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Energy and Transportation Beyond 2000

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As the third millennium begins, society faces the task of creating a transportation system that expands the energy resources available for mobility while reducing negative effects on the environment. This task is international in scope. Three critical issues—oil dependence, air pollution, and greenhouse gas emissions—confront the global transportation and energy system. Meeting these challenges will require energy-efficient technologies that are powered by improved energy sources.

The technologies that determine transportation energy use now were invented roughly a century ago and were unforeseen a thousand years ago. Yet, the underlying needs—society's desire for ever more convenient and rapid access to goods and services—have persisted throughout history. Such desires will continue to shape transportation in the centuries ahead. The years approaching the new millennium have been marked by expansive innovation, offering vehicle and energy technologies that promise to meet both the underlying needs and the challenges posed. Implementing these new options must be accomplished ultimately through market choices.

However, the market alone will not adequately address oil dependence, air pollution, and greenhouse gas emissions. New policies must be developed to guide technological and institutional changes toward a system for transportation energy that provides efficient mobility along with resource security and environmental sustainability. Transportation energy researchers will have an important role to play in assessing these issues in the decades ahead.

BACKGROUND

Energy is essential to transportation. Conveying a person or thing from one place to another is equivalent to the scientific definition of work: force moving mass through distance. Energy is precisely the ability to do work or, in other words, the ability to transport. Energy, work, and transportation can be measured in the same terms (distance times mass). Thus, transportation's need for energy is as fundamental as the laws of physics.

Since the Industrial Revolution, transportation has been a quest for ever-increasing speed, and this quest is likely to continue (*1*). Worldwide travel by fast modes of transportation such as air and high-speed rail could increase 20-fold by 2050 (*2*). Energy use tends to increase with the square of speed because the forces opposing motion (such as drag) also increase. So ensuring economical and environmentally sustainable transportation energy systems for a larger, wealthier, and faster-moving world will be an enormous undertaking.

Of the energy used for transportation in the United States, personal mobility consumes the most. Passenger travel accounted for 15.3 quadrillion British thermal units, 62 percent of the total 24.9 quads used by the U.S. transportation system in 1997 [these data and many others are from S.C. Davis (3)]. Personal highway vehicles (passenger cars, light trucks, and motorcycles) used 84 percent of the energy consumed for personal mobility. Bus and rail together accounted for less than 2 percent, about the same amount of energy Americans used for recreational boating. Air travel held another significant share of energy use (13 percent); it also is the fastest growing mode of transportation.

Freight energy use is dominated by trucks, but its patterns are not well understood. It is difficult to separate freight uses from service uses of light and medium-sized trucks. Ambiguities arise in categorizing passenger versus freight energy use for combined modes such as commercial air. The quality of energy and related activity data is poor for most freight modes.

Energy for transport is supplied in a variety of forms and with varying efficiency, depending on technology, economics, and societal conventions (*4*). In developed economies, nearly all energy for transportation is supplied by a single fossil resource: petroleum. U.S. transportation is 97 percent dependent on petroleum products, although gasoline blending stocks incorporate about 2–3 percent of ethanol or natural gas inputs (*5*).

Twenty-five years ago, petroleum dependence led to the first “energy crisis,” when the Organization of Petroleum Exporting Countries (OPEC) boycotted nations they believed to be key supporters of Israel in the 1973 October War. The Iranian revolution induced another, more severe, oil price shock from 1979–80. Much has happened since then, including the Gulf War in 1990, but the growth of transportation energy demand and its continued reliance on petroleum have not changed. Although it is far from certain that petroleum dependence will reemerge as a significant problem in the 21st century, we have more than adequate cause for concern.

