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CONSERVATION

HYBRID VEHICLE POTENTIAL ASSESSMENT

Volume 10: Electric and Hybrid Vehicle Cost Handbook

By
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MASTER

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Jet Propulsion Laboratory
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Pasadena, California

U. S. DEPARTMENT OF ENERGY

Division of Transportation Energy Conservation

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ELECTRIC AND HYBRID VEHICLE SYSTEM
RESEARCH AND DEVELOPMENT PROJECT

HYBRID VEHICLE POTENTIAL ASSESSMENT
VOLUME X. ELECTRIC AND HYBRID VEHICLE
COST HANDBOOK

September 30, 1979

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PREFACE

In 1976, Congress passed the Electric and Hybrid Vehicle (EHV) Research, Development, and Demonstration Act of 1976, Public Law 94-413, later amended by Public Law 95-238. The Department of Energy is conducting an EHV development program in compliance with that Law. The EHV System Research and Development Project, one element of this Program, is being conducted by the Jet Propulsion Laboratory (JPL) of the California Institute of Technology through an agreement with the National Aeronautics and Space Administration. This report presents the results of the investigations conducted under the Hybrid Vehicle Potential Assessment Task which is a part of the EHV Systems R&D Project.

Early results of this study were used as the technical basis for the Near Term Hybrid Vehicle Development Program now being carried out by the JPL Electric and Hybrid Vehicle System Research and Development Project.

This report is in ten volumes. Volume I contains an overview of the study and the major findings. Volumes II through X are of technical supplementary reports that describe the details of the study and present the most important data generated by the study elements.

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Report No.	Subject	Author(s)
5030-345, Vol. I	Summary	F. T. Surber et al.
5030-345, Vol. II	Mission Analysis	F. T. Surber G. K. Deshpande
5030-345, Vol. III	Parallel Systems	S. P. DeGrey
5030-345, Vol. IV	Series Systems	Z. Popinski
5030-345, Vol. V	Flywheel Systems	S. G. Liddle
5030-345, Vol. VI	Cost Analysis	K. S. Hardy
5030-345, Vol. VII	Hybrid Vehicle Review	K. O. Leschly
5030-345, Vol. VIII	Scenario Generation	K. O. Leschly
5030-345, Vol. IX	Power Train Summary, Component Descriptions, HYVEC Vehicle Simulator	S. G. Liddle S. P. DeGrey
5030-345, Vol. X	Electric and Hybrid Vehicle Cost Handbook	R. C. Heft S. C. Heller

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SECTION I

INTRODUCTION

The purpose of this interim cost handbook is to provide a consistent single-point source of data and procedures for estimating the costs of electric and hybrid vehicles. These costs include manufacturing, acquisition (purchase price), operating, and life cycle. Each suggested Cost Estimating Relation (CER) presented herein is a result of the compilation of currently existing cost estimates and cost relationships. No independent cost analysis was performed for this handbook, nor was any analysis performed to rework existing cost data for consistency in all primary assumptions. These data sources are presented in Appendix B. The cost data is presented in terms of major component and subassembly costs so that any vehicle (electric, hybrid, or conventional) can be costed. The cost estimating relations presented in this handbook are subjective averages of the several independent estimates for each component. Data sources from which these averages were derived are presented in Appendix C.

For the purposes of this handbook, cost estimating relationships have been formulated for the various components in terms of a single parameter, (such as weight) that is assumed to be the principal determinant of the component's cost. These relationships are presented in Section III. Since no consistency exists among the various data sources in the definitions of manufacturing cost, the assumptions used to develop the estimates, or the level of effort expended to develop the estimates, there exists considerable disagreement on the costs for some components. Hence, this data and the associated CERs should be used in a comparative, not absolute, manner. For this handbook, manufacturing cost is defined as cost at factory door, composed of both factory fixed and variable cost (i.e., direct and indirect labor and materials, special tooling, expendable tooling, etc.). Manufacturing cost does not include any corporate level cost, such as general and administrative, R&D, return on investment, cost of sales, etc.

SECTION II

COST METHODOLOGY

The purpose of this cost methodology is to permit the translation of the technical characteristics of an electric or hybrid vehicle and its expected use pattern into cost data and to provide a sufficient breakdown of cost components to identify "cost drivers". This enables comparative cost analysis between an electric or hybrid vehicle and a conventional reference vehicle, or between two or more alternate electric or hybrid candidate vehicles. The principal comparator within this methodology is the present value of the discounted life-cycle cost, which is obtained through a three-step procedure of computing:

- (1) Manufacturing and acquisition cost of the vehicle.
- (2) Operating cost for each year of vehicle operating life.
- (3) Discounted life-cycle cost for the vehicle from (1) and (2).

To use this handbook, the user must have the following:

- (1) A conceptual or engineering design for the vehicle. This must include a characterization of each of the major components in terms of its principal parameter (weight for the chassis, peak power for the motor, etc.).
- (2) The use profile for the vehicle, such as 10,000 miles per year and 10-year lifetime.

The user should note that the manufacturing cost data presented herein is appropriate only for the following assumptions:

- (a) The vehicle R&D programs have been completed, and the vehicle is in a preproduction prototype form.
- (b) Sizable production quantities (300,000 or more vehicles per year) are being produced.
- (c) Production facilities are operating near their planning volumes.
- (d) Costs are in calendar year 1976 dollars.
- (e) Because of the error bounds for the data, COST SHOULD BE COMPUTED ON A COMPARATIVE BASIS, WITH THE BASELINE VEHICLE COSTED BY THESE SAME PROCEDURES.

Any results obtained should not be viewed as a substitute for formal cost estimation, but only as a quick procedure for "coarse" comparisons of alternative concepts.

Although there is a high degree of uncertainty in the data, as can be seen from an examination of Appendix C, no measure of uncertainty is incorporated into the present methodology.

The three principal steps in exercising this methodology are as follows:

1. Manufacturing and Acquisition Cost

Source data for this portion of the computation was derived solely from published sources (see Appendices B and C). The prerequisites to performing this calculation are a conceptual or engineering design for a vehicle of sufficient detail that the principal components can be characterized in terms of their cost parameters, as described in Section III. The results of the computation are the manufacturing cost of the principal components, the manufacturing cost of the vehicle, and the acquisition cost of the vehicle.

