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ELECTRIC VEHICLES

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HISTORY

The electric vehicle is seen by many as the best near-term hope for an emission-free automobile. Not widely realized, however, is the fact that electric vehicles have been around as long as their gasoline-powered counterparts. The very first automobiles were powered by steam engines similar to those used in steam locomotives. Coal, or some other fuel, was used to produce compressed steam, which in turn pushed a cylinder and moved the car. This technology was very cumbersome, potentially dangerous (boiler explosions), and required special know-how to keep it working; as a result, the steam-powered car was short-lived.

Gasoline and electricity both offered a convenient, portable fuel that could be easily turned into mechanical energy using a simple motor or engine. In the early years of the automobile industry, these two technologies competed for supremacy and in the mid to late 1800s, electric vehicles were being developed.

It is reported that a Scottish inventor, Robert Davidson, developed the first prototype electric vehicle in 1837. The first four-wheeled electric vehicle was constructed in 1891 in Des Moines, Iowa. The vehicle, which could accommodate 12 passengers, apparently required 24 storage battery cells, took ten hours to charge, and could run for 13 hours, reaching a top speed of 22.5 km per hour. This vehicle was, however, never mass-produced; that honour belongs to the *Electrobat*, manufactured by a Philadelphia-based company. Between the years 1895 and 1920, nearly 50 companies were in the business of manufacturing electric vehicles.(1) By 1900, 38% of new American automobiles were electrically powered,(2) and by 1912, there were some 34,000 electric vehicles registered in the U.S.

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(1) Electric Vehicle Association of the Americas, (EVAA) http://www.radix.net/^futurev/facts.html, 1997.

(2) A. Haskell *et al., An Introduction to Electric Vehicles,* from Internet address http://www.suhep.phy.syr.-edu/car/links.html.

As is the case today, however, battery technology proved to be the one design feature stopping electric vehicles from keeping up with the competition. The on-board storage of gasoline provided more power, over longer distances, with less weight penalty than electric storage batteries. With the invention of the electric starter in 1912, and the availability of a cheap, plentiful supply of gasoline, gasoline-powered vehicles took over virtually the entire new car market, especially in the United States, where the last electric vehicles for general use were produced in 1940.(3)

The history of electric vehicle development in North America has been an up and down affair. Despite the market domination of the gasoline-powered automobile, automakers around the world have consistently retained at least small programs aimed at developing a competitive electric vehicle. In the 1960s, rising concern over air pollution in car-clogged cities prompted the major car manufacturers to attempt to produce a competitive electric vehicle. Their efforts were again curtailed, however, due to the high cost of these vehicles and the lack of demand. Although the oil crises of the 1970s once more revived interest in this technology, events again conspired to reduce activity drastically in the 1980s as gasoline prices stabilized and gasoline-powered cars became much less polluting and much more fuel-efficient. Electric vehicles seemed destined never to break out of the "chicken and egg" cycle. People would not buy them because they were too expensive, and car makers would not mass produce them (and thus bring down the price) because demand was so low.

The re-introduction of the electric vehicle into the market in recent years has been prompted primarily to meet regulatory requirements in California and a number of other states for zero emission vehicles (ZEVs) to make up a given percentage of the fleet sold by each manufacturer over a specified period of time. Further details of the regulatory requirements are presented in the section of this report entitled "The California Factor."

As a result of these recent developments, the electric vehicle once more appears to be on the threshold of breaking into the market. There are about 4,000 electric vehicles in use today in the U.S., most of which are conversions made from existing cars. It is expected, however, that vehicles that are factory-equipped to use electricity as a fuel will begin to appear in greater numbers starting with the 1997-98 models.

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(3) *Ibid*.

THE CALIFORNIA FACTOR

In California, 1990 amendments to the *California Clean Air Act* included the stipulation that, by 1998, 2% of all cars offered for sale by any auto manufacturer doing business in California must be "zero-emission" vehicles (ZEVs). This quota would rise to 5% by 2001 and 10% by 2003. The electric vehicle is currently the only real contender for the ZEV role. It should be remembered, however, that the electric vehicle is not a truly zero-emission vehicle. The electricity used to charge the batteries of these vehicles must be generated by some energy source. If this source is electricity produced at an oil, coal or natural gas power plant, emissions are produced; these can only be displaced from smoggy urban areas with lots of traffic, to more remote, less polluted areas. Only if the electricity is produced from a non air-polluting source such as nuclear, solar, or wind energy, can the electric vehicle be viewed as being truly "zero emission."

