating, measured in energy-equivalent gallons (EPA 2008).

Table 14.2: Vehicle fuel economy comparison

<i>Vehicle</i>	<i>Composite Mileage</i>	<i>CO₂ Emissions</i>	<i>Relative CO₂ Emissions</i>
Civic	28 mpg	0.31 kg / mile	1
Civic-NG	28 mpg-equiv	0.23	0.75
Civic Hybrid	42 mpg	0.21	0.67
Clarity FCX	60 mile / kg H ₂	0.16	0.5

Note: Comparisons are for for gasoline, natural gas (NG), hybrid and fuel cell vehicles of the same make and approximate size. The CO₂ emissions for the Clarity FCX assume hydrogen is produced from reforming NG without carbon sequestration.

Source: EPA 2008

To put the vehicle fuel consumption rates in perspective, one might ask, what is the best fuel economy that can be expected by future vehicle improvements? The work required to push the vehicle as a glider through standard city and highway drive cycles can be computed to set an expectation for the upper limit on fuel economy. The integration of the velocity time history for the drive cycles depends on the mass, drag coefficient, frontal area, and rolling resistance for the vehicle (Heywood 1988). Using values representative of a Honda Civic and assuming that all of the energy from the gasoline can be converted into motion without any loss, this translates into a maximum test-cycle composite fuel economy of 163 mpg.

Comparing the vehicle mileage ratings to this theoretical maximum mileage suggests that the overall efficiency of converting chemical energy to motion is about 17 percent for the conventional model. The hybrid model achieves 26 percent efficiency measured in this way; however, the hybrid recovers some of the kinetic energy of the vehicle during braking, so the comparison may be artificial. The glider simulation does not include the potential effects of regenerative braking. Since the acceleration term accounts for about 45 percent of the work in the city cycle simulation and 19 percent of the highway cycle work, this limits the amount of energy that could potentially be recovered during braking. The rolling and air resistances will remain and cannot be avoided by drivetrain improvements.

The Honda Clarity has approximately similar glider characteristics to the Civic, but an additional 300 kg, reducing the expected maximum fuel economy to about 131 mpg, so the fuel-to-motion efficiency of the fuel cell vehicle is about 46 percent. While the advancements from conventional to hybrid electric or fuel cell vehicles represent significant improvements, it is likely that the technological evolution is reaching a steeper part of the learning curve.

Glider simulations for a range of vehicle size and mass were performed to suggest a maximum fuel economy for the light-duty fleet. As a representation of the sport utility vehicle segment, repeating the vehicle drive cycle simulations for a Toyota Highlander yields a maximum of 115 mpg. Averaging this with the compact sedan value of 163 mpg, the overall light-duty fleet might be expected to be limited by a value of about 140 mpg, assuming that the vehicle fleet remains apportioned approximately 50/50 between cars/trucks in the future. Some studies (Yang et al. 2009) propose scenarios that assume vehicle mileage as high as 88 to 125 mpg in gasoline equivalents.

While the question of maximum vehicle efficiency provides an interesting perspective on the CAFE requirements, speculations regarding how well the vehicles can eventually do could lead to a number of transition scenarios. However, the ultimate limit on the transition is the case of zero-carbon emissions, which would require that a zero-carbon source of stored energy be supplied to the vehicles.

The last GHG scenario for light-duty vehicles included in Figure 14-1, the medium-dashed blue line, considers a transition to zero-carbon vehicles, ignoring for the moment the question of how this might be accomplished. This transition is centered at 2030, following the suggestion of Greene et al (2008), with a width of nearly 30 years. The maximum reduction achieved by a zero-carbon fleet is about 18 percent lower than the projected growth line by 2050.

The two transitions to more efficient vehicles and zero-emission vehicles would not likely occur independently. More likely is a blended scenario that follows one of the more efficient vehicle curves until it intersects the zero-carbon vehicle curve. This combination would result in a larger decrease in the emissions integrated over the four decades. Nevertheless, the long-term emissions rate per year would be limited by the zero-carbon scenario.

Potential Technologies for Zero-Carbon Vehicles

Potential technologies for vehicles that produce essentially no carbon emissions include biofuels, plug-in hybrid electric vehicles, and hydrogen vehicles. It is important to bear in mind that these vehicle technologies are only zero-carbon if the fuel is produced without emitting carbon dioxide. Electric vehicles that run on grid electricity are not zero-carbon unless all the grid electricity is derived from renewable or nuclear generation. Similarly, the carbon emissions of hydrogen vehicles depend on how the hydrogen is produced.

The most common method of producing hydrogen today is by the steam-methane reforming of natural gas. Comparing the energy content of hydrogen to that of gasoline indicates that one kilogram of hydrogen is roughly equivalent to one gallon of gasoline. For methane-derived hydrogen, a similar rule-of-thumb exists with reference to the carbon emissions. Although natural gas emits 25 percent less CO₂ than gasoline for the same chemical energy, this benefit of the switch between hydrocarbons is offset by the loss in useful energy that is inherent in the reforming process. The most efficient reforming process converts only 70 percent of the chemical energy in the natural gas to hydrogen (Simpson and Lutz 2007). In fact, 70 percent efficiency is the DOE Hydrogen Program goal (DOE 2005). These factors balance, meaning the rule-of-thumb that one kilogram of hydrogen is roughly equivalent to one gallon of gasoline is true both in energy-space and in carbon-space, when the hydrogen is produced by reforming.