2. Operating Cost

Source data for this computation is given in Appendix B. This data was derived principally from the "Motor Vehicle Goals Beyond 1980" and the Phase I final reports of the ERDA Electric Vehicle Research and Development Project. Prerequisites for using this portion of the methodology are: the distance driven for each of the 10 years of the vehicle's lifetime, vehicle acquisition cost, vehicle weight, fuel and electricity consumption rate, and power of the motor and/or engine. The results of this computation are the operating costs for each year of the vehicle's lifetime and the total operating cost for the vehicle in both cents per unit distance and in dollars.

The distinction between maintenance and repair is that maintenance is scheduled adjustments and replacement of expendables which are required throughout the vehicle's lifetime, whereas repair is unscheduled service or replacements. For example: inspection and adjustments of the brake system is maintenance; replacement of pads, shoes, drums or rotors, if the inspection discloses excessive wear, is repair. Maintenance is a function of incremental mileage, repair is a function of cumulative mileage. The repair mileage factor captures the relation of expected average repair cost per mile as a function of cumulative miles traveled. The cost increases as cumulative mileage increases, reaching a constant level of repair cost, then drops toward zero as the vehicle approaches the end of its economic lifetime.

If the vehicle being costed has a lifetime other than 10 years (a high use commercial vehicle such as a taxi may have a 2- to 3-year life) consideration should be given to the following points:

- (1) If the alternative vehicle (electric or hybrid) has a lifetime different from the conventional (ICE) vehicle (e.g., very expensive replacement batteries shortening life or short-range, low-use, lengthening life), both the conventional and alternative vehicles should be replaced until equal lifetimes are achieved.

For example: 15Y electric vs 10Y ICE comparator

the procedure for comparisons is: a sequence of three ICE in comparison with two electrics

$$PVLCC_{ICE} = \sum_{\text{Year 1}}^{10} \text{Discounted Costs} + \sum_{\text{Year 11}}^{20} \text{Discounted Costs} + \sum_{\text{Year 21}}^{30} \text{Discounted Costs}$$

$$PVLCC_{Electric} = \sum_{\text{Year 1}}^{15} \text{Discounted costs} + \sum_{\text{Year 16}}^{30} \text{Discounted costs}$$

and the comparison is

$$\frac{PVLCC_{Electric}}{PVLCC_{ICE}}$$

- (2) If the difference in lifetimes results in inordinately lengthy sequences, a surrogate for the above procedure is to use average (not marginal) cost/mile to cause the lifetimes to be equal. (In the above example, one would add 5 years of average costs of ICE to artificially create a 15-year lifetime.)
- (3) The extensions required of the operating cost and life-cycle cost work sheets are self evident.
- (4) Since the last segments of the repair mileage factor approach zero at the end of the vehicle lifetime, this should be adjusted for lifetimes other than 10 years.

3. Life-Cycle Cost

The prerequisites for this computation are the results of the acquisition cost analysis and the operating cost analysis, in addition to an assumed discount rate. The outcome of this computation is the discounted present value of all the cost associated with owning and operating the vehicle over its 10-year lifetime.

SECTION III

ACQUISITION COST PROCEDURE

A. ESTIMATING VEHICLE MANUFACTURING COST

- (1) From the engineering or conceptual design of the vehicle, collect and group the parts and components into those component groups appropriate to the cost-estimating relationships. (See Appendix A.) If the information is at a general, conceptual design level, all non-propulsion and non-energy storage components can be collected into a component entitled "chassis" (CER-A); a detailed breakdown is not required.
- (2) For each subassembly, determine the value of the key cost parameter on the acquisition cost worksheet (Figure 3-1).
- (3) Using the value of the key cost parameter, determine from the appropriate cost estimating relationship the manufacturing cost and enter it on the worksheet. Use CER A through I, unless sufficient detail is available for those components normally grouped as the chassis subassembly (i.e., brakes, frame, steering, drive system, tires, exhaust, and suspension systems); then, in place of CER A, use CER AA-AG for these individual components.
- (4) Obtain the vehicle assembly cost from CER J by using the vehicle curb weight.
- (5) Sum the component manufacturing cost and the vehicle assembly cost to obtain the total manufacturing cost, and enter total on the worksheet.
- (6) For applications where equations are more useful than graphs, Table 3-1 presents the CER's in equation form.

B. ESTIMATING ACQUISITION COST

The wholesale price to dealer for a vehicle is the sum of the manufacturing cost and corporate-level costs (i.e., general and administrative, required return on investments of facilities and tooling, and cost of sales, etc.) The sticker price is the sum of the cost from wholesaler to dealer and a dealer "discount", ranging from about 15% to 17%. Previous studies have determined that sticker prices range from 1.7 to 2.4 times the manufacturing cost; therefore, for the purpose of this cost handbook, an average factor of 2.0 times the manufacturing cost is used to determine the acquisition cost.

Cost estimating relationships for manufacturing costs start on page 3-3.

	CER	COMPONENT WEIGHT	COST PARAMETER		MANUFACTURING COST
			UNIT	VALUE	
FRAME + BODY	AA		WEIGHT		
FENDERS + PANELS	AB		WEIGHT		
SUSPENSION + BRAKES	AD		WEIGHT		
STEERING	AE		WEIGHT		
WHEELS + TIRES	AF		WEIGHT		
DRIVE SYSTEM	AC		POWER		
EXHAUST, COOLING, FUEL	AG		WEIGHT		
BASIC BODY	B		WEIGHT		
CHASSIS	A		WEIGHT		
ENGINE	I		POWER		
TRANSMISSION(S)	C		POWER		
MOTOR	D		POWER		
CONTROLLER	E		POWER		
FLY WHEEL	F		WEIGHT		
(OR)	F1		ENERGY		
CHARGER	H		POWER		
BATTERY	G		ENERGY		
SUB TOTAL - PROPULSION					
VEHICLE ASSEMBLY	J		CURB WEIGHT		
TOTAL MANUFACTURING					

TOTAL STICKER PRICE

Figure 3-1. Acquisition Cost Worksheet

CER - A TOTAL CHASSIS

CER - AA: FRAME AND BODY (STRUCTURE)

1. FULL FRAME - STEEL
2. UNITIZED FRAME - STEEL
3. FRAME - PLASTIC/COMPOSITES

CER - AB: REMOVABLE PANELS
(FENDERS, HOOD, DOORS, TRUNK LID)

CER - AC: DRIVE SYSTEMS

FWD = ENGINE IN FRONT, DRIVE IN FRONT
RWD = ENGINE IN FRONT, DRIVE IN REAR

CER-AD: SUSPENSION AND BRAKES

CER - AE: STEERING SYSTEMS

CER - AF: WHEELS AND TIRES (5)

