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LIFE-CYCLE COST COMPARISONS OF ADVANCED
STORAGE BATTERIES AND FUEL CELLS FOR
UTILITY, STAND-ALONE, AND ELECTRIC
VEHICLE APPLICATIONS

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PREFACE

This "Life-Cycle Cost Notebook" represents a new concept in comparative economic assessments for battery and fuel cell technologies. In addition to fulfilling the role of a standard comparative economic assessment, the Notebook is designed to be easily updated to remain current with new cost data and technological changes as they affect the estimated cost of battery and fuel cell technologies in end-use applications. The foremost role of the Notebook is that, where data availability allows, it presents credible life-cycle cost (LCC) estimates for batteries, fuel cells, and competing conventional technologies in load-leveling, stand-alone, and electric vehicle applications. In cases where available data is poor in quality or unavailable, necessitating use of engineering judgment, the implications for the final LCC estimates are discussed. Based upon the data collection and normalization process, the absolute differences in total life-cycle cost and differences in component costs are discussed. In essence, the Life-Cycle Cost Notebook is an "encyclopedia" of battery cost data.

It is important to realize that the scope of this assessment did not include an analysis of differential benefits between alternative technologies. For example, battery technologies offer benefits that conventional peaking technologies may not, such as shorter construction lead times, flexible siting characteristics, and modularity (i.e., the ability to add "modules" of capacity in any increment at any time during the facility's life). In addition, battery energy storage may offer environmental benefits over gas turbine technology because the battery storage facilities are environmentally benign. This benefit may be negligible if the storage facility is charged by a fossil-fuel fired power plant. There could be environmental benefits, particularly with respect to CO₂ emissions, if the battery facility is charged by a nuclear power plant. These differential benefits can be extremely site specific, making an equitable assessment expensive and time-consuming; consequently, this assessment did not examine these aspects of battery technologies. This assessment does provide a core of information upon which further assessments can be built.

In addition, it is intended to be both versatile and responsive. Versatility was addressed by presenting three levels of detail to enable a variety of users to have access to any depth of cost data detail they may require, from the original source data through the data normalization process used in this study, to summary-level data at two levels of detail. The Notebook is responsive in that inputs will be sought from current users if future updates are prepared. This process should allow the Notebook to respond to changing or previously unaddressed needs for battery system cost data.

The success of this document as a medium of communication to the battery community depends in part upon constructive feedback from its audience. Comments regarding its usefulness, identification of additional sources for cost data, and general issues would be viewed as extremely valuable and may be directed to the authors in care of Pacific Northwest Laboratory, P.O. Box 999, Richland, WA 99352.

SUMMARY

Life-cycle cost (LCC) estimates are presented in this report for ten battery and fuel cell technologies in utility load-leveling, stand-alone power system, and electric vehicle applications. The most current and complete technology estimates were sought to prepare the LCC estimates. Raw data were normalized to the 1984 George Guidelines (a set of battery cost-estimating guidelines developed by EPRI) and a set of balance-of-plant guidelines adapted from work completed by PSE&G (Abraham et al. 1985c). After normalization, the estimates were adjusted to mid-1988 dollars. The adjusted capital and operating and maintenance (O&M) cost estimates were used, along with financial data (EPRI 1986) and energy cost data (EIA 1988), as input to a life-cycle economic spreadsheet which calculates the levelized cost of energy delivered from each of the technologies in their respective applications.

For the utility application, the LCC estimates presented in this summary are for a 20-MW peaking facility operating 5 hours per day, 250 days per year. For storage facilities the cost of charging energy is 2.5 cents/kWh. This presents an idealized scenario that has been used in most battery technology assessments in the past ten years. It would be inappropriate to make final decisions on any technology based strictly on this scenario. Additional scenarios are presented in the main text of this report for consideration in decision-making. Using the data and methodology presented, it would also be relatively easy to generate cost estimates for scenarios with peaking requirements, costs of charging energy, and other system parameters different from those evaluated in this study.

LCC estimates for the utility load-leveling application are listed in Table S.1. Each of the more conventional peaking technologies evaluated (gas-fired turbine, compressed air energy storage, and conventional pumped-hydro) were found to generally offer lower energy costs than batteries or fuel cells in the 20-MW, 5-hours-of-operation scenario. Sodium-sulfur and zinc-bromine batteries and the phosphoric acid fuel cell may be competitive with the conventional peaking technologies, but require additional development to reach their full potential. Lead-acid battery technology is

TABLE S.1. Utility Load-Leveling Application Life-Cycle Cost Estimates (cents/kWh)

	<u>Nominal^(a)</u>	<u>Range</u>
Aquifer Compressed-Air Storage	8.3	8.0-8.6
Salt Compressed-Air Storage	8.6	8.3-8.9
Rock Compressed-Air Storage	11.3	11.1-11.6
Advanced Gas-Fired Turbine	12.8	11.4-14.5
Conventional Gas-Fired Turbine	13.6	12.1-15.3
Phosphoric Acid Fuel Cell ^(b)	15.3	14.4-16.4
Conventional Pumped Hydro	15.7	NA
Sodium-Sulfur Battery	16.8	15.8-25.1
Zinc-Bromine Battery	20.1	13.3-27.4
Conventional Lead-Acid Battery ^(c)	21.7	NA
Lithium-Iron Sulfide Battery	25.0	NA
Conventional Lead-Acid Battery	30.8	23.9-34.8
Sealed Lead-Acid Battery	36.8	28.4-44.1

-
- (a) Nominal estimates represent likely performance, the cost most frequently projected by developers and investigators, the most comprehensive and recent data, or a combination of these factors.
- (b) This technology was originally developed for intermediate load, not peaking, applications. This estimate assumes no major operational constraints would result from use in a peaking application.
- (c) Based on recent accelerated life-cycle testing, which suggests longer lifetimes than previously projected.

currently available, but unless new battery designs are developed, it will probably not develop a large market due to its high system life-cycle cost. (However, recent data suggest that lead-acid technology may be moving in the right direction with increased cycle life.) The lithium-iron sulfide battery life-cycle cost shows promise for this system, but the estimate was based on a late-1970s battery design and must be considered to have a high degree of uncertainty.

In general, there is a much lower level of confidence in the stand-alone power system LCC estimates than for the utility load-leveling application estimates. Fewer sources with detailed stand-alone estimates were available

for review. In addition, system data that were available tended to be incomplete. LCC estimates are presented in Table S.2. for stand-alone applications. The lead-acid and hydrogen-nickel oxide estimates are particularly suspect, because their respective installation and balance-of-plant costs are nearly an order-of-magnitude higher than expected, even when considering the diseconomies-of-scale associated with their smaller unit size. Preparation of more detailed component estimates would increase the level of confidence in the stand-alone LCC estimates. A considerable amount of stand-alone cost data is available in the public domain; however, it must be collected from a much wider range of sources than is required for data pertaining to the load-leveling application.

The electric vehicle LCC estimates are presented in Tables S.3, S.4, and S.5. The comparisons are made on the levelized cost per kilometer-traveled. This levelized cost includes costs for vehicle and battery purchase, replacement batteries, maintenance and repairs, replacement tires, insurance, parking, tolls, title, registration, and salvage over a vehicle's life. The levelized cost for an internal combustion engine was also estimated to provide a reference for comparison. The differences in the proposed costs of ICE, battery and fuel cell systems are striking for full-performance vans and five-passenger cars. Even given a high world oil price, the ICE has roughly a 9 cents/kilometer advantage over the nearest competing battery system.

TABLE S.2. Stand-Alone Application Life-Cycle Cost Estimates (dollars/kWh)

	<u>Nominal</u> ^(a)	<u>Range</u>
Zinc-Ferricyanide (REDOX) Battery	1.5	NA
Diesel-Electric Generator	0.74	0.27 - 2.2
Hydrogen-Nickel Oxide Battery	1.7	1.1 - 1.8
Sealed Lead-Acid Battery	1.8	1.6 - 2.1

(a) Nominal estimates represent likely performance, the cost most frequently projected by developers and investigators, the most comprehensive and recent data, or a combination of these factors.

