TRANSPORTATION FUELS AND VEHICLES

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Background

Underlying Forces

There are a number of underlying forces that create pressure to advance the state of vehicle technology and begin a shift to reformulated and alternative fuels. Among these are the following: first, mitigation of regional- and urban-scale air pollution; second, reduction of the impact of transportation on the global climate; and third, reduction of economic sensitivity to potential increases in the cost of petroleum. To the extent that long-term visions of transportation vehicles and fuels have been articulated recently, they have tended to emphasize a near-total shift to renewable energy sources (e.g., solar and wind power, biomass), environmentally benign energy storage and conversion (e.g., hydrogen, fuel cells), and highly energy-efficient vehicles. The appropriate path and pace of progress toward that vision appears to be more difficult to define, particularly against the backdrop of developed countries with established infrastructures and rapidly developing countries entering together a much more fluid global economy.

Fuels and Vehicles in Developed Countries

In developed countries, where much of the basic geography created by land development and transportation infrastructure investments is well-established, and where considerable sunk costs already reside in fuel processing and delivery systems, it may be expected that vehicle technology will play a major role in maintaining progress toward these three basic goals. For the next couple of decades, it is expected by most that petroleum-based fuels will continue to be the primary transportation fuels.

New vehicles operated on conventional fuels should continue to become cleaner from the standpoint of regional and local air pollution, as advances in engine and exhaust after-treatment technologies continue to penetrate the fleet, as maintenance practices improve, and as fuels are modified to reduce emissions of the relevant pollutants. On the other hand, these vehicles will likely be more expensive, and the ability to accommodate such cost increases could be declining in developed countries that must deal simultaneously with an aging population and more competitive global labor and capital markets. Maintenance expenditures should also increase, as combinations of periodic inspection, remote sensing, and on-board diagnostics are used as the basis for required repairs to emission control systems. Finally, fuel modification will likely lead to at least minor increases in the cost of gasoline and possibly Diesel fuel.

Because they do not implicitly reduce either fuel consumption or carbon intensity, these advances are not expected to make significant steps toward reducing global climate change and economic sensitivity to petroleum cost increases. Nonetheless, a shift toward significantly more fuel-efficient vehicle technologies in developed countries has the potential to provide large long-term improvements. Therefore, significant efforts are under way by industry and government in most of these countries to accelerate their development and deployment in vehicle prototypes. Although shifts to these technologies could improve environmental sustainability, there could be profound economic implications for developed nations. Changes to materials, manufacturing processes, and vehicle design imply not only new market structures and different labor skills, but also potentially major changes to the repair industry.

Numerous less carbon-intensive fuels are also under consideration, and some may offer reductions in carbon dioxide emissions. In the U.S., the Energy Policy Act (EPAct) of 1992 establishes fleet requirements and incentives designed to stimulate the market for vehicles designed to operate on many such fuels, and some States have established similar programs. However, some of these same fuels would require significant changes to the way fuel is produced, transported, stored, and delivered -- and the implications of such changes may be difficult to characterize prospectively. Magnitude and allocation of fuel-related infrastructure cost will, of course, be a chief concern. This concern will lead to questions regarding the "useful life" of new fuel-related infrastructure, and its ability to meet long-term objectives.

Fuels and Vehicles in the Developing World

In developing countries, where progress toward sprawling mega-cities appears to be the current trend, it seems doubtful that similarly rapid movement toward advanced vehicle technologies will be the norm. In such countries, low-cost vehicles such as scooters, motorized bicycles, and second-hand pickup trucks could be much more numerous for the next couple of decades than clean and efficient, technologically advanced automobiles. Similarly, highly trained repair technicians able to diagnose and repair emission-related failures will probably be scarce. Early pollution control initiatives could be more typified by strategies such as banning lead from gasoline and imposing parking restrictions.