CER - AG: EXHAUST, COOLING, FUEL STORAGE

CER -B: BASIC BODY

CER - C: TRANSMISSIONS

CVT = CONTINUOUSLY VARIABLE TRANSMISSION

CER - D: MOTORS/GENERATORS

CER - E: CONTROLLERS

WEIGHT OF WHEEL + HUB ONLY
(FOR FLYWHEELS WITH LESS THAN 10 kWh STORAGE CAPACITY)

CER - F¹: FLYWHEELS

kWh OF STORED ENERGY REQUIRED (IN FLYWHEEL) FOR
FLYWHEELS OF LESS THAN 10 kWh OF STORAGE CAPACITY

CER - G: BATTERIES

CER - H: BATTERY CHARGER

kw (PEAK CHARGE CAPACITY)
(ON-VEHICLE CHARGER IS ASSUMED TO BE
INTEGRAL WITH CONTROLLER FOR ZERO
ADDITIONAL COST)

-24- CER-I: HEAT ENGINES

CER - J: VEHICLE ASSEMBLY

Table 3-1. Cost Estimating Relations - Equation Form

CER-A: Chassis

x = Total Chassis Weight

1. Steel-based

$$\text{cost} = .80 x \quad 500 < x < 3000 \text{ lbs}$$

$$\text{cost} = 1.76 x \quad 230 < x < 1000 \text{ kg}$$

CER-AA: Frame and Body (structure)

x = Weight

1. Full Frame - Steel

$$\text{cost} = .11 x^{1.22} \quad 480 < x < 600 \text{ lbs}$$

$$\text{cost} = .45 x \quad 600 < x < 1000 \text{ lbs}$$

$$\text{cost} = .29 x^{1.22} \quad 200 < x < 273 \text{ kg}$$

$$\text{cost} = .99 x \quad 273 < x < 450 \text{ kg}$$

2. Unitized Frame - Steel

$$\text{cost} = .42 x \quad 320 < x < 460 \text{ lbs}$$

$$\text{cost} = 2.00 x^{.75} \quad 460 < x < 650 \text{ lbs}$$

$$\text{cost} = .92 x \quad 150 < x < 209 \text{ kg}$$

$$\text{cost} = 3.61 x^{.75} \quad 209 < x < 300 \text{ kg}$$

3. Frame - Plastics/Composites

$$\text{cost} = .67 x \quad 280 < x < 420 \text{ lbs}$$

$$\text{cost} = 1.47 x \quad 130 < x < 200 \text{ kg}$$

CER-AB: Removable Panels (Fenders, Hoods, Doors, Trunk Lid)

x = Total Weight

1. Plastics and Composites

$$\text{cost} = 1.60 x \quad 200 < x < 600 \text{ lbs}$$

$$\text{cost} = 3.52 x \quad 90 < x < 300 \text{ kg}$$

2. Steel

$$\text{cost} = .48 x^{1.10} \quad 275 < x < 1000 \text{ lbs}$$

$$\text{cost} = 1.14 x^{1.10} \quad 130 < x < 450 \text{ kg}$$

CER-AC: Drive Systems

x = Power Through Drive System

1. Engine in Front, Drive in Front

$$\text{cost} = 2.84 x^{.80} \quad 60 < x < 170 \text{ hp}$$

$$\text{cost} = 3.59 x^{.80} \quad 45 < x < 130 \text{ kW}$$

Table 3-1. Cost Estimating Relations - Equation Form (Continuation 1)

2. Engine in Front, Drive in Rear

$$\text{cost} = 2.68 x^{.80} \quad 65 < x < 160 \text{ hp}$$

$$\text{cost} = 3.39 x^{.80} \quad 50 < x < 120 \text{ kW}$$

CER-AD: Suspension and Brakes

x = Combined Weight

1. All Configurations

$$\text{cost} = .54 x^{1.15} \quad 90 < x < 300 \text{ lbs}$$

$$\text{cost} = 1.34 x^{1.15} \quad 40 < x < 140 \text{ kg}$$

CER-AE: Steering Systems

x = Weight

1. Power

$$\text{cost} = 2.18 x^{.90} \quad 45 < x < 100 \text{ lbs}$$

$$\text{cost} = 4.43 x^{.90} \quad 20 < x < 45 \text{ kg}$$

2. Manual

$$\text{cost} = 1.79 x^{.90} \quad 30 < x < 16 \text{ lbs}$$

$$\text{cost} = 3.64 x^{.90} \quad 13 < x < 25 \text{ kg}$$

CER-AF: Wheels and Tires (5)

x = Combined Weight

$$\text{cost} = 2.72 x 10^{-3} x^{2.25} \quad 70 < x < 150 \text{ lbs}$$

$$\text{cost} = 1.60 x 10^{-2} x^{2.25} \quad 30 < x < 70 \text{ kg}$$

CER-AG: Exhaust, Cooling, Fuel Storage

x = Total Weight

$$\text{cost} = .68 x^{.83} \quad 130 < x < 270 \text{ lbs}$$

$$\text{cost} = .16 x^{1.09} \quad 270 < x < 490 \text{ lbs}$$

$$\text{cost} = 1.31 x^{.83} \quad 60 < x < 125 \text{ kg}$$

$$\text{cost} = .38 x^{1.09} \quad 125 < x < 250 \text{ kg}$$

CER-B: Basic Body

x = Basic Body Weight

1. Plastic Based

$$\text{cost} = .77 x^{1.10} \quad 100 < x < 500 \text{ lbs}$$

$$\text{cost} = 1.83 x^{1.10} \quad 45 < x < 230 \text{ kg}$$

Table 3-1. Cost Estimating Relations - Equation Form (Continuation 2)

