Chapter 2

Introduction and Context

This report evaluates the proposition that it is feasible to make rapid changes in automotive technology--away from current steel bodies and conventional drivetrains with gasoline engines, toward aluminum or composite bodies[1] and alternative powertrains, for example. In particular, the report concentrates on evaluating the technical promise, state of development, and potential costs of a range of automotive technologies--from advanced materials to hybrid-electric drivetrains to fuel cells--that would reduce vehicle fuel consumption and, in some cases, yield strong improvements in emission performance. The report also examines U.S. and foreign research and development (R&D) efforts directed toward preparing these technologies for the marketplace.

FORCES FOR INNOVATION

Promoting rapid technological change in the automobile industry is not a novel idea. Environmental groups pursuing twin goals of energy conservation and reduced vehicular emissions have promoted technological innovation for decades, for example, and the federal government has encouraged innovation in the industry in pursuit of similar goals.[2] Currently, there are some additional pressures for innovation. In particular, California's Low Emission Vehicle (LEV) Program requires automakers to begin producing vehicles with substantially reduced emissions; in particular, the LEV program requires 2 percent of the fleets of major automakers to be zero emission vehicles (ZEVs) by 1998, increasing to 10 percent by 2003. Some northeastern states also have adopted these regulations. In this time frame, only electric vehicles will be likely to satisfy the ZEV requirement.[3] Industry responses to the ZEV requirements include both an active campaign to discourage enforcement in California and several northeastern states that have followed California's example and a substantial cooperative research effort to help produce a commercially successful electric vehicle, including formation of an Advanced Battery Consortium with battery manufacturers, electric utilities, and the Electric Power Research Institute. Meanwhile, various development and commercialization efforts have begun independent of the established industry. These include market introduction of several vehicles (most based on conversion of conventional models, which involves removal of engines and transmissions and replacement with EV drivetrain components) and organizing of groups such as CALSTART, which is designed to promote a cooperative effort among California companies and others to design and manufacture electric vehicles and vehicle systems in California.

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1 Or bodies of new high-strength steels, with extensive structural redesign aided by supercomputers.

2 Both the 1975 Corporate Average Fuel Economy Stndards and the Clean Air Act's emission standards were deliberately set high enough to be technology forcing.

3 Proposed modifications to the program ask that full-fuel-cycle emissions be considered. This would allow the ZEV requirement to be fulfilled by vehicles whose total fuel-cycle emissions (including emissions from production and distribution of the fuel) were equal to or less than the fuel-cycle emissions of electric cars-which would include the emissions of the powerplant that generates the recharge electricity.

Another force for innovation is the newly created Partnership for a New Generation of Vehicles (PNGV), an R&D program jointly sponsored by the federal government and the three domestic auto manufacturers. One of the program's three goals is the development of a manufacturable prototype vehicle within 10 years that achieves as much as a threefold increase in fuel efficiency while maintaining the affordability, safety standards, performance, and comfort available in today's cars. Although the Partnership has not yet defined any technology choices, it is clear that there will be a strong research emphasis on new materials and alternative powertrains, especially on hybrid electric configurations.[4]

Whether or not these forces for innovation will actually provide the impetus for an acceleration in the rate of technological change is uncertain, of course. Box 2-1 provides some perspective on the view that such an acceleration will be difficult.

CONGRESSIONAL CONCERNS

Congress has strong interests in future automotive innovation. First, the technologies and vehicle systems promise to increase substantially automotive fuel economy, which would reduce the oil use and carbon dioxide emissions of the U.S. and worldwide fleet of automobiles and light trucks. U.S. oil imports have recently reached 50 percent of total U.S. oil consumption, and the Energy Information Administration projects that imports will reach 60 percent by 2010, if technological improvement continues in a "business as usual" manner. These increases in import levels have strong implications for U.S. energy and economic security (see box 2-2), and a sharp decrease in these imports would represent an important benefit to the nation. Moreover, the spread of such technologies worldwide could ease pressures on global oil markets.

The reductions in carbon dioxide emissions may be a substantial benefit, as well. Carbon dioxide is a "greenhouse gas" that traps heat in the atmosphere. Scientists fear that increasing levels of greenhouse gases, particularly carbon dioxide, will cause substantial warming of the earth's atmosphere and extremely negative impacts on society (see box 2-3). The United States is the world's largest source of greenhouse gases, and its fleet of light-duty vehicles is responsible for about 15 percent of its total emissions. The United States is a party to international agreements that call for all nations to reduce their greenhouse emissions; a rapid shift to more fuel-efficient automotive technology would greatly simplify the task of complying with these international commitments.

