Chapter 6

Electric Vehicles

Electric vehicles, or EVs, are an exciting concept to policymakers because they combine excellent urban pollution benefits-the vehicles emit virtually no air pollutants, and the power generation facilities that “fuel” them, while contributing to problems associated with long-range pollution transport,[1] often play only a minor role in urban air quality—with an existing energy delivery infrastructure (except for charging stations) and a capacity to use a variety of domestic energy resources. Assuming that vehicles would be recharged at night, when electricity demand from most other uses[2] is low, existing electricity capacity could support a very large fleet. Studies done a decade ago found that a fleet of several tens of millions of vehicles could easily be supported by the existing capacity without the use of peaking units.[3] This conclusion almost certainly still holds. Also, EVs offer the potential to reduce greenhouse emissions, particularly if the generating capacity used to recharge the fleet is nuclear or renewable-powered. For the next few decades, with the slowdown in nuclear capacity additions, the current baseload use of existing nuclear plants,[4] the limitations on new sites for hydroelectric power facilities, and the lack of availability of cost-competitive solar electric technology, the greenhouse potential is limited. Moderate improvements will be possible, however, if efficient new powerplants fueled with natural gas can become important sources of EV recharging energy.

VEHICLE CHARACTERISTICS

Although EVs can operate successfully today in certain restricted uses, it is safe to say that large fleets of such vehicles will remain only a tantalizing possibility unless there are either substantial improvements in battery technology, major changes in consumer preferences, or a willingness on the part of the Federal Government to intervene firmly in the transportation market. With available battery technology, EVs will have limited range, performance, and cargo- and passenger-carrying capacity, high first costs (batteries included), and high operating costs, because of low energy and power densities and limited battery lifetimes (which create the need for expensive battery replacements). Also, performance and range will be degraded during cold weather, because of the loss of battery performance as well as the need to heat the passenger compartment. Similarly, air-conditioning requirements during hot weather will degrade performance and range.

Even with today’s limited-capability batteries, however, adequately performing vehicles can be designed for certain urban niche markets. For these markets, various performance characteristics can be traded off+. g., higher accelerations and top speeds can be obtained at the expense of range and/or carrying capacity, or vice versa.

Unlike combustion engines, electric motors will not continue running when the vehicle is stopped, conserving energy in stop-and-go urban traffic.[5] Consequently, electric propulsion can be effective for urban delivery vehicles that travel less than 100 miles per day under heavy traffic. Several hundred English-made Bedford electric vans, called the Griffon in this country and marketed by General Motors, have been used by U.S. utilities during the past few years.[6] These vehicles have a top speed of slightly over 50 mph and a range of 55 to 65 miles

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[1] In particular, acid rain and degradation of visibility.

[2] Space heating is the primary exception.

[3] General Research Corp., *Prospects for Electric Cars*, for U.S. Department of Energy, Washington, DC, 1978, reported in U.S. Department of Energy, ***Assessment of Costs and Benefits of Flexible and Alternative Fuel Use in the U.S. Transportation Sector. Progress Report One: Context and Analytical Framework***, January 1988, DOE/PE-0080. Although inclusion of peaking power would theoretically increase the number of vehicles that could be supported, this is impractical from the standpoint of both cost—peaking power is very expensive-and maintenance-most peaking units are designed for limited operation only.

[4] Utilities use their lowest-operating-cost plants—which often are their nuclear plants—at as high a load factor as they can, so that these plants are likely to be in use even during periods of low load; utilities cycle down their higher-operating-cost plants during these periods (subject to physical limitations on cycling). With rising electricity demand and stagnant nuclear supply, little excess nuclear capacity will be available to charge EVs.

[5] Actually, strictly speaking, combustion engines can be turned off when the vehicle is stopped and restarted when necessary. Although vehicles have been designed with this feature, manufacturers have not placed them on the market because of their doubts about consumer acceptance.

[6] Electric Power Research Institute, “Fleet Vans Lead the Way for Electric Vehicles, ” *EPRI Journal*, vol. 11, No. 5, July/August 1986.

carrying a 1,900 pound payload. Battery life for the $4,750 (in 1986) lead/acid battery is 4 years, so battery replacement is a significant part of total operating costs.[7]

Unless U.S. consumers can be convinced (or coerced) to purchase limited-use/limited-performance vehicles, EVs will not make a substantial impact on total travel until they can, *at a minimum*, extend their range considerably (the ability to travel further than 100 miles on a charge is sometimes cited as a minimum) and perform adequately in a range of traffic conditions, including highway traffic. And although these performance requirements are probably a necessary condition for high market penetration, EVs would still face substantial barriers, discussed later.