2. Steel Based

$$\text{cost} = .65 x^{1.10} \quad 180 < x < 650 \text{ lbs.}$$

$$\text{cost} = 1.55 x^{1.10} \quad 80 < x < 300 \text{ kg}$$

CER-C: Transmissions

x = Power Through the Transmission

1. Continuously Variable Transmission

$$\text{cost} = 2.00 x \quad 20 < x < 100 \text{ hp}$$

$$\text{cost} = 2.68 x \quad 14 < x < 75 \text{ kW}$$

2. Automatic Transmission

$$\text{cost} = 1.50 x \quad 55 < x < 250 \text{ hp}$$

$$\text{cost} = 2.01 x \quad 40 < x < 200 \text{ kW}$$

3. Manual Transmission

$$\text{cost} = 1.00 x \quad 55 < x < 250 \text{ hp}$$

$$\text{cost} = 1.34 x \quad 40 < x < 200 \text{ kW}$$

CER-D: Motors/Generators

x = Rated Power

1. DC Series

$$\text{cost} = 10.00 x \quad 14 < x < 65 \text{ hp}$$

$$\text{cost} = 13.41 x \quad 10 < x < 50 \text{ kW}$$

2. AC Series

$$\text{cost} = 6.00 x \quad 16 < x < 85 \text{ hp}$$

$$\text{cost} = 8.05 x \quad 12 < x < 65 \text{ kW}$$

CER-E: Controllers

x = Power Rating

1. DC

$$\text{cost} = 31.91 x^{.67} \quad 12 < x < 40 \text{ kW}$$

2. AC

$$\text{cost} = 58.04 x^{.67} \quad 12 < x < 55 \text{ kW}$$

Table 3-1. Cost Estimating Relations - Equation Form (Continuation 3)

CER-F: Flywheels (less than 10 kWh of storage capacity)

x = Weight of Wheel + Hub Only

1. Kevlar

cost = 8.75 x	$18 < x < 250$ lbs
cost = 19.25 x	$8 < x < 125$ kg
2. Aluminum

cost = 3.33 x	$180 < x < 500$ lbs
cost = 7.33 x	$80 < x < 250$ kg
3. S-Glass

cost = 3.00 x	$30 < x < 350$ lbs
cost = 6.60 x	$15 < x < 160$ kg
4. Steel

cost = 1.80 x	$250 < x < 900$ lbs
cost = 3.96 x	$125 < x < 400$ kg
5. E-Glass

cost = 1.50 x	$40 < x < 400$ lbs
cost = 3.30 x	$18 < x < 180$ kg
6. Housing

cost = 1.11 x	$16 < x < 22$ lbs
cost = 2.44 x	$7 < x < 10$ kg

CER-F1: Flywheels (less than 10 kWh of storage capacity)

x = Stored Energy Required

1. Aluminum

cost = 667 x	$1 < x < 10$ kWh
----------------	------------------
2. Steel

cost = 467 x	$1 < x < 10$ kWh
----------------	------------------
3. Kevlar

cost = 188 x	$1 < x < 10$ kWh
----------------	------------------
4. S-Glass

cost = 95 x	$1 < x < 10$ kWh
---------------	------------------
5. E-Glass

cost = 60 x	$1 < x < 10$ kWh
---------------	------------------

Table 3-1. Cost Estimating Relations - Equation Form (Continuation 4)

CER-G: Batteries

x = Stored Energy Capacity for Battery Sets

1. Nickel-iron

$$\text{cost} = 100 x \quad 10 < x < 55 \text{ kWh}$$

2. Nickel-zinc

$$\text{cost} = 60 x \quad 10 < x < 55 \text{ kWh}$$

3. Li-Al/FeS_x

$$\text{cost} = 50 x \quad 10 < x < 60 \text{ kWh}$$

4. Sodium-Sulfur (ceramic)

$$\text{cost} = 50 x \quad 10 < x < 60 \text{ kWh}$$

5. Lead-acid

$$\text{cost} = 40 x \quad 10 < x < 55 \text{ kWh}$$

CER-H: Battery Charger - Off-board (on-vehicle charger is assumed to be integral with controller for zero additional cost)

For peak charge capacity between 2.5 and 70 kW

$$\text{cost} = \$306$$

CER-I: Heat Engines

x = Power

1. Stirling

$$\text{cost} = 350 x^{.22} \quad 100 < x < 150 \text{ hp}$$

$$\text{cost} = 373 x^{.22} \quad 75 < x < 115 \text{ kW}$$

2. Brayton Free Turbine

$$\text{cost} = 320 x^{.22} \quad 100 < x < 150 \text{ hp}$$

$$\text{cost} = 341 x^{.22} \quad 75 < x < 115 \text{ kW}$$

3. Otto - 3 Way Catalyst

$$\text{cost} = 138 x^{.33} \quad 100 < x < 150 \text{ hp}$$

$$\text{cost} = 152 x^{.33} \quad 75 < x < 115 \text{ kW}$$

4. Otto - 2 Way Catalyst

$$\text{cost} = 132 x^{.33} \quad 60 < x < 280 \text{ hp}$$

$$\text{cost} = 146 x^{.33} \quad 45 < x < 200 \text{ kW}$$

5. Small Gasoline Engine Technology

$$\text{cost} = 11.67 x \quad 20 < x < 75 \text{ hp}$$

$$\text{cost} = 15.65 x \quad 15 < x < 60 \text{ kW}$$

Table 3-1. Cost Estimating Relations - Equation Form (Continuation 5)

CER-J: Vehicle Assembly

x = Total Vehicle Curb Weight

cost = $.06 x$ $1500 < x < 6500$ lbs

cost = $.13 x$ $700 < x < 3000$ kg

SECTION IV

OPERATING COST PROCEDURE

A. MILE-DEPENDENT COSTS

1. Maintenance Cost

For each factor contributing to maintenance cost, compute cost in cents per unit distance from the cost relationships given in Table 4-1 and Table 4-2; enter these costs and their yearly sums on the operating cost worksheet (Figure 4-1). Note: all maintenance costs should be constant (in cents per unit distance) throughout the lifetime of the vehicle.

2. Repair Cost

For each of the contributors to vehicle repair costs*, compute the repair costs from Table 4-1 or Table 4-2, and sub-total them on line B of the operating cost worksheet. Note that these contributors and their sub-totals should be constant across the lifetime of the vehicle. From Figure 4-2, utilizing the distance driven in each of the 10 years of the vehicle's lifetime, compute the repair mileage factor for each year. Multiply for each year the sub-total of the repair cost and the repair mileage factor, and enter it on line D of the operating cost worksheet.

3. Fuels

Utilizing the yearly average consumption rate for gasoline and electricity and the assumed pump and wallplug prices, compute the fuel cost in cents per unit distance from the appropriate relation in Table 4-1 or Table 4-2, and enter it on line E of the worksheet.

4. Total Cost

Total the maintenance, repair, and fuel costs to obtain a total (in cents per unit distance) for each year of the vehicle's lifetime, and enter it on line F of the worksheet. Record the expected distance travelled for each year on line G of the worksheet, and multiply distance times cost per unit distance to obtain the total dollars expended in each year. Enter the result on line H.

