Personal Transport: Road Vehicles 7

ELECTRIC VEHICLES

Electric vehicles (EVs), powered by batteries or fuel cells, require much new vehicle technology and infrastructure. The competitive potential is great-the whole world is interested in cleaner personal vehicles—but uncertain, both because of the technical problems that still bedevil EVs and because of the difficulties in creating the new infrastructure. Nonetheless, the benefits in technology spillovers and the creation of high-value-added, knowledge intensive jobs could be very substantial, with opportunities for defense and aerospace firms to fill new niches for component suppliers.

Battery electric vehicles emit virtually no air pollutants, and because they draw on electricity that can be produced by a variety of generation technologies, they offer the prospect of considerably reducing dependence on foreign oil. If renewable or nuclear energy were to provide the electricity, EVs could significantly reduce the greenhouse impact of transport. Over their entire fuel cycle, EVs use energy more efficiently than internal combustion engine vehicles (ICEVs). Although the initial generation of the electricity at the power station and its distribution through the grid require more energy than petroleum refining does, the EV's powertrain is more efficient than the ICEV's. Its motor does not run when the vehicle is standing still, offering further savings, and EVs can use 'regenerative braking' to recapture some of the energy that is normally wasted as heat and noise when the brakes are applied.[1]

Fuel cell vehicles also emit little if any pollution. Their main exhaust product is water but, as with battery EVs, their overall environmental impact depends on what happens beyond the vehicle. Hydrogen can be produced by electrolyzing water, an energy intensive process that raises the same issues as other uses of electricity, or by reforming a hydrocarbon, the process used for most of the world's hydrogen today. Reforming releases carbon dioxide. However, if the hydrocarbon used is methanol derived from biomass or organic waste, the net contribution to the greenhouse effect is very low, just as it would be for battery EVs charged with electricity from renewable sources. At present, however, most hydrogen is derived from fossil fuels.

EVs also pose new environmental challenges in their manufacture and disposal. Some kinds of batteries, in particular, incorporate exotic materials, some of them poisonous, caustic, or otherwise dangerous. Extracting and processing these, handling them during manufacture, containing them during use and in case of accidents, and finally disposing of them all require careful attention to ensure human and environmental safety.[2] In some cases there is scope for recycling-lead acid batteries, for example, are already recycled to a limited extent, reducing the quantity of harmful lead introduced to the environment.

Both battery and fuel cell EVs (FCEVs) face competition from other kinds of less polluting vehicles, many of which are better developed and improving all the time. Alternative fuels include methanol and ethanol, straight or blended with gasoline, hydrogen, and natural gas. Gasoline is itself being continuously improved, as are engine technologies; the widespread use of reformulated gasoline might bring significant reductions in air pollution from autos. All of these fuels would require much less new infrastructure than EVs; reformulated gasoline in particular could be smoothly introduced into wide use in the existing fleet. These advantages, combined with the technological gaps in the development of EVs, cast a good deal of uncertainty over the future of EVs. Moreover, recent increased attention to EV research and development today is mostly a result of legislative pressure. The technology is still so immature that continued public pressure of this sort is probably needed to drive development further. Nevertheless, if they succeed, EVs could offer a combination of reduced pollution and decreased dependence on foreign oil that would be hard to match.

Finally, EVs offer considerable scope for using talents and technologies formerly devoted to military purposes. Westinghouse Electric's electronic systems group, for example, is putting its experience of building electric propulsion systems for military underwater devices to use, in collaboration with Chrysler, to design a powertrain for improved EV performance.[3] Hughes Aircraft has developed a battery charging system and was to have provided much of the expertise and labor in developing a GM EV based on the Impact prototype, until the plan was scaled back

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1 Regenerative braking takes advantage of the fact that a motor and a generator are essentially the same thing-a means of transforming energy from one form to another. In a motor, one puts electric current in and gets motion out; in a generator, one provides the motion and gets current out. The physical principles at work and the construction are fundamentally the same in both, so that by turning an electric motor one can use it as a generator, which is what happens in a regenerative braking system. In normal driving the motor turns the wheels, but when the brakes are applied the rotation of the wheels drives the car's motor around, causing a current to flow back through the batteries, which chemically store the energy it carries. As the current flows and energy is stored, so the energy of rotation falls, and the wheels slow down. The wheels in effect do work by pushing against the electromagnetically produced forces on the motor. To achieve effective regenerative braking requires careful wiring and electronic management in practice, but the basic principle is straightforward.

2 See U.S. Congress, Office of Technology Assessment, *Green Products by Design: Choices for a Cleaner Environment,* OTA-E-541 (Washington DC: U.S. Government Printing Office, October 1992) for a study of environmental issues in design and manufacturing.

3 Ted Leicester, Westinghouse Electric, electronic systems group, personal communication, Aug. 27, 1992.

at the end of 1992. Moreover, the Department of Energy's (DOE) national labs have ongoing research programs in several technologies relevant to EVs, notably batteries and fuel cells. Sandia, Argonne, and Idaho National Engineering Laboratory (INEL) are among the labs that have cooperative research and development (R&D) agreements (CRADAs) with the U.S. Advanced Battery Consortium (USABC). Ultracapacitors, energy storage devices that can deliver tremendous power and that might supplement an EV fuel cell, are a result of strategic defense initiative (SDI) research at Lawrence Livermore to develop power sources for laser beams originally meant for space defense.

History

The history of battery EVs as a form of highway transport is as long as that of ICEVs.[4] From the 1880s through the early part of the 20th century, the two forms of vehicle competed intensely. In 1899, the world speed record was claimed by an EV after a hard fought contest between the French count Chasseloup de Laubat and Camille Jenatzy, his Belgian rival, who triumphed in his torpedo-shaped electric car, *Le Jamais Contente,* traveling at 104 kmh (65 mph) and demonstrating in the process that human lungs did not burst at speeds greater than 100 kmh, as some had feared. The turning point for ICEVs came with the 1911 invention of the electric self-starting motor, which did away with the need for heavy cranking by hand. With their advantage in convenience gone, EVs rapidly lost popularity as people increasingly began to enjoy the greater freedom of ICEVs' longer range. Engineering attention fried on the ICEV, so that progress on the EV was slight, and the technology more or less languished for 60 years. EVs continued to be used in specialized applications where their low emissions, low running costs, or silence were of particular value, such as for early morning milk deliveries in the United Kingdom, but the mainstream swung away from them.

Oil crises and increased environmental consciousness began to prod a few auto designers to reconsider EVs—there were particular bursts of interest with the passage of the National Environmental Protection Act in 1967 and the 1973 oil embargo by the Organization of Petroleum Exporting Countries (OPEC)--and there has been a slow increase in the amount of R&D over the last 20 years, accelerating since the late 1980s. This has led to some important breakthroughs-the development of practical AC convertors allowed the use of lighter motors, for example-but overall progress has been incremental. The basic problem of EVs remains energy storage, just as it was when Edison developed the nickel iron battery for EV use. Electric vehicles have long been "the car of the future" in some circles-a future continually predicted to lie 10 years ahead-but without breakthroughs-this future has come no closer. Whether the current interest, prompted this time by recent Californian clean air regulations' stipulations for sales of at least 20,000 "zero emission vehicles" in 1998, can succeed where earlier efforts have not remains to be seen. But the attempt is bringing together a greater number of researchers and established auto manufacturers than ever before.

Technology

An EV uses a motor drawing on electric energy to propel itself along the road. The energy is usually stored by chemical means, either in batteries, or as fuel from which the energy is chemically released in a fuel cell, or a combination of the two. Two physical characteristics are very important in considering how effectively the energy is stored. One is the energy density, or the amount of energy a given weight or volume of the system will store, which dictates how much work a system of a given size can do. The other is the

[4] Information taken from S.R. Shacket, *The Complete Book of Electric Vehicles* (Chicago, IL: Domus Books, 1979).

power density, which indicates how fast the stored energy can be released. In terms relevant to a vehicle, energy density broadly dictates range, and power density the top speed and acceleration.

BATTERIES

Batteries contain chemicals that react to pro-duce an electric current. The reaction is reversible, so that the battery can be recharged, enabling it to produce more current, by connecting it to an external electricity supply. The properties of the battery depend on its combination of materials, for which there are many different possibilities, and its design. Battery research explores these possibilities and pursues the most promising.

The energy and power densities of all battery systems available even in prototype form today are several orders of magnitude lower than those of gasoline. This means that a given amount of gasoline has enough energy in it to propel a car much further than the same weight or volume of batteries. The greater efficiency of electric motors than internal combustion engines compensates for this somewhat, but even so a much greater fraction of the total weight and space of a car is likely to be taken up by batteries than by a gasoline tank, so that in turn a much greater fraction of the energy stored in a battery system will go towards simply moving that system around. In plain terms, this makes it hard to design an electric car with the speed and acceleration of an ICEV, and also that the distance it can travel before the stored energy is exhausted is likely to be short. This range limitation is serious because, unlike the refueling procedure for gasoline, recharging batteries usually ties a long time, typically several hours rather than a few minutes. The length of journey for which an EV could sensibly be used is therefore limited to the distance it can travel on a single charge. For current designs this is usually less than 100 miles.

Batteries are expensive. Mass production may bring down the price, but many of the more advanced batteries under development incorporate rare and expensive materials, as well as demanding sophisticated engineering techniques in their construction. Lead acid batteries for the experimental EV that GM will produce in 1993 are likely to cost at least $2,000 and last for 15,000 miles, probably less than 2 years.[5] This would mean spending over $12,000 on batteries over a 100,000 mile vehicle life. The nickel iron battery packs for the Chrysler electric minivan, the TEVan, cost over $6,000 but are hoped to last up to 75,000 miles.[6] The nickel metal hydride battery under development by Ovonic Battery, a subsidiary of Energy Conversion Devices of Troy, Michigan, is projected to cost $5,000, with a life of over 100,000 miles.[7] Sodium sulphur batteries being installed in six Ford Escort conversions for the Postal Service cost $40,000.[8] For these batteries, which are effectively handmade, the expense is the manufacture; the materials themselves are not expensive--sulphur costs less than 10 cents a kilogram.

Most batteries today would not last as long as the rest of an EV; the number of times they can be put through a cycle of discharging and recharging, the 'cycle life,'' is only a few hundred. When this is reckoned into the running costs of the vehicle, the small cost-per-mile advantage that the electricity consumed by a battery EV offers over the gasoline used by an ICEV is likely to be more than canceled out. The initial price of the complete EV is also likely to exceed that of its ICEV equivalent because of the fact that one has to buy an entire battery system at once when purchasing the car. The Japanese EV program, sponsored by the

[5] William J. Cook, "Motoring Into the Future, " *U.S. News and World Report*, Feb. 4, 1991, p, 62; and Gerry Kobe, "EV Battery Breakthrough,'' *Automotive Industries*, September 1992, p. 63.

[6] Chrysler Corporation, "Electric Vehicles," section in *Chrysler Technology Positions and Programs*, no date, received May 1992.

[7] Kobe, op. cit., footnote 5.

[8] David Phillips, fleet management, United States Postal Service, personal communication, Apr. 15, 1992.

Ministry of International Trade and Industry (MITI) aims to produce EVs costing not more than 1.2 times as much as an equivalent ICEV (see below), while Fiat's Panda adaptation, the Elettra, with a range of about 50 miles, sells for the equivalent of $22,300 ,2.6 times the cost of the gasoline model.[9]

Given these obstacles, the main focus of EV research is now on batteries. Motors and control systems have improved tremendously over the last decade with the development of magnet technology and compact electronics, so that the energy efficiency of many EV systems apart from the battery is well over 90 percent. The goal is to develop a battery that is cheap to manufacture, high in power and energy, reliable, safe, and quickly rechargeable, and that can be easily and safely recycled or disposed of. No battery yet exists that meets all these criteria.

FUEL CELLS

Like a battery, a fuel cell produces electricity through an electrochemical reaction between two electrodes mediated by an electrolyte. But unlike a battery, the electrodes are not fixed in the cell, but must be continually added as fuel, while the product of their reaction is removed. The chemicals used as electrodes are hydrogen, usually stored in some form on board the vehicle, and oxygen, from the air. Fuel cells' main exhaust product is therefore water.

Fuel cells have two particular advantages over batteries. First they do not need to be electrically recharged to restore the electrodes, but instead can be quickly replenished by refueling. Second, because of the great efficiency of the reaction, they allow a much greater range before they need refueling. This overcomes one of the major performance drawbacks of the battery-powered EV.