The California requirements, which have subsequently been adopted by a number of other states, have pushed automakers to redouble their efforts to develop and market mass-produced electric vehicles. The California new-car demand is over 900,000 vehicles per year, offering a potential market for some 18,000 electric vehicles for 1998 (2% of the total). This is a market that auto manufacturers cannot afford to ignore, and that would be large enough to permit mass-production. Legislators in California hope that these new requirements will break the "chicken and egg" cycle. While many view this approach, which provides a market impetus for an environmentally friendly technology, as positive, not everyone is enthusiastic about the perceived "undue haste" with which this generation of automobiles is being brought to market.

In a recent article, a group of researchers at the Massachusetts Institute of Technology (MIT) reviewed the total environmental and economic effects of the manufacture and use of electric vehicles made from a variety of materials and using a range of battery technologies. They also compared the electric-car mandate with alternative approaches for reducing air pollution. They concluded the following:

> Highway-worthy electric vehicles for mass consumption have neither been produced nor tested in significant volumes over the range of likely driving conditions. Their reliability over a standard warranty period, such as 3 years and 50,000 miles (80,468 km), is unknown. Electric vehicles for actual road use are still highly experimental.(4)

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(4) R. De Neufville *et al.*, "The Electric Car Unplugged," *Technology Review*, January 1996, p. 32.

The authors go on to comment that electric vehicles will actually contribute very little to the improvement of urban air quality and will be very costly. They suggest other measures that would be much more cost-effective at achieving the desired reduction in vehicle emissions.

> In our judgement, the electric vehicle policy defined by the California Air Resources Board is neither cost-effective nor practical. Electric vehicles will not contribute meaningfully to cleaner air if they are introduced as now proposed; over the next decade their effect will be imperceptible compared with other major improvements in automotive and other combustion technologies. Furthermore, even if it could be justified on environmental grounds, the technology of electric vehicles is still far from meeting the needs of a mass consumer market and it is unclear when, if ever, it will do so. Finally, the projected costs of implementing the California electric vehicle policy are enormous, requiring subsidies as high as $10,000 to $20,000 U.S. per vehicle.(5)

The authors suggest that Californians would derive more benefit from a range of measures that would produce immediate results more cheaply than would electric vehicles. For example, they suggest a program to buy up and remove the most severely polluting vehicles from the road - among 7 to 10% of older model cars are responsible for producing 50% of on-road hydrocarbon and carbon monoxide emissions; disincentives to driving, such as higher parking fees; promotion of car-pooling; and more use of buses.

California regulators counter that they had to break the “chicken and egg” cycle in which development of electric vehicles was hampered by inadequate demand, and demand remained low because EVs (electric vehicles) were not available. By regulating their introduction in significant numbers, California has done more than any other jurisdiction to push the emergence of electric vehicles. Whether one agrees with the California approach or not, its impact on research and development in this field is indisputable.

Despite early optimism, even California’s pro-EV regulators and legislators have recently had to accept that it will not be possible for carmakers to meet the 1998 goal; in March 1996, the 1998 and 2001 quotas for EVs were eliminated, leaving only the 10% goal for 2003 in place. According to some analysts, at the current rate of progress, only 5,000 additional EVs will be sold in the U.S. before the turn of the century.

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(5) *Ibid*.

WHAT IS AN ELECTRIC VEHICLE?

An EV is radically different from today's gasoline-powered vehicles, in which a combustion engines (ICE) relies on the combustion of fuel stored on-board the vehicle to produce motive power. Conventional vehicles require a constantly running engine whose power is diverted through a series of gears and clutches to drive the wheels and turn a generator providing power for accessories such as lights and air conditioning. Instead of gasoline, an EV stores electrical energy in large, rechargeable batteries. As soon as the car is turned on, a vehicle system controller sends this power directly to the electric drive motors that turn the wheels. There is no need for gears and clutches, or for a muffler system, since there is no noisy combustion. Energy is delivered only when the driver presses down on the accelerator and so is not wasted while the car is at rest or coasting.(6)

Many electric vehicles now coming on to the market are equipped with a regenerative braking system that adds to the efficiency of the operation since the electric drive motor acts as a generator when the car is slowing down. In other words, the motor is "reversed." Instead of generating friction heat when braking (as happens with the disc or drum brakes used in gasoline-powered vehicles) the EV motor helps brake the vehicle and thereby generates electricity to recharge the battery.(7) In this way, as much as one half of the car's kinetic energy can be returned to the battery, giving electric vehicles a decided advantage in stop-and-go urban traffic.