Environmental impact is a major issue, and energy and environmental issues will continue to be intertwined: “Using energy in today’s ways leads to more environmental damage than any other peaceful human activity (except perhaps reproduction)” (*6*). Although this statement is difficult to prove scientifically, fuel combustion is a large source of air pollution and the main source of climate-altering greenhouse gases. Energy production and distribution contribute to water pollution and habitat destruction. Consuming more than 27 percent of the total U.S. energy budget and 66 percent of U.S. petroleum, transportation is a significant source of environmental damage.

Transportation energy problems are becoming increasingly global. In 1950, 70 percent of the world’s 70 million cars and trucks were in the United States. Today, the world fleet stands at more than 670 million, 70 percent of which are located outside of the United States. Motor vehicle populations in Europe are growing at faster rates than in the United States, despite higher vehicle taxes and fuel prices three to four times as high. Vehicle use in the developing world is growing faster still. The motorization of global transport is well under way and has a long way still to go. As Schipper et al. (*7*) summarized,

- Transportation is almost completely dependent on oil,
- Oil demand is concentrated in the transport sector, and
- Transportation holds a growing share of overall energy use and emissions.

A quarter of a century ago, transportation energy use became a prominent problem as we faced apparent fuel shortages. But now, at the turn of the millennium, the question is not, “When will we run out of fossil fuels?” but rather, “How will we achieve energy sustainability?” In other words, “How will we create the technologies and institutions to use fossil energy sources, and develop new renewable sources, in ways that expand rather than contract the world’s wealth of physical, environmental, and human resources?”

Energy is only one facet of the multifaceted context of transportation in society. The social costs of fatalities and injuries from crashes remain enormous. The effects of traffic congestion and land use present perennial challenges. Changes in other aspects of the system will interact with approaches for managing the use of transportation energy. Infrastructure investments can determine modal options and the availability of intermodal systems. Computers and electronic communications technologies will have a profound but as yet unforeseeable influence on all aspects of transportation, including energy use. Information technologies have the potential to replace some travel as well as create new demands; they can facilitate logistical improvements and intermodal transport as well as expand the system’s capacity for energy-intensive modes; they can enable more efficient pricing and lower costs overall.

Clearly, transportation energy issues must be addressed in concert with other societal concerns. Researchers and policy makers will need to be cognizant of both new demands and new opportunities in a future marked by globalization and rapid technological change.

KEY ISSUES FOR 2000 AND BEYOND

The United States and other nations face the challenge of developing secure transportation energy resources and technologies that can accommodate the growth of mobility along with rising expectations for environmental quality. The key aspects of this challenge are

- Continued dependence on petroleum,
- Pollution of the air by fuel combustion, and
- Emissions of greenhouse gases, which contribute to climate change.

Oil Dependence

In the 1970s, worry over the world’s “finite” fossil energy resources spawned studies of the limits to growth and brought about policies for avoiding an imminent energy crisis. A quarter of a century later, most resource economists have abandoned the paradigm of exhaustible resources in favor of one that recognizes the key roles of technology and social institutions in defining, expanding, or abandoning energy resources. This new view recognizes that how much energy can be produced economically and what is and is not considered an energy resource are defined technologically and culturally.

Running out of energy is not the problem facing transportation as it enters the 21st century. Conventional oil reserves total about 1 trillion (10^{12}) barrels. At the current world consumption rate of about 27 billion barrels per year, we can calculate a reserve-to-production ratio of 37 years. Up to another trillion barrels remain to be discovered.

Economically recoverable unconventional petroleum resources (tar sands, oil shale, and heavy oil) are believed to be at least as large. Additional unconventional resources, not presently recoverable, raise the total to nearly 20 trillion barrels. Moreover, liquid fuels can be made from natural gas at close to current market prices. Adding up known and speculative gas resources, including methane hydrates (not exploitable at present), suggests a total of more than 150 trillion barrels of oil-equivalent energy resources. At a production rate of 100 billion barrels per year, roughly four times the current rate, these potential sources of liquid fuels would last 1,500 years—more than another millennium.

