Title
Gearing Up for Electric Cars

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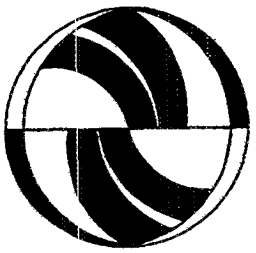
Publication Date
1994



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Daniel Sperling

Reprint
UCTC No 146

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Transportation Center

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The University of California Transportation Center

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Reprinted from
Issues in Science and Technology
Winter 1994-95

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Gearing Up for Electric Cars

The technology is at hand; now government must give the auto industry a push.

The litany of motor vehicle evils is well known Cars account for one-fourth of greenhouse-gas emissions and half of urban air pollution; they consume more oil than the nation produces at home. Efforts to solve these problems by reducing the nation's dependence on cars have failed. Mass transit now carries a smaller proportion of travelers than ever—only about 4 percent of total passenger-miles—and carpooling accounts for only 13 percent of work trips, down from 20 percent in 1980 Instead, policymakers are once again turning to technological solutions creating cleaner, more efficient vehicles.

Over the past five years, electric vehicle (EV) technology has emerged as the most promising alternative to the internal combustion engine. A wave of innovation has begun to build momentum for the widespread commercialization of electric-drive vehicles These will include not only battery-powered cars, whose ultimate role may be modest, but vehicles powered by electric fuel cells or by hybridized combinations of internal combustion engines (ICEs) and electric motors

The potential profits from EV technology are substantial Whoever pioneers large-scale production of electric-drive vehicles will find inviting markets around the world EV transportation is particularly suited to countries in which pollution is severe and intractable, where petroleum imports are a burden or the fuel infrastructure needed for conventional cars is not in place, where excess electricity (usually hydropower) is available in off-peak hours, or where vehicle performance is secondary to reliability and low maintenance Indeed, the Clinton administration has selected EV technology as one of 22 critical technologies for the nation's economic revitalization

It is almost inevitable that EVs will eventually supplant most, if not all, conventional cars The challenge for public policy is to guide this transition wisely. The barriers to a wholesale change in the nation's transportation system (not only economic and technical barriers but also institutional and structural ones) remain high. Only strong government action can level the playing field to give EV technologies

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a chance At the same time, public policy must be flexible enough to permit midcourse corrections and let the market, rather than the government, pick the winners

A compelling alternative

Policymakers have long debated the environmental and economic impacts of air pollution, global warming, and dependence on foreign oil Although they have not arrived at a consensus, it is clear that each of these problems carries some potentially serious risks Electric drive is the only alternative to internal combusion engines that is likely to have a significant impact in all three areas

The most compelling feature of electric-drive vehicles is that they emit no pollutants when driven. As a result, EVs can provide significant air quality benefits in almost all circumstances. The benefits are greatest in regions where air pollution remains severe and where most of the electricity comes from clean sources—tightly controlled natural gas plants or zero-emitting hydroelectric and nuclear plants rather than coal-fired power plants Although pollution-control measures will likely bring air quality up to Environmental Protection Agency (EPA) standards in most parts of the United States within the next 10 years, pollution is likely to remain a serious problem for most of California's cities as well as for 10 or so of the nation's largest metropolitan areas

Electric-drive vehicles are also more energy efficient than conventional automobiles The conversion of chemical energy into mechanical energy—burning fuel—is simply less efficient than using electricity Electric motors are about 90 percent efficient, compared to less than 25 percent for ICEs In addition, EVs can recapture as much as half the energy lost during braking (regenerative braking), they do not need a transmission, which reduces energy use by another 6 percent or so; and they do not consume energy while idling and coasting, saving still another 10 percent. These efficiency gains are partly offset by the low efficiencies of power plants Oil refineries are about 90 percent efficient, compared to efficiencies of about 33 percent achieved by today's power plants fired with oil, natural gas, and coal. But oil refineries are not expected to become more efficient, whereas power plants' efficiency rates are expected to rise to as much as 50 percent as new and improved plants are brought on line

