# A Review of Electric Vehicle Cost Studies: Assumptions, Methodologies, and Results

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by

**Timothy E. Lipman**

Institute of Transportation Studies
One Shields Avenue
University of California, Davis
Davis, California 95616
Tel. 530/752-4909 Fax 530/752-6572
http:\\its.ucdavis.edu
e-mail: itspublications@ucdavis.edu

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## Introduction

Several electric vehicle (EV) cost studies have been prepared in recent years. These studies employ a broad range of assumptions and methodologies, and the disparate results that they report are a testament to the uncertainties surrounding the potential manufacturing costs of EVs. This report section summarizes the results of several cost studies, and briefly critiques their approaches and assumptions. A concluding section summarizes key sources of uncertainty in EV cost estimation, and reasons for the variations observed in the studies reviewed.

## General Accounting Office, 1994, *Electric Vehicles: Likely Consequences of U.S. and Other Nations' Programs and Policies*, GAO/PEMD-95-7.

This study was prepared by the U.S. General Accounting Office in response to a request by the House Committee on Science, Space, and Technology. It investigates a broad array of issues surrounding the introduction of EVs, and is not confined to programs and policies in the U.S. The study assesses the following issues: the current barriers to the introduction of EVs; the policies and programs of various nations for the production, development, and use of EVs; and the environmental, energy, and financial effects of introducing EVs.

The study identifies several barriers to the introduction of EVs, including battery performance limitations, infrastructure requirements, potential safety hazards, an uncertain consumer market, and high initial purchase prices. The study reviews international efforts to address these potential barriers, and generally concludes that EV commercialization efforts in the U.S. have primarily focused on R&D and market establishment, while devoting relatively little effort on demonstrating the technology and on developing assessments of how best to introduce EVs.

### Methodology

The section of the GAO report that addresses the direct costs of EV manufacture is based on a study by the German Ministry of Transportation of the costs to produce an electric Volkswagen, the Citistromer. The focus of that report is to assess the manufacturing cost reductions associated with economies of scale as production expands from low-volume, hand built to large scale production of 100,000 units per year. The GAO study also reports on the results of a Japanese study on the effects of economies of scale on the manufacture of EV battery systems.

The EV lifecycle cost assessment in the GAO study is based on a synthesis of the German and Japanese studies. The lifecycle cost assumptions used by the GAO are detailed in Table 1. The study calculates battery lifecycle costs for a total 100,000 mile vehicle life, and then lifecycle costs in cents per mile are calculated for various countries using the lead acid, lowest cost, battery. The results shown in Table 1 are for the U.S.

### Key Assumptions

The GAO study primarily addresses the role of economies of scale in reducing EV production costs, but learning economies, including such factors as potential improvements in manufacturing processes, are also discussed. The German study apparently only addresses pure economies of scale in reducing production costs, while the Japanese battery study considers both economies of scale and learning effects. The study is relevant to a large manufacturer, with what the GAO calls "relatively extensive experience" in producing EVs. The cost figures discussed are actually costs to the consumer, or retail prices, and not merely manufacturing costs. The study analyzes two production volumes for base vehicles and batteries: 1,000 units and 100,000 units. The study assumes that the advanced batteries analyzed (containing 28.1-44.0 kWh of energy) can be accommodated in the Citistromer by removing its lead gel batteries, which contain only 18 kWh of energy. Further details and lifecycle cost assumptions are shown in Table 1.

### Substantive Results

With regard to production cost, the GAO simply reports the results of the German study (see Table 1). The prices shown include a lead gel battery that is estimated to cost $5,570 at the hand-built production level and $3,900 at higher volumes of production (the GAO does not specify where the break-point is, or if there is a gradual decrease). The production costs decrease from a high value of $42,700, under hand-built conditions, to a low of $18,300 at 100,000 units per year.

The lifecycle cost results are based on a VW Citistromer using a lead acid battery with a life of 26,500 miles. These results rely on the German study for the cost of the Citistromer vehicle excluding the battery pack, and the Japanese study of lead acid battery costs. The report does not specify the electricity and gasoline prices used in the lifecycle cost analysis, but does say that it assumes off-peak EV recharging at two-thirds the standard cost of electricity. The study assumes that maintenance will cost 4 cents per mile for EVs, and 6 cents per mile for ICEVs. At a vehicle and battery production level of 1,000 units per year, the lifecycle cost for operation in the U.S. is estimated at $0.53 per mile, versus $0.25 for a similar ICEV. At 100,000 units per year, the cost of operating the VW Citistromer EV is estimated to be $0.31 per mile.

### Critical Review

The section of this study on the initial costs of EVs is based entirely on two sources -- the German study of the Volkswagen Citistromer and a Japanese study on battery costs. The Japanese study itself is not well documented, and hence the battery cost estimates used in this study are difficult to critique. The specific attributes of the vehicle analyzed are not discussed, other than the basic characteristic that it is a mid-size, four-seat vehicle. There is no discussion of how initial costs might change with variations in vehicle attributes (i.e. range, acceleration, top speed, etc.). The study considers the effects of economies of scale on vehicle production, and the effects of both scale economies and learning economies on battery production, because these are the effects that are considered in the German and Japanese studies. However, the specific assumptions used to estimate the effects of scale and learning economies are not presented.

The lifecycle cost analysis assumes that EVs will be recharged off-peak at two-thirds the standard cost of electricity, but the $/kWh figure used is not specified. The study estimates an operating range of 55 miles for the lead-acid battery powered EV, and that 500 cycles will be possible on a battery pack. The battery packs are estimated to cost $3,344 at 1,000 units of annual production (the "near-term" scenario) and $2,501 at 100,000 units of annual production (the "long-term" scenario). The study assumes that cycle life will be unchanged at 500 cycles in the long-term scenario. Only the lead-acid battery pack is analyzed in detail because it is the most economical battery, according to the Japanese analysis. Finally, it is worth noting that the study estimates lifecycle costs for several other countries as well as the U.S., and in all the others the long-term lifecycle cost of the EV is less than the cost of the ICEV by a few cents per mile; only in the U.S. is the EV at a cost disadvantage, and this is due to the relative high cost of electricity relative to gasoline.

**Moomaw, W.R., et al., 1994, *Near-Term Electric Vehicle Costs*, Prepared for Northeast Alternative Vehicle Consortium.**
This study incorporates a variety of methodologies in order to estimate the future prices of three different electric vehicles: a pickup conversion, a commuter car conversion, and a purpose-built vehicle. A delphi survey of a broad range of vehicle experts, case studies of the three vehicle types, a historical analysis of cost evolution in automobiles and vehicle components, and a study of critical EV components all were conducted to help forecast future EV prices.

### Methodology

The section of the study that assesses EV production costs employs the following methodology. First, a representative vehicle for each of the three cases is identified in order to establish a range of component sizes and costs. Then, components are priced for purchase in 1995 using information from components suppliers, automobile manufacturers, and published sources. Future unit costs of production then are projected using assumed estimates of production levels, and associated volume discounts, for 1996-1998.

The lifecycle cost analysis is built on the vehicle production cost estimates in the study. Estimates for energy efficiency, battery costs and lifetimes, fuel costs, and maintenance costs were derived from "the literature" (a 1994 CARB report is the only source referenced). Using a simple spreadsheet model, costs incurred in each year after purchase are inflated at 4% per year, total costs are discounted back to 1995 using a discount rate of 7%, and the result is divided by the total mileage to arrive at final lifecycle cost estimate in dollars per mile. Further details of the lifecycle cost estimates are shown in Tables 2-4.

<u>Key Assumptions</u>

This study is a near-term analysis, and only includes the time period from 1995-1998. Specific estimates and assumptions associated with each of the three vehicle types are discussed below and shown in Tables 2-4.

The S-10 pickup conversion case is assumed to represent the costs to a small company that specializes in vehicle conversions. The cost of the running chassis or "glider" is assumed to be $10,000 in 1995, and to decline by 40% by year 4 to $6,000. These estimates are reported as being based on manufacturers' current costs of full vehicles, discounted in accordance with savings associated with escalating production volumes. The specific basis for the 40% reduction is not discussed. An initial cost of $8,000 is estimated for the AC motor/controller system used for the conversion, based on data collected from component manufacturers, and the cost is estimated to drop to $6,000 by 1997. A 21 kWh battery pack is estimated to cost $150/kWh based on a single source (see Table 2). Production runs for the pickup conversion are assumed to be 1,000 units in 1995, 3,000 units in 1996, 10,000 units in 1997, and 20,000 units in 1998. Labor costs, which are not clearly defined but which seem to relate to direct labor costs for conversion, in the first year are assumed to be 25% of total costs, not including capital costs. These costs are discounted by 25% after year 1 "to reflect the savings associated with purchasing of gliders and streamlining assembly processes" (p. 4-5). Retail prices, used in the lifecycle cost analysis, for production in 1995 and 1998 are calculated under the assumption that profit is 16% of the total cost of manufacture. Additional details of the vehicle and lifecycle costs estimates are shown in Table 2.

The commuter car conversion is modeled to represent the potential development of a small commuter EV by a large-scale manufacturer. The labor and component cost reduction assumptions are similar to those for the pickup conversion case discussed above, except that labor costs are not discounted beyond the initial level of 25% of total variable costs. However, since this case assumes production by a large-scale manufacturer, the study assumes that a large capital cost of $100 million is necessary, given the propensity of large companies to invest in new product development. The capital cost is assumed to be amortized over four years, such that $25 million is amortized each year. The capital cost associated with each vehicle is thus $25 million divided by the production volume in that year, or $6,200 in year 1 falling to $1,250 in year 4. The battery is assumed to be a 12.5 kWh SAFT nickel cadmium battery, with a cost of $500/kWh. The battery cost is assumed to drop to $400/kWh by 1997. The decision to employ a nickel cadmium battery pack is not discussed, except that the study notes that this is the battery used in a La Rochelle, France, demonstration. The cost estimates for the battery are based on a single source (see Table 3). The drivetrain, an AC induction system, is assumed to cost $3,500 in 1995 and $2,000 in 1998, based on a price quote for a Stayer-Daimler-Puch system reported by Zutter Electric Vehicles.