Although running out of energy is not an immediate problem, the geopolitical concentration of resources and the existence of an organized cartel to exercise monopoly power can result in economic scarcity (*8*). Moreover, the interaction of strong, albeit uneven, demand growth with the long investment cycles needed to exploit any major new energy resource can cause price volatility and transient disruptions with the potential to inflict serious economic damage. Some argue that such problems can be avoided through unfettered access to the many resources available around the world (*9*). However, unfettered access may not be freely given, and the energy supply must compete with many other goals in the global political arena (*10*). History warns that energy security remains a serious concern.

As long as OPEC can exercise power in world oil markets, market disruptions can be a source of lucrative revenues to the cartel and enormous costs to oil-consuming nations. Regardless of whether world oil production begins to decline early in the 21st century, the threat of oil price shocks and monopolistic pricing is real. The near-term outlook is for increasing U.S. dependence on imported oil, and increasing world dependence on OPEC oil (*11*). U.S. oil imports, which now amount to more than 50 percent of supply, are projected to reach 65 percent by 2020 (*12*). OPEC’s share of world production is expected to grow from about 40 percent today to more than 50 percent by 2020. Past oil price shocks have cost the U.S. economy trillions of dollars. Avoiding future shocks by reducing transportation’s dependence on oil and by increasing its ability to respond to fuel price increases could be worth tens of billions of dollars annually to the U.S. economy (*13*).

Air Pollution

The use of energy for transportation is a major cause of air pollution and, subsequently, the mortality, morbidity, and ecosystem damage that it causes. In the United States, transportation vehicles are responsible for 78 percent of all carbon monoxide emissions, 45 percent of nitrogen oxide emissions, 37 percent of hydrocarbon emissions, and 27 percent of anthropogenic emissions of fine particulate matter (*14*).

Today’s vehicles produce less total pollution than they did 25 years ago, even though travel activity has more than doubled. Essentially all progress in reducing pollution to date can be attributed to technological improvements in vehicles and fuels. Even so, transportation sources remain large contributors to unhealthy air in many parts of the United States, and the situation is worse in much of the rest of the world. The harm caused by some pollutants, particularly fine particulate matter, is far from fully reflected in emissions standards, let alone effective control strategies. Public policy and the technological improvements it motivates continue to race against growth in travel, and more robust strategies will be needed to achieve clean air goals.

Despite the negative effects caused by transportation, there are reasons for optimism. Spurred by tighter regulations, auto makers have designed vehicles that emit one to two orders of magnitude fewer pollutants than similar vehicles did 30 years ago. Recent U.S. policy developments, including California's LEV2 rules and federal Tier 2 standards, are pressing pollution control for light-duty gasoline vehicles toward new levels of stringency. (LEV2 and Tier 2 refer to levels set by light-vehicle emissions regulations; both will be phased in starting in 2004. Notable improvements include a greater emphasis on NOx control, targeting reductions by factors of 5 to 10 from current levels; extended durability requirements; near-harmonization of light trucks with passenger-car standards; and a reduction in the national average gasoline sulfur levels by a factor of 10.) Together, the auto and oil industries are designing fuel and vehicle systems to minimize pollution. Lead was phased out of gasoline long ago, sulfur levels are being reduced, and reformulated fuels can reduce both criteria emissions and toxic pollutants. The implication is stunning: Motor vehicles that burn fossil fuel need not produce unhealthy levels of air pollution.

Nevertheless, key tasks remain: reliably and durably implementing such levels of pollution control throughout the vehicle stock, and better characterizing and controlling fine particulate matter. Even new diesel vehicles emit relatively high levels of nitrogen oxide and fine particulate matter. Emissions control breakthroughs or acceptable replacements for diesel engines are crucial research needs.

Although we can identify promising solutions to transportation air pollution, timely and effective implementation remains a challenge. Moreover, transferring such solutions to the rest of the world in an appropriate and timely manner is a formidable task and an additional challenge for the research community.