For these reasons, EVs will be highly effective at reducing greenhouse gas emissions Neither methanol nor natural gas, the two most promising conventional alternative fuels, provides comparable reductions in greenhouse emissions Indeed, the only alternative fuels with the potential for large greenhouse-gas reductions are fuel made from biomass, especially trees and other cellulosic material, or hydrogen fuel made with solar energy. But biomass fuels create other environmental stresses, such as deforestation, and have only modest production potential, and solar hydrogen is more efficiently used in electric fuel cells than in ICEs Conventional alternative fuels are also only slightly better than reformulated gasoline in reducing pollution, and their impact on the nation's energy security is mixed They are low-cost solutions, but they offer only marginal benefits

EVs clearly have the most promise, but it is too soon to predict exactly how they will evolve The key to a successful (and economically efficient) transition to electric drive is to encourage experimentation with a variety of technologies. Battery-powered vehicles, for example, are limited, they are likely to complement rather than entirely supplant ICEs Compared to gasoline, batteries are a bulky and expensive way to store energy. But the battery problem tends to be overstated Not all vehicles need to travel long distances or carry heavy loads In multicar households, which now comprise the majority of car owners, battery-powered vehicles could be designated the short-range vehicles These around-town cars could be built with much smaller and less expensive batteries

A technological revolution—not only in electricity storage and conversion devices but electronic controls, software, and materials—is quietly opening up many new opportunities for electric-drive vehicles. For example, advances in power electronics have resulted in small lightweight DC-to-AC inverters that make possible AC-propulsion-drive systems that are cheaper, more compact, more reliable, easier to maintain, more efficient, and more adaptable to regenerative braking than the DC systems that were used in virtually all EVs through the early 1990s.

Today's EV motor-controller propulsion system is smaller and lighter than a comparable internal com-

bustion engine as well as being cheaper to manufacture and to maintain Consider GM's EV production prototype, the Impact With an AC motor, a compact and efficient inverter, and an ultra-high-efficiency design, it achieves a 70-mile range in city driving using conventional lead-acid batteries and accelerates from 0 to 60 miles per hour in 8 seconds, faster than Nissan's 300ZX sports car. *Popular Science* described the Impact as "possibly the best-handling and best-performing small car that GM has ever turned out."

The Big Three need to be involved in any federally led research partnership but not necessarily as the dominant players.

Although important for the first generation of EVs, batteries are likely to play a modest role in the future. A raft of other energy storage and conversion devices are being readied for the EV marketplace (see sidebar) These include ultracapacitors and flywheels, which can store large amounts of electricity and can charge and discharge quickly and often, and fuel cells, which convert chemical fuel into electricity with only water as a byproduct.

An optimistic but plausible scenario for the future would show battery-powered vehicles making up 10 to 20 percent of the new-car market within about 10 years as competent urban cars. Meanwhile, as battery technology continues to improve, new kinds of electric-drive vehicles will begin to enter the market, using either fuel cells or hybrid engines, in which a small ICE is coupled with batteries, ultracapacitors, or flywheels and connected to an electric motor Within 25 years, electric-drive vehicles could make up 90 percent of the cars in states such as California, where emissions standards are stringent and EV sales and use are strongly supported.