The purpose-built EV case assumes that a composite body structure will be employed. A key assumption in this case is that the transition from hand-molding to molds cast from dies will reduce the running frame cost from $20,000 in prototype production in 1995 to $7,000 in 1998, when 20,000 units are produced. The 65% reduction is explained only as being an "estimate extrapolated from manufacturers' estimates of production price of composite material based on current quoted prices of composite materials including fiberglass and carbon, and high custom labor charges" (p. 4-17). The drivetrain is assumed to cost $9,000 initially, and $2,500 in 1998 -- the basis for this dramatic cost reduction is not disclosed. Additional electrical components, including a charger, gearbox, and DC/DC converter, are assumed to cost $9,000 initially and $4,000 in 1998. The nickel-metal hydride battery is estimated to cost $300/kWh in 1995 and $175/kWh in 1998 -- these figures are taken from interviews with auto manufacturers where "moderate" estimates were used within the ranges quoted. Capital costs, including R&D, are assumed to be $20 million, amortized over the single year of production of 20,000 units in 1998, such that the cost per vehicle is $1,000.

Further details of vehicle and lifecycle cost assumptions used in the study are shown in Tables 2-4.

## Substantive Results

Vehicle and lifecycle cost results for the S-10 pickup EV conversion, the commuter EV conversion, and the purpose-built EV are shown in Tables 2-4. The overall purchase price results for the S-10 conversion case and the commuter EV case are compared to the purchase prices of similar conventional vehicles, but the purpose-built EV prices are not compared with those from a similar conventional vehicle. The study concludes that the unit manufacturing cost of the S-10 conversion will fall from $37,000 in 1995 to $21,000 in 1998 (compared to a purchase price of $15,641 for a conventional S-10 pickup). The price of the commuter EV is projected to fall from $22,500 in 1995 to $12,500 in 1998 (compared to $7,295 for a comparable Geo Metro). The overall manufacturing cost reductions for the four year period for the pickup conversion EV, the commuter conversion EV, and the purpose-built EV are 43.4%, 44.3%, and 62.1% respectively.

## Critical Review

This study is provocative, but it is not particularly well documented, a number of its fundamental assumptions are questionable, and several important errors are apparent. First, there is little or no discussion of important vehicle attributes, such as driving range, curb weight, energy efficiency, and acceleration, and how the vehicle price would vary with changes in these characteristics. While the study claims to have conducted an engineering cost analysis of critical components, this is not evident from the results presented. Rather, the study seems to base estimates of component costs and predictions of price reductions entirely on interviews with manufacturers. For example, the claim of a $2,000 price reduction in an AC propulsion system from 1995 to 1998 is based on a *Business Week* article that reports on interviews conducted with component suppliers, as is the claim of $150/kWh for sealed lead acid batteries. In the case of the purpose-built EV, the dramatic reduction in drivetrain cost from $9,000 in 1995 to $2,500 in 1998 is not discussed or justified (the text reports an initial value of $8,000, but $9,000 is reported in the tables).

In general, the cost declines predicted for various vehicle components are not very well substantiated. The study suggests that for the pickup conversion case, the costs of "other" components such as the battery box and adapters, not included in the drive train or running frame, will decline from $1,000 in year 1 to $800 in year 3, and $500 in year 4 as a "function of production," but this function is neither revealed nor explained. Also, in this "other" category it is not clear what components are included. There is no mention of vehicle heating or AC systems, electrical power steering units, or regenerative braking systems, so it is unclear whether these components are included (they do not seem to be). In the commuter EV conversion case, the running chassis is estimated to cost only $500, and the justification for using this very modest estimate is not disclosed. There is no discussion of the effect of manufacturing experience on lowering costs; the assumption seems to be that price reductions will occur as a function of scale economies. In general, with regard to the initial vehicle cost analysis, some citations are not to particularly authoritative sources, and a number of assumptions are not well substantiated or explained.

With regard to the lifecycle cost analysis, several anomalies are apparent, and some assumptions are questionable. A particularly obvious error is that in all lifecycle calculations the year "2000" is omitted such that, for example, 1999 may be "year 1" and 2001 is then "year 2." It is unclear what effect this error has on the calculations, but battery replacements occur later than they should, and all of the inflation and discounting calculations may be based on the wrong number of years.

All three vehicles are assumed to use 0.25 kWh/mi, and there is no discussion as to why vehicles as different as a steel-bodied S-10 pickup and a lightweight composite vehicle should have this same energy efficiency value. There is no allowance for overcharging or a reduction in overall efficiency for charger losses; the total energy required in any given year is exactly equal to the annual mileage times the vehicle energy efficiency.

While the initial vehicle cost analysis for the purpose-built EV uses a cost estimate for nickel-metal hydride batteries of $175/kWh, a very optimistic value of $100/kWh is used for battery replacements in 2002, 2005, and 2008 (which should be 2001, 2004, and 2007 due to the omission of year 2000).

Finally, the initial vehicle cost assumed in the commuter EV lifecycle cost case for purchase in 1995 is $16,000, but the earlier vehicle cost analysis arrives at a value of $26,000, and not $16,000. This discrepancy is not explained.

**Sierra Research, Inc. and Charles River Associates, 1994, *The Cost-Effectiveness of Further Regulating Mobile Source Emissions*, SR94-02-04, Prepared for the American Automobile Manufacturing Association.**
This study, conducted by Sierra Research and Charles River Associates, attempts to estimate the cost-effectiveness of a wide range of emission control measures, from enhanced inspection and maintenance programs to vehicle vapor recovery systems to the technologies required by the CARB LEV/CF program. A major conclusion of the study is that the CARB regulations would result in a $3,200 increase in the price of new cars sold in California after the 10% level of ZEV production is mandated.

Methodology
The study is based on data supplied by the GM, Ford, Chrysler, a European manufacturer, a Japanese manufacturer, and various vendors. Sierra reports both the weighted average of the estimates provided by the manufacturers, and also a modified "best-case" estimate based on the following methodology. First, Sierra chose the lowest-cost system that would be adequate to meet the goals of the control measure. Then, Sierra made the assumptions that: labor costs would decrease by 5% per year as a function of manufacturing experience, engineering, tooling, and equipment costs would decrease by 50% for each five year production cycle of a given vehicle, and dealers would realize 50% of their standard price mark-ups. In order to obtain a cost per vehicle, Sierra calculated the annual costs of the ZEV program for each year from 1993 to 2010, and then discounted the costs to 1993. Then, the years between 1993 and 2010 during which the vehicles would actually be sold were considered, and a constant vehicle cost was calculated such that the discounted value of the constant vehicle cost was equal to the discounted annual cost of manufacturer fixed and variable costs.

Key Assumptions
Some general assumptions are described above. No other details of the data used in the study are provided, so it is not possible to determine other important assumptions for such items as component costs and manufacturing production volumes.

Substantive Results
The results of the Sierra analysis are shown in Table 5. The figures are incremental costs in $1992, and include the present value of battery replacements. The incremental costs are based on manufacturer "retail price equivalent" costs of manufacturing EVs, and as such they represent the full costs, including profit, of producing EVs instead of conventional vehicles. Sierra reported costs for every year from 1998 to 2010; four representative years are shown below. Also shown are the results of Sierra's analysis of the net present value of producing an EV, relative to producing a Tier 0 or Tier 1 vehicle. The calculation of these net present value

figures was based on Sierra's "best case estimate" of the costs of complying with the ZEV mandate, and followed the methodology described above.

Critical Review

Since many of Sierra's assumptions are not clearly explained, a detailed critique is not possible. Several flaws are nevertheless apparent. First, Sierra bases their estimates of cost figures supplied by major automakers. The specific figures are not revealed, so there is no way to evaluate them in detail, but they clearly could reflect pessimistic assumptions. Second, there is virtually no difference between the "mid" and "high" cases, and the basis for estimating the different cases is not explained. Third, the assumption of a 5% per year labor learning rate is probably conservative, given that 15-30% rates are commonly reported in the literature. Sierra apparently applied the rate only to the labor costs associated with producing EVs, and not to component costs as well. However, component suppliers might also be expected to reduce costs through capturing economies of scale and through the accumulation of manufacturing experience. Furthermore, learning effects are typically portrayed as a function of cumulative production volume and not calendar year, and thus they are pronounced during early years of production and then decrease as production proceeds. Finally, there is absolutely no discussion of the technologies, such as battery and powertrain type, or vehicle characteristics, such as driving range or acceleration, to which these cost figures correspond. The vehicle type is described only as a "small passenger car."

**U.S. Department of Energy, Office of Transportation Technologies, 1995,**
***Encouraging the Purchase and Use of Electric Motor Vehicles.***

This study was prepared in response to Section 616(b) of the Energy Policy Act of 1992, which required DOE to report on methods for encouraging the purchase and use of EVs. The objectives of the reports were to assess the potential costs of purchasing and maintaining EVs, identify methods to reduce, subsidize, or share the costs of EVs, and to suggest policy measures to encourage the purchase and use of EVs.

Methodology

The purchase price of an EV in this study is estimated in comparison with a comparable conventional vehicle. The EV is assumed to be a minivan type vehicle, and as such it is compared with a six-cylinder, 135 hp, Ford Aerostar. The price of the EV was obtained by subtracting $6,000 from the base Aerostar purchase price to account for the removal of the engine, fuel injection system, ignition system, exhaust system, emission control system, power train, and fuel storage and delivery system (the $6,000 estimate was obtained from Danilo Santini at Argonne National Laboratory). Then, the price of various EV components was added to the stripped-down conventional minivan to obtain an EV purchase price.

### Key Assumptions

The EV analyzed in this study is a minivan type vehicle. The analysis is conducted for purchases in the Los Angeles and Washington, D.C. areas, for two time periods, 1998 and 2005. The motor is assumed to be a 60 kW DC motor. Vehicles with four different battery types were compared to the conventional minivan. The batteries analyzed were lead-acid, nickel-metal hydride, sodium-sulfur, and a battery meeting the USABC midterm goals. A key assumption of this study is that all EV component costs, except batteries, are assumed to decrease by 25% by 1998 in response to an assumed production level of 10,000 units, and by 50% by 2005 with a production level of 100,000 units. This assumption is based on a study by Hasuike at the Japanese Institute of Applied Energy. Battery prices for this study for 1998 and 2005 were provided by Ray Sutula of DOE, with the assistance of various DOE laboratories. Lifecycle cost assumptions are shown in Table 6.

### Substantive Results

The DOE report presents the following results for purchases of minivan type EVs in Los Angeles and Washington, D.C. in 1998 and 2005. As can be seen in Table 6, the DOE analysis concludes that EV minivans will be $5,000-$10,000 more expensive than conventional minivans in the near term (1998), but will be cost competitive or perhaps cheaper than conventional minivans by 2005.