So how do analyses (Lutz and Reichmuth 2009; Greene et al. 2008; Hinkle 2009; Thomas 2008, 2009) obtain reduced carbon emissions with hydrogen vehicles? Most often, the hydrogen vehicle is assumed to be significantly more efficient than the conventional vehicle used for comparison. Comparing the natural gas Civic to the gasoline model using the data shown in Table 14-2 yields a 25 percent reduction in CO₂ emissions. The last row in Table 14-2 compares the CO₂ emissions for the Honda fuel cell vehicle, the Clarity FCX, which is rated at 60 miles per kilogram of hydrogen. Assuming the hydrogen is produced by reforming at 70 percent thermal efficiency, the CO₂ emissions per mile are about half those of the gasoline Civic. This is accomplished by efficiency improvements of the vehicle, not by lower carbon associated with

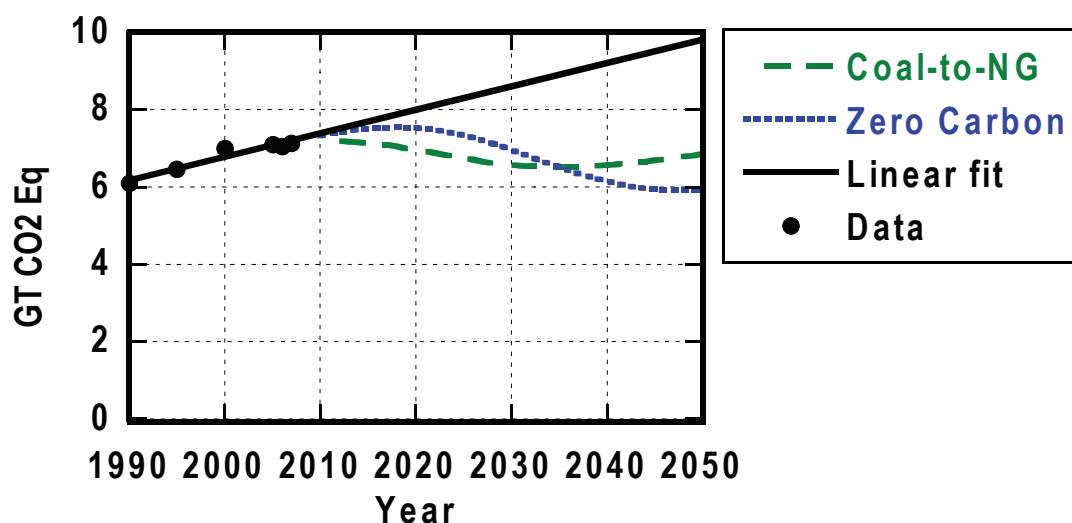
the fuel. The carbon emissions associated with a kilogram of hydrogen are the same as those from a gallon of gasoline.

The approach to zero emissions for a vehicle requires that no carbon be associated with the hydrogen fuel. The present study does not specify the technology to meet the goal of zero-carbon vehicles. This limit in the scope avoids dealing with trade-offs regarding where to apply zero-carbon energy technologies. For example, assertions that renewable or nuclear electricity will be used for producing hydrogen must logically compete with the potential use of the zero-carbon electricity for electric vehicles. Similarly, the carbon emissions associated with electric vehicles depend on assumptions about the future of the electric grid. While some studies are beginning to analyze these interactions for hydrogen vehicles and plug-in hybrid electric vehicles (Yang 2008; Hadley and Tsvetkova 2008; Samaras and Meisterling 2008; Stephen and Sullivan 2008; McCarthy and Yang 2009; Lutz and Reichmuth 2009), this study proceeds to examine the potential reductions in the electricity generation sector on its own.

Reduction Potential of the Electricity Sector

The analysis in this section assumes the LDV and all other sectors grow as projected, but considers reductions in the emissions from the electricity sector alone. The electricity sector currently accounts for roughly one-third of the total U.S. GHG emissions, and coal-fired generation currently emits 80 percent of the GHG emissions from the sector. Since power plants last longer than vehicles, the transition period should be longer, so the analysis uses a width of 40 years. This section presents two scenarios for the electricity sector: replacing coal with natural gas and zero-carbon electricity to replace all fossil fuel generation.

Figure 14-2: GHG emissions projected for the U.S. with reductions due to the electricity sector