TABLE S.3. Light-Duty Electric Van Application Life-Cycle Cost Estimates (cents/kilometer-traveled)

	<u>Nominal^(a)</u>	<u>Range</u>
Sealed Lead-Acid Battery	26.4	NA
Lithium-Iron Sulfide Battery	29.4	NA
Conventional Lead-Acid Battery	31.5	NA
Zinc-Bromine Battery	33.5	NA
Sodium-Sulfur Battery	36.4	NA
Internal Combustion Engine ^(b)	26.9	26.4-27.7

(a) Nominal estimates represent likely performance, the cost most frequently projected by developers and investigators, the most comprehensive and recent data, or a combination of these factors.

(b) Full-performance van.

TABLE S.4. Full-Performance Electric Van Application Life-Cycle Cost Estimates (cents/kilometer-traveled)

	<u>Nominal^(a)</u>	<u>Range</u>
Internal Combustion Engine	26.9	26.4-27.7
Lithium-Iron Sulfide Battery	36.3	NA
Sodium-Sulfur Battery	39.3	NA
Conventional Lead-Acid Battery	39.6	NA

(a) Nominal estimates represent likely performance, the cost most frequently projected by developers and investigators, the most comprehensive and recent data, or a combination of these factors.

**TABLE S.5. Electric Car Application Life-Cycle Cost Estimates
(cents/kilometer-traveled)**

	<u>Nominal^(a)</u>	<u>Range</u>
Internal Combustion Engine	19.9	19.5-20.5
Proton Exchange Membrane Fuel Cell	24.6	NA
Lithium-Iron Sulfide Battery	29.5	NA
Sodium-Sulfur Battery	31.1	NA
Aluminum-Air Battery	46.3	NA

(a) Nominal estimates represent likely performance, the cost most frequently projected by developers and investigators, the most comprehensive and recent data, or a combination of these factors.

This implies that high fuel prices alone will not make full-performance electric vehicles economically feasible. Radical advances in electric vehicle (EV) technology, larger-than-expected increases in fossil fuel prices, or a major change in national policy regarding the use of fossil fuels in vehicles may be necessary for EVs to become an attractive option. Light-duty vans appear more competitive, being relatively equal in cost to full-performance ICE-powered vans. This indicates limited-performance electric vans may be competitive in some applications.

The LCC estimates presented in this report should be used with caution. No consideration is given in this analysis to differential benefits that may accrue to alternative technologies. For example, the services (benefits) provided by battery storage to a utility are almost certain to be different than the services provided by a gas-fired turbine, even though both technologies are generally thought of as alternative peaking technologies. Also, a change in any of the ground rules and assumptions (plant size, discharge period and pattern, charging costs, fuel costs, etc.) as defined in the main text could change either the absolute estimates or their relative ranking. To provide some insight into the effect of variances in key financial, performance, and system operating parameters on the levelized output cost, a number of sensitivity analyses were performed. These analyses were limited to the load-leveling application. The results of these analyses are useful

for identifying general trends in levelized costs as key input parameters vary. They also are useful for roughly estimating the life-cycle cost of any one of the load-leveling technologies in a specific utility load-leveling application that is not the same as the baseline case modeled in this study. For these purposes, cost estimates showing the variance caused by different costs of charging electricity, discount rates, and system configurations are presented in Chapter 3.0.

GLOSSARY

ADL	Arthur D. Little, Inc.
AFDC	allowance for funds during construction
Al-air	aluminum-air battery technology
BEST	battery energy storage test facility
BOP	balance-of-plant
BTU	British Thermal Unit
CAES	compressed air energy storage
CRF	capital recovery factor
EIA	Energy Information Administration
EPRI	Electric Power Research Institute
FCR	fixed charge rate
GNP	Gross National Product
H-Ni Oxide	hydrogen nickel oxide battery technology
ISOA	Improved State-of-the-Art
JHBG	James H. B. George
JPL	Jet Propulsion Laboratory
kW	kilowatt
kWh	kilowatt-hour
LCC	life-cycle cost
Li-FeS	lithium-iron sulfide battery technology
MW	Megawatt
Na-S	sodium-sulfur battery technology
O&M	operating and maintenance
OEM	original equipment manufacturer
PAFC	phosphoric acid fuel cell
PEM	proton exchange membrane fuel cell
P-Hydro	pumped hydro storage technology
PNL	Pacific Northwest Laboratory
Pb-Acid	lead-acid battery technology
SCE	Southern California Edison
TAG TM	Technical Assessment Guide

UPS uninterruptible power supply
Zn-Br zinc-bromine battery technology

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1.0 INTRODUCTION

1.0 INTRODUCTION

This report presents a comparison of battery and fuel cell economics for ten different technologies. To develop an equitable economic comparison, the technologies were evaluated on a life-cycle cost (LCC) basis. The LCC comparison involved normalizing source estimates to a standard set of assumptions and preparing a lifetime cost scenario for each technology, including the initial capital cost, replacement costs, operating and maintenance (O&M) costs, auxiliary energy costs, costs due to system inefficiencies, the cost of energy stored, and salvage costs or credits. By considering all the costs associated with each technology over its respective lifetime, the technology that is most economical to operate over any given period of time can be determined. An analysis of this type indicates whether paying a high initial capital cost for a technology with low O&M costs is more or less economical on a lifetime basis than purchasing a technology with a low initial capital cost and high O&M costs. It is important to realize that while minimizing cost is important, the customer will not always purchase the least expensive technology. The customer may identify benefits associated with a more expensive option that make it the more attractive over all (e.g., reduced construction lead times, modularity, environmental benefits, spinning reserve, etc.). The LCC estimates presented in this report represent three end-use applications: utility load-leveling, stand-alone power systems, and electric vehicles. The combinations of technologies and applications that were evaluated are identified in Table 1.1.

In addition to the Executive Summary, three more levels of detail are included in this document: discussion in the main text of the individual technologies component by component; more detailed description in the main text of where the source data were obtained, what was done to adjust the source data, and how the final results were derived; and the appendixes, which present the source data in raw form and document step-by-step how the data were transformed and normalized to obtain the final results. The appendixes contain enough detail to allow the results of this study to be independently reproduced.

TABLE 1.1. End-Use Applications

<u>Battery or Fuel Cell</u>	<u>Load-Leveling</u>	<u>Stand-Alone</u>	<u>Electric Vehicle</u>
Zinc-Bromine	X	--	X
Sodium-Sulfur	X	--	X
Lead-Acid (Conventional)	X	--	X
Lead-Acid (Sealed)	X	X	X
Aluminum-Air	--	--	X
Lithium-Iron Sulfide	X	--	X
Zinc-Ferricyanide (REDOX)	--	X	--
Nickel-Hydrogen	--	X	--
Phosphoric Acid	X	--	--
Proton Exchange Membrane	--	--	X

2.0 GENERAL APPROACH

A LCC analysis spreadsheet was used for comparing battery and fuel cell systems on the basis of levelized generation cost or levelized output cost, depending upon the technology and end-use application. The input data required for the spreadsheet are system description inputs, cost inputs, and financial inputs. The specific inputs are listed in Tables 2.1 through 2.3. The battery system costs are presented in mid-1988 dollars, with tax implications based upon the 1986 Tax Reform Act. This produces LCC estimates which are as economically correct as possible for the time period in which the systems could be expected to begin operation (1995-2000).