Climate Change

The Intergovernmental Panel on Climate Change, a group of the world's leading scientists, has concluded that human activities, particularly fossil fuel combustion, are probably changing the world's climate: "[C]arbon dioxide remains the most important contributor to … climate change; projections … confirm the potential … to alter the Earth's climate to an extent unprecedented in human history; and … many important aspects of climate change are effectively irreversible. Further, that observations suggest a discernible human influence on global climate … adds an important new dimension to the … issue" (*15*).

Although uncertainties exist about the extent and consequences of climate change, the world has begun to take it seriously. In December 1997 in Kyoto, Japan, the parties to the United Nations Framework Convention on Climate Change set specific targets for reducing greenhouse gas emissions.

The United States is the world's largest emitter of anthropogenic carbon dioxide, accounting for approximately one-fourth of the world's total in 1996. The U.S. transportation sector's 471 million metric tons of carbon emissions from fossil fuel consumption exceed the national fossil carbon emissions of every other country in the world except China. Under the Kyoto Protocol, the United States is to reduce its emissions 7 percent below 1990 levels over the 2008–2012 period. However, even optimistic analyses do not anticipate that the transportation sector can itself achieve such a reduction by then (*16,17*). The limitation is largely the time required for replacing transportation equipment rather than a lack of potential for technological change. DeCicco and Mark (*17*) estimate that transport emissions could be 35 percent lower than 1990 levels by 2030.

Transportation will be called on to begin cutting its carbon emissions significantly over the next decade, and the sooner it starts, the less costly any given reduction is likely to be.

FACING THE DECADES AHEAD

As in the past, technological progress holds vast potential for solving the energy problems faced by the transportation industry. Recent developments illustrate just how dramatically technology can change. But technological progress alone is not enough. Public policy guidance and institutional innovations also will be necessary.

Promise of Technology

Over the past two decades, vehicle technology has progressed substantially. Through the mid-1980s, this progress was harnessed to raise light-vehicle fuel economy. During the past decade, technical progress continued; however, with regulatory requirements unchanged, market forces have pulled technology toward other amenities, such as higher vehicle capacity and performance (*18*). Nevertheless, the potential exists for further incremental improvements in light-vehicle fuel economy of 30 percent or more (*4*). Ambitious research and development (R&D) efforts hope to achieve much higher efficiency improvements. The U.S.-based Partnership for a New Generation of Vehicles (PNGV) is aiming for tripled fuel economy, and similar R&D programs are underway in Europe and Japan. Some of the most promising advanced vehicle technologies involve changes to the fuel as well as to the vehicle. To varying degrees, alternatives to petroleum fuels can address the sector's energy-related challenges; however, it is as yet unclear whether or when any of them will be used widely (*19*).

Technological progress continues to expand the potential for improving the efficiency of conventional vehicles. In Europe and Japan, Japanese manufacturers have introduced lean-burn gasoline direct injection engines, which improve fuel economy on the order of 20 percent. In Europe, direct-injection light-duty diesel engines, which improve fuel economy 40 percent over typical gasoline engines, have gained substantial market share. Presently, these technologies require making a trade-off between emissions and efficiency, because it is not yet known how to control emissions of nitrogen oxide and fine particulate matter to the levels now expected of conventional gasoline vehicles; however, R&D is seeking to overcome these limitations.

Advanced technologies offer yet greater strides in engine efficiency. Hybrid powertrains combine a combustion engine with electric drive components. In December 1997, Toyota introduced the first mass-produced hybrid electric car in Japan. Honda is introducing a small ultra-low-emission hybrid vehicle with gas mileage of more than 70 miles per gallon to the U.S. market. Fuel cells, which were an exotic space-age technology only a decade ago, now power functional prototype cars by Ford and DaimlerChrysler. Hydrogen-powered fuel cells are inherently more efficient than combustion engines and almost pollution free. Additional R&D and production experience at increasing scales promise costs low enough for automotive markets, but substantial hurdles remain regarding on-board fuel storage and fuel supply infrastructure (*20*). All major auto makers now have fuel-cell R&D programs, reflecting expectations of a large role for this technology in the future.