Second, some of the advanced technologies may reduce emissions of hydrocarbons and nitrogen oxides and thus help reduce urban concentrations of ozone. Many U.S. citizens live in urban areas that still do not comply with national ambient air quality standards for ozone. Box 2-4 (at the end of this chapter) discusses several air quality and emissions issues associated with light-duty vehicles.

4 Hybribs are vehicles that combine two or more power sources in one vehicle, for example, an internal combustion engine and a battery, with electric motors providing some or all driving forces to the wheels.

Third, Congress also has oversight responsibilities for federal expenditures of several hundred million dollars yearly for R&D on advanced automotive technologies. This oversight encompasses PNGV and other programs, as well as the Environmental Protection Agency's decisionmaking about the application of the Ozone Transport Commission and several northeastern states to adopt all or part of California's LEV program, including its ZEV mandates. Understanding the technical promise, state of development, and potential costs of the candidate technologies will be essential to exercising this oversight.

Fourth, the automotive industry and industries directly related to it[5] are a critical sector of the U.S. economy, employing an estimated 4.6 million people and accounting for 5 percent of all U.S. employment in 1991.[6] Motor vehicle manufacturers and suppliers generated annual shipments totaling $236 billion in 1992--4 percent of the Gross Domestic Product.[7] Sales of assembled vehicles and vehicle parts are fiercely competitive, with foreign-owned automakers capturing 25 percent of U.S. passenger car sales and 23.7 percent of the vehicle parts and accessories markets in 1991.[8] All three domestic manufacturers export vehicles, and both Ford and General Motors have major positions in the European market. Advocates of rapid innovation in the industry view the development of advanced technologies as critical to the domestic manufacturers' efforts to retain and increase U.S. market share and expand market share overseas. In fact, the White House's original press release for the PNGV stressed "strengthening U.S. competitiveness" as the key goal of this effort:

> The projects developed under this agreement are aimed at technologies that will help propel U.S. industry to the forefront of world automobile production. It will help ensure that U.S. jobs are not threatened by the need to meet environmental and safety goals and that world pursuit of such goals will translate into a demand for U.S. products, not foreign products. This means preserving jobs in a critical American industry.[9]

NATURE OF THE TECHNOLOGY

What types of vehicles would represent a technological "leapfrog" achieving very high levels of fuel economy coupled with significant reductions in emissions? Although formal technical efforts such as PNGV have not specified any particular pathway, a leapfrog vehicle would likely combine several changes from today's vehicles:

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[5] Industries directly related to the automotive industry include motor vehicle and equipment manufacturing, automotive sales and servicing petroleum refining and wholesale distribution road construction and maintenance, taxicabs, passenger car rental and leasing and automobile parking.

[6] American Automobile Manufacturers Association, *AAMA Facts and Figures, 94* (Detroit, MI: 1994), p. 70, citing U.S. Department of Commerce, Bureau of the Census. The employment figures include the truck and bus manufacturing divisions of Ford and General Motors

[7] U.S. Department of Commerce, International Trade Commission, "Motor Vehicles and Parts," *U.S. **Industrial Outlook 1994*** (Washington, DC: January 1994), Chapter *35;* and U.S. Department of Commerce, Economics and Statistics Administration, Bureau of the Census, *Statistical Abstract of the United States 1993,* 113th Ed. (Washington, DC: U.S. Government Printing Office, 1993), p. 442.

[8] Ibid, p. 617; and U.S. International Trade. Commission, *Trade & Industry Summary: Certain Motor-Vehicle Parts and Accessories,* USITC Publication 2751 (Washington, DC: March 1994).

[9] The White House, Office of the Press Secretary, "Historic Partnership Forged with Auto Makers Aims for 3-Fold Increase in Fuel Efficiency in as Soon as Ten Years," press release, Sept. 29, 1993.

1. *Materials.* Substantial changes in materials, especially those used for the vehicle structure and skin. Potential candidates are aluminum and composite materials as well as improved steel. A typical 3,000 pound family sedan might lose 600 or more pounds; some analysts claim that reductions could top 50 percent, although OTA does not agree.

2. *Aerodynam ics.* Reduction in aerodynamic drag, primarily from changing the shape of the vehicle and covering the underside. The aerodynamic drag coefficient of a sedan, where 0.3 would be considered quite good, would be reduced by several hundredths; some claim that values of 0.2 or below are achievable.

3. *Tires.* Tire rolling resistance would be reduced by 20 percent or more by adopting new tire designs that combine higher pressures and new structures and materials.

