Rosenberg

ADVISABILITY OF REGULATING ELECTRIC VEHICLES FOR ENERGY CONSERVATION

A REPORT TO THE CONGRESS AND THE PRESIDENT
FROM THE
SECRETARY OF TRANSPORTATION

AUGUST 1976

U.S. DEPARTMENT OF TRANSPORTATION
OFFICE OF THE SECRETARY
OFFICE OF THE ASSISTANT SECRETARY
FOR SYSTEMS DEVELOPMENT AND
TECHNOLOGY

THE SECRETARY OF TRANSPORTATION
WASHINGTON, D.C. 20590

JUL 26 1976

The President
The White House
Washington, D.C. 20500

Dear Mr. President:

Pursuant to Section 512(b) of the Motor Vehicle Information and Cost Savings Act, as amended by the Energy Policy and Conservation Act (PL 94-163), I am transmitting this report on "Advisability of Regulating Electric Vehicles for Energy Conservation."

Respectfully,

William T. Coleman, Jr.

Enclosure

THE SECRETARY OF TRANSPORTATION
WASHINGTON, D.C. 20590

JUL 26 1976

Honorable Nelson A. Rockefeller
President of the Senate
United States Senate
Washington, D. C. 20510

Dear Mr. President:

Pursuant to Section 512(b) of the Motor Vehicle Information and Cost Savings Act, as amended by the Energy Policy and Conservation Act (PL 94-163), I am transmitting this report on "Advisability of Regulating Electric Vehicles for Energy Conservation."

Sincerely,

William T. Coleman, Jr.

Enclosure

THE SECRETARY OF TRANSPORTATION
WASHINGTON, D.C. 20590

JUL 26 1976

Honorable Carl Albert
Speaker of the House of Representatives
Washington, D. C. 20515

Dear Mr. Speaker:

Pursuant to Section 512(b) of the Motor Vehicle Information and Cost Savings Act, as amended by the Energy Policy and Conservation Act (PL 94-163), I am transmitting this report on "Advisability of Regulating Electric Vehicles for Energy Conservation."

Sincerely,

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PREFACE

This report is required by Section 512(b) of Title V of the Motor Vehicle Information and Cost Savings Act, as ammended by Title III, part A of the Energy Policy and Conservation Act, (P.L. 94-163 which states:

> "Sec. 512(b)(1) Within 180 days after the date of enactment of this title, the Secretary shall prepare and submit to the Congress and the President a comprehensive report setting forth findings and containing conclusions and recommendations with respect to whether or not electric vehicles and other vehicles not consuming fuel (as defined in the first sentence of section 501(5)) should be covered by this part. Such report shall include an examination of the extent to which any such vehicle should be included under the provisions of this part, the manner in which energy requirements of such vehicles may be compared with energy requirements of fuel-consuming vehicles, the extent to which inclusion of such vehicles would stimulate their production and introduction into commerce, and any recommendations for legislative action.
>
> "(2) As used in this subsection, the term 'electric vehicle' means a vehicle powered primarily by an electric motor drawing current from rechargeable batteries, fuel cells, or other portable sources of electric current."

89 STAT. 916

This report was prepared by the Transportation Systems Center, Cambridge, Massachusetts, under the direction of the Office of the Assistant Secretary for Systems Development Technology.

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EXECUTIVE SUMMARY

This report is in response to the requirements of the Motor Vehicle Information and Cost Savings Act as amended by Title III, Part A of the Energy Policy and Conservation Act (PL 94-163). It sets forth findings and contains conclusions and recommendations with respect to:

- Whether or not electric vehicles and other vehicles not consuming fuel* should be covered by this part;
- The extent to which any such vehicle should be included under the provisions of this part;
- The manner in which energy requirements of such vehicles may be compared with energy requirements of fuel-consuming vehicles;
- The extent to which inclusion of such vehicles would stimulate their production and introduction into commerce.

Based upon the findings of the report, the following conclusions and recommendations are given:

- These vehicles should not be covered by this part of the Act.
- Electric vehicle manufacturers should not be required to provide "fuel economy" labels for their vehicles. However, they should be permitted to submit "fuel economy" information to EPA and FEA for inclusion in the annual Fuel Economy Booklet in accordance with EPA and FEA requirements.
- Energy requirements of such vehicles should be compared with energy requirements of fuel-consuming vehicles on the basis of overall vehicle energy efficiency from primary source to ultimate utilization in the vehicle.

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*As defined in Section 501 (5), the term fuel means gasoline and diesel oil.

- o If these vehicles were to be regulated under the Act, the resulting cost of implementation would have an adverse effect on the consumer cost of these vehicles and retard their production and introduction into commerce.

This report is based largely on previous and on-going research, and is focused on the electric vehicle. It includes analyses of current technology for the design and manufacture of electric vehicles, performance characteristics, life-cycle costs, material requirements and availability, and the market potential, with particular emphasis given to the time period through 1985. There has been no attempt to predict long range prospects for electric vehicles other than to note that electric vehicle R&D may have much importance for increasing personal transportation options in the future.

The report compares the energy consumption of electric vehicles and fuel-consuming vehicles which are functionally equivalent, although the electric vehicle will be heavier, will not have comparable acceleration or range performance, and may not be equipped with the full range of accessories normally found in fuel consuming vehicles.

The following summarizes the major findings of the report on which the conclusions and recommendations are based:

<u>Non-Fuel-Consuming Vehicles</u>

- o The principal non-fuel-consuming vehicles include automotive vehicles powered by propulsion systems using electricity, butane, propane, hydrogen, ethanol and methanol.
- o With the exception of the electric vehicle, the principal non-fuel-consuming vehicles have performance characteristics similar to the gasoline or diesel-powered vehicles, but the fuel is more expensive to produce and/or the fuel distribution network would have to be developed and built for refueling such vehicles.

- For non-fuel consuming vehicles other than the electric vehicle, it does not appear that there will be sufficient numbers of vehicles produced by 1985 to warrant consideration for inclusion under the Act provided there is no major shift in Government policy toward these vehicles.

Electric Vehicle Energy Use

- Based on conversion of petroleum to gasoline or to electricity, present electric passenger vehicles have about the same energy efficiency on a seat-mile basis as a comparable gasoline consuming vehicle over the urban driving cycle. Over a multi-stop urban cycle, a light duty electric commercial utility vehicle may be more efficient than a comparable gasoline consuming vehicle, because there are no idling losses when the vehicle is stopped.
- The potential for fuel economy improvement of the electric vehicle by 1985 through modified vehicle design appears to be less than that of the fuel-consuming vehicles. However, the results of continued technology development may alter this outlook.
- Based on the proportion of the electric power generated by various sources, electric vehicles would obtain 80% of their energy from non-petroleum fuels.
- Since electric vehicles are likely to represent a very small fraction of the U.S. automotive vehicle fleet in 1985, their effect on overall energy consumption should be insignificant.

Electric Vehicle Economics

- While operating costs of the potential mass-produced electric vehicles may be somewhat lower than the costs of comparable fuel-consuming vehicles, the life-cycle costs for electric passenger automobiles are estimated to be 10 to 40 percent higher. The life-cycle costs of electric light duty commercial vans are estimated to be about the same as or less than for comparable fuel-consuming vehicles. These cost estimates are sensitive to the operational life of batteries.

- Electric passenger automobiles are expected to be weak competitors with comparable ICE powered automobiles through 1985, based on the estimated life cycle costs and performance characteristics. On the other hand, there may be a gradual increase in the sale of electric light duty commercial vans for urban multi-stop usage.

1.0 INTRODUCTION

This report is required by Title V, Section 512(b) of the Motor Vehicle Information and Cost Savings Act (MVI and CSA) as amended by Title III, Part A of the Energy Policy and Conservation Act. It includes an examination of non-fuel consuming vehicles to determine whether or not any such vehicles should be included under the provisions of the Act. It examines the ways in which energy requirements of such vehicles may be compared with energy requirements of fuel-consuming vehicles, the potential application of the Act to such vehicles, the market potential of such vehicles, and the effects of regulation on their production and introduction into commerce.

The scope of the investigation includes light weight on-the-road vehicles, not powered by gasoline or diesel oil, the two energy sources defined as "fuel" in Title V. A number of potential propulsion systems were investigated; among these were batteries and combustion engines using fuels such as alcohol, butane, propane and hydrogen. A review of the status of technology, the operational characteristics, and manufacturability was made to determine which vehicles were likely to be available in the market by 1985.

The electric vehicle, which is the only non-fuel consuming vehicle currently in production and for which the fuel distribution system is in place, potentially could be in use in large numbers during the period up to 1985. Therefore, the study focuses on an evaluation of electric vehicles. Performance characteristics, life-cycle costs, materials availability, and potential market projections are developed for an electric passenger automobile utilizing three battery systems, lead-acid, nickel-zinc and lithium/aluminum-iron sulfide. The same characteristics are developed for a light duty commercial van. The study emphasizes the near term time including the decade of the 1980's and, therefore, does not consider the potentially large improvements in the electric vehicle technology that may reach commercial application after that period.

This report is based upon a review of existing literature and data on existing components and vehicles. The results reported here are based primarily on the recent Jet Propulsion Laboratory Study, Should We Have a New Engine[1*] and on earlier work by General Research Corporation,[2] Ford Motor Co[3] and others.[6-8,16-19,27,38] Current cost information has been gathered from component and vehicle manufacturers. The methodology for calculation of electric vehicle costs generally follows that developed by the Automobile Manufacturing and Maintenance Panel of the Task Force on Motor Vehicle Goals Beyond 1980.[4] Life-cycle cost estimates use the same method and assumptions that are in the report of the General Research Corporation.[2]

Chapter 2.0 discusses non-fuel-consuming vehicles and their characteristics. The advantages and disadvantages of electric vehicles are outlined and the performance characteristics of electric light duty commercial vans, when operated over their characteristic driving cycles, are developed. Several kinds of electric vehicles are described. In Chapter 3.0, the overall system efficiencies are considered for converting the energy available as fossil fuel in the ground to vehicle propulsion energy for electric and gasoline consuming vehicles. An energy comparison of gasoline and electricity as vehicle fuels is developed with both petroleum and coal as primary sources. Chapter 4.0 discusses the production of electric vehicles and their introduction into commerce. The market potential for electric passenger vehicles and light duty commercial vans is estimated based upon vehicle acquisition costs and projected life cycle costs. Chapter 5.0 discusses the application of Title V of the MVI and CSA to electric vehicles. Chapter 6.0 discusses the effects of regulation on the production and introduction of electric vehicles into commerce. Chapter 7.0 summarizes findings, conclusions and recommendations.

Appendix A contains a discussion of Range versus Energy Economy for electric vehicles including consideration for regenerative braking. Appendices B through G contain information on the

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*Superscript numbers refer to references listed at the back of the report.

methodology and calculation of vehicle and component costs. The Appendices also contain a summary of the material sent to the Docket and list of references.

In the course of this analysis, no assumptions were made nor conclusions drawn concerning the societal or political desirability of an expanded electric vehicle fleet. The desirability of widespread use of electric vehicles and the choice of appropriate incentives to stimulate such use are separate issues beyond the scope of this study. Instead, the report considers whether regulation of electric vehicle fuel economy under Title V of the MVI and CSA would significantly influence the production and use of electric vehicles or create other public benefits and costs.

2.0 DESCRIPTION OF ELECTRIC VEHICLES

2.1 INTRODUCTION

A number of propulsive energy sources have been proposed as alternates for gasoline or diesel fuel in automotive vehicles. Among these are batteries, fuel cells and alternate fuels such as synthetic gasoline and diesel fuel, methane, propane, methanol, ethanol and hydrogen. Performance, fuel economy and emissions of vehicles using the alternate fuels are comparable with those of vehicles using gasoline and diesel fuel. Extensive reviews of these alternate fuels have been presented in the recent past[5,6] and, based on these evaluations, the likelihood of their significant use in transportation, either singly or in combination with current fuels, in the next ten years seems rather low for a variety of technological, economic, availability or safety reasons. Thus, synthetic gasoline and diesel fuel from coal, while compatible with present storage and distribution networks and capable of direct utilization in gasoline and diesel fuel burning vehicles, have not yet been produced on a commercial scale, and major uncertainties exist as to product cost and availability. Methanol would require some vehicle modification and significant distribution and storage network modifications. Methanol is currently estimated to cost more than gasoline from petroleum. If methanol were to be used as a gasoline extender, water miscibility problems would have to be solved. Furthermore, the near term availability of adequate methanol plant capacity is uncertain. If methanol-gasoline blends at the 5 percent level were to be used, the current automotive fuel consumption rate would require a five-fold increase in U.S. methanol production. Hydrogen is quite expensive to manufacture and would require the development of an extensive distribution and storage network. Efficient, compact, on-board storage of hydrogen remains an unsolved technological problem.

As a result of these considerations, this report is limited to electric (battery powered) vehicles. Qualitatively, the perceived advantages and disadvantages of electric vehicles are summarized in Table 2-1.

TABLE 2-1. SUMMARY OF CLAIMED ADVANTAGES AND DISADVANTAGES OF ELECTRIC VEHICLE USE

Advantages

1. Independence of petroleum resource base
2. Energy conversion at fixed installations for more easily optimized conversion efficiencies and more easily controlled emissions
3. Easier match between load profiles and electric propulsion systems in urban and suburban driving
4. No idling losses
5. Some energy recovery possible during deceleration and braking
6. Less audible noise

Disadvantages

1. Relatively low vehicle range.
2. Long "refueling" (recharge) time
3. Relatively poor road performance (in terms of speed and acceleration)
4. Potential vehicle handling problems due to heavy battery system weights
5. Potential crash safety problems
6. Possible large demand for critical materials
7. Higher initial and life cycle costs.

In the past ten years renewed interest in electric vehicles (EV's) has produced many analytical studies and about two dozen experimental cars, usually powered by lead-acid batteries. Characteristically, these vehicles have a driving range of 20-50 miles, display rather poor road performance, show significant range dependence on battery age, driving conditions (terrain and temperature), and recharge behavior, and have high initial and life cycle costs. In this section, evaluations of range, energy economy and performance have been developed or drawn directly from the published literature in order to assess better the merits of existing and future EV's relative to conventional cars. The results reported here are primarily those of the recent Jet Propulsion Laboratory study[1] which used the system shown in Figure 2-1. This system is described in the following paragraphs.

A few candidate battery systems have been selected for this study to represent the many potential options. These are the lead-acid, the nickel-zinc and the lithium/aluminum-iron sulfide batteries. The first represents a well-developed technology currently available, the second is a near term future device showing sufficiently improved energy storage characteristics to be attractive, and the third is an example of a long term future device to which a considerable amount of attention is currently being devoted.

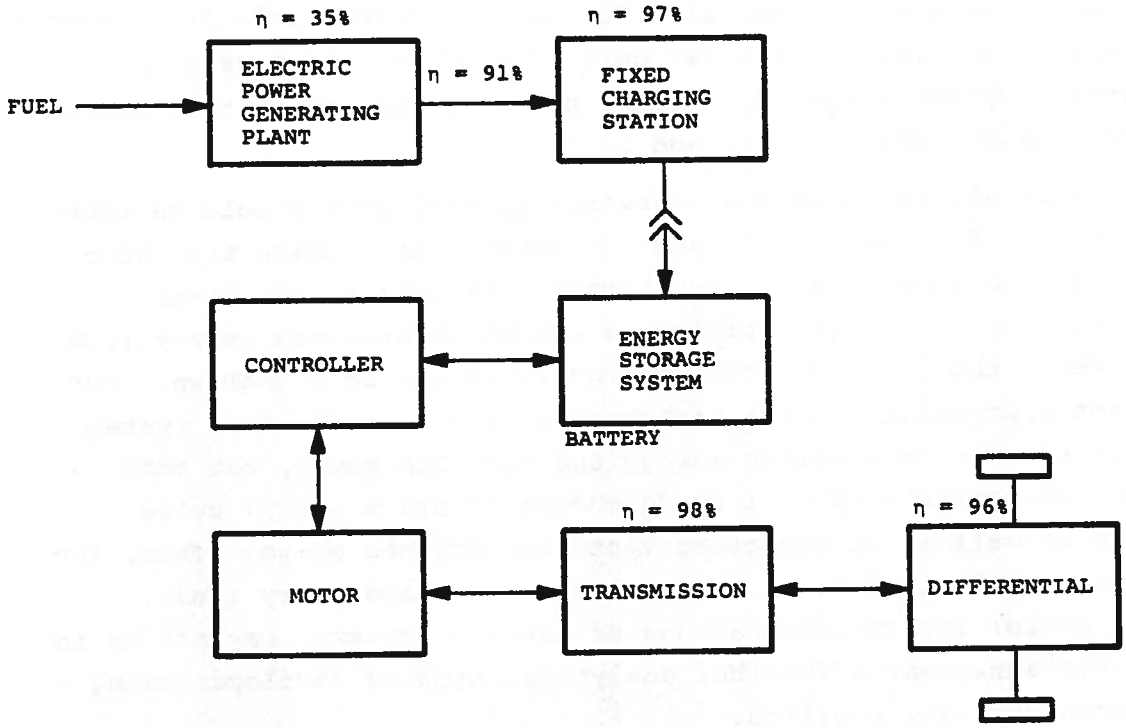

Figure 2-1. Battery System Block Diagram

2.2 RANGE VS. ENERGY ECONOMY*

Various parameters of electric vehicles are of significance in their overall evaluation. At the present time, the greatest technological obstacle to successful implementation of an EV system is the battery, although significant improvements are possible in

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* In the discussion which follows, the term "energy economy" is used. It is defined as the distance traversed by an electric vehicle on expenditure of a given amount of energy (expressed in miles per killowatt-hour).

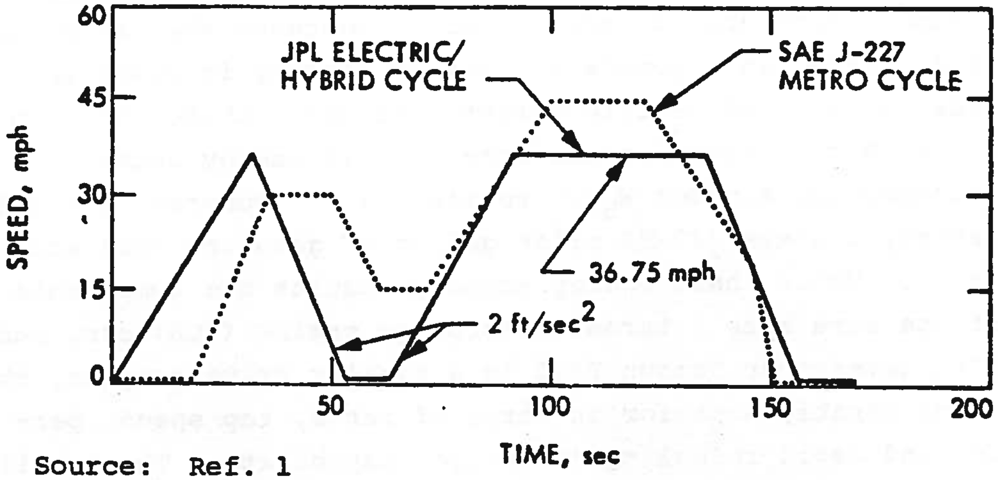
motors, controllers, drivetrains and vehicle structure (both design and weight). The following general discussion is restricted to the battery.

A battery may be characterized in terms of a number of parameters. Among these are total energy capacity (watt-hours), charge-discharge cycle efficiency as a function of rate, cycle life, specific energy (energy storage per unit of storage system weight, watt-hours/pound), specific power (power output per unit of storage system weight, watts/pound) and so on.

While all of these are relevant, special note should be taken of the specific energy and specific power, since these are interdependent to some extent. Put simply, the greater the power required, i.e., the more rapidly one wishes to withdraw energy from a battery, the less the total energy which can be withdrawn. For a first approximation, the performance of a given battery system can be related to specific energy and specific power, but both range and performance will be dependent on drive (duty) cycle chosen as well as on the other factors mentioned above. Thus, the conclusions derived from the Jet Propulsion Laboratory study, while useful for intercomparison of battery systems, may not be in complete agreement with other analytical studies developed using different driving profiles.

In the JPL study, a baseline vehicle is assumed to be 2100 lb. curb weight exclusive of batteries. For this vehicle, JPL assumed a 20-hp electric motor and controller, a 3-speed manual transmission and differential for the drive train. A 40% weight propagation factor was included to account for vehicle changes necessary to accommodate addition or removal of weight attributable to batteries. Gear train efficiencies were as shown in Figure 2-1, and motor and controller efficiencies were chosen from published values.[7] All comparisons included a 300 lb. payload weight. Energy and power density values were assumed as follows: lead-acid, 18W-hr/lb and 60W/lb; nickel-zinc, 40W-hr/lb and 80W/lb; lithium/aluminum-iron sulfide, 60W-hr/lb and 70W/lb. These three battery types were chosen to represent the large variety of potential battery types that may become available in the next ten years with continued development. There is no intent to slight other candidate batteries now in development.

To compare energy economy of electric and gasoline powered vehicles, a gasoline energy content of 125,000 Btu/gal. was used, and an equivalency factor of 12.5 kW-hr/gal between gasoline at the pump and electricity at the wall plug was derived as discussed in more detail in Chapter 3. Tire and aerodynamic loads were included in the analysis. The speed-time mission profile used is shown in Figure 2-2 and closely approximates the SAE-J227 metropolitan driving cycle which is also shown.



Source: Ref. 1

Figure 2-2. Speed-time Profile

An 80% charging efficiency and a 70% depth-of-discharge were assumed. Finally, only vehicle accessories essential to the operation of the powerplant (motor-controller cooling blowers, overload cutouts, panel instruments) were included. Safety related accessories (headlights, taillights, horn, defroster, etc.), driving assists (power steering, power brakes) and comfort equipment (heating, air conditioning, radio, etc) were not factored into the analysis although they would be additional loads on the battery.*

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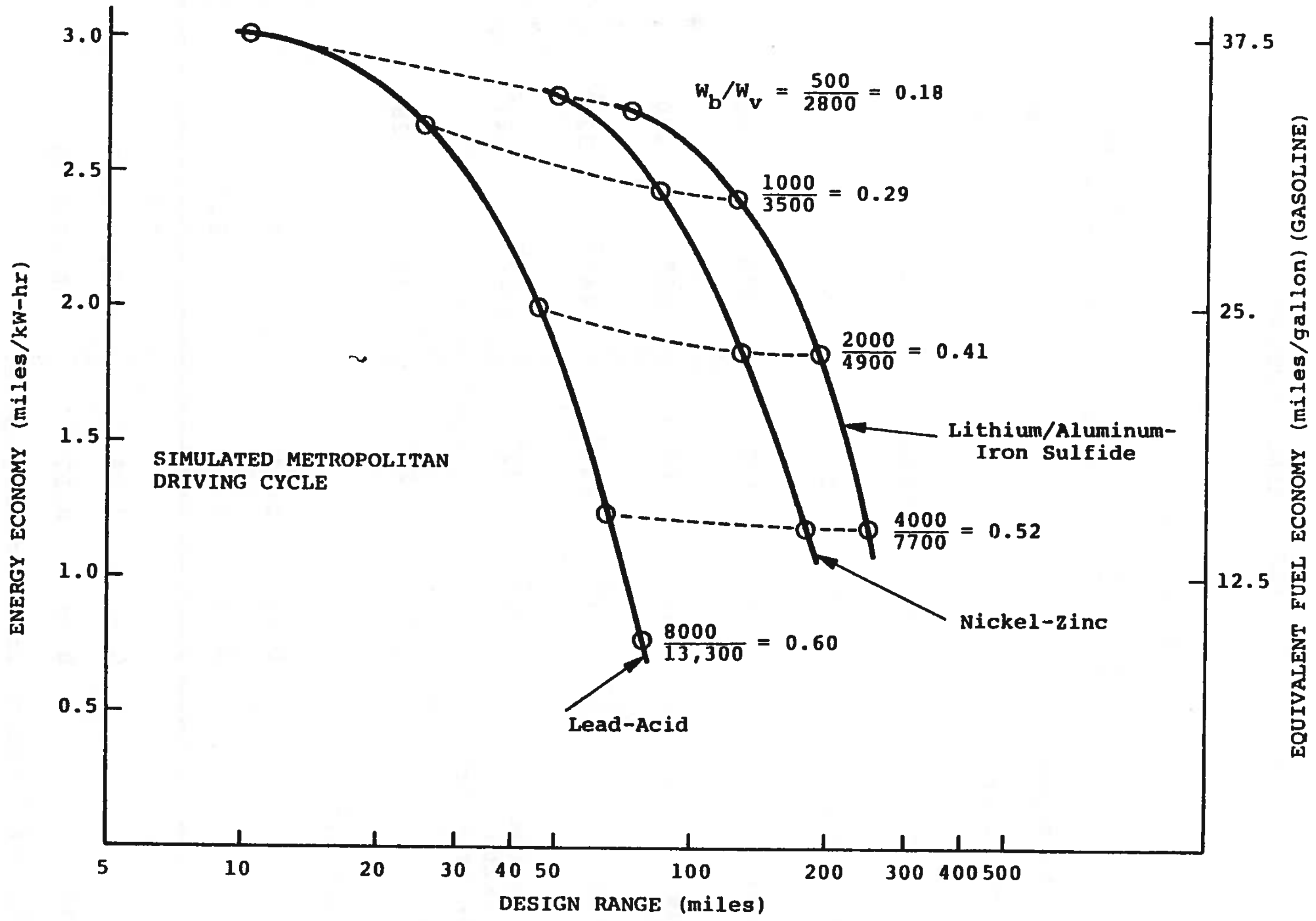
*As a rough generalization, safety related accessories will decrease overall range and energy economy by 2-3% for the simulated metropolitan driving cycle. Comfort equipment represents a high power requirement and can decrease range and energy economy by as much as 15-20% depending on powerplant and vehicle design and driver decisions on the tradeoff between driving range and comfort level.

In Figure 2-3, the relationship between energy economy and range are presented for vehicles powered by the three battery systems. Range/economy data are for the JPL simulated metropolitan driving cycle. Dashed lines permit direct comparison of range/economy relationships for constant ratio of battery weight (W_b) to vehicle weight (W_v). Typical values for W_b/W_v for electric vehicles range from 0.30 to 0.40. Based on this cycle, it can be seen that vehicle range is about 30-40 miles for lead-acid, 85-120 miles for nickel-zinc, and 125-185 miles for lithium/aluminum-iron sulfide. Regenerative braking would increase the range somewhat, as discussed in Appendix A. Energy economy is approximately an inverse function of vehicle weight. Finally, while range increases with high battery performance (higher energy density), energy economy for a given W_b/W_v remains fairly constant for all three battery systems (22-30 miles/gallon of gasoline fuel economy equivalent). While these energy economy results are comparable to those of the same size internal combustion engine (ICE) car, such as a 1976 Chevette or Datsun B210 in a similar driving cycle, the ICE is considerably superior in terms of range, top speed, performance, and rapid refueling (recharge) capability. The detailed data from which these curves are derived are presented in Appendix A.

2.3 PERFORMANCE SUMMARY OF TYPICAL VEHICLE SYSTEMS

Comparative performances of two battery systems (EV) and approximately equivalent internal combustion engine (ICE) cars are presented in Table 2-2. These are taken from the JPL study[1] which, in turn, was based on the results of GRC[2] and Ford Motor Co.[3] studies. While all four cars are subcompacts, the payload accommodations of the EV's are less than the ICE because of the increased volume requirements of the batteries.

The level road acceleration of both vehicle types is acceptable, the differences reflecting design options (e.g., direct drive or transmission). Grade and driving cycle range show more significant differences. The nickel-zinc system is much better than the lead-acid system reflecting the higher energy density and greater



Source: Refs. 1, 27.

Figure 2-3. Energy Economy Vs. Range for Electric Cars Powered by Representative Batteries

TABLE 2-2. PERFORMANCE SUMMARY

	Battery Systems			
	Pb-acid, "Pinto"	Ni-Zn, "4-Pass."	Otto-Engine-Equivalent car	
Otto engine horsepower	-	-	40	80
Electric motor power (peak hp)	40	85	-	-
Traction battery weight, lb	960	1090	-	-
Vehicle curb weight, lb	2900	3230	1960	2100
10-sec. accel. distance, ft	335	370	285	405
50-mph range 6% grade, mi	5.6	60	215	230
Driving cycle range, mi	30[a]	145[a]	445[b]	325[b]
Driving cycle fuel econ., mpg (with regenerative braking)	35[a]	32[a]	37[b]	27[b]
60-mph fuel econ., mpg	26	25	33	28
Emissions (g/mi):[c]				
HC	0.03	0.03	1.5	
CO	0.04	0.04	15.0	
NO_x	0.44	0.48	3.1	
SO_2	0.91	0.99	0.15-0.20	
Particulates	0.09	0.10	0.15-0.40	

[a] Based on SAE J-227 Metropolitan Driving Cycle.

[b] Based on JPL Electric/hybrid vehicle driving cycle.

[c] Equivalent emissions for oil-fired generating plants. For coal-fired plants, SO_2 and particulates could be considerably higher.

Source: Ref. 1.

independence of the energy density on power loading in the former system. Neither of the EV systems is as good as the ICE vehicles by a significant amount in both these range parameters. The driving cycle fuel economy for EV and ICE systems is comparable, with the former about 20% better than the 80 HP ICE. The EV 60-mph fuel economy, however, is not as good. Differences between electric vehicles in these parameters are more a function of the relative curb weights than of intrinsic system differences.

The emissions of hydrocarbons and carbon monoxide produced by the oil-fired power generating station for electric vehicles are negligible compared to those emitted by the ICE vehicles, while oxides of nitrogen are roughly one fourth as high and emissions of oxides of sulfur are four times greater. If the electricity is generated by a coal-fired plant, the emissions of particulates and oxides of sulfur can be expected to be even greater.

2.4 ELECTRIC VANS - CHARACTERISTICS AND PERFORMANCE

The characteristics of commercial urban delivery vehicles are such that they have been considered by some to be the prime market for electric on-the-road vheicles. The types of vehicles considered in this classification include, principally, delivery vans and light utility trucks and, possibly, taxis and small buses.

These vehicles tend to follow a predetermined schedule of limited range on a daily basis. They are required to operate at moderate speeds and accelerations. They tend to make numerous stops and starts, with considerable idle time. The vehicles spend a significant portion of their use time either stationary or coasting, thus not drawing energy from the batteries. They normally return to a base of operations on a daily basis where batteries can be recharged easily. All these route conditions suit the electric vehicles' capabilities and do not greatly stress their limitations.

At the same time, internal combustion engines do not perform best under these conditions. The significant idle time results in a very low fuel economy. The low-speed stop-and-go characteristics of this type of route stress the ICE vehicle, resulting in high maintenance costs. The pollution aspects of the ICE vehicle are especially pronounced in this type of use.

Electric vans have been used commercially for a number of years in England for delivery of milk (milk floats) (Harbilt). The London postal system has been evaluating a fleet of 20 electric-powered vans (Lucas). An electric urban vehicle is now being offered by the same manufacturer. A number of German and Japanese manufacturers are road testing electric vans.

In the United States, the primary impetus for the development of electric vans has come from the U.S. Postal Service which has been experimenting with electric delivery vehicles since 1952. The experience gained by this organization is considered to provide a significant and reliable data base for electric delivery vehicle use in this country.

An extensive test program being run by the Postal Service is in operation in Cupertino, California.[8] The experiment started in August 1971 when an electric van was placed in service in the Cupertino Post Office. This vehicle, a Harbilt van (Model HSV-2), proved to be very reliable in operation on a daily basis. After a year of successful operation of the Harbilt, it was decided to place electric vehicles on each of Cupertino's thirty routes. Thirty new Harbilts (Model HSV-3), leased from the manufacturer, were placed in operation on March 4, 1974.

The specifications of the Harbilt HSV-3 van are presented in Table 2-3. A photograph is shown in Figure 2-4. Their first van has been in service for nearly five years, while the 30 newer vehicles have been in operation for over two years. Operating results for these vans are presented in Table 2-4.

In the Cupertino experiment, the electric vans demonstrated an energy consumption of 1.4 kW-hr/mi (0.21 m/kW-hr), which is equivalent to 8.9 mpg of gasoline.[9] This is 14% higher than the average of 7.9 mpg for ICE jeeps in the same service.[10] Based on the Postal Service's average vehicle utilization of 4152 miles/year[11] and an average fuel economy of 7.9 mpg, an ICE jeep consumes 526 gallons of gasoline per year, while the electric van would consume the equivalent of 465 gallons of gasoline per year.

TABLE 2-3. SPECIFICATIONS FOR HARBILT HSV-3 ELECTRIC VANS USED BY USPS IN CUPERTINO. CALIFORNIA

Height	75"	Deck Width	58"
Width	64"	Deck Length	72-1/2"
Length	148"	Rear Overhang	24"
Deck Height	28"	Turning Circle	36'
Shipping Weight	3565 lbs.	Wheel Base	103"
Pay Load	600 lbs.	Track	48"
Battery	2120 lbs.		

Motor:	BKB 72 Volt Series Wound, 12.5 H.P.
Controller:	Cable Form - Thyristor
Batteries:	Oldham Tubular Traction 36 Cells, 72 Volts, Lead-Acid, 282 AMP
Axle Front:	2800 lbs. Axle Rear: 3600 lbs.
Springs:	Leaf Layer
Brakes	Lockhead Hydraulic - 9" Shoe, Self Adjusting
Body:	Jelco Fiberglass
Battery Charger:	Hobart Model 3R36-200 440/480 Volt
Charge Time:	Four to Six Hours
Maximum Speed:	35 Miles Per Hour
Tires:	155 x 12 Michelin Radial

Source: Ref. 8.

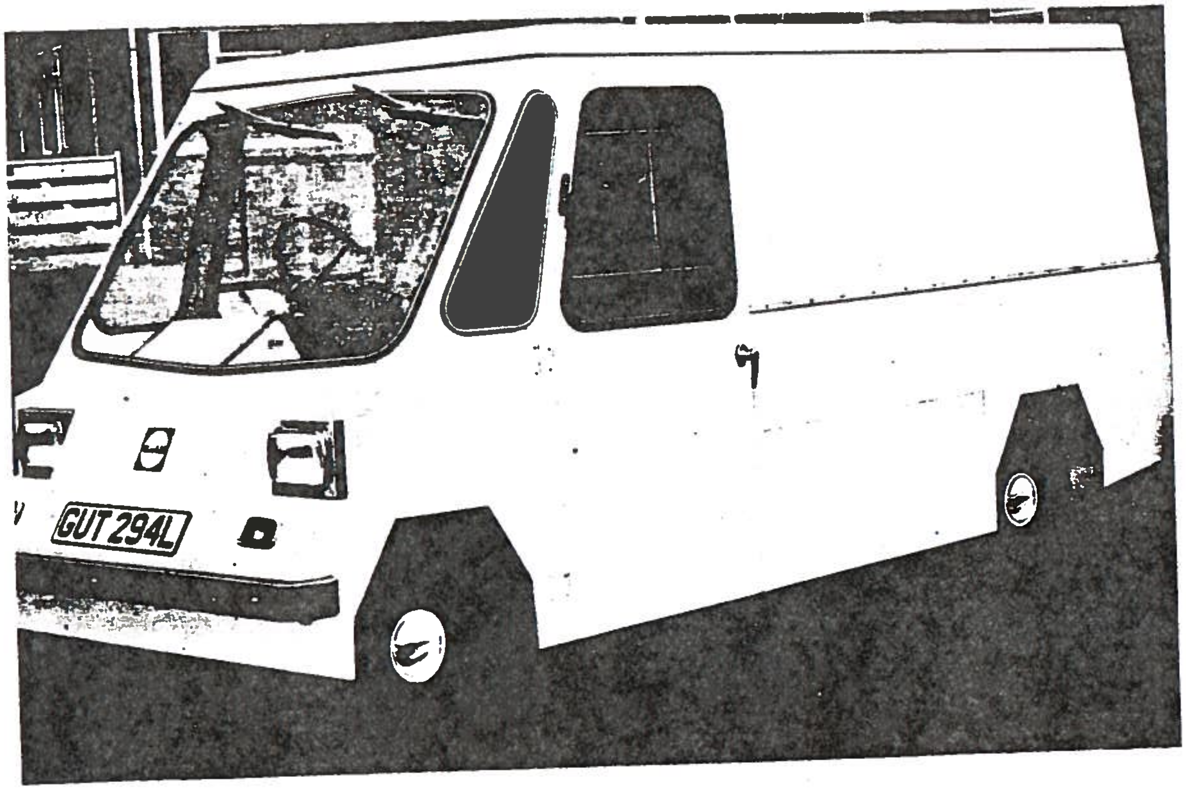


Figure 2-4. Harbilt HSV-3 Electric Type Van Used by USPS in Cupertino, California

TABLE 2-4. SUMMARY OF OPERATING RESULTS OF HARBILT ELECTRIC VANS IN U.S. POSTAL SERVICE OPERATIONS, CUPERTINO, CALIF.

Period Covered	
Original Test Vehicle - Harbilt HSV-2	8/21/71 to 2/1/76
Thirty Test Vehicles - Harbilt HSV-3	3/4/74 to 2/1/76
Average Postal Route Miles per day	10.9
Average Postal Route Hours per day	4.6
Total Miles Traveled	197,506.9
Average Miles per Vehicle for Test Period	6,371.1
Total Electricity Used, kW-hr	277,430.0
Average kW-hr Used per Vehicle	8,949.3
Average kW-hr Used per Vehicle/per day	15.4
Average kW-hr per Mile	1.4
Total Operating Days	17,980.0
Down Days (Vehicle Out of Service)	33

Source: Ref. 9.

The Postal Service considers the low maintenance required for these vans as quite significant. The very low down-time allows the Postal Service to reduce considerably the size of its reserve which is now 5% of the operating fleet. In particular no maintenance has had to be performed on the original Harbilt HVS-2 acquired in 1971. This vehicle is still operating with its original battery pack.

Based on the performance of the Harbilt vehicles in the Cupertino experiments, the USPS procured 350 additional electric delivery vans in order to carry out more extensive field-evaluation trials on a national basis.[12] The specifications for the electric van selected are presented in Table 2-5.[11] The Post Office driving cycle mentioned in the specifications is shown in Figure 2-5. The electric vehicles were delivered during the later part of 1975. These vehicles were assigned to various locations as shown in Table 2-6.[13]

Because of the limited experience obtained to date, the USPS has not released any of the operating data acquired to date on this fleet. It is anticipated that this information will become available during the later part of this year after the electric Jeeps will have been in service for a full year.

A second significant experiment, which is still under way, is being sponsored by the Electric Vehicle Council. In this study, one hundred and seven battery powered vans were acquired by 62 power companies in the U.S. and Canada. The vans were manufactured for the Electric Vehicle Council by the Battronic Truck Corportation, a division of Boyertown Auto Body Works, Boyertown, Pa. The specifications of these vans are presented in Table 2-7.

The results published in a preliminary report[14] on the tests indicate that the average electric consumption of all these vans, driven under widely varying conditions, was 1.4 kW-hr/mile. Over a total of 111,396 vehicle miles, electrical consumption ranged from 0.9 kW-hr/mi to 1.8 kW-hr/mi. It is interesting to note that the average electric fuel consumption in these tests is the same as the one observed by the US Postal Service in its Cupertino experiment.

TABLE 2-5. SPECIFICATIONS OF ELECTRIC DELIVERY VAN SELECTED BY U.S. POSTAL SERVICE FOR ITS 350 VEHICLE FIELD TRIALS

AM General DJ-5E

Specifications

Propulsion Motor

- Type: DC compound, enclosed
- Insulation: Class H
- Size: 11.72 in. dia. x 16.2 in. long
- Weight: 263 lbs.

Controller

- Integrated functions:
  Motor speed and directional control
  Charge regulator
  Auxiliary power converter-regulator
  Battery state of charge sensor
  Cooling — ventilating fan
- Weight: 100 lbs.

Propulsion Battery

- Type: lead-acid semi-industrial EV 27-66E-11
- No. of cells: 27
- Capacity: 330 Ah (6-hr. rating)
- Size: 19 x 29 x 23 in. high
- Weight: 1300 lbs. (including tray)

Auxiliary Battery

- Type: Gould Power Breed
- Rating: 93 Ah (20 hr.), 165 min. at 25 amps
- Size: Group 27 — 12 x 7 x 9 in. high
- Weight: 53 lbs.

Vehicle Weight

- Curb weight: 3625 lbs.
- GVW per U.S. Postal Service spec: 4300 lbs.

Off-Board Charger

- Recharge time: 10 hours maximum
- Input: 240 or 480 volts, 20/10 amp., single phase
- Size: 22 x 14 x 27 in. high; stackable
- Weight: 250 lbs.

On-Board Charger

- Recharge time: 10-16 hours
- Input: 120 volts, 20/15 amp., single phase
- Size: 10 x 18 x 14 in. high
- Weight: 90 lbs.

Axle

- Front: Reverse Elliot Tubular, load range: 2500 lbs.
- Rear: semi-floating, flanged shafts, load rating: 3500 lbs., ratio: 5.89 to 1

Body

- Closed type with two sliding doors and full opening rear door

Brakes

- Service: Servo, self-adjusting with split hydraulic system, size front and rear 11" x 2"; effective lining area 180.48 square inches
- Parking: hand lever actuated; operates on rear wheels

Frame

- Section modulus 1.821 cubed

Performance Data

(U.S. Postal Service Driving Cycle at rated GVW)

- Cruising speed: 33-40 mph
- Acceleration: 0-30 mph/20 seconds
- Gradeability: 10% grade at 16 mph
- Range: 300 Stop/Start Postal cycle . . . 29 miles

Miscellaneous

- Lights: head, parking, tail and stop, direction signals, 4-way hazard flashers, side safety marker lights, back-up lights
- Dual horn
- Electric washers and 2-speed electric windshield wipers; defogger, heater available
- 3 rear-view mirrors, one located inside, and one each left and right side

Seat

- Driver full foam bucket (adjustable)

Shocks

- Front and rear, double action type

Springs

- Front: longitudinal multi-leaf; semi-elliptical; spring rate 330 lbs. per inch
- Rear: longitudinal multi-leaf, semi-elliptical; spring rate 200 lbs. per inch

Steering

- Worm and roller ratio: 24 to 1; turning diameter 35 feet

Tires

- Four CR 78-15 radial ply type, conventional tread, load range C

Wheels

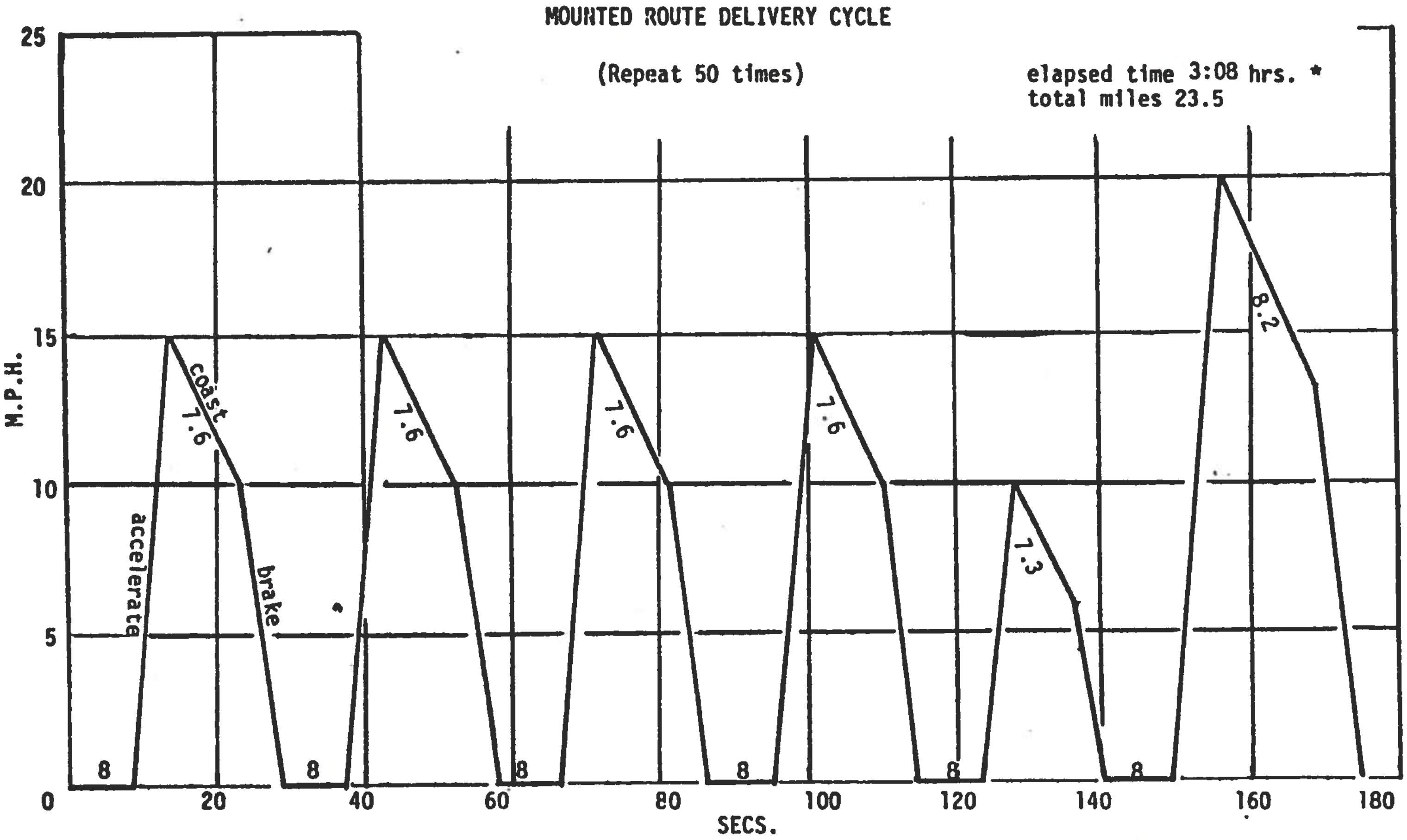
- Four 15 x 5.5 K rims

Cargo Space

- 60 cu. ft.