### Critical Review

The DOE is study is well documented and thorough, but it still has several limitations. First, the assumption that all EV component costs will decrease by a fixed percentage at production levels of 10,000 units and 100,000 units (by 25% and 50% respectively) is not well substantiated. It is unclear whether this assumption is based purely on scale economies, or if it includes learning economies as well. The assumption is based on a single Japanese study that focused on battery costs, and did not consider other EV componentry. There is no discussion of why this assumption should hold for technologies as disparate as DC motors and air conditioners. Also, in the DOE analysis there is little or no discussion of specific vehicle operating characteristics, other than operating range, and how variations in these characteristics might affect purchase prices. Since the analysis is conducted only for minivan type vehicles, there is little insight provided into the costs of non-minivan type EVs.

Some inconsistencies are apparent between the text and the lifecycle cost tables in the appendices. For example, the text says that EV maintenance is assumed to cost 50% that of ICEV maintenance, but some of the tables report 35% and some report 50%. In general, the lifecycle cost assumptions seem reasonable, but as the study notes there is little evidence for the assumptions of such variables as tire life for low-rolling resistance tires, battery life, and maintenance costs.

**New York State Energy Research and Development Authority, August, 1995, *Zero-Emission Vehicle Technology Assessment*, 3175-ERTER-TRN-94, Prepared by Booz-Allen and Hamilton, Inc.**

### Methodology

The NYSERDA study assesses the production cost of a four passenger commuter car for the time period from 1998 to 2004. The study's methodology is to individually examine the costs associated with the following main categories: vehicle equipment (including chassis and powertrain), battery, development, and labor. These categories are addressed individually, and a "plausible range" of costs is established for each. Also, for each category, a "probable" point value is identified. The ranges and plausible values are then simply summed to obtain a final production cost for each year. The cost estimates in the study were developed by Booz-Allen & Hamilton, and were based on data obtained from major automotive OEMs, ZEV industry publications, independent EV manufacturers, battery developers, component manufacturers, government agencies, trade associations, and public and private consortia.

### Key Assumptions

The analysis assumes that the total ZEV market size in 1998 will be 40,000 units, and that the strategy used by OEMs to produce EVs will be to use a redesigned gasoline vehicle chassis together with either an AC or brushless permanent magnet powertrain and a 25 kWh advanced lead-acid battery pack (at $175 per kWh). In 2000, the market is assumed to have grown to 41,000 units, and a 20 kWh nickel-metal hydride battery pack is assumed with a cost of $175 per kWh. In 2002, the market size is set at 107,000 units and the price of the nickel-metal hydride pack has fallen to $150 per kWh. At this point, a purpose built chassis is assumed. Finally, by 2004 the market size has grown to 243,000 units but costs are similar to those in 2002. During the period from 1998 to 2004, the cost of the powertrain drops through "volume and experience" as shown in Table 7.

### Substantive Results

The results of the NYSERDA study are as shown in Table 7. For each category of costs, the study reports both a "plausible range" and a "probable" point cost. The range of total costs is shown to provide an indication of the high degree of uncertainty reported in the study. All costs are in constant 1994 dollars.

### Critical Review

In general, most of the cost values reported in the study seem reasonable, but several assumptions are questionable. The assumption that nickel-metal hydride batteries will be available for $175/kWh in 2000 and that this cost will fall to $150/kWh by 2002 is optimistic. In a previous part of the study, the conclusion is reached that the claim of Ovonics of an ultimate cost of $150/kWh is not reasonable because this cost represents only the cost of materials, and does not include manufacturing costs. Then, later, this very assumption is made without further explanation.

In an early section of the report, prior to the chapter that reports on ZEV costs, the study discusses vehicle range, but in a somewhat perplexing fashion. For each year, the study reports a "high certainty," "probable," and "optimistic" scenario. For the years 1998, 2000, 2002, and 2004, the vehicle ranges given (in miles) for each scenario are 60-90-120, 60-100-150, 80-110-180, and 80-120-200 respectively. It is unclear if these ranges correspond to the battery assumptions used in the cost analysis, and if so why they should vary so widely in the three scenarios. In the cost chapter, the study simply states that a minimum level of performance will be required of EVs, and that this level corresponds to a "100 mile range in city driving under favorable ambient conditions," a comparable acceleration to "today's subcompact cars of 0 to 60 in roughly 15 seconds," and a "similar level of comfort and safety as small conventional gasoline vehicles." Aside from these broad generalizations, the study fails to explicitly explore the relationship of vehicle cost to driving range, or for that matter to any other vehicle parameter.

The study estimates vehicle energy use and battery pack size simply by estimating a vehicle energy efficiency of 0.20 kWh/mile (the study cites the GM EV-1 efficiency of 0.19 kWh/mile, and takes 0.20 kWh/mile as an approximation for a vehicle built on a redesigned conventional vehicle chassis), and calculating that a range of 100 miles at an 80 percent depth of discharge is therefore possible with a 25 kWh battery pack.

Assessments of several important and optional EV components seem to be absent from the analysis, including battery chargers, electric power steering units, and heating and air conditioning systems. It is worth noting that the cost analysis is bounded by a rather wide range of values.

**U.S. Congress, Office of Technology Assessment, September, 1995, *Advanced Automotive Technologies: Visions of a Super-Efficient Family Car,* OTA-ETI-638, Washington D.C., U.S. Government Printing Office.**

Methodology

OTA and its contractors obtained the information for this report from interviews with automobile and advanced vehicle technology manufacturers, and reviews of academic literature and published reports. The performance and costs of various types of advanced vehicles were then calculated based on physical principles and cost accounting methods. The cost calculations performed by OTA derive a "retail price effect," which describes the incremental cost associated with substituting an advanced vehicle type for an established baseline vehicle. The analysis assumes that vehicle manufacturers earn only normal returns on capital, and are not able to charge premiums for what may be unique technologies, but the returns are somewhat higher than would occur in a perfectly competitive market (due to the oligopolistic market structure of the automobile industry, in OTA's view).

In conducting its analysis, OTA first establishes a "business as usual" baseline that reflects relatively constant energy and environmental policies, oil prices, and technologies. These baseline vehicles, assumed by OTA to be representative of the mass vehicle market in 2005 and 2015, are projected to be more efficient than today's vehicles and superior in terms of safety and performance. These improved vehicles are assumed to cost more than today's vehicles, and thus the retail price effect figures presented in the report actually represent increments to better, more expensive vehicles than are presently available.

In its analysis, OTA examines four different vehicle types (subcompact cars, intermediate sized cars, compact vans, and standard pickups) and a range of different advanced vehicle types and technologies, including advanced conventional vehicles, battery EVs, hybrid vehicles, and fuel cell vehicles. This review addresses only the subcompact and intermediate sized, battery electric vehicles examined in the OTA report.

### Key Assumptions

Critical to OTA's conclusions is the methodology used to calculate the "retail price effect" based on the input parameters for fixed and variable costs. This methodology is relatively complex, and it estimates both amortized investment costs (for R&D, engineering, tooling, and so forth) and plant operating costs. The expected rate of return (in real terms) is set at 15% to reflect the higher than normal return typical of an oligopoly. The cost estimation methodology is based on tiers, and it operates as follows. In the first tier, unit costs of investment for drivetrain and body technologies are estimated by multiplying the total manufacturer investment in tooling, facilities, engineering, and launch by 1.358, and then dividing that product by the product of 0.85, 4.487, and 500,000 (for drivetrains) or 0.85, 2.855 and 350,000 (for bodies). The 1.358 figure reflects the net present value of each dollar invested at product launch, using the 15% return assumption. The 500,000 and 350,000 figures are used to reflect "representative average" production levels for automotive body and drivetrain technologies. In the second tier, associated with vehicle assembly, total automobile manufacturer costs are taken to be the sum of the unit investment costs from tier 1, plus the supplier cost to manufacturers of components supplied by outside vendors multiplied by 1.4 (a factor that reflects manufacturer overhead and profit assumptions of 0.25 and 0.20 respectively). Finally, in the third tier, the final retail price effect is calculated by multiplying the total from tier 2 by 1.25, to reflect an assumed dealer margin of 0.25.

The battery cost assumptions used by OTA are as follows. For lead-acid batteries, OTA assumes a cost of $150/kWh. For nickel-metal hydride batteries, OTA uses an estimate of $400/kWh in 2005 and $360/kWh in 2015. OTA acknowledges, with some skepticism, the claim of the Ovonics Corporation of an eventual cost of

$230/kWh, but the report does discus how some cost results would be different with lower nickel-metal hydride battery costs. For example, using a cost of $200/kWh instead of $400/kWh lowers the RPE for a mid-sized EV in 2005, with a 100-mile range, from $19,510 to $8,800. The assumption of $180/kWh in 2015 instead of $360/kWh lowers the RPE of a 100-mile mid-sized EV in 2015 from $8,830 to $2,750. The cost basis used by OTA for lithium-polymer batteries is not disclosed, although the report suggests that an incremental cost of $10,400 would be possible for a mid-sized EV in 2015 with a 300 mile range if the battery succeeds "in meeting the U.S. Advanced Battery Consortium expectations" (it is unclear if OTA is referring to the mid-term goal of $150/kWh, the long-term goal of $100/kWh, or some other specific expectation for lithium polymer technology).

The draft OTA study reveals some, but not all, of the other cost assumptions used to derive EV costs for 2005 and 2015. For a mid-sized EV in 2005, the following cost assumptions are revealed: an AC motor/controller cost of $300 plus $30/kw (peak), and electric power steering unit cost of $65, and a heat pump A/C cost of $300. OTA claims that the cost estimates for batteries and motor/controller systems include the "learning curve" effect in reducing costs, but specific learning curve assumptions, such as curve functional forms and exponents, are not disclosed.

Finally, the study makes the important assumption that alternative vehicle types must have performance capabilities comparable to conventional vehicles. Specifically, the OTA has determined that vehicle performance must include the ability to climb a 6 percent grade at 60 mph and to accelerate from 0 to 60 mph as rapidly as is typical for conventional vehicles. These somewhat arbitrary assumptions, as the study notes, create a "high hurdle" for the new vehicle types. The use of such stringent specifications results in significantly higher prices than if less demanding standards were assumed.

### Substantive Results

The results of the OTA analysis are shown in Table 8. The calculation of retail price equivalent values follows the methodology described above. Additionally, some of the key vehicle characteristics, upon which the cost estimates are based, are reported in Table 9.

### Critical Review

The OTA and its contractors have conducted a detailed and thorough study. One of the study's strengths is its reliance on a range of different sources, including technical literature, interviews with eleven conventional vehicle manufacturers, and interviews with several advanced vehicle component manufacturers. It should be noted, however, that the study seems to be most heavily reliant on data obtained from existing automakers, and it seems to accept these data relatively uncritically. In general, the claims of EV component manufacturers seem to be treated with more skepticism.