4. *New Powertrains.* A variety of new powerplants and powertrain/drivetrain combinations conceivably could supplant (or, more likely, compete with) current spark or compression ignition engine/transmission powertrains. These vary from two-stroke variations of current four-stroke engines that offer substantially reduced engine weight and size for the same power, to electric and hybrid-electric powertrains with power sources ranging from batteries to internal combustion engines to fuel cells. The electric and hybrid vehicles have an added advantage of being able to recapture part of braking energy, an especially valuable feature for urban vehicles.

DEALING WITH UNCERTAINTY

Attempts to project the potential performance, costs, and timing of a rapid introduction of new technologies are hampered by a range of critical uncertainties: several of the key technologies are far from commercialization and their costs and performance are unknown; industry choices of technology and vehicle configurations to be made available to the marketplace, and the timing of any offerings, depend on a range of complex tradeoffs (and on subjective judgments by key individuals) as well as on unknown consumer responses to any changes in vehicle cost and performance; and so forth. Both access to information and information distortion are problems, as well. Much of the research data are held strictly confidential, and industry agreements with government laboratories have made even government test results (for example, results of battery testing conducted by the national laboratories) largely off-limits to outside evaluators.

Moreover, many of the disseminators of technology information have little incentive to reveal any negative test results or other problem areas. For example, smaller companies seeking investment capital and concerned with satisfying existing investors have very strong incentives to portray their results in as optimistic a light as feasible, and few companies are willing to discuss R&D problems and failures. Even Department of Energy research managers must sometimes act as advocates for their technologies to insure their continued finding in a highly competitive research environment. The existence of government mandates for electric vehicles further complicates this problem: small companies hoping that the mandate will create markets for their products have a strong stake in portraying progress in the best possible light; the automakers affected by the mandates have, in contrast, an understandable stake in emphasizing the difficulties in achieving the mandates' requirements.

Despite these uncertainties, there exists enough information to construct a reasoned estimate of the *order of magnitude* of the potential costs and performance of many of the advanced technologies, to identify critical R&D problems that need to be solved to reduce costs or overcome other obstacles to commercialization, to examine some of the tradeoffs among alternative values that will be required, and to define some concerns that can be alleviated by advance attention and policy action. This report focuses explicitly on the technological potential for achieving large gains in fuel economy and emissions performance, the likely price effects of the new technologies and vehicle systems that would achieve the hoped-for gains, and the nature of continuing R&D programs aimed at commercializing these technologies.

STRUCTURE OF THE REPORT

Chapter 3 describes each of the major candidate technologies that may serve as components of an advanced vehicle. It identifies its state of development, major obstacles to its commercialization, and potential advantages and disadvantages, and evaluates claims for its likely cost and performance.

Chapter 4 then discusses the vehicle types that are candidates for introduction in the future. The chapter first briefly describes the energy requirements of light-duty vehicles and, broadly, the strategies available to reduce these requirements. It next projects the fuel economy performance, costs, emissions characteristics, and other characteristics of several alternative pathways of vehicle development for the years 2005 and 2015:

- **Business as usual vehicles with a level** of technology that appears likely to result from continued incremental improvement and no radical changes in oil prices or technology policy;
- **Advanced conventional vehicles that** use various advanced vehicle technologies without changing the **basic *nature*** of the drivetrain--that is, the vehicles retain spark-ignited or compression-ignited engines coupled to transmissions that transmit power to the wheels;
- **Electric vehicles** whose wheels are driven by electric motors , with the electricity provided by onboard storage in chemical (battery) or mechanical (flywheel) form;
- **Hybrid vehicles with an** electric drivetrain (possibly with a mechanical drivetrain as well) and two or more power sources (for example, an internal combustion engine and a battery); and

- **Fuel cell vehicles** that are essentially EVs or hybrids, with primary electricity supplied by an electrochemical device that transforms a hydrogen-bearing fuel (for example, hydrogen, methanol, natural gas) into electricity without combustion.[10]

The report next describes current research activities in the United States, Japan, and Western Europe. Its principal focus is on national and regional programs, and it discusses a range of issues associated with the U.S. government role in supporting automotive R&D. The report concludes with appendices that explain the methodology used by the Office of Technology Assessment to evaluate the performance and price impact of the vehicle systems.

10 The fuel cells most likely to be used for light-duty vehicles require hydrogen as a fuel, so the vehicle must either store hydrogen or extract the hydrogen from a hydrocarbon fuel carried onboard. The latter process does require combustion, and generates small levels of combustion-related emissions.