All specifications subject to change without notice.

Source: Ref. 11.



3 min. stop at each 40th stop
30 min. stop at 150th stop
30 MPH for 1/2 mile at stop 280

* Exclusive of lunch stop

Source: Ref. 11.

Figure 2-5. U.S. Postal Service Driving Cycle

TABLE 2-6. LOCATION OF ELECTRIC JEEPS PURCHASED BY U.S. POSTAL SERVICE

Location	Number of Vehicles
San Bernadino, Calif	295
Falls Church, VA	10
Cherry Hill, NJ	10
Charleston, S.C.	10
Evansville, IND	10
Decatur, ILL	5
Hartford, CONN	5
New Haven, CONN	5

Source: Ref. 13.

TABLE 2-7. CHARACTERISTICS OF BATTRONIC ELECTRIC VAN USED IN THE ELECTRIC VEHICLE COUNCIL TEST PROGRAM

HEIGHT	92 IN
WIDTH	78 IN
LENGTH, OVERALL,	145 IN
WHEELBASE	94.5 in
LOADSPACE DIMENSIONS	
LENGTH	71 IN
WIDTH	69.5 IN
HEIGHT	63.4 IN
VOLUME	161 CU FT
VEHICLE CURB WEIGHT:	5600 lbs
PAYLOAD	800 lbs
GROSS VEHICLE WEIGHT	6400 lbs
BATTERY:	
WEIGHT	2000 lbs
TYPE:	DUAL MODULE INDUSTRIAL BATTERY 300 AH at 6 HR RATE
MOTOR:	112 VOLT, 42 HP DC SERIES WOUND TRACTION MOTOR

Source: Ref. 14.

3.0 ENERGY UTILIZATION EFFICIENCIES OF FUEL-CONSUMING AND ELECTRIC VEHICLES

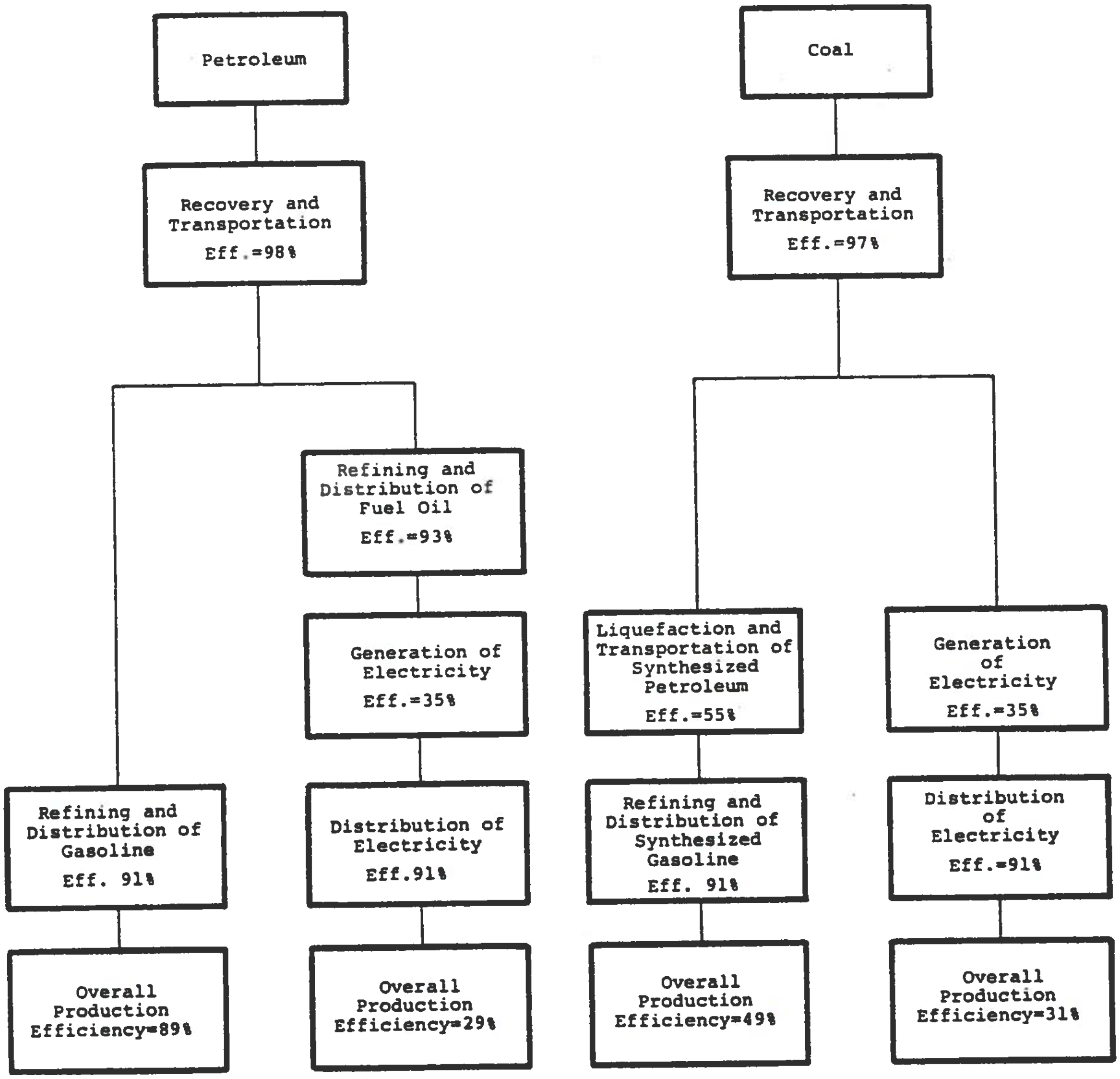
3.1 INTRODUCTION

In this Chapter, the overall system efficiencies are considered for converting the energy originally available in fossil fuel in the ground to vehicle propulsion energy for fuel-consuming and electric vehicles.

In order to determine the relative energy utilization efficiencies of electric vehicles and fuel-consuming vehicles powered by internal combustion engines (ICE), it is necessary to examine, in each case, the fraction of the energy originally available in the primary fuel source, as found in nature, that is ultimately used to drive the vehicle on the road. This involves an examination of the relative efficiencies of alternate fuel manufacturing processes as well as the on-board efficiencies of the two types of vehicle. A comparison of the energy conversion of electricity drawn from the plug for the electric vehicle to that of gasoline at the pump for the fuel-consuming vehicle is not sufficient, for reasons which are discussed in the following subsections.

3.2 ENERGY UTILIZATION EFFICIENCY OF ALTERNATE FUEL PRODUCTION

Fossil fuels can be used to produce either gasoline or electricity, the alternate power sources of ICE-powered and electric cars. The comparisons in this discussion will be limited to the production of gasoline or of electricity from either crude oil or coal as outlined in Figure 3-1 because of the relevance for the time period before 1990. In general, relatively little energy, compared to the contained energy, is required to recover, transport, refine and distribute the various fossil fuel products that are the practical sources of energy in our society. Based on figures commonly quoted in the literature[15,16,17], it is estimated that:



Source: Ref. 17

Figure 3-1. Production Efficiency Comparisons of Gasoline and Electricity

a) The gasoline pumped into the fuel tank of an automobile contains 89% of the energy associated with the crude oil from which it was derived,

b) Fuel oil delivered to a power plant contains approximately 91% of energy content of its crude oil. This assumes that gasoline refining and distribution losses are greater than those involved in the production of fuel oil,

c) Only 3% of the energy content of coal is required to mine, process and ship it to a power plant. The coal fed to the furnaces of a power plant or to a synthetic gasoline plant contains 97% of its original energy.

d) The synthesis of gasoline from coal is a fairly inefficient process. The production of synthetic gasoline from coal is accomplished at the cost of nearly 40% of the energy content of the coal. With additional losses in refining and distribution, synthetic gasoline at the pump contains 49% of the energy originally contained in the coal.

e) The combustion of fuel to generate electricity is a fairly inefficient process. While some modern steam power plants have efficiencies approaching 40%, the U.S. national average efficiency, including nuclear plants, is only of the order of about 35%.[15] Due to losses in the transmission and distribution of electricity from the power plant to the consumer, 91% of the generated electricity is available for consumption. As shown in Figure 3-1, about 30% of the original energy content of a fossil fuel (either coal or oil) is available to the consumer in the form of electrical energy.

In comparing gasoline and delivered electricity, one notes that a given quantity of energy in the form of gasoline from petroleum required significantly less original fuel than the equivalent quantity of energy in the form of electricity, or in the form of gasoline derived from coal.

3.3 ENERGY COMPARISON OF GASOLINE AND ELECTRICITY AS VEHICLE FUELS

The above discussion establishes a basis for comparing the energy contents of gasoline pumped into the tank of an ICE-powered vehicle and electricity used to charge an electric vehicle.

Since a given amount of fossil fuel in the ground can be converted to either gasoline or electricity, the equivalence is based on the relative production efficiencies of these alternate vehicle fuels as delivered to the user.

Referring to Figure 3-1, approximately 3.3 kW-hr of fossil fuel energy, either as coal or petroleum, are required to produce 1 kW-hr of electricity. This same fossil fuel could have been used to produce gasoline. Petroleum with an energy content of 3.3 kW-hr could have also been used to produce gasoline with an energy content of 3.0 kW-hr. If coal were used to synthesize gasoline, coal with an energy of 3.3 kW-hr could have been used to produce gasoline with an energy content of 1.63 kW-hr. Since gasoline has a heating value of 125,000 Btu/gallon, and 1 kW-hr $\equiv$ 3413 Btu, one kilowatt hour of electricty corresponds to 0.080 gallons of gasoline derived from petroleum or to 0.044 gallons of gasoline derived from coal on an energy equivalency basis.

These ratios were used to prepare the energy economy equivalency lines presented in Figure 3-2. For example, 25 miles per gallon is equivalent to an electric energy economy of 2 miles per kilowatt hour, if gasoline is obtained from petroleum. However, if gasoline is obtained from coal, 25 mpg is equivalent to an electric energy economy of 1.12 mi/kW-hr. This is because of the energy losses incurred in synthesizing gasoline from coal.

3.4 VEHICLE ENERGY UTILIZATION EFFICIENCIES

The energy utilization efficiencies of ICE-powered and electric vehicles are summarized in Figures 3-3 and 3-4. As shown in these figures, there are energy losses associated with each part of the propulsion system and drivetrain. In the case of the electric vehicle, the propulsion system is considered to include the battery

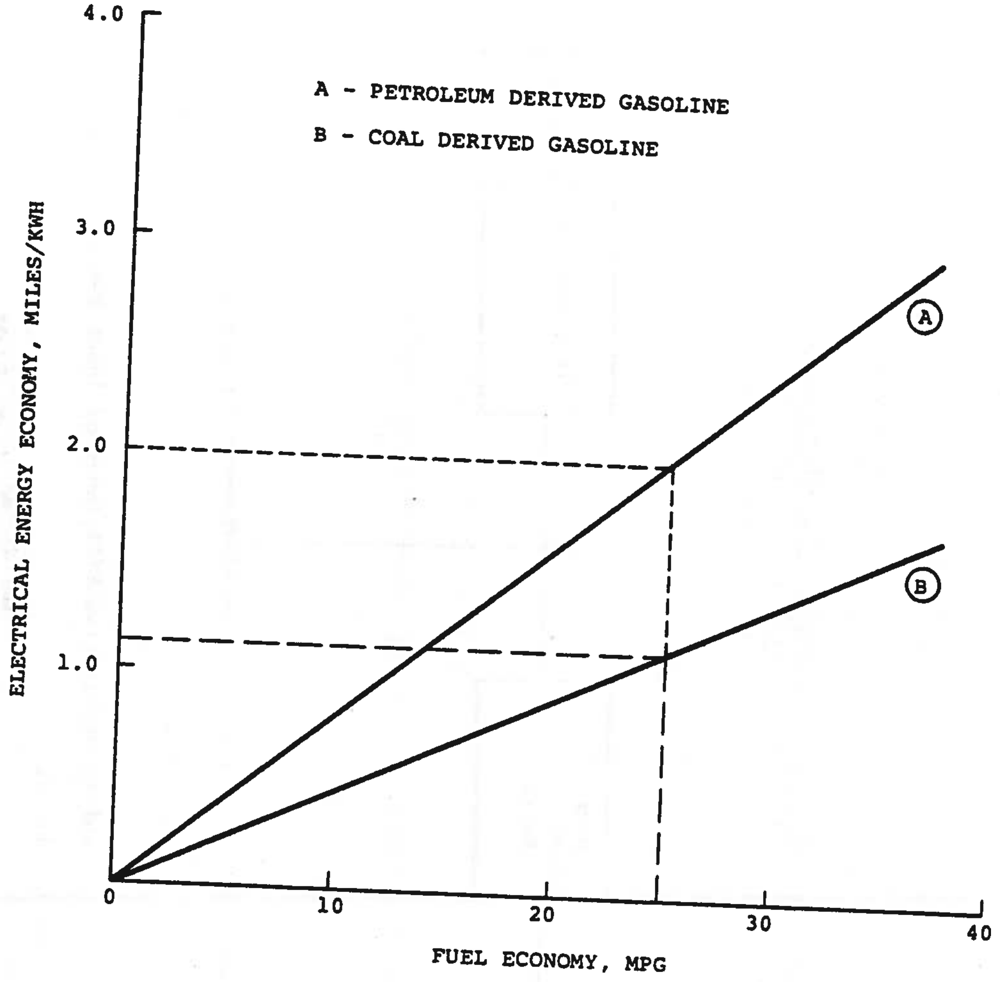
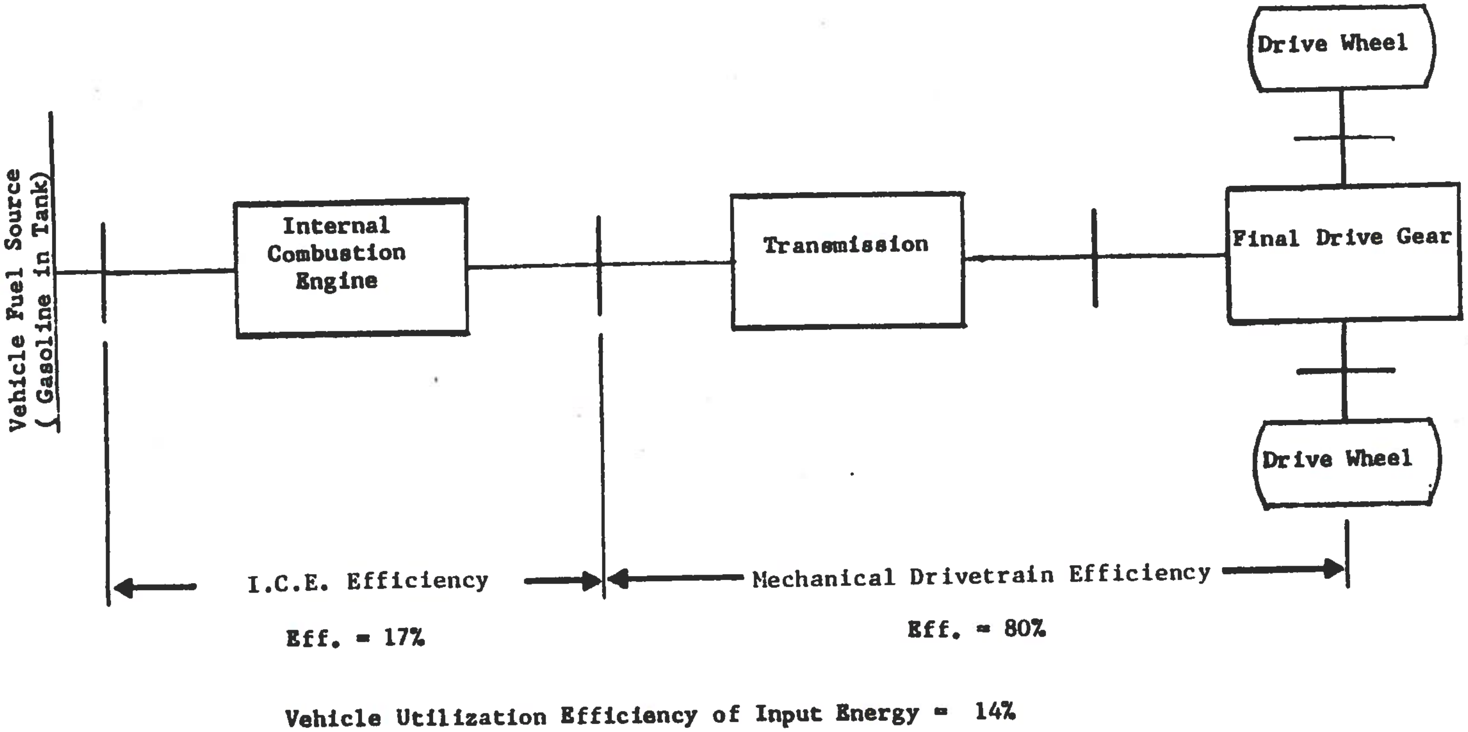
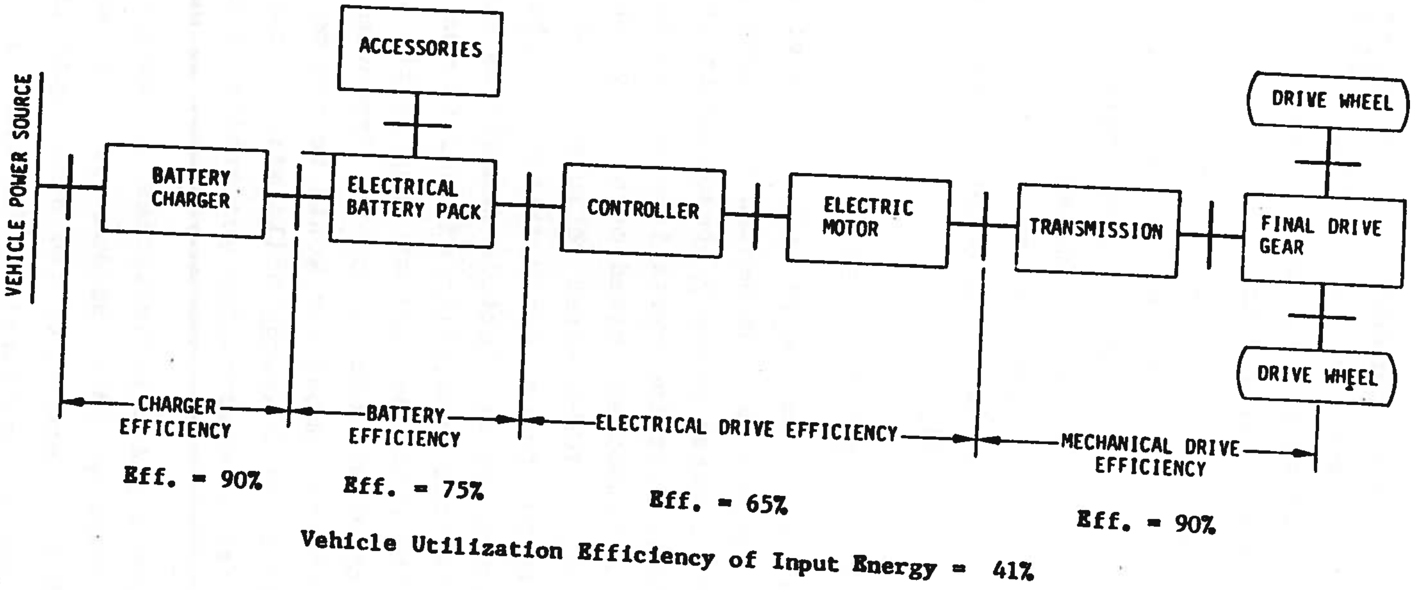


Figure 3-2. Comparison of Equivalent Energy Economies of Gasoline and Electrically Powered Vehicles



Source: Refs. 16,20

Figure 3-3. Propulsion System Energy Utilization Efficiency of the Internal Combustion Car



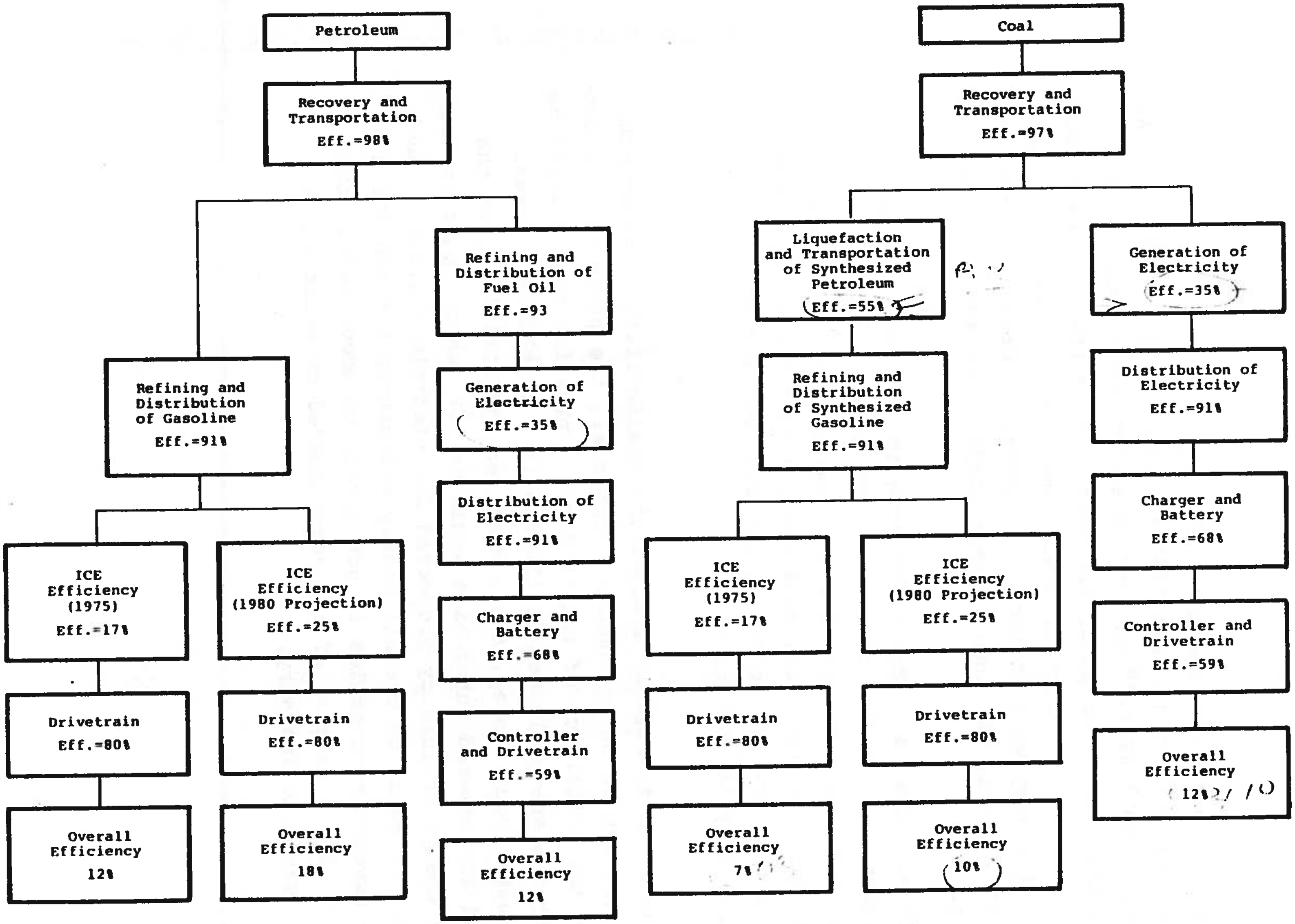
Source: Refs. 15,16,19

Figure 3-4. Propulsion System Energy Utilization Efficiency of the Electric Car charger which need not be on board the vehicle. The assigned efficiency values are representative of values quoted in the literature for average driving conditions.[15,16,19] As shown in Figure 3-4, approximately 41% of the electric power drawn into the battery charger is utilized to drive the vehicle.

The equivalent diagram for an ICE powered vehicle is presented in Figure 3-3. The ICE drive efficiency is representative of values of state-of-the-art engines obtained by Malliaris.[20] The value of the drivetrain efficiency is that assigned by Salihi.[16] As shown in the diagram, (Fig. 3-3) about 14% of the energy content of the fuel (gasoline) in an ICE powered vehicle is utilized effectively.

3.5 OVERALL SYSTEM EFFICIENCIES

The overall system energy utilization efficiencies for ICE and electric vehicles are presented in Figure 3-5 which melds the results of the figures already presented in this section. This figure indicates that the overall energy utilization of electric and gasoline automobiles, based on primary fuels are very similar. In the case of the ICE-powered vehicles, fuel production is efficient on an energy basis, but operation of the vehicle is inefficient. Operation of an electric vehicle is more efficient than an ICE vehicle, but production of fuel is much less efficient. In both cases, the most inefficient step is the combustion of a hydrocarbon to obtain motive power. Improvement in the energy utilization of the combustion would be the most effective means of improving the overall energy utilization efficiency of either system. As far as electricity generation is concerned, it is doubtful that advanced power cycles such as MHD, that offer the promise of power plant efficiencies of about 60%, will be commercially on stream by 1985. Because of this, and because of the already high efficiencies of the other operations in the system, the overall energy utilization efficiency for electric vehicles is not expected to change significantly within the next 10 years. On the other hand, significant improvements in the energy utilization efficiency of ICE powered automobiles are expected between now



Source: Refs. 15,16,17,19,20

Figure 3-5. Overall Energy Conversion Efficiency for Automotive Vehicles and 1985. These improvements in fact will be required if ICE-powered vehicles are to meet 1985 Federal energy guidelines. As outlined by Malliaris,[20] an average energy efficiency of about 25% (an improvement of about 50% over what is now achieved) could be realistically obtained by evolutionary development. If this energy efficiency were to occur, an overall system efficiency of about 18% would be obtained. These projections are also shown in Figure 3-5.

Thus, there is little difference in the overall energy utilization efficiencies of present ICE powered vehicles and electric vehicles. Technical improvements expected within the next 10 years probably will have small impact on the energy utilization efficiency of future ICE powered vehicles compared to those presently in operation

The above discussion assumes the availability of petroleum. If gasoline has to be synthesized from coal, the projected improvements in the efficiency of the internal combustion engine would be offset by the energy losses in the gasoline synthesis process. Under these circumstances, the overall energy efficiency of the projected ICE powered automobile would be 10%, which would be less than the energy efficiency projected for electric vehicles. Such a reversal of relative overall energy efficiency between ICE and electric powered automobiles is not likely to occur before the end of the 1980's because of the years needed to establish a synthetic gasoline industry.

4.0 PRODUCTION OF ELECTRIC VEHICLES AND THEIR INTRODUCTION INTO COMMERCE

4.1 INTRODUCTION

The U.S. electric vehicle industry is now in a formative stage. A few domestic firms are producing small numbers of on-the-road electric vehicles. Complete data are unavailable, but current sales probably are in the order of one thousand vehicles per year.[21] The future growth of the industry and introduction of electric vehicles into commercial and private use will depend on a variety of factors: consumer acceptance, demand at different levels of performance and price, production costs and potential economies of scale, and availability of capital, among others. The fundamental issue, however, is quite simple: will there be adequate return on capital investments to achieve higher levels of production?

The scarcity of data on electric vehicles and their buyers, as well as uncertainties about the future availability and price of petroleum-based fuels, currently prevents a confident analysis of probable growth in the electric vehicle industry. But, it is clear that electric vehicles must compete with conventional vehicles while petroleum is available. Therefore, an assessment of the performance and cost characteristics of electric vehicles relative to those of petroleum-powered vehicles can provide an indication of potential growth in the industry.

To simplify the analysis, the functional attributes of electric vehicles relative to their competitors will be considered separately from cost characteristics. By focusing on the "representative" electric vehicle designs described in Chapter 2, probable consumer acceptance may be judged. First, consumer acceptance is judged in terms of the ability of electric vehicles to functionally replace conventional vehicles in actual use, without regard for costs. This assumption defines an approximate maximum potential market.

Then, constraints on electric vehicle penetration of this potential market, including ownership costs associated with the assumed set of functional attributes, are evaluated to estimate probable future production and sales levels.

It is assumed throughout that electric vehicles will compete with petroleum-powered vehicles in a market largely free of direct government intervention, and that petroleum-based fuels will remain available, although perhaps at higher prices than today. The importance of these assumptions will be discussed later in the evaluation.

4.2 POTENTIAL MARKETS FOR ELECTRIC VEHICLES

In comparing functional attributes, electric vehicles are clearly superior to conventional vehicles in exhaust emissions and noise of operation, and (except for the battery) appear likely to excel in durability. In contrast, their acceleration, cruising speed, and range are inferior to those of conventional vehicles with current or forseeable technology. Little is known about the importance consumers place on such attributes, but it seems possible that reduced noise, exhaust emissions, and maintenance costs might compensate for minor deficiencies in acceleration and cruising speed in typical driving.

Even in typical driving, however, electric vehicle range is sufficiently inferior to constrain market potential. As noted in Chapter 2, current lead-acid battery systems offer a nominal metropolitan driving range of 30-40 miles, while advanced batteries might extend this to 150 miles by 1985. These nominal figures can be significantly reduced by modest hills, cold weather, slippery road conditions, under-inflated tires, and battery deterioration. While nominal range estimates will be used in this analysis, the optimism implicit in these estimates should be recognized.

Coupled with range limitations is the problem of battery recharging. Since effective recharging takes a minimum of several hours, on the road "refueling" in the fashion of conventional cars is virtually impossible. Initially, at least, electric vehicle owners will have to recharge their own battery systems with private electrical facilities. The most frequently envisioned procedure is overnight recharging during periods of off-peak electricity loads.

Under such a scenario, the market for electric vehicles would be limited to:

- replacement for vehicles driven less than the electric vehicle range on a daily basis, and
- users having off-street parking and electrical facilities available.

In this context, two separate market components may be evaluated, secondary passenger automobiles and light duty commercial fleet vehicles.

a. Private Automobiles

Although private passenger automobiles are driven only some 30-35 miles per day on the average, their daily mileage exceeds this amount a significant fraction of the time.[22] Lead-acid battery powered electric vehicles, therefore, could largely satisfy the average demand for mobility, but there would be no additional range capacity for frequent travel requirements in excess of the average. To surmount this problem, it is usually assumed that electric vehicles would replace only secondary cars in multi-car households. The primary ICE-powered auto could then be used for longer trips when necessary.

Restriction of the market to secondary cars, however, is insufficent by itself. Occasionally, all the drivers in a household will simultaneously have daily travel requirements in excess of the electric vehicles's range. The driver of the electric vehicle would then have to change modes or give up a long trip. The extent to which such an inconvenience might be tolerated would depend on frequency of occurrence as well as on any benefits the electric vehicle could offer in return.

Finally, households operating electric vehicles would require off-street parking allowing installation of private recharging facilities. This would currently eliminate most households in multi-family dwellings, leaving households in single-family homes with off-street parking and owning two or more cars as the principal market.

There are insufficient data on the national level to permit a detailed analysis of this market. A study of the Los Angeles region,[23] however, found that 28 percent of area households fell into the above category. Assuming that drivers of electric vehicles would be willing to give up long trips or change their mode of transportation one day out of every 20, the study found that 17 percent of the region's cars could be replaced by lead-acid battery electric cars.

The same fractions appear to hold approximately true for the nation as a whole. Some 30 percent of U.S. households own secondary cars,[24] while there are about 50 million single-family residences in the nation.[25] Thus, around 15 million households are initial candidates for electric vehicle ownership. Assuming a 12-year vehicle life, this implies a maximum steady-state demand of 1.3 million electric vehicles per year.

In the longer term, if advanced battery systems and additional recharging facilities become available, the maximum market potential for electric vehicles would clearly grow. Even with ranges of 100-150 miles, however, electric vehicles would remain incapable of satisfying all trip requirements. But, assuming that all secondary cars could be replaced, some 31 percent of the fleet, or about 30 million vehicles, would represent the potential market. This implies a steady-state annual demand of 2.5 million vehicles.

b. Light Duty Commercial Vehicles

The potential market for electric vehicles in commercial uses is much smaller. Unfortunately, the lack of data on duty cycles of such vehicles and the size of the total fleet make even a rough approximation of this market difficult.

Of the 14 million light trucks and vans on the road in 1972, 55 percent were used for personal transportation.[26] It is assumed, however, that trucks were chosen over automobiles for this purpose because of more strenuous load requirements and driving cycles, so electric vehicles are likely to be poor candidates for replacement, at least in the next decade. An additional 27 percent of the fleet was used for applications in agriculture, manufacturing, mining, etc.

The remaining 2.5 million light duty trucks and vans were used in wholesale and retail trade, utilities, services, and other applications which may involve relatively constant duty cycles covering short distances on a daily basis. Of particular interest are multi-stop delivery vans whose duty cycles comprise gentle acceleration, low cruising speeds, and frequent idling periods. Such driving conditions preclude long daily travel distances, while severely reducing the fuel economy and durability of conventional vehicles. In addition, commercial fleet owners could provide recharging facilities with relative ease because of the more efficient scale of operation.

Unfortunately, the number of vehicles currently driven over multi-stop cycles is unknown. The 2.5 million vehicles remaining after apparently strenuous uses are excluded represent an optimistic estimate of market potential. Based on the Postal Service goal of a ten-year life for their electric vans, this translates to a steady-state demand of 250 thousand vehicles in annual sales. Since range is a minor factor for multi-stop delivery vehicles, advanced battery technology should not significantly increase market potential.

4.3 CONSTRAINTS ON MARKET PENETRATION

The above estimates of potential electric vehicle markets, annual sales of 1.3-2.5 million passenger automobiles and 250 thousand commercial vehicles, represent no more than approximate upper boundaries. Clearly, financial or other incentives could induce at least some households and businesses to restructure their driving patterns in conformance with electric vehicle capabilities, increasing market size. On the other hand, the choice of electric vehicles, even by consumers with minimal travel requirements, entails a loss of mobility for which they will demand compensation.

Manufacturing and ownership costs of electric vehicles are, therefore, the principal constraints on market penetration. Only if electric vehicles offered significant cost savings could they be expected to approach their market potential. Manufacturing costs, however, depend on production quantities and whether economies of scale can be achieved. In addition, the establishment of an infrastructure to support electric vehicle owners might stimulate market penetration or increase market size. Thus, availability of capital to electric vehicle manufacturers is a possible longer-term constraint.

a. Current Production and Ownership Costs

Estimates of current production costs, retail prices, and overall life-cycle ownership costs are summarized in Tables 4-1 and 4-2 for electric automobiles and light duty vans. Each table contains a comparison with an equivalent conventional ICE-powered vehicle. The derivation of these estimates is discussed in detail in Appendices B through G and I.

As Table 4-1 indicates, the production cost of electric automobiles (limited production) is higher than the retail price of equivalent ICE automobiles. Electric cars are about three times as expensive initially. On a life-cycle basis, despite some possible savings in direct operating costs, electric cars are estimated to be 70-120 percent more expensive. The assumption that batteries will have to be replaced after three years (30,000 miles) significantly adds to total life-cycle costs. The development of a long life battery, if achieved, could substantially reduce the cost.

Electric vans in commercial fleets, Table 4-2, are potentially much more competitive, even in limited production. Although the initial price is twice that of ICE vans, significant savings are possible in direct operating costs. In addition, electric vehicles have an expected 10 year life while ICE vans have an average 6 year life. As a result, overall operating costs are more nearly equal. It should be noted, however, that this result is based on the

TABLE 4-1. ESTIMATED COST COMPARISON OF MASS PRODUCED ICE VHIELCES AND ELECTRIC VEHICLES IN LIMITED PRODUCTION

	MANUFACTURING COST $	RETAIL PRICE, $	LIFE CYCLE OPERATING COSTS (CENTS/MILE)	
			COST OF FUEL (1)	TOTAL OPERATING COST
I C E VEHICLE	1,955	3.900	1.87	16.3
ELECTRIC VEHICLE				
LEAD-ACID	4,570	9,150	2.53	27.8
NICKEL-ZINC	5,670	11,350	1.63	35.5
LITHIUM/ALUMINUM-IRON SULFIDE	5,080	10,150	1.44	28.4

NOTE (1) ELECTRICITY 3.2¢/kW-hr
GASOLINE 40¢/Gallon (excluding taxes)
(2) All costs in December 1975 dollars

TABLE 4-2. ESTIMATED COST COMPARISON OF MASS PRODUCED ICE AND LIMITED PRODUCTION ELECTRIC LIGHT DELIVERY VANS IN FLEET USE

	ELECTRIC VAN (LEAD-ACID/BATTERY)	ICE VAN
ESTIMATED MANUFACTURING COST, $	4,367	2,077
ESTIMATED FLEET ACQUISITION PRICE, $	6,315	3,211
ESTIMATED LIFE CYCLE OPERATING COSTS (CENTS/MILE)		
COST OF FUEL (1)	4.5	5.1
TOTAL OPERATING COST	42.4	35.2

NOTE (1) ELECTRICITY 3.2¢/kW-hr

GASOLINE 40¢/gallon (excluding taxes)

(2) All costs in December 1975 dollars.

extremely limited and unvariable duty cycle of postal Service vehicles and unproven expectations of electric vehicle durability.

b. Availability of Capital and Mass Production Cost Estimates

Lack of investment capital by manufacturers might constrain the market penetration of electric vehicles if it prevented achievement of competitive ownership costs or establishment of important service infrastructures. To assess the constraining influence of capital availability, however, it is necessary to determine whether economies of scale or service infrastructures could make electric vehicles significantly more competitive with ICE vehicles.

Estimates of mass production initial prices and ownership costs of electric vehicles are summarized in Tables 4-3 and 4-4. To provide an optimistic comparison with ICE vehicles, the tables assume that gasoline prices will rise to 70 cents per gallon, excluding taxes, while electricity rates remain constant. Details of the economic projections are described in Appendices C, E and F.

Despite 40 percent reductions in manufacturing costs for electric automobiles from the limited production case, estimated mass production retail prices still are 40-70 percent higher, and the life-cycle costs are 8-37 percent higher than they are for equivalent ICE vehicles. Increases in battery life and/or large cost reductions for components would make the electric automobile more competitive.

Mass production of electric vans, on the other hand, could decrease their estimated life-cycle costs well below those for ICE vans. Thus, if mass production could be achieved, electric vans would be an attractive alternative to ICE vans for commerical multi-stop applications.

Based on these cost estimates, it appears, that investments to achieve mass production of electric automobiles would be unwarranted by the available cost reductions. Even with full economies of scale, electric cars could not effectively compete with conventional autos. For electric vans, economies of scale could

TABLE 4-3 ESTIMATED COST COMPARISON OF ICE VEHICLE AND ELECTRIC VEHICLES ON A MASS PRODUCED BASIS

	ESTIMATED MANUFACTURING COST $	ESTIMATED RETAIL PRICE, $	ESTIMATED LIFE CYCLE OPERATING COSTS (CENTS/MILE)	
			COST OF FUEL (1)	TOTAL OPERATING COST
ICE VEHICLE	1,955	3,900	3.27	17.7
ELECTRIC VEHICLE				
LEAD-ACID	2,720	5,400	2.53	21.1
NICKEL-ZINC	3,280	6,500	1.63	24.3
LITHIUM/ALUMINUM-IRON SULFIDE	2,840	5,700	1.44	19.2

NOTE (1) ELECTRICITY 3.2¢/kW-hr

GASOLINE 70¢/gallon (excluding taxes)

(2) All costs in December 1975 dollars.

TABLE 4-4. ESTIMATED COST COMPARISON OF MASS PRODUCED LIGHT DELIVERY VANS IN FLEET USE

	ELECTRIC VAN (LEAD/ACID BATTERY	ICE VAN
Estimated Manufacturing Cost, $	2,610	2,077
Estimated Fleet Acquisition Price, $	4,200	3,211
ESTIMATED LIFE CYCLE OPERATING COSTS (cents/mile)		
Cost of Fuel (1)	4.5	8.8
Total Operating Cost	30.9	39.0

NOTE (1) ELECTRICITY 3.2¢/kW-hr
Gasoline 70¢/gallon (excluding taxes)
(2) All costs in December 1975 dollars.

make a considerable difference in competitiveness. The potential market, however, does not appear large enough to support mass production. At a sales level of 250 thousand vehicles per year, only one mass production line could operate. Thus a single manufacturer would have to monopolize the market and reach a market penetration of 100 percent before mass production would be feasible.

In addition to production capacity expansions, the electric vehicle industry might require capital for establishing service infrastructures in support of owners. The most important potential infrastructure service is "refueling". If electric cars could be recharged on the road in the same way that conventional cars fill up with gasoline, the problem of range limitation could be reduced. Some form of battery leasing system in which depleted battery packs are traded for newly charged packs seems most likely to achieve consumer acceptance. Such an infrastructure would require substantial capital investments. Battery stations would have to be constructed, equipped with specialized electrical facilities, and stocked with a large inventory of battery packs, each worth from $1,000 to $2,000. The use of battery swapping facilities, however, probably would increase fuel costs for electric vehicle owners and make the overall cost of ownership even less attractive than the preceding estimates. Thus, a recharging infrastructure probably would not stimulate sales of the electric vehicles, and lack of capital to invest in such an infrastructure cannot be viewed as a major constraint on industry growth.

Maintenance and repairs are additional services requiring some form of infrastructure to support vehicle owners. A selling point of electric vehicles, however, is their very low level of required maintenance and their durability. Thus, vehicle manufacturers should be able to offer maintenance instructions and assistance through dealerships, like conventional auto companies, with no major additional capital investments required.

4.4 PROBABLE GROWTH OF THE ELECTRIC VEHICLE INDUSTRY

The outlook for major growth in production and use of electric vehicles as private passenger automobiles is rather bleak. Although they have a considerable potential market, even with limited range, their estimated life-cycle costs of ownership are non-competitive with conventional ICE-powered automobile. Even the scale economies of mass production would not eliminate the excess life-cycle costs of electric vehicles, so, capital availability cannot be viewed as a serious problem. Further, it seems unlikely that advanced battery technology will provide significant cost advantages in the next 10 years based upon developers cost estimates. For these reasons, therefore, it is difficult to imagine that the electric automobile market in the next 10 years will exceed a few thousand vehicles per year.

For electric vehicles in commerical use, the prospects are still uncertain, but may be promising. Over multi-stop delivery cycles comprising large percentages of idling and low speed driving, the estimated life-cycle costs of electric vehicles are comparable to ICE vehicles. If mass production could be achieved, electric vehicles might offer major cost advantages. Unfortunately, the number of vehicles driven over such duty cycles is currently unknown. It is not known whether the market is large enough to support mass production, although the projected cost reductions of 15-25 percent over conventional vehicles could conceivably induce additional commercial users to restructure their driving patterns to match electric vehicle capabilities. In any case, commerical acceptance would occur slowly and grow only if electric vehicles demonstrate their hypothetical advantages in actual use.

Obviously, the situation could change if the availability of petroleum-based fuels were drastically reduced. Also, the situation could change if the Federal Government were to intervene in the market. Indeed, government encouragement of the electric vehicle industry could act as an insurance policy against complete dependence on largely imported petroleum-based fuels. The disparity in costs between electric vehicles and conventional vehicles, however, implies that major subsidies or new gasoline taxes would be required to stimulate any significant use of electric passenger automobiles so long as petroleum is available. Such an insurance policy, therefore, would require high premiums.

5.0 APPLICATION OF THE ACT TO ELECTRIC VEHICLES

5.1 INTRODUCTION

Title III of the Energy Policy and Conservation Act establishes a Federal program to regulate the fuel economy of passenger and nonpassenger automobiles. This chapter reviews the implications for electric vehicles and their manufacturers if electric vehicles were made subject to this program.

5.2 SUMMARY OF THE ACT

Title III of the Energy Policy and Conservation Act[a] amends the Motor Vehicle Information and Cost Savings Act to add a new title, "Improving Automotive Efficiency." The provisions of this title establish average fuel economy standards applicable to manufacturers of passenger automobiles[b] and authorize the Secretary of Transportation to set average fuel economy standards applicable to manufacturers of nonpassenger automobiles.[c] An "average fuel economy standard" is a performance standard specifying a minimum average fuel economy (in miles per gallon) which an automobile manufacturer's output must achieve in a model year.[d]

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[a] P.L. 94-163, 89 Stat. 871, 1975 U.S. Code Cong. & Ad. News 871.

[b] §301 of the Energy Policy and Conservation Act, P.L. 94-163, adding §502(a) (15 U.S.C.§2002(a)) to the Motor Vehicle Information and Cost Savings Act (15 U.S.C.§§1901 et seq.). Citations herein refer to the added sections of the latter act.