During the past few years, considerable progress has been made with electric-drive technologies at relatively little cost. Total investment in EVs and EV batteries by U.S. manufacturers and governments in the first four years of this decade probably fell short of a billion dollars. Ford and General Motors reported spending a total of $450 million during the first few years of the decade. (To provide perspective, consider that the oil industry is spending about $10 billion this decade to produce reformulated gasoline.) Achieving the refinements necessary for commercializing EV technologies will likely not require large additional investments in research and development. What's needed instead is a reduction in the uncertainty and risk facing automakers. That can be achieved only by a firm federal commitment to the rapid development and adoption of EV technology

Government's role

Government policy has a tremendous role to play in paving the road for an electric transportation strategy The enactment of the zero-emissions vehicle (ZEV) mandate by the California Air Resources Board (CARB) in 1990 (and later by New York and Massachusetts as well) has spurred more progress in electric propulsion technology than was accomplished in the previous 20 years by the automobile industry and the Department of Energy combined. Almost totally because of the mandate, every major automaker in the world has invested in EV development. Dozens of companies have sprouted to adapt technologies such as batteries, ultracapacitors, flywheels, and fuel cells, whose potential relevance for the transportation sector had been overlooked.

The mandate requires that by 1998, at least 2 percent of the vehicles sold in California by major automakers must have zero emissions, the percentage will rise to 5 percent in 2001 and 10 percent in 2003. Major automakers are defined as those with sales of 35,000 vehicles or more per year in California. They are, in descending order, General Motors, Ford, Toyota, Chrysler, Honda, Nissan, and Mazda. In 2003, the mandate will be expanded to include manufacturers with as few as 3,000 vehicle sales per year Companies will be fined $5,000 per car for the number of sales by which they fall below the quota

The mandate also permits manufacturers to trade EV credits. That is, a company can satisfy the mandate's requirements by buying credits from other companies that have sold more than their quota of ZEVs. This provision is important because it gives mainstream manufacturers the flexibility to buy credits rather than build ZEVs, while providing cash for

industry outsiders, such as small and nontraditional manufacturers of EVs whose ZEV quota is zero

The ZEV mandate is intended to do more than corner a tiny fraction of the market for ZEVs by 1998. Its goal is to spur automaker action by forcing commercialization of EV technology. After all, a 2 percent reduction in ICEs will do little to improve California's air quality in the short run, but by speeding the introduction of electric-drive vehicles, the mandate may make it possible to achieve much larger reductions in the future

The ZEV mandate continues to lead the way in spurring the transition to electric-drive vehicles despite a caution that borders on ambivalence on the part of the Clinton administration Although the auto industry and the administration have launched several high-profile initiatives focused on the creation of environmentally benign vehicles, these are receiving little funding and making little progress In the fall of 1994, the administration established an advisory council known as "Car Talk," composed mostly of leaders from the automotive industry and the environmental movement, to create a plan for reducing greenhouse-gas emissions from the transportation sector President Clinton also created the President's Council for Sustainable Development, which has invited a number of experts to address the car question

But the federal government has provided few regulatory and financial incentives to develop much cleaner and more efficient vehicles and has offered virtually no direct support for EVs For instance, Corporate Average Fuel Economy (CAFE) standards for cars have been frozen since 1985 and the standards for light trucks are weak (less than 21 mpg) More important, the vehicle emission standards enacted in the Clean Air Act Amendments of 1990 were considerably more lax than those adopted in California and contained no requirements for ZEVs

The administration has been reluctant to permit states to strengthen their own emissions standards. In response to frantic lobbying by the Big Three automakers, EPA pressured the northeastern states to back off their February 1994 request to adopt California's more stringent standards and imposed conditions that weakened the states' ability to encourage the development and sale of EVs.

Perhaps the most widely publicized initiative by the Clinton administration has been the formation of the Partnership for a New Generation of Vehicles (PNGV) in the fall of 1993 Its stated purpose is to build a prototype midsize sedan that triples the fuel economy of today's cars by 2004 The program has even been portrayed as a modern counterpart to the Apollo moon program. Initially known as the Clean Car Initiative by government and the Supercar Initiative by the automotive industry, PNGV is a public-private partnership intended to accelerate the development of electric propulsion, ultraefficient and lightweight materials and technologies, and advanced manufacturing processes and materials

The program was devised in part to transfer some of the technological resources developed during the Cold War to the civilian sector Virtually no new funding is planned, instead, the government will divert personnel and resources at the national laboratories, especially the weapons labs, to work with the Big Three auto companies and their suppliers on the development of advanced transportation technologies In theory, everyone benefits The labs would have a renewed mission, thousands of highly trained scientists and engineers would be productively employed, and automakers would receive a much-needed infusion of technical know-how Indeed, the PNGV initiative lends weight to the automakers' argument that EV commercialization and tightened CAFE standards should be delayed until next-generation technologies are developed.