The overall environmental impact of a fuel cell vehicle will depend on the means of production and transportation of the hydrogen it uses. Just as battery EVs may be especially environmentally benign if the batteries can be recharged using renewable energy, FCEVs could have very low overall emissions if biomass or organic waste were used to produce methanol for reforming into hydrogen. Reforming does produce carbon dioxide, but in this case the global carbon budget would not be affected. However, most hydrogen today is derived from fossil fuel hydrocarbons, in a process that is less energy efficient than refining gasoline from crude oil. The fuel cell is so much cleaner and more efficient than the ICE that even under this regime the overall impact of a fuel cell vehicle is less than that of a conventional ICEV; however, the effects are not insignificant. A long-term possibility is to couple solar energy to hydrogen production through photovoltaic cells connected to electrolysis units, using electricity to split water. This would be a very clean method of producing hydrogen, but it is very expensive and likely to remain so for a long time.[10]

Despite their energy capacity, fuel cell systems do not usually provide any better acceleration on their own than batteries. Broadly, the power capacity of a fuel cell depends on its size, while the energy it can provide does not.[11] Most designers of FCEVs therefore favor combining a fuel cell with some kind of storage device that can handle demands for a surge of power when accelerating or climbing a hill, say, allowing the fuel cell to be scaled to the average power demand rather than the peak-which would result in a much heavier system. Such a hybrid vehicle would incorporate a fuel cell for stamina and then for peak power perhaps a small battery, or an ultracapacitor, or even an advanced flywheel, sometimes called a "mechanical battery" (see

9 William R. Diem, "Cost Is Biggest Question, Most Elusive Answer," *Automotive News,* Oct. 12, 1992, p. 34.

10 Mark DeLuchi, *Hydrogen Fuel Cell Vehicles*, research report UCD-ITS-RR-92-14 (Davis, CA: Institute of Transportation Studies, University of California, Sept. 1, 1992).

11 Conversely, a battery's power is fairly constant, but its energy capacity scales with Sire.

Box 7-A—Peak Power Devices

Flywheels-' 'Electromechanical Batteries"

A small contingent in the battery research field maintain that, rather than juggling chemicals, the secret to storing energy successfully lies in using flywheels. The principle is to use a rapidly spinning rotor to store energy, which is then tapped electromagnetically, as in a generator driven **by external** force. The principle of storing energy in a rotating wheel is an old one--potters use it, and many combustion motors employ a flywheel to smooth out fluctuations in their output--but new technology allows rotation speeds far greater than conventional steel-rimmed wheels. Modern flywheels are small and light but strong, and have high energy densities because they spin so fast.

Richard F. Post of Lawrence Livermore National Laboratory has developed designs based on light, strong composite material for the rotor, which would be suspended in a vacuum chamber on magnetic bearings, minimizing frictional This lightweight wheel can spin at tremendous speed (up to 2,000 revolutions a second), storing large amounts of energy. Once spinning, the flywheel system can be left for several months without running down (provided the vacuum is good), until power is needed. Sealed electromechanical systems, of which the flywheel battery is an example, often have very long lifetimes, and the minimal friction of this one certainly suggests that this would be so here. A flywheel battery, unlike an electrochemical battery, would be likely to outlast the rest of the car it was put into, virtually eliminating the cost of replacements.

The energy density predicted for a flywheel system is comparable with batteries under development today, but its most impressive aspect would be power density--far better than the best electrochemical batteries, and even superior to internal combustion engines. This means that a flywheel battery could deliver a tremendous jolt of energy for sudden acceleration. For this reason, some vehicle designers seethe flywheel as a natural adjunct to the fuel cell, which has better energy density than power density. The flywheel could allow regenerative braking, too.

A well-known danger of flywheels as they spin faster is that of sudden failure, when the stresses on the wheel become such that it flies apart explosively. In steel wheels this sends lethal shards of metal flying in all directions at high speed, but the composites used in the proposed wheels shred themselves into a mass of hot, dense fluff, which can be effectively contained by a strong composite box surrounding the vacuum chamber.

The designs have not been built yet, and to do so will demand precision and exacting material and physical specifications. Several groups are working to develop the concept. In addition to Dr. Post at Lawrence Livermore, who is seeking industrial partners to build a trial system, there is American flywheel Systems Inc. (AFS), of Bellevue, Washington. AFS received patents in June 1992 for a flywheel design of which they intend to develop a prototype by mid-1 994, working with Honeywell, Inc., which also has patents in flywheel technology.[2] Honeywell has been using flywheels in space and defense applications for 30 years and brings expertise in bearings, electronic controls, and vacuums to the team.[3] After the prototype, the companies aim to produce commercial battery packs for EVs in 1998. At this early stage, cost estimates are vague, but the materials used are no rarer than those in electrochemical batteries, so that the main factor affecting price is likely to be ease of manufacture. Ford Motor Co. has also announced that it will develop a flywheel system for use in a hybrid EV.[4] Unique Mobility Inc. of Golden, Colorado will be a partner and supplier.

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1 Michael J. Riezenman, "A Different Spin on an EV Battery," *IEEE Spectrum,* November 1992, p. 100; and Glenn Rifkin, "Using Spin to Power Electric Cars," New York *Times,* Nov. 11, 1992, p. D5.

2 A/co/10/ *ink's New Fuels Report, vol.* 14, No. 11, Mar. 15, 1993, p. 1.

3 Dan Kaplan, "Honeywell Joins American Flywheel for Electric Vehicle," *Inside DOT and Transportation Week,* vol. 4, No. 10, Mar. 12, 1993, p. 1.

4 William R. Diem, "Ford Aims to Spin Electric Energy From Flywheel," *Automotive News,*, Apr. 5, 1993, p. 37.

Ultracapacitors

Capacitors store charge on metal surfaces separated by thin layers of insulator. Recent developments in materials technology, including the creation of aerogels--very light porous solids--at Lawrence Liver more, allow the creation of substances with very large surface areas in comparison to their volume, which makes them suitable for the construction of capacitors capable of storing particularly large amounts of charge. These are called ultracapacitors, and t heir electrical properties are such that they can deliver t he stored energy extremely rapidly, in a sudden jolt of high voltage current. Their high power density possibly makes them suitable for combining with some energy storage device that has a higher specific energy but less impressive power density, such as a fuel cell. Their development has been driven in part by the search for very high power sources to fire t he intense lasers used in SDI research. Idaho National Engineering Laboratory is testing ultracapacitors for EV use.

Little direct work has been done on applying ultracapacitor technology to EVs, although rumor has it that an Isuzu "mystery" EV on display in 1990 was powered by a large capacitor, in part because of its high acceleration and its very quick charge up time, another feature of capacitors.[5]

5 Al Haas, "Isuzu's New Device May Propel Work on Electric Car," *Philadelphia Enquirer*, May 13, 1990, p. 1-D.

box 7-A). The presence of such a storage device would also allow the use of regenerative braking to recapture some of the kinetic energy otherwise lost when slowing down.[12] The exact relative size of the fuel cell and battery is a subject of ongoing research that seeks to balance the system's size and weight with demands for range and acceleration.

As well as the engineering of the cell itself, an important challenge to designers of fuel cell systems is the means of storing the hydrogen. This can be done in a number of ways (see table 7-l). Factors at play in the development of hydrogen storage systems include the energy and power densities in terms of weight and volume, the safety during refueling and in case of accidents, and the cost of the materials and construction. The methods likely to see the most use early in the development of fuel cell vehicles are methanol, reformed on board, and compressed gas in strong tanks. The former adds complexity and weight to the system, since an additional device, the reformer that splits the methanol into hydrogen and carbon dioxide, must be carried. Offsetting this is the advantage that methanol is already quite widely and cheaply available. Methanol can be produced from natural gas and is sometimes described as a bridge to wider use of hydrogen in the future, since a pipeline distribution infrastructure could be shared to some extent, and reforming at point of use would allow early use of hydrogen.

Hydrogen compressed in tanks has the virtue of simplicity, and with recent drops in the price of carbon fiber, a reinforcing material strong and light enough to wrap around tanks, it is becoming more economically feasible. One of the leading firms developing compressed hydrogen storage systems for FCEVs is an engineering consulting firm, most of whose previous work has been for the aerospace industry, including the National Aeronautics and Space Administration (NASA), but which received support from Ford to develop automotive applications. Much of the expertise on handling hydrogen as a fuel has developed in the aerospace community, based on experience with hypersonic and rocket propulsion, one of the few previous fuel applications of hydrogen.

Battery-powered EVs will probably arrive in the market place before FCEVs. Fuel cell technology for vehicle propulsion has not received as much attention as battery technology, and far

12 See footnote 1 for an account of regenerative braking.

Table 7-l—Hydrogen Storage Met hods for Vehicles

Storage method	Advantages	Disadvantages	Comments
Compressed H_2 gas	Familiar and available. In principal allows fast refueling like gasoline.	Requires bulky tanks that may be heavy or expensive.	Light and strong advanced materials may be expensive. Carbon-fiber wrapped, aluminum-lined tanks allow storage at 8,000 psi, high enough for energy density competitive with other methods. In the last few years, the price of carbon fiber has dropped from over $50/lb to around $12/lb.
Liquefied H_2	Relatively familiar and simple. High energy density: light and compact.	Requires insulated, crashworthy tanks. Liquefaction is energy intensive. Refueling might be slow.	Could connect to a tanker distribution infrastructure based on liquefied hydrogen. Evaporation likely over a few days of disuse.
Metal hydride	Safe.	Under development. Expensive. Refueling probably slow. Storage bed is heavy.	Powdered metal absorbs hydrogen under pressure and then releases it when heated.
Cryoadsorption	Well-understood technology.	Fairly expensive. Bulky.	Hydrogen is adsorbed on activated carbon at low temperature (150K) and high pressure (825 psi), requiring reinforced, cooled tanks. Refrigeration would use energy. Refueling stations need compressor, refrigerator, and vacuum pump.
Liquid organic hydrides	Safe.	Under early development. Handling methylcydohexane (organic liquid) poses safety challenges. Bulky and heavy.	Under development by Mercedes-Benz as the 'Hypasse' method.
On board reforming of methanol	Methanol is familiar, relatively cheap and widely available.	Must carry heavy reformer on board. $C0_2$ emissions.	Likely to be most common early method because of its relatively advanced development, and the availability of methanol. Could serve as a bridge to pure H_2 use.
Steam oxidation of iron	Potentially cheap. Compact. Safe.	Undeveloped. Heavy.	Steam from the fuel cell is used to oxidize powdered iron in a tank on board the vehicle, releasing hydrogen to be used as fuel. (The oxygen in the water molecule (H_20) reacts with the iron to form rust, the hydrogen is released.) When the entire tank of iron has turned to rust it is exchanged for fresh iron and the oxidized material is reduced back to iron at a central facility. H Power of New Jersey is developing this technology.

KEY: H_2=hydrogen; CO_2=carbon dioxide; psi=pounds per square inch; K=degrees Kelvin

SOURCE: Office of Technology Assessment, 1993, drawing on: Mark DeLuchi, *Hydrogen Fuel Cell Vehicles*, UCD-ITS-RR-92-14 (Davis, CA: University of California, Sept. 1, 1992).

Box 7-B—The PEM Fuel Cell: The Front Runner[1]

The proton exchange membrane (PEM) fuel cell is widely regarded as the most promising type for light duty vehicle use, as it is relatively light and compact, operates at a lower temperature than most other types of fuel cell (between 60 and 100 degrees centigrade), has a long life, and starts quickly. (Some kinds of fuel cell, such as the solid oxide fuel cell, take several minutes to reach operating temperature and to produce significant amounts of power; they are more suitable for large stationary applications.) The PEM cell was first developed for space power in the 1960s and was used in the Gemini program, but was not much used after that until the 1980s, when interest blossomed in its potential for vehicular use.

A jointly funded government and industry effort to develop PEM cells for vehicle use, whose participants include the Department of Energy, GM Allison Gas Turbine Division, GM Technical Staffs, Los Alamos, Dow, and Ballard Power Systems Co., began in September 1990.[2] The program is set to run for 6½ years, culminating in the demonstration of a PEM fuel cell hybrid vehicle. The first phase, which drew to a close in late 1992, attempted to demonstrate the feasibility of the project by producing a working 10kW methanol-fueled cell.

Energy Partners of Florida is designing and building a PEM cell EV that runs on compressed hydrogen and incorporates a peaking battery.[3] H-Power of New Jersey and Rolls Royce are jointly developing a PEM cell vehicle, and Ballard Technologies of Canada is working to demonstrate a 30-foot PEM cell transit bus. In addition, Los Alamos National Laboratory continues to research the applicability of fuel cells to certain space missions, such as for longer term extraterrestrial power supply.[4] The U.S. Army is also investigating PEM cells as a lightweight power source for individual soldiers.[5]

1 Fuel cells are conventionally known by the name of their electrolyte. In a PEM cell the electrolyte is a solid polymer, somewhat like Teflon®. The cells have sometimes also been called solid polymer electrolyte (SPE) cells.

2 James R. Huff, "Fuel Cell Power Plants for Transportation Applications," paper prepared for Seventh Annual Battery Conference on Applications and Advances, Jan. 21-23, 1992, Los Alamos National Laboratory Paper No. LA-UR-91-3900.

3 Mark DeLuchi, *Hydrogen Fuel-Cell Vehicles*, research report UCD-ITS-RR-92-14 (Davis, CA: Institute of Transportation Studies, University of California, Sept. 1, 1992).

4 Nicholas E. Vanderborgh, James C. Hedstrom, and James R. Huff, "Electrochemical Energy Storage Using PEM Systems," paper prepared for Proceedings of the European Space Power conference, Florence, Italy, September 1991, Los Alamos National Laboratory Paper No. LA-UR-91-2377.