[c] §502(b), 15 U.S.C. §2002(b).

[d] §501(7), 15 U.S.C. §2001(7). "Fuel economy" is defined in Title III as "the average number of miles traveled by an automobile per gallon of gasoline (or equivalent amount of other fuel) consumed, as determined by the EPA Administrator in accordance with procedures established under Section 503(d)." § 501(b), 15 U.S.C. §2001(b) (emphasis added). Section 503(d), referred to in the above definition, directs the EPA Administrator to develop fuel economy test and calculation procedures, and to "determine that quantity of any other fuel which is the equivalent of one gallon of gasoline." § 503(d)(2), 15 U.S.C. §2003(d)(2). The conference committee's report states that "It is anticipated that the EPA

Title III specifies the average fuel economy standard for passenger automobiles applicable in model year 1978 (18.0 mpg), 1979 (19.0 mpg), 1980 (20.0 mpg), and 1985 and thereafter (27.5 mpg).[e] The Secretary of Transportation is directed to establish passenger automobile average fuel economy standards for model years 1981 through 1984,[f] and to establish standards for nonpassenger automobiles.[g] Average fuel economy standards are to be set at the maximum feasible average fuel economy level[h] considering technological feasibility, economic practicability, the effects of other motor vehicle standards on fuel economy, and the nation's need to conserve energy.[i] An "automobile" is defined in Title III as a 4-wheeled highway vehicle propelled by fuel which either: (a) is rated at up to 6,000 lbs. gross vehicle weight; or (b) (i) is rated at between 6-10,000 lbs. gross vehicle weight, (ii) is of a type for which standards are feasible, and (iii) either is of a type such that the application of fuel economy standards will result in significant energy conservation, or is of a type used for the same purposes as are vehicles in the 0-6,000 lbs. gross vehicle weight category.[j] "Fuel" as used in the above definition means gasoline or diesel oil, and may include other liquid or gaseous fuels if the Secretary determines that their inclusion is consistent with

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d(cont'd)
Administrator, in determining equivalent amount of other fuel, will make such determination on the basis of Btu equivalency of different quantities of various fuels, taking into account energy required to process such fuels." S. Rep. No. 516, 94th Cong., 1st Sess. 154 (1975).

[e] §502(a)(1), 15 U.S.C. §2002(a)(1).

[f] §502(a)(3), 15 U.S.C. §2002(a)(3). Such standards are to be set at the maximum feasible average fuel economy level and are to result in steady progress toward the 1985 standards.

[g] §502(b), 15 U.S.C. §2002(b). These standards are to apply to nonpassenger automobiles manufactured in model years beginning 30 months after enactment (Dec. 22, 1975).

[h] §502(a)(3), 15 U.S.C. §2002(a)(3) (passenger automobiles); §502 (b), 15 U.S.C. §2002(b) (nonpassenger automobiles).

[i] §502(e), 15 U.S.C. §2002(e).

[j] §501(1), 15 U.S.C. §2001(1).

the need to conserve energy.[k] A "passenger automobile" is an automobile (with exceptions not relevant here) manufactured primarily for transporting not more than 10 persons.[l] Although "nonpassenger automobile" is not explicitly defined, by implication it includes any vehicle which otherwise falls within the definition of "automobile" and which is not a passenger automobile.[m]

Manufacturers of less than 10,000 passenger automobiles in a model year may apply to the Secretary of Transportation for exemption from that model year's passenger automobile average fuel economy standard. If the Secretary issues such exemptions, he must also prescribe alternative average fuel economy standards for exempted manufacturers.[n] Manufacturers may also apply to the Secretary for modification of certain passenger automobile average fuel economy standards based on changes in emission, safety, noise, and property loss reduction standards from model year 1975 base year standards.[o]

A manufacturer of passenger (or nonpassenger) automobiles who fails to meet the average fuel economy standards applicable to it is liable for a civil penalty in the amount of five dollars for each tenth of a mile per gallon by which its average fuel economy fails to meet the standard, multiplied by the number of passenger (or nonpassenger) autos it manufactured during the

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[k] §501(5), 15 U.S.C. 2001(5).

[l] §501(2), 15 U.S.C. §2001(2). The term "passenger automobile" does not include automobiles "capable of off-highway operation," that is, any automobile which has a feature equipping it for off-highway operation (other than 4-wheel drive), and either is a 4-wheel drive auto or is rated at over 6,000 lbs. gross vehicle weight. §501(3), 15 U.S.C. §2001(3).

[m] The conference committee's report provides several illustrative examples of nonpassenger automobiles: certain light duty trucks, recreational vehicles, and other multipurpose vehicles. S. Rep. No. 516, 94th Cong., 1st Sess. 153 (1975).

[n] §502(c), 15 U.S.C. §2002(c).

[o] §502(d), 15 U.S.C. §2002(d)

model year.[p] A manufacturer whose average fuel economy exceeds the applicable standard in any model year is entitled to a similarly calculated financial credit to be applied against penalties imposed in the previous model year or which may be assessed in the following model year.[q] Civil penalties may be compromised by the Secretary of Transportation under certain specified circumstances.[r]

Title III of the Energy Policy and Conservation Act also imposes a labeling requirement on automobile manufacturers. Effective in the 1977 model year and thereafter, a manufacturer must affix on each automobile it produces a label which states that auto's fuel economy,[s] the estimated annual fuel cost associated with that auto's use, and the range of fuel economy available with comparable autos, whether or not produced by the same manufacturer.[t] Comparability of automobiles is to be determined by the EPA Administrator, and may be based on factors such as interior space or performance characteristics.[u]

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[p] §508, 15 U.S.C. §2008.

[q] §508(a)(3), 15 U.S.C. §2008(a)(3).

[r] §508(b)(3), 15 U.S.C. §2008(b)(3).

[s] The meaning of the term "fuel economy" as employed in Title III is discussed in note d, supra.

[t] §506(a), 15 U.S.C. §2006(a). The precise form and content of required labels is to be established by the EPA Administrator.

[u] S. Rep. No. 516, 94th Cong., 1st Sess. 158 (1975).

5.3 APPLICATION OF TITLE III OF THE ENERGY POLICY AND INFORMATION ACT TO ELECTRIC VEHICLES

To bring electric vehicles within the scope of Title III, it would be necessary to expand the meaning of the term "fuel" as used in Title III to include electric energy. Manufacturers of electric automobiles whose vehicles otherwise fit Title III's definition of "automobile"[v] would then become subject to the same passenger or nonpassenger fuel economy standards now applicable to manufacturers of gasoline- and diesel-powered automobiles.[w] In order to calculate the fuel economy of an electric automobile, the EPA Administrator must first determine how much electric power is equivalent to a gallon of gasoline.[x] While the analysis contained in this report makes this determination on the basis of overall energy equivalency of a quantity of electricity (in kilowatt-hours) with one gallon of gasoline,[y] the electricity-gasoline equivalency determination could also be based on petroleum equivalency, that is, the amount of petroleum actually used to generate a quantity of electricity. The latter approach assumes that it is the purpose of Title III to conserve only

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[v] Most (over 95%) electric vehicles now manufactured would not fit within the Act's definition of the term "automobile." These vehicles are either 3-wheeled, and/or are not manufactured for use on public streets and highways. See Appendix F.

[w] If electric automobiles were to be made subject to average fuel economy standards, an interesting question is presented as to how the performance capabilities of electric passenger autos should be considered in estalbishing interim (1981-84) passenger automobile average fuel economy standards (§502(a)(3), 15 U.S.C. §2002(a)(3), or in recommending a change in the 1985 passenger auto standard (§502(a)(4), 15 U.S.C. §2002(a)(4).

[x] §§ 501(6), 503(d)(2); 15 U.S.C. §§ 2001(6), 2003(d)(2).

[y] As observed earlier (see note d, supra), this approach is suggested in the report of the conference committee.

petroleum-based fuels,[z] and would take into consideration the fact that electricity is increasingly being generated by non-petroleum energy sources. Application of this approach would seem ultimately to require a difficult social policy decision balancing the desirability of petroleum consumption versus consumption of other energy sources.

Electric passenger automobile manufacturers producing fewer than 10,000 autos per model year would be eligible to apply for exemption from the average fuel economy standard generally applicable to makers of passenger automobiles.[aa] The Secretary may grant the

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[z] Several submissions to the public docket established in connection with this report assert that Title III of the Energy Policy and Conservation Act is concerned primarily with the conservation of petroleum-based fuels, rather than with achieving an overall reduction in automobile energy consumption, regardless of the type of fuel consumed. Under this suggested interpretation, the EPA Administrator would be required to determine the petroleum equivalency of the alternative fuel, that is, the amount of petroleum embodied in (either directly or in the production of) an alternative fuel, rather than the overall energy equivalency of an alternative fuel. This approach appears to ignore the intent of Congress as expressed (see note d, supra) in the conference committee's report: it would not consider the Btu equivalency of alternative fuels. That energy conservation rather than just petroleum conservation is the intent of the Congress is also indicated by the general statement of the Energy Policy and Conservation Act's purposes contained in § 2 of the Act. In stating the purposes relating to conservation, particularly with regard to automobiles, this section speaks of energy conservation, not just the conservation of petroleum:

> "The purposes of this Act are - ...
>
> "(4) to conserve energy supplies through energy conservation programs, and, where necessary, the regulation of certain energy uses;
>
> "(5) to provide for improved energy efficiency of motor vehicles, major appliances, and certain other consumer products;..."

[aa] To be eligible for this exemption, a manufacturer must have made fewer than 10,000 passenger automobiles in the second model year preceding the model year for which the exemption is sought, and must actually produce less than 10,000 vehicles in the model year for which the application is made. §502(c), 15 U.S.C. §2002(c).

exemption if he determines the otherwise-applicable standard "is more stringent than the maximum feasible average fuel economy level" the applicant can attain.[bb] The Secretary must then establish an alternative average fuel economy standard applicable to the exempted manufactuer. Instead of establishing a separate alternative standard for each electric passenger automobile manufacturer qualifying for exemption, the legislation permits the Secretary to establish an alternative standard applicable to entire "classes" of passenger automobiles. One possible class in this instance could be the class of all electrically-powered passenger autos.[cc] In any event, the alternative standard must be set at the maximum feasible fuel economy level for manufacturer(s) to which the standard applies.[dd]

Manufacturers of nonpassenger automobiles are not eligible for the less-than-10,000 vehicles-per-model-year exemption available to makers of passenger automobiles. Some flexibility is permitted to the Secretary of Transportation in establishing average fuel economy standards for nonpassenger automobiles, however, in that different standards may be set for different "classes" of nonpassenger automobiles.[ee] For example, this provision would permit

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[bb] §502(c), 15 U.S.C. §2002(c).

[cc] Neither the legislation (§502(c), 15 U.S.C. §2002(c)) nor the conference committee's report (S. Rep. No. 516, 94th Cong., 1st Sess.) provides guidance as to how classes of passenger automobiles are to be established. Defining such categories on the basis of common propulsion technology or common energy source, as proposed here, appears to be one of several alternative approaches. Classes could also be based on vehicle weight or passenger carrying capacity. Another classification scheme could focus on the function or use for which passenger vehicles are designed or to which they are put, e.g., taxicabs, minibuses, commuter use, etc.

[dd] §502(c), 15 U.S.C. §2002(c).

[ee] §502(b), 15 U.S.C. §2002(b).

establishment of an average fuel economy standard applicable to the entire class of electric nonpassenger automobiles (grouped together based on their common technology and common energy source). Alternatively, classes could be based on vehicle weight. Or, a series of separate fuel economy standards could be established, with each standard applicable to a specified functional class consisting of both electric and conventionally-powered nonpassenger automobiles.[ff] These classifications would be based on the functions or uses for which such nonpassenger automobiles are designed or to which they are put.[gg] Because of the relatively fuel-efficient performance of electrically-powered automobiles in urban stop-and-go delivery operations, a fuel economy standard applicable to nonpassenger automobiles in this functional category could be based on the electric vehicle's average fuel economy.[hh] Manufacturers of nonelectric nonpassenger automobiles competing within this functional class would then be forced either to improve the fuel economy of their vehicles to meet the standard or to pay any penalties which may be assessed for noncompliance.

Inclusion of electric vehicles as "automobiles" subject to Title III of the Energy Policy and Conservation Act would also bring electrics under the mandatory fuel economy labeling provision of this Title. To facilitate comparison of electric automobile

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[ff] "'Class' would be defined by the ST [Secretary of Transportation], and could be based on functional classifications or other factors." S. Rep. No. 516, 94th Cong., 1st Sess. 155 (1975).

[gg] The latter classification scheme could be accomplished by establishing representative driving cycles descriptive of typical nonpassenger automobile usage patterns.

[hh] This discussion assumes that nonpassenger automobiles are used for these functions. If passenger autos were put to this use, their manufacturers would still be required to meet the applicable passenger automobile fuel economy standards.

[ii] §506, 15 U.S.C. §2006. As an alternative to application of Title III's entire fuel economy regulatory scheme to electric automobiles and their manufacturers, it would seem possible to

fuel economy with the fuel economy of gasoline or diesel automobiles, an electric auto's label should probably state the electric's fuel economy both in miles per unit of electricity (kW-hr) and equivalent miles per gallon of gasoline.[jj] The required estimate of annual fuel cost in connection with an electric automobile's operation could be based on the average cost of electricity in the United States.[kk]

Several alternative approaches are available for selecting the autos whose respective fuel economies are to be compared with an electric automobile's fuel economy. Under one alternative, an electric auto could be compared with all other autos of similar size, carrying capacity, or weight, regardless of the kind of fuel used. Alternatively, an electric automobile could be compared only with other electric automobiles.[ll] As a third alternative

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ii (cont'd)
recast Title III such that only its labeling provisions were applicable to electric autos, perhaps on a voluntary basis. This alternative, which could be made generally applicable to other alternative-fueled automobiles as well as to electrics, would inform the public of the fuel economy performance of alternative-fueled automobiles yet would not subject manufacturers of such vehicles to the expense of extensive fuel economy testing or to the risk of financial penalties for noncompliance. While this alternative would still require fuel economy data, this information could be supplied by manufacturers of eligible automobiles in accordance with EPA procedures (comparable to procedures to be used for testing conventionally-powered autos), and perhaps spot-checked by EPA for accuracy.

[jj] See notes x-z and accompanying text, supra, discussing methods by which fuel economy of electric-powered automobiles can be determined.

[kk] Because electricity is not currently taxed as a motor fuel, a comparison of the annual fuel cost of an electric automobile with the fuel cost of a conventionally-fueled auto would favor the electric vehicle. This inequitable situation could be corrected with the institution of a tax on electricity used as a motor fuel set at a rate comparable to the present level of tax on petroleum-derived motor fuels.

[ll] These two options are derived from the conference report, which mentions the factors of "interior space" and "performance characteristics" as possible bases for selecting comparison vehicles. S. Rep. No. 516, 94th Cong., 1st Sess. 158 (1975).

functional usage categories could be established and comparisons made among all nonpassenger automobiles designed or used for the same function, regardless of the fuels used. As indicated earlier, the establishment of an urban delivery functional category could work to the benefit of electric nonpassenger autos because of their efficient performance in this type of operation relative to petroleum-powered autos.

6.0 CRITERIA FOR REGULATION OF ELECTRIC VEHICLES

6.1 INTRODUCTION

A decision to subject electric vehicles to average fuel economy standards should be based on concrete benefits which the standards would achieve. Any anticipated benefits must be weighed against the costs of regulation as well as the alternative consequences of omitting such standards.

The most important criterion for this decision is potential energy savings that regulation might achieve. The goal of the enabling legislation is, of course, energy conservation. Coupled with this broad objective is the more specific goal of reducing domestic petroleum consumption and national dependence on foreign oil.

Probable economic, environmental, and resource consumption impacts, however, must also be considered. Regulation could have both beneficial and adverse economic impacts on vehicle manufacturers, suppliers, and owners, as well as implications for the level and distribution of employment in the nation as a whole. Similarly, any changes in the level of electric vehicle use brought about by regulation conceivably could affect air quality and consumption of natural resources used in the construction of the vehicles.

To evaluate these factors and assess net benefits and costs of regulation, future levels of electric vehicles sales and use must be anticipated. Although Chapter 4 provides some general guidance in this effort, any quantitative forecasts must be viewed as highly uncertain. Nevertheless, some clear qualitative findings emerge.

6.2 CONSEQUENCES OF NOT REGULATING ELECTRIC VEHICLES

In the absence of fuel economy standards and labeling requirements, the electric vehicle industry would be subject to normal market forces in competition with petroleum-powered vehicles. As noted in Chapter 4, electric automobile ownership costs are substantially higher than their conventional competitors, and should greatly constrain their production and use, so it is difficult to imagine more than a small market with maximum annual sales of a few thousand units for electrically-powered private automobiles. Electric commercial vans are more competitive in costs but their potential market is limited and their capabilities are, as yet, largely unproven. In the next decade, therefore, total annual sales of electric vehicles should remain in the tens of thousands rather than hundreds of thousands or millions.

By comparison, the total U.S. fleet of passenger automobiles and light duty trucks now numbers about 110 million vehicles. Even if 100 thousand electric vehicles were sold every year through 1985, they would amount to less than one percent of the total fleet. Actual sales-volumes are almost certain to be much smaller. Placed in this context, evaluation of the impacts of electric vehicle production and use is greatly simplified.

Electric vehicles that are introduced will have energy efficiencies roughly comparable to the conventional vehicles they replace. As Chapter 3 indicated, however, fuel economy improvements mandated for petroleum-powered vehicles should make them substantially more efficient than electric vehicles. By 1985, individual electric vehicles probably will consume more energy than their conventional counterparts, but too few electric vehicles will be in use to significantly influence national energy consumption.

Individual electric vehicles will, nevertheless, consume far less petroleum than conventional vehicles, since a small fraction of U.S. electricity is generated with oil products. Again, however, national petroleum savings would be minor because of the relatively small number of electric vehicles in use.

TABLE 6-1. IMPACT OF ANNUAL PRODUCTION OF 100,000 ELECTRIC AUTOMOBILES ON DOMESTIC CONSUMPTION OF BATTERY MATERIALS

Battery System	Element	Metal Used* Per Battery (lbs.)	Total Use in Electric Car Production 10^3 Metric Tons/Year)	Electric Car Use** As % of 1974 Domestic Consumption
Lead-Acid	Lead (Pb)	855	38.9	3.1
	Antimony (Sn)	24	1.1	6.0
Nickel-Zinc	Nickel (Ni)	362	16.6	11.7
	Zinc (Zn)	262	12.0	1.1
	Copper (Cu)	11	0.5	-
Lithium-Iron Sulfide	Aluminum (Al)	101	4.6	0.1
	Lithium (Li)	41	1.9	123.
	Molybdenum (Mo)	63	2.9	6.9

*Source Ref 3

**Source Mining Annual Review, Mining Journal, June 1975

Nor would electric vehicles cause measurable changes in air quality in the U.S. The small transfer of pollutant emissions from mobile to stationary sources (i.e., power plants) would be largely self-cancelling. Furthermore, findings of recent studies[23] indicate that even if electric vehicles replaced the majority of conventional automobiles, concentrations of principal auto-related pollutants such as oxides of nitrogen and photochemical oxidants would decrease by only a few percentage points.

Consumption of some natural resources would change moderately as a result of the anticipated production level of electric vehicles. Material requirements, of course, will depend on the types of battery systems used in electric vehicles. Even at production levels of 100 thousand vehicles per year, only the lithium system would cause a significant increase in resource consumption. The U.S. demand for lithium would increase by about 125 percent on an annual basis. The absolute magnitude of this increase, however, is only about 6 tons per day of lithium production. The U.S. has sufficiently abundant reserves of lithium to satisfy such a requirement easily. More detailed estimates of material requirements and potential impacts on resource consumption are presented in Table 6-1.

Anticipated growth of the electric vehicle industry should have no impact on the national economy. Although minor employment dislocations may occur, jobs lost in the conventional auto industry will be largely replaced in the electric auto industry.

6.3 CONSEQUENCES OF REGULATING ELECTRIC VEHICLES

Regulating the fuel economy of electric vehicles would induce some changes in the preceding scenario. As discussed in Chapter 5.0, inclusion of electricity in the definition of "fuel" in Title III of the Energy Policy and Conservation Act would impose two requirements on manufacturers of electric automobiles: average fuel economy standards and labeling of fuel economy and fuel costs. The effect of these requirements will depend to some extent on how electric vehicle fuel economy is compared with fuel economy of petroleum-powered vehicles.

Fuel economy comparison on the basis of overall energy efficiency from primary source to final utilization in the vehicle was suggested in Chapter 3.0 as the most clear-cut and objective procedure. Such a comparison, however, will not account for differences in the "social value" of various primary energy sources--petroleum, coal, etc. If petroleum is viewed as a critical energy source, then fuel economy might be compared largely or solely on the basis of petroleum consumption, disregarding consumption of other primary energy supplies. Effects of both alternatives are considered below.

a. Average Fuel Economy Standards

If electric vehicle fuel economy were calculated on the basis of overall energy efficiency, then electrics would be hard pressed to match the mandated improvements of petroleum-powered competitors. Market impacts of the standards, however, would depend on the level of production reached in the electric vehicle industry.

As long as individual electric automobile manufacturers produce less than 10,000 vehicles per year, they can apply for exemptions from the generally applicable fuel economy standards. The Secretary of Transportation may then establish an alternative standard for electric vehicles based on best practicable electric vehicle technology.* Such a special class standard should have little if any impact on the electric vehicle industry. Since electric automobiles must compete with conventional automobiles, average fuel economy standards for the latter establish <u>de facto</u>

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*Basing the fuel economy standard for electric automobiles on best practicable electric vehicle technology would enable manufacturers of electrics to avoid penalties for noncompliance with the generally applicable standards. This is possible only at low production levels (i.e., 10,000 or less per year for a manufacturer). At higher production levels, the general standards would automatically apply.

goals for the former. Market forces, therefore, will compel manufacturers of electric vehicles to apply the best available electric vehicle technology with or without fuel economy standards.*

If individual manufacturers of electric automobiles reach production levels of 10,000 or more vehicles per year, however, the impact of fuel economy standards could be more severe. Such manufacturers would be subject to the fuel economy standards generally applicable to automobiles without the possibility of exemption. As these standards grow more stringent, electric automobile manufacturers would have to seek fuel economy improvements through vehicle weight reductions, in the same manner as the manufacturers of conventional automobiles. In electric vehicles, however, weight reduction can significantly decrease vehicle performance, most notably range, because most of the weight must come from the battery system. In a lead-acid battery powered electric, for example, a fuel economy equivalent to 23 mpg in metropolitan driving will permit a nominal range of some 50 miles. The range of the same vehicle would decrease to 40 miles in improving fuel economy to 27.5 mpg. Further, the sensitivity of electric vehicle range to fuel economy increases as higher fuel economy levels are sought.**

Requiring electric automobiles to meet the same average fuel economy standards as conventional automobiles would therefore reduce their already marginal competitiveness. Any electric vehicle manufacturers approaching production of 10,000 vehicles per year would have to weigh the implications of exceeding this

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*Even with best available technology, electric automobiles will be only marginally competitive. Use of less efficient technology would further reduce or eliminate the market for electrics.

**See Chapter 2.0 and Appendix A.

production level in terms of a reduction in market size or fuel economy-related civil penalties.* The application of such a fuel economy standard would serve as a disincentive to higher production levels.

If, on the other hand, electric vehicle fuel economy were calculated on the basis of petroleum consumption rather than overall energy efficiency, electric vehicles would easily pass the standards set through 1985. Since only about 20 percent of U.S. electricity is generated with petroleum products, this method of comparison would provide electric vehicles with an immediate five-fold advantage in fuel economy--they can travel well over 100 miles per gallon of petroleum consumed. Thus average fuel economy standards would be of little concern to manufacturers.

This method of fuel economy comparison, however, would not significantly alter future levels of electric vehicle production and use. If petroleum has greater importance than other energy sources, this is not reflected in market prices. No matter how electric vehicle fuel economy is calculated, their life-cycle costs would be unaffected. Automobile manufacturers would have a new incentive to sell electric vehicles, boosting their fleet-average fuel economy levels, but consumers should be no more inclined to purchase electric vehicles. While the persuasive power of a careful marketing strategy and well-funded advertising campaign might stimulate the market for electric vehicles, it could not eliminate the competitive disadvantages of electric passenger cars. Thus, no significant sales increases should result.

b. <u>Fuel Economy Labeling</u>

Including electric vehicles under the regulations of Title III would also establish requirements for manufacturers of electric vehicles to label their vehicles with respect to fuel economy,

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*Manufacturers could opt to pay civil penalties rather than reduce range. Low production volumes would reduce the magnitude of the penalty, and some portion of the penalty could be remitted to prevent insolvency, bankruptcy, or a substantial lessening of competition (15 U.S.C. 2008 (b)(3)).

annual fuel costs, and relative fuel economy levels of comparable vehicles. As Chapter 5.0 noted, there are several possible approaches to determining comparable vehicles, as well as comparing fuel economy.

Regardless of the method used for labeling, however, electric vehicles will retain the same competitive disadvantages in the market place. Even if fuel economy labels reflected the very low petroleum consumption of electric vehicles relative to conventional vehicles, the expected annual fuel costs, shown on the same labels, would reveal that electric vehicles offer little, if any, cost savings. The labeling requirement, therefore, should not affect consumer decisions.

6.4 SUMMARY

Overall, inclusion of electric vehicles under the fuel economy regulations of Title III clearly would have little if any stimulaing effect on the electric vehicle industry. On the contrary, costs to manufacturers for preparing and supplying test vehicles might adversely affect manufacturers. If electric vehicle fuel economy is calculated in terms of overall energy efficiency, manufacturers may face a trade-off between meeting fuel economy standards and decreasing the competitiveness of their vehicles. Calculating electric vehicle fuel economy on the basis of petroleum consumption would eliminate this trade-off, but would not offer electric vehicles any advantage in the marketplace.

On balance, then, regulation would probably be detrimental to the electric vehicle industry. Consequences for the nation as a whole, however, would be minimal. The number of electric automobiles in use by 1985, with or without regulation, should be too small to produce any appreciable impacts.

The number of electric automobiles in use by 1985 is expected to be a very small fraction of the total automotive fleet whether fuel economy regulations are imposed on electric vehicles or not. Imposition of fuel economy standards for electric vehicles under

Title III of the Energy Policy and Conservation Act would probably reduce the number of such vehicles in use.

Because of the small number of electric cars projected to be in use, their impact on energy consumption, air quality, the economy and use of natural resources will be insignificant with or without fuel economy standards. Imposition of standards should serve primarily to mitigate these already small impacts, although some direct costs of regulation would be incurred by the government in setting and enforcing standards.

7.0 FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

7.1 FINDINGS AND CONCLUSIONS

Non-Fuel-Consuming Vehicles

- The principal non-fuel-consuming vehicles include automotive vehicles powered by propulsion systems using electricity, butane, propane, hydrogen, ethanol and methanol.
- With the exception of the electric vehicle, the principal non-fuel-consuming vehicles have performance characteristics similar to the gasoline or diesel-powered vehicles, but the fuel is more expensive to produce and the fuel distribution network would have to be developed and built for refueling such vehicles.
- For non-fuel-consuming vehicles other than the electric vehicle, it does not appear that there will be sufficient numbers of vehicles produced by 1985 to warrant consideration for inclusion under the Act provided there is no major shift in Government policy toward these vehicles.

Electric Vehicle Energy Use

- Based on conversion of petroleum to gasoline and petroleum to electricity, which is an appropriate assumption for the near term, present electric passenger vehicles have about the same fuel efficiency on a seat-mile basis as a comparable gasoline consuming vehicle over the urban driving cycle. Over a multi-stop urban cycle, a light duty commercial utility vehicle may be more efficient than a comparable gasoline consuming vehicle, because there are no idling losses when the vehicle is stopped. Comparable implies only that the electric vehicle will have about the same roominess or cargo space and will be functionally equivalent; however, the electric vehicle will be heavier, will not have comparable acceleration or range performance and may not be equipped with the full range of accessories normally found in Internal Combustion Engine powered vehicles of the same size.

- The potential for fuel economy improvement by 1985 of the electric vehicle by modified vehicle design is likely less than that of the fuel-consuming vehicles. However, the results of continued technology development may alter this outlook.
- Based on the proportion of the electric power generated by various sources, electric vehicles will consume less petroleum than a comparable number of fuel-consuming vehicles. However, the effect of electric vehicles on overall energy consumption should be insignificant, because electric vehicles are likely to represent less than one percent of the U.S. automotive vehicle fleet in 1985.
- In evaluating potential savings of energy as contemplated by the Energy Policy and Conservation Act, the fuel economy of electric and fuel-consuming vehicles should be compared on the basis of overall energy efficiency from primary source to ultimate utilization in the vehicle.

Electric Vehicle Economics

- The current acquisition cost of the electric vehicle (in limited production) is about three times the cost of a comparable fuel-consuming vehicle. In mass production, the overall cost of the electric vehicle without battery is estimated to be about 20% higher than the cost of comparable fuel-consuming vehicles. Moreover, the cost of the electric vehicle in mass production will be increased further by the cost of the vechile battery. It is not expected that mass production will significantly reduce the cost of currently available batteries.
- While operating costs of the potential mass produced electric vehicles may be somewhat lower than the costs of comparable fuel-consuming vehicles, the life-cycle costs

for electric passenger automobiles are estimated to be 15 to 45 percent higher than for comparable fuel-consuming vehicles. The life-cycle costs of electric light duty commercial vans are estimated to be about the same as or less than for comparable fuel-consuming vehicles. These costs estimates are sensitive to the operational life of batteries.

- Electric passenger automobiles are expected to be weak competitors with comparable ICE powered automobiles through 1985, based on the estimated life-cycle costs and performance characteristics. On the other hand, there may be a gradual increase in the sale of electric light duty commercial vans for urban multi-stop usage provided the life cycle costs of these vehicles are proven to be lower than those of comparable ICE vehicles in the future, as the analysis in this report projects.

Electric Vehicle Regulation

- Regulation of the fuel economy of electric vehicles under the Act would not significantly change the impact on a national level of materials availability, fuel consumption, or air quality, because only a relatively small number of electric vehicles is likely to be in operation in the United States through the 1980's. If regulations were imposed, the cost of preparing and supplying test vehicles would probably have an adverse effect on the cost of manufacture of electric vehicles.
- Voluntary labeling of the "fuel economy" of electric vehicles by manufacturers would be useful for consumers interested in their purchase. Mandatory labeling would impose additional costs on the electric vehicle manufacturers and would be another obstacle to successful production and sale.

7.2 RECOMMENDATIONS

- Electric vehicles should not be made subject to average fuel economy regulations under Title V of the Motor Vehicle

Information and Cost Savings Act as amended by the Energy Policy and Conservation Act.

- The manufacturers of electric vehicles should not be required to provide "fuel economy" labels for their vehicles.
- The manufacturers of electric vehicles should be permitted to submit information about the "fuel economy" of their vehicles to EPA and FEA for inclusion in the annual fuel economy booklet required by Section 506 of Title V.

A summary of weight and estimated costs of electric and ICE-powered vehicles is given in Table 7-1.

TABLE 7-1. SUMMARY COMPARISON OF ELECTRIC AND ICE VEHICLES

VEHICLE TYPE	ELECTRIC VEHICLE			
	LEAD-ACID		NICKEL-ZINC	
	VEHICLE DESCRIPTION			
VEHICLE SUBSYSTEM	PERFORMANCE	WEIGHT (LB)	PERFORMANCE	WEIGHT (LB)
CHASSIS		1625		1590
MOTOR, HP	85 pk/34 cont.	315	85 pk/34 cont.	315
CONTROLLER, current (amperes)	500 pk/200 cont.	85	500 pk/200 cont.	85
BATTERY				
Power Density, W/lb	14		70	
Energy Density, W hr/lb	13		40	
Energy Storage, kW hr	20	1500	44	1090
Curb Weight		3525		3080

VEHICLE SUBSYSTEM	PRODUCTION COST (1975 dollars)							
	PILOT		MASS		PILOT		MASS	
	UNIT COST	ITEM COST	UNIT COST	ITEM COST	UNIT COST	ITEM COST	UNIT COST	ITEM COST
CHASSIS	0.9/lb	1490	0.9/lb	1490	0.9/lb	1480	0.9/lb	1480
MOTOR	4.0/lb	1260	1.2/lb	375	4.0/lb	1260	1.2/lb	375
CONTROLLER	6.0/amp	1190	1.1/amp	225	6.0/amp	1190	1.1/amp	225
BATTERY	0.42/lb	630	0.42/lb	630	1.6/lb	1740	1.1/lb	1220
ESTIMATED MANUFACTURING COST		4570		2720		5670		3280
ESTIMATED RETAIL PRICE		9100		5400		11300		6500

VEHICLE TYPE	ELECTRIC VEHICLE		ICE	
	LITHUM/ALUMINUM-IRON SULFIDE		1976 2000 LB SUBCOMPACT	
	VEHICLE DESCRIPTION			
VEHICLE SUBSYSTEM	PERFORMANCE	WEIGHT (LB)	PERFORMANCE	WEIGHT (LB)
CHASSIS		1555		1560
MOTOR, HP	85 pk/34 cont.	315	60	440(1)
CONTROLLER, current (amperes)	500 pk/200 cont.	85		
BATTERY				
Power Density, W/lb	60			
Energy Density, W hr/lb	50			
Energy Storage, kW hr	39	770		
Curb Weight		2725		2000

VEHICLE SUBSYSTEM	PRODUCTION COST (1975 dollars)					
	PILOT		MASS			MASS
	UNIT COST	ITEM COST	UNIT COST	ITEM COST	UNIT COST	COMPONENT
CHASSIS	0.9/lb	1470	0.9/lb	1470		
MOTOR	4.0/lb	1260	1.2/lb	375		
CONTROLLER	6.0/amp	1190	1.1/amp	225		
BATTERY	1.5/lb	1160	1.0/lb	770		
ESTIMATED MANUFACTURING COST		5080		2840	1.0/lb	1995
ESTIMATED RETAIL PRICE		10100		5700		3900

Note: Includes Engine, Engine Components, Fuel System and Exhaust System.

APPENDIX A

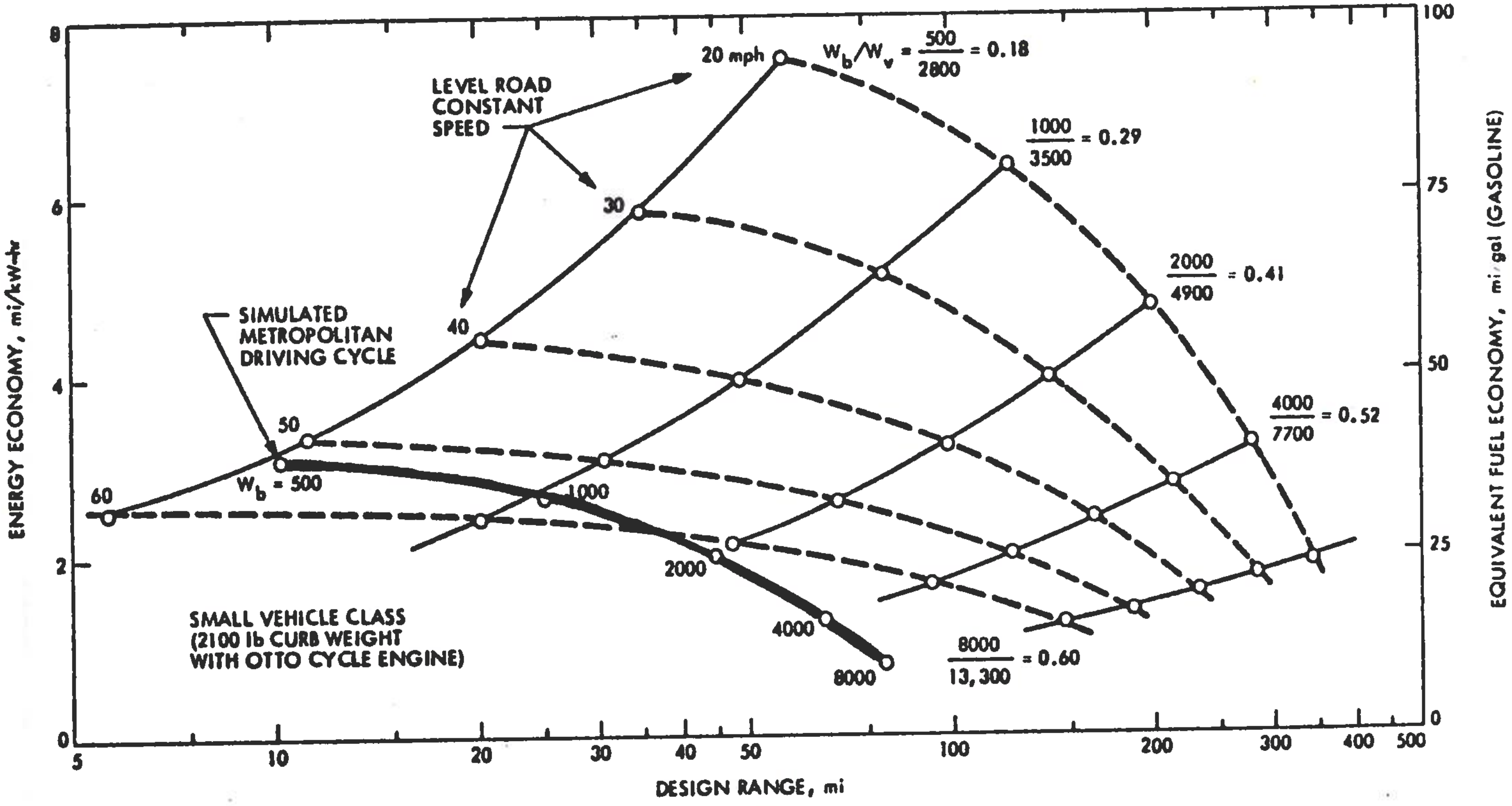
RANGE VS. ENERGY ECONOMY FOR ELECTRIC VEHICLES

A.1 GENERAL

The figures from which Figure 2-4 was derived are shown in Figures A-1, A-2 and A-3 in which the trade-offs between energy economy and range for vehicles powered by each of the three battery systems (lead-acid, nickel-zinc, lithium/aluminum-iron sulfide) are presented.[1,27] Dashed lines show the weight of battery (W_b) expressed as a fraction of total vehicle weight (W_v) which is required to achieve a particular range at constant speed. The light solid lines are lines of constant W_b/W_v. The heavy solid lines show the relationship between range and energy economy for the three battery systems operated over the JPL simulated metropolitan driving cycle. These three curves (heavy solid lines) comprise Figure 2-4 in the main body of the text. It is apparent that the inverse relationship of energy economy and vehicle weight holds at all constant speeds as well as for the driving cycle. Also, range at constant speed is significantly higher (except at 60 mph and low W_b/W_v) than for the driving cycle compared at the same W_b/W_v. This can be misleading. Thus, at a $W_b/W_v = 0.29$, the range of an electric vehicle (EV) powered by lead-acid batteries at a constant speed of 30 mph is approximately 80 miles; its equivalent fuel economy is about 60-65 miles/gallon of gasoline; the equivalent point on the driving cycle curve shows a range of 25 miles and an equivalent fuel economy of about 33 miles/gallon. As noted in the main text, based on the JPL driving cycle, range for the three battery systems at typical values of W_b/W_v are 30-40 miles for lead-acid, 85-120 miles for nickel-zinc, and 125-185 miles for lithium/aluminum-iron sulfide.

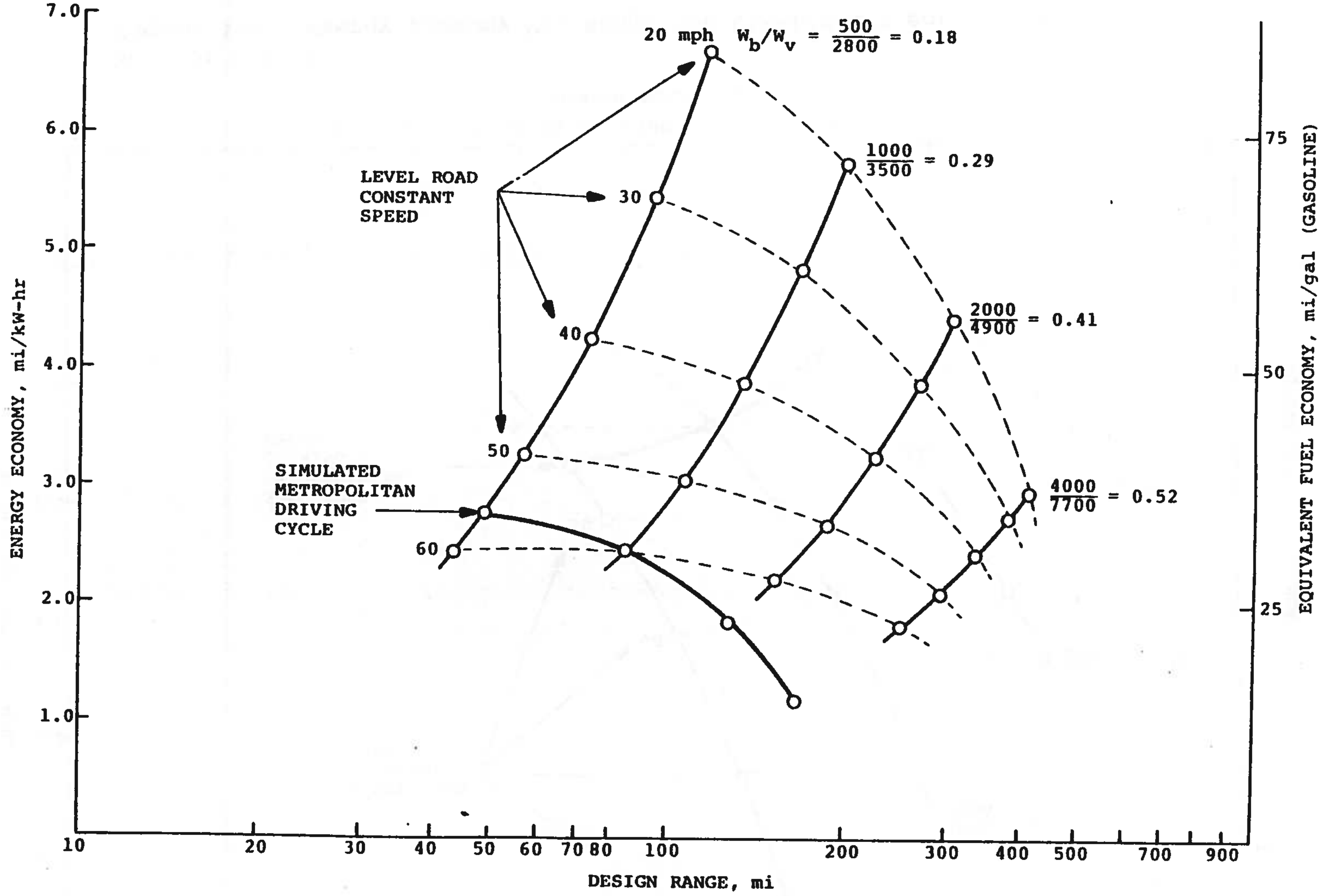
A.2 REGENERATIVE BRAKING

In the calculations on which Figures A-1, A-2 and A-3 (and Figure 2-4) are based, regenerative braking was not included.