B. YEAR-DEPENDENT COSTS

From the relationships given in Table 4-1 or Table 4-2, compute the yearly cost of taxes, licenses, registration, and insurance. Enter these costs on the appropriate line of the worksheet.

*The battery system is expected to have repair costs as do the other major components, however, no data or information is available for estimating such costs.

C. BATTERY REPLACEMENT

Compute the cost of the battery replacement from the relationships given in Table 4-1 or Table 4-2. From the assumed life-cycle of the battery, enter the cost of the replacement battery sets in the appropriate years. Do not enter the battery replacement cost in the first year of the vehicle's lifetime, since this cost is included in the purchase of the vehicle. Do not enter a replacement battery set during the last year of the vehicle's lifetime.

D. TOTAL OPERATING COST

Sum each column to obtain the total dollar cost of operations for each year of the vehicle's lifetime. These are then summed to obtain the total lifetime operating cost. Finally, this number is divided by the total distance driven in the 10-year lifetime to obtain the cost of operations per unit distance (in cents per unit distance).

Table 4-1. Cost Estimating Relations for Operating and Life-Cycle Costs - English Units

Cost Component		CER	
I.	Maintenance	(in cents/mile)	
	Engine	0.18 + 5×10^{-3}	*HP
	Chassis	0.035 + 10^{-5}	*TVW
	Electric	0.060 + 2×10^{-3}	*PHP
	Battery	4×10^{-4}	*BW
	Flywheel	0.070	
II.	Repair	(in cents/mile not including Repair Mileage Factor)	
	Engine	0.28 + 8×10^{-3}	*HP
	Chassis	0.95 + 2×10^{-4}	*TVW
	Electric	0.09 + 2×10^{-3}	*PHP
	Accessories	8×10^{-5}	*TVW
	Transmission	0.05 + 1.3×10^{-3}	*THP
III.	Fuel	(in cents/mile)	
	Gasoline	Price per gallon	*(gal/mile)
	Electricity	Price per Kwh	*(Kwh/mile)
IV.	Yearly Costs	(in dollars/year)	
	Tax, License and Registrations	30	
	Insurance	125 + 0.01	*VPP (first 5 years)
		75 + 0.006	*VPP (last 5 years)
V.	Battery Replacement	2.3 *BMFC (in dollars, for each replacement set)	
VI.	Life-Cycle Cost Components	(in minus dollars)	
	Vehicle Salvage Value	0.1	*VPP
	Battery Salvage Value	1/2	*(2.3*BMFC)* Fraction of life Remaining

Symbols used:

HP	=	Horse Power of Engine
TVW	=	Total Vehicle Weight (lbs)
PHP	=	Peak Horse Power of Motor
BW	=	Battery Weight (lbs)
THP	=	Total Horse Power thru Transmission
VPP	=	Vehicle Purchase Price (dollars)
BMFC	=	Battery Manufacturing Cost (OEM) (dollars)
*	=	Multiplication

Table 4-2. Cost Estimating Relations for Operating and Life-Cycle Costs - Metric Units

Cost Component		CER		
I.	Maintenance	(in cents/km)		
	Engine	0.1	+ 4.16×10^{-3}	*P
	Chassis	0.022	+ 1.37×10^{-5}	*TVW
	Electric	0.037	+ 1.66×10^{-3}	*PP
	Battery		5.48×10^{-4}	*BW
	Flywheel	0.043		
II.	Repair	(in cents/km not including Repair Mileage Factor)		
	Engine	0.17	+ 6.66×10^{-3}	*P
	Chassis	0.59	+ 2.74×10^{-4}	*TVW
	Electric	0.06	+ 1.66×10^{-3}	*PP
	Accessories		10.96×10^{-5}	*TVW
	Transmission	0.03	+ 1.08×10^{-3}	*TP
III.	Fuel	(in cents/km)		
	Gasoline	Price per liter		*(liters/km)
	Electricity	Price per Kwh		*(Kwh/km)
IV.	Yearly Costs	(in dollars/year)		
	Tax, License and Registrations	30		
	Insurance	125 + 0.01	*VPP (first 5 years)	
		75 + 0.006	*VPP (last 5 years)	
V.	Battery Replacement	2.3	*BMFC (in dollars, for each replacement set)	
VI.	Life-Cycle Cost Components	(in minus dollars)		
	Vehicle Salvage Value	0.1	*VPP	
	Battery Salvage Value	$1/2 \times (2.3 \times \text{BMFC}) \times$	Fraction of Life Remaining	

Symbols used:

P	=	Power of Engine
TVW	=	Total Vehicle Weight (kgs)
PP	=	Peak Power of Motor
BW	=	Battery Weight (kgs)
TP	=	Total Power thru Transmission
VPP	=	Vehicle Purchase Price (dollars)
BMFC	=	Battery Manufacturing Cost (OEM) (dollars)
*	=	Multiplication

YEAR		1	2	3	4	5	6	7	8	9	10
DISTANCE DEPENDENT COSTS											
COSTS IN CENTS PER UNIT DISTANCE	MAINTENANCE: ENGINE										
	CHASSIS										
	ELECTRIC										
	BATTERY										
	FLYWHEEL										
	(A) TOTAL										
	REPAIR: ENGINE										
	CHASSIS										
	ELECTRIC										
	ACCESSORIES										
	TRANSMISSION										
	(B) SUBTOTAL										
	(C) RMF										
	(D) TOTAL (B) x (C)										
	FUELS: GASOLINE										
ELECTRIC											
(E) TOTAL											
(F) TOTAL (A) + (D) + (E)											
(G) DISTANCE EACH YEAR											
(H) TOTAL DOLLARS ((F)/100) x (G)											
YEAR DEPENDENT COSTS											
TAX, LICENSE, REGISTRATION											
INSURANCE											
BATTERY REPLACEMENT											

TOTAL OPERATING COST = OPERATING COST PER UNIT DISTANCE =

Figure 4-1. Operating Cost Worksheet

Figure 4-2. Repair Mileage Factor

SECTION V

LIFE-CYCLE COST PROCEDURE

A. ASSUMPTIONS/GROUND RULES

- (1) This calculation assumes a constant, non-inflating dollar (no inflation factor is included in the discount rate), since it is assumed that personal disposable income tracks inflation. Therefore, the discount rate for individuals represents only time preference (opportunity cost) and, as such, is taken to be 2%. For commercial users, a rate of 10% or greater is appropriate.
- (2) The lifetime of the vehicle is taken to be 10 years, in all cases.
- (3) Cost of finance is assumed to be 20% of the original purchase price.
- (4) All expenses are assumed to be costed at the end of each year. Year "Zero" is reserved for those costs which must be incurred before the vehicle is operated.