BOX 2-1: Counterpoint: Forces Against Rapid Technological Change

There are excellent reasons why automobile manufacturers may hesitate to make large, rapid changes in vehicle technology, including shifts to electric drivetrains or alternative energy sources. First, the baseline fuel-gasoline-is in many respects an excellent fuel. Its petroleum feedstock is available in abundance, despite the jitters of the 1970s, and current worldwide proved reserves are higher today than 20 years ago. Worldwide oil prices, corrected for inflation, are at extremely low historical levels; even after adding refining costs, gasoline prices (before taxes) are lower than those of virtually any other processed liquid, including, in most cases, bottled water. Gasoline's energy content, about 125,000 Btu/gallon (higher heating content), is substantially higher than proposed alternatives such as compressed natural gas, ethanol, methanol, hydrogen, or electricity stored in batteries, and recent improvements in gasoline's composition have improved its emissions performance. Furthermore, engine designers' long familiarity with gasoline and its combustion properties provide it with a strong competitive advantage over alternative fuels.

Second, decades of experience with innovation has taught automobile designers that performance in the "real world" of spotty maintenance, wide ranges of driving patterns, unpredictable repair efficiency, and extremes of environmental conditions is often quite different from performance under test conditions, even when these conditions attempt to reproduce actual in-service conditions. All technological managers in the industry are familiar with the many notorious failures of innovative vehicle systems and subsystems such as the Chevrolet Vega's aluminum engine or Mazda's early rotary engine. In today's business environment, automobile purchasers have come to expect extremely high quality levels, and a major technological failure would likely exact a substantial penalty on a company's future market share. Further, in today's litigious environment, any adverse safety consequences, perceived or actual, stemming from a technological change could be extremely costly.

Third, the task-of designing a new vehicle is lengthy and expensive-generally five to seven years from concept to showroom, with a required investment of a billion dollars or more. If the model is a market failure, not only is the investment largely lost, but producing a replacement model for that market segment will take an additional several years. The daunting size of this task, as well as the financial risk it represents, tend to breed conservatism in the form of evolutionary rather than revolutionary design.

BOX 2-2: Energy Security, Economic Concerns, and Light-Duty Vehicle Fuel Use

The substantial dependence of the United States on imported oil to power its economy-especially its transportation sector-creates strong concerns about its economic security. Transportation consumes about 64 percent of U.S. oil use, and light-duty vehicles represent more than half of transportation's share. Consequently, the introduction of advanced, highly efficient vehicles, or any measure that would sharply reduce (or constrain the growth of) the fuel use of light-duty vehicles, will reduce energy security concerns and ease the economic impact of artificially high oil prices.

In practical terms, U.S. oil use exacts costs from the U.S. economy through three mechanisms:

- *Risks and costs of an oil disruption.* The political instability and hostility to Western interests of major sources of oil-primarily the oil producers of the Middle East-has caused severe supply disruptions, and may once again in the future. These disruptions have exacted sharp costs to the U.S. economy in the form of lost productivity, inflation, and unemployment; the Congressional Research Service has estimated these costs to be about $6 billion to $9 billion yearly.[1] The Strategic Petroleum Reserve has likely lessened the potential future costs of supply disruptions, but has itself incurred substantial investment and operating costs. An important point to note: because oil is easily transportable and all major oil markets are linked, price changes will affect U.S. oil prices regardless of how much U.S. oil is imported *or* domestically produced. The key to reducing the costs of an oil disruption is to reduce U.S. oil *use,* thus reducing the impact to the economy of a sudden rise in prices; reducing oil *imports* without reducing use, for example by increasing domestic production, will have less of a protective effect because it will not change the inflationary impact of a price rise (it may help the economy somewhat, however, if the incremental costs to consumers of higher oil prices are more likely to be recycled into the economy when the costs are paid to domestic, rather than foreign, producers).
- *Monopoly price effects.* Because the Organization of Petroleum Exporting Countries (OPEC) artificially restricts world production of oil, world oil prices are higher than they would be under free market conditions even at times of general price stability.[2] Higher oil prices reduce the amount of goods and services the U.S. economy can produce with the same resources and increase the amount of wealth U.S. citizens must shift to foreign oil suppliers. The amount of these effects has varied over the years as OPEC's market power has waxed and waned. The amount also depends on the extent to which dollars transferred to OPEC get recycled back to the United States in the form of purchases of our goods and services. In any case, however, the effects are tremendous-as much as a few trillion dollars since 1972.[3]
- *National security expenditures.* The United States spends large amounts-several tens of billion dollars annually– on military expenditures to protect oil supply, particularly for Middle Eastern flashpoints. Desert Storm cost more than $50 billion, though much of this was paid by U.S. allies, especially Saudi Arabia. There is substantial controversy about what portion of these expenditures should be "charged" to U.S. oil use, because U.S. strategic interests would be involved even without U.S. dependence on imported oil-inasmuch as Japan and Western Europe are themselves more dependent on oil imports than is the United States. There is little argument, however, over the proposition that U.S. oil imports raise the stakes for U.S. involvement in global oil security, and thus raise our costs.