On the other hand, developing countries may have opportunities that are scarcer in countries like the U.S. In addition to having at least the potential to factor concerns regarding sustainability into planning of urban forms, developing countries may also be less burdened by sunk costs related to fuel production and distribution, and therefore more able to consider alternatives to petroleum. Similarly, to the extent that vehicle design can result in cheaper vehicles, developing countries may be able to plan ahead for their distribution and use. Insofar as developing countries are able to take advantage of these potential opportunities as a means to minimize the percent of their GDP that is spent on transportation, and insofar as they are also less burdened by sunk costs associated

Future Fuel and Vehicle Scenarios

The wide range of potential future fuels and vehicle technologies can be explored through scenarios that describe plausible overall systems and key underlying assumptions.

Three such scenarios are summarized (in partial form) through sidebars in the remainder of this paper.

These are not presented as "likely" or "desirable" scenarios, but rather to provide alternative reference points around which to stimulate discussion.

with current vehicle technology, these countries may be able to offer manufacturers an attractive base for leaps straight to new industrial forms best suited to next-generation vehicle technologies.

In any event, the alternative transportation fuels and vehicle technologies broaden the portfolio of options available to address the distinct but related problems of global environmental quality, region/local air quality, and economic sensitivity to energy costs. The best long-term utilization of those tools, and the accompanying transitions, will require significant attention.

Challenges and Opportunities

Transportation Fuels

Because transportation is so heavily reliant on petroleum-based fuels, much of the near-term activity could well be directed at reducing regional and local air pollution problems by reformulating these fuels. On the same time scale, attempts to begin moving away from petroleum-based fuels will likely be initiated through programs directed at niches where alternatives may be acceptable.

Reformulating gasoline is estimated to significantly reduce volatile organic compounds (VOC), carbon monoxide (CO), and air toxics, and to provide meaningful reductions in oxides of nitrogen (NOx). However, there has been significant public resistance to this program in some areas of the country. Complaints surrounding RFG, most of which have been studied at least at some level, include human sensitivity to the oxygenate methyl tertiary butyl ether (MTBE), reduced fuel economy, damage to small gasoline engines, and price differentials between neighboring conventional and reformulated gasoline areas. Although the Clean Air Act establishes a minimum oxygen content for RFG, concerns regarding MTBE as a groundwater contaminant have led to calls for a ban on the use of this oxygenate and/or an elimination of the broader minimum oxygen content requirement. This concern about MTBE also raises questions about other fuels and fuel components -- for example, ethers that could be used in Diesel engines -- that might otherwise be attractive from an air quality perspective.

To date, Diesel fuel has received somewhat less attention on a national level in the U.S., although the CAA now limits sulfur content to 0.05% and requires a minimum cetane rating of 40. In California, attempts to further reduce emissions of fine particulate matter (PM) and NOx from Diesel engines by requiring a maximum aromatic content of 10% were initially met with extreme opposition upon implementation. Complaints by Diesel fuel users in California appeared to be centered mainly around two issues: damage to vehicular fuel pumps (specifically, butyl nitrate O-rings), and large initial price spikes in some areas. The O-ring problem was observed throughout the U.S., and is believed to have resulted from hydrotreating performed to reduce sulfur or aromatic content. In Sweden, reduced lubricity of diesel fuels meeting even more stringent specifications led to catastrophic failure of fuel pumps on some vehicles. However, lubricity additives were subsequently introduced to eliminate this problem.

Estimates of the impact of gasoline fuel reformulation on greenhouse gas emissions have tended to indicate relatively minor, and directionally uncertain impacts. Switching from gasoline to Diesel fuel has been estimated to offer potential net reductions of greenhouse gas emissions well in excess of 10%.

In any event, petroleum-based fuels are likely to continue to dominate in the near term. There is currently a range of expectation regarding the future of the global petroleum supply and marketplace. Some argue that continued improvements in techniques to locate and extract new supplies, coupled with continued weakness of monopolistic supplier organizations, will tend to keep prices for petroleum products low for the foreseeable future. Others counter that remaining supplies will become increasingly difficult to locate and/or extract, and/or that resurgent monopolistic behavior and increasing demand could increase prices and/or price instability.