The PNGV initiative, however, has a fundamental weakness It is not linked to any regulatory incentives that encourage commercialization of the technologies developed The stated purpose of the initiative is to advance technology to the point where government regulation is no longer necessary, it contains timetables for the creation of concept prototypes (2000) and production prototypes (2004) but none for actually manufacturing and marketing EVs

The absence of regulatory bite undermines the credibility of the PNGV initiative. The auto industry has garages full of prototypes As long as the industry feels no push from government to commercialize their research, PNGV cars will be added to their collections, and the movement of technology from lab to marketplace will be slow

If one could elicit a promise that auto manufacturers would swiftly transfer to the marketplace knowledge gained in the laboratory, perhaps regula-

tory pressure would be unnecessary But such promises are difficult to enforce Historical evidence shows that automakers have resisted adopting safety and environmental features, from airbags to catalytic converters, until government action forced them to do so Once the deadlines were set, however, the industry found ways to adapt these technologies cheaply and well

If the federal government is to direct the United States toward an environmentally benign and economically robust new transportation path, it must take strong steps to jump-start the commercialization of electric propulsion In addition, it must restructure its research program to include a broader range of players It must also enact more flexible regulations to guide the future development and application of EV technology

The government should use mechanisms such as taxes, tax credits, fees, and marketable credits to complement technology efforts.

Extending the mandate

The first step for the federal government is to support and extend California's ZEV mandate. The automobile and oil industries are fighting the mandate in court and have sponsored a parade of bills in California's state legislature to overturn it. The auto industry has also lobbied EPA to prevent other states from adopting similar programs, and the oil industry is providing millions of dollars to a variety of citizen groups around the country to counter legislative and electric-utility industry support for EVs

Automakers oppose the ZEV mandate on the grounds that battery technology is not yet commercially ready If sold now, they argue, electric cars would cost too much and have unacceptably short driving ranges According to their estimates, each EV (with batteries) will cost $10,000 to $20,000 more than a comparable gasoline fueled car To bring the price down to a more affordable range, auto companies say they would have to offset their losses by raising the prices of conventional cars, perhaps by as much as $2,000.

Although this argument has some merit, it is greatly overstated. Initial EVs will undoubtedly be more expensive than ICEs, but they need not be as expensive as automakers suggest. Niche vehicles targeted to city dwellers require only a very limited range and can use smaller, less expensive batteries Car manufacturers can minimize their initial costs by inserting electric drivelines into existing gasoline vehicles and making a few design changes They could even sell engineless "gliders" to smaller conversion companies and let those companies do the retrofits A number of companies have already announced plans to pursue one or more of these strategies

In addition, costs and prices are likely to decline as the number of EVs on the market increases There is plenty of evidence to suggest that as more EVs are manufactured and sold to meet the requirements of the mandate, economies of scale will be realized, engineering and production processes will improve, and the vehicles will become cheaper EV prices and their impact on the price of conventional cars will also diminish if costs are spread over a larger number of vehicles. In the meantime, it is not unreasonable to ask the industry to use one type of vehicle to subsidize another. Large automakers typically sell small cars at little or no profit, or even a loss, and subsidize them with profits from larger cars and trucks. This strategy allows manufacturers to meet average fuel economy standards and to hook young buyers who will presumably move up to larger, more profitable cars later