U.S. economic interest is further involved in U.S. oil use and the potential for its reduction because of the market power associated with a large reduction. A substantial reduction in U.S. oil use would reduce world oil prices

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1 Congressional Research Service, Environment and Natural Resources Policy Division, "The External Costs of Oil Used in Transportation," June 3, 1992. Other authors have computed these costs to be somewhat higher or substantially lower; those computing low costs attribute much of the economic damage that followed past supply disruptions to government overreaction, especially in raising interest rates. See D.R. Bohi, *Energy Price Shocks and Macroeconomic Performance* (Washington, *DC:* Resources for the Future, 1989).

2 Estimates of what oil prices *would* be if the world market were competitive range around $7 to $11/barrel, implying that the world economy has been paying a premium of as much as $10/barrel or more for oil during the past 2 decades. D.L. Greene et al., Oak Ridge National Laboratory, "The Outlook for U.S. Oil Dependence," prepared for U.S. Department of Energy, Office of Transportation Technology, May 11, 1995.

3 Ibid.

because it would create, at least temporarily, excess production capacity. The magnitude of this impact is uncertain, however, because of disagreement about oil price's sensitivity to changes in demand and uncertainty about the ability of the Organization of Petroleum Exporting Countries to reduce production in response to a drop in oil use.

There have been substantial changes in oil markets and the world economy between the early 1970s and today. These changes can be summarized as a general shift to more flexible and responsive markets, with closer economic ties between oil producers and users, improved overall supply prospects, and improved capability for effective short-term responses to market disruptions. For example, oil production is more diversified than in 1973; the advent of the spot market and futures trading has made oil trade more flexible; OPEC investments in the economies of the Western oil-importing nations have created a strong disincentive for further market disruptions; and the end of the Cold War has removed an important source of tensions, These and other changes have generally improved U.S. and world energy security. Nevertheless, there are important reasons to remain concerned about energy security-the continued holding by Persian Gulf nations of the major share of the world's oil reserves and most of its excess oil production capacity; continued political instability in the area, although Arab-Israeli tensions have eased; and the existence of groups extremely hostile to the United States and the West in general. Further, even were the threat of new disruptions small, the costs exacted on the U.S. economy of OPEC monopoly behavior will continue as long as OPEC can maintain prices at artificially high levels. Thus, there remain extremely important reasons that both a sharp reduction in U.S. oil use and a decrease in the U.S. transportation sector's dependence on oil, should still be considered to offer an important societal benefit.

BOX 2-3: Greenhouse Emissions and Light-Duty Vehicles

Although air quality and energy security considerations have been the primary impetus for policy seeking to accelerate the development of advanced *automotive* technologies, these technologies also can play an important role in reducing emissions of carbon dioxide and other greenhouse gases. The administration has been sponsoring a greenhouse policy process called “Cartalk” that has brought together representatives of environmental organizations, automakers, and various transportation industries, as well as other interested parties in an effort to devise transportation policies that will reduce U.S. greenhouse emissions. It is OTA’s understanding that policies to accelerate technology development have assumed a prominent role on Cartalk’s agenda.

The “greenhouse effect”--a warming of the earth and the atmosphere-is the result of certain atmospheric gases absorbing the thermal radiation given off by the earth’s surface and trapping some of this radiation in the atmosphere. The earth has a natural greenhouse effect, owing primarily to water vapor, clouds, and carbon dioxide ($C0_2$), that maintains its temperature at about 60°F warmer than it would otherwise be. What is now of concern to scientists is the potential for increasing levels of $C0_2$ and other gases to increase the earth’s temperature even more-causing strong changes in sea level, storm frequency, rainfall patterns, and other conditions that would have enormous consequences on the manmade and natural environment. Although there are some continuing disagreements and uncertainties associated with these impacts, most atmospheric scientists accept the likelihood that global average temperatures will increase by 3° to 8°F, if global $C0_2$ concentrations double-a likelihood in the next century.