5 Richard Jacobs and Walter G. Taschek, "Individual Power for the Soldier System," paper delivered at 1992 Fuel Cell Seminar, Tuscon, AZ, Dec. 1, 1992.

fewer working vehicles run on fuel cells than on batteries. On the other hand, the last 5 years have seen two major technical achievements that improve the prospects for fuel cells. The first was the development of membrane materials by Dow Chemical that allowed a threefold increase in power density, putting the performance of proton exchange membrane (PEM) FCEVs within sight of that of ICEVs (see box 7-B). The second was the patenting by Physical Science Inc. (PSI) of Andover, Massachusetts of a method to reduce the quantity of platinum catalyst in a cell eightyfold, vastly improving the economic feasibility of fuel cells. There is no longer a single major obstacle blocking the eventual use of fuel cell vehicles in the way that the inability to produce a long-lived, light, powerful, and energetic battery has done so far for battery EVs. A growing minority of researchers think that the fuel cell vehicle, rather than the battery EV, represents the auto industry's best hope for the longer term future.

ALTERNATIVE FUELS

Several other technologies for reducing auto emissions will compete with EVs in providing cleaner transport. The Office of Technology Assessment report *Replacing Gasoline: Alternative Fuels for Light Duty Vehicles* em-nines the advantages and disadvantages and states of development of six main alternatives to gasoline: methanol, natural gas, ethanol, hydrogen, reformulated gasoline, and electricity .13 (See table 7-2 for a summary of their pros and cons.) All but electricity can be burned in an ICE, so that the technology of vehicles using them is likely to resemble that of existing gasoline vehicles. The existence of an infrastructure for refueling and servicing ICEVs favors liquid fuel vehicles over EVs, which are likely to require special charging facilities or development of an infrastructure to support hydrogen use.[14] However, as noted, EVs have some decided long-term advantages in protection of the local and global environment and energy independence.

LEGISLATIVE CONTEXT AND FEDERAL R&D SUPPORT FOR EVs

The major legislative efforts to promote means of transport other than gasoline powered vehicles have been of three kinds. Clean air regulations have restricted the emissions of individual cars and of fleets taken in aggregate, encouraging manufacturers to explore alternative types of vehicle, and have been the main driver of most recent interest in EVs. Transport and energy legislation have both supported research and development of alternative technologies directly. A further approach has been the procurement of alternative vehicles for use in government fleets. This approach attempts to reduce uncertainty about finding a market for the technology in its commercial infancy, when companies supplying it will be at their most vulnerable.

Clean Air Requirements

The 1963 Clean Air Act first authorized the setting of Federal standards for automobile emissions, and granted California, alone among the States, the right to set standards stricter than Federal ones. The combination of Federal and California regulation has continued to drive most auto emissions reductions to this day. Technology limitations and lack of incentives for manufacturers pushed back standards and time limits during the 1970s, but the Clean Air Act Amendments of 1990 made two major changes that affect EVs. One requires that government and private operators of fleets must introduce “clean fuel” vehicles in areas that do not meet the ambient air quality standards of the act (nonattainment areas), and the other requires that California establish a pilot program to lead the way in promoting clean fuel vehicles. The clean fuel fleet program requires that in certain ozone nonattainment areas an increasing percentage of new vehicles added to all fleets of 10 or more vehicles starting with model year (MY) 1998 use cleaner fuel. Reformulated gasoline appears to satisfy the act’s definition of cleaner fuel. Although EVs are not specified, certain provisions that allow fleet operators credit for exceeding the requirements may encourage their purchase. Under the California pilot program 150,000 clean fuel vehicles are to be sold during model years 1996 to 1998, and 300,000 a year thereafter. Other States can opt to follow the California plan and adopt its standards.

13 U.S. Congress, Office of Technology Assessment, *Rep[acing Gasoline: Alternative Fuels for Light Duty Vehicles,* OTA-E-364 (Washington DC: U.S. Government Printing Office, September 1990).

14 Hydrogen can be used as a transport fuel in both ICEVs and FCEVs; in both cases the vehicles would have very low emissions, and many of the obstacles are common to both-hydrogen production transport, and on-board storage. If these problems were solved, the choice between hydrogen FCEVs and ICEVs would become more urgent; at the moment small amounts of R&D are being done in both areas, with no clear lead, although fuel cells are more efficient than ICES. A few prototype vehicles of each kind exist. This report explores the technology, employment, and conversion opportunities of EVs as an example of a new technology, and is not intended as an endorsement of this particular technology to the exclusion of all others.

Table 7-2—Pros and Cons of Alternative Fuels

Fuel	Advantages	Disadvantages
Methanol	Familiar liquid fuel. Vehicle development relatively advanced. Organic emissions (ozone precursors) will have lower reactivity than gasoline emissions. Lower emissions of toxic pollutants, except formaldehyde. Engine efficiency should be greater. Abundant natural gas feedstock. Less flammable than gasoline. Can be made from coal or wood though at higher cost. Flexfuel "transition" vehicle available. Make from many feedstocks.	Lower energy density than gasoline, so larger fuel tanks. Would likely be imported from overseas. Formaldehyde emissions a potential problem. More toxic than gasoline. M1OO has non-visible flame, explosive in enclosed tanks. Costs likely somewhat higher than gasoline, especially during transition period. Cold starts a problem for M1OO. Greenhouse problem if made from coal.
Ethanol	Familiar liquid fuel-commercial in Brazil. Organic emissions will have lower reactivity than gasoline emissions (but higher than methanol). Lower emissions of toxic pollutants. Engine efficiency should be greater. Produced from domestic sources. Flexfuel "transition" vehicle available. Lower CO with gasohol (10 percent ethanol blend). Enzyme-based production from wood being developed.	Much higher cost than gasoline. Supply is limited, especially if made from corn. Lower energy than gasoline, so larger fuel tanks. Cold starts a problem for E1OO. Food/fuel competition if at very high production levels.
Natural gas	Though some is imported, likely North American source for moderate supply (1 million barrels a day or more gasoline displaced). Excellent emission characteristics except for potential of somewhat higher NO_x emissions. Gas is abundant worldwide. Modest greenhouse advantage. Can be made from coal.	Range quite limited, need large fuel tanks w/added costs, reduced space (LNG range not as limited, comparable to methanol). Dual fuel "transition" vehicle has moderate performance, space penalties. Retail fuel distribution system must be built. Slower refueling. Greenhouse problem if made from coal.
Electricity y	Domestically produced and widely available. Minimal vehicular emissions. Excess capacity available in some places (for night time recharging). Big greenhouse advantage if powered by nuclear or renewable electricity. Wide variety of feedstocks in regular commercial use.	Range, power very limited. Much battery development required. Slow recharging. Existing batteries are heavy, bulky, and have high replacement costs. Vehicle heating/cooling hard-drains power, limits range, Potential battery disposal problem. Emissions from power generation can be significant.
Hydrogen	Excellent emission characteristics-minimal hydrocarbons. Would be domestically produced. Big greenhouse advantage if derived from renewable or nuclear energy. Possible fuel cell use,	Fuel storage a challenge. Vehicle and total costs high. Extensive research and development effort required. Needs new infrastructure. Fuel cells need further development.
Reformulated gasoline	No infrastructure change except refineries. Probable small to moderate emission reduction. Engine modifications not required. May be quickly available for use by entire fleet, not just new vehicles.	Emission benefits remain uncertain. Costs uncertain, but will be significant, though low in comparison to many other alternatives. No energy security or greenhouse advantage.

KEY: LNG=liquified natural gas; NO_x=nitrogen oxides; Co-carbon monoxide; E1OO-1OO percent ethanol; M1OO-1OO percent methanol.

SOURCE: U.S. Congress, Office of Technology Assessment, *Replacing Gasoline: Alternative Fuels for Light-Duty* Vehicles, OTA-E-364 (Washington, DC: U.S. Government Printing Office, September 1990).

California passed its own Clean Air Act in 1988, setting emission standards stricter than those for the rest of the country. Its timetable was shortened in the California Clean Air Act Amendments of 1990. In September of that year the California Air Resources Board (CARB) promulgated regulations for meeting the targets set by the act.[15] The regulations apply to all manufacturers intending to sell more than 3,000 vehicles a year in the State and require a growing proportion of the vehicles sold each year to fall into increasingly strict categories. The most striking element of the plan is the requirement that in 1998, 2 percent of the vehicles sold must be "zero-emission vehicles, ' a fraction that grows to 10 percent by 2003 (see table 7-3).

California alone is a large market-sales of new cars were 1,059,926 in 1990 and 1,005,896 in 1991, more than 10 percent of the total U.S. sales of 9,159,629 and 8,234,017, respectively[16]—so that its regulations caused automakers to move into action. The Governors of nine northeastern States[17] and the Mayor of the District of Columbia announced on October 29, 1991 that they would present the California standards to their legislative bodies for consideration, a further prod for auto producers. Rhode Island, Vermont, Texas, Illinois, and Colorado announced their interest in the standards shortly afterwards.[18] The initial excitement at this news diminished subsequently, as it became clear that there was considerable opposition to the idea within many States. Legislatures in Vermont, Maryland, and Virginia rejected the California plan and in several other States there has been no further action since the Governors' announcement. Nonetheless, the once-interested States purchased almost half of all cars sold in the United States in recent years .19 Lawmaking is proceeding in some States; on January 31, 1992 Massachusetts became the first northeastern State formally to adopt the California program as law, and Maine and New York followed suit later that year, although a New York judge subsequently ruled that the 2 percent mandate was illegal for the State and that only declines in average emissions could be required.

Zero emission vehicles (ZEVs), the most stringent category, which are first required in California in 1998, can effectively only be electric vehicles. The regulations in effect require that at least 20,000 EVs a year be sold in California starting in 1998, rising to more than 100,000 by 2003. If the eastern States were included, the required market size could increase to over 65,000 in 1998 and almost half a million by 2003.

The regulations remain controversial. Major automakers consider it unjust to impose a requirement that they sell vehicles whose technological development is still uncertain and that they may not be able to manufacture for a price comparable to that of more conventional cars. They argue that the law would force them to sell some vehicles at a considerable loss if they could not otherwise meet their quota of ZEVs, and they are reportedly considering legal action against California on the basis that the requirement is an illegal "taking."[20] If they are forced to sell at a loss, then the

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15 University of California, Los Angeles, Lewis Center fo, Regional Policy Studies, Prospects Alternative Fuel Vehicle Use and Production in Southern California: Environmental Quality and Economic Development, Working Paper No. 2 (Los Angeles, CA: The University, May 1991).

16 "U.S. New-Car Registrations by State," *Automotive News,* "1991 Market Data Book," May 29, 1991, p. 36 and "1992 Market Data Book," May 27, 1992, p. 34.

17 The Sines were Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, and Virginia.

18 David Woo&M and Thane Peterson, "Here Come the Greenmobiles," *Business Week, Nov.* 11, 1991; and Matthew L. Wald, "California's Pied Piper of Clean Air," *The New York Times,* Sept. 13, 1992, p. Cl.

19 "U.S. New-~ Registrations by State,' Automotive News, "1991 Market Data Book," May 29, 1991, p. 36.

20 John Wallace, director, electric vehicle planning, Ford Motor Company, personal communication, Jan. 9, 1992.

Table 7-3-California Clean Air Resources Board Requirements

Vehicle Emission Standards:

	Pollutant emitted per mile (grams)		
Vehicle category	Hydrocarbons	Carbon Monoxide	Nitrogen Oxides
First Step	0.39g	7.0g	0.4g
Second Step:			
To 50,000 miles	0.25	3.4	0.4
To 100,000 miles	0.31	4.2	0.4
Transitional low emission (TLEV)	0.125	3.4	0.4
Low emission (LEV)	0.075	3.4	0.2
Ultra-low emission (ULEV)	0,040	1.7	0.2
Zero emission (ZEV)	0.0	0.0	0.0

Annual requirements:

	Percentages of automakers' sales required to meet emissions standards by given dates					
Model year	First step	Second step	TLEV	LEV	ULEV	ZEV
1991	100	—				—
1992	100	—				—
1993	60	40	—			—
1994	10	80	10			—
1995	0	85	15			—
1996	0	80	20	—	—	—
1997	0	73		25	2	—
1998	0	48		48	2	2
1999	0	23	—	73	2	2
2000	0	0	0	96	2	2
2001	0	0	O	90	5	5
2002	0	0	0	85	10	5
2003	0	0	0	75	15	10

How to read these tables: The upper table defines six categories of vehicles in terms of their emissions. The lower table gives the year by year requirements for the percentage of an automaker's sales in that year that must meet each of the progressively stricter categories. Thus, in 1997, 73 percent of ears sold must be such as not to emit more than 0.259 of hydrocarbons (HC), 3.49 of carbon monoxide (CO), and 0.4g of nitrogen oxides (NO_x) per mile (for the first 50,000 miles), 25 percent must not emit more than 0.0759HC, 3.4g CO, & 0.2g NO_x, and 2 percent must not emit more than 0.04g HC, 1.7g CO, & 0.2g NO_x.

SOURCE: *Automotive* News, Feb. 25, 1991.

inclusion of more States requiring ZEV sales will increase the extent of their loss. Auto manufacturers also raise questions about whether the California standards are appropriate to the northeast, where weather and pollution sources are different. Drivers in the cold northeast, for instance, require heaters in their cars, which can consume a lot of power.[21] The energy density of most batteries also drops off steeply in the cold.