Scenario One: Little Change

- feedstock supply, climate policies, and reformulation lead to only modest increases in the price of fuel
- no major technological breakthroughs
- cleaner conventional vehicles operated on cleaner conventional fuels

Many anticipate the eventual widespread use of renewable energy sources as the feedstock for transportation fuels. This could take the form of solar and wind energy used to generate electricity, either transmitted as such or used to make hydrogen. Biomass could also be the source for either ethanol or methanol. At this time, it does not appear likely that regional/local air quality concerns will require use of these fuels in the foreseeable future. Consequently, economics and perhaps greenhouse gas emissions will likely be much more important factors in considering these fuels.

Attempts have been made to estimate full fuel cycle (and, in some cases, full carbon cycle) impacts of many potential transportation fuels, feedstocks, and vehicular power plants. These have indicated potentially significant improvements from some fuels, and significant penalties from others. Although numerous options may have the potential to significantly reduce greenhouse gas emissions, these must also be understood in terms of their impacts on extraction, production, conversion, distribution, delivery, storage, and vehicles.

As these impacts are characterized, it may be possible to identify the most attractive long-term option(s). However, it will still be necessary to make the transition, or transitions, and these options may be distant enough that intermediate-term diversification of transportation fuels becomes important as a means to mitigate the effect of any increases in petroleum costs. Niche applications, where the economics justify infrastructure investment for fuels such as natural gas, could become more commonplace. However, unless infrastructure costs are sufficiently small relative to supply projections, hopes for a wholesale move to many such fuels could be heavily dampened.

Technology for Automobiles and Light-Duty Trucks

Although emissions from in-use vehicles continue to be difficult to control, emission control systems for automobiles and light-duty trucks have advanced significantly, to the point where proper maintenance and/or hardening of emission controls can minimize emissions of regional/urban air pollutants. More stringent emission standards and phase-in timetables have been established for new vehicles, and it appears likely that, except for currently-mandated ZEV standards, these will be met without fundamental changes to vehicle technology. Incrementally advanced technologies, perhaps including redesigned catalysts and fuel systems, will likely be employed to meet these standards, and potentially to comply with changes to the test procedures used to determine compliance. To facilitate detection and diagnosis of emission-related hardware problems, vehicles carry on-board diagnostic (OBD) systems that notify the driver when maintenance is needed, and can be used by the mechanic to identify probable causes of high emissions. However, enough vehicles without OBD systems are still in operation that near-term reductions in emissions of ozone precursors may depend highly on the success of vehicle inspection and maintenance (I/M) programs, which have encountered significant difficulties.

As long-term measures, more demonstrably advanced and/or alternative technologies are being developed to meet the ZEV mandate associated with the California and Northeastern U.S. LEV programs, and in response to the push by the U.S. and other manufacturing nations to develop more fuel-efficient vehicles. Pure electric vehicles (EVs), as in the past, appear to await only suitable energy storage technology (e.g., batteries and ultracapacitors). Lighter materials (e.g., aluminum) and frame construction may provide weight reductions to offset some of the battery weight, and drive train technologies, such as advanced motors and controllers, have improved efficiency to minimize the battery weight needed for a given level of performance and range. However, at the same level of acceleration, range, and cost, the remaining gap has yet to be bridged.

Considerable research and test and evaluation problems remain to refine energy storage and management options. Recent modifications to California's ZEV mandate will allow a greater role for hybrid electric vehicles (HEVs), which would draw not only on weight-reduction, electric drive train efficiency, and energy storage technologies, but also on advances in energy conversion technology (e.g., direct-injection internal combustion engines). While this increased flexibility opens the door for technologies that are projected by many to be better able to meet customer demands, these systems could be substantially more complex and costly, and have the potential to be similarly sensitive to in-use effects.

Most of these technologies have also received significant attention in light of global climate change and energy consumption. Currently, the

Scenario Two: Hybrids and Reformulated Diesel

- feedstock supply, climate policies, and reformulation lead to major increases in the price of fuel (e.g., 50-100%)
- major gains in control of Diesel engine NO_X and PM emissions
- widespread use of hybrid electric Diesel power trains in highway vehicles

Clinton Administration is joined with DaimlerChrysler, Ford, and General Motors in a Partnership for Next Generation Vehicles (PNGV). The goals of this program are: (i) significant improvements in national manufacturing competitiveness, (ii) near-term implementation of commercially viable innovations from ongoing research on conventional vehicles, and (iii) the development of a vehicle to achieve up to 3 times the fuel efficiency of today's comparable vehicle. This program, and similar European and Asian government/industry initiatives, establish a process whereby significant resources are being devoted to the development of a wide range of technologies such as those mentioned above. However, resource constraints and differences in philosophy regarding the appropriate role of government could limit future activities, at least in the U.S.