In defining the vehicle characteristics that form the basis for the analysis of the EVs studied, the OTA has set a high hurdle for the new vehicle types. The study specifies vehicle performance comparable to conventional vehicles, and these requirements result in significantly higher vehicle prices than would result with less stringent performance specifications. It may be true, as the OTA states, that consumers have come to expect this level of performance and that mass market vehicles must meet these standards, but some EV studies suggest that there may in fact be a significant market for vehicles of lesser performance and lower cost. The OTA clearly acknowledges this point, but it bears noting because it is central to the study's conclusions.

The battery performance estimates used by OTA are relatively conservative. For example, a comparison of OTA assumptions with the conclusions of the battery technical advisory panel to the California Air Resources Board reveal that OTA's assumptions are at the high end of the range of potential costs reported by the battery panel. For lead acid batteries, the OTA uses an assumption of $150/kWh, while the panel reports a range of costs from $120/kWh to $150/kWh. For nickel-metal hydride batteries, the technology subject to perhaps the greatest amount of cost speculation, the OTA study assumes costs of $400/kWh in 2005 and $360/kWh in 2015 (although the study also reports vehicle prices with much lower cost assumptions of $200/kWh and $180/kWh). The battery panel reports costs for this battery type of from $250/kWh to $350/kWh, with a potential eventual cost of $150/kWh. OTA does not clearly disclose its assumption for the cost of lithium-polymer battery technology. The study implies an assumption of a U.S. Advanced Battery Consortium goal, but it is not clear if it is referring to the mid-term goal of $150/kWh or the long-term goal of $100/kWh. At one point, the study refers to an incremental cost of $10,400 for a mid-sized, 300-mile range EV with lithium-polymer batteries, if the battery consortium's "expectations" are met, although the cost eventually shown for the vehicle of that description in the final table is $11,370 and not $10,400.

The OTA reports vehicle price results for both 2005 and 2015, apparently without altering its assumptions of battery costs to reflect reduced costs through higher production volumes and greater manufacturing experience during the intervening period (with the exception of the small decline from $400/kWh to $360/kWh for nickel-metal hydride batteries). Given this approach, and the conclusions of CARB's battery advisory panel, it seems that the battery cost estimates used by OTA are reasonably optimistic for the 2005 scenario, but potentially conservative for 2015. By this later date, economies of scale and refined manufacturing techniques may succeed in lowering battery costs to levels more in line with the projections of the CARB battery panel, in which case the OTA's central case assumption for nickel-metal hydride would be much too high, and the lower cost estimates, which it treats with low probability, would be more accurate. This is clearly a key source of uncertainty in the OTA analysis.

This same implications of OTA's approach to battery costs apply as well to assumptions of other component costs, and thus vehicle prices in general. The potential for technological breakthroughs in component performance (i.e. getting greater performance from the same quantity of material inputs) and manufacturing techniques increases as time passes, and as a result this potential would seem to be significant for a scenario twenty years in the future. Yet OTA's assumptions are relatively constant between the two time periods assessed. OTA notes that technological change has historically not been rapid in the automotive industry, but the flurry of innovation in vehicle technologies in the past decade would seem to indicate that the industry may soon undergo a period of relatively rapid change. As a result, the OTA's conclusions, particularly for 2015, may be somewhat conservative.

**Dixon, L.S. and S. Garber, The Rand Institute for Civil Justice, 1996,** ***California's Ozone-Reduction Strategy for Light-Duty Vehicles: Direct Costs, Direct Emission Effects, and Market Responses.***

In this study, the Rand authors compute narrow cost-effectiveness ratios for various strategies to reduce light-duty vehicle emissions in California. In order to accomplish this for EVs, the authors review several EV cost studies, and from these studies they establish what they believe to be a reasonable range of incremental EV production costs. The authors then forecast EV costs into the future, based on this established range. Hence, this study should be considered a "secondary" cost study, rather than a primary study, in that the cost figures reported are derived from other studies rather than being independently estimated.

Methodology

The cost estimates suggested by the Rand authors are based on their critical analysis of several cost studies, as well as interviews conducted with technical staff at the Big 3 U.S. automakers. The study is split into two time periods; the first period is from 1998-2002 and the second is after 2002. In the 1998-2002 time frame, the Rand authors choose as their lower bound estimate the incremental cost figure reported in the Booz-Allen and Hamilton (NYSERDA) report of $3,320 per vehicle, not including the battery pack. This figure was obtained by calculating a weighted average of the Booz-Allen figures for 1998, 2000, and 2002. The authors believe this estimate to be optimistic because of the relatively low costs of components that it uses, and they therefore use it as their lower bound. As an upper-bound figure, the authors use an estimate of $15,000 that was provided to them by the automakers that they interviewed. This information was reported confidentially, and the study says only that the figures reported by each of the three automakers "did not vary a great deal" around this value. The authors note that, as an average value, this figure is probably pessimistic because it assumes that the automakers will produce only vehicles that are similar to the ICEVs that they currently produce, and that they will not be produced in potentially less costly ways, such as contracting out to companies that specialize in producing lower volume vehicles based on a "glider" strategy.

### Key Assumptions

The Rand study is based on EV costs calculated in other studies, and on interviews with the Big 3. As such, it makes few important assumptions of its own. The incremental variable costs are derived from the NYSERDA study, for the lower bound estimate, and interviews with automakers for the upper bound estimate. In order to project variable costs beyond 2002, the authors assume that under a "fast decline" scenario costs drop with a 75% experience curve (and learning starts when cumulative output reaches 150,000 units) and that under a "slow decline" scenario costs follow a 90% experience curve (and learning starts when cumulative output reaches 400,000 units). For operating costs, in the optimistic scenario the incremental cost is assumed to fall from $3,000 during 1998-2002 along a 75% experience curve to $1,000. In the pessimistic scenario, operating costs fall from $13,000 to $6,500 along a 90% experience curve.

### Substantive Results

The results of the Rand analysis are shown in Table 10.

### Critical Review

In establishing the range of incremental EV costs of $3,320-$15,000, upon which the rest of the study is based, it is unclear how the Rand authors have derived the lower-bound cost estimate from the Booz-Allen study. The $3,320 figure is reported to be derived by averaging the net retail price increments, relative to a conventional Ford Escort and not including amortized fixed costs or battery costs, that Booz-Allen reports for EVs built in 1998, 2000, and 2002. In other words, Rand appears to have subtracted the figures that Booz-Allen reports for amortized fixed costs (these decline from $9,000 per vehicle in 1998 to $6,500 in 2002), and then compared the resulting variable costs of EV production to the retail price reported for the Ford Escort ($9,560 in 1998 and 2000, $9,860 in 2002). However, it is unclear what assumptions Rand made to arrive at the variable cost of the Ford Escort (as opposed to the full retail price) since Booz-Allen only reports the full retail price. In order to replicate Rand's incremental variable cost numbers ($4,800 in 1998, $3,529 in 2000 and $1,829 in 2002), the variable cost of the Ford Escort must be $5,700 in 1998, and $5,671 in 2000 and 2002. These numbers may be reasonable, but amortized development costs and profit may be relatively low for a very high volume vehicle such as the Escort, and Rand does not disclose or justify the assumptions used to arrive at these figures. Furthermore, the Escort is a relatively low cost vehicle, with a retail price well below the median price of new cars, and comparing EVs to a more representative vehicle with higher variable costs would produce lower incremental cost figures. Hence, the $3,320 figure is somewhat arbitrarily derived, particularly since some of the studies reviewed by Rand report incremental variable costs for

EVs (without batteries) that are lower than the costs of comparable conventional vehicles.

With regard to the long-term analysis of EV production costs, Rand has applied an experience curve methodology to forecasting the reduced costs. However, the manner in which experience curve theory is applied differs considerably from the manner in which it is typically employed to forecast costs, or to fit a pattern of historic cost reductions. Rand decides to consider two cases, one in which learning starts in 2000 and follows a 75% curve (the "fast decline" scenario), and one in which learning starts in 2002 and follows a 90% curve (the "slow decline"). The nature of the experience curve relationship is such that cost reductions tend to accrue rapidly at first (since the effect relates a percentage cost reduction to each doubling in accumulated manufacturing experience) and then to decline. By assuming that "learning" does not even start until hundreds of thousands of units have been produced, Rand is essentially assuming that there is no experience gained during the early years of EV production; the study states that the cost estimates used for 1998-2002 are interpreted "to incorporate learning during that period" (p. 235). This is a somewhat curious assumption under the conditions assumed by the study -- of production to meet formerly mandated levels of EV production from 1998 to 2002 -- but, given the recent change in the ZEV mandate to eliminate mandated production from 1998 to 2002, it may now be reasonable to assume that not much experience will be gained in production prior to 2003. However, the important point remains that the study does not initiate the experience curve effect until 150,000 to 400,000 units have been produced (under the revised mandate the 400,000 unit levels would not be reached until approximately 2006).

**Vyas, A. and Cuenca, R., Argonne National Laboratory, "EV Cost Model" (Presentation at 1999 Transportation Research Board Conference), January 11, 1999.**
Argonne National Laboratory has an ongoing EV cost research program to estimate both EV manufacturing costs and operating costs. At the 1999 TRB Conference, A. Vyas presented the most recent results of their overall EV cost model, and a somewhat earlier set of results were written up for inclusion in the Society of Automotive Engineers technical paper series (Vyas, et al., 1998). The cost model underlying the paper and presentation is an Excel spreadsheet model developed by Vyas and Cuenca. The work is still in progress, and a full, final report has not yet been issued.

<u>Methodology</u>
Vyas and Cuenca estimate manufacturing and operating costs for subcompact cars, mid-sized cars, and minivans. Costs are estimated for the years 2000, 2005, 2010, and 2020. Users of the model can select any of six battery types, including lead acid, nickel metal hydride, lithium polymer, lithium ion, and zinc air.

The general method employed by Vyas and Cuenca to estimate EV purchase prices is to estimate the costs of manufacturing components common to EVs and conventional vehicles, and then to add the costs of EV components, including increments for manufacturer profit and dealer mark-up. Users of the model can alter the motor/controller power ratings calculated by the model, in order to allow for higher performance, and the energy of the battery pack can also be changed in order to produce a longer vehicle range. EV operating costs are then computed from fuel, maintenance, and battery replacement costs, and these estimates are combined with amortized vehicle costs to produce EV lifecycle costs.