Worldwide emissions of $C0_2$ are so large-they were 6 billion metric tons of carbon in 19851-that no one source can be singled out as a primary target. However, light-duty vehicle $C0_2$ emissions are large enough to make them an obvious target for reduction. The U.S. light-duty fleet accounts for about 63 percent of U.S. transport $C0_2$ emissions-about 3 percent of world $C0_2$ emissions, or about 1.5 percent of the world’s total greenhouse problem. And, because most technology is “fungible’’--easily transported and adopted-technological advances in the United States stand an excellent chance of spreading to the worldwide fleet, affecting still more of the world’s total greenhouse problem. As a result, improvements in vehicle fuel economy are considered a key strategy in combating future global warming.

Generally, improvements in vehicle fuel economy will scale proportionately with reductions in greenhouse gas emissions. This is not true, however, if there is a fuel change, because vehicles using alternative fuels may have $C0_2$ and other greenhouse gas emissions that are strongly different from the emissions of gasoline vehicles. For example, electric vehicles have zero emissions, at least directly from the vehicle; the electric power used to recharge the vehicles will have $C0_2$ emissions determined primarily by the generation technology and fuel choice--from zero or negligible for nuclear power and hydroelectric power production, to levels high enough, for coal-powered generation, to raise total fuel-cycle emissions for electric vehicles to approximately the same or higher than fuel-cycle emissions for gasoline-powered vehicles.[2]

1 U.S. Environmental Protection Agency data.
2 M. Delucchi, University of California at Davis, results from GHG Emissions Mode1, personal communication, Dec. 7, 1993.

BOX *2-4:* Air Quality Considerations

Improving air quality is a critical goal of most efforts to move advanced technology into the light-duty fleet. For example, California considers its zero emission vehicle (ZEV) requirements critical to its effort to achieve acceptable air quality. Similarly, reductions in vehicle emissions are one of the key Partnership for a New Generation of Vehicles goals; the administration's original name for the partnership was the Clean Car Initiative.

Vehicular emissions are an important source of an ongoing air quality problem-continuing widespread noncompliance with ambient health standards for ozone, primarily in urban areas. Currently, about 50 million people live in counties that exceed the National Ambient Air Quality Standard for ozone.[1] At high concentrations, ozone damages lung tissue, reduces lung function, and sensitizes the lung to other irritants; it also damages crops and natural vegetation. Ozone is formed by the atmospheric reaction of nitrogen oxides (NO_x) and volatile organic compounds (VOCs) in the presence of sunlight, and motor vehicles nationwide are responsible for about 32 percent of emissions of NO_x and 26 percent of VOC.[2]

Vehicles-especially diesel-powered vehicles-are also emitters of very small particulate that have been associated with severe adverse health impacts, including premature deaths. Further, NO_x emissions, of which vehicles are the major source, also form particles in the atmosphere. Although sulfur emissions from power generation are the single greatest source of particulate, vehicle emissions of particulate and particulate precursors occur closer to affected populations. Particulate emissions from heavy-duty diesels and gasoline vehicles will likely decline in the future, but the overall decline in small particulate concentrations may be slowed considerably, if diesel engines are used more widely in light-duty vehicles.

Why Vehicle Emissions Remain a Problem

Government regulations have succeeded in both reducing total emissions from highway vehicles (and other sources) and improving air quality. For example, highway vehicle emissions of volatile organic compounds dropped by 45 percent and carbon monoxide (CO) by 32 percent between 1980 and 1993. During the same period, nitrogen oxide highway vehicle emissions dropped by 15 percent. Ozone air quality standards attainment has fluctuated with weather, but has clearly been improving during the past 10 years, and carbon monoxide attainment has improved dramatically, with a severalfold drop in the number of people living in nonattainment areas.[3]

Vehicles remain a troublesome problem, however. Although "per vehicle" emissions have been drastically reduced, vehicle-miles traveled have doubled over the past 25 years, countering some of the improvement-and highway travel will continue to increase. In addition, although new cars certified at federal Tier 1 emissions standards achieve tested emission levels that are, respectively, 3, 4, and 11 percent of uncontrolled levels of hydrocarbon, carbon monoxide, and nitrogen oxides, actual on-road emissions are considerably higher than regulated levels, especially for hydrocarbons (HC) and CO. Reasons for this higher level of emissions include:

1. *Older cars still on the road.* Many older cars have less effective emission controls, and some have deteriorated systems.

2. *Tampering.* About 15 to 30 percent of all cars have control systems that have been tampered with.[4] Although today's computer-controlled engines and emission control systems have largely eliminated the drivability problems that spurred early tampering, some tampering continues to occur.

3. *Malfunctions.* Many vehicle owners ignore malfunctions of emission control components.

[1] U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, *National Air Quality and Emissions Trends Report, 1993, EPA-450/R-94-026* (Research Triangle Park NC: October 1994).