Another feature offered by EVs is the efficiency with which they convert the available energy into motive force. An EV turns 90% of the electrical energy in its batteries into motive force, while an internal combustion engine uses less than 25% of the energy in a litre of gasoline. Even taking into account that the electricity used in the EV was produced in a generating station, typically operating at about 33% efficiency, this calculation still has a 5% efficiency advantage, which will increase over time with technological improvements in electricity generation, such as combined cycle generation.(8)

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(6) D. Sperling, "The Case for Electric Vehicles," *Scientific American*, November 1996, p. 54-55.

(7) From Ford Motor Company Internet site, January 1997 (www.ford.com).

(8) Sperling (1996), p.55.

THE PROS AND CONS OF ELECTRIC VEHICLES

The EV is promoted as being a clean or even a “zero emission” vehicle with environmental benefits. This is true insofar as operation of the vehicle itself goes. EVs can help to reduce the smog-forming emissions from vehicular traffic. As already discussed, however, the electricity used to charge the batteries can be said to be emission-free only if the source is nuclear, solar, or wind energy. Otherwise, the EV merely relocates the source of pollution away from congested urban areas, rather than eliminating it altogether.

Ford Motor Company publications on EVs note two additional advantages. Electric vehicles are quiet; the motors used emit practically no sound at all. Since no combustion is taking place, there is no need for a muffler to attenuate that noise. Indeed, the company notes that the EV runs so quietly that they are now having to find means of “silencing” other noisy components, such as air conditioners and power steering systems, which are not as audible in a car with an internal combustion engine. The second advantage of EV technology is the smoothness of the drive. Most of the advanced EVs use a single speed AC motor with no transmission, which makes acceleration “smooth and seamless, smoother than the best transmission on today’s luxury cars.”

Not only is the EV quiet and clean running, but the lack of a transmission and conventional drive-train means no more oil changes, no need to use radiator coolant, no requirement for tune-ups and no need for emission testing on a periodic basis. The reduction in use of oil and radiator fluid should have a positive environmental effect, since less of these substances will be spilled to run off and potentially pollute watersheds.

On the “con” side of the environmental argument, some researchers have noted that the widespread use of large, lead-acid batteries, which are at present the batteries most commonly used in EVs, could result in serious increases in lead pollution as the use of EVs spreads. Research conducted at a U.S. university concluded that the lead-acid battery production required for manufacturers to meet the 1998 California goal (2% of cars) would result in the release of 60 times more lead per kilometre from EVs than from a similar number of cars burning leaded gasoline. One of the authors of the study noted that:

> A basic conclusion of our study is that the introduction of electric cars will raise the total level of lead pollution, even though it may shift the deposition from the road to battery manufacturing facilities where it is less visible. In fact, the anticipated lead pollution will be considerably greater than that formerly caused by tetraethyl lead fuel additives.(9)

A second group of researchers suggests, however, that these apparently alarming conclusions were based on flawed data; this group came up with a much lower estimate of the additional lead that would be released as a result of the introduction of EVs. The International Centre for Technology Assessment (CTA) noted in its analysis of the first study that:

> Even in the worst-case scenario, lead-based waste products would be no more than 3 times (not 60 times) the amount of lead released from leaded gasoline. Yet the majority of this material would be in locally controlled solid waste form, not air emissions.(10)

Electric vehicles have, to date, often been criticized for having a rather limited range of operation. For example, the most commonly used battery, the lead-acid battery, offers a range of just 80 km. Other batteries may extend the range up to 160 km. In fact, a Solectrica car recently broke the range record for an electric vehicle, covering some 603 km on a single charge.(11) However, these more advanced batteries remain rather expensive. The Ford Motor Company sums up the situation this way:

> Customers want a vehicle with 100 mile range, and cost as much to purchase and maintain as a conventional vehicle. The reality is that current EVs have a range of just 50 miles (80.4 km), cost two to three times more than conventional vehicles and have batteries that need to be replaced every two to three years at a cost of $3000 to $5000.(12)

Price is the major concern for EV producers and consumers alike.(13) Price estimates vary for EVs vary from $34,000 U.S. for the GM EV1 using lead-acid batteries, to

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(9) J. Haggin, "Electric Cars Projected to Raise Lead Pollution," *Chemical and Engineering News*, 22 May 1995, p. 7.

(10) "Centre for Technology Assessment Refutes Carnegie-Melon Analysis," *The Clean Fuels Report*, April 1996, p. 190.

(11) EVAA (1997), p. 2.