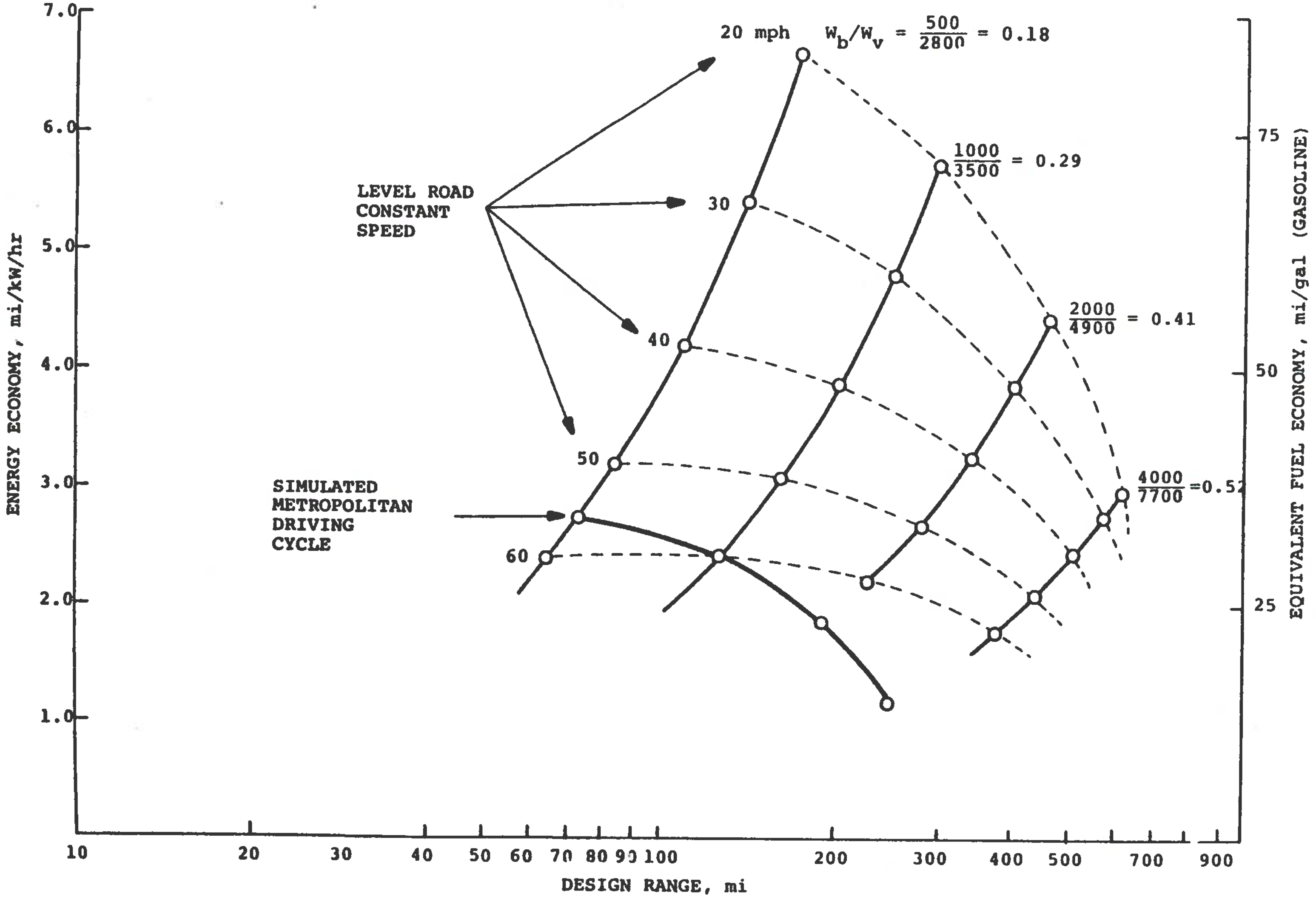
Source: Ref 1

Figure A-1. Energy Economy Vs. Range for Lead-Acid Electric Car



Source: Ref 27

Figure A-2. Energy Economy Vs. Range for Nickel-Zinc Electric Car



Source: Ref 27

Figure A-3. Energy Economy Vs. Range for Li-Al/Fes Electric Car

In the normal (motoring) mode of operation, power passes from the battery to the motor. By appropriate changes in the controller, activated by braking, the motor may be made to act as a generator, passing power to the battery and recharging it. Thus, a certain portion of the kinetic energy of the vehicle is returned to the battery by use of regenerative braking.

The value of regenerative braking is still under discussion. The perceived advantages and disadvantages of regenerative braking are summarized in Table A-1. Estimates and field measurements of range extension due to regenerative braking vary widely (from 5 to 40%) and depend on system design, test cycle profiles, amount of energy available for recovery and efficiencies of motor, controller and battery during recharging.

TABLE A-1. SUMMARY OF ARGUMENTS FOR AND AGAINST REGENERATIVE BRAKING

ADVANTAGES	DISADVANTAGES
1. Improved vehicle range	1. Additional cost
2. Reduced brake wear	2. Additional complexity
3. Brake system redundancy	3. Higher maintenance costs
4. Battery performance improvement	4. Adverse internal physical effects on battery

In their analysis of EV's, JPL[1] has estimated that a 10% improvement in energy economy can be realistically expected as a consequence of regenerative braking during average daily use. This estimate was based upon currently available technology, and, perhaps, improved techniques may be developed in the next ten years to offer greater energy recovery capability. Further, the relative advantage of regenerative braking can be expected to be higher for a multi-stop delivery van.

Assuming a 10% improvement in range, the gain would be about 4 miles for a lead-acid battery system, about ten miles for a nickel-zinc battery system, and about 15 miles for a lithium/aluminum-iron sulfide system.

The cost of regenerative braking has been variously estimated at \$120[3] to \$300[28] depending on production levels. This will add 0.3 to 1 cent/mile to the cost of operating an electric passenger vehicle. The gain in energy economy (assumed to be 10%) will decrease operating cost by about 0.2 to 0.3 cent/mile (fuel at 3.2¢/kW-hr). Compared to the total life cycle operating costs for electric passenger vehicles (Tables B-3 and C-3), the effect is insignificant.

APPENDIX B

COST ESTIMATION FOR ELECTRIC PASSENGER VEHICLE IN LIMITED PRODUCTION

B.1 GENERAL

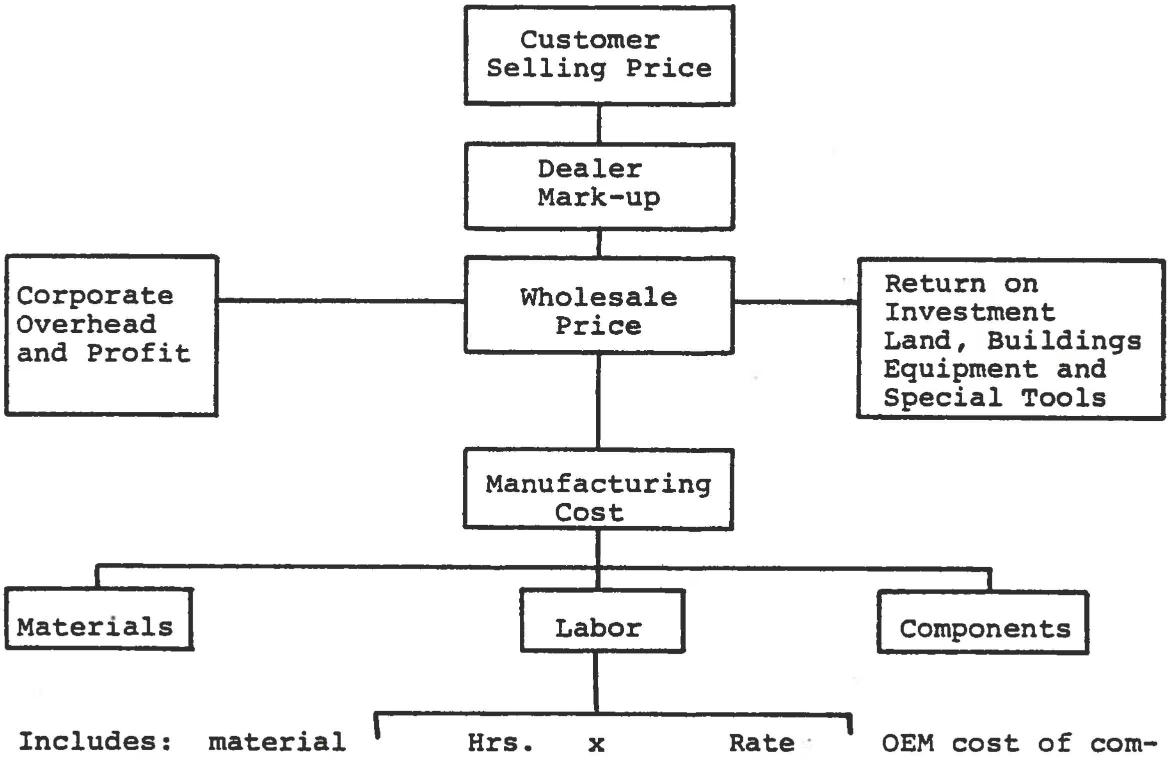
The manufacturing and operating cost estimates presented in this section are those that would apply to a limited production of electric vehicles (less than 50,000 vehicles/year). These costs do not incorporate projected economies of scale that could occur if electric vehicles were mass produced. Projections of electrical vehicle costs at a volume limit which could incorporate probable mass production economies are discussed in Appendix C.

B.2 ESTIMATION OF MANUFACTURING COST OF ELECTRIC VEHICLES

The manufacturing cost of an automobile is the sum of the material cost, the labor cost and the cost of special components. See Figure B-1.

The material costs includes the cost of material and transportation for tires, batteries, glass, steel, iron, aluminum, copper, plastic and other materials. Labor Cost is computed by multiplying labor hours by labor rate. Labor hours includes hours for workers up through the foreman level for fabricating, processing, assembling, inspection, receiving, storage, handling, packing, warehousing, shipping, maintenance, repair, janitorial and watchman services, product development, auxiliary production for plants' own use (e.g, power plant), record keeping and other services closely associated with these production operations at the factory. Supervisory employees above the working foreman level are included in corporate overhead. Labor rate is estimated at $11.00 per hour. This rate includes cost of labor and fringe benefits and in addition the cost of warranty, maintenance, expendable tooling, heat, light, power and other factory overhead expense.

The cost of Special Components is the original equipment manufacturer's (OEM) price paid for the components by the vehicle



Includes: material cost plus transportation for: tires, batteries, glass, steel, iron, aluminum, copper, plastic, and other.

includes: hours for workers up through foreman level for fabrication, assembly, inspection, maintenance, handling, product development, security, record keeping, house keeping, and other services.

includes: cost of labor and fringe benefits. Also included are: cost of warranty, maintenance and repair tooling, and other factory overhead.

OEM cost of components which includes: variable cost for material and labor, transportation, overhead, and profit of vendors.

Figure B-1 Simplified Manufacturing Cost Structure for Automotive Vehicles manufacturer and includes the transportation cost, profit and overhead of the component vendor.

The unit wholesale price includes manufacturing costs, as well as indirect costs not associated with the manufacturing facility. The unit wholesale price includes a return on the capital investment in land, buildings, equipment special tools to include and components overhead and profit. The selling price to the customer is the wholesale selling price marked up by the dealer for the costs of distribution, transportation, and delivery expense.

A rigorous cost analysis of electric vehicle systems entails an examination of all cost elements for which all of the required data were not available. This analysis focuses on developing the manufacturing cost of an electric vehicle.

In order to arrive at a first order estimate of manufacturing cost, electric vehicles (E.V.) were divided into two systems: a drivetrain consisting of a battery pack, electric control elements and electric motor; and a chassis containing everything else. Price estimates for the drivetrain components were obtained from the literature and by contacting manufacturers in the case of state-of-the-art equipment being sold to the off-the-road electric vehicle market. For developmental items, costs are based on estimates published by the developers.

Detailed discussions of the pricing of motors, controllers, and batteries are presented in Appendix F.

For the purposes of this estimate, it is assumed that electric vehicles will be powered by a DC series commutator motor - SCR Chopper System. This system combines a standard traction DC commutator motor, with a modern solid state controller which is used on many of the newer electric drives. Packaged chopper controllers are available commercially from several manufacturers as discussed in Appendix F.

It is assumed that the chassis of an electric vehicle would be very similar to the chassis of an equivalent ICE powered vehicle as would be the cost of final vehicle assembly. It is recognized that a transmission with different characteristics would be used. Instrumentation would also be different, and the structural requirements of an electric vehicle would be different because of the need to support the heavy battery system. The cost differences which may apply to the transmission, instrumentation and structure are assumed to be negligible. Furthermore, it is assumed that the manufacturing facilities, the material costs per unit weight, and the labor required to manufacture and assemble the component parts of the chassis for an electric vehicle would be the same as required for an equivalent ICE-powered vehicle. It is estimated that the variable cost for an electric vehicle chassis weighing 1560 lbs. would be $1473 (in Dec. 1975 dollars)(See Appendix G.) Minor weight modifications in the chassis which change the variable cost of materials, but not the labor content, would change this figure by $0.25/lb (1600 lb. chassis would cost $10 more than a 1560 lb. chassis, i.e., $1483).

In view of the fact that costs are estimated here for a limited production of electric vehicles, the costs may be underestimated.

The manufacturing cost of the electric vehicles described in a recent study by General Research Corporation (G.R.C.) were estimated.[2] The G.R.C. vehicle designs were assumed to be representative of on-the-road electrical vehicles that would be powered by alternate battery packs of lead-acid, nickel-zinc and lithium-sulfur. Vehicle characteristics are presented in Table B-1. In this study, the lithium-sulfur battery was replaced by a lithium-aluminum-iron sulfide battery

The following assumptions were made to arrive at the price estimated presented in Table B-2:

a) The cost of the chassis is based on the discussion in Appendix G.
b) The cost of the motor is assumed to be $4.00/lb., as discussed in Appendix F.
c) The cost of the controller is based on present prices for 200 amp continuous duty controllers, with a 15% quantity

TABLE B-1. CHARACTERISTICS OF 4 PASSENGER ELECTRIC VEHICLE USED IN COST ANALYSIS

Battery	Pb-Acid	Ni/Zn	Li-Al/FeS
Curb Weight (lbs)	3525	3080	2725
Battery Weight (lbs)	1500	1090	770
Motor HP (Peak/Cont)	85/34	85/34	85/34
Motor Weight (lbs)	315	315	315
Controller Current (Peak/Cont)	500/200	500/200	500/200
Controller Weight (lbs)	85	85	85
Estimated Chassis Weight (lbs)	1625	1590	1555

Source: Ref. 3

TABLE B-2. ESTIMATES OF ELECTRIC VEHICLE IN LIMITED PRODUCTION MANUFACTURING COSTS

Battery Type		Lead-Acid		Nickel-Zinc		Lithium/Aluminum-Iron Sulfide	
Vehicle (less battery)							
Component	Unit Price	Units	Price $	Units	Price $	Units	Price $
Chassis		1625 lbs	1490	1590 lbs	1480	1555 lbs	1470
Motor	$4.00/lb	315 lbs	1260	315 lbs	1260	315 lbs	1260
Controller	$1190 ea		1190		1190		1190
Subtotal - Production cost of E.V. (less battery)			3940		3930		3920
Battery Pack							
Battery Cost, o.e.m. ($/lb.)		0.42		1.60		1.10	
Battery Weight, lbs.		1500		1090		770	
Battery Pack Cost, o.e.m., $			630		1740		1160
Total Manufacturing Cost (vehicle + Battery)			$4570		$5670		$5080
SRI Estimate of Manufacturing Cost			$4600				

NOTE: Costs are in December 1975 dollars.

discount or $1190. It is assumed that the automobile manufacturer does not assemble controllers but purchases units from established suppliers.

d) The OEM (original equipment manufacturer) cost of batteries is based on Table B-2 utilizing the more pessimistic projected costs for the nickel-zinc and lithium/aluminum-iron sulfide batteries. This cost is added to the chassis cost to obtain the total manufacutring cost of the vehicle.

Referring to Table B-2, the manufacturing costs of electric vehicles, without their battery packs, are estimated to be approximately $3900. The additional OEM cost of the battery pack would be from $630 (lead-acid battery) to nearly $1740 (niclel-zinc battery). Based on these figures, the total manufacturing cost of an electric vehicle is estimated to be between $4500 and $5700.

The same methodology was also used to estimate the manufacturing cost of a four-passenger lead-acid-battery-powered electric vehicle that is presently being offered by Electric Vehicle Assoc., Inc. of Parma, Ohio, as shown in Table B-3. The EVA vehicle is considered characteristic of the electric passenger vehicles now being manufactured. The estimated manufacturing cost of this automobile is $4616.

For purposes of comparison, the manufacturing cost of a 1 ton urban car with a lead acid battery pack was estimated to be $4000 (1974 dollars) by Stanford Research Institute[29] or $4600 when corrected for inflation.[30]

B.3 VEHICLE RETAIL PRICE

As discussed in Appendix G, the variable manufacturing cost of a 2000 lb. ICE automobile is estimated to be $1955 (December 1975 Dollars). It is noted that in October 1975, the 1976 models of subcompact cars in the 2000 lb. category, such as the Chevette, Fiat 128, Datsun B210, the Volkswagen Beetle, the Volkswagen Rabbit, Renault 12 and the Audi Fox, had dealer sticker prices (manufacturer's recommended retail price) that ranged from $2899 to $4850.[31]

TABLE B-3. ESTIMATED COST OF A SEMICOMMERCIAL ELECTRIC VEHICLE

MANUFACTURER		ELECTRIC VEHICLE ASSOC., INC.*
Model		EVA METRO
Curb Weight lbs		3150
Pb-Acid Battery-Weight lbs		1040
Drive Motor HP (Nom)		14
Controller Current (Nom) amps		200
Chassis Weight lbs		1900
Cost Estimate		
Item	Unit Cost	
Battery	$0.42/lb	440
Motor	$100/HP	1418
Controller	quote	1200
Chassis	(Appendix G)	1558
Subtotal - Production Cost		$4616
Manufacturer's Suggested Retail Price		$9500

*Parma, Ohio 44129

Source: Reference 44, 45

NOTE: Cost are in December 1975 Dollars.

The manufacturer's suggested retail price for the EVA vehicle, which has an estimated manufacturing cost of $4616, is $9500,(49) as shown in Table B-3.

The estimated dealer sticker prices of the other electric vehicles discussed in the previous section are presented in Table B-4. The range of these estimates are based on the data presented in the previous paragraphs. Comparable numbers for a 2000 lb. ICE vehicle are also presented in Table B-4.

B.4 OPERATING COST ESTIMATES

Operating costs were estimated for the various model electric vehicles presented in Table B-5. The methodology used was the one developed by GRC. Except for the cost of electricity, the same data were used for the capital insensitive costs as in the referenced study. The cost of electrical power was assumed to be 3.2¢/kW-hr which, according to the Edison Electric Institute,[32] was the national average retail price of electricity in 1975. Operating costs were also calculated at a price of electricity of 4.2¢/kW-hr, the value used in the GRC Study. Capital sensitive cost data were adjusted to reflect the retail prices assigned to the various vehicles in Table B.4. An acquisition value of money of 5% was assumed.[33] This acquisition value reflects the use of a constant value currency (U.S. dollar in 1975). This figure is lower than quoted present commercial interest rates since these have to provide for the devaluation of the currency due to inflation.

Batteries were treated as capital sensitive items. The replacement cost of batteries was based on the cost data presented in Appendix F (Table F-1 and F-2).

As can be seen from Table B-5, it is projected that the operating costs of electric vehicles will be very high, varying from a low value of 27.8¢/mile to as much as 36.0¢/mile. Capital sensitive costs represent the major part of the total operating cost. The high price of battery packs over the life of the car adds significantly to the operating cost. Total operating costs are

TABLE B-4. ESTIMATED RETAIL PRICE OF ELECTRIC VEHICLE IN LIMITED PRODUCTION

Vehicle/Battery Type	Variable Manufacturing Cost E.V. (Including Battery)	Estimated Vehicle Retail Price Range	Assumed Retail Price for Life Cycle Cost Calculation
Lead-Acid	$4570	$6850-$11400	$9100
Nickel-Zinc	$5670	$8500-$14200	$11300
Lithium/Aluminum-Iron Sulfide	$5080	$7600-$12700	$10100
2000 lb. ICE	$1955	$2899-$4850*	$3900

*Source: Reference B1

NOTE: Values in December 1975 Dollars

TABLE B-5. OPERATING COST ESTIMATES FOR ELECTRIC VEHICLES IN LIMITED PRODUCTION

Assumptions	Lead/Acid		Nickel-Zinc		Lithium/Aluminum-Iron Sulfide	
Vehicle Life (yrs.)	12		12		12	
Vehicle Utilization (miles/yr)	10,000		10,000		10,000	
Total Vehicle Miles	120,000		120,000		120,000	
Electric Power Consumption (kW-hr/mile)	0.79		0.51		0.45	
Initial Retail Price ($)	9,100		11,300		10,100	
Battery Pack Replacement Price ($)	1,260		3,480		2,320	
Nominal Battery Life (yrs.)	3		3		4	
			Operating Costs, Cents/Mile			
Capital Insensitive Costs						
Electric fuel-cost @ 3.2¢/kW-hr (4.2¢/kW-hr)	2.53	(3.32)	1.63	(2.14)	1.44	(1.89)
Repairs and Maintenance	1.09		0.81		0.81	
Tires and Accessories	0.43		0.43		0.43	
Insurance	1.53		1.53		1.53	
Garage, Parking, Tolls	1.96		1.96		1.96	
SUBTOTAL	8.33	(9.12)	6.87	(7.38)	6.62	(7.07)
Capital Sensitive Costs						
Depreciation, Base Vehicle	6.58		6.56		6.53	
Depreciation, Battery	4.20		11.60		5.80	
Finance Costs (5% Compounded over Life of Vehicle or Battery)						
Vehicle	5.24		5.21		5.19	
Battery	0.66		1.83		1.22	
Taxes and Fee (@ 3% Acquisition Cost/Year)	2.74		3.40		3.05	
SUBTOTAL	19.42		28.60		21.79	
Total Operating Costs	27.8	(28.5)	35.5)	(36.0)	28.4	(28.9)

NOTE: Costs in December 1975 Dollars.

relatively insensitive to the price of electrical power.

These operating costs are significantly higher than the operating costs of an equivalent internal combustion engine vehicle (Table B-6). The same operating cost assumptions were used as in the GRC Study, except that a higher acquisition price of the vehicle was used to reflect the present cost of subcompact automobiles. The same base price of gasoline of 40¢/gallon was assumed. At 40¢/gallon, the energy cost in the form of gasoline is equal to the cost of energy in electrical form at 3.2¢/kW-hr. The bracketed higher value (70¢/gallon) is the higher value projected by the Motor Vehicle Goals Study.[33] The disparity in the operating cost of equivalent electric and internal combustion engine vehicles is further accentuated by the shorter life assigned to the ICE vehicle (10 years) than to the electric vehicle (12 years). This tends to moderate the capital costs associated with the electric vehicle.

The cost estimates presented in this section are summarized in Table B-7. Electric vehicles in limited production are more expensive to manufacture and, thus, must sell for a higher price to the consumer than mass produced ICE vehicles. This high acquisition price results in total life cycle operating costs for electric vehicles that are significantly higher than for the equivalent ICE vehicle. For both vehicles, the cost of fuel is low and represents only a small fraction of total operating costs.

TABLE B-6. OPERATING COST ESTIMATES FOR SUB-COMPACT ICE VEHICLE

Assumptions		
Vehicle Life	10 years	
Vehicle Utilization	10,000 miles/year	
Total Vehicle Miles	100,000 miles	
Gasoline Consumption	21.43 miles/gallon	
Retail Price	$3,900	
<u>Capital Insensitive Costs</u>	<u>Operating Costs, Cents/Mile</u>	
Gasoline @ $0.40/gallon ($0.70/gallon) (excluding taxes)	1.87	(3.27)
Oil	0.18	(0.22)
Repair and Maintenance	1.95	
Tires and Accessories	0.40	
Pollution Device and Maintenance	0.86	
Insurance	1.53	
Garage, Parking, Tolls	1.96	
SUBTOTAL	8.75	(10.19)
<u>Capital Sensitive Costs</u>		
Depreciation	3.91	
Finance Cost (5% compounded over life)	2.42	
Taxes - Fees (@ 3% Acquisition Cost/Year)	1.17	
SUBTOTAL	7.50	(7.50)
TOTAL OPERATING COSTS	16.3	(17.7)

NOTE: Costs in December 1975 Dollars.

TABLE B-7. ECONOMIC COMPARISON OF MASS PRODUCED I C E VEHICLES AND ELECTRIC VEHICLES IN LIMITED PRODUCTION

	ESTIMATED MANUFACTURING COST $	ESTIMATED RETAIL PRICE, $	ESTIMATED LIFE CYCLE OPERATING COSTS (CENTS/MILE)	
			COST OF FUEL (1)	TOTAL OPERATING COST
I C E VEHICLE	1,955	3,900	1.87	16.3
ELECTRIC VEHICLE				
LEAD-ACID	4,570	9,100	2.53	27.8
NICKEL-ZINC	5,670	11,300	1.63	35.5
LITHIUM/ALUMINUM-IRON SULFIDE	5,080	10,100	1.44	28.4

NOTE (1) ELECTRICITY 3.2¢/kW-hr
GASOLINE 40¢/Gallon (excluding taxes)

NOTE: Costs in December 1975 Dollars.

APPENDIX C

POTENTIAL IMPACT OF MASS PRODUCTION ON COST OF ELECTRIC VEHICLES

C.1 INTRODUCTION

Appendix B compares manufacturing and operating costs of electric vehicles manufactured in limited quantities to the manufacturing and operating costs of mass produced ICE vehicles. It may be argued that such a comparison is biased in favor of the ICE vehicles. In this appendix, an attempt is made to estimate what the limiting costs of electric vehicles might be if these were produced in mass production quantities.

C.2 MANUFACTURING COSTS

Estimated mass production manufacturing costs of the electric vehicles described in Table B-1 are summarized in Table C-1. In arriving at these estimates, it was assumed that economies of scale would principally apply to motors and controllers as discussed in Appendix F. The same cost was applied to the chassis as in Appendix B since this is already a mass production cost.

As far as the costs of batteries are concerned, it was considered that the cost of lead-acid batteries would not change. The cost of golf-cart batteries is comparable to that of standard automotive batteries which are already manufactured by the millions. As far as nickel-zinc and lithium/aluminum-iron sulfide batteries are concerned, the lowest price projected by the battery developers was assumed.

C.3 VEHICLE RETAIL PRICES

Projected retail prices for mass produced electric vehicles are presented in Table C-2. These prices are for the same class of electric vehicles presented in Table B-4.

For purposes of comparison, the price estimates developed in the GRC[2] study for mass produced electric vehicles are also presented in Table C-2. The GRC data are presented as published in 1973 dollars and also in current dollars to account for inflation.[30]

TABLE C-1. PROJECTED MANUFACTURING COSTS FOR ELECTRIC VEHICLES IN MASS PRODUCTION

Battery Type		Lead-Acid		Nickel-Zinc		Lithium/Aluminum/ Iron Sulfide	
Vehicle (less battery)							
Component	Unit Price	Units	Price $	Units	Price $	Units	Price $
Chassis		1625 lbs	1490	1590 lbs	1480	1555 lbs	1470
Motor	$1.19/lb	315 lbs	375	315 lbs	375	315 lbs	375
Controller	60% of Motor Cost		225		225		225
Subtotal - Production cost of E.V. (less battery)			$2090		$2080		$2070
Battery Pack							
Battery Cost, o.e.m. ($/lb)		0.42		1.10		1.00	
Battery Weight (lbs)		1500		1090		770	
Battery Pack Cost, o.e.m. ($)			630		1200		770
Total Manufacturing Cost (Vehicle + Battery)			$2720		$3280		$2840

NOTE: COSTS IN DECEMBER 1975 DOLLARS

TABLE C-2. PROJECTED RETAIL PRICE OF MASS PRODUCED ELECTRIC VEHICLES

BATTERY	LEAD-ACID	NICKEL-ZINC	LITHIUM/ ALUMINUM-IRON SULFIDE
THIS STUDY (December 1975 Dollars)			
Base Vehicle	$4140	$4100	$4160
Battery	1260	2400	1540
TOTAL = Vehicle Retail Price	$5400	$6500	$5700
GRC STUDY (as published in 1973 Dollars)			
Base Vehicle	$2977	$2945	$2795
Battery	1200	2930	600 (a)
TOTAL	$4177	$5875	$3395
GRC STUDY (Base Vehicle in 1975 Dollars)			
Base Vehicle	$4120	$4080	$3870
Battery	1200	2930	600 (a)
TOTAL	$5320	$7010	$4470

NOTE (a) - Lithium-Sulfur Battery Assumed

An inflation factor was not applied to batteries. The price of lead-acid batteries has not increased significantly since the publication of the GRC report. As far as the advanced batteries are concerned, GRC's prices were already projected prices provided by the developers. It should be noted that the price of the nickel-zinc battery assumed by GRC is a representative average projection, whereas a minimum projected price was assigned to this battery in this part of the study.

The low price assigned to a lithium-sulfur battery in the GRC study is based on a prototype battery design that is no longer considered likely by Argonne National Laboratory. Argonne's preferred present design, which was used in this study, is based on a lithium/aluminum-iron sulfide battery, which is heavier and more expensive.

Aside from these differences, there is fairly good agreement between the GRC estimates and the projected retail prices for mass produced electric vehicles developed here. Even on a mass production basis, the retail price of an electric vehicle will still be higher than the retail price of an equivalent I.C.E. vehicle. The retail price of the base electric vehicle without battery will be approximately $4,100 - $4,200, as compared to the retail price of $3,900 for a comparable ICE vehicle. The retail price of an electric vehicle is increased by the cost of the battery pack, which will add an additional $1,200 to $2,440. This is a significant amount, especially in view of the fact that the battery packs will have to be replaced a number of times during the useful life of the electric vehicle.

C.4 LIFE CYCLE OPERATING COSTS

Life cycle operating costs for mass produced electric vehicles are presented in Table C-3. The operating costs presented in this table are significantly lower than those presented in Table C-1 because of the lower retail price assigned to the electric vehicles. The lowest total operating cost

TABLE C-3. OPERATING COST ESTIMATES FOR MASS PRODUCED ELECTRIC VEHICLES

ASSUMPTIONS						
BATTERY TYPE	Lead-Acid		Nickel-Zinc		Lithium/Aluminum-Iron Sulfide	
Vehicle Life (yrs)	12		12		12	
Vehicle Utilization (miles/yr)	10,000		10,000		10,000	
Total Vehicle Miles	120,000		120,000		120,000	
Electric Power Consumption (kW-hr/mile)	0.79		0.51		0.45	
Retail Price ($)	5,400		6,500		5,700	
Battery Pack Replacement Price ($)	1,260		2,400		1,540	
Nominal Battery Life (yrs)	3		3		4	
Capital Insensitive Costs		Operating Costs, Cents/Mile				
Electric Fuel-Cost @ 3.2¢/kW-hr (4.2¢/kW-hr)	2.53	(3.32)	1.63	(2.14)	1.44	(1.89)
Repairs & Maintenance	1.09		0.81		0.81	
Tires & Accessories	0.43		0.43		0.43	
Insurance	1.53		1.53		1.53	
Garage, Parking, Tolls	1.96		1.96		1.96	
Sub-Total	8.33	(9.12)	6.87	(7.38)	6.62	(7.07)
Capital Sensitive Costs						
Depreciation, Base Vehicle	3.49		3.47		3.45	
Depreciation, Battery	4.20		8.00		3.85	
Finance Costs (5% Compounded over Life of Vehicle or Battery)						
Vehicle	2.77		2.75		2.37	
Battery	0.66		1.26		0.81	
Taxes and Fee (@ 3% Acquisition Cost/Year)	1.63		1.97		1.70	
Sub-Total	12.75		17.45		12.54	
Total Operating Costs	21.1	(21.9)	24.3	(24.8)	19.2	(19.6)

NOTE: COSTS IN DECEMBER 1975 DOLLARS

projected in Table C-3 is 19.2¢ for a lithium/aluminum-iron sulfide battery powered vehicle, assuming a cost of electric power of 3.2¢/kW-hr. This projected figure, however, is still higher than the projected operating cost of an ICE vehicle of 17.7¢/mile, even assuming a price of gasoline of 70¢/gallon.

The cost estimates presented in this section are summarized in Table C-4. It is projected that even on a mass production basis, electric passenger vehicles will be more expensive to manufacture, buy and operate than equivalent ICE-powered vehicles.

TABLE C-4. ECONOMIC COMPARISON OF ICE VEHICLES AND ELECTRIC VEHICLES ON A MASS PRODUCED BASIS

	ESTIMATED MANUFACTURING COST $	ESTIMATED RETAIL PRICE, $	ESTIMATED LIFE CYCLE OPERATING COSTS (CENTS/MILE)	
			COST OF FUEL (1)	TOTAL OPERATING COST
ICE VEHICLE	1955	3900	3.27	17.7
ELECTRIC VEHICLE				
LEAD-ACID	2720	5400	2.53	21.1
NICKEL-ZINC	3280	6500	1.63	24.3
LITHIUM/ALUMINUM-IRON SULFIDE	2840	5700	1.44	19.2

NOTE (1) ELECTRICITY 3.2¢/kW-hr

GASOLINE 70¢/gallon (excluding taxes)

NOTE: COSTS IN DECEMBER 1975 DOLLARS

APPENDIX D
COST ESTIMATION FOR FLEET SERVICE ELECTRIC VANS IN LIMITED PRODUCTION

D.1 GENERAL

Manufacturing, fleet acquisition, and life cycle operating costs of electric and ICE light delivery vans are compared in this Appendix. The cost accounting procedure used is the same as the one previously used to calculate the costs associated with a four passenger urban vehicle. Data obtained from the U.S. Postal Service (USPS) were used wherever possible in these computations. The calculations are limited to lead-acid-battery powered electric vans. As in the case of the electric passenger vehicle, cost calculations were performed for a limited production (less than 250,000 vehicles/year) as well as for mass produced vehicles (See Appendix E). Since the market for light delivery vehicles is limited, mass production costs would only be applicable to electric vans if electric passenger vehicles were being mass produced.

D.2 MANUFACTURING COST ESTIMATE

The light delivery electric vans that were recently procured by the USPS were used as models for cost estimation. Manufacturing costs for these vehicles are presented in Table D-1 based on the specifications presented in Table 2-5 and the methodology of Appendix G. The specifications do not include an explicit electric rating of the controller. The cost of the controller was assumed to be equal to that used in the passenger vehicle calculations based on an equivalent power rating.

The ICE vehicle used in service by the USPS is Model DJ-5C, 1/4-Ton Jeep that has a shipping weight of 2490 lbs.[11] Based on this shipping weight, a manufacturing cost of $2077 is calculated for this ICE vehicle, based on the methodology developed in Appendix G.

TABLE D-1. MANUFACTURING COST OF LIGHT DELIVERY ELECTRIC VAN IN LIMITED PRODUCTION (SIMILAR TO USPS MODEL DJ-5E ELECTRIC JEEP)

ITEM	UNITS	UNIT COST	ITEM COST
CHASSIS	W=1909 lbs		$1560 (1)
MOTOR	263 lbs	$4/lb	1052
CONTROLLER	100 lbs	$1190	1190
SUBTOTAL			$3802
BATTERY			
PROPULSION BATTERY	1300 lbs	$0.42/lb	$ 548
AUXILIARY BATTERY	53 lbs	$0.42/lb	22
VEHICLE MANUFACTURING COST			$4372

(1) See Appendix G.4.
Note: (2) Costs in December 1975 dollars

D.3 FLEET ACQUISTION PRICE

The U.S.P.S procured its electric vans in April 1974 at a price of \$5595/vehicle.(11) They would now cost an estimated \$6315 in December 1975 dollars. This price is lower than the present retail price of approximately \$8000 for this vehicle to the individual buyer.

The present U.S.P.S. contract price for the DJ-5 Jeep (1976 Model) is \$4074.(34)

D.4 LIFE CYCLE OPERATING COSTS

The same accounting procedure used to calculate the life cycle operating cost of the 4 passenger urban vehicle in Appendix B is applied in this appendix to the calculation of the life cycle operating costs of an electric van in Postal Service.

The following assumptions were used to arrive at the operating cost of electric light delivery vans presented in Table D-2:

a) The vehicle acquisition price is \$6315 as discussed in the previous section.

b) The vehicle will have a useful life of 10 years. During this period of time, it will be driven 4200 miles/year which is the average for light delivery vans in the USPS.[11]

c) The battery pack will have a nominal 4 year life. The replacement price of the battery pack is based on a unit cost of \$0.67/lb. which is 1.6 x times the o.e.m. price of batteries. This assumes that a fleet user obtains a 20% discount over the normal retail price.

d) Fuel costs are based on fuel consumption of 1.4 kW-hr/mile, the average value obtained with English Harbilt vans in the Cupertino, CA experiment of the USPS. In the evaluation of the life cycle cost for the electric vehicle, the assumed costs of electricity were 3.2¢/kW-hr, the present national average, and 4.2¢/kW-hr the GRC forecasted value.

TABLE D-2. OPERATING COSTS OF AN ELECTRIC VAN IN POSTAL SERVICE (LIMITED PRODUCTION CASE)

ASSUMPTIONS		
Vehicle Life, years	10	
Vehicle Utilization, miles/year	4,200	
Total Vehicle Miles	42,000	
Electric Power Consumption, kW-hr/mile	1.41	
Initial Acquisition Cost	$6,315	
Battery Pack Replacement Cost	$ 910	
Nominal Battery Life, years	4	
Capital Insensitive Costs	Operating Costs, (¢/Mile)	
Electric Fuel @ 3.2¢/kW-hr (4.2¢/kW-hr)	4.5	(5.9)
Repairs & Maintenance	2.5	
Sub-Total	7.0	(8.4)
Capital Sensitive Costs		
Depreciation Base Vehicle	14.1	
Depreciation Battery	5.4	
Finance Costs (5% Compounded over Life)		
Vehicle	8.9	
Battery	1.2	
Taxes + Fees (3% Acquisition Cost per Year)	4.8	
Sub-Total	34.8	
Total Operating Costs	41.4	(42.8)

Note: Costs in December 1975 dollars

e) Repair and maintenance costs are based on the experience of the USPS with the Harbilt electric fleet in Cupertino, California, which is summarized in Table D-3.

The life cycle operating costs of ICE Vans in equivalent service presented in Table D-4 are based on the following assumptions:

a) The vehicle is an American General 1976 DJ-5C Jeep which has a fleet acquisition price of $3211.

b) The vehicle will have a useful life of 6 years. During this period of time, it will be driven 4200 miles/year. These figures are characteristic for light delivery vans used by the USPS.

c) Fuel costs are based on:
   1) A fuel economy of 7.9 mpg which was the average fuel economy of ICE Jeeps used in the Cupertino experiment.[9]
   2) A gasoline price of either $0.40/gal or $0.70/gal, exclusive of taxes. These are the same prices as were assumed in calculating the life cycle costs of the ICE urban passenger vehicles.

d) Repair and maintenance costs are obtained by the USPS based on its total light delivery van fleet of 64,053 1/4 ton trucks for Postal Fiscal Year 1975.[11] These costs include parts and materials (2.3¢/mile) direct maintenance labor (6.2¢/mile) and outside maintenance contract costs (2.3¢/mile). These maintenance figures do not include any overhead costs since these were not applied to the costs of electric vehicles in the Cupertino experiment.

A comparison of Tables D-2 and D-4 indicates that with the chosen assumptions electric vehicles are competitive with ICE vehicles in van applications. The lower fuel and maintenance costs of the electric vans offset their higher capital sensitive costs. Because of the higher fuel efficiency of the electric

TABLE D-3. MAINTENANCE COSTS ASSOCIATED WITH USPS OPERATION OF ELECTRIC VEHICLES IN CUPERTINO, CA

PERIOD COVERED		
Original Test Vehicle	Harbilt HSV-2	8/21/71 to 2/1/76
31 Test Vehicles	Harbilt HSV-3	3/4/74 to 2/1/76
TOTAL MILES TRAVELED		197,506.9
MAINTENANCE	FLEET	AVE. PER VEHICLE
Distilled Water Used, Gallons	1513.3	48.8
Hours Labor, Battery Maintenance	160.6	5.1
Hours Labor, Repair Maintenance	188.1	6.0
Parts and Materials Cost	296.36	9.56
Total Maintenance Cost	$4898.69	$158.02
Total Maintenance Cost Per Mile	2.48¢	

Source: Ref. 13

TABLE D-4. OPERATING COSTS OF AN ICE VAN IN POSTAL SERVICE

Assumptions	
Vehicle - 1976 DJ-5C 1/4 Ton Jeep, 6 cyl., 232 in^3 engine	
Vehicle Shipping Weight, lbs	2490 lbs
Vehicle Life	6 years
Vehicle Utilization	4200 miles/year
Total Vehicle Miles	25,200 miles
Gasoline Consumption	7.9 mpg
Initial Acquisition Cost	$3211

	Operating Costs, (¢/Mile)	
Gasoline @ $0.40/gallon (0.70/gallon)(excluding taxes)	5.1	(8.9)
Repair & Maintenance	10.8	
Sub-Total	15.9	(19.7)
Capital Sensitive Costs		
Depreciation	12.7	
Finance Costs (5% Compounded over Life of Vehicle)	4.3	
Taxes - Fees (3% Acquisition Cost/Year)	2.3	
Sub-Total	19.3	
Total Operating Cost	35.2	(39.0)

*Note: All costs are in December 1975 dollars.

vehicles, they are less sensitive to changes in price of energy. The comparison further favors electric vans if the vehicles are driven more than 4200 mi/year, since this will decrease the capital sensitive cost on a driven mile basis. A key assumption that still has to be demonstrated is that an electric van will have a useful life of at least 10 years. If this can not be demonstrated, the capital costs will be significantly higher, making the electric vehicles significantly more expensive than the ICE counterpart.

In deriving the life cycle costs of an electric postal van, the capital costs were based on the price paid by the USPS for its fleet of American General Electric Jeeps. Since these vehicles have been only recently put into service, the USPS has not yet been in a position to release operating data on the performance of this fleet in the field. The direct operating costs are, therefore, based on the experience obtained on the fleet of 31 Harbilt electric vans in Cupertino, California over a 2 year period. Since these vehicles were leased by the Postal Service, and since they were partially manufactured and assembled in England and the U.S., a realistic fleet acquisition price does not exist for this group of vehicles against which an estimated price could be compared. Based on the specification in Table 2-4 it was estimated that the Harbilt Van would have a manufacturing price of $3870 and a fleet acquisition price of $6200 which is close to the price of the AM General Jeep configuration.

The USPS leased the Harbilt fleet on a 2 year renewable contract at a cost of $7.50/day for a 304 day year.[10] This amounts to $2280/year. Based on a vehicle utilization of 4200 miles/year, this corresponds to a lease cost of 54¢/mile. This lease cost is approximately 1.5 times the capital sensitive costs assigned to an electric vehicle in Table D-2. This relatively high lease cost probably reflects the experimental nature of the Cupertino program.

Table D-5 summarizes the comparison of the manufacturing cost, acquisition price and life cycle operating costs of mass produced ICE and limited production electric light delivery vans in an equivalent duty mode for the USPS.

TABLE D-5. ECONOMIC COMPARISON OF MASS PRODUCED ICE AND LIMITED PRODUCTION ELECTRIC LIGHT DELIVERY VANS IN FLEET USE

	ELECTRIC VAN (LEAD-ACID/BATTERY)	ICE VAN
ESTIMATED MANUFACTURING COST, $	4,367	2,077
FLEET ACQUISITION PRICE, $	6,315	3,211
ESTIMATED LIFE CYCLE OPERATING COSTS (CENTS/MILE)		
COST OF FUEL (1)	4.5	5.1
TOTAL OPERATING COST	41.4	35.2

NOTE (1) ELECTRICITY 3.2¢/kW-hr
Gasoline 40¢/gallon (excluding taxes)

Note: Costs in December 1975 dollars

APPENDIX E
POTENTIAL IMPACT OF MASS PRODUCTION ON COST OF ELECTRIC VANS

The methodology developed in Appendix C was used to project the impact of mass production on the manufacturing cost of electric vans, and consequently, on their fleet acquisition price and life cycle operating costs.

The mass production manufacturing cost of an electric Jeep is projected to be $2,613 as shown in Table E-1. This is 60% of the limited production cost presented in Table D-1. As a result, the fleet acquisition price of an electric vehicle and the capital sensitive operating costs would also be 60% of the values assigned to these vehicles manufactured in limited production. The revised life cycle operating costs based on a fleet acquisition price of $4,200 per vehicle are presented in Table E-2. These projected costs are significantly lower than the life cycle operating costs for an ICE van in the same service, presented in Table D-2. The capital sensitive costs for the electric van are now only 4.2¢/mile higher for the electric van than for the ICE van. This is significantly less than the difference in fuel and maintenance costs between these vehicles, which is at least 20¢/mile less for the electric vehicle.

It is reemphasized that the basis of these operating cost estimates rests on two key assumptions, namely that:

a) An electric van will have a useful life of ten years, and

b) Urban electric passenger automobiles are also being mass produced.

Since the market for electric vans is limited, the economies of scale assumed in this section will not be achieved if only electric vans are being produced.

TABLE E-1. PROJECTED MANUFACTURING COST OF LIGHT DELIVERY ELECTRIC VANS IN MASS PRODUCTION (SIMILAR TO USPS MODEL DJ-5E ELECTRIC JEEP)

ITEM	UNITS	UNIT COST	ITEM COST
CHASSIS	1909 lbs		$1560
MOTOR	263 lbs	$ 1.13 /lb	297
CONTROLLER	ea	60% Motor Cost	188
SUBTOTAL			$2045
BATTERY			
PROPULSION BATTERY	1300 lbs	$ 0.42 /lb	546
AUXILIARY BATTERY	53 lbs	$ 0.42 /lb	22
VEHICLE MANUFACTURING COST			$2613

Note: Costs in December 1975 Dollars.

TABLE E-2. OPERATING COSTS OF A MASS PRODUCED ELECTRIC VAN IN POSTAL SERVICE

Assumptions		
Vehicle Life, years	10	
Vehicle Utilization, miles/year	4,200	
Total Vehicle Miles	42,000	
Electric Power Consumption, kW-hr/mile	1.41	
Initial Acquisition Price	$4,200	
Battery Pack Replacement Price	910	
Nominal Battery Life, years	4	
Capital Insensitive Costs	**Operating Costs, (¢/Mile)**	
Electric Fuel @ 3.2¢/kW-hr (4.2¢/kW-hr)	4.5	(5.9)
Repairs & Maintenance	2.5	
Sub-Total	7.0	(8.4)
Capital Sensitive Costs		
Depreciation Base Vehicle	7.9	
Depreciation Battery	5.4	
Finance Costs (5% Compounded over Life)		
Vehicle	6.3	
Battery	1.2	
Taxes + Fees (3% Acquisition Cost per Year)	3.1	
Sub-Total	23.9	
Total Operating Costs	30.9	(32.3)

Note: Costs in December 1975 Dollars.