### Key Assumptions

The default configuration of the Vyas and Cuenca model assumes that EVs will be produced in escalating volumes from "<10,000" in 2000, to "10,000-40,000" in 2005, to ">40,000" in 2010 and 2020. Vyas and Cuenca use two different sets of battery cost data in the model, and the model user can select between the two sets. One set is based on the results of the CARB battery panel, and the other is based on the results of a delphi survey.

With regard to operating costs, Vyas and Cuenca assume that EV maintenance costs are 20% those of conventional vehicles, that tire costs are the same for both vehicle types, and that EV oil and filter costs are zero. EV battery replacement costs are computed by adding a battery replacement when either the battery shelf life or cycle life expires.

### Substantive Results

In the default configuration, the Argonne analysis covers three vehicle types, six battery types, and two sets of battery cost data, resulting in thirty-six EV manufacturing cost and lifecycle estimates. Presented at the 1999 TRB conference were results for subcompact and minivan EVs using lead-acid, NiMH, and lithium ion batteries. Table 11 presents the detailed results of one of these cases -- the NiMH subcompact EV using the CARB battery data -- in order to illustrate some of the input variables and data used in the model. Table 12 includes all of the final vehicle price and lifecycle cost results presented at the TRB conference.

### Critical Review

The ANL analysis appears thorough and sound, although complete documentation has not yet been released. It is thus not possible to fully evaluate the latest results. One detail of the analysis that was apparent in an earlier version of the spreadsheet was that EV drivetrain costs were calculated as a linear function of peak kW rating. Based on data supplied by manufacturers and discussed in the drivetrain cost section of this report, this could be somewhat inaccurate because controller costs do not appear to scale well in this way. However, in response to ITS-Davis comments this calculation has recently been modified to more accurately estimate controller costs as a function of peak power rating (Vyas, 1999).

This study relies on two different sources for battery cost estimates, but in the case of the CARB battery panel cost estimates, the results have been "modified" by Vyas and Cuenca based on data gathered in ANL's battery cost research. However, these modifications have not been documented and an assessment of the manner in which the CARB battery cost estimates were revised, and the effect this has on the model results, will have to await the release of the full report and further details of the battery cost estimation procedure.

## Conclusions

The EV cost studies performed from 1994 to 1999 by various government agencies, coalitions, and research organizations report somewhat disparate results. All studies conclude that EV costs will be higher than conventional vehicle costs in the near-term, but a few studies suggest that EV costs could relatively quickly drop to levels comparable to those of conventional vehicles, particularly on a lifecycle basis (Moomaw, et al., 1994; U.S. DOE, 1995). Most studies suggest that EV purchase costs are expected to remain a few to several thousand dollars higher than conventional vehicle costs, with lifecycle costs also remaining somewhat higher (Dixon and Garber, 1996; NYSERDA, 1995; OTA, 1995; U.S. GAO, 1994; Vyas, 1999). Finally, one study concludes that EV purchase prices are likely to remain much higher than conventional vehicle prices, through 2010 (Sierra Research, 1994).

Some of the variation in the reported results of EV manufacturing costs can be explained by considering the vehicle classes, production volumes, and battery types considered in the various analyses. However, aside from these critical study parameters, considerable variation remains in the vehicle purchase price and lifecycle cost estimates reported here. Uncertain parameters that help to account for the remaining differences in cost estimates include the assumed performance of the vehicle (and in lieu of an explicit performance analysis the general sizing of components for a given vehicle type), the $/kWh costs of the assumed battery type, and costs of accessories and additional equipment needed for the EV such as battery chargers, HVAC systems, and electrical power steering units.

Table 13 summarizes the EV purchase price results of the studies reviewed above. Note that in some cases the figures refer to full retail prices of EVs, while in other cases the figures refer to incremental costs, relative to comparable conventional vehicles. Table 14 summarizes EV lifecycle cost estimates.

Table 1: U.S. GAO EV Cost Projections and Assumptions

| Cost category | Year and/or production volume | | | | | |
|---|---|---|---|---|---|---|
| | Hand-built | 1,000 per year | 5,000 per year | 10,000 per year | 50,000 per year | 100,000 per year |
| <u>Vehicle cost assumptions</u><br>Component costs:<br>Lead acid battery | $5,570 | $3,900 | $3,900 | $3,900 | $3,900 | $3,900 |
| Other variable costs | | | | | | |
| Fixed costs | | | | | | |
| Total production cost | | | | | | |
| Retail price | $42,700 | $36,900 | $28,700 | $27,000 | $23,900 | $18,300 |
| <u>Lifecycle cost assumptions</u> | <u>1,000 per year</u> | | | <u>100,000 per year</u> | | |
| Battery costs and capacities: | | | | | | |
| Lead acid battery | $3,344 (28.1 kWh) | | | $2,501 (28.1 kWh) | | |
| Sodium sulfur battery | $38,500 (44.0 kWh) | | | $7,568 (44.0 kWh) | | |
| Nickel cadmium battery | $22,006 (41.6 kWh) | | | $14,352 (41.6 kWh) | | |
| Nickel iron battery | $26,146 (41.9 kWh) | | | $13,911 (41.9 kWh) | | |
| Range/cycle life/total battery distance/number of batteries for 100,000 miles: | | | | | | |
| Lead acid battery | 55 urban miles/500 cycles/26,500 miles/3.64 batts. | | | | | |
| Sodium sulfur battery | 100 urban miles/500 cycles/50,000 miles/2.0 batts. | | | | | |
| Nickel cadmium battery | 75 urban miles/2,000 cycles/150,000 miles/0.67 batts. | | | | | |
| Nickel iron battery | 75 urban miles/2,000 cycles/150,000 miles/0.67 batts. | | | | | |
| Battery cost for 100,000 mile vehicle life: | | | | | | |
| Lead acid battery | $12,160 | | | $9,094 | | |
| Sodium sulfur battery | $77,000 | | | $15,136 | | |
| Nickel cadmium battery | $14,671 | | | $9,568 | | |
| Nickel iron battery | $17,430 | | | $9,274 | | |
| Lifecycle costs with lead acid battery and VW Citistromer vs. (ICEV VW Citistromer) | <u>Near Term</u><br>$0.53 per mile<br>($0.25 per mile) | | | <u>Long Term</u><br>$0.31 per mile<br>($0.25 per mile) | | |
| Method of calculation | Retail costs are based on a German study of the costs of producing a VW Citistromer EV. Lifecycle cost estimates are based on a combination of the German study the results of a Japanese battery cost study. | | | | | |
| Sources of data | German study: Unterrichtung durch die Bundersregierung: Vierte Fortschreibung des Berichtes uber die Forderung des Einsatzes von Elektrofahrzeugen," publication 12.3222, German Federal Parliament, session 12, Bonn, September 7, 1992.<br>Japanese study: H. Hasuike et al., "Economic Study on Advanced Batteries for Electric Vehicles," in *The 11th International Electric Vehicle Proceedings*, vol. 2, Florence, September, 1992. | | | | | |

Source: (U.S. GAO, 1994)

Table 2: NAVC Cost Projections and Assumptions for S-10 Conversion EV[a]

| Cost category | Year and/or production volume | | | |
|---|---|---|---|---|
| | 1995 1,000 per year | 1996 3,000 per year | 1997 10,000 per year | 1998 20,000 per year |
| Vehicle cost assumptions | | | | |
| Component costs: | | | | |
| Running frame | $10,000 | $10,000 | $6,000 | $6,000 |
| Sealed lead acid battery | $3,150 | $3,150 | $3,150 | $3,150 |
| Drivetrain (AC induction) | $8,000 | $8,000 | $6,000 | $6,000 |
| Charger (3 kW) and other[b] | $3,000 | $2,500 | $1,800 | $1,500 |
| Other variable costs (labor) | $7,970 | $5,853 | $4,195 | $4,121 |
| Fixed costs | $5,000 | $1,667 | $500 | $250 |
| Total production cost | $37,120 | $31,170 | $21,645 | $21,021 |
| Retail price | $43,000 | | | $24,300 |
| Lifecycle cost assumptions | 1995 Prices | | 1998 Prices | |
| Inflation rate | 4.0% | | 4.0% | |
| Discount rate | 7.0% | | 7.0% | |
| Vehicle purchase price | $43,000 | | $24,300 | |
| Vehicle life | 10 years | | 10 years | |
| Annual mileage | 12,000 miles | | 12,000 miles | |
| Salvage value (5% of purchase) | $2,150 | | $1,215 | |
| Energy efficiency | 4 mi/kWh | | 4 mi/kWh | |
| Electricity cost | $.05/kWh ($1994) | | $.05/kWh ($1994) | |
| Battery cost and capacity: | | | | |
| Lead acid battery ($150/kWh) | $3,150 (21 kWh) | | $3,150 (21 kWh) | |
| Battery life | 3 years | | 3 years | |
| Maintenance | $468/year | | $468/year | |
| Lifecycle cost (comparison conventional SV-10) | $0.461/mile<br>(0.272/mile) | | $0.311/mile<br>($0.272/mile) | |
| Method of calculation | For vehicle cost, addition of glider, components, labor, and capital costs. Labor is 25% of total costs, excluding capital (fixed) costs for year 1, then reduced by 25% for future years.<br>For lifecycle cost, simple spreadsheet model | | | |
| Sources of data | Solar Car Corp. for labor costs; unnamed component suppliers for drivetrain; EVAA for charger; Woodruff et al. (1994) article in *Business Week* for lead acid battery cost. | | | |

Source: (Moomaw, et al., 1994)

Notes:

[a] Costs are in $1995.

[b] Other components are identified as "battery box, adapters, etc."