ADVANCED TECHNOLOGY

Developments during the 1980s in batteries and powertrains indicate that the design conditions necessary for successful EVs maybe moving within reach with further engineering development. Advances in microelectronics have made it possible to build lightweight dc-to-ac inverters, which allow the use of ac motors rather than the heavier, more expensive dc motors typical of previous EVs.[8] This technology has important benefits for both vehicle weight and cost, to the extent that an EV using this technology is likely to be similar in cost, *excluding* battery cost, to a comparable internal-combustion-engine-powered car. And advanced batteries, some apparently moving closer to commercialization, offer the potential for substantial improvements in performance and durability over lead/acid batteries. Advanced battery types include nickel/iron, nickel/cadmium, zinc/bromine, lithium/iron sulfide, sodium/sulfur, and metal-air.

Because none of the advanced batteries is actually commercially available, and all (with the possible exception of the nickel-iron battery) need considerable engineering development, there are strong uncertainties about their eventual durability and cost, and analysts disagree about their relative promise. For example, some analysts view the nickel-iron battery as an especially promising candidate for the next generation of EVs and close to commercialization, because it has convincingly demonstrated long cycle life and ruggedness and somewhat higher energy density than lead/acid technology.[10] However, these batteries produce substantial quantities of hydrogen during recharge, have high water consumption, and are relatively inefficient.[11] They may also be quite expensive, although cost estimates for all of the noncommercial battery types are speculative. Finally, the supply of nickel could become a constraint if similar batteries were adopted worldwide. Leading European battery developers apparently have given up on development of nickel-iron batteries.[12] However, Chrysler's concept TEVan, an electric minivan based on the Caravan/Voyager vans and apparently under discussion for production in the early -1990s timeframe, uses a nickel-iron battery developed by Eagle Picher Industries.[13]

Although requiring more development work than the nickel/iron battery, the high-temperature sodium/sulfur battery is viewed as extremely promising if cost and durability uncertainties can be resolved favorably. This battery offers much higher energy and power densities than its lead/acid and nickel/iron counterparts, no water requirement, no gas production when charging, very high charging efficiencies, and cheap, abundant reactant materials.[14] Important potential problems with the sodium/sulfur battery include durability, associated with corrosion problems from sodium compounds

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[7] Ibid.

[8] M.A. Deluchi, Q. Wang, and D. Sperling, "Electric Vehicles: Performance, Life-cycle Costs, Emissions, and Recharging Requirements," *Transportation Research*, vol. 23A, pp. 255-278.1989.

[9] W. Hamilton, *Electric and Hybrid Vehicles*, paper prepared for the Department of Energy Flexible and Alternative Fuels Study, May *26,1988*, draft.

[10] DeLuchi et al., op. cit., footnote 8, table 3. Characteristics of EV storage batteries. The nickel-iron battery designed for Chrysler's TEVan, which Chrysler hopes to introduce by the 1990s, has a specific energy 65 percent greater than the lead-acid batteries in GMs G-Van L.G. O'Connell, Electric Power Research Institute, personal communication.

[11] DeLuchi et al., op. cit., footnote 8.

[12] E. Eugene Ecklund, Alternative Transportation Fuels Foundation, personal communication.

[13] Electric Power Research Institute, "The Chrysler Electric TEVan. High Performance for the Growing Minivan Market," brochure EU.2022.6.89. The brochure claims a payload of 1,200 pounds, range of 120 miles, top speed of 65 mph, and 0 to 60 acceleration of 14.0 seconds. This level of performance greatly exceeds existing commercial vehicles and would seem likely to make the vehicle quite attractive if lifecycle costs are competitive.

[14] Ibid.

formed at the battery electrodes, and requirements for heavy insulation to maintain high temperatures inside the battery.

For the longer term-beyond the year 2000-the metal-air batteries are intriguing because they combine high power density with mechanical rechargeability, that is, they can be recharged rapidly by replacing the metal anodes, adding water, and removing byproducts. These batteries are also farthest from commercial readiness, and their eventual practicality is far from assured; important problems remain concerning their cost, durability, the need for practical CO_2 scrubbers, and their complexity.