On the basis of many discussions with auto industry executives, I sense that opposition to the mandate goes far beyond quarterly profit statements Commercialization of EVs may spell major structural changes within individual automobile companies and in the industry as a whole Electric propulsion technology requires a fundamental shift in many aspects of car manufacturing More than one-third of the value of EVs will be composed of entirely new components. Another one-third of the components will need to be redesigned. Manufacturers will have to adopt new materials, collaborate with new companies, and reduce the size of production runs. For example, companies are much more likely to use lightweight composite materials in EVs in order to

make the vehicles more efficient Unlike steel and aluminum, these materials offer less striking economies of scale, they are suited to small-scale decentralized assembly rather than mass production on the level usually found in Detroit

Similarly, a company's success in marketing EVs may depend on its ability to find new ways to sell and service them. Vehicles may be far more specialized, giving consumers an incentive to trade vehicles more frequently. A person who gets a new job 20 miles away or a couple having their first child might need a different type of electric car. One solution would be for consumers to lease vehicles rather than own them, with manufacturers bearing the responsibility for insuring and maintaining them. Just as some computer companies sell "computing capability," allowing companies to upgrade their equipment without having to buy or sell, EV manufacturers could sell "transportation capability" rather than vehicles. Because many of the first EVs will be fleet vehicles, implementing this concept may not be as complicated as it sounds The high reliability of EVs, compared to gasoline-fueled cars, could help make such arrangements viable.

Detroit executives have been slow to appreciate the opportunities created by the emergence of EV technology The emergence of a niche market for limited-range second cars and the advantages of home recharging and low maintenance do not seem to register in their minds. A vast cultural and organizational mismatch exists between the conventional car industry and the qualities needed to thrive in the EV market. Automakers acknowledge this problem but appear unprepared (or unwilling) to respond

New companies, new technologies

The passage of California's zero-emission vehicle (ZEV) mandate spurred the formation of new, small companies and drew a number of large companies into electric vehicle (EV) research. Today, about 10 to 20 small U S companies are converting gasoline fueled cars to EVs The largest, U.S. Electricar in northern California, has produced a little over 100 vehicles but is gearing up to produce thousands of cars in the near future. The company is negotiating agreements with Ford and GM to convert their engineless "gliders" into EVs

Many technology companies, especially defense department contractors and auto industry suppliers, are also investing in EVs. They are also finding ways to make conventional automobile components and accessories such as tires and heating and cooling systems more energy efficient so that they can be used in EVs Heating and cooling systems are not a problem in ICE vehicles because they can draw on waste heat and surplus power from the engine. But EV engines do not generate enough heat to warm the cabin, nor do they store enough energy for conventional heating and cooling An EV using the same type of air conditioner and heater as an ICE would lose 20 percent of its range or more Creative solutions include high-efficiency heat pumps, window glazing to reduce the sun's heating effect in the cabin, air cooling channeled through the seat rather than dispersed through the cabin, and solar-powered fans to cool the vehicle when it is parked

Established companies have also become involved in research on EV components and batteries. For instance, the U.S Advanced Battery Consortium, established in 1991 and sponsored by the Department of Energy, the electric utilities, and the Big Three auto companies, is funding research to increase energy and power capability, extend the life, and reduce the cost of batteries as they are scaled up to sizes suitable for EVs. Its budget calls for $230 million to be spent by 1995 and $100 million to be spent per year into the early years of the next century EV battery technology has been inadequate largely because of lack of effort: Virtually all battery research has been focused on small batteries

The ZEV mandate is a blunt but effective instrument for overcoming market uncertainty, contrary corporate cultures, and technological barriers Although it will initially impose substantial costs on automakers, tinkering with it at this time would be costly to the many companies making substantial investments based on the mandate Any indication that it might be changed or abandoned would freeze

for the multibillion-dollar consumer-products market rather than the $200-million market for batteries to power golf carts, forklifts, and the like. The passage of the ZEV mandate created a much larger market that justifies more research.