B. IMPLEMENTATION

- (1) Twenty percent of the purchase price (from the acquisition cost worksheet (Figure 3-1)) is entered on the appropriate line of the life-cycle cost worksheet in year "Zero" (Figure 5-1); 33-1/3% of the purchase price is entered in years 1, 2 and 3, for a total cost price (including the cost of finance) equal to 120% of the purchase price.
- (2) Fuel, maintenance and repair, and battery replacement costs are copied from the operating cost worksheet (Figure 4-1) to the same position on the life-cycle cost worksheet (Figure 5-1). Taxes, licenses, registration and insurance are copied to the previous year on the life-cycle cost worksheet (i.e., start with year Zero, end with year 9).
- (3) Salvage values are taken from Table 4-1 and entered as a minus cost in the tenth-year column.
- (4) Discount factor = $1/(1 + i)^t$ is computed for each year (where t = year 0 to 10 and i = the discount rate).
- (5) For each year, the discount factor times the cost gives the present value of the cost for that year. These are summed to provide the discounted present value of the life-cycle cost.

- (6) The value computed in step 5 is divided by the total distance driven to provide the life-cycle cost per mile (Km) and this is expressed in cents per unit distance.

C. INTERPRETATION

For alternatives of equal total distance driven, the one with the lower discounted present value of life-cycle cost is economically more attractive. For alternatives of differing total distance driven, the cost per unit distance is a better comparator. The significance attributed to differences in life-cycle cost is dependent upon both the uncertainties within the data and the magnitude of the technological differences between the alternatives; i.e., when only one technological variable is changed between alternatives, the differences are more significant than in the comparison of two completely different vehicles.

	YEAR										
	"0"	1	2	3	4	5	6	7	8	9	10
1 PURCHASE PRICE											
2 FUEL + ELECTRICITY											
3 REPAIR + MAINTENANCE											
4 BATTERY REPLACEMENT											
5 LICENSE, TAX, INSURANCE											
6 CHASSIS SALVAGE (MINUS)											
7 BATTERY SALVAGE (MINUS)											
8 TOTAL (1-7)											
9 DISCOUNT FACTOR	1.0										
10 PRESENT VALUE (8 x 9)											

11 PRESENT VALUE OF LIFE CYCLE COST (SUM OF 10) =

12 PRESENT VALUE OF LIFE CYCLE PER UNIT DISTANCE
(11 / TOTAL DISTANCE DRIVEN) =

Figure 5-1. Life-Cycle Cost Worksheet

APPENDIX A

COMPONENT BREAKDOWN FOR COST ESTIMATING

When attempting cost analysis from an engineering or conceptual design, it is necessary to disaggregate the vehicle into costing units numbering less than the actual several thousand parts and more than the single vehicle. This handbook uses a division into two basic assemblies: the propulsion system, and the chassis system. Each of these is then divided into six to eight subassemblies.

The chassis system is all that which comprises the vehicle with the exception of those systems providing motive power. The exception to this is the drive, exhaust, cooling and fuel systems for conventional gasoline or diesel engines which are included in the chassis system. This inclusion is done in deference to customary automotive assembly procedures where these subassemblies are installed on the chassis assembly line and not on the engine assembly line. If only first-order cost estimates are required or if there is no fundamental difference in design between the electric (or hybrid) and the baseline comparator vehicle, then CER-A, the cost estimating relationship for the collection of all the assemblies in the chassis, can be used. When a more detailed breakdown is available or is necessary, the chassis assembly may be disaggregated into the following subassemblies

1. Frame and Body - This subassembly is composed of the structural frame or the structural unitized frame and body generally including the underchassis, front stub-frame bumper assemblies and structural sheet metal surrounding the passenger compartment.
2. Fenders and Panels - This is composed of the nonstructural panels such as hood and rear deck lids, "removable" sheet fenders, inner fenders and doors.
3. Suspension and Brakes - This subassembly is composed of all the parts between the road wheels and the structural frame with the exception of steering parts and rear axle. Included are the brake pedals, master and wheel cylinders, brake lines, drums, calipers, disks, shoes, all other brake parts, all springs, shock absorbers, front axles, etc.
4. Steering - This is the complete steering assembly, beginning with the steering wheel and extending to the end of the steering arms on the front axles. Included, is the power steering pump, if required.
5. Wheels and Tires - This includes the four road wheel assemblies and a spare wheel assembly, if required. The assembly includes the wheel and tire, and tubes, hubcaps, wheel nut/bolts, if present.

6. Drive Systems - This is the mechanical power transfer system beginning at the end of the transmission and extending to the driven axles for front wheel drive, and extending to the rear wheel assembly for rear wheel drive.
7. Exhaust Cooling and Fuel - The exhaust system begins at the header pipe connection to the exhaust manifold and ends at the tail pipe. The cooling system is composed of the radiator only. The fuel system begins at the inlet to the fuel tank and ends at the input to the engine's fuel distribution system.
8. Basic Body - This is composed of the glass about the green house, and all interior trim and furnishings, including seats, rugs, sound and thermal insulation, instrument panel, dashboard controls, road lights, and the heat/air conditioning system.

Most of the cost tradeoffs for an electric or hybrid vehicle are expected to be focused upon tradeoffs within the propulsion system. This handbook stratifies the propulsion system into six subassemblies:

1. Engine - This is a fuel burning heat engine. The "envelope" around the engine subassembly is defined by the input to the fuel distribution system, the output shaft to the transmission, the coolant hoses to the radiator or cooling assembly, and the connection between the exhaust manifold and header pipe. Customary engine-mounted assemblies, such as alternators, water pumps, etc., are deemed to be part of the engine assembly.
2. Transmission - This component includes all mechanical power conversion systems which either incrementally or variably change the torque-rpm relationships from input shaft to output shaft. These may connect either engines, motors, or flywheels, to each other or to the driven wheels.
3. Motor - This is the electrically powered motor, the "envelope" defined by the electrical power connections from the controller and the output shaft to either the drive or the transmission assembly. Included are ancillary motor accessories such as cooling systems.
4. Controller - This is the electrical power conversion system between the battery and the armature and/or field coils of the electrical motor. In addition, it is assumed to contain any battery regeneration circuitry and an integrated battery re-charging circuit. Heat engine control circuitry necessary for hybrid vehicle operations is included in the controller.