Nonetheless, all the major auto manufacturers, despite their reluctance at some levels, are proceeding with research, development, and design

[21] Climate control is a problem for current EVs. Existing heating, ventilation, and air-conditioning (HVAC) systems draw heavily on electrical supplies; in an EV they would eat into energy reserves and seriously diminish its range. A component of EV R&D is the development of high-efficiency, low-energy subsidiary systems such as HVAC.

of the technology to comply with the new requirements. In December 1992, the U.S. Council for Automotive Research (US CAR), an organization formed by the Big Three in June 1992 to promote cooperative precompetitive research, announced that anew consortium would focus on EV technology .[22]

Whether the California regulation stands in its present form or not, the momentum of the world automobile industry is veering towards new, cleaner, more efficient technologies. Auto companies worldwide are exploring many different approaches to meeting the demands of the next decades for cleaner personal vehicles.

Electric Vehicle R&D

A total of $98 million has been appropriated for EVs in 1993--$61 million for DOE, more than half of it for batteries; $12 million for the Department of Transportation (DOT); and $25 million for the Advanced Research Projects Agency (ARPA). At present there is little overall strategy guiding Federal spending on EVs. Instead each appropriation funds separate programs.

ISTEA

A landmark piece of Federal legislation affecting transport, passed by the 102d Congress, was the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA).[23] The stated intent of the act is to develop ''a national intermodal transportation system that is economically efficient, environmentally sound, provides the foundation for the Nation to compete in the global economy and will move people and goods in an energy efficient manner. ' The act authorized $119.5 billion for highways and $31.5 billion for mass transit through fiscal year (FY) 1996, and gives State and urban authorities much greater discretion in how to spend grant money. The money actually spent will depend on the size of DOT's appropriations over that time.

ISTEA contains some support for EVs. It established a program to stimulate the development of advanced transportation systems and electric vehicles by authorizing $12 million for FY 1992 to support at least three EV consortia. The consortia are to design and develop EVs and advanced transit systems, related equipment, and production processes. The act encourages the consortia to include small businesses and defense and aerospace firms. At least one-half of the funds to support consortia must come from nonfederal sources. From the $12 million, four awards have been made: Calstart, a California consortium that includes Hughes Aircraft, Allied Signal, and Fairchild Manufacturing is getting $4 million (see below); the Chesapeake consortium (Chrysler, Westinghouse Electric, Baltimore Gas and Electric, and the State of Maryland) gets $4 million to developed an advanced powertrain; a consortium of the New York Metropolitan Transit Authority, Bus Industries of America, General Electric, and several New York utilities, including Consolidated Edison and Niagara and Mohawk, is getting $2.3 million to develop a 40-foot standard transit bus that runs as an electric hybrid with an independent electric drive motor in each wheel; and the Advanced Lead Acid Battery Consortium, composed of researchers from the research triangle of North Carolina, gets $1.2 million to develop rapid recharging and battery monitoring systems for advanced lead acid batteries.

THE DEPARTMENT OF ENERGY

The DOE conservation and renewable energy program has a FY 1993 budget of $60.8 million for the Electric and Hybrid Vehicle Research program, an increase of 39 percent over FY 1992. DOE spending on EVs dropped from a high point

22'1''h,is is in addition to eight already existing consortia under the umbrella of USCAR, on such subjects as recycling, gasoline emissions, the use of lightweight materials for more fuel economical designs, on board electronics, and better crash simulation.

23 Public Law 102-240.

Table 7-4-DOE Electric Vehicle Spending FY 1978-93 ($ millions)

Year	Current year dollars	1992 constant dollars
1978	$ 0.0	$ 0.0
1979	37.2	70.5
1980	37.0	63.3
1981	36.8	57,2
1982	18.0	26.1
1983	13.9	19,2
1984	11.7	15.6
1985	8.3	10.7
1986	8.3	10.4
1987	13.3	16.2
1988	14.1	16,5
1989	13.8	15.5
1990	17.7	19.1
1991	25.0	25.8
1992	43.0	43.0
TOTAL	$298.1	$409.1
1993 appropriation	$60.8	

SOURCE: U.S. Department of Energy.

of $70.5 million (1992 constant dollars) in 1979 to remain around $15 million during the second half of the 1980s, until starting to climb again in 1990 (see table 7-4). The funding is divided among fuel cells, which get $12 million; a hybrid vehicle development program ($16.8 million); and batteries, which got the remaining $31.5 million, the bulk of this going to the USABC, described below.[24] The rest of the battery money goes directly to the national labs.

The 1992 Energy Act contained further support for EVs as well as general provisions mandating Federal fleet purchases of alternative fueled vehicles. It authorized a total of $50 million to be spent over the next 10 fiscal years to fund an EV commercialization demonstration program based in several metropolitan areas; no one project may receive more than 25 percent of the available funds. The act allows for discount payments to be made to project proposers to be passed on to users of EVs to make up any difference in price between the EV and a comparable ICEV. A further $40 million for the next 5 fiscal years was authorized for joint ventures, with at least a 50 percent nonfederal cost share, to develop EV infrastructure and support technology. No money was provided for either of these programs in DOE's 1993 appropriation, so that in early 1993 the agency was revising its internal budget to try to comply with the legislative intent by drawing on overhead funds and other conservation programs. It was also revising the 1994 budget request to seek extra funding for these new programs.

ARPA

ARPA received $25 million for FY 1993 to stimulate commercial EV demonstration programs, $5 million of it to be spent in Hawaii and $2.5 million in Sacramento, the rest without restriction. The funding is for setting up consortia with industry and utilities, sharing at least 50 percent of the cost, starting in the first quarter of 1993. A broad agency announcement (BAA)[25] to solicit proposals went out in late 1992. ARPA has never funded commercial EV work before, although it has long been involved in the development of electric drives for military vehicles such as tanks and personnel carriers.[26] The agency also received an appropriation of $11.8 million to develop fuel cells for a range of applications including automotive, with the authorizing legislation urging the Department of Defense (DoD) to encourage dual-use aspects through cost sharing with industry and cooperation with DOE.

THE UNITED STATES ADVANCED BATTERY CONSORTIUM

The shape of national battery research has changed considerably since January 1991, with the formation of the United States Advanced

24 $0.5 million goes to a separate capital and equipment account.

25 A BAA is like a request for proposals (RFP), but less specific in its requirements.

Rick Cope, land systems, Advanced Research Projects Agency, personal communication, Dec. 16, 1992.

Battery Consortium.[27] Previously, most research was piecemeal. Automakers and small firms did some-Ford patented the sodium sulphur battery in 1965—and the national laboratories kept up small programs, with Lawrence Berkeley Laboratory and Sandia taking the lead.[28]

USABC, whose principal members are the Big Three U.S. motor companies, was established to focus national attention and research on batteries deemed by the members to have the greatest commercial potential.[29] Decisions as to which technologies will be pursued are no longer in the hands of the DOE labs, but are made by the consortium. Those technologies selected will be the object of more research, with much larger budgets than they previously had in the DOE program; funding for other types of batteries will be heavily reduced. The boost for the selected technologies is considerable: the budget for the first 4 years of USABC is approximately $260 million, provided in equal shares by DOE and the nongovernment participants.

Chrysler, Ford, and GM are each providing between $36 and $40 million, and $11 million comes from the Electric Power Research Institute (EPRI), a research consortium for the electric utility business. The Federal Government matches research funds, and the contractors doing the research themselves supply some funding. In FY 1993 the DOE contribution to USABC was at least $24.2 million, out of a total $60.8 million the agency contributed for EVs.

The consortium is planned to run for 12 years, although a partner may withdraw at any time, USABC has set performance and development goals for mid- and long-term batteries on a timetable largely shaped by the coming requirements of California emissions law (see table 7-5).[30] The goal for mid-term batteries is to have completed all the design and development work and the successful pilot production of a prototype by 1994. The goals for the longer term batteries are to have demonstrated feasibility by 1994 and to be able to produce the battery by 1997.

Table 7-5--USABC Battery Technical Objectives

	Mid term	Long term
Specific Energy (Wh/kg).	100	>200
Energy Density (Wh/L)	135	>300
Specific Power (W/kg)	150	>400
Power Density (W/L)	250	>600
Life (years)	5	10
Life (cycles to 80% discharge)	600	1,000
Cost ($/kWh)	<$150	<$100
Operating Temperature Range (°C)	-30 to 65	-40 to 85
Recharge Time (hours).	6	3

SOURCE: United States Advanced Battery Consortium.

The consortium is focusing its attention on a relatively few battery technologies that seem to offer the best hope of meeting the goals they have set, probably a main choice and a second choice in both the mid- and long-term categories. The main mid-term choice is the sodium sulphur battery .31 It has higher power density than today's principal working batteries, lead acid and nickel iron, and has been the subject of more research than most rivals. As well as awarding development contracts, USABC will buy some batteries for testing from companies that do not wish to give up any of their proprietary rights by doing

27 Dr. Frank Jamerson, assistant program manager, electric vehicles, General Motors, personal communication, Jan. 13, 1992; John Wallace, director, electric vehicle planning, Ford Motor Company, personal communication Jan. 9, 1992.

28 Kim Kinoshita, Lawrence Berkeley Laboratory, personal communication, Mar. 23, 1992; and Gary Henricksen, Argonne National Laboratory, personal communication Apr. 8, 1992.

29 United States Advanced Battery Consortium, "Chrysler, Ford, General Motors Form Advanced Battery Research consortium," press release, Jan. 31, 1991.

30 United States Advanced Battery Consortium, "Information Sheet," Oct. 22, 1991.

31 Representatives of Chrysler, Ford, and General Motors all suggested that this was so during separate interviews in early 1992, and the final announcement was reported in William R. Diem, "Sodium-SulfurB attery Gets Consortium Backing," *Automotive News*, Apr. 5, 1993, p. 22.

funded research.[32] The consortium will hire a technically qualified company to perform tests on battery systems.

The first contract awarded, however, was for the development of a nickel-metal hydride prototype.[33] The Ovonic Battery Company of Troy, Michigan, was awarded $18.5 million to develop their technology, already employed in a range of small electronic products such as laptop computers and cellular telephones, into a larger cell suitable for use in an EV. The contract also called for initial production of the battery once development is complete. The technology is promising; if goals are met, Ovonics expects to produce a battery commercially in 1994, which if used in place of the lead acid batteries in a car like the GM Impact would more than double its range while reducing lifetime cost.[34] On October 29, 1992 the consortium announced further contracts, totaling $42 million, with three companies and Argonne, Sandia, and Idaho National Engineering Lab, and further CRADAs with Lawrence Berkeley Lab and the National Renewable Energy Lab (see table 7-6).[35]

The goals set by the consortium are ambitious; they require progress in some cases from the level of a single cell of 2 volts, achieved in a laboratory, to an entire battery of such cells, capable of delivering 300 volts. The step up in performance demands engineering successes that are far from straightforward. Critics of the consortium worry that it has put its eggs into too few baskets, and that many battery technologies are at too early a stage in their development to allow sensible decisions to be made about which to support. They fear that promising opportunities will be lost when money dries up for some of the technologies not chosen by the USABC. However, the arguments for concentration of effort on a few battery types are practical: the pressure of California's coming requirements on manufacturers demands that they strongly support those technologies that appear to offer the best chance in the near term.

A further source of strain in the consortium, and one that slowed its early progress, has been clashes among the Big Three, DOE, national labs, and small businesses over intellectual property rights. The USABC agreement was concluded at the highest level of DOE, in the office of the Secretary of Energy, and takes a different approach to issues of property rights from that adopted in most technology transfer agreements between labs and industry worked out at lower levels of DOE. The USABC agreement requires that companies participating in research give up some intellectual property rights to USABC. Some experienced government officials see this as a strong disincentive to participation, particularly for small businesses, which are often a fertile source of new ideas and whose competitive position depends largely on the ability to profit from this inventiveness.[36]

The USABC agreement does grant small businesses exclusive rights to their inventions in all fields other than the automotive, and in the automotive field requires that USABC pay royalties to the firm or lab scientists that made the invention, although the consortium retains the

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32 Jack Guy, Electric Power Research Institute, personal communication Sept. 24, 1992.

33 Boyce Rensberger, "New Battery Required for Autos of Future," *The Washington Post, May 25, 1992,* p. A3; and USABC, "United States Advanced Battery Consortium Announces First High-Tech Battery Contract With Ovonic Battery Co.," press release, May 19, 1992.

34 Gerry Kobe, "EV Battery Breakthrough?" *Automotive Industries,* September 1992, p. 63.

USABC, "U.S. Advanced Battery Consortium Announces $54 Million in Battery Development Contracts; Three More National Labs Join USABC Research," press release, Oct. 29, 1992.

36 U.S. Department of Commerce, Office of the Undersecretary for Technology, "Statement of Concerns Relating to DOE's 'Exceptional Circumstances' Determination," undated, and accompanying letter from Robert M. White, Department of Commerce, to John J. Easton, general counsel, U.S. Department of Energy, Jan. 15, 1992.