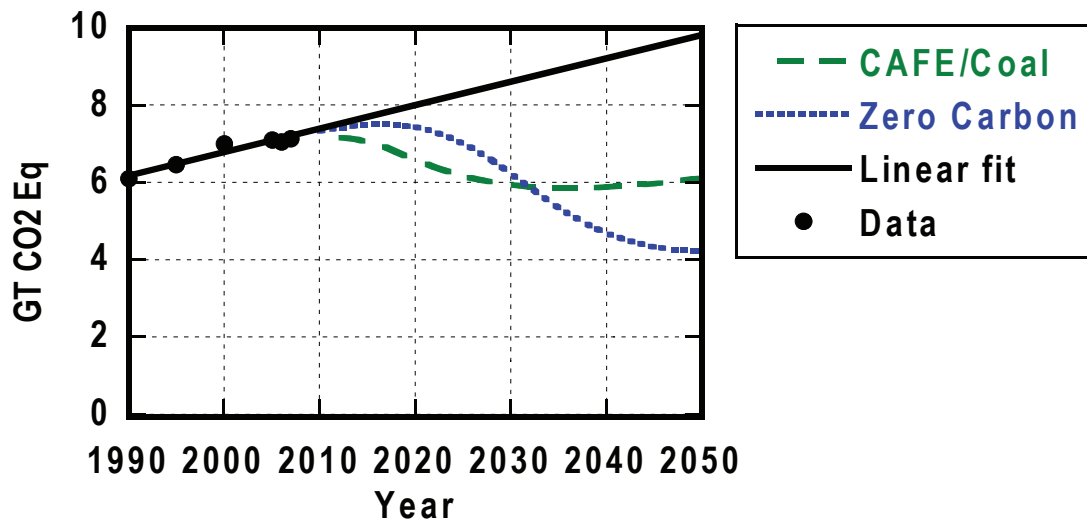
The first scenario uses a “carbon intensity” of 1.4 metric tons of CO₂ per megawatt hour (MWh) to represent typical coal-fired generation. This value is roughly equivalent to pulverized coal generation at 30 percent thermal efficiency. The dashed line (green) in Figure 14-2 shows the transition to natural gas, combined-cycle electricity generation at a thermal efficiency of 60 percent, which has a carbon intensity of 0.3 metric tons of CO₂ per MWh. When the transition is completed, this change reduces the CO₂ emissions from the electricity sector by 74%. Since the transition is centered relatively late (2020) and occurs relatively slowly, it is not entirely completed by 2050. Nevertheless, at this point, the dashed green line in Figure 14-2 shows that replacing coal-fired generation with higher efficiency natural gas generation can reduce overall emissions by 30 percent by 2050.

As a limiting scenario, the dotted blue curve in Figure 14-2 shows the effect of zero-carbon electricity generation, using the same transition width as in the coal replacement scenario, but centered at 2030. Replacing all fossil-fuel generation with zero-carbon electricity leads to an emissions reduction of 40 percent of the total GHG emissions projected at 2050 in the linear fit model.

Combined Potential of the Two Sectors

Figure 14-3 shows combinations of the potential contributions of the LDV fleet and the electricity sector. The dashed green curve represents the combined reduction of efficiency improvements, assuming an LDV fleet at 35.5 mpg and replacement of coal-fired electricity generation with electricity from natural gas at 60 percent thermal efficiency. This combination of efficiency improvements results in total GHG emissions roughly equal to the 1990 rate.

Figure 14-3: GHG emissions projected for the U.S. with combined reductions from the LDV fleet and the electricity sector



For comparison, the limiting combination of carbon-free technologies for both LDV and electricity generation leads to total GHG emissions about 30 percent below the 1990 level. This means that, at current growth rates, reducing total GHG emissions below 1990 levels by changes to the LDV and electricity sectors alone will require the drastic achievement of developing technologies that emit near-zero carbon.

Conclusions

The conclusion of this study is that the potential to reduce CO₂ emissions from both LDVs and electricity generation is limited. Proposed changes to the CAFE regulation and replacing coal-fired power with natural gas will only overcome the estimated growth by the middle of the century. Together, these two sectors currently comprise half of the total U.S. GHG emissions nationwide and represent most of the growth. While any extrapolation 40 years into the future is highly uncertain, a linear extrapolation suggests that growth will offset the potential reductions that are possible from improved efficiency in these sectors. Further reductions below 1990 emissions will require the ultimate of carbon-free technologies in these two important sectors.

Secondly, the approach to defining possible transition periods used in this study suggests that 2050 is not far away. The period for turning over the road fleet of LDVs is about two decades. Unless the relatively long-lived power plants are to be retired before their designed end-of-life, it will be difficult to complete a transition to a new technology by 2050.

Acknowledgements

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Appendix A:

Biographies of Editors and Authors

Co-Editors

Daniel Sperling is Professor of Civil Engineering and Environmental Science and Policy, interim director of the Energy Efficiency Center, and Director of the Institute of Transportation Studies at the University of California, Davis (ITS–Davis). He also serves on the California Air Resources Board. Dr. Sperling was recently honored as a lifetime National Associate of the National Academies, is author or editor of 200 technical articles and 11 books, and has testified 11 times before the U.S. Congress and California Legislature on energy and climate change issues. He was a recent chair of the Transportation Council of the Davos World Economic Forum and the Transportation Sustainability and Alternative Fuel Committees of the Transportation Research Board of the National Academies. He earned his PhD in Transportation Engineering from the University of California, Berkeley, with minors in Economics and Energy & Resources, and his BS in Environmental Engineering and Urban Planning from Cornell University. Professor Sperling worked two years as an environmental planner for the U.S. Environmental Protection Agency and two years as an urban planner in the Peace Corps in Honduras.