Table E-3 summarizes the comparison of manufacturing, cost acquisition price and life cycle operating costs between mass produced electric and ICE light delivery vans.

TABLE E-3. ECONOMIC COMPARISON OF MASS PRODUCED LIGHT DELIVERY VANS IN FLEET USE

	ELECTRIC VAN (LEAD/ACID BATTERY)	ICE VAN
Estimated Manufacturing Costs, $	2613	2077
Estimated Fleet Acquisition Price, $	4200	3211
ESTIMATED LIFE CYCLE OPERATING COSTS (cents/mile)		
Cost of Fuel (1)	4.5	8.9
Total Operating Cost	30.9	39.0

NOTE (1) ELECTRICITY 3.2¢/kW-hr
Gasoline 70¢/gallon (excluding taxes)

(2) Costs in December 1975 Dollars.

APPENDIX F
COST OF COMPONENTS

F.1 COST OF BATTERIES

Performance characteristics and costs of the three battery packs considered in the cost analysis of an electric urban passenger vehiclea are presented in Table F-1.

Lead-acid Battery - In the cost estimation, it was assumed that the electric vehicle would be powered by advanced golf cart batteries. These are the type of batteries most commonly used in the limited number of on-the-road electric automobiles now being produced. Three leading battery manufacturers and a national retailing chain were contacted in order to obtain wholesale (o.e.m.) and retail prices for these batteries. These prices are summarized in Table F-2. On a unit weight basis, the o.e.m. price of these batteries ranged from $0.39/lb to $0.43/lb, with an average value of $0.42/lb. This was the value chosen for the manufacturer's cost of batteries in estimating the manufacturing cost of electric vehicles and vans powered by lead-acid batteries. The manufacturer's recommended retail prices ranged from $0.80/lb. to $1.35/lb with an average value of $1.14/lb. The actual retail price of such a battery in the automotive department of a major retail chain is $41.99 (without-trade-in), or $0.70/lb. The retail price of lead acid batteries for electric vheicles is estimated to be $0.84/lb. This is a mass production figure.

TABLE F-1. PERFORMANCE CHARACTERISTICS AND COST OF BATTERIES FOR MODEL ELECTRIC PASSENGER VEHICLES

BATTERY TYPE	LEAD-ACID	NICKEL-ZINC	LITHIUM-ALUMINUM/ IRON-SULFIDE
RECOMMENDED BATTERY WEIGHT FOR E.V. STUDY DESIGN, LBS.	1500	1090	770
CYCLE LIFE	300-400	200-400	∿1000
INITIAL (o.e.m.) COST, \$/LB.(*)	0.42	1.10-1.60	1.00-1.50
REPLACEMENT COST, \$/kW-hr	0.84	2.20-3.20	2.00-3.00
INITIAL (o.e.m.) COST, \$/kW-hr	33	31-46	20-30
INITIAL (o.e.m.) BATTERY COST, \$	630	1200-1740	740-1160
REPLACEMENT BATTERY COST, \$	1260	2400- 3480	1540- 2320

(*) December 1975 Price

TABLE F-2. CURRENT PRICES OF GOLF CART LEAD-ACID BATTERIES

MANUFACTURER	BATTERY	VOLTS	SPECIFIC CAPACITY	PEAK CAPACITY	WET WEIGHT	BATTERY PRICE, $		BATTERY PRICE, $/LB	
			W-hr/lb	mins*	lbs	o.e.m.	recommended retail	o.e.m.	recommended retail
A	1	6	10.4	88	59.8	$23.30	$47.92	0.39	0.80
	2	6	11.5	106	65.1	$28.10	$57.13	0.43	0.88
B	3	6	9.3	75	56.5	$23.00	$68.65	0.41	1.22
	4	6	11.1	100	63.2	$27.00	$81.95	0.43	1.30
C	5	6	10.1	82	57.0		$72.00		1.26
	6	6	11.2	100	63.0		$85.00	—	1.35
				88	60.0		AVERAGE	0.42	1.14
RETAIL CHAIN	7	6		88	60.0		$41.99		0.70 (actual)

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*At 75 amp discharge to 5.25 volts at 77°F.

F.2 COST ESTIMATION OF DC TRACTION MOTORS FOR ELECTRIC VEHICLES

F.2.1. MOTOR CHARACTERISTICS

For purposes of cost estimation, it was assumed that electric vehicles would be powered by a d.c. series wound motor used in conjunction with an SCR chopper controller. This type of equipment has been used successfully for a number of years in electric locomotives, fork lift trucks, delivery vans and golf carts and is thus available commercially. Their high starting torque, as well as their simplicity and, reliability are attractive features of series wound d.c. motors in this type of application.

While d.c. series motors have been the primary choice for off-the-road commercial electric vehicles, and for the limited number of on-the-road electric vehicles that have been built, these motors have their limitations in terms of cost, maintenance and energy conversion efficiency. As discussed in the literature, other types of a.c. and d.c. moters are being investigated as potential power sources for electric vehicles, which one day could supplement or replace present d.c. traction motors.[3,39].

F.2.2 COSTS

Price estimates for the cost of DC motors of the type that could be used to drive electric vehicles were obtained by contacting electrical motor manufacturers to obtain o.e.m. prices, by contacting local dealers of fork lift trucks to obtain retail prices, and from the literature. For purposes of comparison, prices were also obtained for equivalent non-traction DC motors.

F.2.3 O.E.M. MOTOR COSTS

The most reliable source of cost data for traction motors was an August 1975 catalogue and price list obtained from a major manufacturer of DC traction motors. The representative catalogue prices are presented in Table F-3 for both low voltage, low speed

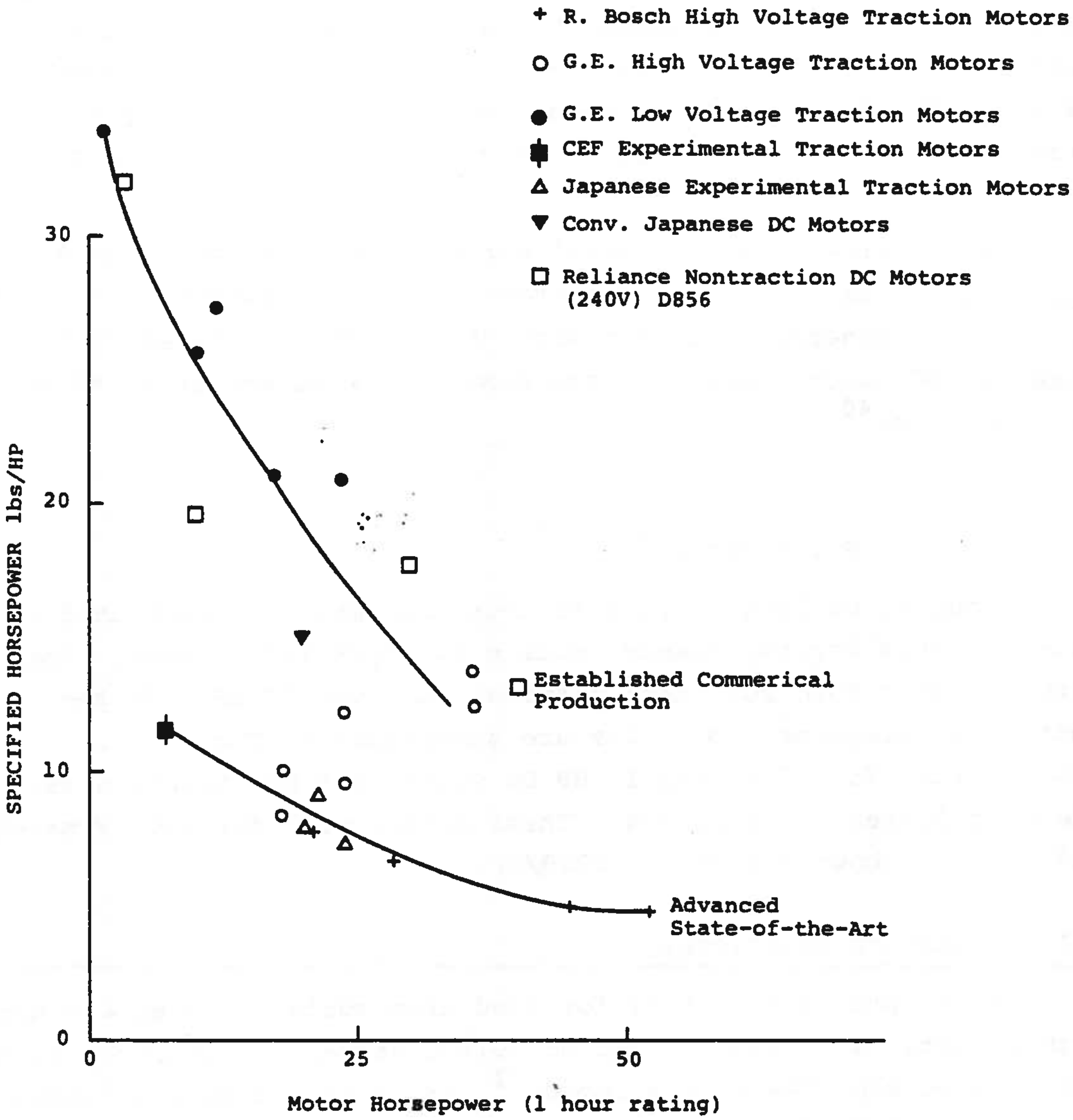

Figure F-1. Specific Motor Output Vs. Motor Output

DC traction motors and high voltage, high speed DC traction motors. Because of two price revisions since last August, present prices (12/75) for the purchase of 50 motors or more are approximately 15% higher. The lower voltage motors in the 10 HP to 24 HP range sell for an average price of \$3.83/lb. (with a range of \$3.46/lb to \$4.07/lb). On a horsepower basis, these motors cost approximately \$89/HP on the average (from \$100/HP at 10 HP to \$78/HP at 24 HP). The higher voltage motors sell for an average of \$5.76/lb (range \$4.46/lb to \$7.47/lb) or about \$62/HP (ranging from \$57/HP to \$67/HP).

These prices are in general agreement with rough telephone quotations obtained from other traction motor manufacturers. They are also in general agreement with the average o.e.m. price for integral DC motors obtained from Census of Manufacturers, as shown in Table F-4.[40]

F.2.4 RETAIL MOTOR PRICES

A number of local fork lift truck dealers were contacted to obtain prices for replacement motors for fork lift trucks. The largest motor sold for these purposes is about 10 HP. Representative telephone quotations are summarized in Table F-5. Quoted price for 10 HP and 15 HP DC motors for non-traction use are also listed in Table F-4. These motors sell for approximately \$10/lb from about \$150/HP to \$300/HP.

F.2.5 SCALE OF MANUFACTURE

The shipments of motors for land transportation uses are not insignificant. In 1972, a total of 55,000 self-propelled golf carts and related vehicles were shipped.[41] It is estimated that about 70%, or about 40,000 of these were electrically powered. Approximately,

TABLE F-3. CHARACTERISTICS AND PRICE (8/75) OF REPRESENTATIVE D.C. TRACTION MOTORS

HORSEPOWER 1 Hour Thermal Rating	COOLING	VOLTAGE	RPM	WEIGHT lbs	BASIC MOTOR Price/ Each $ (Lot of 50 or more	lbs/HP	COST $/HP	COST $/lb
2.0	TENV	24-72	~1000	68	371	34	$188.50	$5.4
10.3	TENV	24-72	~1000	265	1028	25.7	$ 99.81	3.8
12.2	TENV	24-72	~1000	334	1154	27.4	$ 94.59	3.4
17.6	TENV	24-72	~1000	370	1507	21.0	$ 85.63	4.0
23.6	TENV	24-72	~1000	490	1832	20.8	$ 77.63	3.7
18	Sep. Vent	120	3100	150	1120	8.3	$ 62.22	7.4
18	Sep. Vent	120	2400	180	1210	10.0	$ 67.22	6.2
24	Sep. Vent	120	3000	230	1370	9.6	$ 57.08	5.9
24	Sep. Vent	120	1800	290	1560	12.1	$ 65.00	5.3
36	Sep. Vent	120	2100	445	2050	12.4	$ 59.94	4.6
36	Sep. Vent	120	1500	495	2210	13.8	$ 61.39	4.4

TABLE F-4. DC MOTOR COST ESTIMATES BASED ON 1972 CENSUS OF MANUFACTURERS

HORSEPOWER RANGE	NUMBER MANUFACTURED	TOTAL VALUE (1972)$	AVERAGE PRICE PER MOTOR (1972)	AVERAGE PRICE PER MOTOR DEC. 1975*	PRICE AVERAGE HP
1-5 HP	16×10^3	6.7×10^6	$ 419	$ 578	$193
5 - 20 HP	10×10^3	18.6×10^6	$ 930	$1283	$102
21 - 50 HP	5.3×10^3	10.4×10^6	$1962	$2708	$ 76
Total	41.3×10^3	35.7×10^6			

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* 1972 Electric Equipment Index 103.5
Dec. 1975 143.3

Inflation Factor = 1.38

Source: Ref. 40

TABLE F-5. REPRESENTATIVE RETAIL PRICES FOR ELECTRIC DC MOTORS (12/75)

Manufacturer	Motor	Output	Weight (lbs)	Retail Price
<u>Traction Motors</u>				
A	DC Series Wound self ventilated open motor	6.6 HP (36 V) 8.7 HP (48 V)	∿150	$1650
A	DC Lift Motor	7 HP (36V) 10 HP (48V)	100-125	$1390
B	DC Series Wound	5.5 HP	∿170-200	$1400 (rebuilt) $2000 (new)
<u>Non-Traction</u>				
C	DC Motor, 3500 RPM Drip proof, shunt wound	10 HP	190	$1940.52
C	DC Motor, 3500 RPM Drip proof, shunt wound	15 HP		$2366.94

50,000 electric trucks and tractors were also shipped. Of these 2,900 were pedestrian cart motorized hand trucks and 19,200 were riding vehicles.[42]

In 1972 the industrial truck industry consumed 59,800 integral horsepower electric motors (1 HP and over) with a value of $9.6 million.[42] Most of these were low horsepower motors. The total value of motors and generators for storage battery transportation and electric buses shipped in 1972 amounted to $51.6 million.[40] This is approximately 45% more than the value of the 41,000 1 HP to 50 HP DC motors and generators listed in Table F-4 that were shipped for non-traction use in that year and which have similar characteristics.

Based on the above, at least 200,000 DC motors of the general type that would be used to drive electric vehicles are now manufactured annually in the U.S. It is expected that the same manufacturing technology and cost structure would apply to electric motors destined for use in on-the-road electric vehicles.

Based on the above, it is expected that $4/lb is a realistic o.e.m. price for motors for electric vehicles. This is representative of the price of low voltage fork lift truck motors that are now manufactured in significant quantity. These motors would have the performance characteristics of the higher advanced state of the art motors described in Figure F-1. On a power output basis, these motors would cost $32/horsepower (1 hour rating).

F.3 COST OF CONTROL ELEMENTS FOR ELECTRIC VEHICLES

In estimating the manufacturing costs of an electric vehicle, it was assumed that the current to the motor would be controlled by a SCR chopper converter without a regenerative braking capability. These semiconductor based controllers are now commonly used to control integral DC motors. Price and performance characteristics of SCR chopper controllers are shown in Table F-6 and Figure F-2. The price of these units varies with continuous current rating, battery voltage, peak current capability, and the quantity purchased.

TABLE F-6. PRICE RANGE OF ELECTRIC VEHICLE CONTROLLERS*

Manufacturer	Component	Continuous Current Rating, amps at Room Temp (77°F)	Peak Current Rating, amps	Input Voltage	Price per unit, $ units Purchased 1-99	100-999	1000 or more
A	SCR Chopper 1	100	450	12-24		(440)	(~ 350)
	2	170	650	to			
	3	250	850	84-144		(750)	(~ 600)
	4	350	1100			(1000)	(~ 800)
B	SCR Chopper 1	200	650	30-40	700	600	
	2a	400	800	40-80	800	680	
	2b	400	800	80-130	1000	850	
	3	400	1200	130-170	2000	1700	
C	SCR Chopper 1	100	250	36-90	649	549	
	2	200	500	36-90	1170	1000	
D	Switching Transistor 1	200	1000	12-96	250	200	
	2	400		12-96	450	360	
	3	600		12-96	675	590	
	4	800		12-96	800	(640)	

* Note: December 1975 price
Values in Parentheses ( ) are Estimates

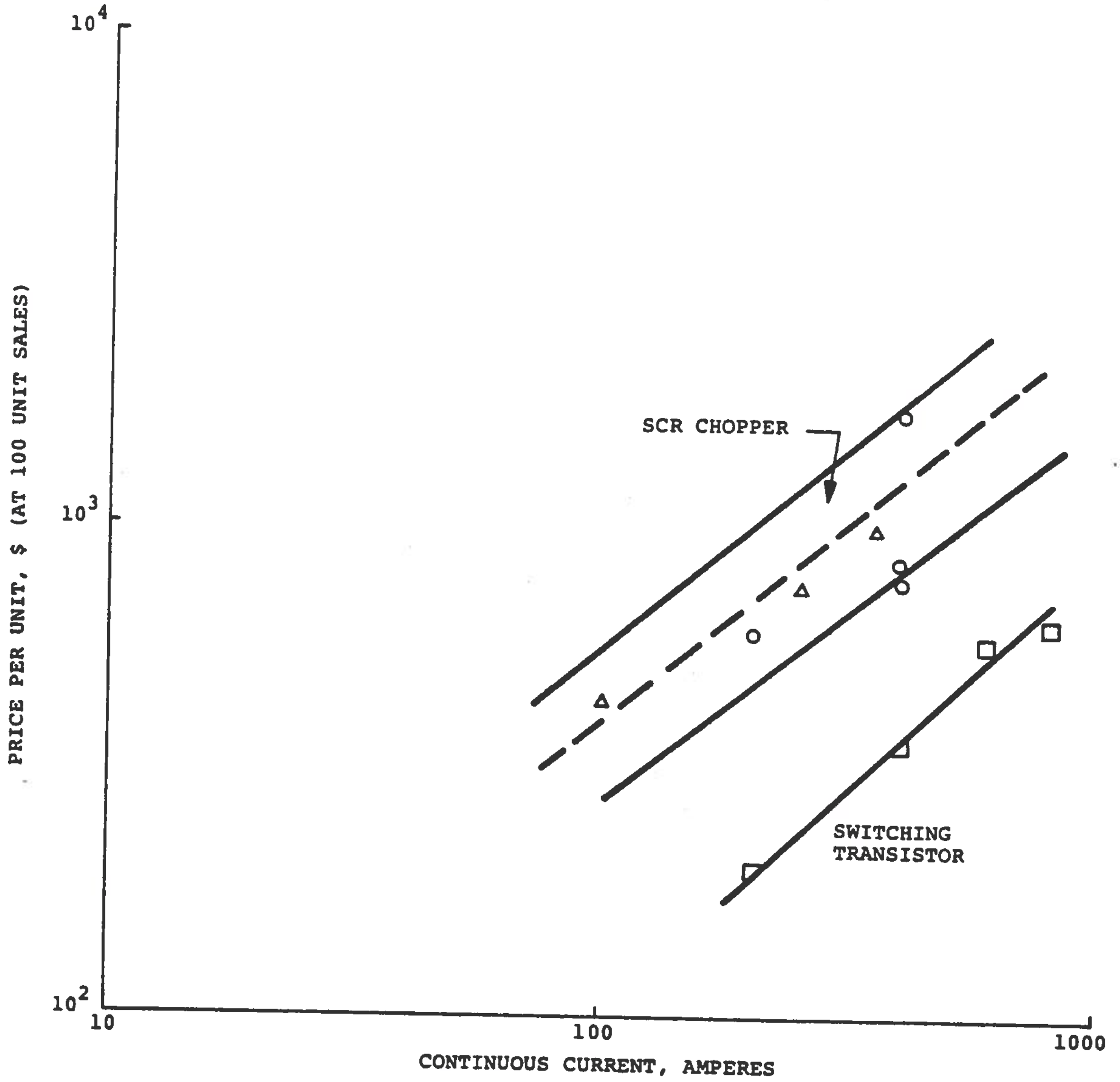

Figure F-2. Limited Purchase O.E.M. Price of Electric Vehicle Controllers without Accessories

A recent development is the commercialization of a switching transistor to control the current of a DC motor. These units have just been introduced to the market by manufacturer D. If these switching transistors perform effectively in service, this will result in a significant reduction in the cost of DC current controllers within a short period of time. The price of these switching transistors is also presented in Table F-6 and Figure F-2.

In addition to the motor and controller, the electric circuit of an electric vehicle contains a number of other elements which contribute significantly to the cost of the circuit. These include contractors, cables, analyzers, and meters. The prices of double pole, double throw, high current contactors are presented in Table F-7 and Figure F-3. The contactor rating specified is usually 1.5 times the continuous current rating of the controller.

The other elements of the circuit which are not sensitive to the current rating contribute about $250 more to the cost of the circuit. For example, the manufacturing cost of electrical components for an electric vehicle would be as follows:

200 amp SCR Controller	(Figure F-2)	$700
300 amp DPDT Contactor	(Figure F-3)	$240
Other circuit elements		$250
TOTAL		$1190

This price assumes that the components are purchased in lots of 100 units or more.

F.4 PROJECTED MASS PRODUCTION COSTS FOR ELECTRIC MOTORS AND CONTROLLERS

F.4.1 D.C. TRACTION MOTORS

While it is impossible to present with great accuracy what the exact cost of electric vehicle traction motors would be if these were produced in millions, some guidelines can be obtained from the data published in the 1972 Census of Manufacturers for SIC 3621 - Motors and generators.[43] According to the Census, cost of

TABLE F-7. PRICE RANGE OF DPDT REVERSING CONTACTORS FOR ELECTRIC VEHICLES

Manufacturer	Current Rating Amperes	Price Per Unit, Dollars 1 unit,	100 units,	1000 units or more
A	100-350	20 to 40% of controller price		
B	300	300	255	
C	75	200		
	150	249	199	
	300	300		

Note: December 1975 Prices

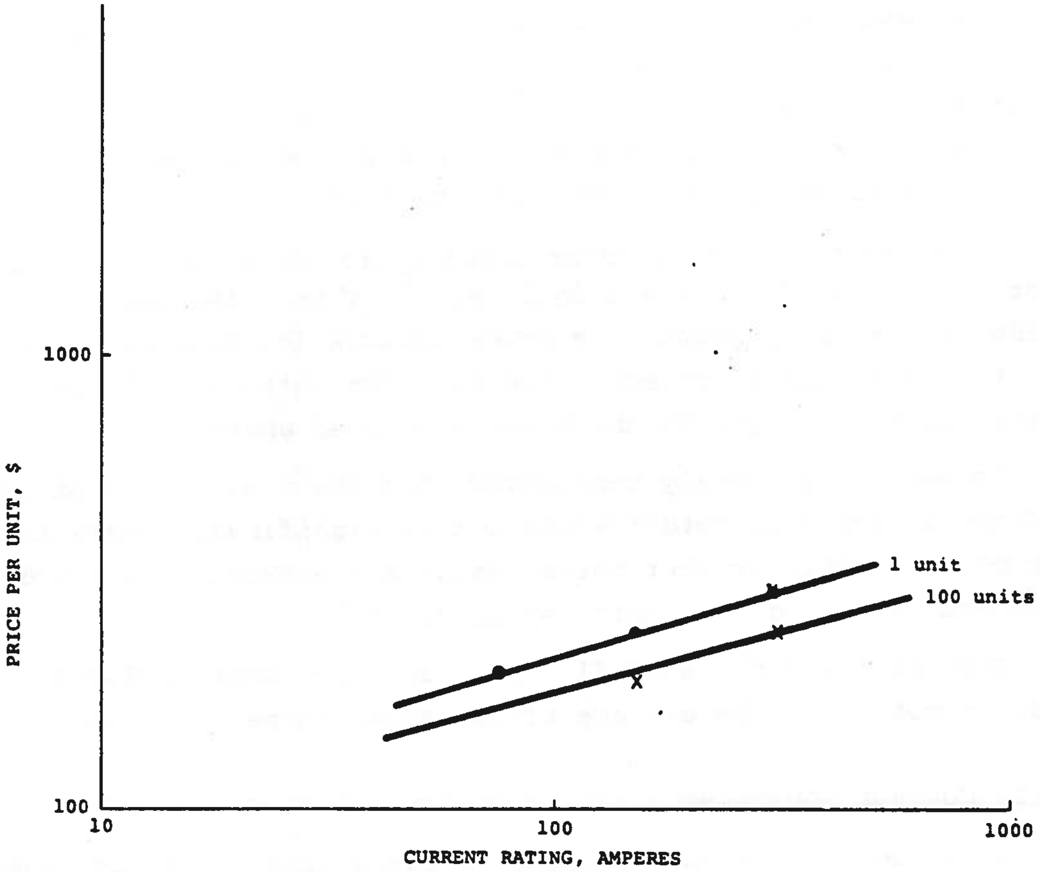

Figure F-3. Price Range of Double Pole Reversing Contactors for Electric Vehicles materials represented $0.42 of every dollar of shipments. Conversely, the ratio of o.e.m. motor price to the cost of materials that were used to produce this motor is 2.38.

The material composition of an electric vehicle DC traction motor was published in a recent JPL report, and is presented in Table F-8,[1] as are current material prices.[44] Using a typical manufacturing scrappage rate of 35%, it is estimated that the cost of materials for this motor is $136.51 or $0.43/lb.

If millions of these motors were manufactured on an annual basis, it would not be unreasonable to assume that industry average statistics would apply to this item. Thus, the manufacturer's sale price could be assumed to be 2.38 x 0.43 or $1.02/lb. The 315 lb motor mentioned in Table B-1 would thus cost $322 o.e.m. instead of $1260, a reduction of $938.

Unnewehr of the Ford Motor Company projected an o.e.m. DC motor cost of $0.82/lb (1972 dollars).[45] This value was multiplied by the ratios of the wholesale price indices for December 1975 and 1972 to obtain a projected o.e.m. motor cost of $1.07/lb which agrees quite closely with the value developed above.

Unnewehr alternately considered that the o.e.m price of mass produced DC traction motors would not be significantly more than that of automobile starter motors which are presently mass produced and have an o.e.m. price of $1.29/lb.[46]

The projected price of $1.13/lb. used for mass produced traction motors is the average of the above three estimates.

F.4.2 CONTROL EQUIPMENT

It is believed that the price of controllers would decrease significantly as well. According to the 1972 census, total value of motors and generators for all land transportation was $270.3 MM, while the value of control equipment was 60% of the cost of motors and generators.[43] Assuming this ratio would apply to mass produced electric vehicles, the cost of the controller and other control elements in the motor described in Table F-8 would be $214. At the

TABLE F-8. COST OF MATERIALS FOR A DC MOTOR

	WEIGHT, LBS	UNIT PRICE $/LB (1)	COST
COPPER	47	0.88 (1)	$ 41.36
IRON	189	0.10 (2)	18.90
STEEL	40	0.143(3)	5.72
ALUMINUM	32	0.49 (4)	15.68
OTHER	7	1.00 (5)	7.00
SUB-TOTAL	315		$ 88.66
SCRAPPAGE (35% OF PURCHASED MATERIAL)	170		47.85
TOTAL PURCHASED MATERIAL	485		$136.51
PRICE OF MATERIALS/LB OF MOTOR PRODUCED			$ 0.43

1) BARE COPPER WIRE
2) NO 2 FOUNDRY IRON
3) COLD REDUCED MOTOR LAMINATION SHEET
4) 380 ALLOY INGOT
5) NOMINAL ASSUMED VALUE

Source: Ref. 43

1 million unit production level, Unnewehr[45] projected an o.e.m. price of $135 (current dollars) for a DC chopper for a 40 HP DC motor without regeneration and of $254 (current dollars) if regeneration were provided. These prices do not include any other components of the electric circuit.

If one includes the cost of all the electric circuit elements, with the exception of the motor and the charger, in the cost of the controller, the estimated controller price based on 60% of the price of the motor does not seriously disagree with Unneweher's price for a controller without regeneration. This was the approach used in the mass production estimates presented in Appendices C and E.

APPENDIX G

MANUFACTURING COST OF AN AUTOMOBILE CHASSIS

G.1 METHODOLOGY AND ASSUMPTIONS

It was assumed that the chassis of an electric vehicle would be similar to the chassis of an ICE-powered vehicle. It is assumed that the material costs per unit weight, the production facilities and tooling, and the labor required to manufacture and assemble the component parts into a vehicle, other than for the cost of the engine and accessores would be the same. Subtracting the manufacturing cost of the engine and accessories from the manufacturing cost of the complete ICE-powered automobile, gives an estimate of the manufacturing cost of the chassis including final vehicle assembly for an ICE automobile, and by analogy, for the electric vehicle.

G.2 MANUFACTURING COST OF ICE-POWERED VEHICLE

The manufacturing cost methodology used in this report is the same as that used in Chapter 6 of the Working Draft of Report of the Task Force on Motor Vehicle Goals Beyond 1980.(50) This manufacturing cost (Cp) is the sum of the following:

$$C_p = C_m + C_c + C_L$$

where

C_m = Cost of purchased raw and finished materials

C_c = Cost of components

C_L = Cost of labor

Table G-1 gives the unit cost estimates for raw and finished materials and special components.

TABLE G-1 - UNIT COST ESTIMATES FOR RAW AND FINISHED MATERIALS AND SPECIAL COMPONENTS FOR AN AUTOMOTIVE VEHICLE IN 1975 DOLLARS

Raw and Finished Materials

Steel	$.18 per pound
Iron	.12
Aluminum	.59
Copper	.89
Plastic	.79
Tires	.54
Batteries	.42
Glass	.42
Other	.37
Total Vehicle	$.25 per pound
Special Components Catalytic Converter	$58.00

The cost of labor is computed by multiplying labor hours times the cost of labor per hour. It was assumed that labor hours were independent of vehicle size for vehicles of equal complexity. Labor hours of 127 hours per vehicle were determined from an analysis of the 1972 Census of Manufacturers. Labor included hours of workers up through the working foreman level engaged in fabrication, assembly, inspection, storage, receiving handling, packing, warehousing shipping, maintenance, repair, janitorial and watchman services, product development auxiliary production for plants' own use (e.g., power plant), recordkeeping, and other services closely associated with these production operatins at the plant. Supervisory employees above the working foreman level are included in corporate overhead. The labor hours included all the labor required to manufacture and assemble all the components of the vehicle except the catalytic converter which was treated as a purchased component.

The cost of labor was $11.00 per hour. This cost includes labor cost, benefits and the cost of warranty maintenance and repair tooling and other factor overhead.

The manufacturing cost of a 2000 lb. ICE-powered vehicle is given in Table G-2.

G.3 MANUFACTURING COST OF AN INTERNAL COMBUSTION ENGINE AND ASSOCIATED PARTS

The internal combustion engine and associated parts of an ICE-powered vehicle consisted of the engine and accessories, the fuel system, and the exhaust system. These are the parts of an ICE-powered vehicle that would be replaced by an electric motor, controller and battery system in an electric vehicle.

As determined from Appendix I, the engine and associated parts generating plant for a 2000 lb. ICE-powered automobile would weigh approximately 440 lbs and would have a manufacturing cost of $482 (Dec. 1975 dollars).

TABLE G-2

MANUFACTURING COST OF 2000 LB ICE AUTOMOBILE (*)

	Units	Unit Cost	Cost
Raw Materials	2000 lbs.	0.25/lb.	$500
Labor	127 manhours	$11/manhour	$1397
Components (Catalytic Exhaust System)**	1 ea.	$58	58
TOTAL			$1955

Sources (*) Ref. 50

(**) Ref. 51

NOTE: Costs are in December 1975 dollars

G.4 MANUFACTURING COST OF AN AUTOMOBILE CHASSIS

By substracting the manufacturing cost of the engine and associated parts from the cost of the total vehicle, the manufacturing cost of the chassis and reset of assembling of the vehicle is obtained.

From Table G-2, the cost of the 2000 lb of $1955 vehicle is obtained. Subtracting $482 for the cost of the engine and associated parts yields an amount of $1473 for the manufacturing cost for a chassis weighing 1560 lbs.

For vehicles in the same general category, variations in chassis weight would only effect the amount of materials required and not impact the labor costs. The production costs, C_p of chassis that weight W lbs. can be expressed by the following equation.

$$C_p = \$1473 + (W-1560)\ (0.25)$$

G.5 CAPITAL INVESTMENT FOR A VEHICLE MANUFACTURING FACILITY (250,000 VEHICLES/ANNUAL CAPACITY)

If the propulsion subsystem of an electric vehicle is considered to consist of purchased components, the capital investment required to mass produce electric vehicles at given annual production rate would be equal that required to mass produce ICE vehicles less the capital investment required to manufacture the power generation plant.

A detailed analysis of the capital investment required for a manufacturing complex with an annual production capability of 500,000 ICE automobiles was recently published by the Task Force on Motor Vehicle Goals (50). These results are presented in Table G-3. The only investments that would not be required to manufacture an equivalent number of electric vehicles would be those needed to build the engine line and the foundry. Even though the foundry makes castings for other sections of an automobile than the engine (e.g., the transmission), the total cost of the foundry assigned to ICE power plant since most of the castings made go into the engine. To balance this exagerating assumption, no capital investment was

TABLE G-3 - TOTAL LAND, BUILDING FACILITIES AND EQUIPMENT COSTS FOR A MANUFACTURING COMPLEX FOR THE ANNUAL PRODUCTION OF 500,000 AUTOMOTIVE VEHICLES

	Engine	Foundry	Stamping	Trim	Vehicle (1) Assy	Trans-mission
Land	0.8	0.8	0.1	0.1	5.0	.7
Land Improvement	16.8	30.0	3.4	1.2	26.8	14.3
Buildings	68.6	129.5	173.6	58.5	100	52.0
Materials Handling	3.9	34.9	22.8	7.6	43.8	3.0
Environmental Control	28.0	5.5	16.7	5.5	40.0	20.0
Power House	11.5	22.3	16.1	5.5	34.0	10.0
Tooling	37.7	9.6	105.3	10.0	77.4	15.0
Equipment	106.1	35.0	50.0	40.0	372.7	40.0
Launching	25.4	6.4	21.3	10.0	68.8	20.0
Total	298.8	274.0	409.3	138.4	769.5	175.0
Grand Total		2065.0				

(1) Includes component manufacture and assembly by vehicle manufacturer.

NOTE: Cost are in millions of 1974 dollars

Land: 1900 acres of $4000 per acre

Buildings: 9×10^6 ft.^{2} at $77 per ft.^{2} average assigned to the manufacture of components of the fuel and exhaust systems that were made in-house. Based on Table G-3, 72% of the grass roots costs of an ICE automotive manufacturing facility would be required for an electric vehicle facility.

The capital investment requirements in December 1975 dollars for a complex manufacturing 250,000 vehicles a year are presented in Table G-4. It was assumed that the capital investment is directly proportional to the production rate, or half the values presented in Table G-3. The wholesale price index for all industries (50) was used to adjust the as published costs (in 1974 dollars) to December 1975 dollars.

Accordings to Table G-4, at the 250,000 vehicle/year production level, an ICE manufacturing facility would require an investment of about $1.2 billion. An equivalent E.V. manufacturing facility would require an investment of about $850 million. If a twenty year life is assumed for these facilities, the capital investments per vehicle are respectively $237 and $171 for the two vehicles.

The difference of $66/vehicle is due to the elimination of the capital requirements for the engine plant and foundry for the ICE vehicle. Because the motor, controller and battery are components manufactured by others than the vehicle manufacturer, the capital requirements required for the manufacture of these components will be borne by the vendors and is reflected in the price of these components.

This small difference of $66 per vehicle in capital requirements is only about 1% of the projected purchase price of the vehicle, and thus will not effect it significantly.

TABLE G-4

CAPITAL INVESTMENT REQUIRED FOR A MANUFACTURING COMPLES FOR THE ANNUAL PRODUCTION OF 250,000 ICE AUTOMOBILES

	Foundry & Engine Plant	Chassis & Vehicle Assembly Plants	Total Facility ICE Automobiles
	CAPITAL INVESTMENT* (Million $)		
Facilities	205	378	583
Tooling, Equipment, Launching	128	476	604
Total	333	854	1187
	CAPITAL INVESTMENT (PER UNIT PRODUCED**)		
Facilities	$41.0	$75.6	$116.6
Tooling, Equipment, Launching	$25.6	$95.2	$120.8
Total	$66.6	170.8	$237.4

(*) In December 1975 Dollars
(**)Based on a 20 yr Facility Life

APPENDIX H
PUBLIC DOCKET SUBMISSIONS

To assist in the preparation of this report, a public docket was opened to solicit information and comments. On March 3, 1976, the following notice was published in the Federal Register (Vol. 41, No. 43, page 9221):

> FUEL ECONOMY STANDARDS FOR ELECTRIC AND OTHER NON-FUEL VEHICLES
>
> Request for Information and Public Comment
>
> The Department of Transportation is conducting a study of the advisability of including electric vehicles and vehicles that operate on fuels other than gasoline or diesel fuel within the regulatory framework for increased motor vehicle fuel economy established in section 301 of the Energy Policy and Conservation Act (Pub. L.95-193). That act added a new Title V to the Motor Vehicle Information and Cost Savings Act of 1972 which provides for mandatory fuel economy standards for new motor vehicles powered by gasoline and diesel fuel. Section 512(b) of Title V requires the Department to report to the Congress and the President on the advisability of including electric and other non-fuel vehicles within the coverage of Title V. Non-fuel vehicles are defined as those fueled by other than gasoline or diesel fuel. Section 512(b) addresses attention to four items:
>
> 1. The extent to which electric and other non-fuel vehicles should be covered by Title V.
> 2. The manner in which the energy requirements of such vehicles may be compared with the energy requirements of fuel-consuming vehicles.
> 3. The extent to which inclusion of such vehicles would simulate their production and introduction into commerce.
> 4. Any recommendations for legislative action.
>
> To assist in the study, the public is invited to submit information and comments relevant to the four issues above, plus any other information and comments pertinent to the object of the study. Comments (three copies, if possible) should identify the file number (OST file No. 42) and be sent to the Docket Clerk, Office of the General Counsel, TGC, Department of Transportation, Washington, D.C. 20590. The target date for submission of the report is June 1, 1976; therefore, all comments received by the close of business Friday, April 9, 1976, will be considered. Material submitted to the file will be available for public inspection and copying, and for

responsive comment, in the Office of the Assistant General Counsel for Operations and Legal Counsel, Department of Transportation, Room 10100 Nassif Building, 400 Seventh Street, SW., Washington, D.C., between 9:00 a.m. and 5:30 p.m. local time, Monday through Friday, except Federal holidays.

Issued in Washington, D.C., on February 26, 1976.

Dr. Richard L. Strombotne,
Chief, Energy and Environment
Systems Division.

[FR Doc. 76-6106 Filed 3-2-76;8:45 am]

[OST FILE NO. 41; Notice 76-1]

Ten groups submitted materials and opinions: Chrysler Corporation; the Electric Vehicle Council; Ford Motor Company, Inc.; General Motors Corporation; General Research Corporation; Lucas Industries Limited; Sebring Vanguard, Inc.; the U.S. Energy Research and Development Administration; the U.S. Environmental Protection Agency; and the U.S. Postal Service. Opinions diverged on each of the four items raised in the notice.

Most respondees asserted that fuel economy standards for electric and other non-fuel-consuming vehicles would be premature, and should consider only petroleum consumption rather than total energy consumption. Opposition to regulation was based largely on the assumption that no significant petroleum savings would accrue.

Opinion was evenly divided on whether fuel economy should be compared based on overall energy efficiency from primary source to final utilization or on petroleum consumption alone. Some concern was expressed that currently used driving cycles do not provide adequate comparison of electric and conventional vehicle fuel economy, and that electric vehicles should not be penalized for inefficiencies in electricity generation.

Submissions disagreed as to whether regulation would stimulate the market for non-fuel-consuming vehicles. Several respondees believed that a valid comparison of fuel economy would stimulate the market, particularly in some applications and if comparison were based on petroleum consumption. The balance of the respondees asserted that regulation would have no stimulating effect, and could discourage small manufacturers.

Recommendations for legislative action centered on continued support for research on new technology, data collection, and demonstration of electric vehicle technology. In addition, fuel economy labeling of electric vehicles was recommended to assist consumer decisions, without accompanying fuel economy standards.

Individual responses are summarized in Table H-1 for each major item defined in the request for information and public comment. The full text of the submissions is reproduced on the following pages.

TABLE H-1 SUMMARY OF INDIVIDUAL RESPONSES

Respondee*	1. Title V Coverage?**	2. Manner of Comparison**	3. Effect of Inclusion on Production**	4. Recommendation**
Chrysler	No, it would not save petroleum	Electrics should not be penalized for inefficiencies in electricity generation	No, no significant effect	-
Electric Vehicle Council	Yes, if only on-board energy is considered and valid test cycles developed; otherwise no	Based on on-board fuel using an electric vehicle duty cycle	Valid comparison of fuel economy would stimulate sales	-
Ford Motor Co.	Yes, to the extent that they use petroleum	Overall efficiency using SAE metro cycle with payload considered	Could stimulate sales for some uses	Fuel economy labelling should be required; no other incentives
General Motors	No, but their petroleum requirements should be considered	Based on petroleum consumption	No, may discourage manufacturers	-
General Research Corporation	No	Overall energy efficiency; valid comparison not feasible at this time	No, would discourage manufacturers	-
Lucas Industries	No, would not save petroleum	Current cycles inappropriate	Valid comparison would stimulate sales	-
ERDA	No	Overall energy efficiency, with credit for low petroleum use	Credit for low petroleum consumption could stimulate sales	Continuing assessment
Postal Service	No	Overall energy efficiency	No, would discourage developers	Electric vehicle demonstration program

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*Information submitted by Sebring Vanguard, Inc., and the Environmental Protection Agency did not include opinions on these questions.

**See numbered items in Request for Information and Public Comment, page H-1.

CHRYSLER
CORPORATION

S. L. TERRY
VICE PRESIDENT
PUBLIC RESPONSIBILITY
AND CONSUMER AFFAIRS

April 7, 1976

Docket Clerk
Office of the General Counsel
TGC
Department of Transportation
Washington, D. C. 20590

Re: OST File No. 42
Request for Information and Public Comment
"Fuel Economy Standards for Electric and
Other Non-Fuel Vehicles"

Chrysler Corporation submits the attached comments on the reference notice published in the Federal Register, Vol. 41, No. 43, March 3, 1976, Page 9221.

Attached are our comments on each of the four specific questions listed in the notice.

Also attached is a copy of Chrysler Corporation's comments to Senator Moss on proposed legislation involving electric vehicles. Other than Federal support of electrical car research as outlined in that statement, we recommend no additional legislation at this time with respect to Title V.

Sincerely,

SL Terry by RJ

/ms

Attach.

P. O. BOX 1919, DETROIT, MICHIGAN 48231

CHRYSLER CORPORATION COMMENTS

ON

DOT REQUEST FOR INFORMATION AND PUBLIC COMMENT REGARDING "FUEL ECONOMY STANDARDS FOR ELECTRIC AND OTHER NON-FUEL VEHICLES"

RFERENCE: OST File No. 42; Notice 76-2;
Notice in Federal Register,
Vol. 41, No. 43, March 3, 1976,
Page 9221

The following comments are provided in response to the four specific items noted in the above reference notice:

(1) "The extent to which electric and other non-fuel vehicles should be covered by Title V."

The basic purpose that fostered Title V was conservation of petroleum in order to reduce the use of our petroleum resources in the United States and to reduce our dependence on uncertain foreign supplies. If and when electric or other non-fuel powered cars are substantial users of petroleum for their basic power source we believe they should be covered by Title V. However, in view of the small number of such vehicles now involved, and the possible conversion of much of the electric generating capacity of the country to non-petroleum energy sources such as coal and nuclear energy, we recommend that they not be included at this time.

(2) "The manner in which the energy requirements of such vehicles may be compared with the energy requirements of fuel consuming vehicles."

$$\text{Miles/Gallon of Gasoline} = \frac{\text{Miles}}{\text{Kilowatt-hours}} \times \frac{\text{6 Kilowatt-hours}}{\text{Lb. Gasoline}} \times \frac{\text{6 Lbs. Gasoline}}{\text{Gal. Gasoline}} = \text{Miles/Kwh} \times 36$$

(2) (continued)

Knowing the electric vehicle's consumption in miles/kwh, the "equivalent" miles per gallon of gasoline may be calculated. Line losses and losses at the generating plant have not been included in determining the kwh input to the electric vehicle. Since these losses apply to lighting and other electric appliances, and the electric car is a potential efficiency improver for the utilities by virtue of its load leveling use of off-peak power, it would not be fair to penalize the electric vehicle for inefficiencies it cannot control.

(3) "The extent to which inclusion of such vehicles would stimulate their production and introduction into commerce."

Electric vehicles have many inadequacies at their present stage of development. These include higher initial cost, poor performance, excess weight, and very limited range (50-100 miles on level ground at 80°F with dramatic reductions if the temperature drops or the vehicle must climb hills). Until these technological problems are resolved to make electric vehicles more competitive with currently available vehicles, we do not believe their inclusion or exclusion will have any material effect to stimulate their introduction into commerce, or to induce American consumers to purchase them.