(12) *Ibid*.

(13) Sperling (1996), p. 58.

$75,000 U.S. for the independently developed Solectria. The major contributor to this price differential is the battery technology used in the two vehicles; the GM car uses advanced lead-acid batteries, while the Solectrica uses nickel-metal-hydride batteries. It is clear that improvements in battery technology hold the key to reducing costs and improving the range of electric vehicles, thereby allowing them to gain more widespread acceptance. Many companies around the world are investing a great deal of money in research and development of improved battery technology. Progress in this area has come rapidly in recent years, spurred on, in large part, by the mandated market in California.

BATTERY TECHNOLOGY

A. Lead-Acid Batteries

Most of us are already familiar with the lead-acid battery, since this is the type found in today's conventional cars. When the engine is running, the battery is charged through a generator and then an alternator. Power from the battery runs the electronic components of the automobile such as the starter, lights, heater, air conditioner and radio. In an electric vehicle, the batteries also drive electric motors that are directly connected to the wheels and make the car move. Regenerative braking on many EVs allows for some re-charging while the vehicle is in use. With this type of system, the flow of electricity is reversed when the driver steps on the brake, recharging the battery, and thereby extending its range.

It is obvious that, in order to provide all of the power for an EV, the lead-acid battery would have to be larger and more powerful than current technology. Conventional batteries would wear out after about 30 recharge cycles and would so be unsuitable. The lead-acid batteries used in EVs are known as deep-cycle batteries. They feature tall, thin lead plates and are designed to last through 400 to 800 charge-discharge cycles. With temperatures at the freezing point, however, current deep-cycle batteries operate at only 70% capacity. In Canada's climate, an insulated battery box and a thermal management system of some sort will clearly be required.(14)

In 1992, the need for improvements in battery technology led to the formation of a consortium of 49 U.S. companies to carry out basic research to improve the lifespan and

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(14) EVAA (1997), p. 1.

specific energy of lead-acid batteries, while preserving their power density and cost advantages. The Advanced Lead Acid Battery Consortium (ALABC) also sought ways to significantly reduce the time taken to recharge the batteries. The work of this consortium has resulted in many of the advances seen to date; a recent publication reported that the consortium is having a great deal of success in meeting its goals.

With regard to recharge time, a new technique known as fast-pulse charging has proven to be very successful, reducing the time needed to recharge a battery from 80% depth of discharge from several hours to just 15 minutes. As an additional unexpected benefit, this new method of recharging also apparently increased the expected life of the battery from about 250 cycles to nearly 1,000 cycles.[(15)]

The ALABC is also working on reducing the weight of its batteries by using new curing methods and by adding different alloys. The use of stronger, thinner, more corrosion-resistant grids has already improved the specific energy (watt-hours produced per kilogram of weight) from 35 watt-hours in 1994,[(16)] to 48 watt-hours per kilogram in 1996[(17)] in a prototype battery. The range of the vehicle using a lead-acid battery remains at about 241 km between recharging.

As a result of these improvements, the cost of lead-acid batteries has declined sharply in the last five years. In 1992, the cost of ownership was $1.11 U.S. per mile, which was reduced to $0.11 per mile by 1995; if progress continues at the current rate, by 1998 it could drop as low as $0.05 per mile.[(18)] Clearly such advances will improve consumer response to electric vehicles.

B. Nickel-Cadmium and Nickel-Iron Batteries

Nickel-cadmium battery technology is not new. These rechargeable batteries are commonly used in everyday electronic equipment, from portable radios to hand-held video games. They have been looked at by some North American companies for use in electric

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(15) "Advanced Lead-Acid Battery Consortium Meets First Phase Goals," *The Clean Fuels Report*, November 1996, p. 176.

(16) D. Ilman, "Automakers Move Towards New Generation of "Greener" Vehicles," *Chemical and Engineering News*, 1 August 1994, p. 12.

(17) *The Clean Fuels Report* (Nov., 1996), p. 177.

(18) *Ibid*.

vehicles but have not been as widely accepted here as in Europe. In October 1995, the Saft Company in France opened the first plant to produce batteries in volume for electric vehicles. The plant, which cost some $20 million U.S. to construct, will initially produce about 5,000 nickel-cadmium batteries per year.