A common concern with the advanced batteries, and for that matter with commercial lead-acid batteries as well, is the environmental implication of the large disposal and recycling requirement associated with battery production and for any major market penetration of EVs.

MARKET COMPETITIVENESS

Despite the renewed optimism about EVs in some circles, their eventual acceptance as a significant portion of the vehicle market is highly uncertain. First, total EV costs may be quite high, though available cost estimates cover a wide range. As noted above, the advanced batteries necessary for EVs to make major inroads in the urban market are too far away from mass production to allow reliable cost estimates to be made. However, even conventional lead-acid batteries will add a few thousand dollars to initial vehicle cost, and all of the advanced batteries will be even more expensive. Consequently, it is virtually certain that EVs will be more expensive than competing gasoline-fueled vehicles. Taking into account the cost and performance uncertainties associated with the batteries as well as other uncertain variables such as electricity price, cost evaluations can yield lifecycle costs that range from extremely attractive to extremely unattractive. For example, in a recent analysis, the "breakeven price" of gasoline--the price for which an EV's lifecycle cost was the same as that of a similar gasoline-powered vehicle—ranged from $0.04/gallon assuming low nighttime charging rates ($0.05/kWh) and very optimistic EV performance and cost,[15] to $3.90/gallon for a higher electricity cost ($0.09/kWh) and pessimistic EV performance and cost.[16] In this analysis, the startlingly low ' 'optimistic breakeven price" results in part from assumed maintenance costs that are much lower than for the gasoline vehicle, vehicle lifetimes twice as long (which reduces the annual vehicle depreciation costs, a substantial portion of vehicle ownership costs), and a very high powertrain efficiency. Although the minimum breakeven gasoline price seems absurdly low, it can be put into better perspective by remembering that fuel costs represent less than one-sixth of total vehicle lifecycle costs today,[17] and maybe even less of a factor in the future as fuel economy increases.

In another analysis, the Department of Energy has projected roughly equal lifecycle costs for competing EVs and gasoline vehicles for a 1995 EV using nickel-iron batteries. The analysis assumes that battery life will be 10 years and specific energy is 53.1 Watt-hours/kilogram, about a 50 percent increase over the best lead-acid technology available today .18 The vehicle would have a 90 mile range and quite slow acceleration (O to 50 mph in 16.4 seconds), with an initial cost nearly $6,000 higher than for a competing gasoline vehicle. As with all such analyses, the lifecycle cost estimates are extremely sensitive to uncertain future costs of gasoline and electricity; the near breakeven lifecycle cost case assume 1995 gasoline costs of $1.34/gallon and nighttime electricity charging rates of $0.05/kWh (1987 dollars).[19]

Second, the EV is competing against conventional automobiles that essentially represent a moving target. Although high gasoline prices are not absolutely necessary for successful market entry of large numbers of EVs—the use of lightweight ac

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[15] Vehicle cost excluding battery, $400 less than comparable gasoline vehicle; lifetime twice as long; half the maintenance and repair costs; battery cost of $4,000; high powertrain efficiency 6.1 times competing gasoline vehicle powertrain efficiency.

[16] DeLuchi et al., op. cit., footnote 8. The analysis assumes a sodium/sulfur battery system; the equivalent gasoline-powered automobile is assumed to achieve 30.5 mpg.

[17] S.C. Davis et al., *Transportation Energy Data Book: Edition 10*, Oak Ridge National Laboratory report ORNL-6565, September 1989, table 2.23.

[18] W. Hamilton, *Electric and Hybrid Vehicles* (draft), report to DOE, Santa Barbara, CA, July 1989, cited in U.S. DOE, ***Assessment Of Costs and Benefits of Flexible and Alternative Fuel Use in the U.S. Transportation Sector. Technical Report Five: Vehicle and Fuel Distribution Requirements,*** draft, January **1990.**

[19] Ibid.

drivetrains coupled with a high level of success in battery performance and cost could allow lifecycle cost competitiveness at moderate gasoline prices—the most likely scenario for a major attempt at an EV market breakthrough is one with high fuel prices. These prices may also stimulate the entry of ultra-efficient gasoline vehicles for the market niche to be occupied by EVs. Several vehicle prototypes have achieved fuel economies of nearly 100 mpg or higher in practical configurations of relatively moderate power; in fact, these perform much like a practical EV is likely to. These vehicles should provide stronger competition than the baseline vehicles typically assumed in cost analyses.[20]

The newly announced General Motors Impact is an example of a promising EV prototype with design features that, if incorporated in a gasoline-fueled configuration, would produce a vehicle capable of achieving ultra-high fuel efficiency. The Impact is discussed in box 6-A.