James S. Cannon is an internationally recognized researcher specializing in energy development, environmental protection and related public policy issues. He is President of Energy Futures, Inc., which he founded in 1979. Energy Futures publishes the quarterly international journal *The Clean Fuels and Electric Vehicles Report* and the bimonthly newsletter *Hybrid Vehicles*. Mr. Cannon has written several books on alternative transportation fuels and technologies, including *Harnessing Hydrogen: The Key to Sustainable Transportation*, and edited three books, the most recent of which is *Reducing Climate Impacts in the Transportation Sector*. Since 2008, he has written several studies of air pollution from container port operations around the world. Over the past two decades, Mr. Cannon's research into alternative transportation fuels has taken him to over 20 countries on five continents. He holds an AB in chemistry from Princeton University and an MS in biochemistry from the University of Pennsylvania.

Authors

Nicholas Robert Chase is an industry economist with the Energy Information Administration's (EIA's) Office of Integrated Analysis and Forecasting, Demand and Integration Division. He is part of the transportation team that models demand for light duty vehicles and alternative fuels, as well as estimating energy demand in air, rail, heavy truck, marine, and pipeline and military energy use. Prior to joining the EIA, Mr. Chase received his BA from the University of Michigan in Ann Arbor and his graduate degree from the Johns

Hopkins University. He is especially interested in analyzing the costs and benefits of new technologies and analyzing mode choice.

Kathryn Clay is the Director of Research for the Alliance of Automobile Manufacturers. Previously, she served on the professional staff of the Senate Energy and Natural Resources Committee, where she helped develop the Energy Independence and Security Act of 2007 and Energy Policy Act of 2005. She helped craft the America COMPETES Act of 2007, which promotes federal investment in science and technological innovation. Dr. Clay has held positions with the Energy Subcommittee of the U.S. House of Representatives Committee on Science; at the Massachusetts Division of Energy Resources; and as a research fellow in the Alternate Fuels Vehicle Division of Ford Motor Company. An adjunct professor of physics at Georgetown University, she co-founded the university's Program for Science in the Public Interest. She received her PhD in physics and her MS in electrical engineering from the University of Michigan.

John J. Conti is the Director of the Office of Integrated Analysis and Forecasting (OIAF) at the Energy Information Administration (EIA). His duties include managing teams of professionals to produce projections of energy markets, to produce estimates of greenhouse gas emissions, to record entities' efforts to mitigate greenhouse gas emissions, and to perform analyses of the impact of legislation on energy markets. The OIAF produces the *U.S. Annual Energy Outlook*, the *International Energy Outlook*, the *Emissions of Greenhouse Gases in the United States*, the *Voluntary Reporting of Greenhouse Gases*, and numerous analyses of potential energy legislation. Mr. Conti has worked in a number of positions in EIA. He has a Master of Science degree in management and policy sciences and an undergraduate degree in economics from the State University of New York at Stony Brook.

James J. Corbett, P.E., PhD conducts technology/policy research related to transportation, including research on air emissions from maritime transport, energy, and environmental impacts of freight transportation, and assessment of technological and policy strategies for improving goods movement. Dr. Corbett is a professor in the College of Earth Ocean and Environment and in Civil and Environmental Engineering in the College of Engineering at the University of Delaware. Drs. Corbett and James Winebrake are leading collaborators in a multi-university Sustainable Intermodal Freight Transportation Research program, an international research collaboration to improve the effective use of highway, waterway, railroad, and air transportation infrastructure.

Elizabeth Deakin is Professor of City and Regional Planning and Urban Design at the University of California, Berkeley, where she also is an affiliated faculty member of the Energy and Resources Group and the Master of Urban Design. Dr. Deakin's research focuses on transportation and land use policy, the environmental impacts of transportation, and equity in transportation. She has published over 200 articles, book chapters, and research reports on topics ranging from environmental justice to transportation pricing to urban development policies and practices.

John M. DeCicco, PhD, is a senior lecturer at the University of Michigan School of Natural Resources and Environment, where he teaches and guides student projects on sustainable energy strategies with a focus on transportation climate issues. From 2001 to June 2009, he was senior fellow for automotive strategies at the Environmental Defense Fund, where he was engaged in policy development for addressing transportation sector greenhouse gas emissions. From 1990 to 2000, he was transportation director at the American Council for an Energy-Efficient Economy (ACEEE). Dr. DeCicco was a pioneer in developing consumer-oriented automotive eco-ratings as the creator of ACEEE's *Green Book* and as designer of the Yahoo! Autos Green Ratings. He has written three books and over 70 publications. Dr. DeCicco received his PhD in Mechanical Engineering from Princeton University in 1988.

Trevor Demayo is Senior Planning Engineer at Chevron Energy Technology Co. He obtained his BSc in Engineering Physics at Simon Fraser University in Burnaby, British Columbia, Canada, and an MS and PhD in Mechanical and Environmental Engineering at the University of California, Irvine. Dr. Demayo leads the Low Carbon Energy Team, which evaluates future trends for a wide range of new energy-related technologies and business opportunities, particularly those involving advanced technology vehicles,

alternative fuels, advanced and renewable power, life cycle analyses, and carbon mitigation costs. Dr. Demayo has managed and co-authored several comprehensive technology whitepapers for Chevron's upper management on renewable and emerging energy technologies including geothermal, nuclear, solar, ocean energy, fuel cells, advanced lighting, and hydrogen production.