The battery purchase cost element includes the part of the battery system that is replaced at the end of the battery's cycle life. The shipping and installation cost element is based on the cost to ship the battery cells from the factory 1000 miles and install them in the plant. The energy-related balance-of-plant (BOP) generally includes auxiliaries, buildings, and support equipment. The specific BOP items included for each technology vary and, therefore, are detailed as each technology and corresponding application is discussed in the sections that follow and in Appendixes B and E. The power-related BOP includes the converter, AC/DC interfaces, and master site controller. The costs for this system remain relatively constant from technology to technology; where there are differences, they are discussed under the specific technology and application to which the change pertains. Salvage costs include removal of the old batteries at the end of their cycle life, shipping to a scrap or reclaiming facility, and a scrap value credit or cost. Operating and maintenance costs are divided into three types for ease of input into the model.

An economic parameter explicitly estimated in some studies is an allowance for the use of funds during the construction (AFDC) of the plant. For simplification in economic models, construction expenditures are generally presumed to occur at the end of each construction year. The construction time for the battery storage and fuel cell plants is presumed to be one year, so all initial capital expenditures are assumed to be incurred at the end of

TABLE 2.1. System Description Inputs to the
Life-Cycle Cost Calculations

Battery Type
Application
System Storage Capacity (kWh)
System Power Rating (kWe)
Auxiliary Electricity Consumption (kWh/Year)
Auxiliary Fossil Fuel Consumption (MBTU/Year)
Cycle Life (#)
Cycles/Year
Efficiency (Roundtrip)

TABLE 2.2. Cost Inputs to the Life-Cycle
Cost Calculations

Battery Purchase (\$/kWh)
Battery Shipping and Installation (\$/kWh)
Energy-Related BOP (\$/kWh)
Power-Related BOP (\$/kWe)
Net Salvage Value (\$/kWh)
Cost of Electricity (\$/kWh)
Cost of Fossil Fuel (\$/MBTU)
Annual Recurring O&M (\$/year)
Equal Interval Maintenance:
 Periodic Maintenance Interval (years)
 Periodic Maintenance Cost (\$/occurrence)
Varied Interval Maintenance:
 Maintenance Year (year)
 Associated Maintenance Cost (\$)

that construction year or at "time zero" for the project. Thus, no AFDC is incurred and the total construction cost is equivalent to the overnight construction cost for battery and fuel cell technologies. AFDC is included for comparison technologies which have a construction period of greater than one year.

TABLE 2.3. Financial Inputs to the Life-Cycle Cost Calculations

Price Year	Average Annual Inflation Rate
First Operational Year	Discount Rate
System Life (years)	Tax Rate
Capital Escalation Rate	Tax Credit
Maintenance Escalation Rate	Other Tax Rate (Property and Insurance)
Electricity Escalation Rate	ACRS Battery Property Type (year)
Fossil Fuel Escalation Rate	ACRS Plant Property Type (year)
Average Annual Inflation Rate	

The financial methodology used in the LCC model is similar to "required revenue" methodology prepared for the U.S. Energy Research and Development Administration and the Electric Power Research Institute (EPRI) (Doane et al. 1976) and that presented by EPRI in its Technical Assessment Guide (TAG) (1986). All cost and financial inputs, and hence the levelized output cost, are based on a real (constant) dollar analysis (as opposed to a current or nominal dollar analysis) with a price year of 1988. The inflation rate assumption used in the life-cycle cost calculations is only used to convert "nominal" depreciation credits to "real" depreciation credits.^(a) The discount rate and "other" tax rate are based on financial information in EPRI's TAG; fossil fuel prices and energy escalation rates were obtained from the Energy Information Administration (EIA). The cost of electricity for charging storage was set at 2.5 cents/kWh for the utility, 4.3 cents/kWh for the electric vehicle applications, and 20.0 cents/kWh for the remote stand-alone application. Tax treatment is based on the 1986 Tax Reform Act using

(a) Depreciation credits are fixed at the time a purchase is made, in the dollars of the purchase year. For example, a \$1000 purchase is made in 1987 and 20% is depreciated each year for five years, the owner may depreciate \$200 (1987\$) per year. In a real-dollar analysis, an inflation rate must be used to devalue future depreciation credits. For example, a \$200 (1987\$) depreciation credit is worth less in 1988\$ and still less in 1989\$. If such a procedure were not used, the life-cycle estimates would be produced in mixed-year dollars.

asset depreciation range (ADR) property lives and Accelerated Depreciation with a mid-year convention. The economic methodology is detailed in Appendix J.

All of the LCC estimates presented in this report are based on the projected costs and characteristics of each technology presuming mass-production of the batteries and fuel cells and reasonable technological improvements in their designs. It is possible that the life-cycle costs could be reduced substantially if major technological breakthroughs occur; however, presuming that such breakthroughs will occur carries considerable uncertainty. All of the source estimates used in this study have been normalized to the extent possible using a procedure that yields estimates with a similar basis. The procedures for normalization are discussed in the chapters pertaining to each application. Although the estimates have been converted to the same basis, the scope of this study did not include verifying the accuracy of individual elements of the source estimates. Types of data that have not been normalized and might be scrutinized in future studies include material and purchased component costs, labor hours, manufacturing methods and their associated costs, imbedded labor costs and any other factors not specifically stated as normalized in this study.

3.0 UTILITY LOAD-LEVELING APPLICATION

The results of the utility load-leveling application LCC modeling for a system size of 100-MWh, 20-MW operating 250 cycles/year are graphically presented in Figure 3.1. For each battery technology, a comparison of the contribution of each system component (i.e., battery purchase, shipping and installation, energy and power-related BOP, and salvage) to their respective nominal LCC estimates is presented in Figure 3.2. Providing sufficient data were available, three estimates were developed for each of the battery and fuel cell technologies. The nominal estimate represents the life-cycle cost based upon the cost most frequently projected by developers and investigators, with the most comprehensive and recent data weighted more heavily than older, less complete data. The high and low estimates represent the high- and low-cost projections encountered in the review of each technology. In some cases the estimates reflect subjective increases or decreases in the source estimates. All of the subjective adjustments made are discussed in the particular technology section to which they pertain. Generally, the subjective changes were made because of uncertainty in the system design that was identified in the source study but not accounted for in the final source estimate.

The high, nominal, and low estimates for the comparison technologies [gas turbine, compressed air energy storage (CAES), and conventional pumped hydro] represent three fuel price scenarios. The low estimate corresponds to a current average fuel price to utilities of \$2.36/MBTU (1988\$), with future escalation based on EIA's "low" world oil price scenario. This was the price for natural gas purchased by electric utilities in the year 1988, as estimated by the EIA (1988). The nominal estimate relates to the same initial fuel cost, with future escalation based upon EIA's "likely" world oil price scenario. The high estimate uses the same initial fuel cost, with future escalation based on EIA's "high" world oil price scenario.

Of the conventional technologies evaluated for the load-leveling application, the gas-fired turbines, CAES technologies, and conventional pumped-hydro are at the forefront of economic competitiveness. However, both CAES

FIGURE 3.1. Levelized Output Cost for Load-Leveling Systems

FIGURE 3.2. Component Contributors to the Levelized Output Cost of Load-Leveling Systems

and conventional pumped-hydro rely on restrictive geographical and/or geological conditions to be technically and economically feasible. This leaves the gas-fired turbine as the main competitor of fuel cells and battery energy storage for peaking applications.

The only emerging technology that falls within the range of economic competitiveness without consideration of differential benefits is the phosphoric acid fuel cell (PAFC). This technology has approximately the same levelized output cost as the conventional pumped-hydro storage system, one of the most expensive conventional peaking technologies evaluated. Experience in the logistics of operating a PAFC in a peaking application is limited; therefore, it is difficult to predict operating and maintenance (O&M) costs. This analysis assumes that severe operational considerations would not significantly impact cost due to the operation of the PAFC in a peaking application, as opposed to an intermediate application toward which most available data is oriented. This is likely an optimistic assumption.