5. Flywheel - This component is composed of the flywheel, its casing and containment, any stepdown gears, vacuum pumps, oil diffusion pumps, etc., necessary for the operation of the flywheel systems.
6. Charger - Two different types of chargers are encompassed in this component definition. One is the very inexpensive modification to a solid state controller to provide charging capability from a wall plug. The second is a large, stand alone, high current fast charge unit.
7. Battery - This is the electrical energy storage device and all ancillary components necessary for its operation such as pumps, heaters, coolers, vacuum casings, thermal casings, etc.

Chassis Taxonomy from Rath and Strong's Report
Estimated Weights and Manufacturing Cost of Automobiles
As a part of "Fuel Economy Goals Beyond 1980"

Frame - Body

Body structure
Frame/stubframe

Removable Panels

Grill
Hood
Fenders
Quarter panels
Trunk lid

Basic Body

Trim set - interior - exterior
Lights
Glass
Heater system
Air conditioning system
Windshield wiper system
Dash board
Instrument set

Drive - Drive Housing

- Differential case assembly
- Axle ring and pinion gear set
- Rear axle
- Drive shaft

Suspension Systems

- Control arms
- Shock absorbers
- Steering knuckles
- Ball joints
- Stabilizer bar
- Wheel bearings
- Springs

Brake System

- Parking brake assembly
- Master cylinder
- Disks and drums
- Caliper or shoe assembly
- Vacuum booster

Steering System

- Wheel and column
- Linkage
- Recirculating ball or rack-pinion assembly
- Hydraulic pump assembly

APPENDIX B

DATA SOURCES

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- (3) Estimated Weight and Manufacturing Costs of Automobiles, Rath & Strong, Inc., Contract DOT-TSC-1067 Task 1 for Department of Transportation, TSC.
- (4) Characterization and Applications Analysis of Energy Storage Systems, Aerospace Corporation, for National Science Foundation, Report #ATR-77 (7538)-1, April 1977.
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- (6) Impact of Future Use of Electric Cars in the Los Angeles Region, Vols. I-III, General Research Corporation, for EPA, October 1974.
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- (8) Cost and Emission Studies of a Heat Engine/Battery Hybrid Family Car, TRW, Contract #66-04-0058 for EPA, April 1977.
- (9) Should We Have A New Engine (APSES) Vols. I-II, JPL #SP.43-17, August 1975.
- (10) "How to Figure True Cost of Car Ownership, Why Some Figures Differ So Much," by D. Moffitt, Wall Street Journal, November 15, 1976, p. 44.
- (11) Energy Storage System for Automobile Propulsion, Lawrence Livermore Laboratory, October 1977.
- (12) Automobile Manufacturing and Maintenance, Report of a Panel of the Interagency Task Force on Motor Vehicle Goals Beyond 1980, (Parts 1 and 2), March 1976.
- (13) National, Industrial and Consumer Economics, Report of a Panel of the Interagency Task Force on Motor Vehicle Goals Beyond 1980, (Parts 1 and 2), March 1976.

- (14) The Phase 1 Final Reports from:
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Garrett Corporation
ASL Engineering
for the ERDA Electric Vehicle Development Project
- (15) Cost of Operating an Automobile, L. L. Liston and R. W. Sherrer,
U.S. Dept. of Transportation, Federal Highway Administration,
April 1974.
- (16) Characterization and Applications Analysis of Energy Storage
Systems, Aerospace Corporation, ATR-77 (7538)-1, April 1977.
- (17) Energy Storage Systems for Automobile Propulsion, Volume II,
Lawrence Livermore Laboratories, CVRL-52303, September 30, 1977.
- (18) Representative Future Batteries for Urban Electric Cars, W.
Hamilton, General Research Corporation, November 1978.

APPENDIX C
CER DATA POINTS

CER - A CHASSIS AND (ALL COMPONENTS)
CER-AA FRAME STRUCTURE

DATA SOURCE

A. AIREASEARCH/R & S
B. GE
C. SRI

1. FRAME & BODY - STEEL - FULL FRAME - (A)	7. STEERING SYSTEMS - MANUAL - (A)
2. FRAME & BODY - STEEL - UNITIZED - (A)	8. STEERING SYSTEMS - POWER - (A)
3. FRAME & BODY - PLASTIC - (A)	9. BRAKE SYSTEMS - ALL - (A)
4. REMOVABLE PANELS - STEEL - (A)	10. WHEELS (S) (A)
5. REMOVABLE PANELS - PLASTIC - (A)	11/11. TIRES BIAS - RADIAL (S) (A)
	12. HOUSINGS - GEAR BOX - FLYWHEEL (A)

CER - A CHASSIS - DATA POINTS
AND
CER - AA FRAME AND BODY
AND
CER - AB REMOVABLE PANELS

CHASSIS WEIGHT

1. FRAME & BODY - STEEL: RATH & STRONG
2. FRAME & BODY - STEEL, UNITIZED: RATH & STRONG
3. FRAME & BODY - PLASTIC COMPOSITE: GARRETT - PHASE I
4. TOTAL CHASSIS: SRI
5. REMOVABLE PANELS - PLASTIC: GARRETT - PHASE I
6. REMOVABLE PANELS - STEEL: GARRETT - PHASE I
7. TOTAL CHASSIS: GE - PHASE I
8. REMOVABLE PANELS - PLASTIC: RATH + STRONG
9. REMOVABLE PANELS - COMPOSITE: RATH + STRONG
10. TOTAL CHASSIS: RATH + STRONG

CER - AC: DRIVE SYSTEMS - DATA POINTS

1. FRONT WHEEL DRIVE: RATH & STRONG
2. REAR WHEEL DRIVE: RATH & STRONG
3. REAR WHEEL DRIVE: GARRETT - PHASE 1

CER - AD: SUSPENSION AND BRAKES: DATA POINTS

1. SUSPENSION SYSTEM - ALL CONFIGURATIONS: RATH & STRONG; GARRETT - PHASE I
2. BRAKES - ALL CONFIGURATIONS: RATH & STRONG; GARRETT - PHASE I
3. SUM OF (1) AND (2)

CER - AE: STEERING ASSEMBLY: DATA POINTS

1. STEERING - MANUAL: RATH & STRONG; GARRETT - PHASE 1
2. STEERING - POWER: RATH & STRONG; GARRETT - PHASE 1

CER - AF: WHEELS AND TIRES: DATA POINTS

1. WHEELS - STOCK - (5): RATH & STRONG; GARRETT - PHASE 1
2. TIRES - BIAS & RADIAL (5): RATH & STRONG; GARRETT - PHASE 1
3. SUMMATION (1) AND (2)