Table 3: NAVC Cost Projections and Assumptions for Commuter Conversion EV[a]

| Cost category | Year and/or production volume | | | |
|---|---|---|---|---|
| | 1995<br>4,000 per year | 1996<br>5,000 per year | 1997<br>10,000 per year | 1998<br>20,000 per year |
| Vehicle cost assumptions | | | | |
| Component costs: | | | | |
| Running frame | $500 | $500 | $500 | $500 |
| NiCd battery | $6,250 | $5,625 | $5,000 | $5,000 |
| Drivetrain (AC induction) | $3,500 | $3,000 | $2,000 | $2,000 |
| Charger and other[b] | $2,000 | $1,500 | $1,000 | $1,000 |
| Other variable costs (labor) | $4,043 | $3,506 | $2,805 | $2,805 |
| Fixed costs | $6,250 | $5,000 | $2,500 | $1,250 |
| Total production cost | $22,543 | $19,131 | $13,805 | $12,555 |
| Retail price | $16,000[c] | | | $14,500 |
| Lifecycle cost assumptions | 1995 Prices | | 1998 Prices | |
| Inflation rate | 4.0% | | 4.0% | |
| Discount rate | 7.0% | | 7.0% | |
| Vehicle purchase price | $16,000[c] | | $14,500 | |
| Vehicle life | 10 years | | 10 years | |
| Annual mileage | 12,000 miles | | 12,000 miles | |
| Salvage value (5% of purchase) | $800 | | $725 | |
| Energy efficiency | 4 mi/kWh | | 4 mi/kWh | |
| Electricity cost | $.05/kWh ($1994) | | $.05/kWh ($1994) | |
| Battery cost and capacity: | | | | |
| NiCd battery ($500/kWh) | $6,250 (12.5 kWh) | | $6,250 (12.5 kWh) | |
| Battery life | 10 years | | 10 years | |
| Maintenance | $468/year | | $468/year | |
| Lifecycle cost<br>(comparison conventional Metro) | $0.178/mile<br>(0.158/mile) | | $0.168/mile<br>($0.158/mile) | |
| Method of calculation | For vehicle cost, addition of glider, components, labor, and capital costs. Labor is 25% of total costs, excluding fixed (capital) costs.<br>For lifecycle cost, simple spreadsheet model | | | |
| Sources of data | Solar Car Corp. for labor costs; Zutter Electric Vehicles for drivetrain; EVAA for charger; Dunning and Remy (1992) article in *ESD Technology* for NiCd battery cost. | | | |

Source: (Moomaw, et al., 1994)

Notes:

[a] Costs are in $1995.

[b] Other components are identified as "battery box, adapters, etc."

[c] This value appears to be an error. Using the assumption of a 16% profit level yields a purchase price of approximately $26,000. While the study discusses a $16,000 cost estimate for a Peugeot Citroen EV, it is unclear why the $16,000 value is given and not the $26,000 that would be calculated using the study methodology.

Table 4: NAVC Cost Projections and Assumptions for Purpose-Built EV[a]

| Cost category | Year and/or production volume | |
|---|---|---|
| | 1995<br>Prototype | 1998<br>20,000 per year |
| <u>Vehicle cost assumptions</u> | | |
| Component costs: | | |
| Running frame | $20,000 | $7,000 |
| NiMH battery | $7,500 | $3,000 |
| Drivetrain (AC induction) | $9,000 | $2,500 |
| Electrical components[b] | $9,000 | $4,000 |
| Other variable costs (labor) | $15,015 | $5,445 |
| Fixed costs | | $1,000 |
| Total production cost | $60,515 | $22,945 |
| Retail price | | |
| <u>Lifecycle cost assumptions</u> | | |
| Inflation rate | | 4.0% |
| Discount rate | | 7.0% |
| Vehicle purchase price | | $20,000 |
| Vehicle life | | 3 years |
| Annual mileage | | 12,000 miles |
| Salvage value (5% of purchase) | | $1,000 |
| Energy efficiency | | 4 mi/kWh |
| Electricity cost | | $.05/kWh ($1994) |
| Battery cost and capacity: | | |
| NiMH battery ($100/kWh) | | $2,250 (22.5 kWh) |
| Battery life | | 10 years |
| Maintenance | | $468/year |
| Lifecycle cost | | $0.24/mile |
| Method of calculation | For vehicle cost, addition of glider, components, labor, and capital costs. Labor is 25% of total costs, excluding fixed (capital) costs.<br>For lifecycle cost, simple spreadsheet model | |
| Sources of data | Running frame cost estimated from "extrapolated manufacturer estimates" of production prices for composite materials and custom labor charges; unnamed component suppliers for drivetrain costs; Solectria Corp. for electrical component costs; unnamed auto manufacturers for NiMH battery costs. | |

Source: (Moomaw, et al., 1994)

Notes:

[a] Costs are in $1995.

[b] Includes 3 kW charger ($3,870), Solectria AT600 gearbox ($2,920), 750W DC/DC converter ($790), and other miscellaneous components.

Table 5: Sierra Research Cost Projections and Assumptions for Small Passenger EV

| Cost category | Year and/or production volume | | | |
|---|---|---|---|---|
| | 1998 | 2002 | 2006 | 2010 |
| Component costs | | | | |
| Other variable costs | | | | |
| Fixed costs | | | | |
| Total production cost | | | | |
| Incremental cost: low case | $10,000 | $7,000 | $4,250 | $4,250 |
| Incremental cost: mid case | $27,143 | $17,254 | $18,565 | $17,476 |
| Incremental cost: high case | $27,143 | $17,254 | $20,280 | $22,726 |
| NPV of total costs relative to Tier 0 vehicles | California<br>$21,034 | | Nationwide<br>$12,588 | |
| NPV of total costs relative to Tier 1 vehicles | California<br>$20,978 | | Nationwide<br>$12,532 | |
| Retail cost | | | | |
| Lifecycle cost assumptions | | | | |
| Method of calculation | | | | |
| Sources of data | GM, Ford, Chrysler, one Japanese automaker, and one European automaker | | | |

Source: (Sierra Research, 1994)

Table 6: U.S. DOE Minivan EV Cost Projections and Assumptions[a]

| | Year and/or production volume | | | |
|---|---|---|---|---|
| | Los Angeles | | Washington, D.C. | |
| Cost category | 1998 | 2005 | 1998 | 2005 |
| Vehicle cost assumptions | | | | |
| Component costs: | | | | |
| Lead acid battery | $4,669 | $2,868 | $4,669 | $2,868 |
| Sodium sulfur battery | $6,600 | $4,298 | $6,600 | $4,298 |
| Nickel-metal hydride battery | $9,105 | $4,111 | $9,105 | $4,111 |
| Base vehicle | $10,425 | $10,425 | $10,100 | $10,100 |
| Motor (Soleq 60 kW DC) | $1,146 | $764 | $1,146 | $746 |
| Controller (Soleq 60 kW) | $2,735 | $1,823 | $2,735 | $1,823 |
| Transmission | $122 | $81 | $122 | $81 |
| Charger | $1,484 | $989 | $1,484 | $989 |
| Accessories[b] | $2,958 | $1,972 | $2,958 | $1,972 |
| Recharging station | $424 | $283 | $424 | $283 |
| Other variable costs | | | | |
| Fixed costs | | | | |
| Total production cost | | | | |
| Retail price | | | | |
| Low | $25,938 | $20,788 | $25,409 | $20,318 |
| High | $30,739 | $22,254 | $30,155 | $21,767 |
| With USABC goal | $25,432 | $19,960 | $24,910 | $19,500 |
| Conventional vehicle comparison | $20,831 | $21,520 | $20,361 | $21,042 |

Table 6 (cont'd): U.S. DOE Minivan EV Cost Projections and Assumptions[a]

| Lifecycle cost assumptions | Los Angeles | | Washington, D.C. | |
|---|---|---|---|---|
| Inflation rate | 4.18% | | 4.18% | |
| Discount rate | 7% | | 7% | |
| Battery life | Lead-acid and sodium sulfur batteries last 4 years when purchased in 1998 and 5 years when purchased in 2005, nickel-metal hydride batteries last 5 years when purchased in 1998 and 8 years when purchased in 2005. Battery replacement cost is assessed entirely in the year replacement is required. | | | |
| Tire life | Low rolling resistance tires are assumed to cost $360 per set, and to be replaced every 25,000 miles (twice as often as regular tires). | | | |
| Efficiency | EV efficiency is assumed to be 0.35 kWh/mile. | | | |
| Maintenance | Maintenance costs for EVs are 50% that for ICEVs, and all maintenance costs are based on an Abacus model. | | | |
| Electricity | $0.12/kWh | | $0.09/kWh | |
| Registration | 2.25% of capital cost for first three years, then 10% decrease per year | | $98/year | |
| Insurance | $3,552/year | | $1,838/year | |
| | Insurance rates are assumed to drop 10% per year "for a good driving record" and then to decline 46% after five years to reflect dropping collision coverage. | | | |
| Lifecycle costs | 1998 | 2005 | 1998 | 2005 |
| Recurring costs ($/mile) | $0.34-$0.39 | $0.32-$0.37 | $0.24-$0.26 | $0.22-$0.24 |
| Lifetime Net Present Value | $74,353-$86,448 | $66,722-$74,544 | $61,039-$68,196 | $53,477-$57,413 |
| Method of calculation | Study uses "subtraction and addition" method for assessing EV production costs<br>Lifecycle costs are calculated using a simple spreadsheet model that enters inflated purchase costs in year 1 (either 1998 or 2005), inflated recurring costs in the year that they are assumed to occur, and that then calculates NPV figures. | | | |
| Sources of data | R. Sutula, DOE Office of Transp. Tech. for battery costs.<br>Various manufacturers for EV subcomponents. | | | |

Source: (U.S. DOE, 1995)

Notes:

[a] All costs shown are in $1994. Purchase costs and recurring costs are subsequently inflated by 4.18% per year for each year after 1994 in which they occur.

[b] Accessories include battery heater, voltmeter, ammeter, amp-hr counter and shunt, DC-DC converter, and air conditioner.