Third, the difficulty of rapidly recharging EVs represents an important, though uncertain, market barrier. Even though EVs would be likely to be important niche vehicles--eg., second or third cars used primarily for commuting, delivery, or shopping—many potential owners may wish the flexibility of being able to use the vehicles for more extensive trips. An inability to accommodate such trips might prove an insurmountable barrier to many potential EV buyers.

Except with metal-air batteries, which are unlikely to be available within the next few decades, rapid recharging must involve either an actual exchange of batteries or a high-current recharge. Each has problems. Battery exchanges require a high degree of battery uniformity and a leasing system, since, with privately owned batteries, EV owners would not be willing to exchange a relatively new battery for an older one. High-current recharges require expensive charging equipment and a special battery capability that is far from assured technically; even then, it is unlikely that charging could be accomplished in less than 20 minutes.[21] If charging stations would have to be highly utilized to be profitable, EV operators could have to wait through one or more charging cycles to gain access to a charger. This may create an important barrier to wide market acceptance of EVs.

HYBRID VEHICLES

An alternative to rapid recharging is to add a small internal combustion (IC) engine (and fuel tank) sufficiently powerful to maintain reasonable highway speeds.[22] This type of dual system could substantially extend an electric vehicle's useful range. Such hybrid vehicles are being actively pursued by the same Department of Energy program supporting EV research and development.[23] DOE-sponsored analyses project that such vehicles may be able to attain lifecycle costs similar to EVs.[24]

An offshoot of the above hybrid vehicle concept is to combine a small IC engine working at constant speed as an electric generator (the engine would not be needed for short trips) with a battery designed to achieve high power density (most EV engines aim primarily at high *energy* densities, to maximize range, although power density is important as well). It is hoped that such a combination could allow a hybrid EV to combine adequate range with enough power to compete evenly with gasoline-powered vehicles in performance--an attractive prospect. To achieve this goal, batteries with power densities of 600 to 1,000 watts/kilogram are necessary. Although battery developers have high hopes for being able to achieve such levels in a commercial battery—the sealed bipolar lead-acid battery is one contender—success is uncertain and, at best, demands substantial further development.[25]

The primary criticism of hybrid vehicles using IC engines is the pollution impact of the vehicle's fuel use. Advocates of the constant-speed IC generator concept argue that it would attain the oil displacement and air quality benefits generally sought by EV advocates by:

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[20] Typically, comparative analyses have electric vehicles competing against gasoline vehicles obtaining 35 mpg or so. See DeLuchi et al., op. cit., footnote 8.

[21] Ibid.

[22] For a streamlined vehicle with an efficient drivetrain, maintenance of 60 mph speeds requires little power.

[23] U.S. Department of Energy, Office of Transportation Systems, *Electric and Hybrid Vehicles Program: 12th Annual Report to Congress for the Fiscal Year* 1988, February 1989.

[24] Hamilton, op. cit., footnote 9.

[25] Personal communication, Kenneth Barber, U.S. Department of Energy.

Box 6-A-GM's Impact: A Niche Vehicle

As discussed previously, carefully designing a vehicle to fill an appropriate niche may allow EVs to compete with gasoline-powered vehicles under special circumstances. The recently announced General Motors Impact, a sporty two-seater, is an early example of a vehicle carefully designed from the ground up to compete in a limited market. The vehicle attains an unusual combination (for an EV) of good performance (0 to 60 mph in 8 seconds) and excellent EV range (124 miles on the Federal Urban Driving Cycle) by limiting carrying capacity (350 pounds in a 2,200 pound curb weight vehicle) and introducing a number of design elements to achieve unusual vehicle efficiency. Notable efficiency features include:

