Appendix E

Forecasting Vehicle and Fuel Technologies to 2020

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As transit use and ridesharing continue their steady decline, motor vehicles are becoming more dominant than ever. They are also becoming larger, increasingly powerful, and more laden with accessories and conveniences. One adverse consequence of motor vehicle proliferation—air pollution—is being mitigated by a continuing stream of technological enhancements, while concern for other consequences, especially petroleum consumption and greenhouse gas (GHG) emissions, languishes. What will be the response to continuing calls for still cleaner air, and episodic (and perhaps intensified) concern over growing petroleum imports and global climate change? Extraordinary consumer wealth in the United States, combined with a veritable revolution in automotive technology, creates the potential for a large array of responses. As the magnitude and potential effectiveness of these technologies become appreciated more widely, the well-documented hesitancy of U.S. political leaders to reduce the harmful consequences of vehicles by restricting their use is likely to be still further weakened.

In this paper, the author focuses on the role of air quality and energy in the design and commercialization of vehicles and fuels. Other adverse consequences—such as noise, land consumption, and aesthetics—are unlikely to play as central a role in the evolution of vehicles.

Today, virtually all motor vehicles are powered by internal combustion engines (ICEs) and petroleum fuels: larger vehicles generally burn diesel fuel in compression ignition engines, whereas lighter vehicles tend to burn gasoline in spark ignition engines. But to what extent and in what way will

energy and environmental concerns alter these patterns? Because more stringent emission standards are in place and good progress is being made in achieving them, one outcome is highly certain: emissions of conventional pollutants will continue to decline. What is less certain is whether regulatory and legislative initiatives will force a reduction in fuel use or a shift away from petroleum fuels and ICEs. This paper focuses on how, when, and where these changes may occur, and the implications of those changes for the transportation sector.

ICE VEHICLES

Even if ICE technology is retained, extensive changes are likely, though the implications of these changes for users, the environment, and society would be modest. For instance, continued modifications of gasoline and diesel fuel composition are likely, as refiners and regulators search for the optimal trade-off between emissions and cost. Refiners already have been modifying fuels for years as a means of reducing lead levels, increasing octane, adapting temporally and geographically to different climates, and responding to the needs of electronic fuel injection. Since 1990 these efforts have been accelerated as a result of regulatory requirements for reduced emissions from gasoline and diesel fuel. Future petroleum fuels will have varying amounts of oxygenated compounds and other components, with major implications for refiner investment, but little effect on vehicle users and suppliers.

Greater changes are likely with the engines and vehicles. For instance, huge investments are being made in electronics for the following purposes: safer operation, lower emissions, greater energy efficiency, route navigation, emergency notification, and enhanced accessories. Likewise, the use of lightweight materials, especially lighter steels and aluminum, continues to grow. More composite materials are also being used, but high costs still limit their use (NRC 1996).

The effect of these many innovations on fuel consumption is difficult to predict. Certainly, the energy efficiency of vehicles will continue to improve. Whether these efficiency gains will be translated into fuel economy gains is uncertain. For instance, from 1986 to 1996 average vehicle weight increased 8 percent (from 3041 to 3285 lb) and average acceleration improved 23 percent (from 13.2 sec for 0 to 60 mph to 10.7 sec), but fuel consumption per mile barely changed (Heavenrich and Hellman 1996). The fuel efficiency gains were offset by growing sales of larger vehicles (more than 44 percent of new light vehicles are vans, pickups, and sport utility trucks), increasing power, and more fuel-consuming features such as four-wheel drive (NRC 1996). Sales of light trucks, which exceed 40 percent of the light-duty market, are forecasted to continue increasing, possibly reaching 50 percent in the early years of the next century. The result is that, despite the veritable revolution in electronics and materials, the overall fuel economy of light-duty vehicles is unlikely to improve much, if at all, in the near future. With the slowly expanding use of vehicles, total fuel consumption will also probably expand.