Table 7-6--USABC Awards as of October 1992

Awarded to:	Value	Duration	Research area
Contracts			
Ovonic Battery Co.	$18.5 million	2 years	Mid-term nickel metal hydride batteries.
W.R. Grace& Co.	$24.5 million	3 years	Lithium polymer battery.
Johnson Controls, Inc. SRI International EIC Laboratories UCAR Carbon Company, Inc.	$6.3 million in first year		
Saft America Argonne National Lab	$17.3 million	3 years	Lithium iron disulphide.
Delco Remy Valence Technology, Inc.	not yet announced	not yet announced	Tentative contract subject to DOE approval, to develop ambient temperature lithium polymer technology.
CRADAs			
Sandia National Lab	$3 million	1 year	Applied research on lithium polymer battery materials.
Argonne National Lab	$7.3 million	38 month	Lithium metal sulphide research (ANL invented this technology).
Argonne National Lab	$1 million	36 month	Nickel metal hydride and high-temperature battery testing
Idaho National Engineering Lab	$900,000	24 month	Nickel metal hydride and high-temperature battery.
Lawrence Berkeley Lab	$1.1 million	3-4 years	Lithium polymer battery.
National Renewable Energy Lab	$2.2 million	3-4 years	Insulation for high-temperature batteries.

SOURCE: U.S. Advanced Battery Consortium, press release, Oct. 29,1992.

rights to it.[37] Lab staff remain uneasy that they have been forced to surrender one of the most powerful incentives they could offer their researchers to do cooperative research, although the round of CRADA announcements in late 1992 suggests that problems are being ironed out. Early negotiations were further protracted by the variations among the national labs in their handling of intellectual property under CRADAs (see ch. 4). USABC negotiators abandoned the attempt to make a blanket CRADA covering all their dealings with the labs; instead they forge separate ones with each participating lab.

The concentration of effort and resources is intended to push the technology forward to meet the demands of clean air legislation. Despite its slow start, the formation of the consortium has dramatically increased the attention paid nationally to battery research and to EVs in general, and this may ultimately prove a benefit to all battery technology research.

FUEL CELL R&D

Funding for fuel cell research has lagged far behind that for battery R&D. Fuel cells have received only small amounts of DOE funding for a number of years, a few million dollars per year, starting with $1 million in 1986 (see table 7-7).[38] This provides for small research programs at Argonne and Los Alamos national labs and more recently an $1 l-million demonstration program at Georgetown University to build three phosphoric

USABC/DOE Cooperative Agreement, Nov. 4, 1991, p. 1.

38 pm&t Patil, fuel cell program, vehicle propulsion division, conservation and renewable, U.S. Department of Energy, personal communication, May 14, 1992.

acid fuel cell buses.[39] Several transit operators, including those in New York City and Los Angeles, are interested in testing the buses. The other major DOE effort is a contract with Allison Gas Turbine, a division of GM, to develop PEM fuel cells.

DOE is preparing a program plan to increase its support of fuel cell technology, keeping in mind the possibility of using resources that may become available within the department's national labs.[40] A DOE spokesman suggested that the program might learn from the formation of the USABC and try to link different groups involved in fuel cell development more closely in order to coordinate research on several of the most pressing issues. Defense firms might be among those to become involved in such a program; aerospace and other defense technology has found application in fuel cell research, both directly, as a result of the industrys work on fuel cells for its own uses, and in other ways, through improvements in materials. The graphite cloth used in the fabrication of wings and tailplanes on some aircraft has enabled researchers at Texas A&M University to develop plates for a PEM fuel cell that have the potential to greatly reduce the weight of the cell.[41]

Markets for EVs: Fleets

Several institutions already have experience in the use of EVs as fleet vehicles through Federal purchases. Fleets are among the most promising potential markets for battery EVs in the near future. In many fleets the vehicles are driven on short routes, and are centrally parked at night, easing charging and maintenance. The advantages of EVs, such as their efficient use of power in stop-and-start driving, are often appropriate to the kind of use delivery or service vehicles get. For this reason, EV makers and interest groups have targeted commercial and government fleets. So far, fleet purchases of EVs that have taken place have been too small to constitute a significant demand, but the numbers are likely to rise as the requirements of the Clean Air Act start to take effect. Annual fleet sales in the United States are about 1.7 million vehicles, so laws that require a fraction of these to be less polluting are likely to affect many more vehicles than are covered in programs simply designed to demonstrate and encourage a particular new technology, such as the DOE site operator program described here.

Table 7-7—DOE Fuel Cell Funding (with funding for batteries and EV systems for comparison)

	FY 1990	FY 1991	FY 1992	FY 1993
	(millions of dollars)			
Fuel cells	$3.6	$8.9	$10.4	$12.0
Batteries.	7.9	8.9	26.7	31.5
EV systems	6.7	7.3	6.1	16,8

SOURCE: Pandit Patil, U.S. Department of Energy, Vehicle Propulsion Division, Presentation at Princeton Fuel Cell Conference, Princeton University, Center for Energy and Environmental Studies, Oct. 21, 1992.

Electric vehicles still have certain disadvantages even for fleets, primarily their high price. Nor has all past experience of their performance been favorable: the Postal Service found the 200 electric jeeps it ran in the 1970s to be unreliable and costly to service. Legislation that targets fleet owners can try to reduce the costs of early investment in EVs through tax incentives and other financial benefits.

A FEDERAL EV DEMONSTRATION PROGRAM: DOE SITE OPERATOR PROGRAM

Several institutions are acquiring EVs for use in their fleets with the financial support of DOE through its Site Operator Program, a small

Sam Romano, principal investigator, advanced vehicle development department, Georgetown University fuel cell bus program, personal communication May 4, 1992.

40 Pandit Pa@ op. cit., footnote 40.

41 John Appleby, director, Center for Electrochemical Systems and Hydrogen Research Texas Engineering Experiment Station, Texas '&M University, personal communication May 6, 1992.

program established in the mid-1970s in response to the first oil crisis.[42] It began as a demonstration program, under which DOE provided financial support for EVs run by 13 different organizations around the country, and has since evolved to have a strong testing component as well. Each year the site operators come to DOE with a proposal for the coming year's agenda, including the purchases they want DOE to support. This support can cover up to half of the cost of an EV.

The site operators, which include utilities, universities, a technical college, and the U.S. Navy, run small fleets of EVs and give quarterly reports on their performance to the central management of the program, at DOE's Idaho National Engineering Lab.[43] The program is thus accumulating a useful body of data on life-cycle costs, efficiencies, performance, and so forth for a variety of vehicles, motors, and batteries. In FY 1991 the program's budget was $1.8 million, but the redistribution of DOE's EV money as a result of the birth of USABC reduced this to $1.2 million for FY 1992.

THE U.S. POSTAL SERVICE

The U.S. Postal Service (USPS) ran 200 electric jeeps in the 1970s, but abandoned the program because of problems with the basic lead acid batteries used by the vehicles at the time.[44] The memory of the vehicles' drawbacks is still strong within USPS, and disinclines the service to try its luck again.[45]

Even though the Post Office vehicles drove only 20 to 30 miles a day, the 500 or so stops and starts made on some routes put a great strain on the batteries, which were less advanced than those available today and which had the additional problem that they required constant maintenance, such as regular topping up of the water in them. The charging and control equipment was expensive because it was made by only a few manufacturers, and the eventual running costs of the EVs worked out to be three times those of the ICEVs ordinarily used by the Post Office.

The Postal Service is nonetheless acquiring other alternative fueled vehicles for its nationwide fleet of 180,000 vehicles. Most of these at the moment are versions of the standard long life vehicle (LLV) built by Grumman and converted to run on compressed natural gas (CNG). This choice illustrates the need for caution in assessing the future potential of EVs: there are other low-polluting alternatives to gasoline vehicles available, and these often perform better and cost less than EVs. The improvements in air quality that EV use could bring may not appear to individuals and companies to warrant their price and performance penalties.

Although CNG is the main focus of Postal Service fleet alternatives, the service planned to test six electric Ford Ecostars running on sodium sulphur batteries in late 1992 in southern California (see section on current EVs below). The vans were made in the United Kingdom and are right-hand drive vehicles, which fits postal requirements for stopping frequently at the curb and getting in and out safely. The batteries cost $40,000, emphasizing that the economics of the Postal Service's fleet do not obviously favor electric vehicle use at the moment. LLVs, when

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Farley Warren, manager, DOE Energy programs Site @rater Program, Idaho National Eng;ineering Laboratory, personal communication, Apr. 14, 1992.

43 The members are eight utilities-Arizona Public Service, Los Angeles Department of Water and Power, Orcas Power and Light (Washington State), Pacific Gas and Electric (California), Platt River Power Authority (Colorado), Potomac Electric Power Company (Washington DC), Public Service Electric and Gas Company (New Jersey), and Southern California Edison; three universities—Kansas State University, Texas Engineering Experimental Station at Texas A&M, and University of Southern Florida; York Technical College (South Carolina); and the U.S. Navy.

44 David Phillips, fleet management, U.S. Postal Service, Apr. 15, 1992, personal communication.

45 One of the risks of too precipitate a rush t. buy early EVs for large fleets is that bad experiences such as that of USPS will keep users from buying future vehicles, even if they are much better than the earlier ones.

bought in the quantities the Postal Service does, cost $13,000; they are driven 6,000 or 7,000 miles a year, so that gasoline costs are $400 to $500 a year. At these prices a battery pack would have to cost one-third to one-quarter the present cost of even relatively cheap lead acid batteries to compete. The Postal Service is discussing with Hughes the possibility of testing a version of the sealed lead acid battery developed for GM's Impact, and Grumman has made initial enquiries of BMW on the possibility of developing a power source for the LLV around their sodium sulphur battery.

GENERAL SERVICES ADMINISTRATION

The General Services Administration (GSA), which manages 25 percent of the vehicles owned by the U.S. Government, has no EVs in its fleet of 136,000, but does have 65 alternative fuel vehicles (AFVs) that can use up to 85 percent methanol. GSA is expanding its AFV fleet considerably .[46] Executive Order 12759, of which section 11 enjoins the executive branch to acquire as many AFVs as possible, is driving the increase. GSA's choice illustrates again that when "less polluting vehicles" are stipulated, there are choices other than EVs, and these alternatives may often be preferable.

As the buyer of almost half the 300,000 nonmilitary Federal vehicles, GSA represents a major potential purchaser of EVs. However, a possible obstacle is regulations that restrict how much can be paid for particular items. If government agencies are to buy EVs, allowance must be made for their high cost.

EXISTING AND NEAR-TERM EVs

The first EVs to be produced commercially will almost certainly be aimed at the California market, where the 1998 ZEV regulations are designed to force open a niche for producers.[47] With this opportunity as an incentive, a range of vehicles is being developed.

■ Amerigon

A group that is directly attacking the challenge of redirecting aerospace and defense capability in Southern California towards transport is Amerigon, of Monrovia, California.[48] The chairman, Lon Bell, who founded the company in 1991, is coordinating small and medium aerospace and other high-tech firms in the area to produce subsystems for EVs; the company unveiled a prototype "showcase EV" in December 1992.[49] Bell spent the previous 20 years as owner, and then, after selling it to TRW, manager of Technar, a company he founded that produces high-quality automobile and aerospace parts such as&accelerometers for use in triggering airbags and self-locking seat belts.

Amerigon's vehicle is intended to highlight strengths of local high-tech firms as quality suppliers to potential and current manufacturers of automobiles-conventional as well as EVs. By matching lists of customer or user requirements with available skills, Amerigon has broken down the EV into 45 subsystems that can be developed independently, and is seeking the appropriate local engineering firm to work on each of them. If the initial vehicle is well received, there is a

46 William Rivers, director of alternative fueled vehicles, General Services Administration personal communication, Apr. 17, 1992.

47 An earlier attempt was made to stimulate EV production in a January 1989 effort known as the b Angeles Initiative, which sought proposals to supply the Los Angeles market with 5,000 electric cars and 5,000 electric vans by 1995, However, the outcome of this effort is increasingly in doubt. None of the Big Three responded to the RFP, and a small Swedish company won the contest. It has fared badly in California's troubled economy, and has failed to raise the private money it requires to match the support it has received from the city. By the second half of 1992 the project was operating at a reduced level until a major sponsor could be found. ((Lars Kyrkhmd, president, Clean Air Transport, personal communication, Jan. 14, 1992; E.J. Constantine, legal consultant, Clean Air Transport, personal communication Sept. 17, 1992; Jerry Enzenauer, Los Angeles Department of Water and Power (DWP), personal communication, Jan. 23, 1992.))

48 Lon Bell, chairman, Amerigon, personal communication, Sept. 23 and 24, 1991, Oct. 17, 1991, and Jan. 23, 1992.

49 Kristine Stiven Breese, "Calif. Group Unveils Electric Concept Car," *Automotive News*, Dec. 7, 1992, p. 14.

possibility that Amerigon would produce it commercially.

Many of the subsystems could have application in conventional vehicles as well as EVs, and the intention is to turn the high-tech industry of Southern California into a resource for the auto industry. Heating, ventilation and air-conditioning (HVAC) systems, for example, present a pressing challenge to potential EV makers, since there is no waste heat to use from the engine, nor can they consume a lot of electricity, as this would detract from the range of the vehicle, already a weakness of EVs. A good solution to this design problem could find application in a wider range of vehicles, and even in buildings. Amerigon is working on a design based upon a heat exchange turbine system, which would have a further advantage of eliminating chlorofluorocarbons (CFCs) from the cooling system.

So far the showcase vehicle project has 11 firm participants besides Amerigon, including Allied-Signal Aerospace, the Composites Automation Consortium, Fairchild Manufacturing, Hughes, and Intel.[50] Each participant will internally fund its own R&D on specific components, and contribute an additional sum of between $25,000 and $50,000 to overall marketing, system design, and program management costs. The total proposed budget for the program is $10.4 million.