Carmen Difiglio is the Deputy Assistant Secretary for Policy Analysis in the Office of Policy and International Affairs at the U.S. Department of Energy (DOE). He is responsible for DOE's analyses of energy policies. Dr. Difiglio previously served as Head of the Energy Technology Policy Division at the International Energy Agency (IEA's) in Paris, where he developed a new world energy model and contributed to IEA's *World Energy Outlook*s. Mr. Difiglio has chaired various energy committees, including the Transportation Research Board's Committee on Energy and Transportation, and is now Vice Chair of the IEA Committee on Energy Research and Technology. His doctorate is from the University of Pennsylvania.

K.G. Duleep, a Managing Director at ICF, Inc., has been involved with automotive fuel economy issues for over 25 years. He has extensive experience with issues surrounding manufacturing cost analysis and is an internationally known expert on automobile fuel economy technology. Mr. Duleep has directed several studies evaluating new technologies for vehicular engine and fuel combinations (including methanol, natural gas, and other alternative fueled vehicles) in the U.S. These studies have compared technical feasibility, economics, performance, maintenance, and air emissions impacts. He is currently assisting the National Academy of Sciences in a study of light vehicle fuel economy potential to 2030. He has been retained by the International Energy Agency and the European Council of Ministers for Transport to develop strategies for improving the fuel economy of on-road vehicles in the European Union. Mr. Duleep has several advanced degrees in Engineering from the University of Michigan and also has an MBA in Finance from the Wharton School.

Lewis Fulton has worked internationally in the field of transport/energy/environment analysis and policy development for 20 years. He is a senior transport energy specialist with the International Energy Agency (IEA) in Paris, France. During 2006-2007, Dr. Fulton worked in Kenya with the United Nations Environment Program to develop and implement sustainable transport projects leveraging funding from the Global Environment Facility. His IEA reports include *Transport, Energy and CO₂: Moving Toward Sustainability* (October 2009), *Saving Oil in a Hurry* (2005), *Biofuels for Transport: An International Perspective* (2004), and *Bus Systems for the Future* (2002). Dr. Fulton has held previous positions at the U.S. Department of Energy, Office of Policy (1992-1996) and the Independent University, Bangladesh (1996-1997). He received his PhD in Energy Management and Environmental Policy from the University of Pennsylvania in the United States in 1994.

Anthony Greszler is Vice President of Government and Industry Relations at Volvo Powertrain North America. Mr. Greszler has been involved with diesel engine design and development since 1977. In 2005, he assumed responsibilities for advanced engineering for engines and vehicle propulsion with focus on diesel combustion and emissions, hybrid propulsion, advanced transmissions, and alternative fuels. He is currently focusing on carbon dioxide mitigation from road freight transport. Other activities include serving as an officer of the Engine Manufacturers Association, a member of the Transportation Research Board Special Task Force on Climate Change and Energy, and the Committee for Potential Energy Savings and Green House Gas Reduction from Transportation. Mr. Greszler earned a BS in Mechanical Engineering from Case Western Reserve University, Cleveland, Ohio, in 1972, followed by a MS in 1976.

John (Jack) E. Johnston is a retired Planning Executive and Senior Scientific Advisor from ExxonMobil Research & Engineering. He has a BS in chemistry from the University of Notre Dame and a PhD in polymer science from the University of Akron. He joined Exxon Chemical in 1980 and joined Exxon Research & Engineering Corporate Research Labs in 1991. He represented ExxonMobil in the California Fuel Cell Partnership and the Transportation Research Board Committee on Alternative Fuels. Since retirement, Dr. Johnston has worked with SFB Associates, a firm specializing in R&D Leadership and Management.

Jay Keller is the department manager of Hydrogen and Combustion Technologies at the Combustion Research Facility, Sandia National Laboratories in California. Previously, he studied unsteady turbulent flows, publishing more than 75 articles. From 1999 to 2003 he managed Sandia's engine research program, consisting of nine laboratories devoted to the investigation of in-cylinder combustion fluid dynamics that control engine performance. Since 1994 he has been the Hydrogen Program Manager at Sandia. Under Dr. Keller's leadership, his department focuses on technologies that show promise for a net-zero carbon energy system, including coal and biomass gasification, hydrogen combustion, fuel cells, materials for hydrogen storage, and hydrogen systems analysis. Dr. Keller holds a PhD from the University of California, Berkeley, awarded in 1982.

Andy Lutz has performed engineering analysis at Sandia National Laboratories since 1981. His research interests include combustion, chemical kinetics, thermodynamics, and energy systems. He has developed three of the applications in the Chemkin software collection, which is licensed and distributed worldwide. Recent activities include thermodynamic analysis of energy systems, specifically for hydrogen and biofuels. Dr. Lutz holds a PhD from the University of California, Davis, awarded in 1988.

John D. Maples is an Operations Research Analyst for the Energy Information Administration's (EIA's) Office of Integrated Analysis and Forecasting. He leads the transportation team, which researches and analyzes issues related to transportation energy demand, emissions, and forecasting and develops and employs the transportation model within the National Energy Model System. Prior to joining the EIA in 2001, Mr. Maples was employed as the senior transportation analyst at Trancon, Inc., where he served on the U.S. Department of Energy Office of Transportation Technologies' Laboratory Analytic Team. He has 20 years of experience analyzing energy, security, economic, technological, and environmental issues related to the transportation sector. Mr. Maples received a Bachelor of Science degree in Transportation and Logistics from the University of Tennessee. He is an active member of the Transportation Research Board and has served as an officer on the Governing Board of the Society of Automotive Engineers' Washington, DC, chapter.