Technology for Heavy-Duty Vehicles (On- and Off-Road)

Heavy-duty (HD) highway vehicles (trucks and buses), powered predominately by Diesel engines, have seen various technological changes associated at least at some level with emissions and fuel economy. For example, electronic controls have been added to attain better control over the combustion process. After-coolers have been added to reduce combustion chamber temperatures, and therefore NOx emissions. To reduce particulate matter (PM) emissions, manufacturers have increased fuel injection pressure, improved turbocharging, improved combustion chamber swirl, and have introduced electronic injection rate shaping. Fairings have been added to many trucks to reduce drag and fuel consumption.

Scenario Three: Fuel Cells and Methanol

- feedstock supply, climate policies, and reformulation lead to major increases in the price of fuel (e.g., 100-200%)
- major breakthroughs in cost and performance of PEM fuel cells
- no major breakthroughs in hydrogen production and distribution
- widespread use of PEM fuel cells with methanol reformers

From an emissions standpoint, conventional wisdom has indicated much less sensitivity (than light-duty vehicles) to in-use effects -- a view supported by the historical lack of after-treatment devices. However, emissions of fine particulate matter (PM) -- for which EPA recently promulgated stricter air quality standards -- may be more heavily influenced by problems like tampering. Concern about in-use effects could be heightened in the future, as more heavy-duty vehicles are fitted with emission control devices (e.g., oxidation catalysts, lean mixture NOx catalysts, exhaust gas recirculation (EGR) systems). However, emissions testing for HD highway vehicles to support either recall or periodic inspection programs are complicated by the fact that HD engines are currently tested out-of-chassis. Moreover, periodic inspections of line-haul trucks could be complicated by the geographic aspects of their ownership and use.

EPA standards promulgated in 1997 are expected to further reduce HD engine NOx emissions beginning in 2004. Although this creates an impetus for further advances in HD engine technology, it is currently expected that manufacturers will be able to comply with these standards even without further changes in Diesel fuel quality. However, changes in Diesel fuel might be important as a means to enable even further reductions of NOx and/or fine PM.

Perhaps because businesses involved in freight hauling are fairly sensitive to fuel costs even at today's prices, there has been less impetus to apply a regulatory approach such as CAFE to the HD vehicle market. Nonetheless, some attempts have been made in the U.S. to stimulate the development of fuel-efficient technologies suited to the medium- and heavy-duty markets. A notable example is the Advanced Vehicle Technologies Program, which is managed by the Department of Transportation in partnership with other federal agencies (e.g., Department of Defense, Department of Energy), private companies, research institutions, and state and local governments.

Transitional Issues

In light of the underlying forces and technological challenges and opportunities discussed above, many plausible configurations of the future vehicle/fuel system can be constructed, and three scenarios are presented here for consideration. If the long-term goals of stabilizing the global climate, reducing regional and urban pollution, and reducing economic sensitivity to energy costs are met through technologically discontinuous vehicles, and renewable low- or non-carbon fuels, significant transitions will have to occur. Wherever there are established infrastructures, questions regarding responsibility for sunk costs will arise. Access to capital required to go through transitions will be important, as will training for workers in the affected industries.

These are issues that will be particularly important in developed countries, where significant sunk costs tend to reside. In developing nations, there could conceivably be an opportunity to make significant gains in a global transition to alternative fuels and advanced technology vehicles. If and when petroleum costs eventually do rise, these countries may be in a better position to move the use-oriented infrastructures (e.g., fuel, service) more directly into compatibility with alternative fuels and next-generation vehicle technologies. To the extent that these countries are able to develop in a way that minimizes the economic burden of mobility, they may be better able to grow economically while continuing to provide attractive wage scales. These countries might therefore be able to move more directly toward more sustainable long-term solutions.