- drag coefficient of 0.19, compared to about 0.3 for conventional low-drag vehicles;
- 65 psi tires that achieve about half the rolling resistance of typical tires;
- regenerative braking
- heat pump-based space conditioning
- extremely lightweight dc/ac inverter coupled with high-efficiency induction motors (90 to 95 percent efficient) and gearbox (94 to 98 percent efficient)[1]

Additional features that add to the vehicle's market attractiveness are a 2-hour recharge time and an on-board battery charger, eliminating the need for special charging equipment.[2]

Although the Impact is, at first look, a most attractive vehicle, it has uncertain long-term economic viability and remaining technical uncertainties. General Motors claims that its operating cost--electricity plus battery replacement cost—is about twice that of a gasoline-powered car in the Ins Angeles area, with future increases in battery life reducing the operating margin.[3] However, the current expected battery life of 25,000 miles is only an estimate that awaits confirmation with further testing. Further, manufacturing costs for the vehicle may be significantly higher than for a comparable gasoline-powered vehicle (with much greater range)--preliminary rough estimates are in the range of $15,000 to $20,000.[4] Other significant uncertainties remain, including tire life and ride acceptability, vehicle component longevity, cold weather operating characteristics,[5] and so forth.

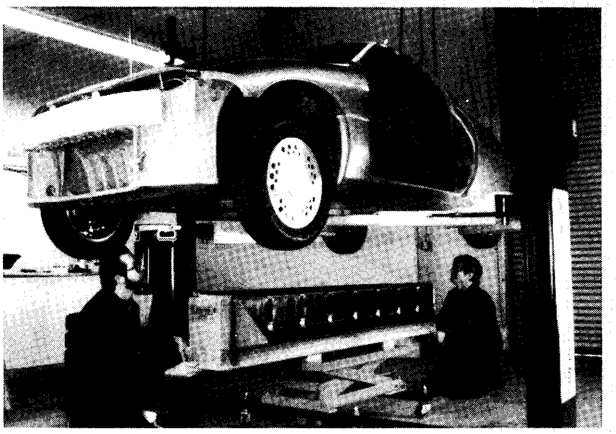

Photo crelit: General Motors Corp.

The Impact's battery pack, shown being installed, takes up the center portion of the vehicle.

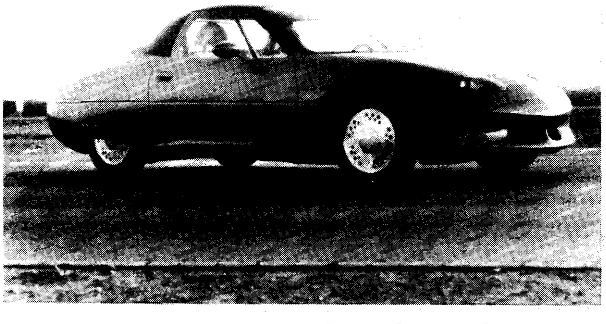

Photo credit: General Motors Corp.

General Motors' prototype electric vehicle (EV), the Impact, combines high performance (O to 60 mph in 8 seconds) with high EV range (over 100 miles).

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[1] General Motors Corp., "Impact Technical Highlights," General Motors Technical Center, Warren, MI, Jan. 3, 1990.

[2] Ibid.

[3] General Motors Technical Center press release on the Impact vehicle, Jan. 3, 1990. According to David Sloan at the Technical Center, the gasoline vehicle was similar to a Pontiac Fiero, a vehicle with similar accommodations and utility to the Impact vehicle. However, the Fiero incorporates none of the efficiency improvements used in the Impact. In our view, it would be preferable to compare Impact to a similar size/carrying capacity vehicle incorporating similar efficiency measures, especially with respect to drag and tire resistance. This comparison would yield a less attractive *relative operating* cost estimate for the electric vehicle.

[4] David Sloan, General Motors Technical Center, Warren, MI, personal communication% Feb. 23, 1990.

[5] Cold weather presents a dual problem to the vehicle—loss of battery capability, and, at extremes, inability of the heat pump system to maintain acceptable passenger comfort.

- operating battery-only on short trips
- displacing longer trips that could otherwise be made only by petroleum-fueled vehicles, with less oil usage and pollution because part of the trip energy would be supplied by battery storage, and the constant speed engine can be both more efficient and less polluting than the larger variable-power engine it would displace.