Relative to other emerging technologies evaluated, the sodium-sulfur system ranked high in economic viability, second only to the PAFC. Presuming cell reliability and cycle life can be increased, there is good potential for load-leveling systems using the sodium-sulfur cell. Currently, cell failures would necessitate prohibitively expensive cell replacement operations. With respect to O&M, most of the information currently available is in the form of cost goals or possible scenarios that have a larger confidence interval than desired. Considering this factor, O&M cost estimates for the sodium-sulfur battery system may be optimistic. Fortunately, it does not appear O&M costs are a major LCC contributor (see Figure 3.2).

Within the limits of accuracy associated with the estimates, the zinc-bromine battery system is essentially equal on a LCC basis with the sodium-sulfur battery. Like the sodium-sulfur cell, the zinc-bromine battery has technical problems that must be overcome for it to achieve the estimated life-cycle cost. O&M cost information is ill-defined for the zinc-bromine battery, and information related to cell stack replacement in particular is vague. In order to improve the quality of zinc-bromine estimates, it will be important to develop detailed O&M scenarios.

Of the battery technologies, the zinc-bromine and sodium-sulfur battery systems show the most promise for being competitive in the load-leveling market. For this reason further, more detailed, cost studies are warranted.

Ranking below these four technologies in economic viability is the lithium-metal sulfide battery. Some concern exists as to the accuracy of this estimate, because it is based on data prepared approximately ten years ago. Since that time, the battery has been redesigned and new, detailed estimates have not yet been published. In order to develop good LCC estimates, the current design must be evaluated. The large uncertainty associated with the lithium-metal sulfide LCC estimate makes it unwise to draw any major conclusions from it.

The most expensive of the load-leveling technologies evaluated are the two lead-acid systems. The sealed lead-acid system has a slightly higher efficiency and lower O&M costs than the conventional lead-acid system, but its shorter cycle life results in a higher net life-cycle cost relative to the conventional lead-acid battery system. O&M cost estimates are poor for both lead-acid systems but better than O&M estimates for most other battery technologies. The conventional lead-acid cell will not gain favor as a load-leveling cell unless its high initial capital and replacement costs can be reduced (see Figure 3.2). It is possible that new, advanced lead-acid designs will have attributes, such as increased cycle life, that will make them competitive for lead-leveling applications. Test data on a new conventional lead-acid battery design suggests that it may be able to last much longer than many previous cycle life estimates predicted. If these new cycle life estimates become a reality, then advanced lead-acid battery designs could become quite competitive with other advanced batteries. Presently, lead-acid batteries will provide valuable operations experience, because they are currently available and have high reliability relative to other battery technologies.

Several key component cost differences which have been touched upon are elucidated by Figure 3.2. As illustrated by this figure, O&M is a minor contributor to the total life-cycle cost. Furthermore, the difference in O&M costs between battery technologies is very small. It is, however, still

important to develop good O&M cost estimates which specifically identify the necessary O&M functions, because until credible O&M cost estimates are available there will continue to be skepticism regarding O&M costs. Like O&M costs, the energy component cost is not significantly different between alternative battery technologies. In addition, even the BOP costs are relatively equal across the range of battery technologies evaluated. The two major cost drivers are battery purchase cost and installation and battery replacement costs. It should be obvious from Figure 3.2 that there is significant potential for absolute cost reductions by investing technological efforts in increasing battery cycle life and decreasing the battery purchase cost. Either of these two items would reduce replacement costs, and thus, total life-cycle cost.

As mentioned in the introduction to this document, the estimates presented are for mature systems assuming normal technological innovation from current technology and cost reductions due to mass production and multiple similar installations. This could lead an individual to conclude the emerging technologies evaluated in this study will never be economically viable, which is definitely not the case. Two basic factors that are not captured in the estimates presented here will determine the ultimate widespread viability of emerging peaking technologies: major technological breakthroughs and differential benefits. Obviously, it is difficult or impossible to quantify the likelihood of major technological breakthroughs, and such breakthroughs should not be used as a primary justification for the development of emerging technologies. Differential benefits, however, are a major consideration that deserves further evaluation. Such benefits might include the economic value of reduced emissions, flexible siting, the ability to add capacity in small increments deferring the capital investment of larger conventional facilities, spinning reserve, minimal space requirements, reduced operational noise levels, minimal land requirements, and many others. As we move into an era of reduced land availability, greater concern for the immediate environment, awareness of the potential for global climate change from the use of fossil fuels, and reduced funds for major capital improvements, differential benefits coupled with reliable technology will be a strong selling point to the utility industry.

In addition, it should be recognized that the estimates presented in Figures 3.1 and 3.2 have different uncertainties associated with them. (Uncertainty analysis of the estimates--that is, analysis of the probability that estimated costs will be achieved--is not specifically addressed in this study.) For example, the likelihood that projected costs of advanced gas turbines will be achieved is greater than the likelihood that projected costs of sodium-sulfur systems will be achieved. This is due to the greater understanding of the former technologies and a greater ability to control the progress made in new designs. This factor should be considered when interpreting the estimated costs shown in Figures 3.1 and 3.2

3.1 SPECIFIC APPROACH FOR LOAD-LEVELING SYSTEMS

Life-cycle costs for load-leveling applications are based on a 100-MWh, 20-MW facility which has a 30-year system life. The system is presumed to be operated by an investor-owned utility for one full cycle per day, 250 days per year. The costs of owning and operating the system are included in the LCC estimates; however, no consideration of benefits, which may vary between systems, has been included. To arrive at the appropriate inputs for the LCC model, both independent and developer estimates were reviewed and normalized to the same set of ground rules. To develop the utility load-leveling LCC inputs to the economic model, the most current and complete source estimates were reviewed. Older and less complete estimates were used to increase the confidence in newer estimates and to help develop ranges into which cost elements might fall. During final determination of the LCC estimates, the newer and more comprehensive estimates were given the majority of the weight.

To the extent possible, all the estimates used for determining the battery purchase cost input were adjusted to be in compliance with the ground rules set forth in "Guidelines for Estimating the Capital Costs of Battery-Based Energy Storage Systems," prepared by James George (1984). These guidelines are the most current estimating procedure in the ADL/George series for developing estimates of battery module F.O.B. costs. The cost-related ground rules for the current George guidelines and each of the previous versions of the guidelines are outlined in Appendix A. The step-by-step

method used to normalize the battery manufacturing cost estimates to the 1984 George guidelines is also covered in this appendix.

The battery installation and BOP estimates were normalized to a set of BOP guidelines which are a slight modification of a BOP estimating procedure originally developed by PSE&G (Abraham et al. 1985c). These guidelines presume that once battery load-leveling facilities are built in large numbers, contractors who specialize in building BOP systems for these load-leveling facilities will exist. Each BOP contractor is assumed to install enough facilities to support 2500-MWh per year of battery storage capacity. The BOP guidelines quantify cost reductions that allow for increases in labor efficiency due to contractor specialization, quantity material purchases, and cost optimization of the equipment installed. Appendix A also presents the BOP guidelines used in this study.

The remaining cost inputs were determined using the estimates generated by both independent investigators and battery developers. The shipping cost estimates presume 1000 miles of transportation by truck. The O&M cost input was developed by comparing the available O&M data from each of the source reports. From this comparison, likely O&M scenarios were costed. Salvage value was similarly determined and includes allowances for removal of batteries, shipping to a disposal facility, and scrap value.

3.2 TECHNOLOGIES REVIEWED

In total, six battery and fuel cell technologies were evaluated on a LCC basis for the utility load-leveling application. They include the conventional lead-acid battery, the sealed lead-acid battery, the zinc-bromine battery, the sodium-sulfur battery, the lithium-iron sulfide battery, and the PAFC. For each of the technologies, source estimates were gathered and normalized as previously described. Each of the source estimates was then used to develop the nominal and range estimates used as the LCC model inputs.

Each technology section includes a summary sheet containing the nominal and range estimates used in the LCC analysis, the system characteristics which affect the life-cycle cost, the LCC spreadsheet results, and the results of a set of sensitivity comparisons prepared for each technology.