Most approaches to achieving a leap forward in fuel economy involve combining higher powertrain efficiency with reduced vehicle mass, along with streamlining and other energy-saving techniques. Concepts that involve intensive use of aluminum and other light-weight materials can cut vehicle mass 40 percent without compromising size or crashworthiness. However, the overall safety outcome will depend on how lightweight technologies are deployed. Focusing first on heavier segments of the light-duty fleet could enhance safety (*21*), but making cars lighter while leaving light trucks unchanged could increase the safety risks due to incompatibility (*22*). Understanding and developing approaches for optimally balancing vehicle efficiency improvement with traffic safety is a crucial topic for research.

Although light-duty vehicles dominate, other modes of transportation collectively consume 40 percent of energy for transportation. Freight trucks are the second largest energy users, and some options exist for both improving efficiency and reducing criteria emissions (*23*). Promising technologies for air, rail, and marine transport exist but receive far less attention. Technological advances for heavy trucks and jet aircraft are especially needed, because their energy use is growing steadily. Developing and implementing advanced, energy-saving technologies for these modes of transportation is another notable task.

Challenge for Policy

Public policy will play a key role in addressing transportation energy issues, just as it has helped shape the transportation and energy sectors that exist today. Public investments in infrastructure—such as highways and airports—influence not only the demand for use of those facilities but also the modal structure of transportation and its energy intensity. Government actions have played a strategic role in developing domestic energy supplies and securing access to foreign resources. Environmental policies also influence transportation technology and the way it uses energy. Federal funding underwrites a substantial share of research, from Intelligent Transportation Systems to the PNGV.

In general, R&D progress is not sufficient to ensure the implementation of technologies in ways that address the concerns surrounding transportation energy consumption. The desired benefits include public goods: reduced dependence on oil, cleaner air, and lower greenhouse gas emissions. Markets typically ignore such benefits, so government intervention is necessary to ensure that technologies are deployed in ways that address the problems at hand.

Clearly, new policies will be needed for the transportation sector to meet any significant goals for reducing carbon dioxide emissions. Developing such policies can be a daunting challenge. In 1994, a Federal Advisory Committee was appointed to develop recommendations for reducing greenhouse gas emissions from light-duty vehicles. Despite an intensive effort, this group of representatives (from the auto, oil, and utility industries; environmental and other public interest groups; and federal, state and local governments) was unable to reach a consensus. However, the committee produced a list of 65 policy options and some analysis of their efficacy (*24*).

Past experience provides guidance on how to use technology to improve energy efficiency. Mechanisms differ greatly among modes. For light-duty vehicles, the Corporate Average Fuel Economy (CAFE) standards, along with the fuel shortages and price shocks of the energy crisis years, led to a substantial increase in fuel economy (*21*). Measurable efficiency has been gained through market-driven improvements in technical and operational efficiency for both air travel (*25*) and rail freight (*26*). Freight truck technology has improved, but data limitations make it difficult to observe clear trends in aggregate energy efficiency. As the 20th century draws to a close, none of the ongoing technology refinements in any major mode is improving fuel efficiency enough to offset the growth in travel (*27*). Improvements in vehicle efficiency—particularly for addressing petroleum dependence and greenhouse gas emissions—may need to be complemented with alternative fuels and, perhaps, modal shifts.

A range of policies exist for motivating and directing technology change related to transportation energy use. Options include efficiency and emissions standards, incentives for commercializing technology, cultivation of strategic niches, information and marketing programs, fuel and vehicle taxes, and R&D. Analyzing the effectiveness, costs, and interactions of these policies—with each other and with the many nonenergy issues that confront the sector—will be an important task for transportation energy researchers in the years ahead.

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