The counterpoint to this argument is that the very attractiveness of the hybrid, concept might discourage development of, and compete in the marketplace with, advanced battery-only vehicles with longer range than today's best vehicles and emissions benefits superior to those of the hybrid. Also, a battery-only vehicle will have a longer range "battery only" capacity-and thus can replace a higher percentage of trips in a "zero vehicle emission" mode—than the hybrid because it does not carry the added weight and volume of the IC engine and fuel tank, and can substitute additional battery capacity in their place.

A third, possibly longer term alternative is to forego battery storage entirely and generate electricity from a fuel cell fueled with hydrogen or methanol. The advantage of such a system is that it combines key benefits of EVs--essentially zero vehicle emissions (including no emissions of CO_2 if hydrogen is the fuel) and high efficiency powertrain—with fast refueling capability and longer range than offered by currently available batteries of the same weight and volume as the hydrogen or methanol storage tanks plus fuel cell. It eliminates problems with NO_x and hydrocarbon emissions (the latter from engine oil burning) from hydrogen vehicles using IC engines (see next chapter on hydrogen), and of course eliminates the stronger concerns associated with methanol IC emissions. DeLuchi estimates that a high-efficiency vehicle based on hydrogen (equivalent in design and performance to a 40-mpg gasoline vehicle) with a 200 mile range would have a hydrogen storage system displacing about 40 gallons-about 8 times the volume of a gasoline tank yielding the same range—if the hydrogen was stored as a 4,500 psi compressed gas.[26] The hydrogen could also be stored as a cryogenic liquid or as a hydride, though the former would be challenging for general use because liquid hydrogen is extremely cold, and the latter would add considerable weight unless major improvements in storage capacity were made to hydride systems. A methanol-fueled vehicle should have range capability similar to that of a gasoline vehicle with similar storage volume, because of the efficiency advantages of the fuel cell/electric motor system.

Methanol would be cheaper than hydrogen and would add substantial range, though it would require the addition of a reformer to dissociate the methanol. If the issue at stake were only to reduce oil use at moderate cost, methanol would appear the superior choice. However, hydrogen offers the potential of essentially eliminating $C0_2$ emissions from the fuel cycle, so that policymakers might choose to trade off the added fuel cost for the reduction in CO_2. The fuel cell itself would emit no CO_2 if fueled with hydrogen. Also, despite hydrogen's current manufacture from fossil fuels, with consequent emissions of $C0_2$, some analysts believe that the cost of photovoltaically generated dc electricity-producing zero Co_2—will drop dramatically within a decade or two and become a cost-competitive energy source for generating hydrogen.

Aside from the options of focusing on either methanol or hydrogen, an alternative strategy would focus on both. Although considerable development work will be necessary to construct a fuel cell capable of meeting the requirements of general fleet use, which include long life, low cost, and compactness, the fuel cell work should not take nearly as long as the hydrogen work. Conceivably, if development of a commercial vehicular fuel cell came first, methanol could serve as a bridge fuel until a PV-based hydrogen fuel supply could be developed.

INFRASTRUCTURE

Although additional generating capacity may eventually be required to support a large EV system, tens of millions of EVs can be recharged daily with no additional capacity if the recharging is accomplished at night, following the evening demand peak. Consequently, the fuel delivery infrastructure required for an EV fleet consists of the charging stations. Although rapid charge stations are technically possible, they are unlikely to be widely used (see discussion above). Most recharging will likely be accomplished at millions of home stations offering overnight recharging. DOE estimates the cost for a station to be $400 to $600, assuming a

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[26] M. DeLuchi, letter to Allan Lloyd, South Coast Air Quality Management District, California, Dec. 14, 1989.

240-volt, 30-amp outlet, ground-fault circuit interruptor to guard against electrical shock, and a time-of-use meter or other device to obtain reduced nighttime charging rates.[27] With 45 million EVs needed to displace 1 mmbd of gasoline, the infrastructure costs—attributed solely to charging facilities-are $21.8 billion for this level of oil displacement.[28]

EFFECTS ON EMISSIONS AND AIR QUALITY

Although EVs must surmount substantial market difficulties, and may be unlikely to save much oil (if the competing vehicles are highly fuel efficient), they *will* have an important positive impact on urban air pollution if they become a significant factor in urban travel. The vehicles have virtually no emissions[29] and the emissions from the generating facilities that would power an EV fleet are spread out over a wide area and, in most cases, have only moderate effect on any specific area such as a city. Also, although not universally true, many urban areas obtain their power from relatively distant generating facilities, and an increase in their net emissions will have little impact on the urban area's air quality.[30]