Following the summary information is an overview discussion of each LCC model input. Each input subsection defines where the source estimates came from, how individual numbers were normalized, and why particular estimates were given more or less credence than other estimates. A shorter section is included for each of the comparison technologies (conventional and advanced gas-fired turbines, CAES using three types of storage media, and conventional pumped-hydro) which summarizes the model inputs used. Appendix B presents the raw source data and the step-by-step normalization methodology.

CONVENTIONAL
LEAD-ACID BATTERY

3.2.1 Conventional Lead-Acid Battery

Although the conventional lead-acid cell is functional in many applications, current versions will not gain favor as a load-leveling cell unless their high initial capital and replacement capital costs can be reduced to improve its life-cycle economics. Otherwise, they will not have an economic advantage over other battery systems, such as the sodium-sulfur and zinc-bromine batteries, as these are developed to their full potential. It is possible, however, that new advanced lead-acid designs will have attributes, such as increased cycle life, that will enable them to compete for load-leveling applications. In fact, recent accelerated cycle life testing on new battery cells at Argonne National Laboratory suggest that these cells may last as long as 4000 cycles. A summary of the life-cycle economics of a conventional lead-acid battery system is presented in Table 3.1.

A number of sensitivity analyses were performed for the conventional lead-acid battery system. During the sensitivity comparison only one variable was changed at a time in the nominal estimate. Tables 3.2 presents the sensitivity cases.

Due to their relative maturity with respect to other battery technologies, a number of cost analyses have been performed for conventional lead-acid systems. For this reason, the LCC estimates developed in this analysis are based on a wider range of sources than most of the other technologies evaluated. The source reports that were used are listed in Table 3.3. In addition to the source data being generally incomplete, the O&M cost estimates are particularly weak for large (100-MWh) systems. Fortunately, O&M costs do not appear to be the major cost driver.

3.2.1.1 Battery Purchase Cost

Of the source reports reviewed, the PSE&G (Abraham et al. 1985a) estimate of the GNB battery was given the most credibility because it was based on developer input, was prepared according to the George guidelines by an independent investigator, and is relatively recent. This estimate was normalized to the 1984 George guidelines and escalated to mid-1988\$ to arrive at the normalized PSE&G (GNB) estimate of \$134/kWh (mid-1988\$).

TABLE 3.1. Conventional Lead-Acid Battery System Life-Cycle Economics:
Baseline Case

Cycle Life: 2000
Cell Efficiency: 0.725
System Efficiency: 0.64

Nominal Estimate (mid-1988\$)

Battery Purchase Cost (\$/kWh): 134
Battery Installation (\$/kWh): 28.5
Energy-Related Balance-of-Plant (\$/kWh): 45.1
Power-Related Balance-of-Plant (\$/kWe): 121
Net Salvage Value (\$/kWh): 5.6

Annual Operating & Maintenance Costs (\$/yr): 117,000

Levelized Output Cost: 30.8 cents/kwh of energy retrieved

Range of Estimates (mid-1988\$)

Battery Purchase Cost (\$/kWh): 93 - 143
Battery Installation (\$/kWh): 28 - 33
Energy-Related Balance-of-Plant (\$/kWh): 33 - 49
Power-Related Balance-of-plant (\$/kWe): 121 - 188
Net Salvage Value (\$/kWh): 5.6 - (-4)

Annual Operating & Maintenance Costs (\$/yr): 62,000 - 137,500

Levelized Output Cost: 23.9 - 34.8 cents/kWh of energy retrieved

**TABLE 3.2. Conventional Lead-Acid Battery System Life-Cycle
Economics: Sensitivities**

<u>Variable</u>	<u>Baseline Value</u>	<u>New Value</u>	<u>New Levelized Output Cost (cents/kWh)</u>	<u>Percent Change</u>
Discount Rate	4.2%	3%	29.9	-2.5%
		5%	31.4	+2%
		6%	32.3	+5%
		7%	33.3	+8%
Cycle Life	2000	3000	25.6	-17%
		3500	24.7	-20%
		4000	21.7	-30%
Charging Cost	\$0.025	\$0.01	28.4	-8%
		\$0.015	29.2	-5%
		\$0.020	30.0	-2.5%
		\$0.030	31.5	+2.5%
System Size: 50-MWh, 10-MW			36.5	+2.5%
Energy-Related BOP	--	\$54/kWh	--	--
Power-Related BOP	--	\$139/kW	--	--
Annual O&M	--	\$58,500	--	--
System Size: 30-MWh, 10-MW			33.9	+10%
Energy-Related BOP	--	\$72/kWh	--	--
Power-Related BOP	--	\$139/kW	--	--
Annual O&M	--	\$39,500	--	--
Cell Efficiency	0.725	0.775	28.7	-7%
		0.825	27.0	-12%

TABLE 3.3. Bibliography of Key Sources Used to Evaluate the Conventional Lead-Acid Battery Technology

1. Abraham, J., et al. 1985a. Technical and Economic Assessments of Electrochemical Energy Storage Systems: Lead-Acid Battery Plant Description, Cost Estimate, Credible Accident and Efficiency Assessment.
2. Abraham, J., et al. 1985c. Technical and Economic Assessments of Electrochemical Energy Storage Systems: Topical Report on the Potential for Savings in Load-Leveling Battery and Balance-of-Plant Costs.
3. Bechtel Group, Inc. 1982. Study of Installed and Life-Cycle Costs of Photovoltaic Power Systems.
4. Eckroad, S. W. 1985. Design and Cost of Standardized Lead-Acid Battery Systems for Utility Energy Management.
5. Eckroad, S. W., et al. 1986. "Conceptual Design and Cost Estimate: 10-MW Utility Battery Facility."
6. Electric Power Research Institute (EPRI). 1986. Technical Assessment Guide.
7. Energy Research Corporation (ERC). 1986a. "Development of Zinc-Bromine Batteries for Utility Applications."
8. Ramsay, G. B., and A. Edgecomb. 1982. Comparison of Prices for Conventional and Advanced Storage Batteries for Residential, Commercial and Utility Applications.
9. Stolte, W. J., and S. W. Eckroad. 1984. Economic Analysis of Specific Customer Side-of-the-Meter Applications for Battery Energy Storage, Volume 1: Study Results.
10. Stolte, W. J., and S. W. Eckroad. 1985. Updated Cost Estimate and Benefit Analysis of Customer-Owned Battery Energy Storage.

Additional data sources, which were used to develop a range of estimates and as quality checks on the PSE&G (GNB) estimate, included Bechtel's estimate of an ESB load-leveling cell (Bechtel 1982), Bechtel's estimate of the proposed Southern California Edison (SCE) plant (Eckroad et al. 1986), PSE&G's review of a 1982 Gould, Inc. estimate (Abraham et al. 1985a), and PSE&G's review of a C&D Eltra estimate (Abraham et al. 1985a). To normalize the ESB cell estimate (Bechtel 1982), both Bechtel's and ESB's (Ferrell et al. 1977) data were used. After normalization to the current George

guidelines and a lead price of 20 cents per pound, a low estimate of \$93/kWh and a high estimate of \$143/kWh were obtained. The Bechtel/SCE estimate of \$181/kWh, with a range of \$149/kWh to \$192/kWh (mid-1988\$), is based on current production levels and current technology. Although the Bechtel/SCE estimates are not directly applicable to this study, they do provide a cross-check on the other estimates. Since the Bechtel/SCE estimate does not account for high production levels (2500 MWh/yr) or advanced technology, it can be expected to fall slightly above estimates which apply to this study's ground rules. The last two source estimates used are PSE&G's review of Gould, Inc. and C&D Eltra estimates. The PSE&G document does not go into detail as to how these two estimates were adjusted in the study by PSE&G. To avoid making incorrect interpretations regarding the basic assumptions that apply to these estimates, they were only escalated to mid-1988\$ from the (presumed) 1983 price year. The resulting estimates were \$113/kWh for the Gould, Inc. battery and \$114/kWh for the C&D Eltra battery. Because there is considerable uncertainty as to how PSE&G initially developed these estimates, they were used as a cross check on the values for which there was a higher degree of confidence; that is, the PSE&G (GNB) and the Bechtel (ESB) estimates. All the cost estimates reviewed and the final nominal and range estimates used in the model are summarized in Table 3.4.