The use of intelligent transportation system (ITS) technologies is not expected to alter this trend much. Improved traffic management and greater availability of traffic and route information will reduce delay due to incidents, but there has been no evidence to suggest that total vehicle travel, energy use, or emissions would be affected substantially by deploying these technologies. Indeed, greater ease of travel may result in more travel. This would almost definitely be the case with automated controls, and possibly with traffic management and information technologies as well. The only prospect for substantial reductions in travel, energy use, or emissions is the application of ITS technologies to paratransit and ridesharing, but because current trends are in the opposite direction—away from transit—most analysts are skeptical of the potential for increased transit and paratransit use, even with smart paratransit and ridesharing. The institutional barriers arrayed against paratransit and strong security concerns of individuals are acting to undermine efforts to expand this intermediate mode.

If fuel consumption is to be reduced, it will require some mix of technology changes, alterations in consumer preferences, and government action to alter market signals and corporate behavior. In the United States, government has been averse to discouraging fuel and vehicle use by consumers, and since the late 1980s has become more reluctant to impose direct fuel-economy restrictions on vehicle suppliers. With low oil prices, fading public concern for energy security, and apathy toward climate change, consumers have lost interest in fuel economy. That could change, with dramatic effects on fuel consumption. For instance, if consumers were to roll back their expectations for power and interior space to levels witnessed in the early 1980s—when light trucks accounted for only about 30 percent of light-duty vehicle sales and acceleration times for 0 to 60 mph were 40 percent less (Heavenrich and Hellman 1996)—then considerably improved

fuel economy and modest overall reductions in light-duty vehicle fuel use would be possible. But as automaker fears of more stringent fuel economy standards recede, and as demand continues to grow for the least-efficient vehicles (light trucks), automaker investments are directed away from those technologies and products that could lower fuel consumption.

The trend toward increased fuel consumption by heavy trucks is even stronger. From 1970 to 1993, fuel economy for medium and heavy-duty trucks improved only 15 percent, from 4.8 to 5.5 mpg (Greene 1996). These small improvements were swamped by huge increases in truck travel, as well as other factors such as greater traffic congestion. As a result, energy use by trucks has grown rapidly and is not expected to slow. For instance, from 1970 to 2010, energy use by light-duty vehicles is expected to increase 44 percent (11 percent from 1990 to 2010), compared with 200 percent for heavy-duty vehicles (trucks over 10,000 lb gross vehicle weight plus buses) (Mintz and Vyas 1993).

With dim prospects for expanded transit use and ridesharing, and with increasing car and truck use, all signs point to heightened dependence on private motor vehicles. As indicated in the following, with trends toward larger and more powerful vehicles, one cannot escape the conclusion that technology strategies for reducing fuel use and GHG will become even more central.

The transition to new fuels and vehicle technologies is less predictable than it might be for many other new technologies. That is because motor vehicles have a large effect, both real and perceived, on a variety of energy and environmental concerns. But because these concerns are mostly outside the marketplace, they are manifested principally through government action. Thus, vehicle design and fuels marketing are subject not only to the normal uncertainties of innovation and market demand, but also to the vagaries of government action. Understanding the relative influence and salience of the various energy and environmental concerns provides considerable insight into the evolution of propulsion technologies and fuels.

UNCERTAIN AIR QUALITY INFLUENCES

Government has been more aggressive and effective in curtailing air pollution than any other energy or environmental concern. This focused commitment is likely to waver, since most metropolitan areas—with the notable exception of most of California and a few other major regions—are expected to attain federal ambient air quality standards within the next decade. Because clean air has such strong public support, and air quality laws and rules have such strong enforcement provisions built into them, public interest groups have used air quality concerns as a surrogate for a raft of other environmental, energy, and social concerns, including "livable cities," urban sprawl, and decay of urban downtowns. But will curtailed federal commitment to clean air slow efforts to create more benign motor vehicles? Probably not, for three reasons.

First, continued growth in population and vehicle usage in many regions of the country will forestall federal efforts to absolve itself of responsibility. As air pollution concentrations continue to drop, local regulators will probably dispense with the less effective strategies—especially those aimed at reducing travel—in favor of more effective technology-based initiatives.