CER - AG: EXHAUST, COOLING, FUEL STORAGE: DATA POINTS

1. SUM OF EXHAUST, COOLING AND FUEL TANK: RATH & STRONG
-300 DAY STUDY

CER - B: BASIC BODY: DATA POINTS

BASIC BODY WEIGHT

1. BASIC BODY - STEEL: RATH & STRONG
2. BASIC BODY - STEEL: GARRETT - PHASE 1
3. BASIC BODY - PLASTIC: GARRETT - PHASE 1

CER-C: TRANSMISSIONS: DATA POINTS

1. MANUAL: RATH & STRONG
2. AUTOMATIC: RATH & STRONG
3. CVT - (TURBO HYDRAMATIC BASE)
RATH & STRONG
4. CVT -: AEROSPACE CORP.
5. AUTOMATIC: AEROSPACE CORP.
6. MANUAL: AEROSPACE CORP.

DATA SOURCES

- A. GARRETT - PHASE 1
- B. G.E.
- C. AEROSPACE
- D. TRW
- F. LLL

CER - D: MOTORS/GENERATORS: DATA POINTS

1. D/C MOTOR (A)
2. DC MOTOR (B)
3. AC POLYPHASE MOTOR (B)
4. DC MOTORS (D)
5. AC MOTORS (D)
6. DC MOTORS (E)
7. DC MOTORS (F) LLL

DATA SOURCES

- A. GARRETT - PHASE 1
- B. G.E. - PHASE 1
- C. AEROSPACE
- D. TRW (MY 72 \$)
- E. LLL

CER - E: CONTROLLERS: DATA POINTS

1. CONTROL UNIT FOR DC MOTOR 15 - 30 kW RANGE (C)
2. CONTROL UNIT FOR AC MOTOR 15 - 30 kW RANGE (C)
3. DC - DC CHOPPER (B)
4. DC - DC CONTROLLER (A)
5. POWER CONDITIONING UNIT FOR DC MOTOR (D)
6. DC CONTROLLER 15 - 31 kW RANGE (E) (L/REGENERATION) LLL AS IS

CER - F: FLYWHEELS (WHEEL AND HUB):
DATA POINTS

DATA SOURCE

- A. AEROSPACE
B. GARRETT - PHASE 1

1. E - GLASS COMPOSITE (A)	5. ALUMINUM (A)
2. STEEL (A)	6. KEVLAR (A)
3. S - GLASS COMPOSITE (A)	7. HOUSING - STEEL (B)
4. S - GLASS COMPOSITE (A)	

CER - F: FLYWHEELS: DATA POINTS
(HYBRID DESIGN)

1. E - GLASS (A)
2. S - GLASS (A)
3. KEVLAR (A)
4. STEEL (A)
5. ALUMINUM (A)

DATA SOURCE

- A. AIRESEARCH
- B. G.E. - PHASE 1
- C. LLL
- D. AEROSPACE
- E. GRC

CER-GA: LEAD ACID BATTERIES: DATA POINTS (TYPICAL INSTALLATION: 20-30kWh)

KEY

- 1. LEAD ACID 16 kWh (A)
- 2. LEAD ACID 13 kWh (B)
- 3. LEAD ACID AT \$23 kWh (B)
- 4. LEAD ACID (C) \$45 kWh AS IS
- 5. LEAD ACID (D)
- 6. LEAD ACID (C)
- 7. LEAD ACID (E)

CER -GB: NICKEL - IRON BATTERIES: DATA POINTS
(TYPICAL INSTALLATION: 20-30 kWh)

DATA SOURCE
(A) AEROSPACE
(B) LLL

1. NICKEL-IRON (A)
2. NICKEL-IRON (B)

CER - GC; NICKEL-ZINC BATTERIES: DATA POINTS
(TYPICAL INSTALLATION; 20-30 kWh)

DATA SOURCE

- A. GRC FOR EPA
- B. AEROSPACE
- C. LLL
- D. GRC

- 1. NICKEL-ZINC 49 kWh (A)
- 2. NICKEL-ZINC AT \$65 kWh (B)
- 3. NICKEL-ZINC (D)
- 4. NICKEL-ZINC (B)
- 5. NICKEL-ZINC (C)

CER-GD: SODIUM-SULFUR BATTERIES:
DATA POINTS (TYPICAL INSTALLATION:
20-30 kWh)

DATA SOURCE

- A. AEROSPACE
- B. GRC
- C. LLL

- 1. SODIUM-SULFUR (CERAMIC) (A)
- 2. SODIUM-SULFUR (CERAMIC) (B)
- 3. SODIUM-SULFUR (CERAMIC) (C)

CER - GE: Li-Al/FeS_x BATTERIES: DATA POINTS
(TYPICAL INSTALLATION 20-30 kWh)

DATA SOURCE

- A. AEROSPACE
- B. LLL
- C. GRC

- 1. Li-Al/FeS (A)
- 2. Li-Al/FeS₂ (A)
- 3. Li-Al/FeS_x (B)
- 4. Li-Al/FeS_x (C)

DATA SOURCES

- A. GARRETT - PHASE - 1
B. LLL

CER - H: BATTERY CHARGER: DATA POINTS

1. BATTERY CHARGER (A)
 $C_c = 8.0 \text{ kW}_c$
2. CHARGER (B)
(\$306 EACH)

DATA SOURCE

- A. ATSP REVISIONS
- B. CONVERSATIONS WITH
TECHNICAL STAFF,
BRIGGS AND STRATON

CER - I: HEAT ENGINES

- 1. OTTO 2-WAY CATALYST (A)
- 2. OTTO 3-WAY CATALYST (A)
- 3. BRAYTON - FREE TURBINE (A)
- 4. STIRLING (A)

DATA SOURCE

A. R&S - 300 DAY

B. GARRETT - PHASE 1

CER - J: VEHICLE ASSEMBLY COSTS

1. VEHICLE AND CHASSIS (INCLUDING POWER PLANT) (A)
2. & 3. VEHICLE AND CHASSIS (B)

DATA SOURCE

A. RATH & STRONG

TOTAL WT. VS TOTAL COST (OEM)

1. TOTAL VEHICLE - CONVENTIONAL ICE (A)
IS 75¢/lb CURB WEIGHT