Batteries produced in this new plant will be installed in all of France's volume-produced EVs. These include the Citroen AX, the Peugeot 106 and Renault's Clio and Express. The advantages of nickel-cadmium batteries are their low maintenance requirements and long life, thought to be some 96,558 km. High cost, environmental concerns over the use and recycling of highly toxic cadmium and a tendency to overheat are the major concerns raised with respect to the use of these batteries in electric vehicles.(19)

Nickel-iron batteries have high energy density (amount of energy relative to the size of the battery) so that they have the advantage of being smaller than other batteries delivering the same power. To be fully charged, however, the battery must be overcharged by 11%; this results in a loss of water and a build-up of potentially dangerous hydrogen.(20) The Advanced Battery Consortium is working on these problems and the nickel-iron and nickel-cadmium batteries are included in their category of "near-term" batteries expected to be available commercially between 1996 and 1998.

C. Nickel-Metal-Hydride Batteries

The nickel-metal hydride battery appears to be one of the leading contenders to replace lead-acid batteries in EVs in the mid-term (1999-2001). As it is composed of non-toxic recyclable materials, it is seen as environmentally friendly.(21) Consisting of nickel hydroxide and an alloy of vanadium, titanium, nickel and other metals, it offers a range double that of current lead-acid battery technology. In the U.S. the Ovonics Battery Company of Troy, Michigan, is leading the development of this technology.

This type of battery, unlike some others under development, operates at room temperature, and is totally sealed and maintenance-free. It can operate effectively in ambient air temperatures ranging from -6.6 to 48.8°C and can be recharged in only 15 minutes. These are all

(19) "Saft Making Progress with a Number of Batteries," *The Clean Fuels Report,* June, 1996, p. 174.

(20) EVAA (1997), p. 2.

(21) *Ibid*.

features that make the technology very attractive. In the past two years the NiMH battery has been tested in a variety of conversion and purpose-built EVs, logging 160,930 km in 20 different vehicles, from sub-compact cars to pick-up trucks. These tests have shown that the NiMH battery offers double the range of advanced lead-acid batteries in EVs.

However, as in so many new battery systems, cost remains a problem, as does commercial production. For the Ovonics company, commercial production in 1997 will be equivalent to about 2,000 EV battery packs. This number will be increased slowly, so as to preserve the high quality and reliability of the prototypes. If commercial production and demand can reduce the price differential, NiMH batteries could give lead-acid batteries a run for their money in the future.[22]

D. Sodium-Sulphur Batteries

The Ford Motor Company used a sodium-sulphur (NaS) battery in its 1992 Ecostar because it offered three to four times the energy density of lead-acid batteries; in other words, a physically smaller battery could provide the same power. The NaS battery also has a range of about 241 km, roughly twice that of an EV powered with lead-acid batteries.

This technology, however, has not received widespread acceptance for a number of reasons. For one, it is not considered "user friendly." Because one of the electrodes is made of molten sulphur, the battery must be kept at a temperature of 300 to 350ºC. To keep the sulphur, and the sodium, from solidifying, the batteries have built-in heaters. As a result of these stringent operating requirements, NaS batteries currently cost seven times as much as lead-acid batteries.

In addition, safety concerns were raised when two Ford test vehicles caught fire while using NaS batteries. This technology is not likely to emerge as an early leader in the race to find the best battery for electric vehicles. Companies in at least seven countries believe that it offers great potential, however, since it uses relatively cheap, abundant materials. These companies are all working to build on the advantages of the technology, while ridding it of its more troublesome problems.[23] As with any of these new battery technologies, mass production could quickly reduce costs.

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(22) *Ibid*.

(23) *Ibid*.

E. Lithium-Ion Batteries

The lithium-ion battery has been under joint development since 1992 by the Nissan Motor Company and Sony Corporation in Japan. The Nissan Prairie Joy EV, which will be available in spring 1998 on a limited lease/sale program, is the only vehicle currently on the market (or about to enter the market) which uses this battery technology. About 100 vehicles will be involved in the program in Japan and in late 1997 the lithium-ion battery will be field tested in California in approximately 30 newly developed minivans.

The lithium-ion battery offers about three times the energy storage capacity of lead-acid batteries and about one and one-half times that of nickel-metal-hydride batteries. It also exceeds the power density of these competitors, giving it a greater range. The battery is much lighter than other batteries, and its recharging is much more efficient.

On the negative side, lithium-ion batteries are about twice as expensive as lead-acid batteries, partly because of the ventilation system needed to keep the batteries cool and partly because of the materials used. The anode is made of oxidized cobalt, the electrolyte is a highly purified organic material and the cell control system needed to operate a vehicle powered by lithium-ion batteries is very complex.(24)

A number of other lithium-based batteries are also the subject of research in North America. These include a battery based on a lithium alloy/molten salt/metal-sulphide electrochemical system, and a lithium-polymer battery. Both offer certain advantages over the advanced lead-acid battery technology, but cost and a number of technical problems are barriers to their development. These batteries are, at best, long-term rivals to other current and evolving battery systems.