[2] Council on Environmental Quality, *Environmental Quality: The Twenty-Fourth Annual Report of the Council on Environmental Quality* (Washington, DC: 1995),p. 435.

[3] Ibid, pp. 435,447.

[4] J.G. Calvert at al., "Achieving Acceptable Air Quality: Some Reflections on Controlling Vehicle Emissions," *Science,* vol. 21, July 2, 1993.

4. ***Poor gasoline quality.*** Many U.S. gasolines have sulfur levels and/or vapor pressures that exceed specifications; and some brands do not contain adequate deposit-control additives.[5] High sulfur levels in gasoline reduce catalyst efficiency for all criteria pollutants; high vapor pressure yields high levels of evaporative emissions; and dirty valves, injectors, and combustion chambers raise carbon monoxide, hydrocarbon, and NO_x emissions.

5. *Off-test driving patterns.* The Environmental Protection Agency (EPA) emission control certification test does not include periods of high speeds, hard acceleration, or hill climbing, and automakers design their vehicles to comply with these tests. Auto designers meet the need for increased engine power during acceleration and hill climbing, however, by adjusting the air/fuel ratio to run "rich," that is, with excess fuel, which substantially increases hydrocarbon emissions during these periods.

6. *Limitations of current Inspection and Maintenance (I&M) Programs.* Although the I&M programs established in areas of noncompliance with air quality standards are designed to identify and correct those vehicles with higher-than-normal emissions, current programs are limited in effectiveness for several reasons:

- Because they test vehicles that are fully warmed up, they do not measure cold-start emissions, responsible for the majority of vehicle emissions.

- Because they do not use dynamometers, they cannot test emissions during acceleration, also a key element of total emissions.

- They measure exhaust emissions only, whereas evaporative emissions represent a growing share of total vehicle emissions.

- Some fraud exists, particularly in programs dependent on independent garages. In addition, some owners alter their vehicles' control systems to pass the test.

- Exemptions are granted when repairs exceed relatively low dollar amounts, although vehicles in need of expensive repairs often are the worst offenders.

Ongoing Emission Control Programs

The Clean Air Act Amendments have established numerous new programs designed to correct several of the aforementioned problems. First, emission standards for new vehicles have been made more stringent, and certification limits for emission controls have been extended to 10 years or 100,000 miles, up from the previous 5 years or 50,000 miles.

Second, new vehicles will be required to have electronic measuring systems that will provide warning when vehicle emission control systems malfunction. Third, new "reformulated gasolines''--gasolines that have been chemically altered to have lower Reid vapor pressure (to reduce evaporative emissions), increased content of oxygenated compounds (to reduce CO emissions), and other features that will reduce vehicle emissions-will be sold in noncomplying areas and other areas that "opt in" to this program.

Fourth, I&M programs are to be improved. EPA's initial definition of the act's "enhanced I&M" was a shift to more sophisticated tests using dynamometers and measuring evaporative emissions as well; the act also increased the

5 Ibid. The authors cite a 1992 American Automobile Manufacturer Association survey of gasoline as concluding that 20 percent of commercial fuels exceeded established distillation cutpoints and 40 percent exceeded sulfur cutpoints, both contributing to high exhaust emissions.

repair bill amount for exemption to $450. Fifth, EPA is planning to change the current test procedures to account for off-cycle driving patterns.

In addition to the Clean Air Act requirements, the Energy Policy Act establishes a series of fleet requirements and economic incentives to increase the use of alternative (nonpetroleum) fuels. Qualifying fuels include natural gas, ethanol, methanol, propane, and electricity.

California has gone beyond the federal requirements by demanding the gradual addition to the new car fleet of vehicles meeting a set of emission standards that are more stringent than the new federal standards. The standards include a requirement for 2 percent of the new car sales of major auto companies to be ZEVs--practically speaking, electric vehicles-by 1998, with the percentage increasing to 10 percent by 2003.

What Will In-Place Programs Accomplish?

The federal programs now in place appear to have a substantial potential to address the several problem areas that have prevented satisfactory control of vehicle emissions. The combination of reformulated gasoline and I&M targeting of evaporative emissions should greatly improve control of these emissions in noncomplying regions. Improved I&M programs, coupled with more stringent standards, onboard diagnostics, and increased emission control warranties for new vehicles, should reduce the number of "superemitters" among relatively new vehicles. Some past problems with misfueling catalyst-equipped vehicles with leaded fuel (which poisons the catalyst) will cease because leaded fuel is no longer available in the general market. Further, today's vehicles, with their sophisticated computer controls, are far less vulnerable to tampering problems. In addition, increased use of alternative fuels, especially natural gas and electricity, should have some positive effect.