Calstart

Since the Amerigon showcase vehicle plan was first conceived its scope has grown considerably. It is now one of seven projects taking shape under the banner of Calstart, a nonprofit consortium.[51] Calstart is intended to create a new industry in California providing transportation systems and technologies; it includes utilities, aerospace companies, universities, small high-tech companies, transit agencies, and representatives of labor and environmental interests. Its proposed funding is **$37 million, of which $23 million ($4 million in** cash and **$19** million in kind) was accounted for by the contributions and commitments of members by mid-1992. Calstart received $4 million in Federal funds under ISTEA, as one of four EV grants awarded in mid-1992, and $2 million from the State of California, and was trying to raise further private support.

Besides the showcase EV program, Calstart includes projects on EV infrastructure, an electric bus/mass transit program, a "neighborhood EV," EV testing, the linkage of university and Federal lab research, and a fund for discretionary R&D. The Los Angeles Department of Water and Power will manage the $14.7-million EV infrastructure program, which will coordinate activities already underway individually by each of California's five utilities, including work on charging, servicing, and battery recycling. Participants include Hughes, which has expertise in inductive recharging, as well as the utilities. The Electric Bus project, with a budget of $4.7 million, is headed by Southern California Edison. The project plans to run four electric shuttle bus demonstrations, and then use the resulting data to develop prototype light duty transit vehicles.

Strong support for the project has come from the city of Burbank, a potential site for housing Calstart's headquarters and a manufacturing plant to produce new vehicles.[52] Lockheed Corp. recently closed its Burbank facility and relocated to Georgia, and the city is suffering economically as a result. An EV manufacturing industry could potentially provide work for some of the hundreds of skilled workers left unemployed by this departure and cutbacks by other area aerospace companies. The International Association of Machinists and Aerospace Workers backs the idea, and is working with the University of California at Berkeley to match the skills of workers to those

50 Calstart, "Executive *Summary,* " unpublished document, 1992,

Lon Bell, chairman, Amerigon, *personal* communication May *5, 1992.*

"Group Seeks a Place to Park Electric Car Industry," *Los Angeles Times,* Jan. 22, 1992.

needed for the new industry .53 Lockheed has provided a 155,000 square foot facility rent-free for 2 years, starting in mid-1992, and the City of Burbank has approved $110,000 for minor improvements to speed up the move-in.

The Established Auto Industry

The big auto manufacturers are also moving, although to a more protracted timetable, towards EV production. Although each of the Big Three has its own EV program, discussion was underway in early 1993 of cooperation on many aspects of EV design, including the standardization of processes and components such as charging systems.[54] This is taking place under the umbrella of a US CAR consortium announced in December 1992. The pressure of the California requirements is driving the U.S. automakers, along with the knowledge that the Japanese auto industry is already working on EV issues through MITI.[55] Each U.S. manufacturer has a small development program of its own, but the numbers of jobs involved have been very small so far-100 or 200 in each case.

GM announced in April 1992 that it would be producing a commercial EV 2 years later, in the spring of 1994, based on the Impact, first shown as a concept car at the 1990 Detroit motor show, but backed away from this decision later in the year.[56] The project was scaled back because of its expense and GM's financial difficulties (the company had spent $400 million on its EV program by late 1992), compounded by uncertainties about the market for a two-seater EV and the performance of the Impact's advanced lead acid batteries compared with what might develop in some of the USABC projects. Plans to use ex-aerospace workers from Hughes, and a Hughes facility in Torrance, California, were on hold in early 1993. The current plan is to produce not more than 50 of the vehicles during 1993 for trial use in utility fleets. All of these are to be built in the Lansing, Michigan, Technology Center. A GM vehicle, the British-built Griffon, provides the basis for another EV, the GVan, a light van with a 60-mile range that runs on lead acid batteries. About 100 are in service, mostly in the fleets of electric utilities, and they come in both passenger and cargo configurations.

Ford is adapting 80 of its European Escort vans to run as EVs powered by sodium sulphur batteries (a technology patented by Ford in 1965), built by Silent Power and Asea Brown Boveri.[57] The vans, to be known as Ecostars, will have a top speed of 75 mph, a range of about 100 miles, and carry a 900 pound payload (less than the 1,700 pound payload of the ICE version because of the 800 pounds of batteries on board). The drivetrain was developed by General Electric at their Cincinnati plant.[58] The vehicles will be leased to fleet customers—mainly electric utilities-for $100,000 for 30 months, a price that does not cover the cost of building them. Ford representatives estimate that about 100 engineers are directly working on the program.

Chrysler plans to produce an electric version of its popular minivan, the Plymouth Voyager,

Lou Kiefer, international representative, Western Region, International Association of Machinists and Aerospace Workers, personal communication Sept. 27, 1991.

54 Larry Weiss, U.S. Council for Automotive Research, personal communication Feb. 16, 1993.

55 Jack Keebler, ' 'It's Team U.S.A. vs. Team Japan Now, " *Automotive News*, Dec. 14, 1S92, p. 53.

56 Phil Frame, ' 'GM Readies Electric Car for '94 Debut,'' *Automotive News*, Apr. 27, 1992, p, 1; and General Motors, ''GM Electric Vehicles Progress Report,'' winter 1993.

57 Roberta Nichols, manager, electric vehicle strategy and planning office, and Ann Nazareth Manning, governmental affairs associate fOr environmental matters, Ford Motor Company, personal communication, Sept. 16, 1992.

58 Kathy Jackson, ''Ford Upgrades Its Electric Vehicle Project, " *Automotive News*, July 20) 1992, p. 7.

called the TEVan.[59] This van will seat five passengers and use nickel iron batteries to achieve a range of more than 100 miles and a top speed of 65 mph, with a battery life of 100,000 miles. The 50 or so vans to be produced in 1993 will cost $120,000 apiece to fleet buyers.

If the Big Three succeed in moving into EVs, they will become large buyers of subsystems and components, some of which might be supplied by former aerospace and defense contractors. On March 3,1992, Chrysler Corporation and Westinghouse jointly announced a program to develop an improved propulsion system—an AC electric motor and controller-for electric vehicles.[60] Their goal is to improve the acceleration and range of EVs by increasing the efficiency and power of the propulsion system. Westinghouse has long experience with EVs—the company even built one in 1908--but its recent work has derived from research in the electric systems group (ESG) on underwater propulsion units, mainly for the Navy.[61] Many of the 30 to 40 people working on EV propulsion within Westinghouse started on ESG defense projects. The division now does 70 percent commercial work, and the rest defense-related.

Foreign car manufacturers are also developing EVs. Fiat is the world leader in EV sales: it has sold 450 Elettras, an electric version of the Panda. BMW, Mercedes-Benz, Renault, Peugeot, Audi, Fiat, Mazda, Toyota, Nissan, and the Swiss watch firm Swatch all have EV programs at various stages of development.[62] There are also more small firms in the United States (e.g., Solectria of Arlington, Massachusetts) and Europe (e.g., Solcar, Horlacher).

EVs in Japan: MITI's "EV Extension Program"[63]

The Machinery and Information Division of Japan's Ministry of International Trade and Industry (MITI) announced an "EV Extension Program' on October 14, 1991. The program is ambitious, and considerably further advanced than any U.S. plans thus far. It aims to develop EVs and supporting technology so that by 2000 an EV production industry should be able to take off autonomously. To this end performance targets have been set-mileage per charge of 155 miles, 75 mph top speed, a battery life of 4 years, and a price about 1.2 times that of a corresponding ICEV; plans are for an EV population of 200,000 on the roads of the Tokyo and Kanagawa areas by the year 2000, with production of 100,000 units that year. In 1992 there were about 1,500 EVs operating in Japan.[64]

The program has four phases. The first efforts will be to introduce EVs into use in governmental agencies through subsidized purchases, and to support R&D to improve the technology. The government will also provide infrastructure for charging and servicing. The second phase, between 1994 and 1997, targets utilities and commercial delivery fleets as users of EVs, with subsidies through taxation and financing advantages, and incentives such as preferential parking. For the last 3 years of the decade the focus shifts to developing a wide public demand for EVs by

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Chrysler Corporation, "Chrysler Announces 1992 Electric Vehicle Production, Cites Company's Alternative-Fuel Vehicle Leadership,' press release, Apr. 15, 1992.

60 Chrysler Corporation and Westinghouse, "Chrysler, Westinghouse Join in Development of New Electric Vehicle Propulsion System," press release, Mar. 3, 1992.

61 Ted Leicester, Westinghouse Electric, Electric Systems Group, personal communication, Sept. 10, 1992.

EV efforts reported over 1992 in *Automotive News*, *Automotive Industries*, *Review*, *The Wall Street Journal*, *The New York Times*, and elsewhere.

63 From information provided on May 29, 1992 by the Office of the Assistant Secretary for Technology Policy of the U.S. Department of Commerce Technology Administration, Washington DC, drawn from the incoming telegrams from the U.S. Embassy in Tokyo, April 1992.

64 Richard Johnson, "Japanese Seek Electric Car Standards," *Automotive News*, Aug. 31, 1992, p. 6.

bringing the price down and establishing mass production and servicing facilities. The fourth and final phase, from 2001 onward, is envisaged as a time of successful maturation for the technology, with continuing extension of their use as personal transport, and no need for special promotion measures since demand and supply will have been well-established. Further details have not been announced. Japanese automakers met in August and September 1992 to begin to set standards for major EV components.[65]

MITI also announced a 10-year battery development program starting in April 1992 with a first year budget of 257 million yen ($2 million) expected to grow to between 1.37 billion yen ($10.5 million) and 2.23 billion yen ($18.5 million). The program will concentrate on developing lithium batteries for utility load leveling and long-term storage (long life) and for electric vehicle use (high energy), and will culminate in pilot production. Some effort will also be expended on continuing existing research into basic components for sodium sulphur and zinc bromine batteries. A further program by the auto division of MITI assigns 1.85 billion yen ($14.2 million) for Japanese FY 1992 to a new 5-year EV infrastructure research project.

EMPLOYMENT AND COMPETITIVENESS

The overall employment effects of the birth and growth of an EV industry are hard to gauge. For the next several years EVs are unlikely to dent ICEV sales at all, while the scale of production and consequent employment will be small. Each of the Big Three has 100 or 200 employees engaged in EV-related work. Smaller EV operations and the first-tier suppliers of major components like powertrains and batteries probably employ several hundred more.

In the longer term, if EVs simply replaced ICEVs, employment in auto manufacturers would probably fall, even if their overall sales stayed the same, as EVs have fewer complex parts for assembly and are therefore likely to require less labor.[66] None of the automakers is willing to divulge employment projections for EV production, but one can make some estimates. If between 40 and 50 percent of the cars sold in the year 2003 were in areas where laws required that 10 percent be ZEVs, then EV sales night be on the order of 500,000 a year. Based on discussion with companies cooperating with current Big Three efforts and the pattern of employment in today's auto industry, one can estimate that the production of this number of vehicles might support on the order of 1,000 jobs in powertrain production, and 10,000 in vehicle assembly.[67] The broader supplier base on which this was founded would extend to many more workers—several thousands in an array of manufacturing industries. The distribution of these jobs of course would differ from that in ICEV production; there would be no call on the 19,000 jobs in carburetor, piston ring, and valve production, for instance, but a considerable increase in the 23,000 jobs in auto battery production (1990 auto industry figures).[68] These figures are highly speculative, however, based as they are on the assumption of widespread adoption of the California standards. This is still in doubt, given the current state of development of the technology, and the record of past relaxation of environmental regulations in the face of concerted industrial opposition.

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65 ibid.

66 For today's ICEVs, the proportion of auto industry jobs in assembly is 27 percent (1990 figure, down from 35 percent in 1975). (U.S. Department of Labor, Bureau of Labor Statistics, *Employment and Earnings, 1991.)*

67 The figure of *1,000 in* powertrain production might be compared to the appro ximately 1,000 employed in one of today's most efficient engine factories producing 430,000 ICES a year. The 10,000 order of magnitude for assembly workers is arrived at by taking a ratio of assembly jobs to vehicles produced somewhat less than that for ICEVs (equivalent to having 25 percent of total employment in assembly).

68 U.S. Department of Labor, Bureau of Labor Statistics, *Employment and Earnings*, January 1991.

Some of the supplier firms are likely to be companies with experience in aerospace and defense production. *After the Cold War,* an earlier report in OTA's assessment of effects of the defense build-down on the civilian economy, found that second-tier military suppliers are often already diversified.[69] The machine shops, semiconductor manufacturers, foundries, and other component suppliers that competed for defense orders and many of which already supply the auto industry would naturally compete to supply an EV industry. In the intermediate tier-suppliers of major subsystems-several firms are already involved-notably Hughes, through GM, and Westinghouse, in collaboration with Chrysler. Their experience thus far reflects a number of familiar conversion lessons: the technology match is often good; workers can adapt; management and corporate structures reflecting years of dealing with DoD are major obstacles. Even when firms do successfully refocus efforts, the scale of EV opportunity is not comparable to the level of defense activity in the mid-1980s. The 30 people working on EVs at Westinghouse must be set against the 1,600 defense workers the company laid off in 1991, and the 5 percent attrition through along hiring freeze that has accompanied the defense build-down. This is not to say that the opportunities are not good, but simply to reiterate another familiar point from the earlier report in this assessment—there is no single solution to company conversion needs.