F. Zinc-Air and Aluminium-Air Batteries

In these two batteries the metal (zinc or aluminium) reacts with atmospheric oxygen, in the presence of an electrolyte to produce electricity and a metal compound. The metal plates in the battery are literally consumed in the process. When the aluminium or zinc is exhausted, the vehicle is taken to a refuelling station where the used plates and the waste metal

(24) *Ibid.*, p. 5.

are removed, new plates are inserted into the battery and the vehicle goes on its way in a matter of minutes. The waste metal can then be recycled and made into new battery plates.

An Israeli firm, Electric Fuel, has developed and is testing a zinc-air battery in 40 test vans. This battery has an energy density (amount of energy relative to its size) that is 10 times that of a lead-acid battery.(25) Several U.S. firms are also working on this technology and a zinc-air battery recently powered an EV to a new record of over 1,609 km on a single charge. Cost remains a problem for this technology, as it does for the aluminium-air battery. The aluminium-air battery has been of interest to researchers since the early 1980s.(26) Not only does it remain costly, but its large size means that it will probably find use in larger vehicles only.

G. Fuel Cells

A fuel cell is an electric cell in which the chemical reaction between air, or oxygen, and a gaseous fuel results in a release of electrical energy. The fuel cell differs from a traditional battery in several ways. A battery is simply an energy storage device; the energy it can deliver depends on the mass of the chemical reactants stored within it. Over time, the reactants are consumed and the battery is discharged; it must be recharged from an external electrical source before it can be useful again.

By contrast, a fuel cell is an energy conversion device. None of the fuel cell components are consumed in its operation, and so it can continue to function as long as the chemical reactants are provided. For example, in some fuel cells hydrogen and oxygen are mixed together, producing water and a flow of electricity. As long as hydrogen and oxygen are supplied, the cell will keep producing electricity. Fuel cell research and development received a boost during the 1950s and 1960s as the space race began to take off. Spacecraft and satellites all required a stable, highly efficient electricity supply, just what the fuel cell provided.

A Canadian company, Ballard Power Systems, has been active in this field since 1979. It has developed a fuel cell that is lighter and smaller than many others on the market. It uses lightweight polymer materials (a proton exchange membrane) and is highly efficient. The Ballard Fuel Cell is the "battery" that powered the world's first operating zero-emission vehicle

(25) *Ibid.*, p. 7.

(26) House of Commons Special Committee on Alternative Energy and Oil Substitution, *Energy Alternatives*, June 1981, p. 196 .

– a transit bus. The development of this system began as a joint venture with the Province of British Columbia and BC Transit. It culminated in the 1995 introduction of Ballard's commercial prototype fuel-cell-powered transit bus in 1995. The last phase of development is underway, with a multi-year fleet demonstration program, involving BC Transit and the Chicago Transit Commission.

Ballard, which also has strategic partnerships with a number of automobile companies, including Daimler-Benz, General Motors and Nissan, is working on proton exchange membrane (PEM) fuel cells for use in cars. The Ballard PEM fuel cell appears to offer the advantage of being lighter and smaller than its competitors. More efficient, lighter and less bulky means of storing the fuel (usually hydrogen or methanol) are still needed, but in the long-term, fuel cell technology should be able to compete well with more traditional battery technologies.

HYBRID-ELECTRIC VEHICLES

The introduction of large numbers of electric vehicles could be hampered somewhat by infrastructure problems and by reduced performance of vehicles. Both of these factors cause consumer resistance. In an attempt to overcome such problems, and to take advantage of the best of several technologies, researchers in a number of countries are also working on a hybrid electric vehicle (HEV) which would combine the best features of an efficient engine and of an electric drivetrain.

In most HEV research, an internal combustion engine is coupled with a battery system and an electric drivetrain. In a hybrid vehicle both technologies could be optimized to achieve much higher overall efficiency than is achieved by vehicles using either power supply separately. For example, it has been estimated that HEVs can double or triple the efficiency of today's passenger cars.(27) All of the major automakers are working on HEVs but, until very recently, none have had them available for sale to the public. In October 1997, Toyota Motor Corporation announced that it would begin marketing the Prius HEV immediately.(28)

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(27) *The Clean Fuels Report* (1996), p. 183.