Second, California, where air pollution is a permanent problem, has always been the international leader in reducing vehicle pollution; recent examples of California being imitated include reformulated gasoline and tightened "low-emission vehicle" standards. Even where the federal government has not consciously imitated California, it has adopted initiatives intended to provide a relief valve, as with the Partnership for a New Generation of Vehicles, or indirect support, as with the U.S. Advanced Battery Consortium (US ABC). The US ABC, funded half by the U.S. Department of Energy (DOE) and half by industry, has provided more than $200 million in the past few years to develop advanced batteries for use in the zero emission (battery-powered electric) vehicles (ZEVs) mandated by California. The PNGV, a loosely organized program of the Big Three automakers and the Clinton Administration, was in part a desire to develop an environmentally attractive alternative to battery electric cars (i.e., California's mandated ZEVs) that has performance attributes more comparable to those of conventional cars.

Because of the continuing air pollution problems in California, the state will probably continue to pursue clean air aggressively through zero emission technology. On March 28, 1997, it softened the ZEV mandate, adopted earlier in 1990, by eliminating the requirement that 2 percent of vehicle sales be zero emitting in 1998 and 5 percent in 2001, instead requiring that the seven largest marketers of cars in California implement what is essentially a very large demonstration of advanced electric vehicle (EV) technology. The requirement for 10 percent ZEVs in 2003 was retained. Whether the 10 percent requirement continues to be retained depends in large part

on automaker success in building and marketing EVs during the rest of the decade.[1]

Third, air pollution levels are increasing and becoming of greater concern in many cities of Europe and Asia. As a result, other nations and European and Japanese automotive companies are stepping up their investments in fuel cells, hybrid electric drivelines, and other very clean (and efficient) propulsion technology. The unveiling by Mercedes-Benz of a fuel cell car on May 14, 1996, and its announcement that it may be ready to sell fuel cell cars by 2010, indicates global demand for environmentally benign vehicles and the intention of international companies to supply that technology.

In summary, because of its continuing air pollution problems, the large size of its market, and recognized leadership role, California will most likely be effective in continuing to stimulate investments in EV (and other electric-drive) technology. Growing concern for air pollution elsewhere in the world will probably strengthen support for these advanced technologies. However, momentum will likely slow, in the United States at least, if air pollution continues to be the sole policy justification.

LANGUISHING ENERGY AND ENVIRONMENTAL CONCERNS

Public demand for reductions in imported oil, GHG emissions, and other environmental impacts such as noise have been muted. Energy security arouses occasional interest, but government initiatives since the early 1980s have become weaker. Perhaps the only notable action has been to increase corporate average fuel economy (CAFE) standards for light trucks by a small 0.1 mpg per year, but in 1996 Congress called for an end to even these small increases.

Government intervention on behalf of other concerns has been even less visible. Although the Clinton Administration signed an international agreement to reduce GHG emissions to 1990 levels and prepared a "Climate Action Plan," the only substantive GHG reduction initiative aimed at the transport sector launched in recent years has been the PNGV. Meanwhile, a high-level advisory board to the President (known as "Car Talk"), estab-

[1] New York and Massachusetts, the only other states with mandates for ZEV sales requirements, did not drop their 2 percent ZEV sales requirement and have thus far survived court challenges from the automobile manufacturers.

lished to create a consensual plan of action, disbanded in fall 1995 for lack of consensus.

Whether these non-air quality goals will gain strength is unknown. Public concern for these other goals appears to be far off. Indeed, in recent years, vehicle travel and fuel consumption have increased substantially—personal vehicle travel, mostly because of less ridesharing, greater participation by women in the market economy, and increasing suburbanization; and fuel consumption, because of more travel, more trucks, flat fuel economy, and more air travel.

Eventually, petroleum import concerns and global climate change will become more urgent—the result of increasing oil imports by the United States, rapidly expanding oil consumption in developing countries leading to probable increases in the volatility and level of oil prices, and increasing concentrations of GHGs. But calls for reduced petroleum use, GHGs, and pollution run up against the strong desire for travel. The two fundamental strategies to reduce energy use and pollution are (*a*) reduced travel (by encouraging transit use, less driving, and other shifts away from car use), and (*b*) the introduction of more benign vehicles and fuels. Below is a discussion of vehicles and fuels, a more likely and potentially far more effective strategy.