Table 7: NYSERDA Cost Projections and Assumptions for Subcompact EV[a]

| Cost category | Year and production volume | | | |
|---|---|---|---|---|
| | 1998<br>40,000/yr | 2000<br>41,000/yr | 2002<br>107,000/yr | 2004<br>243,000/yr |
| Component costs: | | | | |
| Vehicle chassis[a] | $5,000 ($3,500-8,000) | $5,000 ($3,500-8,000) | $4,500 ($3,500-6,000) | $3,000 ($2,800-6,000) |
| Powertrain[b] | $3,500 ($2,500-5,000) | $2,500 ($2,500-4,000) | $2,000 ($1,500-2,500) | $2,000 ($1,800-2,500) |
| Battery Pack[c] | $4,375 ($3,750-5,000) | $3,500 ($3,000-4,500) | $3,000 ($2,800-3,500) | $3,000 ($2,800-3,500) |
| Other variable costs (labor) | $2,000 ($1,500-2,500) | $1,700 ($1,200-2,500) | $1,000 ($1,000-2,000) | $1,000 ($800-1,600) |
| Fixed costs | $9,000 ($4,500-18,000) | $9,000 ($4,500-18,000) | $6,500 ($3,750-13,000) | $6,500 ($3,750-13,000) |
| Total production cost | $23,875 ($15,750-$38,500) | $21,700 ($14,700-$37,000) | $17,000 ($12,550-$27,000) | $15,500 ($11,950-$26,600) |
| Retail price | $28,173 | $25,606 | $20,060 | $18,290 |

Table 7 (cont'd): NYSERDA Cost Projections and Assumptions for Subcompact EV[a]

| | | | | |
|---|---|---|---|---|
| Lifecycle cost assumptions | | | | |
| Inflation rate | 6% | 6% | 6% | 6% |
| Discount rate | | | | |
| Vehicle purchase price | $28,173 | $25,606 | $20,060 | $18,290 |
| Vehicle life | 12 years | 12 years | 12 years | 12 years |
| Annual mileage | 10,000-12,500 | 10,000-12,500 | 10,000-12,500 | 10,000-12,500 |
| Salvage value | 0 | 0 | 0 | 0 |
| Energy efficiency | 0.25 kWh/mile | 0.22 kWh/mile | 0.19 kWh/mile | 0.19 kWh/mile |
| Charging efficiency | 0.80 | | | |
| Electricity cost | $0.085/kWh | $0.086/kWh | $0.086/kWh | $0.087/kWh |
| Battery cost and capacity: | 25 kWh Pb-acid<br>($175/kWh) | 20 kWh NiMH<br>($175/kWh) | 20 kWh NiMH<br>($150/kWh) | 20 kWh NiMH<br>($150/kWh) |
| Battery life | 4 years | 5 years | 5 years | 7 years |
| Maintenance | $0.03/mi. | $0.03/mi. | $0.03/mi. | $0.03/mi. |
| Lifecycle cost ($1994/mile) | | | | |
| Vehicle (10,000 mi/yr) | $0.28 | $0.26 | $0.20 | $0.18 |
| Vehicle (12,500 mi/yr) | $0.23 | $0.21 | $0.16 | $0.15 |
| Battery (12,500 mi/yr) | $0.08 | $0.07 | $0.06 | $0.04 |
| Maintenance and tires | $0.03 | $0.03 | $0.03 | $0.03 |
| Electricity | $0.021 | $0.019 | $0.016 | $0.016 |
| Total (12,500 mi/yr) | $0.36 | $0.33 | $0.27 | $0.24 |
| Comparison conventional vehicle cost (Ford Escort)[d] | $0.17 | $0.17 | $0.18 | $0.18 |
| Method of calculation | For production cost, Booz-Allen estimates of "plausible range" and "probable" costs for vehicle chassis, dirvetrain, battery pack, labor, and amortized development.<br>For lifecycle cost, addition of per mile vehicle costs, tire and maintenance costs, battery costs, and fuel costs. | | | |
| Sources of data | Unspecified manufacturers for component costs. Amerigon, Inc. and Booz-Allen projections for labor costs.<br>American Automobile Association for tire and maintenance costs, public utility publications and EIA for electricity costs. | | | |

Source: (NYSERDA, 1995)

Notes:

[a] Redesigned gasoline chassis from 1998-2000, purpose built from 2002-2004.

[b] Unspecified AC induction or brushless permanent magnet drivetrain.

[c] 25 kWh advanced lead acid in 1998, 20 kWh NiMH from 2000-2004.

[d] Escort lifecycle costs reflect vehicle purchase costs of $9,560 in 1998 and 2000 and $9,860 in 2002 and 2004 and gasoline costs of $1.34/gallon in 1998, $1.37/gallon in 2000, $1.41/gallon in 2002, and $1.44/gallon in 2004 (all in $1994).

Table 8: U.S. OTA Cost Projections and Assumptions for EVs

| Cost category | Year and production volume | | | |
|---|---|---|---|---|
| | Subcompact 2005 (24,000/yr) | Mid-size 2005 (24,000/yr) | Subcompact 2015 (24,000/yr) | Mid-size 2015 (24,000/yr) |
| Component costs: | | | | |
| Lead acid battery (34.9 kWh @ $150/kWh) | | $5,240 | | |
| AC motor/controller (105.9 kW) | | $3,480 | | |
| Electric power steering | | $65 | | |
| heat pump A/C | | $300 | | |
| Total | | $9,085 | | |
| Other variable costs | | ($3,500)[a] | | |
| Fixed costs | | $900 | | |
| Total production cost (incremental) | | $10,900[b] | | |
| Retail price effect:[b] | | | | |
| Lead acid battery, 80 mile range | $8,090 | $10,920 | $2,260 | $3,175 |
| NiMH battery, 100 mile range | $14,590 | $19,510 | $6,150 | $6,800 |
| NiMH battery, 200 mile range | $56,600 | $74,100 | $25,560 | $33,090 |
| Li-polymer battery, 300 mile range | n.a. | n.a. | $8,720 | $11,370 |
| Lifecycle cost assumptions | | | | |
| Method of calculation | Calculation of a retail price equivalent, based on "glider" production strategy, as an incremental production cost over advanced conventional vehicles - see text and note b. | | | |
| Sources of data | Unspecified automakers, component manufacturers, and literature sources. | | | |

Source: (OTA, 1995)

Notes:

[a] Savings from engine, transmission, and emission controls.

[b] Retail price effect is calculated as 1.4 times variable cost, plus fixed cost, times 1.25 (1.25 * (1.4V + F)).

Table 9: Characteristics of EVs Assessed by U.S. OTA

| Battery Type and Range | Vehicle Characteristic | Year 2005 Subcompact | Year 2005 Intermediate | Year 2015 Subcompact | Year 2015 Intermediate |
|---|---|---|---|---|---|
| Lead Acid<br>80 mile range | Wt. (kg)[a] | 587/1500 | 776/2003 | 394/1080 | 515/1430 |
| | Eff. (kWh/km)[b] | 0.195 | 0.260 | 0.140 | 0.185 |
| | Price ($)[c] | 8,090 | 10,920 | 2,260 | 3,175 |
| Nickel-metal hydride<br>100 mile range | Wt. (kg)[a] | 294/1027 | 389/1377 | 210/783 | 230/968 |
| | Eff. (kWh/km)[b] | 0.124 | 0.166 | 0.095 | 0.117 |
| | Price ($)[c] | 14,590 | 19,510 | 6,150 | 6,800 |
| Nickel-metal hydride<br>200 mile range | Wt. (kg)[a] | 1057/2229 | 1381/2928 | 611/1378 | 788/1791 |
| | Eff. (kWh/km)[b] | 0.269 | 0.354 | 0.167 | 0.216 |
| | Price ($)[c] | 56,600 | 74,100 | 25,560 | 33,090 |
| Lithium-Polymer<br>300 mile range | Wt. (kg)[a] | n/a | n/a | 116/638[d] | 150/839[d] |
| | Eff. (kWh/km)[b] | n/a | n/a | 0.075 | 0.099 |
| | Price ($)[c] | n/a | n/a | 8,720 | 11,370 |

Source: (OTA, 1995)

Notes:

[a] Battery weight/total vehicle weight, rounded to nearest kg

[b] Efficiency is electricity consumption at the outlet, assuming 94% charger efficiency, in kWh/km

[c] Price is incremental price over same size conventional vehicle

[d] Total weight includes 60 kg of capacitors for subcompact, 80 kg of capacitors for intermediate

Table 10: Results of Rand Institute EV Cost Assessment

| Cost category | Year and production volume | |
|---|---|---|
| | 1998-2002 | post 2002 |
| Component costs | | |
| Total variable costs (incremental to ICEV)[a] | $3,320-$15,000/vehicle | decline with 75%-90% experience curves |
| Total fixed costs | $1.05-$4.20 billion | |
| Total production cost | | |
| Retail cost | | |
| Lifecycle cost assumptions: | | |
| Vehicle efficiency | 3-5 mi/kWh (passenger)<br>2-4 mi/kWh (minivan) | 4-5 mi/kWh (passenger)<br>3-4 mi/kWh (minivan) |
| Battery cost per kWh delivered | $0.20-0.55/kWh | $0.16-$0.39/kWh |
| Repair and maintenance | 67-100 percent of ICEV | 50-100 percent of ICEV |
| Electricity cost | $0.05-$0.12/kWh | $0.05-$0.12/kWh |
| Total incremental operating cost[b] | $1,316-$11,251 (passenger)<br>$608-$15,799 (minivan) | $1,234-$6,459 (passenger)<br>$1,023-$7,920 (minivan) |
| Method of calculation | Incremental variable costs range from a low estimate based on the Booz-Allen analysis to a high estimate provided by automakers. Operating costs are based on the assumptions shown above. For long-term scenario, lower bound costs decline with 75% experience curve, upper bound costs decline with 90% experience curve. | |
| Sources of data | Abacus (DOE), Booz-Allen (NYSERDA), Moomaw et al., and GAO cost studies; interviews with Big 3 automakers | |

Source: (Dixon and Garber, 1996)

Notes:

[a] The incremental cost figures do not include the cost of batteries, which are included as lifecycle costs.

[b] Incremental operating costs are based on comparisons with ICEV vehicles assuming vehicle efficiencies of 27.5 miles per gallon (passenger cars) and 18 miles per gallon (minivans) and gasoline prices of $1.20-1.38 per gallon for 1998-2002 (includes taxes) and $0.75-$0.91 (excludes taxes) for long-term scenario. The range of total operating costs reported in the table is the range from the 5th to the 95th percentile in the Rand analysis.