Calstart is the most aggressive attempt to link the rise of the EV to the decline in the fortunes of the aerospace and defense industries with the end of the Cold War. It has government support through the ISTEA demonstration program and some State programs. Its organizers continue to look for further support, both financial and in kind. Calstart hopes to acquire cheaply some of the equipment mothballed by Lockheed in their Burbank facility, for example, including office equipment such as desks and chairs, computer-aided design (CAD) systems, and numerically controlled milling machines.

One concern expressed by some members of the existing automobile industry is that government support for a fledgling EV industry in California would be inappropriate because such jobs as might be created would come at the expense of workers in Detroit, as the new EV industry cut into existing markets. Displaced aerospace workers would benefit at the expense of auto workers, they argue. These arguments probably have a greater emotional than factual content. At least until the late 1990s and probably after that, any jobs created in California will be predominantly in the preproduction stage of vehicle manufacture. Few EVs will be sold, and those that are sold are not necessarily going to be bought instead of ICEVs: they will be second and specialized cars for the most part. There may be some longer term truth in the claim that, if successful, a program such as Calstart's will lead to a slow restructuring of the geographical distribution of some auto supplier and manufacturing jobs, but it is by no means clear that in the absence of such programs Detroit, Atlanta, or Spring Hill would retain those jobs.

America at the moment leads the world in much EV technology, particularly motor and controller design, but the seriousness with which MITI and the European manufacturers are pursuing batteries, fuel cells, hydrogen storage, fast-charging, light-weight materials, and a host of other EV-related technologies indicates that this lead can only be retained if the country strives to do so. Most of the major European and Japanese automakers have EV development programs, motivated both by domestic demand--EVs have been available and used for commuting on a small scale in Switzerland and Germany for several years-and by the promise of a market in California. Pressure mounts to develop alterna-

U.S. Congress, Office of Technology Assessment, *After the Cold War: Living With Lower Defense Spending,* OTA-ITE-524 (Washington, DC: U.S. Government Printing Office, February 1992).

tive vehicular technologies, and while the risks are great for the first entrant in this potentially large business, the danger of being left behind when the plunge begins is at least as bad.

California will be the first large market, but the rewards for success, producing a vehicle that gives vigorous performance at a reasonable price, will extend to export markets as well. Europe is enacting environmental standards more exacting than those of the United States in some other auto fields-Germany's recycling laws, for example--and consumer awareness is high. The demand for personal vehicles is likely to grow steeply in developing countries, both those traditionally thought of as the Third World, and in Central Europe. Japan is pursuing markets in South East Asia vigorously—it exported 473,749 vehicles to the region in 1988, with particularly heavy sales to such industrializing nations as Thailand and Indonesia.[70] These countries have an opportunity to leapfrog the gasoline ICEV and a consequent heavy dependence on imported oil. China, where the density of vehicles per capita is very low, but which has doubled its number of vehicles every 6 or 7 years, is rich in coal and comparatively poor in oil, and might be a large market for nongasoline vehicles.

Perhaps the United States' greatest asset will prove to be its strength in fuel cells, if these are developed in the next few years to the point where they can economically power a mass production vehicle. Supplying the advanced material components, let alone complete fuel cells, or cars incorporating them, could be a great export opportunity for the U.S. companies that hold crucial technology leads and patents in these areas.

INTELLIGENT VEHICLE AND HIGHWAY SYSTEMS

Interest has grown recently in applying advanced engineering to road transport through a range of technologies encompassed by the terms ''smart cars and ''smart highways"--or, more formally, intelligent vehicle and highway systems (IVHS). The idea behind this is that part of the answer to increasing congestion on roads is not to build more of them (more difficult as environmental and urban demands on land grow), but to use the existing ones more efficiently, by carefully directing the flow of traffic, and more intensively, by increasing the number of cars that can safely occupy a given stretch. Proponents claim that IVHS can increase safety, reduce pollution and oil consumption, make driving more pleasant, and, by reducing congestion, save time that some estimate to be worth billions of dollars annually in lost productivity.[71]

The range of technologies is considerable, and markets for IVHS-related industries could potentially be large. IVHS America, a nonprofit association of private, government, and academic parties that promotes and coordinates the development and deployment of IVHS and that serves as a Federal Advisory Committee, sketches scenarios in which by 2001, $9.95 billion is being spent on traffic management, traveler information, vehicle control, and other systems.[72] Japan and Europe, like the United States, are devoting increasing resources to IVHS.

Several obstacles stand in the way of the development of IVHS. Some of the greatest benefits from IVHS could result from the combination of many technologies and systems. The incremental benefits of some of these may not be sufficient to attract commercial investment and

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70 Motor Vehicle Manufacturers Association of the United States, Inc., *World Motor Vehicle Data, 1990 Edition* (Detroit, MI: The Association, 1990).

71 Moshe Ben-Akiva, David Bernstein, Anthony Hotz, Haris Koutsopoulos, and Joseph Sussman, ''The Case for Smart Highways,'' *Technology Review,* July 1992, pp. 38-47.

72 Intelligent Vehicle Highway Society of America, Strategic *Plan Intelligent Vehicle-Highway Systems in the United Stales,* IVHS America Report No: IVHS-AMER-92-3, May 20, 1992, appendix D.

there is concern about lack of confidence that other supporting systems will be built. It is not clear whose interest lies in leading some IVHS efforts where the costs are high and the benefits widely distributed; the question is especially pointed in the United States, where government and industry cooperation is less the norm it is in Japan and Europe. On the other hand, since 1990 there has been a marshaling of effort in the United States to overcome just this "chicken and egg" problem.

The complexity of IVHS also raises the possibility that institutional barriers will hinder attempts to install systems across the country. Planning a traffic system for greater New York, for instance, involves Federal, State, and local governments, each with overlapping and sometimes conflicting interests and regulations.[73] A further obstacle to some IVHS technology, and a major one, is the potential for lawsuits over the liability for accidents. Advanced vehicle control systems, in which some of the driver's control of the vehicle is ceded to automated systems, would be likely to make the manufacturer vulnerable to a damaging lawsuit in the case of a crash, harming its reputation and the acceptability of IVHS even if crashes actually occurred less often than previously. This consideration has reportedly kept Detroit from pursuing research begun as long as 30 years ago.

Technologies

IVHS technologies are usually classified by application into three broad groups: advanced traffic management systems (ATMS), advanced traveler information systems (ATIS), and advanced vehicle control systems (AVCS).[74] The groups overlap and there are synergies between them, but the categories are widely used, even if the designation of particular technologies sometimes varies.

ATMS

The first of these, advanced traffic management, uses surveillance and communications technology to improve the management of traffic. Surveillance is achieved by widespread traffic sensors along roads (using computer vision, radar, or induction loops in the road). A traffic management center processes the information from the sensors and other sources, such as vehicles on the move acting as ''probes,' and uses it to regulate traffic flow through signal timing, freeway ramp controls, and signs with changeable displays. Systems like this already operate in a few cities, and new technology is being added to them continually.

ATIS

Advanced traveler information adds a further loop to this network. It provides travelers in their cars with a range of information on traffic conditions and alternative routes. Systems in the car might include electronic maps, route guidance based on "dead-reckoning' sensors or the global positioning system (GPS), and information on local amenities.

AVCS

The most complex of these categories, automated vehicle control, helps drivers by simplifying or assisting in various driving tasks. The range of possible technology extends from head-up displays that appear to project dashboard information out ahead of the vehicle into the driver's field of vision to the fully automatic road, in which the driver would cede. complete control of the car to automatic systems guided by sensors in the car and the road. This vision of the distant

[73] This problem has hampered even non-intelligent highway infrastructure development in the past. See OTA, *Delivering the Goods: Public Works Technologies, Management, and Finance,* OTA-SET-477 (Washington, DC: U.S. Government Printing Office, April 1991).

[74] U.S. General Accounting Office, Smart *Highways: An Assessment of Their Potential To Improve Travel,* GAO/PEMD-91-18 (Washington DC: U.S. Government Printing Office, May 1991).

Table 7-8—Federal IVHS Funding, FY 1989-93
(millions of dollars)

	1989	1990	1991	1992	1993
General operating expenses appropriations	$2,3	$4	$20	$137,9	$30.0
ISTEA	—	—	—	19.2	187.7
Total	$2.3	$4	$20	$157.1	$217.8

SOURCE: U.S. Department of Transportation, Federal Highway Administration, Office of Traffic Operations and Intelligent Vehicle Highway Systems,

future would allow ‘‘platooning’ of vehicles into tight clots of three or four vehicles whizzing along bumper to bumper, greatly increasing the volume of traffic a road could carry. In between these lie shorter term prospects for obstacle detection using microwave or laser radar; adaptive cruise control, which uses radar or computer vision to control distance from the car in front as well as speed; lane guidance; and infrared night and fog vision enhancement.

APPLICATIONS OF IVHS

Some of the technologies described above, and others such as vehicle tracking and smart card,[75] are used to address particular kinds of transport problem. For example, electronic and communications technology allows precise tracking of a company's vehicles to enhance their quick, efficient dispatch, and can also speed up the monitoring that is required when goods are moved across the country. Roadside beacons and sensors can record information about passing vehicles, such as their loading and weight, that at present requires a stop. They could also be used for toll collection on the move, with vehicles equipped with meters that registered a charge as certain toll points were passed. This has application to all traffic, not just commercial. Electronic toll systems are already in use on the North Dallas Tollway, the Oklahoma Turnpike, the New Jersey Turnpike, and in Louisiana.[76]

IVHS applied to public transport can provide operators and users with information enabling more efficient use of high occupancy vehicles like buses and pool vans. Smart card technology could make payment and transfer within a system easier.

Much of the early IVHS work focused on urban and large highway applications such as congestion and routing. However, in-car safety systems and location technologies, for example, can have particular value in a rural setting.

Federal Funding[77]

Federal IVHS funding grew dramatically from 1989 to 1993 (see table 7-8) and partially changed form with the passage of ISTEA. It now has two components: IVHS appropriations bill (General Operating Expenses) funding and ISTEA funding. ISTEA funding for IVHS programs comes from the Highway Trust Fund and does not need a separate appropriation. However, the congressional appropriations committees do determine the overall annual obligations from this trust fund, so that there can be a proportionate increase or decrease across all programs funded from it. The appropriations bill money is separate and supple-

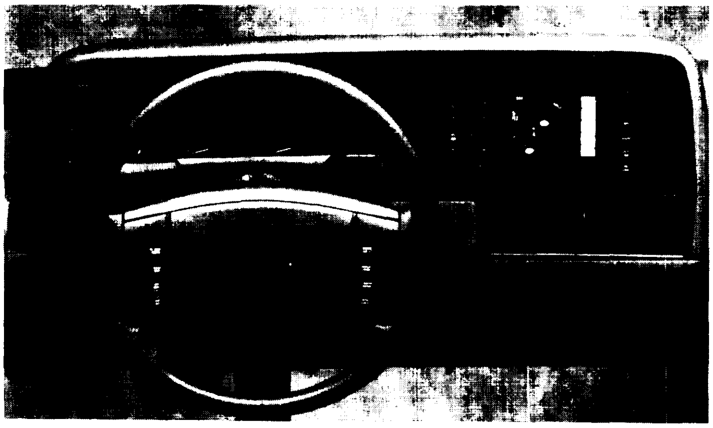
75 Smart cards are small cards, somewhat like credit cards, with the capacity to store information and perhaps process it, using magnetic stripes and perhaps some embedded electronics. Versions have been used for storing personal medical information in some State programs.

76 Ben-Akiva et. al., ‘‘The Case for Smart Highways,’ op. cit., footnote 73.

77 Federal funding information is drawn from U.S Department of Transportation, Federal Highway Administration, Office of Traffic Operations and Intelligent Vehicle Highway Systems, “An Overview of IVHS Program Implementation Plans in FHWA,’ March 1992; and Susan Lauffer, U.S. Department of Transportation, Federal Highway Administration, personal communication Sept. 15, 1992

Box 7-C–TravTek[1]

TRAVTEK



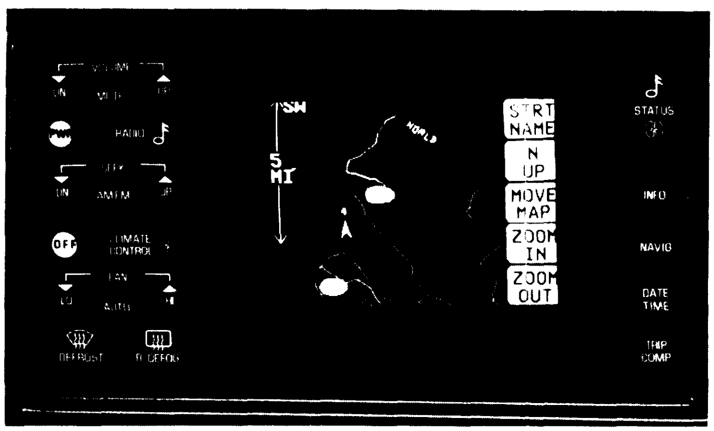
Dashboard of TravTek vehicle.