The California emission programs, which may be adopted by some northeastern states, create the potential for sharp drops in the certified emission levels of the new car fleet. There has been substantial controversy about the most extreme of these measures, the ZEV and ultralow emission vehicle (ULEV) standards. Auto manufacturers have argued that attainment of ULEV standards will be extremely expensive ($1,000 or more for each vehicle), and that battery technology is not yet sufficiently advanced to allow enough vehicle range and battery longevity to satisfy consumers. Recent developments appear to have improved the prospects for attainment of ULEV levels at substantially lower cost for at least some classes of vehicles–the 1994 Toyota Camry came very close to ULEV certification levels, and Honda has recently announced attainment of these levels with a modified Accord, at a few hundred dollars per vehicle.[6] The potential for EVs is discussed in some detail in this report.

There are potential limitations to the effectiveness of some of the emission control programs. For example, some studies have shown that a significant percentage of vehicles that underwent repairs after failing I&M tests were inadequately repaired. Furthermore, EPA has recently backed off the I&M dynamometer requirements and central testing for states now using decentralized testing, and the survival of these requirements is in doubt. This may compromise the ability of the I&M program to ensure the identification and repair of noncomplying vehicles. And, although fuels such as natural gas and electricity will yield substantial "per vehicle" emissions reductions, it is far from clear whether the existing programs will result in widespread availability of these fuels.

Another issue, often raised by the auto manufacturers, is the extent to which the regulatory focus on obtaining higher and higher levels of control efficiency from new cars, with obviously diminishing returns, can backfire. The argument here is that it is the turnover of the fleet, driven by the sales of new cars and retirement of old ones, that is the most effective mechanism for reducing vehicle emissions. If greater emission control requirements cause vehicle prices to rise, this will slow turnover and impede this critical mechanism. Although this argument clearly is qualitatively correct, proponents of more stringent regulation argue that any negative effects will be small because: 1) emission control costs have dropped over time; 2) some technologies introduced primarily for emission control (fuel injection, improved engine controls) have substantially enhanced engine performance and reliability and, thus, have been an incentive for purchasing new vehicles, and; 3) there are limits to the length of time that vehicle owners will delay purchases, so that any slowdown in fleet turnover will be limited in duration.

[6] This cost assumes, however, that the vehicle is equipped with Honda's VTEC-variable valve control-technology. If this technology must be added, the price is substantially higher, but the vehicle owner gains a substantial boost in power and/or fuel economy.

The potential for continuing problems with identifying and fixing vehicles with high levels of emissions, and continuing problems with "off-cycle" emissions theoretically places a premium on new propulsion systems that offer low emissions without eventual deterioration, potential for malfunction, or high off-cycle emissions. The emissions performance of advanced technologies should be examined in this light.

An Added Concern: Small Particulate

Vehicle emissions of particulate have not been handled with the same urgency by regulatory agencies as nitrogen oxides, hydrocarbons, and CO, partly because particulate emissions have not generally been considered as a major health problem and partly because vehicle emissions are low and other sources (windblown soil, power generation) are so much greater. Recent studies, however, have found a strong statistical association between fine particulate (diameter less than 2.5 microns) and aerosols and mortality and morbidity rates. A recent study by the Harvard School of Public Health finds that death rates increase by as much **as 26** percent as fine particulate or sulfates rise from the least polluted of the six cities in their study to the most polluted-after adjusting for other causes of death such as smoking.[7]

Diesel engines have substantially higher particulate emission rates than gasoline vehicles, by about a factor of 10,[8] and their emissions have long been considered a problem because most are in the size range[9] where body defenses do a poor job of filtering, and they tend to be coated with organic compounds often associated with cancer. The newest generation of diesels have sharply reduced particulate emission rates, but these rates are still higher than those of gasoline vehicles. To the extent that diesel engines are used in advanced vehicles, and thus enter the fleet in large numbers, they may raise concerns about particulate air pollution.

7 D. W. Dockery et al., "An Association Between Air Pollution and Mortality in Six U.S. Cities" *New England Journal of Medicine,* **vol. 329, Dec.** 9, 1993, pp. 1753-1808.

8 K.A. Small and C. Kazimi, "On the Costs of Air Pollution from Motor Vehicles," ***Journal of Transport Economics and Policy,*** January 1995.

9 Over 90 percent are less than 1 micron in diameter. Tom Cackette, California Air Resources Board, personal communication, May 18, 1995.