(4) "Any recommendations for legislative action."

Attached is a statement giving Chrysler Corporation's views on electric vehicles and legislation pertaining to such vehicles. As indicated in that statement we believe "The total welfare of the country would be best served by government support of the substantial research and development required to realize a viable electric vehicle, rather than the premature, subsidized introduction of an at best marginal product.

"When a viable electric vehicle results from the products of this recommended research, the economies of the marketplace and the competitive nature of American industry will combine to dictate the prompt production of this, or any product, which can truly serve the public need."

CHRYSLER
CORPORATION

October 2, 1975

The Honorable Frank E. Moss
Chairman
Subcommittee for Consumers
Committee on Commerce
United States Senate
Washington, D. C. 20510

Dear Senator Moss:

This is in reply to your recent letter to J. J. Riccardo, Chairman of the Board, Chrysler Corporation, inviting us to comment on S. 1632 and H. R. 8800, the Electric Vehicle Research, Development and Demonstration Act of 1975.

Attached is a statement giving Chrysler Corporation's views on electric vehicles and legislation being considered. The statement also answers most of the questions submitted with your letter. We hope it will be useful to you and the Committee in your deliberations on these bills.

We request that the statement be included in the record of the Senate Commerce Committee's hearings on electric vehicles.

Sincerely,

John D Withrow Jr.
J. D. Withrow, Jr.
Director-Research

JDW:mg
Attachment

bc: G. F. Butts
R. Connors
J. Lunan
R. O. Sornson
D. M. Teague

CHRYSLER CORPORATION COMMENTS ON S. 1632 AND H. R. 8800

As a manufacturer of motor vehicles Chrysler Corporation is fully aware of the necessity of reducing transportation energy requirements, particularly as they relate to petroleum products. To this end, we have maintained a substantial research and development effort on alternate power plants, including electric vehicles as well as fuel cell and battery research.

In time we believe that electric vehicles will play an increasingly important role in private transportation. However, there is much fundamental research and engineering development that has to be done to improve the limited performance currently available in electric vehicles, before they will meet with general public acceptance. Therefore, while we feel that the objectives of S. 1632 insofar as they promote the technologies necessary to the development of a successful electric vehicle are to be commended, we cannot agree that a purchase demonstration plan using currently available vehicles is the optimum way of encouraging the necessary development. Our assessment is that currently available electric vehicles powered with lead-acid batteries can be used efficiently only in specialized applications with limited ranges, such as urban mass transit, delivery and service vehicles. Present performance of currently available electric passenger cars is not adequate for safe intermixture with regular vehicles in normal urban and suburban traffic. In our view their operations would be best limited to restricted rights of way, such as in resorts and retirement villages. The energy available from lead-acid batteries, and the energy required, regardless of source, for a safe, minimally acceptable vehicle (in terms of performance, traffic mixing, etc.) differ by a factor of from 4 to 10. Use of electrical accessories would further widen this gap; passenger compartment heating would almost certainly require fossil fuels. We feel that these conclusions have been demonstrated by Chrysler and others, and well documented in the literature, and indicate that immediate large scale demonstrations of available electric passenger vehicles would serve no purpose in advancing technology, but would rather show the limitations of the present state-of-the-art, and may inhibit public acceptance.

We would like to suggest an alternate course of action which in our opinion would lead more rapidly to a vehicle accepted by the public, and suitable to a mass market.

As stated before, we believe that stored electrical energy is one viable alternative to the present internal combustion engine in certain applications, but only if such a vehicle can compete on near equal terms with a heat-engined counterpart, size for size. In our opinion, this cannot be done by simple adaptation or conversion of existing vehicles to electric power. To realize the full potential of electric vehicles, it will be necessary to undertake, or continue substantially funded research and engineering development programs on:

- Improved batteries, including advanced lead acid and alkaline cells for the short and near term, and molten salt for the longer term.

- Light weight, high efficiency traction motors, and associated power trains, including transmissions.

- Design of light weight vehicle structure and running gear, with maximum strength/weight ratio, reduced needs for power assists, and minimum aerodynamic and road losses.

Such a program, undertaken and administered by E.R.D.A. would be a more rapid and cost effective method of introducing a more viable electric vehicle, than premature mass demonstrations of current technology.

In parallel with, and possible preceding these technical developments, a study should be made of the nationwide role of the electric vehicle, as has been done for the Los Angeles area. Inputs concerning the most likely usage of a vehicle may affect the direction of research programs. It is not anticipated that within the next 8-12 years any single electric vehicle can be built as a specific replacement for most passenger cars. It is more likely that the first generation of electric passenger vehicles will be sub-compacts, increasing in size where necessary as energy storage systems improve.

In offering the foregoing alternate to an immediate purchase/demonstration of electric passenger vehicles we have been guided by our engineering judgment, experience and knowledge of other alternate power plants, the state-of-the-art of electro chemistry as it pertains to energy sources, and the economics of the marketplace. It is our opinion that the magnitude and long-term nature of the research still required is such that it is appropriate to have Federal government support. Equally, given the requisite technology, the introduction of a new product can best be left to private industry.

In the above general discussion, we have addressed some of the points raised in your questions particularly in regards to the program approach. The following offers further comments on some of the technical questions.

Even with possible improvements in energy density and cycle-life, we do not feel that the lead-acid battery is a serious contender as a means of energy storage. Nickel-zinc is the best candidate for a near term (1980?) "stop-gap" vehicle battery, but the energy density (88 watt-hours/kg) is only about twice that of the lead-acid cell. Cycle life is still a problem and nickel is not a low cost material. For the longer term (1985-1990) the molten salt lithium-sulfur and sodium sulfur cell may achieve 300-350 watt-hours/kg. In both these and similar cells, the operating temperatures of 700-1200°F pose severe engineering problems. Assuming no safety problems, this energy density would be adequate for a medium to light weight vehicle. In both cases, the time table would depend greatly on the level of research funding. Given the present level of public and private funding, it is our opinion that there will not be adequate improvements in the most promising developmental batteries (sodimum-sulphur, lithium-sulfur and lithium-chloride).

The hybrid vehicle has been offered as a power plant combining the best features of the I.C. and electric power plants, but, again based on our own engineering information, and the results of several government funded studies (AiResearch, TRW, Hamilton, etc.) as well as the most recent Ford-funded study by J.P.L. on Alternate Power Plants, we feel that the hybrid vehicle cannot meet any reasonable cost benefit criteria, and shows little, if any, advantage with respect to emissions and fuel economy. Hybrid vehicles, and at this time, even electric vehicles, would not offer any major reduction in petroleum consumption and will probably increase total (all fuels) energy consumption. Total environmental impact with fossil fueled power plants would not be lessened; simply transferred back to the central power station.

Further, based on our engineering judgment and experience, as well as that of others, most recently the Jet Propulsion Laboratory of the University of California, we believe that other power plants, such as the gas turbine, Stirling, Diesel and certain types of stratified charge engines have the potential for greater fuel savings.

As for the required infrastructure, this would be a major long range problem correlative to any transportation system with a significant electric vehicle component. It is an excellent example of the type of problem that must be confronted and solved before embarking on a large purchase/demonstration program of the scope set out in S. 1632. A gradual, orderly increase in the electric vehicle population will bring in its wake public charging facilities sponsored by local government and private sector entrepreneurs. Service facilities would grow with private dealerships.

SUMMARY

A mass purchase of available electric passenger car vehicles, and those likely to be obtainable in the next 18-24 months, would serve no purpose other than to confirm presently documented problems and limitations.

Substantial funding for energy storage research and development would be more productive in accelerating the introduction of an electric vehicle that could compete economically in the private transportation sector. Parallel, unbiased studies on a national scale could define the probable role of various electric vehicles, and resolve the presently clouded issues of total energy and environmental impacts.

The total welfare of the country would be best served by government support of the substantial research and development required to realize a viable electric vehicle, rather than the premature, subsidized introduction of an at best marginal product.

When a viable electric vehicle results from the products of this recommended research, the economics of the marketplace and the competitive nature of American industry will combine to dictate the prompt production of this, or any product, which can truly serve the public need.

Application No.	Exemption No.	Applicant	Regulation(s) affected	Nature of exemption thereof
E75 138 ...	DOT-E [illegible]	U.S. Department of Defense, Washington, D.C.	49 CFR 173.[illegible] Note 11.	To ship monomethylhydrazine in a DOT specification MC 312 cargo tank constructed of [illegible] stainless steel having molybdenum content of less than 0.5 pct (mode 1).
E75 1 ...	DOT-E 7085	[illegible] Corp., San Pedro, Calif.	49 CFR 173.[illegible], 173.[illegible], 173.190, 173.[illegible].	To ship an explosive device, classified as class C, in DOT specification 12B fiberboard boxes having inside cellular packaging (mode 1).
E75 11 ...	DOT-E 7088	NASA, Oakland, Calif.	49 CFR 173.[illegible], 173.92 (a)(1), (b); 14 CFR 103.9.	To make a 1-time shipment of certain explosives exceeding the quantity limitations of 14 CFR 103.9 (mode 4).
E75 5 ...	DOT-E 7091	Owens Illinois, Toledo, Ohio.	49 CFR 173.119(d) ...	To ship a flammable liquid not otherwise specified in a DOT specification 57 portable tank (mode 1).
E75 3 ...	DOT-E 70[illegible]	Monsanto Co., St. Louis, Mo.	49 CFR 173.[illegible] ...	To ship an instant foam solution in a 16-oz-capacity glass bottle containing 252 g of solution (mode 1).
EMERGENCY EXEMPTIONS				
EE76 70...	DOT-E [illegible]	Dow Chemical Co., Midland, Mich.	49 CFR 173.315 ...	To ship liquefied ethylene in a cargo tank comprised of an aluminum inner tank, insulated with polyurethane covering, and an outer steel jacket (mode 1).
EE76 71...	DOT-E 70[illegible]	The Center for Disease Control, Atlanta, Ga.	14 CFR 103.7 ...	To make a 1-time shipment of an etiologic agent, specially packaged, via air (mode 5).
EE76 72...	DOT-E 70[illegible]	[illegible] Caribbean, San Juan, P.R.	46 CFR 146.22 [illegible] ..	To ship nitrocarbonitrate aboard vessels loaded at nonisolated facilities (mode 3).
EE76 73...	DOT-E 70[illegible]	Phoenix, Inc., Minneapolis, Minn.	49 CFR 173.[illegible]	To make a limited number of shipments of solid waste (class B poison) in covered open top semitrailers (mode 1).

ALAN I. ROBERTS,
Director, Office of
Hazardous Materials Operations.

[FR Doc.76-5799 Filed 3-2-76;8:45 am]

[OST FILE No. 42; Notice 76-2]

FUEL ECONOMY STANDARDS FOR ELECTRIC AND OTHER NON-FUEL VEHICLES

Request for Information and Public Comment

The Department of Transportation is conducting a study of the advisability of including electric vehicles and vehicles that operate on fuels other than gasoline or diesel fuel within the regulatory framework for increased motor vehicle fuel economy established in section 301 of the Energy Policy and Conservation Act (Pub. L. 94-163). That act added a new Title V to the Motor Vehicle Information and Cost Savings Act of 1972 which provides for mandatory fuel economy standards for new motor vehicles powered by gasoline and diesel fuel. Section 512(b) of Title V requires the Department to report to the Congress and the President on the advisability of including electric and other non-fuel vehicles within the coverage of Title V. Non-fuel vehicles are defined as those fueled by other than gasoline or diesel fuel. Section 512(b) addresses attention to four items:

1. The extent to which electric and other non-fuel vehicles should be covered by Title V.

2. The manner in which the energy requirements of such vehicles may be compared with the energy requirements of fuel-consuming vehicles.

3. The extent to which inclusion of such vehicles would stimulate their production and introduction into commerce.

4. Any recommendations for legislative action.

To assist in the study, the public is invited to submit information and comments relevant to the four issues above, plus any other information and comments pertinent to the object of the study. Comments (three copies, if possible) should identify the file number (OST file No. 42) and be sent to the Docket Clerk, Office of the General Counsel, TGC, Department of Transportation, Washington, D.C. 20590. The target date for submission of the report is June 1, 1976; therefore, all comments received by the close of business Friday, April 9, 1976, will be considered. Material submitted to the file will be available for public inspection and copying, and for responsive comment, in the Office of the Assistant General Counsel for Operations and Legal Counsel, Department of Transportation, Room 10100 Nassif Building, 400 Seventh Street, SW., Washington, D.C., between 9:00 a.m. and 5:30 p.m. local time, Monday through Friday, except Federal holidays.

Issued in Washington, D.C., on February 26, 1976.

DR. RICHARD L. STROMBOTNE,
Chief, Energy and Environment
Systems Division.

[FR Doc.76-6106 Filed 3-2-76;8:45 am]

[OST FILE No. 41; Notice 76-1]

FUEL FLOW METERS

Request for Information and Public Comment

The Department of Transportation is conducting a study of the advisability of requiring that each new automobile be equipped with a fuel flow instrument reading directly in miles per gallon and the most feasible means of equipping used automobiles with such instruments. The study will result in a report to the Congress and the President as required by section 512(a) of the Motor Vehicle Information and Cost Savings Act of 1972, as added by section 301 of the Energy Policy and Conservation Act (Pub. L. 94-163). Section 512(a) addresses attention to four items:

1. The effectiveness of such instruments in promoting voluntary reductions in fuel consumption.

2. The cost of such instruments.

3. Means of encouraging automobile purchasers voluntarily to purchase automobiles equipped with such instruments.

4. Any other factor bearing on the cost and effectiveness of such instruments and their use.

To assist in the study, the public is invited to submit information and comments relevant to the four issues above, plus any other information and comments pertinent to the objects of the study. Specific attention is invited, however, to the following questions:

1. Would meters reading directly in miles per gallon be effective in promoting a reduction in fuel consumption?

2. What is an appropriate basis for deciding whether each new automobile should be equipped with such a device on either a mandatory or optional basis?

3. Under what conditions would it be appropriate for used automobiles to be equipped with such devices?

4. What total price is reasonable to pay for such a device installed in an automobile and why?

5. What savings in fuel cost would justify costs of the meter?

6. What other driver aids merit consideration? What reasons and supportive data exist for judging their effectiveness?

7. If meters reading directly in miles per gallon are effective, how can their use be stimulated effectively?

Comments (three copies, if possible) should identify the file number (OST File No. 41) and be sent to the Docket Clerk, Office of the General Counsel, TGC, Department of Transportation, Washington, D.C. 20590. The target date for submission of the report is June 1, 1976; therefore, all comments received by the close of business Friday, April 9, 1976, will be considered. Material submitted to the file will be available for public inspection and copying, and for responsive comment, in the Office of the Assistant General Counsel for Operations and Legal Counsel, Department of Transportation, Room 10100 Nassif Building, 400 Seventh Street, SW., Washington, D.C., between 9:00 a.m. and 5:30 p.m. local time, Monday through Friday, except Federal holidays.

Issued in Washington, D.C., on February 26, 1976.

DR. RICHARD L. STROMBOTNE,
Chief, Energy and Environment
Systems Division.

[FR Doc.76-6105 Filed 3-2-76;8:45 am]

Electric Vehicle Council
90 Park Avenue, New York, N.Y. 10016 Telephone 212-573-8700

April 8,1976

RE: OST File # 42
Docket Clerk
Office of the General Counsel, TGC
Department of Transportation
Washington, D.C. 20590

RE: Fuel Economy Standards for Electric Vehicles

1. The extent to which electric vehicles should be covered :
I'll come back to this at the end.

2. The manner in which energy requirements of such vehicles may be compared with fuel-consuming vehicles :

As we understand the present standards, fuel economy means the average number of miles travelled by an automobile per gallon of gasoline consumed, as tested by EPA 1975 procedures (55% urban cycle, 45% highway cycle).

There are two facets of this procedure to which we would like to address ourselves : (A) In the testing of gasoline-powered automobiles, the reference is what we would call "on-board fuel," ie., gasoline in the tank. If any standard were developed for comparing electric vehicle fuel economy, it should therefore also be "on board fuel," namely battery energy. Battery energy consumed in a fuel economy test can be measured by replacing the energy in a re-charge process and determining the energy replaced in AC KWH. The method of determining the state of battery charge at the start of the test and at the finish of the recharging is set forth in standards such as SAE J227(A) and IEC-TC69. Having determined the AC KWH used, this can be converted to BTU (3412 BTU per KWH) and compared with the energy content of gasoline. (B) The use of the EPA driving cycles and the mix between urban and highway could probably not be applied to existing electric vehicles, and would also not address itself to some of the prime advantages of electric power. First, the driving cycles : most present electric vehicles could not achieve the highway cycle (they won't go fast enough nor long enough). The only suggestion we could offer in 1976 would be to test electric vehicles according to SAE J227(A) and test gasoline vehicles in the same driving cycle, in order to make a comparison. The second part of this ("B") statement concerning the advantages : The electric vehicles would be consuming no gasoline and emitting no pollution of any sort ; present day electric vehicles are suited to "second car" use in urban and

Fourth International Electric Vehicle Symposium [illegible] Aug/Sept 76

suburban commuting and shopping which are primarily apart from highway driving ; yet they would meet most of automobile users' needs, since 85% of all trips are 15 miles or less ; the average of all automobile use is only 26.3 miles per day ; 54% of all autombile use is for commuting.

What we're getting at is that the EPA fuel economy driving cycles do not represent average use for any kind of passenger vehicle, gas or electric (since, for instance, they are not used 45% on highways). A driving test should, ideally, be representative of vehicle usage.

But there is another electric vehicle advantage which would not be revealed by an EPA test, and that is the fact that the e.v.consumes no energy when standing still...at traffic lights, in traffic congestion,etc.

In the USPS tests at Cupertino, California, they compared the performance in use on regular daily delivery missions with gasoline-powered jeeps doing the same work. The gasoline powered vehicles averaged only 6.65 miles per gallon, largely because a great deal of time was spent with the motor idling, since the driver found it advantageous to leave it running while delivering on foot. Electric powered vehicles at this location, when their power consumption was translated in to the same (BTU) terms, were four times as efficient as the gasoline vehicles !

For these several reasons, we do not believe a valid comparison of fuel economy between electrics and gasoline vehicles could be made, based on present EPA procedures for gas vehicles.

3. IF, however, valid and satisfactory comparisons could be made, we believe it would stimulate the introduction of electric vehicles , for the inescapable advantages of the electrics would be made valid by Government measurements.

1. Coming back to the first question, concerning the extent to which electric vehicles should be covered, we believe they should be covered if and only if (A) the procedure were confined to on-board fuel, as described in # 2 above and (B) the testing procedure were one designed for use with electric vehicles, such as the SAE (Society of Autmotive Engineers) or IEC (International Electro-technical Commission) standards mentioned in # 2 above.

If such were not the case, we would be strongly opposed to including electric vehicles in the Fuel Economy Standards as suggested in the Request for Information and Public Comment to which this letter is addressed.

Thank you for the opportunity to make these comments. We would be happy to provide more detailed explanations if requested.

Cordially

Edward A Campbell
Executive Secretary

April 8, 1976

FORD MOTOR COMPANY RESPONSE TO U. S. DEPARTMENT OF TRANSPORTATION FOR INFORMATION ON FUEL ECONOMY STANDARDS FOR ELECTRIC AND OTHER NON-FUEL VEHICLES (REF: OST FILE #42; NOTICE 76-2)

Ford Motor Company (Ford) hereby responds to the Department of Transportation's request for information and comment on the advisability of issuing regulations on electric vehicles and vehicles that operate on fuels other than gasoline or diesel fuel (41 F.R. 9221, March 3, 1976). Ford, a manufacturer of motor vehicles, engines and motor vehicle equipment, has considerable research and development experience on new concept storage batteries and on experimental electric vehicles.

Set forth below are responses to the specific items listed in the Notice.

<u>ITEM 1.</u> The extent to which electric and other non-fuel vehicles should be covered by Title V (of the Energy Policy and Conservation Act, Pub. L. 94-163),

<u>RESPONSE</u>

To the extent that electricity for electric (and other "non-fuel") vehicles is chiefly generated from petroleum, the restrictions of Title V should apply to these vehicles. If this electricity is chiefly generated from non-petroleum sources, the Title V restrictions should not apply to electric vehicles. However, the application of Title V to electric and other non-fuel vehicles is equally important from the standpoint that such application will influence the future development and future application of these vehicles, hopefully along energy conserving paths, as it is already influencing development and application of conventional vehicles. There is much evidence to support the conclusion that there are many applications for which electric vehicles will not conserve energy in comparison to conventional vehicles. The judicious application of Title V can, therefore, serve as a guideline for the developers of the newer, non-conventional vehicles.

<u>ITEM 2.</u> The manner in which the energy requirements of such vehicles may be compared with energy requirements of fuel consuming vehicles.

<u>RESPONSE</u>

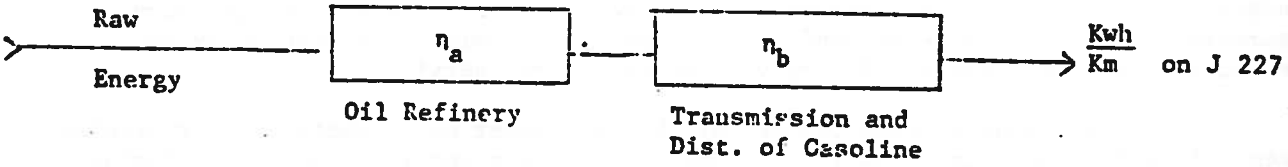
The following comments are made on the basis of electric vehicle studies, and, therefore, may not be totally applicable to other non-fuel vehicles.

Energy requirements of electric vehicles should be made on the basis of "overall" energy consumption. The term, "overall" energy consumption is meant to describe the total energy consumed between the source of raw energy - coal, oil, nuclear energy, etc., - and the highway as a vehicle is being driven. Many authorities have noted that an electric power train is much more efficient - by a factor of two or more - than a conventional internal combustion engine power train. However, the energy lost or consumed in bringing energy to the electric vehicle from the source of raw energy is much greater than for the similar process in a conventional vehicle.

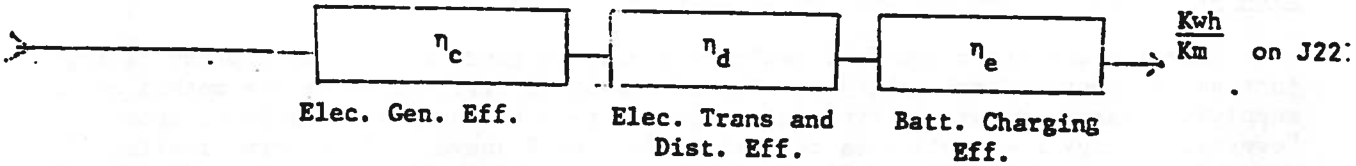
Secondly, it is suggested that the energy requirement be based upon the vehicle's driving of the SAE Metropolitan Cycle (SAE, J227). This cycle results in approximatel equal energy consumption per mile to that obtained when driving the metro (CVS) cycle, presently used to determine the "metro" fuel economy of conventional vehicles by EPA. Some electric vehicles have not been able to accelerate at the rates specified in the CVS cycle. The SAE metropolitan cycle has somewhat relaxed acceleration and high speed requirements compared to the CVS cycle, and is probably more typical of the acceleration levels to be expected in electric vehicle applications. Regenerative braking, when available, should be operational during the test.

The calculation of overall energy consumption in kilowatt-hours/kilometer (Kwh/Km) can be obtained as follows:

A. Conventional vehicle



B. Electric vehicle



The vehicle energy input on the right side of the above diagrams can be obtained by actual test track driving or by use of a rolls dynamometer. The energy/mile can then be referred back to "overall" energy/mile by working through the various conversion efficiencies, right to left, as shown on the above diagrams. Several U.S. Government agencies maintain statistical data from which efficiencies η_a, η_b, η_c, η_d, η_c can be accurately defined and impact of system changes predicted.

The third suggestion for comparing fuel consumption between conventional and non-fuel vehicles is to include the vehicle pay load. Electric power trains tend to be heavier than conventional power trains - especially at the present time when lead-acid batteries are the primary available energy device. This added power train weight often requires, for a given load carrying capacity, greater structural weight, hence greater propulsion energy requirements. Since present EPA measurement of fuel economy is based on inertia weight, the load carrying capacity of the vehicle is not necessarily indicated from the EPA tests. Therefore, the following parameter for comparison of energy requirements is suggested:

$$\frac{\text{Overall Kwh/Km on SAE-J227}}{\text{Pay-load weight (Kg)}} \qquad \frac{\text{Kwh}}{\text{Kg - Km}}$$

A low value for the above parameter signifies a low fuel consumption (or high fuel economy).

ITEM 3. The extent to which inclusion of such vehicles would stimulate their production and introduction into commerce.

RESPONSE

Most studies of vehicular energy consumption have shown that electric vehicles are superior to conventional vehicles in terms of *overall* energy consumption *only for driving modes characterized by relatively low speeds, many stop-start operations, and many periods at standstill*. Therefore, it is expected that introduction of this proposed energy consumption parameter will promote the introduction of electric vehicles into such applications as mail delivery, other types of city delivery service, city taxicabs, some non-freeway commuting service, and inner city and suburban "runabout" (many trips of very short length) service.

It is also expected that the use of this parameter may promote further development of hybrid power trains which combine electric and internal combustion engine systems in such a way as to make use of the best energy conserving features of both systems.

ITEM 4. Any recommendations for legislative action.

Electric and other non-fuel vehicles should be given a fuel consumption rating just as are conventional vehicles. Due to the basic differences in the method of supplying energy to various types of vehicles, this rating should be based upon "overall" energy consumption as defined in Section 2 above. If uniform, realistic measurements are required and if the public is made aware of the results, demand may grow for cost-saving, energy-saving vehicles and vehicles will be produced to meet that demand. No tax or other artificial incentives should be required to induce the public to make a sensible, practical choice if it is informed.

General Motors Response To

FUEL ECONOMY STANDARDS FOR ELECTRIC AND OTHER NON-FUEL VEHICLES

OST File No.42

Submitted to:

U.S. Department of Transportation
Washington, D.C.

April 9, 1976

Please Refer to: FE 0973

Environmental Activities Staff
General Motors Corporation
General Motors Technical Center
Warren, Michigan 48090

April 9, 1976

Docket Clerk
Office of the General Counsel, TGC
Department of Transportation
Washington, D.C. 20590

Dear Sir:

Enclosed is General Motors' response to OST File No. 42; Notice 76-2, Fuel Economy Standards for Electric and Other Non-Fuel Vehicles, Request for Information and Public Comment which was published in the Federal Register, Vol. 41, No. 43, Wednesday, March 3, 1976.

Very truly yours,

T. M. Fisher, Director
Automotive Emission Control

JEP/aaf/w/412

Enclosure

General Motors Reponse to FR Doc. 76-6106
Fuel Economy Standards
for Electric and Other Non-fuel Vehicles

OST File No. 42

In order to fully evaluate the impact on the nation's energy resources, a consideration of "fuel economy" for electric vehicles must recognize the quantity and type of fuel used at the electric generating plants (i.e., natural gas, coal, oil, hydroelectric, nuclear, etc.). The intent of the automobile fuel economy title of the Energy Policy and Conservation Act of 1975 as it applies to gasoline and diesel-powered vehicles is to achieve a reduction in the use of "endangered fuels", the proposed intent of any regulation for electric and other non (petroleum) fuel vehicles should also be to conserve these fuels.

Moreover, in order to fully protect the public interest it must also recognize the atmospheric emissions at the generating plant (particulates, sulfur compounds, nitrogen oxides) resulting from the generation of additional electric energy used to recharge these vehicles.

Effect on the environment from exhaust emissions of gasoline and diesel powered vehicles has been related to increases in vehicle and operating costs. It seems, therefore, that the same type of information should be developed in relation to the operation of electric vehicles. An example calculation of power plant emissions attributable to operation of a small electric car is given.

Emissions from Electric Generating Plants

	Grams/KWH		
1980	NOx	SO_2	Particulates
Coal 2% S	5.31	15.4	1.2
Oil 1.3% S	2.91	6.76	0.29

To estimate power plant emissions per mile travelled by an electric car, it is necessary to determine the motor output in KWH/mile for the driving cycle. Then, using 45% as the efficiency from electric power output at the generating plant to motor shaft output (transmission, distribution, battery charge and discharge, motor and controls), the emissions can be estimated as follows:

For a very small, limited performance electric car requiring a motor output of 0.1 KWH/mile, the pollutant emissions in 1980 from generating plants per mile travelled would be:

	Grams/Mile		
	NOx	SO_2	Particulates
Coal 2% S	1.18	3.43	0.267
Oil 1.3% S	0.65	1.5	0.065

Regarding the advisability of including electric and other "non-fuel" vehicles within the fuel economy regulatory network: Since the purpose of regulating vehicle fuel economy is to conserve petroleum supplies, any vehicle that requires petroleum for its energy source should be included in the control network. However, because electric and other "non-fuel" vehicles do not directly consume petroleum, but rather use an energy source that may be only partially produced through the use of petroleum, e.g., electricity, the vehicle petroleum requirements will necessarily have to be estimated. In the case of electric vehicles, the percentage of electrical energy generated at various intervals of the day and night from crude oil, and possibly more scarce natural gas, will have to be determined on a regional basis. Then, the percentage of day and night charging as well as the regional efficiency of producing electricity must be applied to the actual vehicle energy requirement.

These energy use relationships are difficult to establish and the actual setting of fuel economy standards for electric or non-petroleum fuel vehicles at this time would be premature. The development of such vehicles is in an early stage, as is the development of significant non-petroleum, pollution-free electric generating capacity. Standards that are compatable with the current level of development would surely become obsolete as petroleum dependence is alleviated through the adoption of non-petroleum energy sources such as coal, nuclear, geothermal, solar, etc. Also such standards could tend to discourage the development of electric and non-fuel vehicles.

General Motors has recently completed a study of the energy utilization of gasoline and electric vehicles which addresses the key issues described in the D.O.T. request for information and public comment. The results of this study are attached as S.A.E. paper No. 760119, "A Study of the Energy Utilization of Gasoline and Battery-Electric Powered Special Purpose Vehicles".

EAS/Automotive Emission Control
4/7/76 APSH/aaf/w/400

FREEDOM AND PROGRESS THROUGH MOBILITY

AMERICAN REVOLUTION BICENTENNIAL 1776-1976

SOCIETY OF AUTOMOTIVE ENGINEERS, INC.
400 Commonwealth Drive, Warrendale, Pa. 15096

A Study of the Energy Utilization of Gasoline and Battery-Electric Powered Special Purpose Vehicles

David C. Sheridan, John J. Bush,
and William R. Kuziak, Jr.
Research Labs., General Motors Corp.

SOCIETY OF AUTOMOTIVE ENGINEERS

Automotive Engineering Congress and Exposition
Detroit, Michigan
February 23-27, 1976

760119

760119

A Study of the Energy Utilization of Gasoline and Battery-Electric Powered Special Purpose Vehicles

David C. Sheridan, John J. Bush,
and William R. Kuziak, Jr.
Research Labs., General Motors Corp.

ABSTRACT

The depletion of the supply of liquid hydrocarbon fuels in the predictable future has accelerated interest in vehicles powered by different forms of energy. The battery is one form of energy storage that has successfully found application in special-purpose vehicles for nearly three-quarters of a century. Heavy duty lift-trucks and tugs, golf carts and delivery vehicles are among the vehicle types powered by battery-electric systems. Personal transportation needs have been served to only a limited extent by electric vehicles because of the low power, limited range and lack of durability provided by the conventional lead-acid battery. However, recent changes in the energy availability picture have necessitated reconsideration of the electric vehicle.

In order to compare the efficiency of utilization of the Earth's fossil energy resources (petroleum and coal) by battery-electric and gasoline powered special-purpose urban vehicles, an analytic study was conducted. The guidelines of this study restricted it to three special-purpose cars that are smaller and have lower performance than conventional subcompact cars and a delivery van. The vehicle power train components represent demonstrated current technology. The most important guideline of the study required the performance levels and load carrying capacity of the gasoline and electric-powered vehicles to be the same. The results of the study indicate that a lead-acid battery powered, two-passenger shopper vehicle with a 40 km range consumed about 90% more petroleum per kilometer of driving than does its spark ignition engine powered counterpart. With coal as the prime source, they consume about the same amount of energy. Increases in desired range, performance and vehicle size beyond that of the shopper increase the electric vehicle energy consumption with respect to the gasoline powered version.

The position of the electric vehicle is improved with respect to the gasoline vehicle by the development of advanced batteries, increased electric component efficiencies and an actual electric vehicle mass less than assumed due to a reduced mass compounding factor. An aspect related to the conventionally powered vehicle that tends to reduce the advantage over the electric is a potential efficiency penalty of the spark ignition engine due to its small size. Incorporation of these considerations into the study produce results more favorable for the electric version. The energy consumption of a nickel-zinc battery powered shopper is only about 30 percent more than its spark ignition engine powered counterpart considering petroleum as the prime source of energy. With coal as the prime source, the advanced technology electric vehicle consumes about 30 percent less than the spark ignition engine powered version.

DISCUSSION

THE ENERGY UTILIZATION of battery-electric and gasoline powered vehicles has received considerable attention in recent years. The results of studies indicate that battery-electric cars require anywhere from one-third the energy [1][1] to about the same amount of energy [2] as a similar gasoline powered vehicle. Such results reflect the use of advanced high energy density batteries, unusually high electrical component efficiencies, reduced electric vehicle rolling and wind resistance or operation at steady, level road operation. The gasoline powered vehicle used as a basis for comparison is generally the conventional passenger car manufactured in the U.S. today. It is logical to ask if the same conclusions would be reached without speculation or extrapolation beyond current day battery and electrical component technology and if the comparison was made between two vehicles with similar load capacity and performance capabilities. The answer to this question is the objective of this study.

Using the same basic guidelines, the comparison should be extended using reasonable assumptions concerning future battery development, and electrical component efficiency improvements. The question of how the electric-vehicle gasoline-vehicle energy consumption comparison turns out for the ultimate improvement in battery technology (electrical vehicle mass equals gasoline vehicle mass) could also be answered. These two subjects will be addressed after the primary objective has been achieved.

GUIDELINES

The guidelines of this study were selected to insure a realistic comparison. A variety of vehicle types was examined so that a crossover in the results could be found if it existed. The basic guidelines established for this study were:

(1) The special-purpose vehicles examined would be smaller and have significantly lower performance than conventional subcompact cars.

(2) The performance levels and load carrying capacity of the gasoline powered and battery-electric powered vehicles should be identical.

(3) Current technology supported by the best available experimental data should be utilized.

(4) Energy consumption, in terms of equivalent prime source energy (coal and petroleum), and driving range should be determined for operation over an appropriate driving cycle.

VEHICLE DEFINITION

The vehicles selected for study are all special-purpose vehicles intended for use in urban and/or suburban areas. Minimal range and performance capabilities would be expected from these vehicles in contrast to one that would be used for long distance, country driving. The specific vehicle types and the curb masses associated with the gasoline powered version of each are listed in Table I.

The masses of the shopper and commuter vehicles are based on the 512 and 511 urban car prototypes built for the General Motors Progress of Power Show of May 1969. The small sedan would reflect the XP-883 design prototype built for the 1969 POP show. Although these vehicles were not built to the Federal Motor Vehicle Safety Standards, it was felt their application was justified for this analytical study. It should be noted that changes to satisfy MVSS, if required by such special purpose vehicles, should result in more added mass in the electric version and an increase in energy consumption relative to the gasoline version. The delivery van selected for study would be similar to a 240 cm wheel base, 450 kg payload, electric mini-van that is commercially available.

Determination of the mass of the battery-electric powered version requires some critical assumptions and an actual vehicle prototype would be required to verify them. In this study, the electric powered version curb mass was assumed to reflect a 50 percent mass "compounding" factor. Simply stated, this means that for every 100 kg of battery required, 50 kg of vehicle structure must be added for support. The electric vehicle mass also reflects the estimated difference between gasoline and electric powertrain masses. An expression defining the curb mass of the electric vehicle (EV) for a particular battery mass is shown below:

$$(M_{curb})_{EV} = (M_{curb})_{SI} - (M_{P/T})_{SI} + (M_{P/T})_{EV} + M_{Bat} + M_{comp} \qquad (1)$$

where
$$(M_{P/T})_{SI} = 0.20 \times (M_{curb})_{SI} \qquad (2)$$

$$M_{comp} = 0.50 \times (M_{Bat}) \qquad (3)$$

The SI vehicle powertrain mass includes the engine, fuel and exhaust systems, radiator and grille. The 20 percent factor used to estimate this mass is based on data for vehicles ranging from sub-compact to full size. Al-

Table I - Gasoline Vehicle Curb Masses

Shopper (two-passenger)	426 kg
Commuter (two-passenger)	544 kg
Sedan (four-passenger)	816 kg
Delivery Van (454 kg payload)	1360 kg

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[1] Numbers in brackets are References listed at end of text.

though determined for powertrain components of conventional automobiles, the 50 percent mass-compounding factor was employed because substantiation for a lower factor that might be applicable to small, low performance vehicles does not exist.

Besides mass, other vehicle parameters that require defining so that an accurate characterization can be made are frontal area, tire size, rolling resistance and drag coefficients. The gasoline and battery powered vehicles were both assumed to have the same frontal area although in reality the EV would undoubtedly be somewhat larger in area to accommodate the volume of batteries on board. Little error would result however at the relatively low speed driving cycles to be considered in this study. The frontal areas, tire size, drag and rolling resistance coefficients for the four vehicles are listed in Table II.

The passenger car vehicle coefficients are based on experimental values determined for an imported mini-car operating with radial tires. They include transmission and axle spin losses. The rolling resistance coefficient for the van also includes spin losses and is based on tests with LR78-15 radial tires. Wind tunnel test measurements produced the drag coefficient.

Performance criteria established for the four vehicle types were based on the assumption that acceleration rates considerably less than obtainable with conventional subcompact cars would be acceptable in these special-purpose vehicles. In order to avoid penalizing the EV, range requirements felt to be the minimum acceptable for each type of vehicle were chosen. Such low level requirements should produce the most favorable comparison for the battery-electric vehicle. Increases in performance and range would require additional batteries and increase the electric-vehicle energy consumption with respect to the gasoline version. Listed in Table III are the various performance criteria established for each of the vehicle types. Corresponding values for a typical SI subcompact are shown for comparison.

It should be noted that these criteria are not necessarily compatible with one another and were set down as minimum guidelines to be satisfied.

POWERTRAIN CHARACTERIZATION

The performance of the gasoline and electric powerplants were both defined using experimentally determined characteristics. The electric motor performance was obtained from a chopper controlled, series-wound 15 kW DC motor designed for vehicular application [3]. The characteristics of this motor are shown in Figure 1. The efficiency levels for this particular motor controller combination are considered representative of currently available hardware of this type.

The mass of each electric motor considered in this study was estimated using the correlation shown in Figure 2. It is based on data from the A. D. Little report [4] replotted as shown. Other data obtained from the literature along with that for the motors considered in this study are also indicated.

The spark ignition engine performance used for each vehicle type was scaled from experimental data for a 1.2-liter, 4 cylinder, European car engine. This data is shown in Figure 3 as power-speed characteristics with specific fuel consumption contours indicated. Scaling to output levels less than the 42 kW rating of this engine was done assuming efficiency was unaffected. Such an assumption was justified using best specific fuel consumption data from a variety of engines plotted as a function of percent of maximum output power. These data, shown in Figure 4, indicate that all but one of the engines considered, which have a 6 to 1 range of displacements, show minimum fuel

Table II - Vehicle Parameters

	Frontal Area m^2	Tire Size rev/km	Drag Coef.	Rolling Resis. Coef.
Shopper	1.67	597	0.62	0.0133
Commuter	1.86	597	0.62	0.0133
Sedan	1.86	597	0.62	0.0133
Van	3.90	447	0.50	0.0133

Table III - Vehicle Performance Criteria

Criteria	Shopper	Commuter	Sedan	Van	SI Sub-Compact
Maximum car speed, km/h					
2% grade, 24 km/h headwind		72	72		
0% grade, 0 km/h headwind	72	~97	~97	89	~125
Distance in 4 seconds, m	15	-	-	12	23
Distance in 10 seconds, m	-	91	91	-	122
0-48 km/h time, s	20	-	-	15	6
0-72 km/h time, s		30	30	-	12
5% grade speed, km/h	24	24	24	24	-
20% grade speed, km/h	~0	~0	~0	~0	-
Electric vehicle range, km	40	~80	120	80	n/a
Duty cycle, GMPG	Central Business District	Suburban	Suburban	Central Business District	

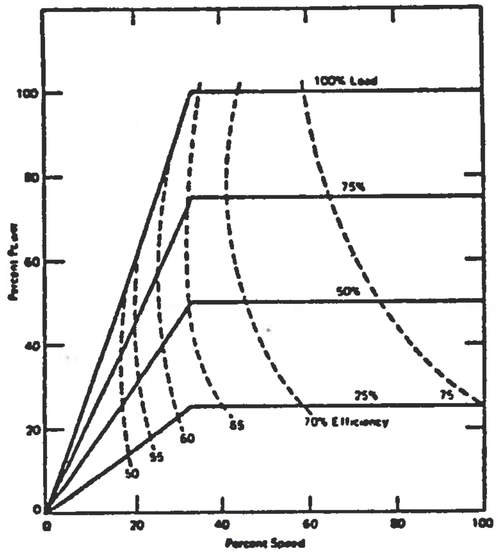

Fig. 1-Characteristics of 15 kW direct current motor with chopper control

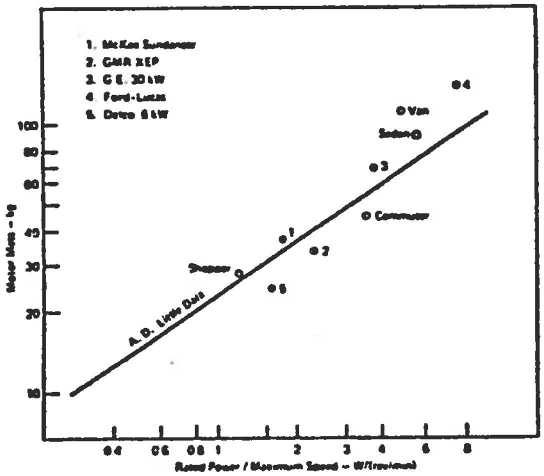

Fig. 2-Relationship of direct current motor mass with rated output and speed

consumption levels within 20 percent of one another. It was reasoned that scaling to 21 kW or half the 4-cylinder rating is acceptable, as a 2 cylinder version would provide such performance. In addition, scaling as much as another 67 percent to 7 kW at the same efficiency was minimally permissible with some room for debate as to its validity.

The mass of the components unique to the spark ignition engine powered vehicle was

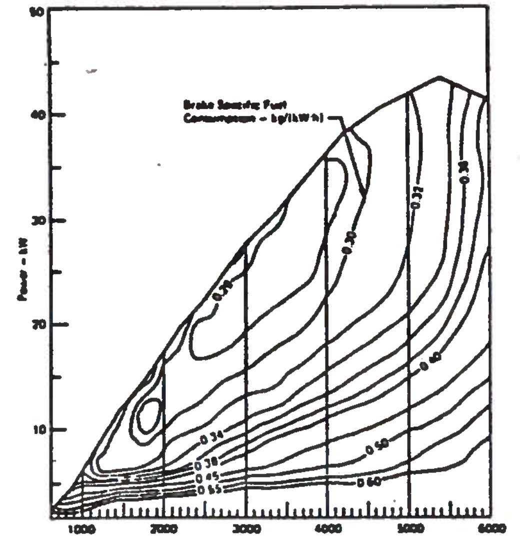

Fig. 3-Engine performance map for 1.2 l, 4-cyl. engine

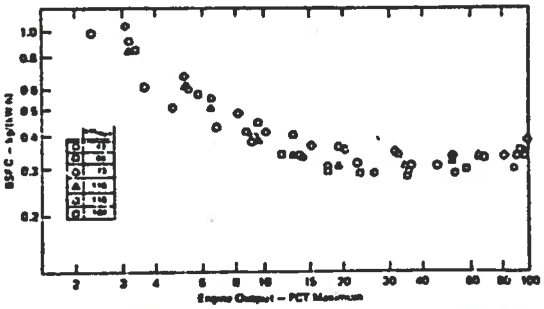

fig. 4-Minimum engine specific fuel consumption versus percent of maximun output

assumed to be 20 percent of the curb mass as was explained in the section above.

The remaining portions of the vehicle driveline, including syncromesh transmission, rear axle, clutch, and tires were also characterized on the basis of current experimentally determined information. In Table IV, the efficiencies used throughout the study are listed.

A final consideration for each vehicle powertain is the definition of the accessory loads being driven. Two levels of load were considered: a minimum load to provide for ventilation, radio, power steering and power brakes; and a much higher level to account for maximum lighting, wipers, air conditioning or an auxiliary heater if necessary. The power requirements for the accessories are based on data obtained from late model car equipment or

Table IV - Driveline Component Efficiencies

Tires		0.95
Rear Axle		0.96

Transmission:

Ratio	SI	EV
4.5	0.96	-
2.5	0.97	0.96
1.5	0.98	0.98
1.0	1.0	1.0

equipment proposed for future production. The gasoline powered vehicle accessories were assumed belt driven in the conventional manner. Figure 5 illustrates the variation in the accessory requirements with accessory speed. Drive ratios were selected to maintain ratios of accessory speed (rev/min) to vehicle speed (km/h) of 29.7 and 74.6 for the air conditioning compressor and alternator, respectively. In Table V, the accessory loads at 56 km/h in 4th gear are shown for comparison with the electric vehicle accessory loads. Note that the maximum load assumed for the gasoline powered van does not account for air conditioning as it was felt none would be required.