Trading local, low-level, small-source pollution for centralized pollution sources with tall stacks is not, of course, uniformly positive. As discussed below, the types of pollutants change, but the change of pollution distribution can have some negative effects as well-especially the increased contribution to long-range transport of pollution to other regions. Given the diversity of air-quality-related parameters--powerplant location in relation to population centers, powerplant fuel and control effectiveness, urban meteorologic conditions and pollution mix, regional long-range transport characteristics, and so forth-gauging the air quality benefits and costs of major shifts to electric vehicles requires location-specific examinations.

The net effect on total emissions of a shift to EVs will be mixed. Power for nighttime recharging of EVs will come from baseload and intermediate plants not needed to meet ordinary (low) nighttime demand; depending on region, these will be primarily coal-fired steam electric generators (coal fueled 57 percent of all generation in 1987, and higher percentages of baseload power[31]), natural gas-fired steam electric plants, and hydroelectric plants; some additional power will come from natural gas-fried combined cycle plants (though most of these plants are likely to be used as intermediate rather than baseload plants). Although nuclear steam electric generators provided 18 percent of baseload power in 1987,[32] they are rarely cycled down when load declines and thus may not be available to supply excess power to charge EVs.[33] Similarly, hydroelectric capacity may not be available in most cases because these plants generally are the last to cycle down.

Because utility electric generators emit few emissions of hydrocarbons and carbon monoxide, the net effect of EVs on emissions of these pollutants will be highly positive--emissions per mile of these pollutants would be reduced over 90 percent.[34] Older coal and gas-fired baseload plants produce considerable emissions of NO_x, and the net effect on NO_x emissions of a large EV fleet will be negative, especially for coal plants. More recent plants with moderate controls will have a positive net effect, so that overall, with a mix of older and newer plants, the net effect on NO_x emissions is likely to be small and, in areas with considerable nuclear and hydro capacity or with stringent NO_x controls, would be highly positive.[35] Finally, because even stringently controlled coal plants emit more SOx than automobiles on a comparative ''per mile' basis, market penetra-

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[27] DOE Technical Report Five, op. cit., footnote 18.

[28] Ibid.

[29] There *are* minor emissions from paint, adhesives, and so for@ and possibly release of some gases from the batteries, depending on their type. Also, EVs used in cold climates may have fossil-fueled heaters.

[30] However, the net increase in powerplant emissions *will* affect air quality over a wide area and will also affect acid rain and visibility.

[31] Energy Information Administration *Annual Energy Review 1987, DOE/EIA-0384(87), May,* 1988, table *83.*

[32] Ibid.

[33] At the present time, *some* excess nuclear power *is* available *t. some* utilities *at* low *cost* for off@& use. The *long-term* availability of such power is problematic.

[34] Q. Wang, M.A. DeLuchi, and D. Sperling, ''Emission Impacts of Electric Vehicles,' Transportation Research Board Paper 890682, 1989.

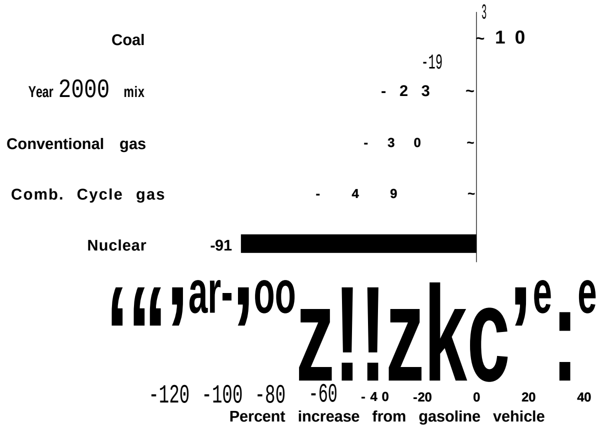
[35] Ibid.

tion of EVs will increase sulfur emissions. The actual effect will depend heavily on the timeframe (if long enough, some of the older, dirtier powerplants will retire), future controls placed on existing powerplants, and future plant retirement programs (plant life extension currently is an important part of most utilities' capacity planning programs).