NATURAL GAS AND ALCOHOL FUELS

Enthusiasm for alternative transportation fuels has waxed and waned since the turn of the century, in the United States and elsewhere (Sperling 1988). The national Energy Policy Act of 1992 set a goal of 10 percent market penetration by alternative transportation fuels by 2000 and 30 percent by 2010; to initiate the transition, it adopted ambitious requirements for alternative-fuel vehicle purchases by government and private fleets, amounting to millions of vehicles by 2000.

Despite the existence of strong economic and environmental constituencies for alternative fuels, and strong rhetoric on their behalf by the federal government and some states, their penetration has been slow. As of 1995, less than 2 percent of vehicle fuel consumption might be characterized as alternative fuels. Less than 1 percent is ethanol made from corn, fewer than 0.2 percent of vehicles (250,000) are powered by propane, about 50,000 vehicles are powered by natural gas (virtually all are bi-fuel with gasoline), about 15,000 are methanol- and ethanol-compatible (but rarely operate on the alternative fuel), and a few thousand are powered by electricity (ORNL 1995). The corn-ethanol fuel is twice as expensive as gasoline and exists

only because of a generous federal tax subsidy. Propane vehicles have existed for decades, but propane is derived from petroleum and natural gas and is in limited supply. Methanol is no longer considered a viable alternative for ICE vehicles, because other options are economically and environmentally superior, though one day it may gain acceptance as a fuel for fuel cell vehicles.

Natural gas has some promise. It is less expensive than gasoline, accounts for about 20 percent fewer GHGs (on a fuel cycle basis) when used in a vehicle dedicated (and optimized) to that fuel (Deluchi 1991), and emits considerably fewer emissions of conventional pollutants. The potential environmental benefits are considerably smaller than those from electric-drive options, and the refueling infrastructure is expensive (at least $300,000 additional cost per fuel station). The major automakers are offering light-duty natural gas vehicles (NGVs) for sale, but future sales are uncertain, especially in the light of a 1995 decision by the national Natural Gas Vehicle Coalition, the premier advocacy group for NGVs, to focus its support on heavy-duty applications, where the potential air quality benefits are much larger (both particulates and nitrogen oxides can be sharply reduced) and the fuel consumption per vehicle is much higher (leading to greater economies in refueling infrastructure).

The most effective alternative fuel for reducing GHG emissions is alcohol made from cellulosic biomass. The preferred biomass feedstock for transport fuels currently is corn (and sugar cane in Brazil). This preference for corn is due to large federal and state subsidies, and the ease of producing the ethanol fuel. But the cost is twice that of gasoline, and the air pollutant and greenhouse benefits are negligible. A more attractive biomass fuel option, from an energy and environmental perspective, is to convert more abundant cellulosic material—such as trees, grasses, and solid waste—into ethanol or methanol. But the cellulose conversion processes are more complex and not commercially proven, the capital costs greater, and lead times longer because of the need to create energy plantations around the site of the process plant (because feedstock collection and transport are expensive). Thus, even though production costs are expected eventually to be much less than corn-ethanol costs, and even though cellulosic biomass fuels are eligible for the substantial subsidies now received by corn-ethanol, there has been no significant investment in the United States in cellulosic biomass fuels for use in transportation. The National Renewable Energy Laboratory continues to receive about $30 million per year for research and development (R&D) on improved cellulosic conversion processes.

The 10 and 30 percent alternative-fuel goals of the Energy Policy Act of 1992 are not likely to be attained. The centerpiece of the act's strategy for reaching those goals is a set of rules requiring fleets to switch to alternative fuels. But in the 4 years since the act was passed, only the rules pertaining to federal fleets had been adopted, and funding for that program had been mostly eliminated. Rules for state government and fuel provider fleets are pending, and rules pertaining to the vast majority of fleet vehicles, those belonging to nonenergy businesses, are not under consideration at this time. Where fleet rules *are* adopted, the preferred choices are fuel-flexible alcohol vehicles (which are almost always fueled with gasoline) and NGVs, but congressional enthusiasm for fleet rules has mostly dissipated.