TABLE 3.4. Conventional Lead-Acid Battery Purchase Cost:
Summary of Normalized Estimates

(mid-1988\$; Lead Price 20 Cents per Pound)

Source	Normalized Estimates	
	Nominal	Range
PSE&G (GNB) (Abraham et al. 1985a)	\$134/kWh	-
Bechtel (ESB) (Bechtel 1982)	-	\$93/kWh - \$143/kWh
Bechtel (SCE) (Eckroad et al. 1986)	\$181/kWh	\$149/kWh - \$192/kWh
PSE&G (Gould) (Abraham et al. 1985a)	\$113/kWh	-
PSE&G (C&D ELTRA) (Abraham et al. 1985a)	\$114/kWh	-
Input Nominal Estimate: \$134/kWh		
Input Range Estimate: \$93/kWh - \$143/kWh		

For evaluating the life-cycle cost of 50-MWh, 10-MW and 30-MWh, 10-MW systems, the unit battery purchase cost was kept equivalent to the nominal cost estimate for the 100-MWh, 20-MW.

3.2.1.2 Shipping and Installation Cost

Shipping cost data are limited or nonexistent in most of the source estimates. The two sources which did include shipping cost data were Bechtel's 1982 estimate (Bechtel 1982) and Bechtel's 1986 estimate (Eckroad et al. 1986). The 1982 estimate projected the shipping cost of the ESB cell for a 6-MWh plant as \$7.57/kWh (1980\$). This was escalated to \$10.6/kWh (mid-1988\$). The 1986 Bechtel estimate projected shipping as \$10/kWh (\$11/kWh, mid-1988\$) for the 50-MWh, 10-MW SCE plant. Making the assumption that little or no economies-of-scale would occur when shipping cells for a 100-MWh plant as opposed to the 50-MWh SCE plant, the shipping cost was established at \$11/kWh.

Installation costs were estimated based on three source estimates; Bechtel 1982, Bechtel (Eckroad et al. 1986), and PSE&G (GNB) (Abraham et al. 1985a). Bechtel's 1982 estimates for the ESB cell were based on 2-MWh and 6-MWh systems. Adjusting the 2-MWh and 6-MWh cost estimates to include 1) both direct labor and the associated indirect labor, 2) a cost reduction for multiple installations, and 3) price year results in normalized estimates of \$24.7/kWh and \$23.9/kWh (mid-1988\$), respectively. In the 1986 Bechtel estimate, they projected the likely installation cost as \$22/kWh with an estimated range of \$20/kWh to \$24/kWh (mid-1986\$). After a reduction in the estimated cost for multiple installations and dollar year, a likely value of \$19/kWh with a range of \$17/kWh to \$21/kWh results. The installation cost estimate by PSE&G (GNB), when escalated to mid-1988\$, is \$16/kWh. It is surprising that the PSE&G estimate is the lowest, because it includes installation of an automatic watering system that is not specifically listed in the other estimates. The lack of detail made it impossible to adjust for this apparent difference. The nominal installation estimate was taken as the average of the Bechtel/SCE and PSE&G estimates. Shipping and installation

costs were assumed equal on a unit-cost basis for 100-MWh, 50-MWh, and 30-MWh systems. Table 3.5 presents a summary of the normalized shipping and installation costs from each source.

3.2.1.3 Energy-Related Balance-of-Plant Cost

The energy-related BOP includes battery auxiliaries, site auxiliaries, engineering, and other capital system costs not included in any other input category. Different source estimates include the same items in different subaccounts, or otherwise characterize BOP items differently; therefore, BOP components are presented item-by-item in Appendix B for each source estimate.

A PSE&G report (Abraham et al. 1985a) was used as the main source cost estimate. PSE&G itemized the energy-related BOP in great detail as presented in Appendix B.1. PSE&G's bottom-line value for the BOP, after an adjustment for a stacked-battery system and for multiple installations, is \$38.7/kWh (1983\$). After escalation, it is \$45.1/kWh (mid-1988\$). This cost represents a 67% reduction in engineering costs and a 29.7% reduction in the remaining BOP components from the BOP cost estimate for PSE&G's one-time installation of a stacked lead-acid battery system.

Four Bechtel estimates were used to develop the range of estimates and as an additional check on the validity of the PSE&G estimate. The first Bechtel estimate, based on the SCE plant (Eckroad et al. 1986), was adjusted for multiple installations by scaling down the engineering by two-thirds and

TABLE 3.5. Conventional Lead-Acid Battery Shipping and Installation Cost: Summary of Normalized Estimates (mid-1988\$)

Source	Shipping	Installation	
		Nominal	Range
Bechtel (2-MWh) (Bechtel 1982)	--	\$24.7/kWh	--
Bechtel (6-MWh) (Bechtel 1982)	\$11/kWh	\$23.9/kWh	--
Bechtel (SCE) (Eckroad et al. 1986)	\$11/kWh	\$19/kWh	\$17 - 21/kWh
PSE&G (GNB) (Abraham et al. 1985a)	--	\$16/kWh	--
		avg. \$17.5/kWh	

Input Nominal Estimate: \$28.5/kWh

Input Range Estimate: \$28 - \$33/kWh

the remaining BOP by 29.7%, the reductions quantified by PSE&G. The final, normalized Bechtel (SCE) estimate is then \$33/kWh with a range of \$33 - 49/kWh. The remaining Bechtel estimates are from the 1982 photovoltaic systems report (Bechtel 1982). These estimates are for 6-MWh, 2-MWh, and 643-kWh systems. They were used in two ways for this study. First, the 6-MWh system was adjusted to allow for multiple installations and escalated to mid-1988\$. The unit cost arising from these adjustments was \$47/kWh (mid-1988\$). Since economies of scale are to be expected when scaling the BOP from 6-MWh to 100-MWh, the 6-MWh unit cost of \$47/kWh is too high for a 100-MWh plant. Second, a power-function regression was performed on all three Bechtel estimates, the 643-kWh BOP, the 2-MWh BOP, and the 6-MWh BOP. From the equation derived in the regression, a BOP unit cost of \$9/kWh (mid-1988\$) was projected for a 100-MWh system. Because the projection was based on three relatively small systems, the achievable economies-of-scale are exaggerated. Therefore, the true energy-related BOP cost will likely be well above \$9/kWh.

Summarizing, from the three Bechtel estimates, the estimated energy-related BOP cost should definitely fall between \$9/kWh and \$47/kWh (mid-1988\$). Both the PSE&G and the Bechtel (SCE) estimates fall within this range, as expected. This adds confidence to both of these estimates. Table 3.6 presents all the normalized estimates. The nominal input estimate was taken as \$45.1/kWh, the PSE&G value. A range estimate of \$33 - 49/kWh was based on the low and high Bechtel/SCE estimates.

TABLE 3.6. Conventional Lead-Acid Battery Energy-Related Balance-of-Plant Cost: Summary of Normalized Estimates (mid-1988\$)

Source	Nominal	Range
PSE&G (Abraham et al. 1985a)	\$45.1/kWh	--
Bechtel (SCE) (Eckroad et al. 1986)	\$33/kWh	\$33 - 49/kWh
Bechtel (6-MWh) (Bechtel 1982)	\$47/kWh	--
Bechtel (curve fit) (Bechtel 1982)	\$9/kWh	--
Input Nominal Estimate: \$45.1/kWh		
Input Range Estimate: \$33 - \$49/kWh		

Using a parametric cost curve (Stolte and Eckroad 1985) and engineering judgment, the energy-related BOP unit-cost for a 50-MWh system was estimated as 20% more than the comparable unit cost for a 100-MWh system. The unit cost of the energy-related BOP for a 30-MWh system was estimated as costing 60% more than 100-MWh system. Working from the nominal 100-MWh energy-related BOP estimate of \$45.1/kWh, estimates for the 50-MWh and 30-MWh systems of \$54.1/kWh and \$72.2/kWh (1988\$) result, respectively.