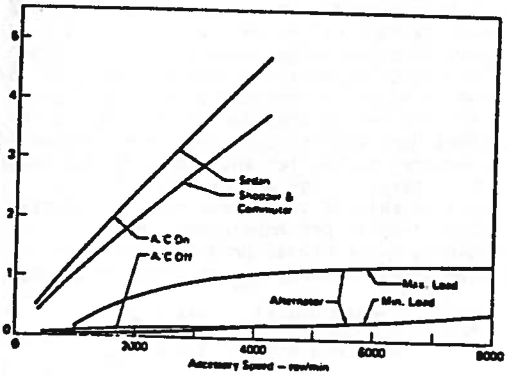

Fig. 5-Accessories power requirements for SI engine powered special purpose vehicles

Table V - Gasoline Vehicle Accessory Loads
At 56 km/h, 4th Gear, Watts

	Minimum	Maximum
Alternator	190	1000
Air Conditioner (Shopper & Commuter)	40	1440
Air Conditioner (Sedan)	40	1790
Total - Shopper & Commuter	230	2440
- Sedan	230	2790
- Delivery Van	190	1000

Table VI below lists the accessory loads for the electric vehicle. They were assumed to be a constant load powered by the main battery pack. Note that the maximum load for the electric powered van includes an auxiliary heater, which was assumed to be a 2.05 kW load.

Operation of the entire vehicle-powertrain system was simulated using a complex system of computer programs developed for this purpose [5]. Standing-start, full-throttle acceleration performance, gradeability and driving schedule operation for the battery-electric and spark ignition engine powered vehicles were examined during the course of the study in order to satisfy the performance criteria established.

BATTERY MODEL

The battery model used for this study consists of three basic constituents: (1) A specific energy vs. specific power variation for vehicle range determination; (2) an efficiency value to account for internal battery losses during the discharge and charge processes; and (3) a charger efficiency.

The specific energy vs. specific power characteristic reflects the amount of energy (watt-hours) available from a given mass of batteries discharged to a particular terminal voltage at a constant power level (watts). Figure 6 illustrates the experimentally determined characteristics for a Delco-Remy lead-acid battery developed in the late 1960's for an electric vehicle prototype [6]. Also shown in the figure are the characteritics for a typical automotive SLI (starting-lighting-ignition) battery and a heavy duty traction battery. Initially, the study was carried out assuming the use of the high-energy lead acid batteries. It was later extended to include nickel-zinc cells, also characterized in Figure 6. It should be noted here that these characteristics all reflect the use of batteries operating at 294 K (70°F) with few accumulated duty cycles.

In applying the battery characteristic to driving cycle operation, it was assumed that the amount of energy (kilowatt-hours) available from the batteries is the value from Figure 6 at a power drain equal to the maximum demand of the motor. When the available quantity of energy was withdrawn, the next vehicle maneuver requiring maximum power would result in the battery terminal voltage dropping below a specified "cut-off" level. The distance traveled by the vehicle prior to this instant was then defined as its range. For example, the energy consumption during operation over one cycle of the driving schedule and the maximum power demanded by the motor from the batteries is calculated by the vehicle simulator computer program. The total energy available, assuming it is drained at this maximum power rate, can be determined from the battery characteristics in Figure 6. The ratio of the total energy available to that used for the single driving cycle calculation is the

Table VI - Electric Vehicle Accessory Loads, Watts

	Minimum	Maximum
Radio	31	31
Blower	144	144
Headlights		154
Brakelights		48
Wipers		55
Air Conditioner (Shoper & Commuter)		1640
Air Conditioner (Sedan)		2050
Power Brakes	10	10
Power Steering	70	70
Heater (Shopper & Commuter)		1640
Heater (Sedan & Delivery Van)		2050
TOTAL - Shopper & Commuter	255	2152
- Sedan & Delivery Van	255	2562

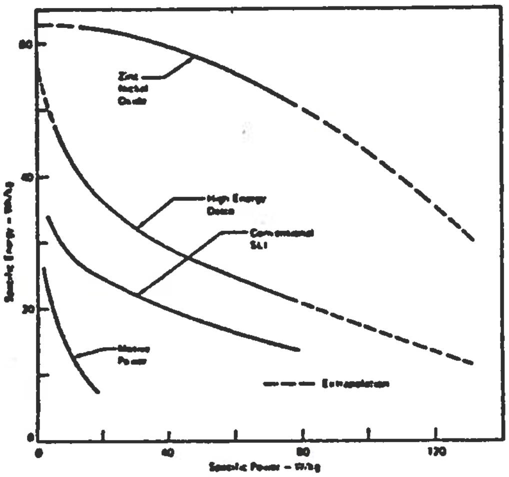

Fig. 6-Specific energy versus power characteristics for various lead-acid batteries and an advanced zinc-nickel battery

total number of cycles that can be driven at the same vehicle performance levels.

This method of energy (watt-hours) additivity is a modification of the method of charge (ampere-hours) additivity described by Agruss [7], which is accepted as an accurate method of electric vehicle range determination. Cairns, et al. [8], and Unnewehr [9], both emphasized the importance of using the charge additivity method. Although underestimates of range were anticipated using the energy additivity method, parallel calculations employing the charge additivity method for one of the vehicle types produced range increases of less than 5 percent.

It is worth noting that considerable energy is left in the battery, i.e., 40 to 50 percent, at the point where vehicle range is determined by the driving cycle demands. Operating at reduced power levels would enable additional range to be obtained at terminal voltage levels above the "cut-off" value.

The efficiency of the charge-discharge process was determined after making some additional assumptions. If charging is done over an 8 hour period with a charger that allows a linear current variation with time, as shown in Figure 7, calculations made using the charge characteristics obtained from Mueller [10] and shown in Figure 8 produced a value of 2.26 watt-hours per ampere-hour added. Adding 10 percent more ampere-hours than were removed is recommended by Mueller and others to guarantee a full charge. High energy Delco battery discharge data at the 2 hour rate, indicates 1.93 watt-hours per ampere-hour drained. Combining these values produces a charge-discharge efficiency, η_{CD} of about 78 percent.

$$\eta_{CD} = \frac{1.93(\text{W}\cdot\text{h/A}\cdot\text{h})_D}{2.26(\text{W}\cdot\text{h/A}\cdot\text{h})_C} \times \frac{1(\text{A}\cdot\text{h})_D}{1.1(\text{A}\cdot\text{h})_C} = .78 \quad (4)$$

This value for charge-discharge efficiency was used throughout the study. The efficiency of the charging device was assumed to be 90 percent. This value is representative of a diode-reactor battery charger, a type suitable for on-board vehicle applications.

Charge recuperation affects the available range of lead-acid battery powered vehicles in that, if left in the open circuit condition for several minutes, the charge level of a battery will rise. Driving habits that result in idle or stop time that is substantially longer than driving time will provide increases in range if vehicle cold start effects do not become a significant counteracting influence. The recuperative effects of such long idle periods were not considered in this study.

Regenerative braking is another means of increasing vehicle range which was not considered in this study. Lead-acid batteries are not aptly suited for the high charging rates

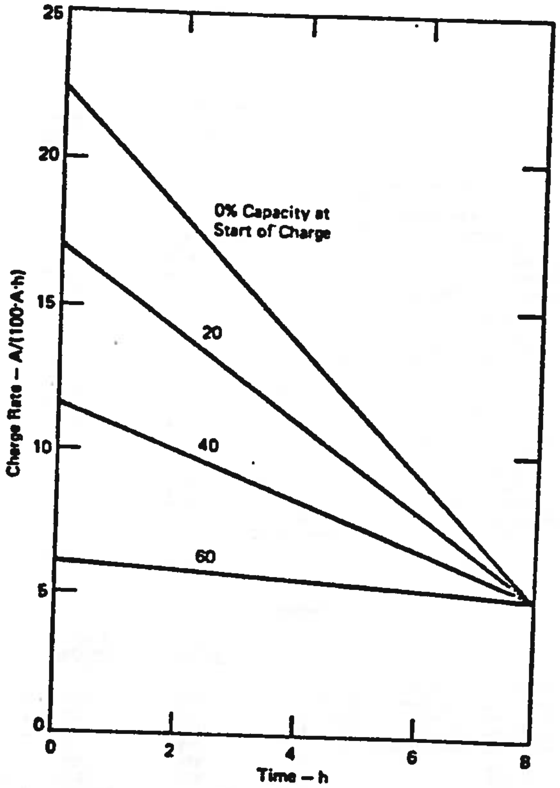

Fig. 7-Variation in lead-acid battery charge rate with time

which would be encountered. Furthermore, it is the concensus of most investigators [1, 6, 11] that range would increase by less than 10 percent.

VEHICLE RANGE, PERFORMANCE AND ENERGY CONSUMPTION

Each of the four vehicle types were evaluated using the characterizations described in the previous sections. The battery mass carried by the EV's was varied to determine the exact amount required to satisfy the driving schedule range criterion. All EV's were assumed to have a 3-speed syncromesh transmission to satisfy the gradeability requirements. The electric motor was sized and axle ratio selected to satisfy the maximum vehicle speed criterion regardless of the battery mass carried. The spark ignition engine powerplant for each vehicle type was sized similarly. A 4-speed transmission was assumed to provide gradeability and a driving "feel" similar to the electric version.

Vehicle acceleration performance was

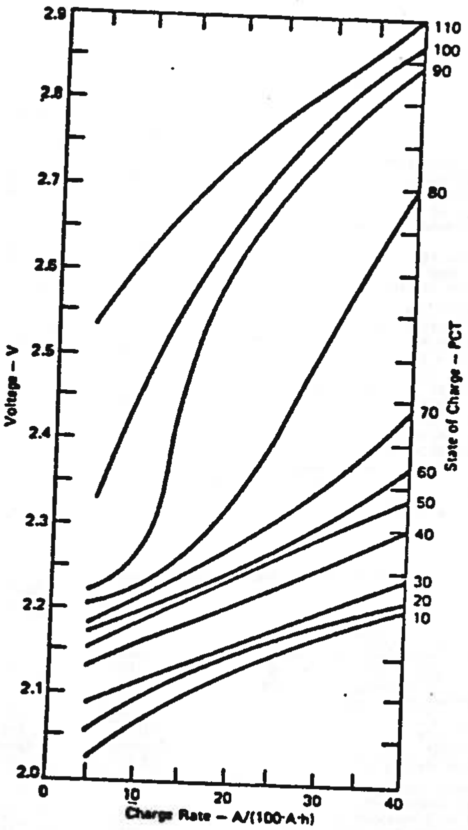

Fig. 8-Lead-acid battery charging characteristics (10)

determined assuming the minimum accessory load in each case. Driving cycle range and energy consumption was determined for both minimum and maximum accessory loads. In Tables VII, VIII, IX and X a summary of vehicle specifications, performance, range and energy consumption are shown for the shopper, commuter, sedan and delivery van respectively. The mass of the electric vehicles includes 150% of the battery mass required to provide the range specified due to the "compounding" effect discussed previously. The performance and range criteria initially specified are indicated in parentheses. Only the range and maximum speed criteria are satisfied exactly. The others were used only as minimum value guidelines.

Except for the two-passenger shopper, the gasoline powered versions accelerate somewhat better than their electric counterparts. Improving the performance of the EV's so that their acceleration was identical to that of the SI version would require increased motor output and more batteries for the same range. Satisfying the maximum speed criterion therefore

Table VII - Two Passenger Shopper

		Electric	Spark Ignition
Vehicle Specifications:			
Curb Mass (w/o Powertrain), kg		341	341
Motor and Controls or Engine, kg		61	85
Batteries (High Energy Delco), kg		227	-
Mass Compounding Effect, kg		114	-
Load, kg		136	136
Test Mass, kg		879	562
Transmission		3-speed	4-speed
Powerplant Rating, kW		7.93	7.49
Performance Summary:			
Max. Car Speed, km/h	(72)	72	72
Distance in 4 s, m	(15)	16.8	15.3
Distance in 10 s, m		69.9	68.7
0-48 km/h Time, s	(20)	16.6	14.3
5 pct. Grade Max. Speed, km/h	(24)	41	49
20 pct. Grade Speed, km/h	(>0)	14	17
Driving Schedule Range, km			
Min. Accessories	(40)	40.6	-
Max. Accessories		25.1	-
Driving Schedule Energy Consumption at AC Outlet or Service-Station Pump, mJ/km			
Min. Accessories		0.727	1.18
Max. Accessories		1.11	1.90

Table VIII - Two Passenger Commuter

		Electric	Spark Ignition
Vehicle Specifications:			
Curb Mass (w/o Powertrain), kg		435	435
Motor and Controls or Engine, kg		84	109
Batteries (High Energy Delco), kg		748	-
Mass Compounding Effect, kg		374	-
Load, kg		136	136
Test Mass, kg		1777	680
Transmission		3-speed	4-speed
Powerplant Rating, kW		23.47	17.94
Performance Summary:			
Max. Car Speed, km/h			
24 km/h Headwind, 2% Grade	(72)	72	72
0 km/h Headwind, 0% Grade		101	97
Distance in 4 s, m		19.4	21.1
Distance in 10 s, m	(91)	84.5	94.5
0-72 km/h Time, s	(30)	26.5	17.9
0-97 km/h Time, s		76.3	64.4
5 pct. Grade Max. Speed, km/h	(24)	59	75
20 pct. Grade Speed, km/h	(>0)	20	37
Driving Schedule Range, km			
Min. Accessories	(80)	80.5	-
Max. Accessories		65.4	-
Driving Schedule Energy Consumption at AC Outlet or Service-Station Pump, MJ/km			
Min. Accessories		1.27	1.59
Max. Accessories		1.53	2.13

results in a lower limit estimate of the electrical vehicle energy consumption.

The energy consumption values listed for each vehicle refer to the amount obtained from an AC outlet during battery charging or from a retail gasoline pump. To add meaning to these values, converting the units from megajoules per kilometer to miles per gallon for both the battery-electric and the spark ignition engined vehicles is helpful.[2]

Reflecting on the values in Table XI several things must be kept in mind. First, the EV and SI economies are not directly comparable as the efficiency of producing and distributing their energy supply has not yet been considered. Second, the extremely high values are a result of the small size and very low performance capabilities built into each vehicle. Third, the rapid drop in electric vehicle economy going from the shopper to the sedan is due to the large increase in vehicle mass, most of which is due to required batteries. Such a large battery mass, particularly in the small sedan, would never be considered practical. However the vehicle range limitation of lead-acid batteries is aptly illustrated.

Comparing the efficiency of gasoline and battery powered vehicles without taking into account the differences in energy consumption which reflect vehicle mass differences is commonly done. Such a comparison is meaning-

Table IX - Four Passenger Sedan

		Electric	Spark Ignition
Vehicle Specifications:			
Curb Mass (w/o Powertrain), kg		653	653
Motor and Controls or Engine, kg		136	163
Batteries (High Energy Delco), kg		1700	-
Mass Compounding Effect, kg		850	-
Load, kg		204	204
Test Mass, kg		3543	1020
Transmission		3-speed	4-speed
Powerplant Rating, kW		36.19	20.36
Performance Summary:			
Max. Car Speed			
24 km/h Headwind, 2% Grade	(72)	72	72
0 km/h Headwind, 0% Grade		109	99
Distance in 4 s, m		15.1	18.4
Distance in 10 s, m	(91)	71.9	83.0
0-72 km/h Time, s	(30)	33.5	22.3
0-97 km/h Time, s		80.3	61.8
5 pct. Grade Max. Speed, km/h	(24)	50	69
20 pct. Grade Speed, km/h	(>0)	16	23
Driving Schedule Range, km			
Min. Accessories	(120)	120.2	-
Max. Accessories		103.8	-
Driving Schedule Energy Consumption at AC Outlet or Service Station Pump, MJ/km			
Min. Accessories		2.23	2.01
Max. Accessories		2.55	2.67

Table X - Delivery Van

		Electric	Spark Ignition
Vehicle Specifications:			
Curb Mass (w/o Powertrain), kg		1088	1088
Motor and Controls or Engine, kg		168	272
Batteries (High Energy Delco), kg		1455	-
Mass Compounding Effect, kg		728	-
Load, kg		454	454
Test Mass, kg		3893	1814
Transmission		3-speed	4-speed
Powerplant Rating, kW		32.27	25.88
Performance Summary:			
Max. Vehicle Speed, km/h	(88.5)	88.5	88.5
Distance in 4 s, m	(12)	14.3	15.3
Distance in 10 s, m		65.4	69.2
0-48 km/h Time, s	(15)	17.6	13.7
0-72 km/h Time, s		49.8	34.1
5 pct. Grade Max. Speed, km/h	(24)	41	57
20 pct. Grade Speed, km/h	(>0)	13	29
Driving Schedule Range, km			
Min. Accessories	(80)	80	-
Max. Accessories		68	-
Driving Schedule Energy Consumption at AC Outlet or Service Station Pump, MJ/km			
Min. Accessories		2.82	3.59
Max. Accessories		3.29	3.79

---

[2] MPG =

$$\frac{(6.28\ \text{lbm/gal})(18600\ \text{Btu/lbm})(3.6\ \text{MJ/kWh})}{\left(\frac{\text{MJ}}{\text{km}}\right)(3413\ \text{Btu/kWh})(1.609\ \text{km/mi})} = \frac{76.5}{\left(\frac{\text{MJ}}{\text{km}}\right)}$$

Table XI - Equivalent Driving Cycle Economy in Miles per Gallon - Minimum Accessories

	Shopper	Commuter	Sedan	Van
Battery-Electric	105	60	34	27
Spark Ignition	65	48	38	21

less, but the actual values can be of interest if not taken out of context. Determination of the average operating efficiency over their duty cycle revealed the values shown in Table XII for the electric and spark ignition engine powered vehicles.

To illustrate the constant-speed level-road range and energy consumption of the vehicles at both accessory load levels, Figure 9, 10, 11 and 12 are shown. Again, energy consumption is referred only to the gasoline pump or AC outlet. Of particular interest in these four figures is the driving range at steady speeds and over an operating schedule, which is plotted on the ordinate. The importance of determining range on a driving cycle is readily apparent. The same observation concerning energy consumption can also be made when comparing the steady speed consumption with the driving schedule consumption which is also plotted on the ordinate.

ENERGY PRODUCTION AND DISTRIBUTION

The amount of energy consumed or lost producing and distributing electricity and gasoline must be considered so that the utilization of the Earth's prime energy sources by gasoline and battery-electric powered vehicles can be evaluated and compared. There are many steps involved in transforming crude oil to electricity and even more in producing synthesized gasoline from coal. Estimates on the efficiency of these processes vary considerably, so care must be taken not to select values that may bias the conclusions of any energy utilization study. Listed below are the efficiency estimates used for this study.

The only efficiencies shown in Table XIII that may vary considerably are those of electricity generation (32-38%) and coal liquefaction (35-85%). Only the latest, very large (700-1000 MW) generating plants have efficiencies near 38 percent so a representative value of 35 percent was selected. The only large scale liquefaction plant in operation has an efficiency of about 35 percent and the two most practical processes being examined today have efficiencies of 55 to 65 percent based on small scale pilot plant operation [12]. A value of 55 percent was used in this study. The overall production efficiency of gasoline and electricity originating from the two prime sources, petroleum and coal, are illustrated in Figure 13.

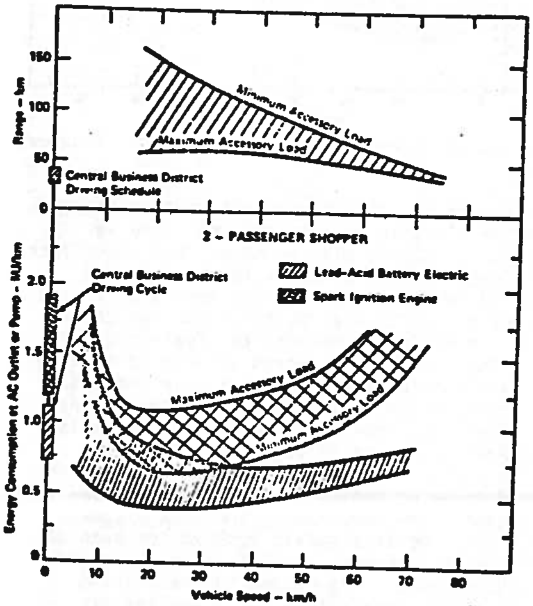

Fig. 9-Range and energy consumption of two-passenger shopper

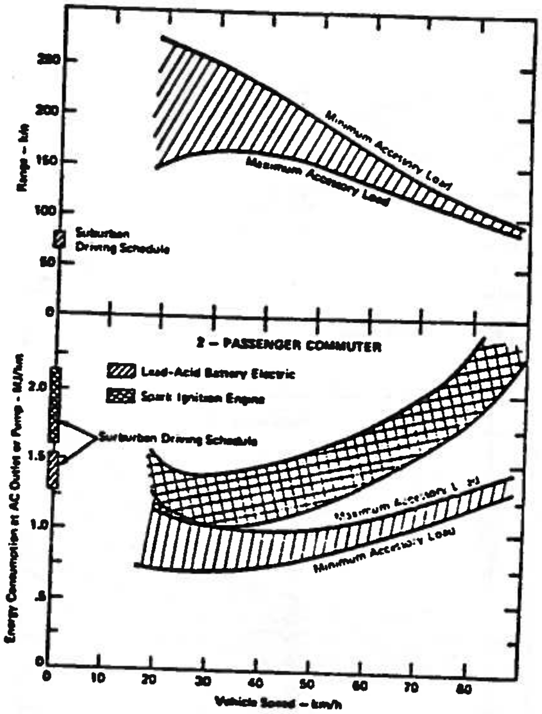

Fig. 10-Range and energy consumption of two-passenger commuter

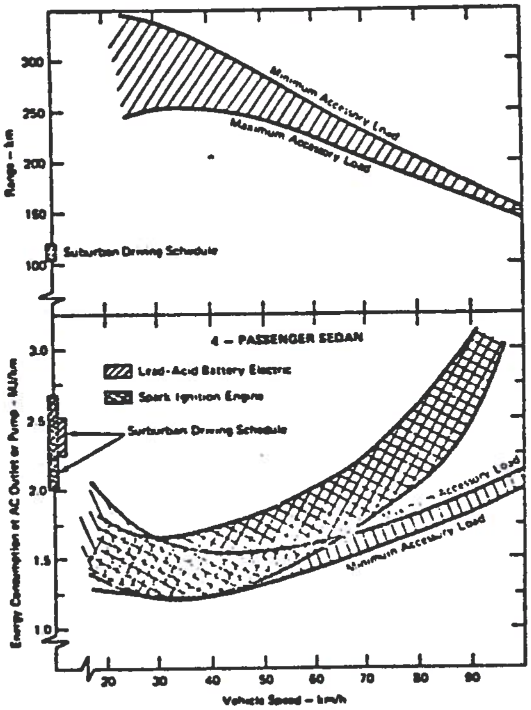

Fig. 11-Range and energy consumption of four-passenger sedan

VEHICLE PRIME SOURCE ENERGY UTILIZATION

Factoring in the production efficiencies of gasoline and electricity to the calculated energy requirements of each vehicle enables a direct comparison between the requirements of the battery-electric and spark ignition engine powered versions to be made. These comparisons are shown in Figures 14, 15, 16 and 17 for the shopper, commuter, sedan and van, respectively. They are in the form of prime source energy consumption in megajoules per kilometer over the specified driving schedule as a function of vehicle mass. The energy consumption of the battery-electric vehicle is shown as a broad band (reflecting the effect of accessory load) increasing as vehicle mass is increased by the addition of batteries and associated structure. The electric vehicle mass corresponding to the desired range (i.e., 40 km for the shopper vehicle with minimum accessory load) available from the high energy lead-acid batteries considered in the study is indicated. The energy consumption of the spark ignition powered counterpart at its maximum and minimum accessory load levels is plotted at the appropriate vehicle mass.

In the top graph of each figure, a band indicating the significant effect of accessory load on electric vehicle driving range is shown. It should also be noted that the effect of accessory load on spark ignition engine powered vehicle range is also very significant assuming a particular gasoline storage capacity. However, increasing the fuel-storage capacity of the ICE-powered vehicle to provide for accessories does not materially increase its mass, which is in contrast to the EV case.

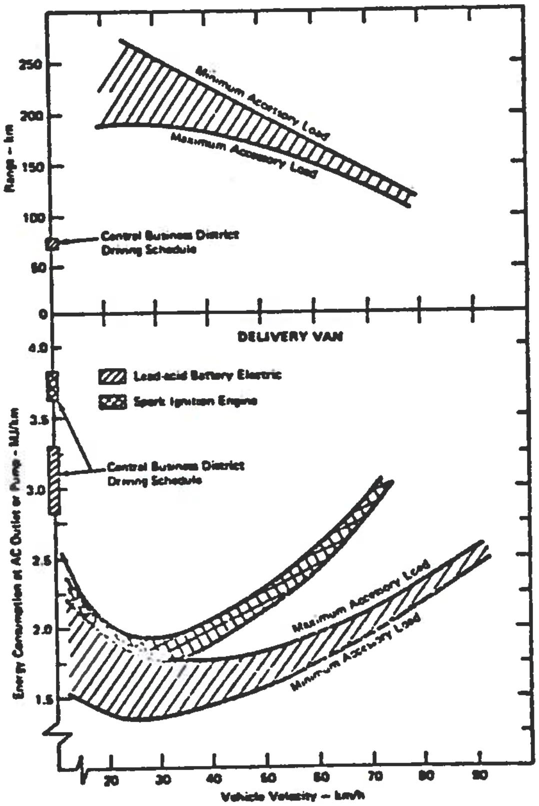

Fig. 12-Range and energy consumption of delivery van

The data from all four vehicle types is compared in Figure 18 assuming coal as the prime source. Log-log coordinates enable the broad range of vehicle mass and energy consumption to be compared in the same figure. Note that the data points spotted for each of the special purpose vehicles is at the minimum accessory load. Also shown is the driving cycle energy consumption for a variety of battery-electric powered vehicles as found in the literature [1, 2, 6, 10, 13, 14, 15] or reported publicly [16]. Equivalent energy consumption of the small General Motors' 512 spark ignition engine powered experimental shopper [6], and three 1975 Chevrolet auto-

Table XII - Average Driving Cycle Operating Efficiencies

	Electric	Spark Ignition
Motor or Engine	74%	23%
Driveline (Tires to Transmission Input and Accessories at Min. Load	80%	78%
Battery and Charger	70%	-
Overall Vehicle	41%	18%

Table XIII - Energy Production and Distribution Efficiency

Recovery and Transportation - Coal	97%
Recovery and Transportation - Petroleum	98%
Generation of Electricity	35%
Refining and Distribution of Fuel Oil	93%
Refining and Distribution of Gasoline	91%
Liquefaction and Transportation of Synthesized Petroleum	55%
Distribution of Electricity	91%

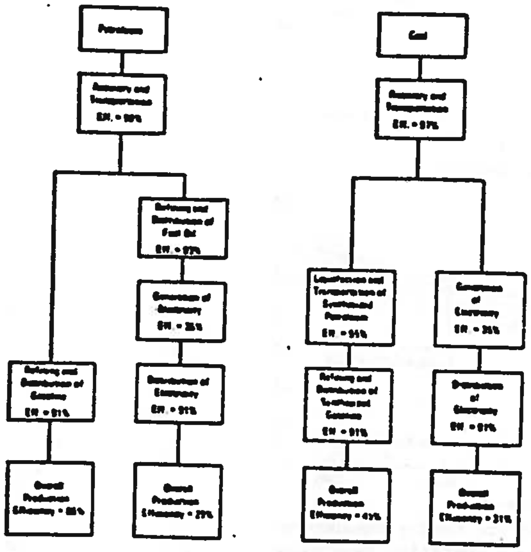

Fig. 13-Production and distribution efficiencies of gasoline and electricity from petroleum and coal

mobiles [17], i.e., a 4-cylinder Vega, a 6-cylinder Nova and an 8-cylinder Impala are also shown. As a point of reference these values represent fuel economies of 47.6, (measured on a city driving schedule) 22, 16 and 12 mpg (measured on the EPA urban test procedure) respectively.

To summarize the comparison, the ratio of battery-electric powered vehicle to spark ignition engine powered vehicle consumption is shown in Table XIV.

ADVANCED BATTERIES

Considering availability, durability and cost, lead-acid batteries are the only storage cells that can currently be utilized for electric vehicle application. The potential of other battery types, however, should not be ignored. Nickel-zinc batteries are currently the most advanced type adaptable to vehicular application in the near term. Using the specific energy-specific power variation shown in Figure 6, vehicle range can be determined in the same manner as for the lead-acid battery. Figure 19 illustrates the significant vehicle mass reductions possible when nickel-zinc batteries are used in place of the high-energy lead-acid type originally considered. If the overall charge-discharge efficiency of 70 percent assumed for the lead-acid batteries is assumed for the nickel-zinc batteries, vehicular prime-source energy consumption can be obtained directly from Figures 14 through 17 at the lower test masses required using the nickel-zinc batteries. In Table XV, the ratios of nickel-zinc battery-electric powered vehicle to spark ignition engine powered vehicle energy consumption are shown.

The 10 to 40 percent improvement over the lead-acid battery based values of Table XIV

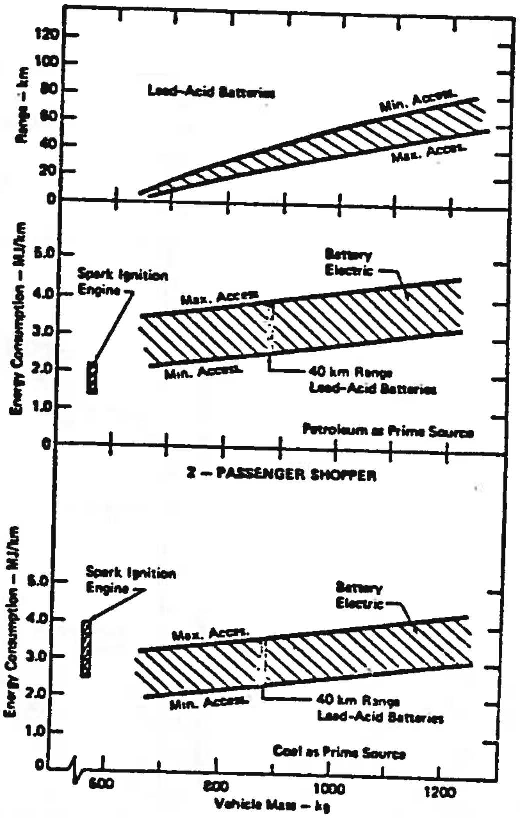

Fig. 14-Range and prime source energy consumption of two-passenger shopper operating over central business district driving schedule

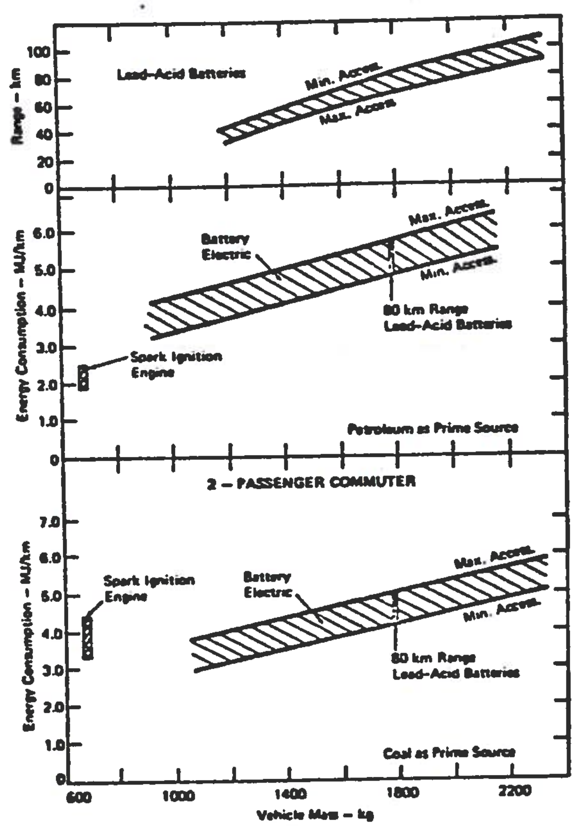

Fig. 15-Range and prime source energy consumption of two-passenger commuter operating over suburban driving schedule

illustrate the desirability of advanced batteries, particularly in longer range vehicles.

High temperature batteries, such as lithium-sulphur and lithium-chloride offer potential increases in energy density of from 5 to 10 times that of the lead-acid battery. Although such increases result in an energy capacity less than two percent of gasoline (∼ 12000 W·h/kg), these cells may make it possible for a very limited range electric vehicle to weigh no more than a comparable gasoline fueled vehicle. Linearly extrapolating the prime source energy consumption for each battery-electric vehicle type to the test mass of the comparable spark ignition engine powered vehicles, enables a comparison of the two vehicles to be made at equal test masses. Table XVI lists the energy consumption ratios obtained in this manner.

ADDITIONAL CONSIDERATIONS

With the exception of advanced battery considerations, the study thus far has been limited by the guidelines and assumptions set down at its onset. If some of these guidelines are relaxed and projections are made of electric motor efficiency levels, advanced battery performance, improved generating plant efficiency, etc., the EV energy consumption is improved with respect to the SI engine powered vehicle. Conclusions based on any unsubstantiated assumptions are without meaning and therefore will not be made. However, consideration of alternate assumptions and guidelines, if based on sound reasoning, will lend credence to some projections for the future.

Electrical component efficiency increases of 4 to 5 percentage points from the levels shown in the motor performance of Figure 1 are anticipated. Such increases could result from improved chopper controller performance and the use of a small choke (inductance) to reduce the magnitude of the controller produced voltage pulsations seen by the motor. A dual chopper system to limit the voltage variations required

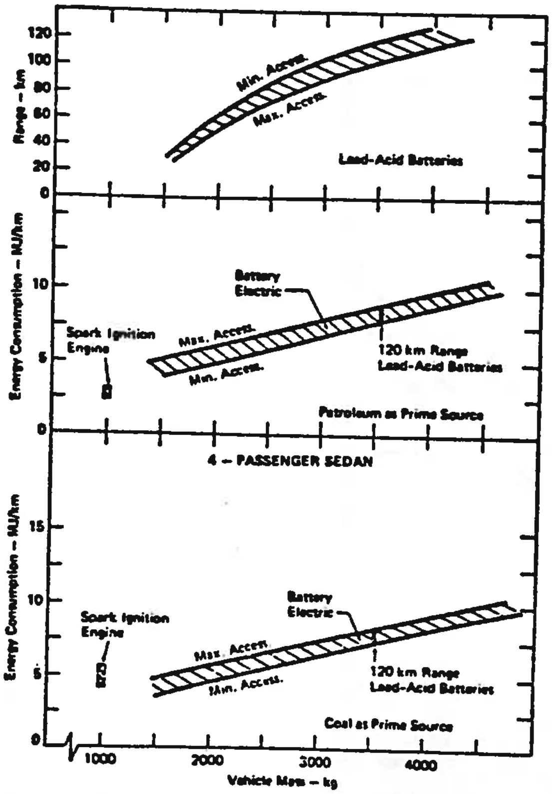

Fig. 16-Range and prime source energy consumption of four-passenger sedan operating over suburban driving schedule

at part load conditions will also increase motor efficiency, as will the use of a separately excited motor in place of the series wound type considered in this study. The potential for an overall 5 percent reduction in vehicle energy consumption over a driving schedule is felt to be reasonable for these reasons.

A critical assumption made at the study onset is the 50 percent overall mass "compounding" factor assumed for the electric vehicles to account for the additional mass required to support the batteries carried. Although no substantiation for a lower factor exists, the basis for the 50 percent value used is a study of only conventional, relatively high performance cars. It has been suggested that since the vehicles under consideration are very small and have low performance, consideration should be given to a lower compounding factor, such as 30 percent.

One final consideration pertains to the spark ignition engine efficiency levels assumed for the study. Though reasonable justification exists for maintaining these levels for scaled-down versions of the engine, there is still room for debate as to the validity of such an assumption when applied to such a small powerplant. To allow for the possibility of lower efficiency levels in the scaled down engines, a more or less arbitrary 20 percent increase in overall vehicle driving cycle fuel consumption was considered for all the spark ignition engine powered vehicles.

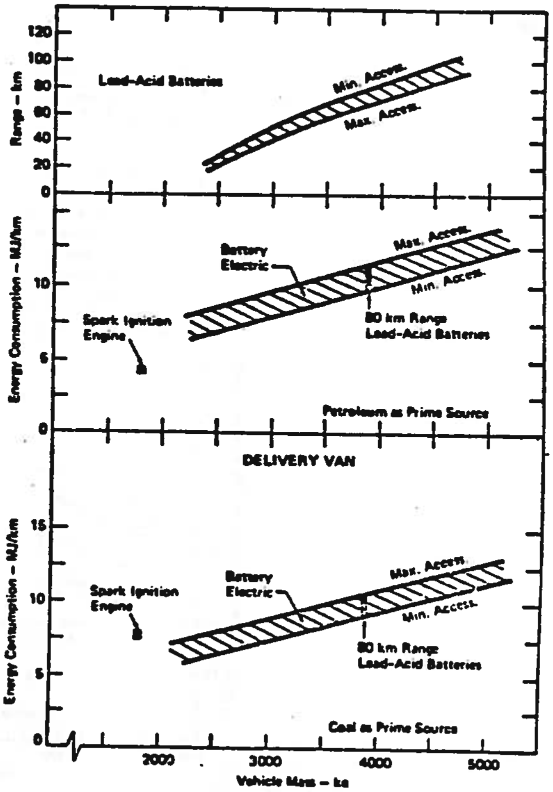

Fig. 17-Range and prime source energy consumption of delivery van operating over central business district driving schedule

The three additional considerations outlined above were incorporated using the study results previously obtained, for both lead-acid and nickel-zinc batteries. Only the minimum vehicle accessory load was considered. In Table XVII, the results of these considerations are presented as the ratio of battery-electric to spark ignition engine vehicle energy consumption.

In Figure 20, a summary of the calculated prime source energy consumption for the four types of vehicles powered by electricity and gasoline are shown. The ranges of energy consumption values indicated by the hatched

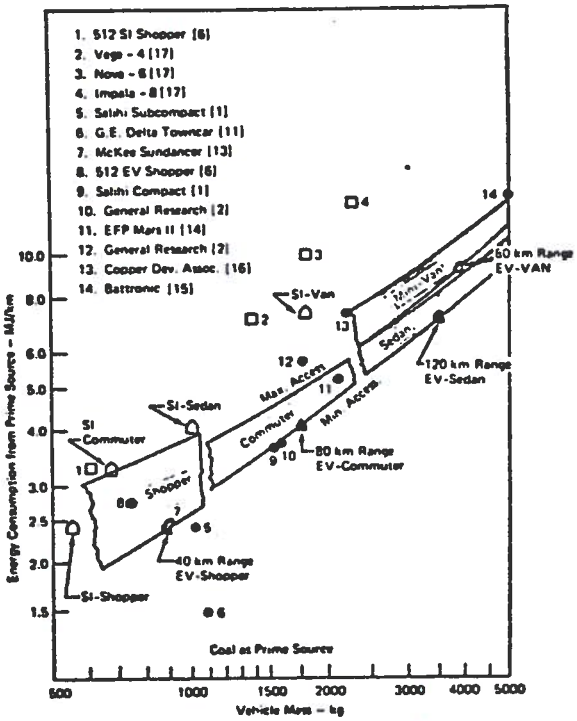

Fig. 18-Comparison of energy consumption with coal as prime source

Table XIV - Prime-Source Energy Consumption Ratio: Lead-Acid EV/SI (Minimum Accessory Load)

	Petroleum	Coal
Shopper	1.88	0.97
Commuter	2.43	1.26
Sedan	3.39	1.75
Delivery Van	2.41	1.24

sections at the top of the bars result from the variation of the mass "compounding" effect and the powertrain efficiency levels described above.

In summary, it can be said that a battery-electric powered vehicle utilizes petroleum derived energy much less efficiently than an identically performing spark ignition engine powered vehicle. The use of advanced high energy batteries, increased efficiency electric components and significant EV mass reductions will not reverse this situation. Only if petroleum is unavailable for use is there any energy consumption advantage for electric vehicles.

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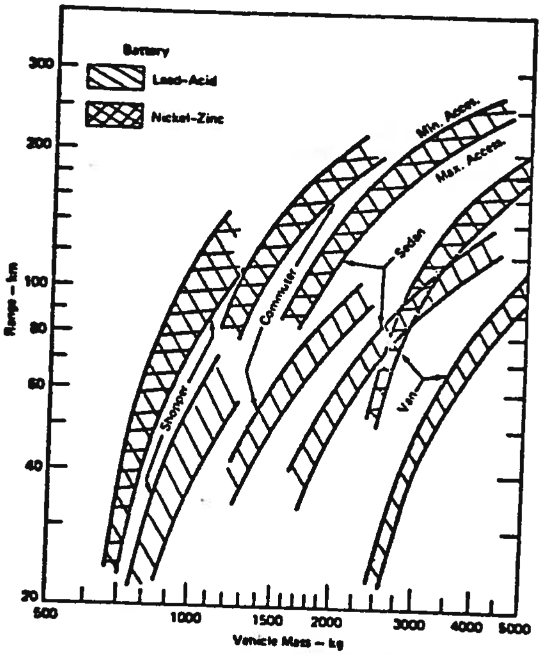

Fig. 19-Variation in range of special purpose vehicles with battery mass and accessories load

Table XV - Prime-Source Energy Consumption Ratio: Nickel-Zinc EV/SI (Minimum Accessory Load)

	Petroleum	Coal
Shopper	1.63	0.84
Commuter	1.79	0.92
Sedan	1.98	1.02
Delivery Van	1.72	0.88

Table XVI - Prime-Source Energy Consumption Ratio: EV/SI Mass of EV Equal to SI

	Petroleum	Coal
Shopper	1.40	0.72
Commuter	1.31	0.67
Sedan	1.33	0.68
Delivery Van	1.30	0.67

Table XVII - Prime-Source Energy Consumption Ratio: EV/SI Increased Efficiency and Decreased Mas; Compounding for EV; Decreased Efficiency for SI

	Petroleum	Coal
Lead-Acid Batteries		
Shopper	1.42	0.73
Commuter	1.74	0.90
Sedan	2.24	1.16
Delivery Van	1.66	0.88
Nickel-Zinc Batteries		
Shopper	1.26	0.65
Commuter	1.35	0.69
Sedan	1.48	0.77
Delivery Van	1.30	0.67

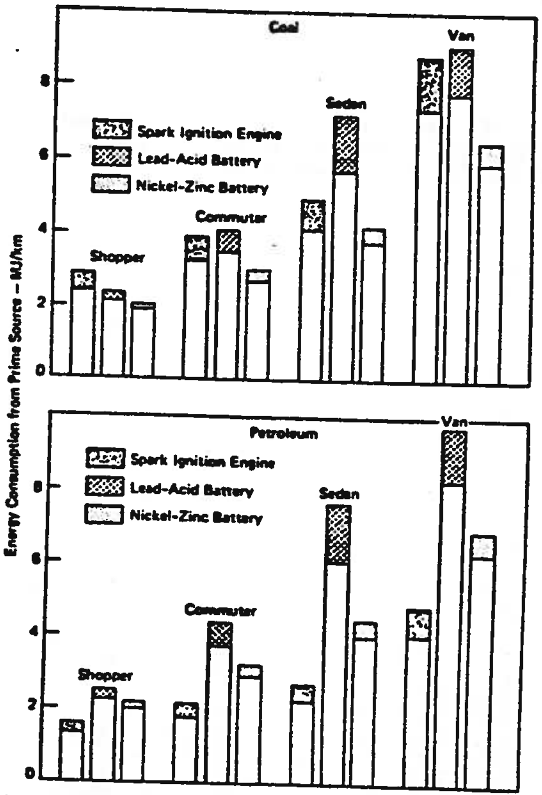

Fig. 20-Comparison of utilization of prime source energy for SI engine and battery-electric powered special purpose vehicles

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March 31. 1976

Docket Clerk
Office of the General Counsel
TGC
Department of Transportation
Washington, D.C. 20590

Comments for OST File No. 42

The following comments deal only with electric vehicles. They are based on experience obtained in preparing comprehensive analyses of the impacts of future electric car use in the Los Angeles, St. Louis, and Philadelphia urban regions.[1,2]

1. Electric vehicles should not be covered by Title V.

2. Energy requirements of electric vehicles may be compared with the energy requirements of fuel-consuming vehicles according to their per-mile use of the primary energy resources for electric recharge power: coal, fuel oil, and nuclear materials. Such comparisons are a poor basis for any general conclusions, however, for several reasons:

   a. the mix of primary energy sources which would actually provide recharge power for electric vehicles varies greatly from one urban region to another, and within each urban region according to time of day and season of the year;

   b. the efficiencies with which recharge power is generated for and transmitted to electric vehicles from a given primary energy source varies from region to region;

   c. the efficiency with which electric power is utilized in battery recharging depends strongly not only on the battery charging equipment, which may or may not be a part of the electric vehicle, but also on the distance driven between recharges and the frequency with which the operator gives "equalizing" charges in order to enhance battery life and function;

   d. electric vehicles are not directly comparable with gasoline vehicles in driving range and performance, so it is difficult or impossible to select or define an "equivalent" gasoline vehicle for energy comparison with a given electric vehicle: typical electric vehicles owe much of their low energy use to their low accelaration, topspeed, hill-climbing ability, and driving range, all of which are usually much less than those of gasoline vehicles with equal payload capability. There is no reasonable way to equalize all these factors simultaneously.