ELECTRIC-DRIVE TECHNOLOGY

EVs encompass a much wider range of technologies than just battery-powered vehicles, and the potential benefits are far broader than air quality. One can hybridize a small ICE (e.g., gas turbine, gasoline, or diesel engine) with an electric motor, by combining it with a small energy storage device such as a flywheel, ultracapacitor, or small battery. Alternatively, a fuel cell could be substituted for the ICE. The advantages of electric-drive vehicles are many, but they vary depending on the source of energy and the combination of power system technologies. It is this rich profusion of technological opportunities that makes electric-drive vehicles so attractive. In addition to energy and environmental benefits, various technological combinations provide consumers with the benefits of less noise, lower energy cost, greater reliability, longer vehicle life, less maintenance, and the ability to recharge at home (Sperling 1995).

Although these various attractions exist, they have not been sufficient to inspire automotive companies to invest seriously in electric-drive vehicle technology. The start-up costs and risks are too large. California's ZEV mandate, premised solely on air quality benefits, has been the principal motivation. But electric-drive vehicles provide other large nonmarket benefits: reduced use of petroleum and GHGs, in virtually all combinations and settings. These reductions, approaching 100 percent for some combinations and fuels, are the result of greater energy efficiencies with electric drive and the greater potential for fuel substitution. The point is, electric-drive vehicles provide the potential for huge improvements along a number of environmental dimensions, not just air quality. If the momentum is to be sustained by government action outside California, it will have to be for reasons other than just air quality.

But all environmental effects of electric-drive technology are not uniformly positive across technologies and space, which creates even more uncertainty over government support for electrics. For instance, the emissions benefits of battery EVs are much greater in regions with very clean electricity generation, such as California, than in those that burn mostly coal. The use of batteries introduces large amounts of new materials into the environment, some of which may be toxic. This problem, seepage of battery materials into the environment, may be more perceptual than real, however. The more toxic materials, such as cadmium, are likely to be restricted, and others are likely to be almost completely recycled.

Very little of the lead from the more than 70 million lead-acid batteries sold each year for ICE vehicles ever causes a health risk because virtually all the lead is recycled, and lead processing plants are tightly controlled. (Lead levels in blood dropped 86 percent between 1960 and 1990, from 20 μg/dL to 2.8, despite increased sales of lead-acid batteries and a 17 percent increase in total lead usage per capita over that period. The drop in lead levels was due to reduced use of lead in gasoline. Industrial production and the use of lead in batteries are considered a minor health threat.) In any case, lead-acid batteries are unlikely to gain much usage in EVs, and other battery materials are likely to be less toxic. Moreover, the large size and weight of batteries and the high value of the materials almost ensure close to 100 percent recycling of traction batteries. The reality is that all new technologies and fuels will have some adverse environmental consequence; the regulatory process will guide investment choices toward those choices that are more benign.

The roadblocks to electric-drive vehicles are many. These roadblocks have much to do with uncertainty over cost and performance, as well as public commitment to energy and environmental goals. If costs and performance do not improve sufficiently and government fails to reward the energy and environmental advantages of more benign vehicles and fuels, the market for electric-drive vehicles will be limited to niches. Technological progress and government intervention are a function of many factors, most of them linked to corporate and consumer support.

How the interplay of interest groups will play out is difficult to determine. Certainly, the powerful oil industry, whose economic interests are threatened, will oppose (and have opposed) government support for electric-drive vehicles, but other industrial interests will provide support, including the electricity and perhaps natural gas industries, and the various high-technology industries that see an opportunity to expand their sales to the automotive industry.

Many believe that EVs are doomed to failure, at least in the near future, because of automaker skepticism. Automobile industry response is complex and difficult to predict. But unlike oil companies, which see no self-interest in battery electric vehicles, and relatively little in other electric-drive options, automakers are less unified. Automakers oppose mandates as a matter of principle, but they have become a highly competitive global industry in the past few decades, and many companies are eager to gain an edge over their competitors. The likelihood of a large market for electric-drive vehicles outside the United States provides extra motivation to automakers to sustain investments in electric technology. The automaker response to the California regulators and California market, as well as the potentially larger international market, cannot be predicted. It appears likely that battery EVs will continue to be pursued; the question is how broadly and successfully; likewise, with hybrid and fuel cell technology.