Robert C. Marlay, PhD, PE, is currently Acting Director of the Office of Climate Change Policy and Technology at the U.S. DOE. Dr. Marlay has held leadership positions in national security, energy programs, energy policy, science and technology policy, climate change, international affairs, and the planning and management of research and development programs. In his present position, he is responsible for formulating and managing a portfolio of activities addressing global climate change policy, programmatic and legislative analyses, technological research, development, deployment, greenhouse gas emissions reductions, and related international cooperation. Dr. Marlay holds a PhD in energy technology and policy from the Massachusetts Institute of Technology.

Carolyn McAndrews is a PhD candidate in City and Regional Planning at the University of California, Berkeley campus. Her research focuses on the social and institutional aspects of transportation planning, policy, and design, particularly as they relate to urban development, climate change mitigation, and health, safety, and security in cities.

David McCurdy joined the Alliance of Automobile Manufacturers, a leading trade association for the automotive industry, as president and CEO in February 2007. He previously served as president and CEO of the Electronic Industries Alliance for eight years. Mr. McCurdy also had a distinguished career in the United States House of Representatives, serving 14 years from 1981 to 1995 from the 4th Congressional District of Oklahoma. He held numerous leadership positions in the House of Representatives, including Chairman of the House Intelligence Committee; Chairman of the Military Installations and Facilities Subcommittee of the House Armed Services Committee; and Chairman of the Transportation Aviation and Materials Subcommittee of the Science and Space Committee. He was the youngest person in Congressional history to chair a full committee. In 2008, Secretary of Defense Robert Gates appointed Mr. McCurdy to the Defense Policy Board, which provides the secretary with independent, informed advice and opinion concerning matters of defense policy. He was reappointed to the Defense Policy Board in 2009 by the Obama Administration. A 1972 graduate of the University of Oklahoma, Mr. McCurdy received his JD

in 1975 from Oklahoma's Law School. He studied international economics at the University of Edinburgh, Scotland, as a Rotary International Graduate Fellow.

Mike McKeever, AICP, has served since 2001 as Blueprint Project Manager and then Executive Director of the Sacramento Area Council of Governments (SACOG). During his tenure at SACOG, the organization has established itself as a national leader in sustainable, integrated regional planning. Mr. McKeever was a key contributor to California Senate Bill (SB) 375, the nation's most comprehensive regional planning law linking climate change, transportation, land use, and housing planning. He chairs the Regional Targets Advisory Committee, a 2-person statewide committee to assist in the implementation of SB375. Prior to joining SACOG, Mr. McKeever led planning projects across the country, authored several manuals on regional collaboration, and was the primary developer of the innovative I-PLACE3S planning software. He received his BA with Honors from the University of Oregon.

Johannes-Joerg Rueger is the Senior Vice President, Engineering for Diesel Systems for Robert Bosch LLC. In this position, Dr. Rueger is responsible for all areas of diesel engineering for Bosch in North America, including systems engineering, hydraulic components, electrical control units, and exhaust gas aftertreatment for passenger cars and commercial vehicles. His engineering organization is based in Farmington Hills, Michigan, and Charleston, South Carolina.

Lee Schipper earned his PhD at the University of California, Berkeley in astrophysics. He is Project Scientist with Global Metropolitan Studies at Berkeley and Senior Research Engineer at the Precourt Energy Efficiency Center at Stanford University. Previously he had been Director of Research for EMBARQ, the World Resources Institute Center for Sustainable Transport, which he helped found in 2002. Dr. Schipper came to EMBARQ from the International Energy Agency (IEA) in Paris, where he had been visiting scientist from 1995 to 2001. Dr. Schipper has authored over 100 technical papers and a number of books on energy economics, environment, and transportation. He is a member of the U.S. Transportation Research Board's Committees on Sustainable Transport, Energy, and Developing Countries. Dr. Schipper leads a jazz quintet and has appeared at every Asilomar transportation workshop since 1991.

David Vincent is Director, Projects at the Carbon Trust in the United Kingdom. He graduated from the University of Kent, Canterbury with a degree in Chemical Physics, adding a PhD in 1972. Dr. Vincent's current focus is to develop the Carbon Trust's international outreach activities, including low-carbon buildings strategy, policy and program development, and the creation of new low-carbon commercial enterprises. He is a member of the Carbon Trust's management team.

James J. Winebrake, PhD is a professor and chair of the Department of STS/Public Policy at the Rochester Institute of Technology (RIT) in Rochester, New York. Dr. Winebrake is also co-director of the RIT Laboratory for Environmental Computing and Decision Making and director of the University-National Park Energy Partnership Program. He has published on a wide range of energy and environmental topics, including the environmental impacts of goods movement and lifecycle analysis of alternative fuels. Drs. Winebrake and James Corbett are leading collaborators in a multi-university Sustainable Intermodal Freight Transportation Research program, an international research collaboration to improve the effective use of highway, waterway, railroad, and air transportation infrastructure.