The curious can gain a feel for what it's like to drive a smart car by visiting Orlando, Florida, where a group of public and private organizations are trying out several advanced traveller information systems (ATIS) and advanced traffic management systems (ATMS) in a program dubbed TravTek (short for Travel Technology). One-hundred General Motors Oldsmobile Toronados equipped with computers programmed with maps and information about the Orlando area are available through Avis Rent A Car. The American Automobile Association, GM, the Federal Highway Administration, the City of Orlando, and the Florida Department of Transportation are the major partners in the $12-million, 3-year project (the driving test part of which will last 12 months) and will study the way the system performs and how drivers respond to it.

The experience of being told where to go by one's car is impressive and sometimes entertaining. The system works well enough to enable strangers to find their way around Orlando with only a few hitches. The car's special equipment is not difficult to grasp. The dashboard and wheel have more buttons than most cars but the effect is not overwhelming (see photos). TravTek has added to the display screen that comes as standard in the Toronado two computers with hard disk drives that handle the routing and the navigation functions, a global positioning satellite (GPS) data receiver, a dead-reckoning system to track the car's movements, and a two-way communication system to link each car to the Orlando Traffic Management Center (TMC). The screen serves as the main interface between the car's occupants and the computers, with a synthesized voice as an additional means for TravTek to convey its thoughts to the world.

When the car starts, the computer turns on automatically (there is a password as a security measure). Instructions and choices are typically provided in a menu of options on the screen. Various destinations are offered-hotels, restaurants, and local attractions, with information about what they offer, how near they are, and price. One can also enter a street address or the intersection of two streets, using letter keys that appear on the screen when this option is selected. This selection process must be done while the car is in "park," to reduce the risk of the driver's attention being drawn from the road. With the destination selected and the route planned (the system takes a few seconds to do this), the car issues

TRAVTEK



Detail of TravTek screen with map displayed.

vocal commands (which can be switched off) that supplement the visual display. The voice is startling at first, with a metallic timbre and an oddly Scandinavian inflection. Two choices are available for the visual display: a conventional route map, on which an arrow locates the car, or a schematic map that just indicates directions for the next short stretch.

The basic system thus allows travelers to pick a destination in a city of which they know little or nothing, and be guided there. The car keeps track of its own position by continually comparing the information it receives every minute from GPS and the results of the dead reckoning process with its database of geographic information. The system is generally accurate, although the arrow marking the car's location is sometimes slightly askew, especially if the distances covered are short.

A further feature of TravTek is the connection of the system's cars to Orlando's central Traffic Management Center. The communication is two-way, so that the TMC receives information about how fast TravTek vehicles are moving, which supplements the traffic reports of observers, video monitors on certain busy roads, and construction reports. This allows the TMC to build up a more detailed picture of traffic conditions in the Orlando area, and to broadcast to TravTek cars warnings of delays or diversions. Route planning by the TravTek in-car system takes account of this information, and if a relevant update is received while a journey is underway, the voice will notify the driver that there may be delays ahead and ask whether the computer should plan a new route that avoids it.

According to the TMC staff, the existing communication system would not easily cope with many more than the present 100 TravTek vehicles, if they were all to transmit information back to the TMC. Given the potential intrusion on a driver's privacy of having movements tracked, t his feature might be limited to a specialized, limited group of "probe vehicles." Taxis would be natural candidates, as they are likely to be in use for a much greater proportion of time than private vehicles and would therefore provide more traffic information.

1 Research for this box was done on an OTA staff visit to Orlando, Florida on July 27-28, 1992, which included interviews with Elford D. Jackson, traffic signal system manager, Bureau of Transportation Engineering, City of Orlando, and Don L. Gordon, project manager, Research and Development, American Automobile Association.

ments trust fund money for a number of IVHS programs.

The Federal Highway Administration (FHWA) continues to encourage joint funding by nonfederal participants such as State and local government and private sources, aiming to achieve a 50-50 split wherever possible. ISTEA imposes a limit of at most 80 percent Federal IVHS funds on any project.

As of May 1992, FHWA listed 63 IVHS projects underway in the United States.[78] These comprised 23 operational tests, 14 in advanced traffic management, 7 in advanced traveller information, and 2 in commercial vehicle operations; 13 advanced public transportation projects; 6 deployment studies; 16 FHWA research programs; and 5 Federal Transit Authority evaluation and research projects. (See box 7-C for a view of one of these projects.)

Competitiveness and Employment Effects

IVHS is not yet a big employer, but it has grown fast since 1987 and may continue to do so with the upswing in national interest. A dozen people attended the first meeting of Mobility 2000, the predecessor of IVHS America, in July 1987; 1,180 people attended IVHS America's second annual meeting in May 1992, a hun-

78 Office of Traffic Management and IVHS (HTV-1), Federal Highway Administration and Office of Technical Assistance and Safety (TTS-1), Federal Transit Administrating *Intelligent Vehicle-Highway System (IVHS) Projects in the United States,* May 1992.

dredfold increase in 5 years.[79] A May 1990 survey of 82 North American organizations suggested that at that point at least 760 people were working full-time on IVHS.[80]

The recent growth in the level of involvement and the potential value of the market suggest that IVHS has the potential to spawn numerous jobs across a wide range of engineering, manufacturing, and construction disciplines. IVHS America's strategic plan, which was used in the preparation of the federally mandated FHWA plan in late 1992, envisages expenditure of over $200 billion over the next 20 years, about 20 percent of it public funds.

The value added to an individual car will probably be of the order of $1,000 or $2,000 (IVHS America take a figure of $1,500 average for their cost calculations), in ATIS and AVCS. Motorola's GPS unit sold for $400 in 1992, and navigation units are typically based around one of these, a PC, and perhaps an optical disk memory. Motorola's market research suggests that customers of cars costing $25,000 and more might be prepared to pay between $500 and $2,500 for a system giving route and navigation information. At the moment even the higher of these figures would be hard to achieve, but the price is likely to fall fast as sales volume grows. Cellular phones, which embody some of the same technology, frost went on sale in October 1983 for $3,500; by 1992 they could be had for less than $100. Indeed, cellular phones are sometimes literally given away, as the companies make their profits from selling the service, which may well also prove to be the case with ATIS. The distinction between information services specifically for travelers and other forms of personal communication and information service is unlikely to remain sharp, as each grows and diversifies, The American Automobile Association (AAA) is experimenting with different ways of making this "yellow pages" information available to AAA members, through computer terminals at hotels and airports, at home, or in the car.[81]

Foreign IVHS

Both Europe and Japan have had large IVHS R&D programs for longer than the United States. Europe has two principal programs, Prometheus (Program for European Traffic with Highest Efficiency and Unprecedented Safety) an $8-million, 8-year project focusing on vehicle technologies such as collision avoidance and on-board navigation systems, and Drive (Dedicated Road Infrastructure for Vehicle Safety in Europe), which completed its 3-year, $170-million first phase in 1991.[82] Drive encompasses over 70 projects on the development of basic IVHS infrastructure, such as cellular broadcasting beacons and communications centers. The second phase, running from 1992 to 1994 and planned to cost $280 million, focuses on demonstrating the technologies investigated in the frost part.[83] Several smaller European programs, including tests of ATIS equipment, are also underway.

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79 William M. Spreitzer, manager, Vehicle/Systems Coordination, General Motors Research Laboratory, personal communication Sept. 22, 1992.

80 The survey is reported in William M. Spreitzer, "M-IS Activities in the United States, " presentation made at National Leadership Conference: implementing Intelligent Vehicle-Highway Systems, May 3-5, 1990, Orlando, Florida. The survey asked respondents to characterize their IVHS efforts as small-1 to 5 full-time people working; medium-6 to 25; or large-26 and over. The figure 760 was arrived at by assigning the lowest number to each category and multiplying it by the number of organimations reporting this level of activity. Thus small programs counted as 1 person, medium as 6, and large as 26. Seventy-two of the 82 organizations approached responded to the survey, in a similar distribution to the original 82.

81 Don L. Gordon, project manager, Research and Development, American Automobile Association, personal communication, July 28, 1992.

82 Ben-Akiva et al., "The Case for Smart Highways," *Technology Review*, op. cit., footnote 73,

83 "Special Report/Transportation: Testing the Concepts Worldwide," *IEEE Spectrum*, May 1991, pp. 30-35.

Table 7-9—Summary of Potential Impacts of EVs and IVHS on Technology Advance and Employment, and Prospects for Use of Defense Technology and Resources

	Electric vehicles	Intelligent vehicle highway systems
Technology advance	Battery and fuel cell work drives R&D in materials, catalysis, membranes. Fuel cells can stimulate R&D in a range of hydrogen related technologies--production, transport, storage--contributing to wider availability and use of this clean fuel. Development of efficient subsystems could have benefits beyond EVs--e.g. in other autos and, for HVAC, in housing construction.	IVHS work rovers many technologies and might stimulate cross-fertilization between fields. More than driving individual new technologies, IVHS is likely to bring together and apply diverse technologies developed elsewhere, providing a potentially large market for them.
Employment effects	Small near-term employment effects; numbers currently involved in EV R&D low-in the 100s. If 50 percent of the cars in the United States came under regulations like those passed in California (as would be the case if every State that expressed an interest in doing so were to pass such regulations, an unlikely outcome at this point), sales of EVs might be 500,000a year by 2003, providing on the order of 10,000 jobs in assembly, with perhaps three times as many in parts supply. This is highly speculative, however; environmental regulations have been scaled back in the past when industry made a forceful case that it could not satisfy them economically, and there is considerable opposition in the northeast to imposing the California standards. In the longer term, direct substitution of EVs for ICEVs would be likely to lead to a decrease in overall auto employment, owing to simpler construction, as well as a redistribution of skills. Export opportunities to developing countries in central Europe and the South are a possibility.	Greatest potential employment effects in the long term could be large numbers of construction jobs installing smart highway infrastructure. Supply of communication equipment and other components of IVHS is another potentially large employment opportunity, with the greatest near-term effects in the supply of in-car systems. Independent vehicle-installed equipment such as navigation computers and automated steering and braking systems would generate little ongoing employment after installation. Infrastructure based services such as traffic management would generate sustained employment in operation and maintenance. Increasingly technologically sophisticated vehicles are likely to demand correspondingly more complex servicing.
Defense conversion	National labs are developing batteries for USABC and fuel cells for DOE, and Argonne has an EV testing facility. Defense contractors are performing some of the cooperative research. Ultracapacitors, developed through SDI, might complement fuel cells in an EV. Advanced materials developed for aerospace can be used in designing lightweight vehicle bodies, though they are often very expensive. Defense firms are working in collaboration with Big Three on power trains, inductive charging.	Opportunities for systems integration by defense primes. Sensing and communications technology developed for military important for navigation and lane sensing. Traffic management can draw on air traffic control technology and experience.

SOURCE: Office of Technology Assessment, 1993.

OTA interviews suggest that the U.S. IVHS community is less concerned about falling behind Europe, where no clear lead has emerged, than about Japan, which is well positioned to compete in producing ATIS units to go in vehicles. Japan already dominates in technologies, such as compact disk drives and flat panel displays, that are important components. The keiretsu system facilitates the kind of cooperation between companies that IVHS demands, and the historical tendency for close cooperation between government and industry also favors integrated development of systems.

Some IVHS technology has already been commercialized in Japan; about 200,000 vehicles have been equipped with GPS navigation systems. Most of these have been built by Nippondenso and installed in Toyota cars, or built by Sumitomo for Nissan Cars.[84] Some of the success of these systems is probably due to the difficulty of navigating in Tokyo, where streets are haphazard and houses numbered according to when they were built rather than their position on a street or within a block. In addition, 74 Japanese cities operate traffic surveillance and control systems, such as the one in Tokyo, where the messages on roadside signs can be varied in response to information from sensors along the roads collecting data on traffic volume and speed. This traveler information system is being further developed, and by 1995 is expected to provide continuous data radio broadcast of travel information in all major cities, receivable by an on-board unit costing a few hundred dollars. A recent University of Michigan report on IVHS in Japan concluded that "[especially in the imminent deployment of a system for communicating traffic data in real time, Japan appears to be well ahead of other regions of the world. ' '[85]

CONCLUDING REMARKS

Clean air legislation is pushing electric vehicle development. The intensive focus on rapid technology development provides opportunities for the defense industry and weapons labs to contribute their considerable experience in advanced engineering research and applied science. The research may lead to broader application of some of the technologies developed. The near- to medium-term employment effects are likely to be small, however. Without major improvements in performance and price, the EV is unlikely to penetrate the market beyond what is mandated, and even the extent of this may not be very great, if legal challenges and other opposition, or a slackening of government commitment, limit mandates for ZEVs. If the pressure were to pay off, however, and an EV industry to establish itself, perhaps serving an export market as well as domestic, the country might enjoy considerable benefits in reduced reliance on oil, reduced pollution, and technology advance.

IVHS offers potentially more new high-tech jobs in the next decade than EVs do, as navigation and other units are built and installed in cars. While it may not drive new technology development to the same extent as EVs, IVHS will draw on existing technology, including some developed for defense, and broaden the market for it considerably. See table 7-9 for a summary of the potential impacts of EVs and IVHS.

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84 Robert D. Ervin, *An American Observation of IVHS in Japan* (AM Arbor, MI: The University Of Michigan, 1991).

85 Ibid., p. 1.