(28) "Toyota Introduces Gasoline-Electric Hybrid Car," *The Ottawa Citizen*, 16 October 1997, p. D4.

The Prius will be sold only in Japan for now; it will retail for about $18,000 U.S., although it costs the company an estimated $41,000 U.S. to produce. The company apparently regards this subsidy to consumers as an acceptable advertising cost. By going ahead, Toyota has the honour of being the first company in the world to enter what it hopes will be a lucrative market.

The idea of operating each of the two “engine” technologies at their optimum level is fulfilled in this new car. At lower speeds, when a gasoline engine is at its least efficient, it will run on electricity, but it will automatically switch over to gasoline when the vehicle reaches a certain speed. As far as consumer acceptance is concerned, the HEV will have the advantage over an electric vehicle, since it can be refilled at existing gas stations. The gasoline engine and the regenerative breaking system keep the batteries charged.

Consumer acceptance aside, one might question the rationale for adding a polluting gasoline engine to an electric car when the goal is to cut pollution; however, because the engines that will be used in hybrid vehicles are so efficient, the level of emissions will be very low. A recent study by a U.S. consulting firm noted that, where the electricity to power the EV comes from coal-fired generation, the HEV could actually be less polluting than the EV on a full life-cycle basis. The consultant commented:

> In the United States over one-half of the electricity is generated from coal. Consequently, in the United States EVs will generally have higher greenhouse gas emission levels than emission levels projected for gasoline-fuelled HEVs of comparable size.(29)

This fact has not escaped California regulators, who continue to look for ways to cut pollution from cars, even though they have had to loosen the regulations for the phase-in of zero-emission vehicles. They have now created new standards for ZEV-equivalent technologies, to allow HEVs into the market. It is not yet clear, however, whether the very stringent standards that have been set can be reached by current HEV technology. It remains to be seen whether this technology can meet the challenge and capture markets in the years that it will take to “perfect” electric vehicle technology.

(29) *Ibid*.

ELECTRIC VEHICLES ON THE MARKET IN 1997[30]

All of the major automobile manufacturers in North America, parts of Europe and Japan have 1997 model electric vehicles for sale. This section provides a brief account of the vehicles being offered to meet the California ZEV mandate. Table 1 provides this information, along with specifications for EVs for use in international demonstration projects, those available from specialist EV manufacturers, and a number of prototype vehicles under development.

General Motors is currently offering the EV1 for sale at a cost of $34,000 U.S. This vehicle claims to have a range of 112 km in the city and 144 km on the highway (at a constant speed of 100kph). The EV1 uses lead-acid batteries. At 220 volts the EV1 takes about three and a half hour for a full recharge. The owner of an EV1 will have to purchase a $2,500 home charger and pay for its installation or pay a $70 per month lease charge.[31] For 1996-97 the EV1 will be available only at selected Saturn showrooms in California and Arizona, and will only be for lease, not for sale. The company feels that this will protect the early customers from expensive repairs or maintenance should these first production vehicles run into trouble. It also means that the consumer will not have to cover the expense of battery replacement.

GM also is marketing a Chevrolet S-Series EV Pick-up, which uses a recyclable lead-acid battery pack that can be recharged (from 15% to 95% state of charge) in two and a half hours. The pick-up can cruise for about 96.5 km at a constant speed or for 64 km in stop-and-go traffic.

The Chrysler Epic minivan is the EV version of the Dodge Caravan and Plymouth Voyageur, designed with the "second family car" market in mind. Available to customers in 1998, it will feature 27, 12-volt lead-acid batteries. It has a range of about 100 km, and a top speed of 128 kph.

In the 1997 model year, the first factory-produced Ford Ranger EV pick-up trucks will be available. Until this year Ford has sold the "gliders" (frame or shell of the vehicle without motor or powertrain, to another company (Transportation Design and Manufacturing) which installed the electric drive train. Designed primarily for fleet customers, the Ranger uses

(30) Unless otherwise footnoted, information in this section is from various 1996 and 1997 issues of *The Clean Fuels Report.*

(31) J. Hiscock, "New Electric Car Has Enough Zip To Give GM Lead In Technology Race," *The Ottawa Citizen,* December 6, 1996, p. C9.

39, 8-volt lead-acid batteries and has regenerative braking. It has a range of 56 km at 0°C, with the heater operating) to 100 km in warmer temperatures, but without the air conditioning. The payload is about 226.8 kgm and the price tag about $34,000 U.S.