Sonia Yeh is a research scientist at the Institute of Transportation Studies, University of California, Davis. She is a faculty member of the Graduate Group in Transportation Technology and Policy and an adjunct assistant professor at the Department of Engineering and Public Policy, Carnegie Mellon University. Her primary research interest is to advance the understanding of future energy systems and their environmental and social impacts, and to seek policy solutions that improve the societal process of making decisions for our future energy systems. Dr. Yeh serves on the Transportation Energy Committee of the Transportation Research Board of the National Academy of Science.

Appendix B:

2009 Asilomar Transportation Conference Attendees

Hayato Akizuki	Nissan Technical Center North America
Fabian Allard	Natural Resources Canada
Jeff Alson	U.S. EPA
Andrew Altevogt	California EPA
Dave Austgen	Shell Hydrogen
Nick Beck	Natural Resources Canada
Louise Bedsworth	Public Policy Institute of California
Allen Biehler	Pennsylvania DOT
Robert Bienenfeld	American Honda Motor Company
Carl Blumstein	California Institute for Energy and Environment
John Boesel	CALSTART
Andre Bourbeau	Transport Canada
Bill Boyce	Sacramento Municipal Utility District
James Boyd	California Energy Commission
Thomas Briggs	BP Alternative Energy
Joe Browder	Dunlap & Browder
Austin Brown	U.S. DOE
Nathan Brown	U.S. Federal Aviation Administration
Susan J. Brown	California Energy Commission
Cynthia Burbank	Parsons Brinckerhoff
Andrew Burke	UC Davis
David Burwell	BBG Group
John Cabaniss	Association of International Automobile Manufacturers
Tom Cackette	California Air Resources Board
Eric Cahill	X PRIZE Foundation
Todd Campbell	Clean Energy
James Cannon	Energy Futures, Inc.
Nancy Chinlund	California DOT
Joy Chiu	New York State DOT
Giovanni Circella	UC Davis
Susan Cischke	Ford Motor Company
Kathryn Clay	Alliance of Automobile Manufacturers
Michael Coates	Robert Bosch LLC
John Conti	U.S. DOE
James Corbett	University of Delaware

Michael Cunningham	Bay Area Council
Robert Czarnowski	BorgWarner
Greg Dalton	Commonwealth Club, San Francisco
Adriana de Almeida Lobo	Center for Sustainable Transport, Mexico City
Jamie Dean	Packard Foundation
Danielle Deane	Hewlett Foundation
John DeCicco	University of Michigan/Consultant to EDF
Trevor Demayo	Chevron
Carmen Difiglio	U.S. DOE
Clarence Ditlow	Center for Auto Safety
Sandrine Dixson-Deceleve	Hart Energy Consulting
Steve Douglas	Alliance of Automobile Manufacturers
Mort Downey	Parsons Brinckerhoff
Thomas Downs	Veolia Transportation NA
K.G. Duleep	ICF International
Alexandre Dumas	Transport Canada
Louise Dunlap	Dunlap & Browder
Connell Dunning	U.S. EPA
Catherine Dunwoody	California Fuel Cell Partnership
Amanda Eaken	Natural Resources Defense Council
Michael Eaves	Clean Energy
Tyson Eckerle	Energy Independence Now
Jill Egbert	PG&E
Duncan Eggar	BP (Retired)
Anthony Eggert	California Air Resources Board
Shannon Eggleston	AASHTO
Thomas Eizember	Exxon Mobil Corporation
Daniel Emmett	Energy Independence Now
Bob Epstein	Environmental Entrepreneurs
Kevin Eslinger	California Air Resources Board
Anthony Finizza	UC Irvine
Kimberly Fisher	Transportation Research Board
Damon Fordham	AASHTO
Emil Frankel	Bipartisan Policy Center
Danielle Fugere	Friends of the Earth
Tom Fulks	Robert Bosch LLC
Lew Fulton	International Energy Agency
Cynthia Gage	U.S. EPA
Chris Ganson	World Resources Institute
Remy Garderet	Energy Independence Now
John German	International Council on Clean Transportation
Angus Gillespie	Royal Dutch Shell
Kenneth Gillingham	Stanford University
Brian Gouge	University of British Columbia
David Greene	Oak Ridge National Laboratory
Larry Greene	Sacramento Metropolitan AQMD
Lance Grenzeback	Cambridge Systematics
Anthony Greszler	Volvo Powertrain
Andrew Grieshop	University of British Columbia
Jamie Hall	CALSTART
Paula Hammond	Washington State DOT
Melinda Hanson	ClimateWorks Foundation
Ryan Harrington	U.S. DOT
Timothy Hayes	BP Biofuels