The greenhouse impact of a significant shift to EVs will be extremely sensitive to the mix of power generation facilities used to power the vehicles, the efficiency of the EVs themselves, and the efficiency of the vehicles they replace. As discussed above, for the immediate future, EV power generation is likely to come from fossil fueled power plants (particularly coal-freed plants), except in the few areas where excess nuclear or hydro capacity is available. As shown in figure 6-1, if coal is the dominant fuel source for EV recharging, a switch to EVs will cause greenhouse gas emissions to increase slightly even with a high-efficiency vehicle. One source estimates that the EV/coal fuel cycle generates about 3 to 10 percent higher greenhouse emissions than a similar gasoline vehicle fuel cycle, with an EV system using the projected year 2000 mix of power generation yielding about 25 percent less greenhouse emissions than the gasoline cycle.[36] In the longer term, nonfossil capacity availability for EV recharging is likely to decrease, because no new nuclear plants have been ordered for years and no large hydroelectric facilities are in progress or planned. On the other hand, natural gas in efficient plant configurations (e.g., combined cycle plants) may dominate new plant capacity for the next few decades, and these plants offer both increased efficiency and reduced carbon emissions per unit of fuel burned. If these plants figure heavily in EV recharging, the net greenhouse effect will improve; an EV system based on these plants is estimated to yield about a 50 percent reduction in greenhouse emissions compared to gasoline vehicles.[37] The potential for powering large numbers of EVs with nonfossil electricity must wait for a revival of nuclear power or the development and construction of economically competitive solar or biomass power generators.[38]

Figure 6-l—Effect of Electricity Source on Greenhouse Impact of Electric Vehicles

(Total fuel cycle considered except construction materials manufacture)



Vehicle: EV powered by sodium sulfur batteries, ac powertrain, 150-mile range, 650-pound weight penalty v. competing gasoline car.

SOURCE: D. Sperling and M.A. DeLuchi, ***Transportation Fue/s and Air Po//ution,,*** **prepared for Environment Directorate, OECD, March 1990, draft.**

For the light-duty fleet, EVs seem most likely to replace vehicles with limited performance and carrying capacity, since the EVs themselves are likely to have these characteristics. Examples of ultra-high-mileage automobiles often share these characteristics. It is possible, therefore, that the fossil fuel savings and greenhouse benefits of a shift to EVs will be smaller than many analyses show, because EVs could replace gasoline or diesel vehicles with very high fuel economy rather than replacing ''average'' vehicles.

ELECTRICITY OUTLOOK AND TIMING

Electric vehicles are extremely attractive in concept, because they produce no vehicular pollution, would be fueled from domestic sources, and can rely on existing power generation capacity so long as charging is done at night. Recent important improvements in EV powertrains--lightweight dc-to-ac converters coupled with small, efficient ac motors—have moved EVs considerably closer to practicality for mass application. Unfortunately, inadequate

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[36] D. Sperling and M.A. DeLuchi, University of California at Davis, *Alternative Transportation Fuels and Air Pollution*, report to the Environment Directorate, Organization for Economic Cooperation and Development March 1990, draft. The postulated EV uses a sodium/sulfur battery.

[37] Ibid.

[38] At the present time, the solar thermal generators built by Luz in California and the wood waste-powered generators and Cogenerators Operated by the paper and wood processing industry are the primary examples of such facilities.

Photo credit: Ford Motor Co.

One potential niche market for electric vehicles is urban delivery by vans. The ETX-II Aerostar research vehicle, built by Ford and General Electric, achieves a 65 mph top speed and 100-mile range with a sodium sulfur battery.

battery technology remains a major hurdle for EVs. Without successful development of advanced batteries with high power and energy densities, EVs will have limited range and power, restrained to niche applications. Also, the environmental effects of power generation for EVs deserve careful attention.

Proponents of EV technology claim that commercialization of advanced batteries awaits only engineering development, which, they assert, could be accomplished within a reasonably well-defined time frame given adequate resources. However, more basic R&D may be needed, with considerable uncertainty about both time required and likelihood of eventual success. Certainly, the time frame suggested for alternative fuels programs in current legislative initiatives-manufacture of large numbers of vehicles starting in the mid-1990s--is too short for EVs to compete for a significant share of the programs. In the longer term, though, EVs conceivably could play an important role in urban passenger travel if there are important successes in battery development.