Japanese carmakers are also getting into the EV production business, with an eye to the lucrative California market. In the spring of 1997, the Nissan Motor Company offered for lease/sale a limited number (probably fewer than 100) of Prairie Joy EVs. These vehicles are unique in that they use lightweight, high-energy storage capacity lithium-ion batteries. The vehicle seats four and has a range of over 200 km between charging. A full recharge takes about three hours. The Prairie Joy EV is aimed at the delivery fleet market.

Honda has also entered the race to supply California with electric vehicles. In the spring of 1997 it will begin leasing about 300 two-door, four-passenger EVs to industrial consumers in Sacramento and Southern California. The Honda EV Plus boasts a range of 200 km to 100% depth of discharge and 160.9 km at 80% discharge, with a top speed of about 128 kph. No lease fee has yet been announced. The extra range of this vehicle is attributable to its use of the Ovonic Battery Company's nickel-metal-hydride (NiMH) batteries. These batteries can be recharged from 100% discharge in eight hours using 220 volts and are expected to have an average life of 100 cycles or four to five years. They are, however, considerably more expensive than lead-acid batteries.

Toyota has already tested its RAV4-EV in California and New York with utility companies and at its own test facilities in California and Michigan. The RAV4-EV is a sport-utility vehicle that uses NiMH batteries developed by Masushita Corporation. These batteries have a life of six to eight years and give the vehicle a range for combined highway/city driving of 188 km at a top speed of 120 kph. Toyota will begin selling 320 of these sport-utility vehicles in 1998 in California. A final selling price has yet to be determined.

CONCLUSION

Whether one agrees or not with the approach taken by California in mandating the use of zero-emission vehicles, there can be no doubt that it has begun to produce results in providing the incentive for vehicle and battery manufacturers to improve the performance of electric vehicles. Hundreds of companies are involved in the race to produce the best electric vehicle, with the longest range, shortest refuelling time and, of course, the lowest price.

If the level of competition continues and the market created by regulations in the U.S. continues to grow, moderately priced, quiet, efficient electric and/or hybrid electric vehicles should be available to all consumers, including those in Canada, in the not too distant future.

Table 1
ELECTRIC VEHICLE PERFORMANCE

Manufacturer	Vehicle	Seats	GVW[(1)] (kg)	Range (km)	Max Speed (kph)	0-97 kph Acceleration (sec)	Motor Type	Power (hp)	Battery Type
Offered to Meet California ZEV Mandate									
Chrysler	EPIC Van	5	2,676	97	129	16	AC induction	100 peak	lead/acid
Ford	Ranger EV			56-121	121	<13 (to 81 kph)	AC induction	90	lead/acid
General Motors	EV1	2	1,347	113-145	129	8.5	AC induction	137	lead/acid
General Motors	Chev. S10 Pickup		2,336	64-97		10.3 (to 81 kph)	AC	114	lead/acid
Honda	EV Plus	4	1,633	97-201	129	30.1	DC brushless	66	NiMH
Nissan	Prairie Joy EV	4	1,690	193	121		perm. magnet	83	Li-ion
Toyota	RAV4 EV	5	1,465	171-209	127	17.5	AC	60	NiMH
Offered for Use in International EV Demonstration Programs									
Citroen	Saxo Electrique	4		85					NiCad
Fiat	Panda Elettra	2	1,148	64	68	17.5		10	lead/acid
Renault	Clio RT	4		90	97				NiCad
Samsung Motors	SEV-IV	4		161			DC		lead/acid
Volkswagen	Golf City Stromer	4	1,497	80	97			24	lead/acid
Specialist EV Manufacturers									
BAT International	Electrovan		217						zinc/air
Bombardier	NEV	2	578	48	40		DC	5	lead/acid
Corbin-Pacific	Sparrow	1	449	97	97		DC series	15	lead/acid
Daihatsu	Micro	1	470	35	45				
Electric Auto Corp.	Silver Volt II	4		241-322	161	10	DC	163	lead/cobalt
PIVCO	City Bee	2	750	105					NiCad
Solectria	Force	4	1,084	64-72	113	19	AC induction		lead/acid
Solectria	Force (option)			129-161					NiMH
Prototype Vehicles									
AC Propulsion	t-ZERO	2	1,089	97-161	140	5	AC	221	lead/acid
Bertone	Z.E.R.	2		465	119				lead/acid
Horlacher	Electric Coupe								
Zytek	Lotus Elise	2	870	193	145	11.2 (to 145 kph)	DC brusheless	201	NiCad

(1) GVW = Gross Vehicle Weight
Source: The Clean Fuels Report, June 1997, p. 175.