Appendix E

Forecasting Vehicle and Fuel Technologies to 2020

Daniel Sperling
Institute of Transportation Studies
University of California, Davis

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
UNCERTAIN AIR QUALITY INFLUENCES

The evolution of production technologies and their effects on air quality and environmental concerns provides considerable insight into the interaction between industrial facilities and their impact on the environment. Understanding the relative impact and relative importance of these two factors is critical to the development of effective policies and strategies. This interaction is complicated by the fact that air pollution and environmental concerns are often interrelated. Thus, the development of policies that address both issues is necessary. The identification of interrelated factors and their impact on the environment is critical to the development of effective policies.

The key to addressing air quality concerns is to focus on reducing the sources of pollution. This can be achieved through the implementation of emission control technologies and the development of new technologies that can reduce emissions. The development of new technologies is critical to the reduction of pollution, as traditional technologies often have significant limitations. The development of new technologies requires significant investment and research, but the benefits of reducing pollution are significant.

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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 abdicate 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.
NATURAL GAS AND ALCOHOL FUELS

The introduction of more efficient vehicles and fuels is an opportunity to improve the national energy security, reduce the nation's dependence on foreign oil, and address the environmental impacts of transportation. The use of alternative fuels, such as natural gas and alcohol, can help achieve these goals. Natural gas vehicles are available and are becoming more common, offering a reduced greenhouse gas footprint compared to traditional gasoline-powered vehicles.

By 2020, the national energy policy of 1992 (enacted by the Energy Independence and Security Act of 2005) seeks to reduce oil dependency and increase energy efficiency. The goal is to reduce the oil dependence on transportation by 20% by 2020. The introduction of more efficient vehicles and fuels is an important step towards achieving this goal.
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.
In this note of these issues, DOT the Federal Highway Administration has seen the need for better-the Environmental Protection, the agency that focuses on pollution and its effects, is looking into how to address the problem of pollution from vehicles. The current system for regulating air and water pollution is based on scientific principles and public health considerations. The government is also looking into the use of alternative technologies, including electric vehicles, to reduce emissions. Moreover, the government is exploring the use of electric vehicles for various services, such as public transportation and delivery services. However, the cost of electric vehicles is still high, which is a significant barrier to their widespread adoption. The government is working on reducing the cost of electric vehicles and is encouraging the development of new technologies to make them more affordable. The transportation sector is considering the use of electric vehicles for various services, including public transportation, delivery services, and even personal use. The government is also looking into the use of electric vehicles for disaster response and emergency services, as they can be more reliable and efficient than traditional vehicles in these situations. The government is working on developing a comprehensive plan for the transition to electric vehicles, which will include regulations, incentives, and infrastructure development. The transition to electric vehicles is not only about reducing pollution but also about creating new jobs and improving public health. The government is committed to making this transition happen as quickly as possible, and it is working with the private sector and the public to achieve this goal.
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.

REFERENCES

Abbreviations

NRC National Research Council
ORNL Oak Ridge National Laboratory