3.2.1.4 Power-Related Balance-of-Plant Cost

The power-related BOP cost inputs were based on three sources: PSE&G (Abraham et al. 1985a) and three Bechtel estimates. PSE&G projected the installed cost for the converter, interfaces, and controls as \$103.82/kW (1983\$) based on the use of multiple 2-MW converters. After escalation, a cost of \$121/kW (mid-1988\$) is obtained. Many conceptual plant designs use multiple small converters as opposed to one larger converter for efficiency and reliability. The first Bechtel source (Eckroad et al. 1986) was based on current technology and production levels. This estimate was \$247/kW (mid-1988\$), and was used only as a guide to future prices. The second source was a Bechtel-developed parametric curve (Stolte and Eckroad 1984), which projected the cost of an advanced, mass-produced converter as \$110-210/kW (1982\$). The low-end value corresponds to \$133/kW in mid-1988\$. The third and final Bechtel source (Eckroad 1985) projected the cost of mass-produced converter systems for a 4.7-MWh, 6-MW and 1.6-MWh, 2-MW plants as \$188/kW (1988\$). Because of the small plant size, this estimate of \$188/kW may be slightly high for a 100-MWh plant. Each of these power-related BOP cost estimates is summarized in Table 3.7. The nominal input estimate selected was PSE&G's (Abraham et al. 1985a) estimate, \$121/kW (mid-1988\$). The appropriate range was judged to be from \$121/kW to Bechtel's high-end estimate of \$188/kW (the cost of a converter system using today's technology, a small converter size and mass production).

For the sensitivity cases, the figure-of-merit is the cost difference between 10-MW and 20-MW systems. Assuming all power-related BOP costs would scale at the same rate as converter costs, the cost versus size curve (Stolte and Eckroad 1984) was used as a relative scaling base. From the curve it

TABLE 3.7. Conventional Lead-Acid Battery Power-Related
Balance-of-Plant Cost: Summary of Normalized
Estimates (mid-1988\$)

<u>Source</u>	<u>Estimate</u>
PSE&G (Abraham et al. 1985a)	\$121/kW
Bechtel (SCE) (Eckroad et al. 1986)	\$247/kW
Bechtel (Stolte and Eckroad 1984)	\$133/kW
Bechtel (Eckroad 1985)	\$188/kW

Input Nominal Estimate: \$121/kW

Input Range Estimate: \$121 - \$188/kW

appears a 10-MW unit costs approximately fifteen percent more per kilowatt than a 20-MW unit. Therefore, the unit cost of a 10-MW power-related BOP is estimated as 15% greater than \$121/kW or \$139/kW.

3.2.1.5 Net Salvage Value

The net salvage value for the conventional lead-acid system includes battery removal cost and a scrap credit. One salvage scenario (Bechtel 1982) suggested that cells could be rebuilt, but for simplicity, a straight scrap credit has been assumed. Based on Bechtel's (1982) scrap scenario, the cost of shipping to the scrap facility was considered negligible, because lead reclaiming facilities are already widespread. Based on the same Bechtel document, salvage by scrap was estimated to range from 6-17% of the purchase cost. The nominal scrap value was taken as the average of the range, 12 percent. Battery removal cost was estimated as 60% of installation cost.

Using the base information above, salvage value nominal and range estimates were determined as follows. The nominal salvage value is the total of the nominal scrap credit (12%) times the nominal battery purchase cost (\$134/kWh), less 60% of the nominal installation (\$17.5/kWh). This yields a nominal salvage value of \$5.6/kWh (mid-1988\$). The high range (high system life-cycle cost) estimate is the total of the low scrap credit (6%) times the high battery purchase cost (\$143/kWh), less 60% of the high installation cost (\$21/kWh). This calculation yields a high-end salvage value of \$-4/kWh (mid-1988\$). The low-end (low system life-cycle cost) salvage value is estimated in a similar manner. The product of the scrap credit [high credit value

(17%) times low purchase cost (\$93/kWh)] less the battery removal cost [60% of the low installation cost (\$17/kWh)] results in a low-end scrap value of \$5.6/kWh. The nominal estimate of \$5.6/kWh was used in all the sensitivity cases. Table 3.8 summarizes the salvage cost estimates.

3.2.1.6 Operating and Maintenance Cost

O&M cost estimates are quite scarce and fragmented. The data evaluated came from six sources. The first source, a 1982 Gould, Inc. study (Ramsay and Edgecomb 1982), estimated O&M costs for 50-kWh, 10-kW and 2-MWh, 400-kW systems. The second source, a Bechtel (1982) report presented O&M costs of four systems of which the largest was 2-MWh. While both sources may provide reasonable estimates for small systems, they can't be applied directly to large systems. They were used as a general guide to possible O&M plant functions. Bechtel's cost estimate of the SCE plant (Eckroad et al. 1986) contains O&M costs for a large-scale system (50 MWh, 10 MW). However, Bechtel's fixed O&M estimate is an order-of-magnitude higher than three other estimates. Because Bechtel did not have any supporting documentation, this estimate was not used. Bechtel's variable O&M costs of 0.14 to 0.42 cents/kWh were considered reasonable. The remaining three sources provided costs but no supporting data. The sources included EPRI's Technical Assessment Guide (1986), an Energy Research Corporation (ERC) presentation (1986a), and an economic comparison done by EPRI.^(a) Averaging the source data, variable costs of 0.34 cents/kWh (0.38, 1988\$) and fixed costs of \$0.98/kW-yr (1.10, 1988\$) were calculated. The range of variable costs was set as 0.14-0.42 cents/kWh (0.16-0.47, 1988\$). These values were converted to dollars per year based on the average discharge hours per cycle and system size. The

TABLE 3.8. Conventional Lead-Acid Battery Salvage Value:
Summary of Normalized Estimates (mid-1988\$)

Input Nominal Estimate: \$5.6/kWh

Input Range Estimate: \$5.6 - (-4)/kWh

(a) "Screening Curve Analysis." 1986. Presentation by R. Schainker, Electric Power Research Institute, Palo Alto, California.

nominal estimate was the basis for the sensitivity comparisons. The results are enumerated in Table 3.9. The nominal estimate was taken as the average of the estimated variable costs plus the fixed cost estimate.

3.2.1.7 Cycle Life

There is considerable variation in cycle life estimates. Cycle life data are usually presented as cycles achieved, life expectation, or projected cycle life. Projected or expected cycle lives obviously entail a greater level of uncertainty than results already achieved in the laboratory. Table 3.10 presents lead-acid cycle lives from source documents. A nominal cycle life of 2000 cycles was chosen. This value should be achievable as experience is gained in the near term. Cells are currently warranted from 1500-2000 cycles (Eckroad et al. 1986). Although warranties are often written for periods longer than the actual life with coverage on a pro-rated-new-battery-discount-basis, this offers an incentive for purchasers to return to the same manufacturer. To evaluate life-cycle cost at a range of cycle life values, sensitivity cases were run assuming 3000, 3500, and 4000 cycles in the battery's lifetime.