Table 11: Results of Argonne National Laboratory EV Cost Assessment - Subcompact NiMH Vehicle Case

| Cost category | Year and production volume | | | |
|---|---|---|---|---|
| | 2000 (<10K/yr) | 2005 (10-40K/yr) | 2010 (>40K) | 2020 (>40K/yr) |
| Component Prices: | | | | |
| common components | $11,840 | $11,840 | $11,840 | $11,840 |
| controller | $2,410 | $1,840 | $1,440 | $1,230 |
| motor | $980 | $900 | $810 | $760 |
| gear drive | $180 | $170 | $170 | $160 |
| other body parts | $350 | $330 | $320 | $310 |
| HVAC drive | $120 | $110 | $110 | $100 |
| battery | $10,580 | $8,360 | $6,120 | $4,490 |
| Other variable costs | Prices of components reflect these categories | | | |
| Fixed costs | | | | |
| Total production cost | | | | |
| Retail price | $26,500 | $23,600 | $20,900 | $18,900 |
| Comparison conventional vehicle | $15,500 | $15,500 | $15,500 | $15,500 |
| Lifecycle cost assumptions | | | | |
| electricity cost | 1.37 c/mi | 1.31 c/mi | 1.23 c/mi | 1.22 c/mi |
| non-fuel cost | 1.82 c/mi | 1.85 c/mi | 1.88 c/mi | 1.94 c/mi |
| battery cost | 23.83 c/mi | 14.68 c/mi | 9.32 c/mi | 6.74 c/mi |
| Total lifecycle cost | 42.54 c/mi | 32.49 c/mi | 26.42 c/mi | 23.55 c/mi |
| Comparison Conventional vehicle | 24.50 c/mi | 24.40 c/mi | 24.35 c/mi | 24.57 c/mi |
| Method of calculation | Spreadsheet model that estimates costs of common and unique EV components, and then computes lifecycle costs | | | |
| Sources of data | CARB and ANL delphi study for battery costs, unpublished Cuenca and Gaines report for drivetrain costs, EVTECA analysis for EV energy use | | | |

Source: (Vyas, 1999)

Table 12: Results of Argonne National Laboratory EV Cost Assessment

| Cost category | Year and production volume | | | |
|---|---|---|---|---|
| | 2000 (<10K/yr) | 2005 (10-40K/yr) | 2010 (>40K) | 2020 (>40K/yr) |
| Vehicle Prices: | | | | |
| Subcompact EV (delphi lead-acid battery) | $19,000 | $18,300 | $17,800 | $17,700 |
| Subcompact EV (CARB lead-acid battery) | $18,500 | $18,300 | $18,000 | $17,800 |
| Subcompact EV (delphi NiMH battery) | $30,300 | $27,500 | $24,900 | $23,900 |
| Subcompact EV (CARB NiMH battery) | $26,500 | $23,600 | $20,900 | $18,900 |
| Subcompact EV (delphi Li-ion battery) | $38,800 | $35,900 | $32,900 | $30,300 |
| Subcompact EV (CARB Li-ion battery) | $41,400 | $30,900 | $21,600 | $18,900 |
| Subcompact Conventional Vehicle | $15,500 | $15,500 | $15,500 | $15,500 |
| Minivan EV (delphi lead-acid battery) | $28,000 | $27,100 | $26,300 | $26,000 |
| Minivan EV (CARB lead-acid battery) | $27,300 | $27,100 | $26,600 | $25,900 |
| Minivan EV (delphi NiMH battery) | $45,600 | $41,300 | $37,200 | $35,100 |
| Minivan EV (CARB NiMH battery) | $39,600 | $35,000 | $30,800 | $27,400 |
| Minivan EV (delphi Li-ion battery) | $58,500 | $53,900 | $49,400 | $44,100 |
| Minivan EV (CARB Li-ion battery) | $63,500 | $46,600 | $32,000 | $27,500 |
| Minivan Conventional Vehicle | $22,700 | $22,700 | $22,700 | $22,700 |
| Vehicle Lifecycle Costs: | | | | |
| Subcompact EV (delphi lead-acid battery) | 34.37 c/mi | 31.58 c/mi | 29.62 c/mi | 28.87 c/mi |
| Subcompact EV (CARB lead-acid battery) | 29.78 c/mi | 26.70 c/mi | 25.26 c/mi | 24.93 c/mi |
| Subcompact EV (delphi NiMH battery) | 47.79 c/mi | 40.56 c/mi | 35.42 c/mi | 33.73 c/mi |
| Subcompact EV (CARB NiMH battery) | 42.54 c/mi | 32.49 c/mi | 26.42 c/mi | 23.55 c/mi |
| Subcompact EV (delphi Li-ion battery) | 71.74 c/mi | 59.61 c/mi | 48.15 c/mi | 41.62 c/mi |
| Subcompact EV (CARB Li-ion battery) | 64.40 c/mi | 39.32 c/mi | 27.81 c/mi | 24.99 c/mi |
| Subcompact Conventional Vehicle | 24.50 c/mi | 24.40 c/mi | 24.35 c/mi | 24.57 c/mi |
| Minivan EV (delphi lead-acid battery) | 50.69 c/mi | 46.77 c/mi | 43.78 c/mi | 41.74 c/mi |
| Minivan EV (CARB lead-acid battery) | 43.72 c/mi | 39.23 c/mi | 37.00 c/mi | 35.71 c/mi |
| Minivan EV (delphi NiMH battery) | 70.61 c/mi | 60.41 c/mi | 52.53 c/mi | 48.69 c/mi |
| Minivan EV (CARB NiMH battery) | 62.10 c/mi | 47.49 c/mi | 39.97 c/mi | 33.37 c/mi |
| Minivan EV (delphi Li-ion battery) | 107.52 c/mi | 89.39 c/mi | 71.89 c/mi | 59.99 c/mi |
| Minivan EV (CARB Li-ion battery) | 96.38 c/mi | 58.12 c/mi | 40.42 c/mi | 35.52 c/mi |
| Minivan Conventional Vehicle | 34.13 c/mi | 34.01 c/mi | 33.90 c/mi | 33.88 c/mi |

Source: (Vyas and Cuenca, 1999)

Table 13: Summary of EV Purchase Price Estimates

| Cost Study | Purchase Price[a] | | | |
|---|---|---|---|---|
| Argonne Nat'l Lab (Vyas and Cuenca, 1999): | 2000<br>(<10K/yr) | 2005<br>(10-40K/yr) | 2010<br>(>40K) | 2020<br>(>40K/yr) |
| Subcompact EV | $18,500 - 41,400 | $18,300 - 35,900 | $17,800 - 32,900 | $17,700 - 30,300 |
| Minivan EV | $27,300 - 63,500 | $27,100 - 53,900 | $26,300 - 49,400 | $26,000-44,100 |
| -Booz-Allen & Hamilton (1995):<br>Compact EV | 1998<br>40,000/yr<br>$28,173 | 2000<br>41,000/yr<br>$25,606 | 2002<br>107,00/yr<br>$20,060 | 2004<br>243,000/yr<br>$18,290 |
| Office of Technology Assessment (1995):<br>Incremental Price (Retail Price Effect) | Subcompact<br>2005<br>(24,000/yr)<br>$8,090 - $56,600 | Mid-size<br>2005<br>(24,000/yr)<br>$10,920 - $74,100 | Subcompact<br>2015<br>(24,000/yr)<br>$2,260 - $25,560 | Mid-size<br>2015<br>(24,000/yr)<br>$3,175 - $33,090 |
| Sierra Research (1994):<br>Small Passenger EV -- Incremental Price | 1998<br>$10,000 - 27,143 | 2002<br>$7,000 - 17,254 | 2006<br>$4,250 - 20,280 | 2010<br>$10,000 - 22,726 |
| U.S. GAO (1994):<br>Compact EV | Handbuilt<br>$42,700 | 1000/yr<br>$28,700 | 10,000/yr<br>$27,000 | 100,000/yr<br>$18,300 |
| NAVC (Moomaw, et al., 1994)<br>Purpose-Built EV | 1995 (prototype)<br>$60,515 | | 1998 (20,000/yr)<br>$22,945 | |
| U.S. DOE (1995):<br>Minivan EV | 1998<br>$25,409-30,739 | | 2005<br>$20,318-22,254 | |
| Rand Institute (1996):<br>Compact EV -- Incremental Price | 1998-2002<br>$3,320-$15,000 | | | |

Note:

[a] Or incremental price where noted.

Table 14: Summary of EV Lifecycle Cost Estimates

| Cost Study | Lifecycle Cost[a] | | | |
|---|---|---|---|---|
| Argonne Nat'l Lab (Vyas and Cuenca, 1999):<br>Subcompact EV | 2000<br>(<10K/yr)<br>$0.30-0.72/mi | 2005<br>(10-40K/yr)<br>$0.27-0.60/mi | 2010<br>(>40K)<br>$0.25-0.48/mi | 2020<br>(>40K/yr)<br>$0.24-0.42/mi |
| Minivan EV | $0.44-1.08/mi | $0.39-0.89/mi | $0.37-0.72/mi | $0.33-0.60/mi |
| NYSERDA-Booz-Allen & Hamilton (1995):<br>Compact EV | 1998<br>40,000/yr<br>$0.36/mi | 2000<br>41,000/yr<br>$0.33/mi | 2002<br>107,00/yr<br>$0.27/mi | 2004<br>243,000/yr<br>$0.24/mi |
| NAVC (Moomaw, et al., 1994)<br>Purpose-Built EV | | | 1998 (20,000/yr)<br>$0.24/mi | |
| Rand Institute (1996):<br>Passenger EV - Lifetime Incremental Cost<br>Minivan EV - Lifetime Incremental Cost | 1998-2002<br>$1,316-$11,251<br>$608-$15,799 | | post 2002<br>$1,234-$6,459<br>$1,023-$7,920 | |
| U.S. DOE (1995):<br>Minivan EV | 1998<br>$0.24-0.39/mi | | 2005<br>$0.22-0.37/mi | |
| U.S. GAO (1994):<br>Compact EV | Near Term<br>$0.53/mi | | Long Term<br>$0.31/mi | |

Note:

[a] Or lifetime incremental cost where noted.

## References

Dixon, L.S. and S. Garber, *California's Ozone-Reduction Strategy for Light-Duty Vehicles*, ISBN: 0-8330-2392-6, Rand Institute for Civil Justice, Santa Monica, (1996).

W.R. Moomaw, et al., *Near-Term Electric Vehicle Costs*, Northeast Alternative Vehicle Consortium, Boston, October (1994).

NYSERDA, *Zero-Emission Vehicle Technology Assessment*, 95-11, New York State Energy Research and Development Authority, August (1995).

Office of Technology Assessment, *Advanced Vehicle Technology: Visions of a Super-Efficient Family Car*, OTA-ETI-638, Office of Technology Assessment, U.S. Congress, Washington, D.C., September (1995).

Sierra Research, Inc. and Charles River Associates, *The Cost-Effectiveness of Further Regulating Mobile Source Emissions*, SR94-02-04, Sacramento, February 28 (1994).

U.S. Department of Energy, *Encouraging the Purchase and Use of Electric Motor Vehicles*, Office of Transportation Technologies, U.S. Department of Energy, Washington, D.C., May (1995).

U.S. Government Accounting Office, *Electric Vehicles: Likely Consequences of U.S. and Other Nations' Programs and Policies*, GAO/PEMD-95-7, Washington, D.C., December (1994).

A. Vyas, Personal Communication, February 5 (1999).

A. Vyas and R. Cuenca, "EV Cost Model," Presentation at 1999 TRB Conference, January 11 (1999).

A. Vyas et al., "An Assessment of Electric Vehicle Life Cycle Costs to Consumers," *SAE Technical Paper Series* **982182** (1998).