The Partnership for a New Generation of Vehicles, a joint endeavor by the federal government and the automobile industry, draws on EV research by the national weapons and energy laboratories. A principal focus is the development of fuel cells, devices that transform hydrogen and oxygen into electricity. First used to provide electricity in spaceships in the 1960s, they are at least twice as efficient as gasoline-fueled engines and produce little or no waste heat, pollution, or noise. Unlike batteries, fuel cells do not store energy; instead, fuel (probably methanol or hydrogen made from natural gas in the early models) is supplied continuously. Fuel-storage containers can be easily resupplied, eliminating the problem of limited driving range. They perform much like conventional ICEs and require no fundamental changes in operation.

A fall-back option if fuel cells fail to meet expectations is the use of batteries, flywheels, or ultracapacitors. Flywheels and ultracapacitors are energy-storage devices that could help to power the vehicle during acceleration and absorb regenerative braking energy during deceleration. A flywheel stores energy in a lightweight carbon-composite rotor that spins at over 100,000 revolutions per minute; an ultracapacitor stores energy in two conductive plates separated by an insulator. The first high-powered ultracapacitors and flywheels are likely to enter the marketplace in the late 1990s. They will be paired with batteries to provide peak power surges, allowing batteries to be downsized and extending their life.

Flywheels and ultracapacitors are the critical enabling technologies for the development of hybrid ICE-EV vehicles. Hybrid vehicles would use a small ICE coupled with batteries, flywheels, or ultracapacitors and connected to an electric motor. Hybrid vehicles could be highly energy efficient, though less so than those powered by fuel cells. Some would operate in a pure electric (zero-emissions) mode most of the time; others would operate the ICE most of the time and could have very low but not zero emissions.

development investments in hundreds of companies, especially in small companies dependent on outside financing.

At the federal level, EPA should strongly back the mandate as well as state efforts to enact similar programs. A number of state governments, particularly in the Northeast, are looking for ways to improve regional air quality without imposing undue burdens on local industries. EPA can encourage them by providing regulatory relief and financial support for pursuing ZEVs.

Accelerating EV research

The federal government must continue to take the lead in accelerating investment in advanced EV technologies. A research partnership between government and industry is essential if we are to surpass the limited use of battery-powered vehicles and sustain the transition to an environmentally benign transportation system.

The PNGV initiative offers a framework for this kind of research, but it relies too heavily on the national laboratories (particularly weapons labs) and the Big Three. The labs have a store of potentially valuable knowledge and technology—in particular, expertise in core areas of basic science relevant to electric propulsion. However, the weapons labs are not oriented to designing products destined for the marketplace. They focus on basic science, fundamental technological innovation, and the design of high-performance equipment, not on designing products and engineering processes to improve performance and reduce costs.

If basic science were the critical missing ingredient in EV technology, then the national weapons laboratories might have an important role to play. That, however, is not the case. Many promising technology concepts already exist in prototype form. The principal need over the next 10 to 15 years is not new science or new technology but cheap technology. That is a challenge for engineering and manufacturing, not basic science. It may be a national priority to save the jobs and expertise of these institutions, but that goal is only tangentially compatible with the goal of mak-

ing cleaner and more energy-efficient vehicles

Reliance on the major automakers is also problematic Certainly they need to be intimately involved in any federally led research partnership but not necessarily as the dominant players. They are best suited to directing the research agenda for incremental technologies—refining some materials and manufacturing processes—especially because they and their suppliers are likely to be the principal users of these technologies. However, their history of resisting energy, environmental, and safety innovations suggests that they should not play a central role in developing advanced propulsion technologies Instead, the government should seek out the smaller companies that are pioneering these technologies and forge closer links with them. For example, smaller companies should be allowed to participate in the cooperative research and development agreements (CRADAs) negotiated between private companies and the national labs CRADAs give the company exclusive rights for five years to any technology developed with the lab. Currently these agreements are open only to the Big Three. It will take substantial effort to create collaborative links between smaller companies and the national laboratories, but the result may be quicker commercialization of the research