3. Inclusion of electric vehicles would discourage, not encourage, their introduction into production and commerce. Most electric vehicle production and development is now accomplished by small businesses, which would find federal requirements for testing and documentation a considerable impediment to marketing electric vehicles.

In summary, we feel that energy economy standards for electric cars are neither feasible nor desirable. The real importance of electric cars lies in their ability to provide highway transportation from energy sources other than petroleum. This they can achieve regardless of their overall energy efficiency.

William Hamilton

William Hamilton
Director, Transportation Programs
General Research Corporation
Santa Barbara, CA

nr

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Lucas Industries

Lucas Industries Limited
Central Legal Department
Shirley Solihull
West Midlands B90 4JJ

Telephone: 021-744 8522
Telex: 336749

The Docket Clerk
Office of the General Counsel
T.G.C.
Department of Transportation
Washington D.C. 20590
U.S.A.

5 April 1976
EHB/SEM

Dear Sir

OST File No 42 - Notice 76-2

We enclose herewith the comments of our Electric Vehicle Development Project on the above matter.

Yours faithfully
for and on behalf of
LUCAS INDUSTRIES LIMITED

E H Blount (Miss)

Registered office Great King Street Birmingham B19 2XF Registered no.54802 London

OST FILE NO 42; NOTICE 76-2
FUEL ECONOMY STANDARDS FOR ELECTRIC AND
OTHER NON-FUEL VEHICLES
REQUEST FOR INFORMATION AND PUBLIC COMMENTS

Telephone: 021-744 8522
Telex: 336749

5 April 1976

Joseph Lucas Limited ("Lucas") is a subsidiary of Lucas Industries Limited and is carrying out a number of projects on the development of battery-powered electric propulsion systems for road vehicles, and would comment as follows.

1 Referring to the extent to which electric and other non-fuel vehicles should be covered by Title V: Lucas observes that fuel economy standards have been introduced for the purpose of conserving liquid hydro-carbon fuel in the U.S.A. Electricity can be produced without using such fuel and Lucas avers that the application of fuel economy standards to electric vehicles does not assist this primary purpose.

2 From observations made so far Lucas has reason to believe that the standard test cycles used to compare gasolene-engined vehicles with one another are inappropriate for electric vehicles. Lucas intends to establish alternative methods to enable the performance of electric vehicles to be compared with one another and for electric vehicles to be compared with gasolene-engined vehicles. It will be some time before this work is completed.

3 Regarding the extent to which the inclusion of such vehicles would stimulate their production and introduction into commerce: Lucas is of the opinion that an electric vehicle will be shown to be no less efficient in its use of primary energy resources than a gasolene-engined vehicle, even if the primary resource considered was confined to liquid hydro-carbon. No proof of this could be produced in the time available and furthermore Lucas considers that a bias exists against electric vehicles because there is a certain fixation in the public mind with the utilization of refined gasolene. If electric vehicles can be fairly assessed, they will be shown to be efficient and desirable, and their introduction and production will certainly be stimulated.

4 Lucas has no recommendations for legislative action at this time.

SEBRING [illegible]ARD INC

ELECTRIC VEHICLES

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Sebring Air Terminal, P. O. Box 1479, Sebring, Florida 33870
Telephone: (813) 385-1561

March 8, 1976

Mr. Richard L. Strombotne
Chief, Energy and Environment Division
Office of the Assistant Secretary for Systems
Development and Technology
U. S. Department of Transportation
Washington, D. C. 20590

Dear Mr. Strombotne:

We are grateful to the Department of Transportation for the attention you are giving to the development of the electric car industry in the United States.

To dispute your statement in a recent issue of TRANSPORTATION USA, I am pleased to enclose some information on the energy efficiency of CitiCar. It is quite self-explanatory.

If you have any other questions about CitiCar which I might be able to answer, please do not hesitate to contact me.

Sincerely yours,

Robert M. Stone

Robert M. Stone II
Marketing Manager

RMS:iah- Enclosures:
Fact Sheet/Calculation Sheet
Passenger Protection Plan

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	ELECTRIC CAR	GAS-OPERATED SUBCOMPACT
Typical Daily Usage	25 Miles	25 Miles
Time Period	One Year/365 Days	One Year/365 Days
Total Mileage	9,125 Miles	9,125 Miles
Energy Consumption Rate	3.92 Miles/KWH * ? (Kilowatt Hours)	20 Miles/Gal. of Gasoline
Total Energy Consumption	2327.8 KWH	456.25 Gals. of Gasoline
Consumer Cost	$93.11 (4¢ per KWH)	$273.75 (60¢ per Gal.)
No. of KWH Generated by Power Plant Oil	372.448 KWH **	N/A
Gal. of Crude Oil Required	29.7 Gals. of Crude Oil ***	543.2 Gals. of Crude Oil ****

SAVINGS OF OIL, ELECTRIC VS. GAS: 513.5 GALLONS OF CRUDE OIL PER YEAR OR $180.64!

* Based upon October 1, 1975, Energy-Efficiency Test of 1976 CitiCar, with standard equipment. A kilowatt hour is a unit of measure for electricity usage.

** Nationwide, only 16% of all electricity is oil-generated.

*** Each gallon of crude oil can generate 13.5 KWHs of electricity, all transmission inefficiencies taken into account. Refining process of power plant (distillate) fuels is about 93% efficient.

**** Represents 84% overall efficiency in gasoline refining.

If ten million Americans drove an electric car (an average of 25 miles per day) instead of a gasoline-operated subcompact, we could reduce our oil imports by over 121 million barrels per year.

HELP AMERICA BECOME ENERGY INDEPENDENT - DRIVE AN ELECTRIC CITICAR.

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WHY CURRENTLY AVAILABLE ELECTRIC CARS OFFER A PRACTICAL ALTERNATIVE TO THE GASOLINE AUTOMOBILE

33.7% of all automobile travel is driving to and from work where the average trip length is 9.4 miles and the average number of occupants per car is 1.4.

19.3% of all automobile travel is for family business (shopping, doctor appointments, etc.) where the average trip length is 5.6 miles and average occupants per car number 2.0.

87.5% of all automobile trips are 15 miles or less, one way.

The average annual miles driven by male licensed drivers are 11,352 or 31 miles per day. The average annual miles driven by female licensed drivers are 5,411 miles or 15 miles per day.

There are about 24,000,000 households in the United States which own two or more cars. This represents 33.8% of all U.S. households.

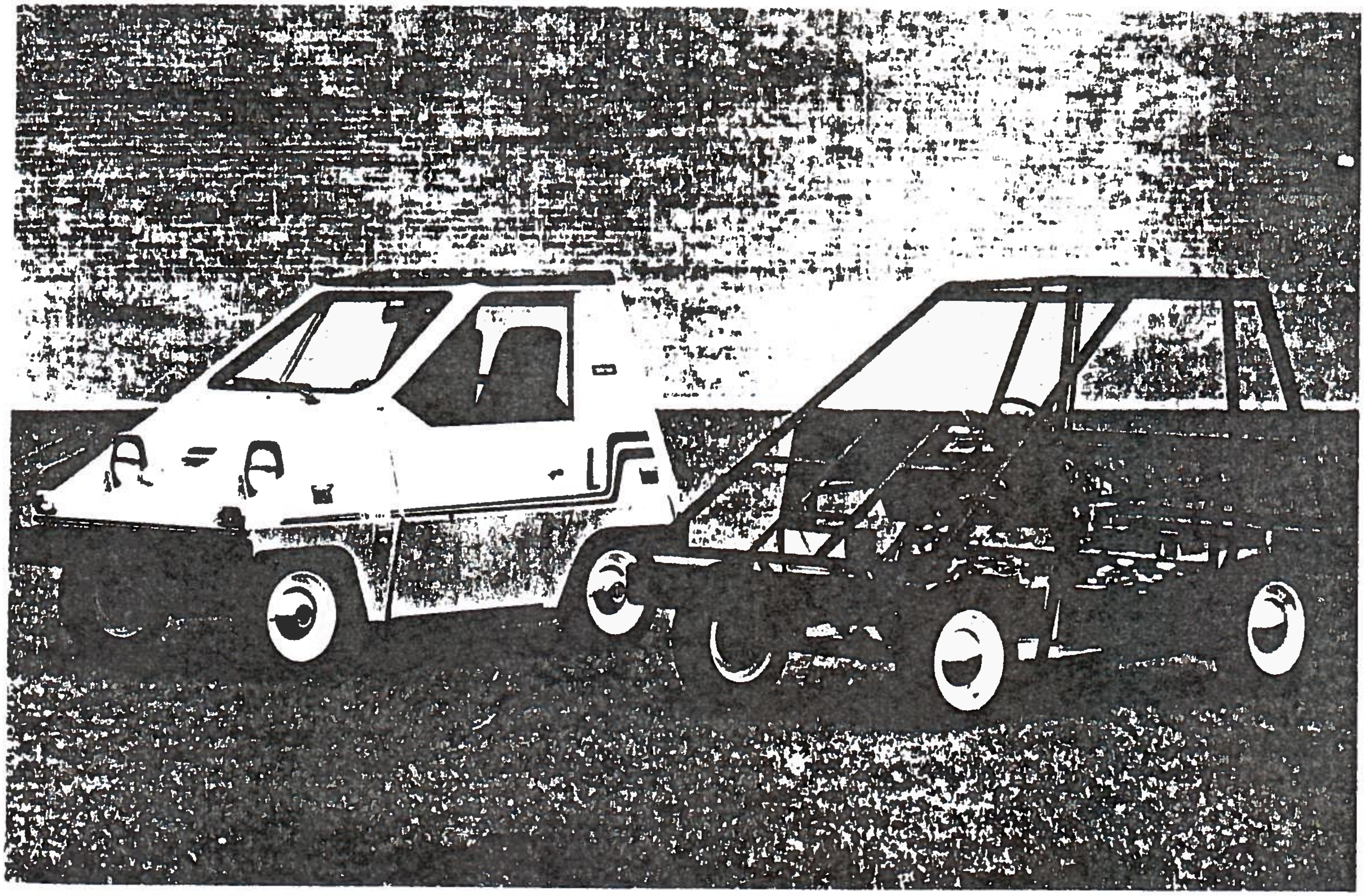
In 1973, the average miles per gallon travelled was 13.10 mpg. This is lower than the 1972 figure of 13.49 mpg.

In 1973, the average miles per vehicle was 9,992 annually, down from 10,184 the year before. This is equivalent to 27 and 28 miles per day, respectively. *

* Compiled by the Motor Vehicle Manufacturers Association, 1975 AUTOMOBILE FACTS & FIGURES.

Hertz Leasing Corporation has reported that the cost of operating a gasoline car is highest for cars driven 10,000 miles a year or less. The 1975 estimates show that costs range from 21¢ a mile for a sub-compact, to 24¢ a mile for an intermediate-size two-door sedan, to 31¢ a mile for a standard-size car, all at the 10,000 mile per year rate.

The cost of operating CitiCar is expected to be much less than a conventional car. All over America, thousands of people are switching to electric cars to save money and uncomplicate their lives. Examine your own driving habits considering the above information. Perhaps you, too, should own an electric car for most of your driving needs and use a gasoline car or mass-transportation for long distance travel.



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Manufactured by [illegible] VANGUARD, [illegible]

SEBRING-VANGUARD, INC

The 1976-1/2 CitiCar is equipped with the following standard features:

- Integral rollbar-type passenger protection system
- Bright impact-resistant space-age plastic body (Cycolac) rust and corrosion-proof
- "Silent drive" Dana Differential
- Door/Window Locks
- Fully Automatic Solid State On-board Built-in Charger
- 6 Horsepower G.E. Motor
- Heavy Duty Electric Car Batteries by Exide
- "Fuel-less" Heater/Defroster System
- Custom Sliding Windows
- 4-Wheel Bendix Brakes
- Dual Master Cylinder
- Drip Rail Moldings
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- Custom Woodgrain Dashboard
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- High Impact Urethane Bumpers
- Laminated Safety Glass Windshield
- Shoulder Harness Seat Belts
- Inner Door Straps
- Dual Speed Windshield Wiper
- Windshield Washer
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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

9 APR 1976

OFFICE OF THE
ADMINISTRATOR

A-DOT-A86097-00

Docket Clerk
Office of the General Counsel
Department of Transportation (TGC)
400 Seventh Street, S.W.
Washington, D.C. 20590

Dear Sir:

This will respond to your March 3, 1976 Federal Register, Request for Information and Public Comment on two items: (1) Fuel Economy Standards for Electric and Other Non-Fuel Vehicles (OST File Number 42; Notice 76-2); and (2) Fuel Flow Meters (OST File Number 4; Notice 76-1).

Fuel Economy Standards for Electric and Other Non-Fuel Vehicles

Enclosed is a recently prepared EPA fact sheet entitled "Electric Vehicles as a Solution to Air Pollution and Fuel Shortages." We believe you will find the information to be helpful, especially with respect to your question on the manner in which the energy requirements of electric and other non-fuel vehicles may be compared with the energy requirements of fuel-consuming vehicles.

Fuel Flow Meters

The effectiveness of fuel flow meters in reducing national fuel consumption will depend upon the degree to which the instruments are heeded by the driving public.

One way to ascertain the probable effectiveness of this type of device would be to install such meters on a large group of in-service automobiles, monitor the fuel economy achieved by these cars over a given period of time, and then compare those results with the fuel economy achieved during the same period of time by an equally large controlied group of cars (of identical specifications) not equipped with the meters.

We believe, however, that an instrument, sensitive to changes in throttle position might be a more effective device for promoting good driving habits than would be a fuel-flow meter (such as you propose). Since instruments that read directly in miles-per-gallon must necessarily sense fuel-flow rate, probably between the fuel pump and the carburetor, the instantaneous fuel-flow rate changes that occur in the carburetor with throttle position changes are to a degree damped out when measured up-stream of the carburetor. A manifold vacuum meter or a set of lights operated by manifold vacuum would be sensitive to and indicate the momentary changes in throttle position caused by the driver, thus making it a more sensitive and effective device than a fuel-flow meter. Of course, effectiveness of even this type of meter would depend upon the driver's heeding its readings.

If you have any questions regarding the above comments, please contact either Mr. George Kittredge of the Office of Mobile Source Air Pollution Control (Tel. No. 426-2514) or Ms. Meri Bond on my staff (Tel. No. 245-3006).

Sincerely yours,

Rebecca W. Hanmer

Rebecca W. Hanmer
Acting Director
Office of Federal Activities (A-104)

Enclosure

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

Electric Vehicles as a Solution To Air Pollution and Fuel Shortages

The Environmental Protection Agency has received many inquiries about the feasibility of using electrically-powered vehicles as a solution to air pollution problems and fuel shortages. This Fact Sheet has been prepared to respond efficiently to those inquiries.

Technical feasibility of Electric Cars

Electric vehicles were in common use early in this century. However, with the gradual improvement in internal combustion engines electric vehicles could no longer compete in terms of range of travel, ease of refueling, and acceleration and high speed characteristics. Widespread use of electric cars was abandoned in this country except for highly specialized and limited short range applications.

The EPA has sponsored studies on the technological, energy, environmental, and economic impacts associated with presently available and projected future electric car technology and its application. These studies are being continued by the Energy Research and Development Administration.

Although there is room for some engineering advances to improve performance and efficiencies of electric vehicles, the basic technology required to build such vehicles is readily available. However, the major obstacle standing in the way of the widespread use of electric vehicles to meet urban transportation needs is the unavailability of batteries of acceptable cost with sufficiently high power and energy density to provide adequate vehicle range and road performance, approaching that of conventional gasoline-fueled vehicles of comparable utility. Unfortunately, the lead-acid batteries in common use, and used in the few electric vehicles on the market today, are inadequate to provide such operating range and performance.

Batteries currently available limit electric vehicles to a range of from 30 to 50 miles of low-speed urban driving before needing electric recharge. Development programs are in progress to develop higher performance batteries, but the technology needed to produce practical versions of advanced batteries is not expected to be available before 1980 at the earliest.

FS-19

Relative efficiency of energy use by Electric Cars

Electric cars with advanced types of batteries could be of comparable efficiency to their ICE counterparts; however the major advantage of electric cars over the ICE is not improved efficiency but their ability to utilize power generated from more abundant energy sources. The electric car would still provide reduced range. In addition, acceptance of electric cars would necessitate some changes in the ways the general public uses their cars, to accomodate the lessened capability to support accesory and comfort subsystems such as heating, air conditioning and other power consuming accessories, as well as inherently reduced range.

With lead acid type storage batteries of the types available today, an electrically powered car with performance features that approach as much as possible those of comparable utility internal combustion engine powered cars would consume more energy, if it is assumed that the energy in both cars is derived from petroleum. However, if the energy were derived from coal, the comparison would favor electrically powered vehicles, because coal can be burned directly to generate electrical power for charging the batteries of the electrics, whereas it must undergo extensive chemical conversions having relatively low efficiencies in order to be converted into gasoline of a quality which can be utilized in internal combustion engines. Thus, the real potential for widespread use of electrically powered vehicles in future years lies in their inherent independence on the type of fuel used to generate electricity, and thus their ability to reduce petroleum consumption.

Until advanced batteries are developed, or until a shift is made from petroleum to coal as a primary source of energy for both electric power generation and for automotive transportation, it is not realistic to expect a significant substitution of electric cars for gasoline-powered cars, and thus not realistic to count on environmental benefits in terms of reduced air pollution from the use of electric cars.

Over the very long term, the ability of electric cars to utilize energy generated by nuclear power plants and hence be completely independent of fossil fuel reserves, would seem to be a compelling reason to continue with research and development on better batteries. However, the increasing public concerns over safety of nuclear systems would appear to cast some doubt on the prospects for rapid expansion in this direction.

OMSAPC/March 1976

UNITED STATES
ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
WASHINGTON, D.C. 20545

APR 9 1976

Docket Clerk, Office of General Counsel
TGC, Department of Transportation
Washington, D. C. 20590

Dear Sir:

This letter provides comments in response to the notice appearing in the March 3, 1976, Federal Register (OST No. 42) for information regarding the advisability of including electric and other non-fuel vehicles within the coverage of Title V of the Motor Vehicle Information and Cost Savings Act of 1972. These comments represent the position of the Office of Conservation of the Energy Research and Development Administration. This Office has responsibility for implementing the authorities of ERDA with regard to Research, Development and Demonstration of electric vehicles.

The statements presented in A and B below are based on the fact that the mandatory fuel economy standards for new motor vehicles powered by gasoline and diesel fuels were imposed with the purpose of limiting the future usage of petroleum, and not for the purpose of regulating vehicle energy efficiency, per se. This limitation is important in that the issue of "relative value" of petroleum-, coal-, and nuclear-based energy sources is raised when considering the four questions specified in your request for information.

A. Electric Vehicles

The term "electric vehicles", as utilized herein, refers to all vehicles designed specifically to obtain all or a major portion of their motive energy requirements from electric power generated by utility power plants. It thus encompasses all-battery-powered vehicles, flywheel-with-electric-drive-motor vehicles, and battery or flywheel "hybrid" vehicles which may also contain a heat engine for range extension or minor recharging purposes. These vehicles are being offered with the principal objective of shifting the resource base from petroleum-based gasoline and diesel fuels to electric power generated by the current petroleum/coal/nuclear utility system and by the future utility systems energy resource mix (e.g., coal, nuclear, solar, geothermal).

1. The Extent to which Electric Vehicles should be covered by Title V

Title V imposes petroleum-based fuel consumption restrictions on the manufacturers of vehicles designed to use petroleum-based gasoline and diesel fuels. The manufacturer of an "electric vehicle" (as defined herein) in the strict sense has no control over the amount of petroleum being used by the United States utility system in producing the electrical energy to be required by "electric vehicles". Current and projected trends imply a gradual conversion from the present petroleum/coal/nuclear mix to a less petroleum intensive resource mix at some point in the future. To impose petroleum-based fuel consumption restrictions on the manufacturers of electric vehicles would require the establishment by the government of a "petroleum equivalency" factor for utility power generation which could then be applied to the energy requirements of the electric vehicle over a federal test cycle. Such a "petroleum equivalency" factor would be expected to change with time as the energy resource mix of the utility system changes. Since the "electric vehicle" industry is not well developed and projected sales in the time period of interest are small, it would seem premature to consider covering them in Title V at this time, in view of the foregoing uncertainties.

2. The Manner in which the Energy Requirements of such Vehicles may be compared with the Energy Requirements of Fuel-Consuming Vehicles

Assuming a given equivalent federal test cycle, the measured energy requirements of the "electric vehicle" over the test cycle would have to be adjusted to account for the efficiencies of battery or flywheel recharging, electric power transmission from the power station to the charging facility, and for power generation inefficiencies, in order to compare the energy utilization characteristics of the two vehicle classes. To compare on the basis of petroleum utilization, the "petroleum equivalency" factor noted in 1 above could then be applied to the electric vehicle. If the utility resource mix were predominantly coal and nuclear, for example, the "petroleum equivalency" factor would be near zero in this case, for all-electric vehicles. Hybrid vehicles utilizing on-board heat engines would have to account for actual petroleum consumed in the test cycle plus the "petroleum equivalent" of the electric power used.

Based on current electric vehicle technology, on an energy basis of comparison, electric vehicles and petroleum-base-fueled vehicles consume approximately the same amount of energy when the inefficiencies of power generation, transmission, and recharging are considered. Thus, the major potential of the electric vehicle is not to save total energy, but to aid shifting the resource base to non-petroleum generated power.

3. <u>The Extent to which inclusion of such vehicles would stimulate their production and introduction into commerce</u>

Assuming that "electric vehicles" were included in Title V (including the determination of the requisite "petroleum equivalency" factor and similar values for recharging, generation, and transmission losses), the net result should be that a manufactured electric vehicle would be credited with or assigned a very high "equivalent-mpg" value because of very low consumption of petroleum in the utility power system resource mix. By being included in Title V, if the manufacturer <u>also</u> produced gasoline or diesel fueled vehicles, his ability to meet the sales-weighted mpg requirements of Title V would be considerably enhanced if he produced a sufficient number of electric vehicles. On this basis, a manufacturer could be encouraged to develop, produce, and market such vehicles, at least to a limited extent. On the other hand, the extremely low "petroleum equivalency" values (i.e., very high "equivalent mpg" values) for the electric vehicles produced, for the stipulated mpg standards set forth in Title V, would permit this same manufacturer to <u>increase</u> the petroleum consumption of his gasoline and diesel fueled vehicles (decrease their mpg capabilities) and still meet the standards.

4. <u>Recommendations for Legislative Action</u>

. It is recommended that continuing assessments of electric vehicle technology, capability, and manufacturing status be carried out, perhaps by ERDA for DOT, in order to advise the Congress at the appropriate time as to the nature and extent of energy-efficiency regulations that are compatible with electric vehicles.

B. <u>Other Non-Fuel Vehicles</u>

The term "other non-fuel vehicles", as utilized herein, refers to all vehicles designed specifically to obtain all or a portion of their motive energy requirements from non-petroleum-based fuels carried on-board the vehicle. It thus principally includes conventional type automotive vehicles using coal-derived gasolines and distillates, methanol and methanol-gasoline blends, and hydrogen.

1. The Extent to which other non-fuel vehicles should be covered by Title V

To the extent that Title V is aimed at reducing petroleum consumption, the "other non-fuel" vehicle class accomplishes this purpose by direct fuel substitution. However, the restrictions of Title V are imposed upon the vehicle manufacturers, not the alternative fuel producers. The inclusion of "equivalency factors" or "credits" for non-petroleum-based fuel use in Title V would not impose any hardship on a motor vehicle manufacturer and possibly could encourage cooperation between vehicle manufacturers and fuel producers which in turn, could accelerate the use of non-petroleum-based fuels such as coal-based gasolines and distillates, methanol, and methanol-gasoline blends. In the case of hydrogen, it is generally agreed there will be no substantial production in the next decade, and still no definition as to its eventual form of storage on-board the vehicle (e.g., liquid vs. hydride storage); therefore, it would seem inappropriate to include hydrogen at this time.

2. The manner in which the energy requirements of such vehicles may be compared with the energy requirements of fuel-consuming vehicles

It is suggested that the most straightforward method of comparing non-petroleum fuels with petroleum fuels is to compare their lower heating values in Btu's, and to adjust mpg values in accordance with the ratio of lower heating values.

In addition, in order to stimulate the use of non-petroleum fuels, a system of "credits" or "equivalency factors" could be devised to increase the mpg rating of a vehicle designed to operate on non-petroleum fuel, based on the need and desire of the government to stimulate such use.

3. The extent to which inclusion of such vehicles would stimulate their production and introduction into commerce

As noted in item 1 above, if non-petroleum-based vehicles were included in Title V and provided with an incentive in the form of a credit or a mpg-multiplier factor, this could result in pressure on the part of vehicle manufacturers to have such fuels made available for more general use.

4. Recommendations for Legislative Action

It is recommended that an analysis and assessment of methods and techniques for developing and establishing credit factors be carried out for non-petroleum-based fuel use for possible later inclusion in Title V-type regulations in order to provide guidance for the automotive manufacturers and fuel producers.

Sincerely,

Gene G. Mannella

Gene G. Mannella
Deputy Assistant Administrator
for Conservation

cc: E. Stork
R. Hemphill
T. Ratchford

OPERATIONS GROUP
Washington, DC 20260

April 8, 1976

Docket Clerk
Office of the General Counsel
TGC
Department of Transportation
Washington, DC 20590

Subject: OST File No. 42; Notice 76-2, "Fuel Economy Standards for Electric and Other Non-Fuel Vehicles"

Gentlemen:

The U. S. Postal Service has experimented with electric vehicles since the early 1900's. As new concepts with potential for Postal Service use have become available, they have been evaluated and tested. The fuel crisis of 1973 provided greater impetus to the electric vehicle program and to the search for viable alternative fuels to replace petroleum. Additionally, each one-cent increase per gallon in the cost of gasoline costs the Postal Service about $3.5 million per year.

Our studies and tests have clearly demonstrated the operational feasibility of using electric vehicles in mail delivery on the shorter, more level postal routes. They are non-polluting at least in ground level emissions, quiet and essentially vibration-free when compared to conventional internal combustion engine (ICE) vehicles. After 2 years of testing 30 electrics our records reflect that they have operated cheaper than ICE's in both maintenance and "fuel". It is too early for valid life cycle cost projections but we are encouraged by the program thus far.

The Postal Service procured 350 AM General electric, 1/4-ton, delivery vehicles which have just been received. They are being placed in delivery operation and detailed cost accounting procedures installed. Data gathered, including energy use, will be used to evaluate the vehicles and their cost effectiveness and to guide plans for procurement of additional electrics within the next year.

Our experience indicates that in the Postal Service delivery cycle electric vehicles require only 75 to 80% of the total BTU requirement of gasoline vehicles on the same cycle (measured from oil well or coal mine to the vehicle drive wheels). A major factor in this reduction is the impact of engine idling on gasoline economy.

From what we have learned in keeping abreast of developments in other than electric vehicles (i.e. hybrid, hydrogen fueled, energy flywheels, etc.) we conclude that their treatment in relation to Title V should be similar to that of electric vehicles.

Comments concerning Section 512(b) items are:

Item 1. The extent to which electric and other non-fuel vehicles should be covered by Title V.

> Comment. Electric and other non-fuel vehicles have not enjoyed the widespread use necessary to establish a base from which to determine valid fuel economies which may reasonably be required of them. It is suggested that mandatory fuel economy measures may be more equitably applied when the vehicles have been more fully developed and have accumulated more user experience and acceptability. The uncertain future of petroleum supplies may require that other fuels be used regardless of fuel economy. Should this transpire, viable alternative vehicular systems must be fully developed and rapid transition effected. It would appear detrimental to new concept development to impose restrictive fuel economy standards at this time. Developers must give serious consideration to fuel economy because of its growing importance in marketing their products.

Item 2. The manner in which the energy requirements of such vehicles may be compared with the energy requirements of fuel-consuming vehicles.

> Comment. Comparison may be made in BTU from source (well, mine, etc.), through the manufacturing/converting/exchanging process, to the vehicle wheels (i.e., BTU per mile). Of importance here, however, is the extent with which the power source may be independent of petroleum, for example, coal, water, nuclear and solar electric power.

Item 3. The extent to which inclusion of such vehicles would stimulate their production and introduction into commerce.

> Comment. It is not believed that inclusion of these vehicles in Title V would stimulate their manufacture and/or use.

Item 4. Any recommendations for legislative action.

> Comment. Recommend legislation to assist developers of electric and other non-fuel vehicles in large scale user testing (several thousand) of any vehicular system which demonstrates reasonable feasibility as replacement for 10% or more of the presently used vehicles in the United States.

While we recognize and concur in the importance of fuel conservation and the fuel savings inherent in Title V, we believe that mandatory fuel economy standards may retard the development of alternative power sources at a time when their use could become critical to the transportation requirements of this country almost overnight.

Sincerely,

Donn P. Crane

Donn P. Crane, Director
Office of Fleet Management
Delivery Services Department

APPENDIX I

ESTIMATES OF PRODUCTION AND CAPITAL COSTS FOR THE POWER GENERATION PLANT OF A 2000 LB CURB WEIGHT INTERNAL COMBUSTION ENGINE AUTOMOBILE (250,000 UNITS/YEAR)

I.1 DEFINITION OF POWER GENERATION PLANT

For purposes of this report, a power generation plant in an Internal Combustion Engine (ICE) is defined as consisting of:

a) Engine and accessories such as the radiator, the engine electrical system (battery, alternator, etc.), the carburetor, etc.

b) Fuel System including, gas tank, fuel lines, fuel cannister, etc.

c) Exhaust system, including muffler, fuel pipe, catalytic converter, etc.

The power generation plant does not include the components needed to transfer the power obtained from the engine to the wheels driving the vehicle (e.g., transmission).

I.2 METHODOLOGY AND ASSUMPTIONS

The following assumptions were made in deriving the costs developed in this report:

a) The engine manufacturing facilities were considered to include a foundry, the lines necessary to machine the major components of the engine (such as the engine block, the engine cylinder heads, intake and exhaust manifolds, valves, pistons, connecting rods and crankshaft) and the final assembly line.

b) Specialized parts and assemblies (such as the radiator, the battery, the engine electrical equipment, catalyst for exhaust system) are purchased from outside vendors.

The items assumed to be made in-house are listed in Table I-1. The purchased component parts are listed in Table I-2. The components listed in these Tables were obtained principally form a recent

TABLE I-1 WEIGHT AND COMPOSITION OF COMPONENTS OF AUTOMOTIVE POWER GENERATION PLANT ITEMS ASSUMED MADE IN-HOUSE

MATERIAL OF CONSTRUCTION	STEEL	ALUMINUM	FEREOUS CASTING	COMPO-SITE	PLASTIC	TOTAL
ENGINE						
AIR CLEANER BASE	4.1					4.1
AIR CLEANER TIP	1.5					1.5
CAM SHAFT			8.4			8.4
CONNECTING RODS	9.8					9.8
CRANK SHAFT			67.3			67.3
ENGINE BLOCK			241.4			241.4
ENGINE HEADS			40.0			40.0
EXHAUST MANIFOLD			26.0			26.0
EXHAUST VALVES	2.0					2.0
FAN	3.0					3.0
FAN SHROUD					4.0	4.0
INTAKE MANIFOLD			52.8			52.8
MISCL. ALUMINUM		4.3				4.3
MISCL CAST IRON			13.6			13.6
MISCL STEEL	31.2					31.2
OIL PAN	6.3					6.3
PISTONS		13.3				13.3
PULLEYS			5.0			5.0
VALVE COVERS	3.4					3.4
WATER PUMPCASTINGS			11.6			11.6
SUB-TOTAL ENGINE	69.3	17.6	466.1	—	4.0	549.0
EXHAUST SYSTEM (NOCATALYST)						
EXHAUST PIPE	10.9					10.9
MUFFLER	16.6					16.6
TAILPIPE	8.6					8.6
TAILPIPE HANGERS				1.7		1.7
SUBOTOTAL EXHAUST SYSTEM	36.1	—	—	1.7	—	37.8
FUEL SYSTEM						
FUEL CANNISTER BRACKET	0.4					0.4
FUEL FILLER BRACE	0.2					0.2
FUEL FILLER CAP	0.4					0.4
FUEL TANK LOWER	13.0					13.0
FUEL TANK LOWER BRACKET	5.7					5.7
FUEL TANK UPPER	17.5					17.5
FUEL TANK SUPPORT	2.4					2.4
SUB-TOTAL FUEL SYSTEM	39.6					39.6
TOTAL POWER GENERATION PLANT	187.0	17.6	466.1	1.7	4.0	626.4

SOURCE: Ref. 52

TABLE I-2 WEIGHT AND COMPOSITION OF COMPONENTS OF AUTOMOTIVE POWER GENERATION PLANT ITEMS ASSUMED TO BE PURCHASED COMPONENTS

	COMPONENT WEIGHT, LBS
ENGINE	
AIR CLEANER FILTER	0.5
AIR CLEANER TUBING	0.7
AIR INLET CONDO	0.7
ALTERNATOR	16.4
BATTERY	40.0
BATTERY CABLES	0.6
CARBURETOR	7.0
ENGINE DETAIL	24.2
FASTENERS	12.5
RADIATOR ASSEMBLY AND SUPPORTS	16.0
STARTER ASSEMBLY	18.3
STARTER SOLENOID	0.8
STARTER SWITCH	0.5
STARTER WINDINGS	2.0
VOLTAGE REGULATOR	0.7
SUB-TOTAL ENGINE	140.9
EXHAUST SYSTEM	
NONE	
FUEL SYSTEM	
FUEL CANNISTER	3.2
FUEL FILLER TUBE	1.7
FUEL HOSES	2.5
FUEL LINES	2.6
HOSE CLAMPS	0.2
SUB-TOTAL	10.2
TOTAL POWER GENERATION PLANT	151.1
ADDITIONAL COMPONENTS NOT INCLUDED ABOVE	
CATALYTIC EXHAUST CONVERTER	20.0
TOTAL WITH ADDITIONAL COMPONENTS	171.1

SOURCE: REF 52

study by Luetje and Martin (52) of Armco, who disassembled a 1973 Ford F-100 Ranger one-half ton pick-up truck and then photographed and examined all the component parts of the vehicle. The data include the component part, its weight and composition. The truck was powered by a 302 cubic inch, 137 HP (53) V-8 engine. A number of the Ford Motor Company's compact and intermediate size passenger automobiles of at model year were powered by the same engine (54). The information in the Armco report on the power generation plant is therefore applicable to passenger automobiles as well as to light trucks.

The vehicle examined by Armco did not have a catalytic converter for emissions control, which would now be a standard component. For this study, a catalytic converter is assumed to be a purchased component and was added to the list of items presented in Table I-2.

Further assumptions include:

c) Based on available data on sub-compact cars in the 2000 lb range, it was estimated that the weight of the power generation plant, as here defined, was approximately 22% of the vehicle curb weight, or 440 lbs., (55, 56).

d) The production cost, C_P, of the engine was taken to be equal to the sum

$$C_P = C_M + C_C + C_L$$

where

C_M = cost of purchased RAW materials

C_C = cost of vendor parts

C_L = cost of production labor

e) In developing a production cost, it was assumed that the cost of raw materials varies with the weight of the power generation plant, but that the weight and cost of the specialized components (such as the battery, alternator and distributor) and the amount of labor require to produce an engine, are essentially independent of the size of the power generation plant.

I.3 ESTIMATION OF PRODUCTION COST

a) Raw Materials

The unit cost of raw materials was based on the prices published in trade journals, such as American Metal Market, in Dec. 1975 (44) and some recent automotive pricing studies (50) as shown in Table I-3, and the relative amounts of these materials in the in-house made parts. In manufacturing these parts, a scrappage rate of 35% of the total material purchased was assumed. The average price of these materials of 19.1¢/lb. reflects this scrappage rate.

The amount of raw materials used in the power generation plant was assumed to be the difference between the total weight of the power generation plant (440 lbs) and the total weight of purchased components as given in Table I-2 (171 lbs.). The weight and cost of raw materials in the power generation plant are therefore estimated to be 269 lbs and $51.

b) Vendor Parts and Components

The cost of vendor parts are presented in Table I-4. These were principally derived from data published in the 1972 Census of Manufactures (57), adjusted to December 1975 costs by using the industry price indices published by the U.S. Department of Commerce (58), as shown in Tables I-5 and I-6. The price of a catalytic converter was based on cost data for a three-way catalytic pellet converter for a 4-cylinder engine engine published in 1974 report by the National Science Foundation (51). The cost of the voltage regulator solenoids was based on data on miscellaneous automotive electric equipment published in the 1972 Census of Manufactures. The cost of the fuel cannister is an estimate, for lack of data.

c) Production Labor

The number of man-hours required to manufacture the in-house made parts and assemble the power generation plant were based on the results of a study performed by International Research and

TABLE I-3 UNIT PRICE OF RAW MATERIALS FOR AUTOMOBILE POWER GENERATING PLANT

(Excluding Purchases Components)

MATERIALS SUMMARY FROM TABLE I, LBS	137.0	17.6	466.1	1.7	4.0	626.4
MATERIALS BREADKOWN, PERCENT	21.9	2.8	74.4	0.3	0.6	100.0
MATERIALS UNIT COST, $1 LB (4A, 5A)	0.143	0.49	0.10	0.50	0.54	
MATERIALS COST/UNIT WEIGHT, ¢/LB	3.13	1.37	7.44	0.15	0.35	12.44
PURCHASED MATERIALS COST/UNIT WEIGHT, ¢/LB (NOTE 1)						19.14

NOTE 1: Includes assumed scrappage rate equal to 35% of Purchased Materials

SOURCES: REF 44, REF 50

TABLE I-4 COST OF PURCHASED COMPONENTS

		1972 Unit Price (a)	Inflation Factor (b)	12/75 Unit Price	Units/ Vehicle	12/75 Cost/Vehicle
	AIR CLEANER FILTER	1.60	1.53	2.45	1 ea	$ 2.45
	AIR CLEANER TUBING	0.51	1.39	0.71	0.7 lb	0.49
	AIR INLET CONDUIT	1.12	1.61	1.80	0.7 lb	1.26
	ALTERNATOR	16.11	1.30	20.94	1 ea	20.94
	BATTERY	11.29	1.32	14.90	1 ea	14.90
	BATTERY CABLE SET	2.43	1.30	3.16	1 set	3.16
	CARBURETOR	15.07	1.30	19.59	1 ea	19.59
	FASTENERS	0.48	1.32	0.62	12.5 lb	7.92
	RADIATOR ASSEMBLY AND SUPPORT	26.97	1.28	34.52	1 ea	34.52
	STARTER MOTOR ASSEMBLY	16.30	1.30	21.19	1 ea	21.19
	STARTER SWITCH	0.74	1.30	0.96	1 ea	0.96
	STARTER SOLENOID, MISC. VOLTAGE REGULATOR (c)	5.95	1.30	7.73	1 set	7.73
ENGINE DETAILS	IGNITION HARNESS	2.26	1.30	2.94	1 ea	2.94
	DISTRIBUTOR	8.35	1.28	10.69	1 ea	10.69
	SPARK PLUGS	0.33	1.28	0.42	4 ea	1.68
	IGNITION COIL	2.53	1.30	3.29	1 ea	3.29
	CONDENSER	0.30	1.30	0.39	1 ea	0.39
	BREAKER POINTS	0.40	1.30	0.52	4 ea	2.08
	FUEL PUMP ASSEMBLY	2.76	1.28	3.54	1 ea	3.54
	FUEL FILTER	0.56	1.53	0.86	1 ea	0.86
	THERMOSTAT	0.89	1.28	1.14	1 ea	1.28
	BELTS	0.85	1.39	1.18	3 ea	3.54
	RADIATOR HOSES	0.66	1.39	0.92	2 lb	1.94
	OIL FILTER	1.06	1.53	1.63	1 ea	1.63
	FUEL CANNISTER (d)			0.50	3.2 lb	1.60
	FUEL FILLER TUBE	0.18	1.60	0.30	1.7 lb	0.51
	FUEL HOSES	0.66	1.39	0.92	2.5 lb	2.30
	FUEL LINES	0.26	1.60	0.42	2.5 lb	1.09
	HOSE CLAMPS	0.48	1.32	0.63	0.2 lb	0.15
	CATALYTIC EMISSION CONTROLLER (e)			58.00	1 ea	58.00
	TOTAL					$232.62

a) Source: REF 57
b) Source: Table I-6
c) Source: Estimate Based on REF 57
d) Engineering Estimate
e) Source: REF 51

TABLE I-5 INDEX OF WHOLESALE PRICES MANUFACTURING INDUSTRIES (1967 = 100)

	DATE (Month, Year)					
	12/75	12/74	12/73	12/72	12/71	12/70
ALL INDUSTRIES	174.7	166.9	135.1	120.7	115.1	111.2
IRON AND STEEL	204.3	196.7	142.4	129.5	125.3	116.5
FABRICATED STRUCTURAL METAL PRODUCTS	190.9	182.9	131.8	123.3	120.4	114.2
GENERAL PURPOSE MACHINERY AND EQUIPMENT	183.7	170.9	130.7	123.4	120.5	117.0
MISCL. MACHINERY	167.0	153.1	126.3	121.0	117.9	115.6
ELECTRICAL MACHINERY	143.1	136.5	114.0	110.6	109.3	108.2
MOTOR VEHICLES AND EQUIPMENT	150.9	140.7	121.4	118.4	117.5	113.4
MISCL. PRODUCTS	151.1	142.4	121.6	115.1	113.2	111.9
PULP, PAPER AND ALLIED PRODUCTS	173.1	167.2	128.7	115.1	110.7	108.5
CHEMICAL AND ALLIED PRODUCTS	183.4	174.0	115.6	104.8	103.4	103.3
PETROLEUM PRODUCTS, REFINED	274.7	283.5	141.7	112.0	106.1	107.5
RUBBER AND PLASTIC PRODUCTS	151.9	149.4	116.5	109.8	109.4	109.4

Source: REF 58

TABLE I-6 INFLATION FACTORS NORMALIZED TO DECEMBER 1975 BASED ON WHOLE PRICE INDEX

Time Periods Compared	$\frac{\text{Dec 1975}}{1974}$	$\frac{\text{Dec 1975}}{1972}$	$\frac{\text{Dec 1975}}{1970}$
		INDEX RATIO	
ALL INDUSTRIES	1.16	1.48	1.57
IRON AND STEEL	1.20	1.60	1.75
FABRICATED STRUCTURAL METAL PRODUCTS	1.21	1.43	1.67
GENERAL PURPOSE MACHINERY AND EQUIPMENT	1.22	1.51	1.57
MISCL. MACHINERY	1.20	1.40	1.44
ELECTRICAL MACHINERY	1.14	1.30	1.32
MOTOR VEHICLES AND EQUIPMENT	1.15	1.28	1.32
MISCL. PRODUCTS	1.14	1.32	1.33
PULP, PAPER AND ALLIED PRODUCTS	1.17	1.53	1.60
CHEMICAL AND ALLIED PRODUCTS	1.27	1.76	1.78
PETROLEUM PRODUCTS, REFINED	1.41	2.52	2.56
RUBBER AND PLASTIC PRODUCTS	1.14	1.39	1.39

Source: TABLE I5

Technology Corp. (IRT) for the U.S. Department of Transportation (59). According to this study, the direct labor content on a typical engine assembly line is approximately 4.5 direct man-hours per engine. This estimate excludes casting, electrical components and purchased components. The foundry labor is estimated to be about two-thirds of the assembly labor, or 3.0 hrs. The total direct labor content of an engine, excluding purchased components, is thus 7.5 man-hours. Based on Chrysler employment data, IRT estimated that total production labor, including the indirect labor associated with engine manufacture (e.g. maintenance) was 2.36 times the direct labor or 17.7 man-hours.

This figure was rounded off to 18 man-hours in order to allow for the in-house manufacture of the components of the fuel and exhaust system not included in the IRT analysis. Assuming a labor rate of $11.00/man-hour (including fringe benefits), the cost of production labor for the power generating plant is thus $198.

d) Production Cost Estimate

The production cost estimate of $482 for a 440 lb ICE power generating plant for a subcompact passenger automobile is presented in Table I-7. It is the sum of the three components listed above. This figure does not include any overhead costs, supervisory costs, capital costs and allowance for profit.

TABLE I-7 PRODUCTION COST ESTIMATE OF 440 lb POWER GENERATION PLANT
(December 1975 Dollars)

	UNITS	UNIT COST	COST
RAWMATERIALS	269 lbs	$0.191	$51.38
PURCHASED COMPONENTS			232.62
PRODUCTION LABOR	18 m-hrs.	$11.00	198.00
TOTAL			$482.00

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