SMALL VEHICLES

One ancillary outcome of government support for EVs could be the creation of a market in the United States for very small cars and trucks. Such vehicles are common elsewhere: about a fourth of vehicles sold in Japan are minivehicles (defined as having engines of less than 660cc, about half the size of the smallest engines sold in the United States). Automakers are responding to the high cost and large size of batteries by building hybrid and fuel cell vehicles, but another response is to build smaller vehicles. Very small vehicles of the type sold in Japan and elsewhere would require only very small battery packs, which would not have the cost or weight burdens of larger cars and trucks.

Already entrepreneurial companies are exploring the market for a variety of very small vehicles, from electric-assist bicycles for difficult terrain and less fit individuals; to "glorified" golf carts sold by some companies in retirement and resort communities, national parks, and large industrial, military, and educational campuses; to somewhat larger vehicles for nonfreeway use. These vehicles have a variety of attractions: they are generally easier to operate and park, cost less, are rechargeable at home, require less space, consume less energy, and produce less pollution. Small gasoline-powered vehicles could be designed to give some of the same benefits as small EVs, but the much more positive image of electrics, government incentives for their purchase and use, and the relatively small cost handicap of small battery packs mean that most small vehicles are likely to be battery-powered electrics.

IMPLICATIONS FOR THE TRANSPORTATION COMMUNITY

The transportation community confronts four sets of responsibilities in responding to the prospects for more benign fuels and vehicles: R&D, infrastructure design and investments, regulatory policy, and financing.

Transportation agencies have sponsored little research on advanced vehicle propulsion technology and nonpetroleum fuels. The most notable program in this regard was the Federal Transit Adminstration's funding of a fuel cell bus program. A review of the PNGV program by a National Research Council committee criticized the U.S. Department of Transportation (DOT) for allocating no funds to PNGV technologies (NRC 1996). Virtually all federal vehicle propulsion R&D is funded by DOE. DOT has practically no expertise in fuels and electric-drive vehicles. Its primary interest has been in helping transit operators accommodate alternative fuels and in worrying about how to collect fuel taxes in a post-gasoline era. This attitude of benign neglect could continue, but at considerable risk.

The risks are the following. First, other federal and state programs will direct vehicle technology and fuels in directions that are not compatible with road infrastructure programs and deployment plans for intelligent technologies. For instance, electronics capabilities of EVs are very different from those of gasoline vehicles. Likewise, determinations of air quality conformity could be sensitive to vehicle propulsion and fuel strategies. And emergency services may be different for EVs.

Second, opportunities to diversify vehicle technology are stunted by rules and regulations aimed at standardizing all streets and highways for use by all vehicles, and safety standards that ignore the entire road system in favor of highly specific and uniform vehicle standards.

Third, the federal system for regulating fuels and vehicles is rigid and is tied to existing technology. It is not well suited to the different emissions, energy, and safety attributes of new fuels and vehicles; it hinders innovation, does not allow trade-off between different attributes, and is insensitive to regional differences. While the Environmental Protection Agency plays a lead role in most of these issues, DOT and the Federal Highway Administration (FHWA) have an abiding interest.

Fourth, the transition away from gasoline and diesel fuel can be seen as a threat to the financial integrity of the transportation financing system, or as an opportunity. FHWA could passively await steadily diminishing gas tax revenues or could start devising new methods that are more rational and equitable (Reno and Stowers 1995).

CONCLUSIONS

In summary, abetting the public pressure to create more benign vehicles and fuels is a far-reaching revolution in various vehicle-related technologies. Recent and continuing advances in storing electricity and gases, electrochemically converting chemical fuels to electricity, biologically converting cellulose to chemical fuels, designing less expensive and bulky electronics, storing and manipulating information, and manufacturing inexpensive lightweight materials are bringing more benign vehicles closer to commercial reality. What is unknown, and unknowable, is which of these technological improvements will be commercialized first and in what combinations. The implications for the transportation sector are not revolutionary, but they could be significant and far-reaching.

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Abbreviations

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ORNL Oak Ridge National Laboratory

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