A government-industry partnership will be most productive if it includes a broader range of labs and technology companies than are currently involved in the PNGV initiative In particular, it should create small independent research facilities, most likely at universities, to provide benchmarks for technological progress, to evaluate the achievements of the partnership, and to tap more of the country's intellectual resources

Forging market solutions

All things being equal, sustained change is most effectively achieved by harnessing market forces The ZEV mandate cannot stand alone, nor should it stand long. Once startup barriers have been overcome (when EV sales reach 5 to 10 percent of the market) strict commercialization requirements should be phased out in favor of measures that rely more heavily on market forces to guide transportation choices toward reduced social and environmental costs.

With this goal in mind, the federal government needs to overhaul the regulatory structure that shapes the nation s transportation strategy One reason the policy debate over EVs (as well as alternative fuels) has been so contentious is that the oil and auto industries are shackled by rigid and fragmented regulations Automakers must meet every single standard for every single pollutant, which rules out any kind of tradeoff if dramatic improvements are made in one area For example, lean-burn and two-stroke engines, which cut energy use and emissions of greenhouse gases, hydrocarbons, and carbon monoxide, are precluded from the market because they slightly increase nitrous oxide emissions In addition no provisions exist to regulate emissions on a full fuel-cycle basis The result is that emissions from power plants, refineries, and fuel stations are not incorporated into the final calculation of environmental impact On a full fuel-cycle basis, the use of a hybrid vehicle may actually result in lower overall emissions than use of a battery-powered car, yet the hybrid is not treated as a ZEV.

The government should use mechanisms such as taxes, tax credits, fees, and marketable credits to complement technology initiatives aimed at reducing or eliminating emissions For example, automobile companies should be allowed to average emissions across their fleet of vehicles to meet emissions standards, just as they do to meet fuel-efficiency requirements (Average emissions should be set at a level that permits total emissions reduction to match or exceed the unaveraged standard) Even more economically efficient is emissions trading allowing manufacturers to sell emission reductions from zero-emission vehicles to conventional-vehicle manufacturers Allowing banking of emissions reductions from year to year would provide the additional bonus of giving manufacturers an incentive to invest sooner in technologies that will let them outperform today s standards in anticipation of even stricter standards down the road California has taken tentative steps in this direction but EPA has not.

Initiatives like the ZEV mandate will be much more effective if combined with price signals that reward consumers use of clean and efficient fuels and vehicles For instance, the government could offer a revenue-neutral "feebate" in which consumers who purchase energy-efficient vehicles receive a rebate whereas those who purchase gas guzzlers pay a fee

The synergies achieved by coordinating tech-

nology initiatives with regulatory and financial incentives are huge By themselves, such incentives would have little effect and more often than not would be rejected in the political arena. Combining technology initiatives with incentives is not only effective, it is also politically more appealing Only a flexible, incentive-based public policy will create the framework needed to guide business and consumer decisions in an efficient manner toward a sustainable future

Though the technological basis for a transition to electric drive is falling into place, progress will remain slow and inefficient until some way is found to reduce the risk for automotive manufacturers and create a firm but flexible regulatory structure The recommendations presented here force commercialization forward but also encourage innovation and experimentation as technological lessons are learned Thanks in large part to the ZEV mandate, our society can now choose from a menu of transportation opportunities that did not exist only a few years ago Not to nurture and exploit those opportunities would be poor public policy and bad business

Recommended readings

International Energy Agency *Electric Vehicles Technology, Performance and Potential* Paris Organization of Economic and Cooperative Development, 1993

James MacKenzie, *The Keys to the Car* Washington, D C World Resources Institute, 1994

Michael Brian Schiffer, *Taking Charge The Electric Automobile in America* Washington, D C Smithsonian Institution Press, 1994

Ernest Wakefield, *History of the Electric Automobile* Warrendale, Penn Society of Automotive Engineers, 1994