Reid Heffner	Booz Allen Hamilton
Heather Hood	San Francisco Foundation
Grace Hsu	Natural Resources Defense Council
Cornie Huizenga	Clean Air Initiative Center
John Hutchison	Ontario Ministry of Environment
Roland Hwang	Natural Resources Defense Council
Michael Jackson	TIAX LLC
Jeffrey Jacobs	Chevron
Gib Jersey	ExxonMobil Research and Engineering
Michael Johnsen	U.S. DOT
Norman Johnson	Robert Bosch LLC
Brian Johnston	Nissan Technical Center North America
Jack Johnston	ExxonMobil (Retired)
Fanta Kamakaté	International Council on Clean Transportation
Dean Kato	Toyota
Jay Keller	Sandia National Laboratories
Edward Kjaer	Southern California Edison
Andreas Klugescheid	BMW Group
Jamie Knapp	J Knapp Communications
Ben Knight	Honda R&D Americas, Inc.
Martha Krebs	UC Davis
Kenneth Kurani	UC Davis
Robert Larsen	Argonne National Laboratory
Robert Larson	U.S. EPA
Mark Laser	Dartmouth College
Illmari Lastikka	Neste Oil
John Lawson	University of British Columbia
Arthur Lee	Chevron
Martin Lee-Gosselin	Université Laval, Québec
Paul Leiby	Oak Ridge National Laboratory
Galen Lemei	California Energy Commission
Sharyn Lie	U.S. EPA
Zhenhong Lin	Oak Ridge National Laboratory
Jane Long	Lawrence Livermore National Laboratory
Michael Lord	Toyota Technical Center
Michael Love	Toyota Motor Sales
Nicholas Lutsey	UC Davis
Jeremy Madsen	Greenbelt Alliance
Dawn Manley	Sandia National Laboratories
Jason Mark	Energy Foundation
Robert Marlay	U.S. DOE
Eric Mazzi	University of British Columbia
Michael McCoy	UC Davis
Dave McCurdy	Alliance of Automobile Manufacturers
Mike McKeever	Sacramento Area Council of Governments
Walter McManus	University of Michigan
Alan Meier	UC Davis/Lawrence Berkeley National Laboratory
Mark Melaina	National Renewable Energy Laboratory
Tom Menzies	Transportation Research Board
Adam Millard-Ball	Stanford University
Deb Miller	Kansas DOT
Marianne Mintz	Argonne National Laboratory
Philip Misemer	California Energy Commission

John Moavenzadeh	World Economic Forum
Ralph Moran	BP America
Michael Morris	U.S. DOE
Simon Mui	Natural Resources Defense Council
Louis Neudorff	Iteris, Inc.
Mary Nichols	California Air Resources Board
Mary Nickerson	Toyota Motor Sales
Robert Noland	Rutgers University
Mark Norman	Transportation Research Board
Joan Ogden	UC Davis
Patrick Oliva	Michelin Group
Richard Plevin	UC Berkeley
Joel Pointon	Sempra Utilities
Joanne Potter	Cambridge Systematics
Jesse Prentice-Dunn	Sierra Club
Stephen Prey	California DOT
Jim Ragland	Aramco Services Company
Farideh Ramjerdi	Institute of Transport Economics, Norway
Peter Reilly-Roe	International Council on Clean Transportation
Francis Ries	University of British Columbia
Jonathan Rubin	University of Maine
Deborah Salon	UC Davis
Francisca Santana	Energy Foundation
Michael Savonis	U.S. Federal Highway Administration
Robert Sawyer	UC Berkeley
Lee Schipper	Stanford University
Susan Schoenung	Longitude 122 West, Inc.
Ingo Scholz	Volkswagen
Dennis Schuetzle	Renewable Energy Institute International
Marcy Schwartz	CH2M HILL
Paul Scott	ISE Corporation
Ruth Scotti	BP Biofuels
Josh Seidenfeld	Energy Foundation
John Shears	Center for Energy Efficiency and Renewable Technologies
Harrison Sigworth	Chevron
Aaron Singer-Englar	BMW Group
Sarah Siwek	Sarah J. Siwek & Associates
Steven Skerlos	University of Michigan
JoAnna Smith	U.S. DOT
Sabrina Spatari	Drexel University
Dan Sperling	UC Davis
Jennifer Stettner	ConocoPhillips
Jane Summerton	Swedish National Road and Transport Research Institute–VTI
George Sverdrup	National Renewable Energy Laboratory
Ruth Talbot	Natural Resources Canada
Dean Taylor	Southern California Edison
Margaret Taylor	UC Berkeley
Mariana Torres-Montoya	World Economic Forum
Gary Toth	Project for Public Spaces
Tom Turrentine	UC Davis
Lars Ullrich	Robert Bosch LLC
John Viera	Ford Motor Company
David Vincent	The Carbon Trust
Barry Wallerstein	South Coast AQMD

Jerry Walters	Fehr & Peers
Yunshi Wang	UC Davis
Justin Ward	Toyota Technical Center
Jonathan Weinert	Chevron
Tom Wenzel	Lawrence Berkeley National Laboratory
Al Weverstad	General Motors
Peter Whitman	U.S. DOE
Stephanie Williams	ConocoPhillips
James Winebrake	Rochester Institute of Technology
Steve Winkelman	Center for Clean Air Policy
Maggie Witt	U.S. EPA
Brian Wynne	Electric Drive Transportation Association
Christopher Yang	UC Davis
Ken Yeager	Santa Clara County Board of Supervisors/CARB
Sonia Yeh	UC Davis
Bob Yuhnke	Southwest Energy Efficiency Project
Theodoros Zachariadis	Cyprus University
Amy Zimpfer	U.S. EPA
Bill Zobel	Sempra Utilities