TABLE 3.9. Conventional Lead-Acid Battery Operating and Maintenance Cost: Summary of Normalized Estimates (mid-1988\$)

<u>System Size</u>	<u>Average Discharge Hours Per Cycle</u>	<u>Fixed</u>	<u>O&M Cost, \$/yr Variable</u>
100-MWh, 20-MW	5.0	\$22,000	\$40,000-\$117,500
50-MWh, 10-MW	5.0	\$11,000	\$47,500
30-MWh, 10-MW	3.0	\$11,000	\$28,500

Input Nominal Estimate: \$117,000/yr

Input Range Estimate: \$62,000 - \$137,500/yr

TABLE 3.10. Conventional Lead-Acid Battery Cycle Life Summary

<u>Source</u>	<u>Cycle Life</u>	<u>Certainty</u>
Podder et al. (1981)	4000	Ultimate projection
Podder et al. (1981)	1800	Achieved
Stolte (1982)	1000-3000	Expected
Ferrell et al. (1977)	2000	Expected
Bechtel (1982)	1500-2000	Expected
PSE&G (Abraham et al. 1985a)	1500-2000	Expected

SEALED LEAD-ACID
BATTERY

3.2.2 Sealed Lead-Acid Battery

Similar in nature to the conventional lead-acid battery, the sealed lead-acid battery offers reduced operating costs and higher efficiency in exchange for a higher capital cost and shorter life. Information pertaining to the sealed battery is limited for large systems; therefore, most of the estimates presented were derived by scaling corresponding elements of the conventional lead-acid battery system. The degree to which cost elements were scaled up or down was derived by comparing sealed and conventional system cost estimates for systems of the same size. Table 3.11 presents the complete life-cycle economics and performance characteristics of the sealed lead-acid cell.

TABLE 3.11. Sealed Lead-Acid Battery System Life-Cycle
Economics: Baseline Case

Cycle Life: 1500
Cell Efficiency: 0.75
System Efficiency: 0.66

Nominal Estimate (mid-1988\$)

Battery Purchase Cost (\$/kWh): 151
Battery Installation (\$/kWh): 28.5
Energy-Related Balance-of-Plant (\$/kWh): 36.1
Power-Related Balance-of-Plant (\$/kWe): 121
Net Salvage Value (\$/kWh): 5.6

Annual Operating & Maintenance Costs (\$/yr): 47,000

Levelized Output Cost: 36.8 cents/kWh of energy retrieved

Range of Estimates (mid-1988\$)

Battery Purchase Cost (\$/kWh): 105 - 177
Battery Installation (\$/kWh): 28 - 33
Energy-Related Balance-of-Plant (\$/kWh): 26 - 39
Power-Related Balance-of-Plant (\$/kWe): 121 - 188
Net Salvage Value (\$/kWh): 5.6 - (-4)

Annual Operating & Maintenance Costs (\$/yr): 32,500 - 52,900

Levelized Output Cost: 28.4 - 44.1 cents/kWh of energy retrieved

Conventional lead-acid batteries are more technologically mature than their sealed counterparts. It will be interesting to track the cost and performance of the sealed battery as it matures to see if its capital cost can be reduced or other battery characteristics improved, thus giving it an advantage over the conventional lead-acid battery. At this point, it is not clear that the sealed system would outperform a conventional lead-acid battery system on a life-cycle cost basis. Table 3.12 presents the inputs and results to the sensitivity analyses performed on the nominal system estimate for the sealed lead-acid battery system. The sources upon which the estimates were based are listed in Table 3.13.

3.2.2.1 Battery Purchase Cost

Sealed lead-acid battery cost estimates are limited in availability. Therefore, development of the sealed battery cost estimate is based on scaling the cost estimate developed for the conventional lead-acid battery. The factor by which to scale the conventional lead-acid battery cost estimate was determined by comparing two somewhat older Gould, Inc. estimates (Ramsay and Edgecomb 1982) that were developed using the same methodology. One of the cost estimates is for a conventional lead-acid battery, the other for a sealed system lead-acid battery.

After adjusting Ramsay's conventional lead-acid battery cost estimate to a lead cost of 20 cents per pound and the 1984 version of the George Guidelines (the ground rules of this study), a normalized cost of \$81.93/kWh (1983\$) results. Escalating to mid-1988\$ yields a cost of \$94.22/kWh. The sealed cost estimate was adjusted using the same procedure to yield a normalized cost of \$106.78/kWh (1988\$). The difference between the sealed battery cost estimate and the conventional lead-acid battery cost estimate is 13%. While these estimates are somewhat older and were not considered in the development of the conventional lead-acid battery cost estimate presented in Section 3.2.1, they provide useful data with respect to the relative cost of the two technologies.

TABLE 3.12. Sealed Lead-Acid Battery System Life-Cycle Economics:
Sensitivities

<u>Variable</u>	<u>Baseline Value</u>	<u>New Value</u>	<u>New Levelized Output Cost (cents/kWh)</u>	<u>Percent Change</u>
Discount Rate	4.2%	3% 5% 6% 7%	36.0 37.4 38.2 39.2	-2% +1.5% +4% +6.5%
Cycle Life	1500	2000 2500 3000	31.1 26.6 25.6	+15% -28% -30%
Charging Cost	\$0.025	\$0.01 \$0.015 \$0.020 \$0.030	34.5 35.3 36.0 37.5	-6% -4% -2% +2%
System Size: 50-MWh, 10-MW			37.4	+2%
Energy-Related BOP	--	\$43.3/kWh	--	--
Power-Related BOP	--	\$139/kW	--	--
Annual O&M	--	\$23,500	--	--
System Size: 30-MWh, 10-MW			39.5	+7%
Energy-Related BOP	--	\$57.8/kWh	--	--
Power-Related BOP	--	\$139/kW	--	--
Annual O&M	--	\$18,500	--	--
Cell Efficiency	0.50	0.80 0.85	34.2 32.4	-7% -12%

As qualitative check on the 13% cost difference, several commercially available sealed batteries intended for uninterruptable power supply (UPS) and communications applications were compared to similar conventional batteries (Johnson Controls 1986). Generally, the sealed batteries ranged from approximately equal in cost to twenty percent more expensive than their conventional counterparts. The center of this range is roughly 15%, which is quite close to the 13% calculated from the Ramsay data. While this

TABLE 3.13. Bibliography of Key Sources Used to Evaluate the Sealed Lead-Acid Battery Technology

1. Abraham, J., et al. 1985a. Technical and Economic Assessments of Electrochemical Energy Storage Systems: Lead-Acid Battery Plant Description, Cost Estimate, Credible Accident and Efficiency Assessment.
2. Abraham, J., et al. 1985c. Technical and Economic Assessments of Electrochemical Energy Storage Systems: Topical Report on the Potential for Savings in Load-Leveling Battery and Balance-of-Plant Costs.
3. Bechtel Group, Inc. 1982. Study of Installed and Life-Cycle Costs for Batteries in Photovoltaic Power Systems.
4. Eckroad, S. W. 1985. Design and Cost of Standardized Lead-Acid Battery Systems for Utility Energy Management.
5. Eckroad, S. W., et al. 1986. "Conceptual Design and Cost Estimate: 10 MW Utility Battery Facility."
6. Electric Power Research Institute. 1986. Technical Assessment Guide.
7. Energy Research Corporation. 1986a. "Development of Zinc-Bromide Batteries for Utility Applications."
8. Ferrell, D. T., et al. 1977. Design and Cost Study for State-of-the-Art Lead-Acid Load-Leveling and Peaking Batteries.
9. Johnson Controls. 1986. Globe Stationary Battery Catalog.
10. Podder, A., et al. 1981. Data Base on Batteries, Power-Conditioning Equipment, and Photovoltaic Arrays.
11. Ramsay, G. B., and A. Edgecomb. 1982. Comparison of Prices for Conventional and Advanced Storage Batteries for Residential, Commercial and Utility Applications.
12. Schainker, R. 1986. "Screening Curve Analysis."
13. Stolte, W. J. 1982. Feasibility Assessment of Customer-Side-of-the-Meter Applications for Battery Energy Storage.
14. Stolte, W. J., and S. W. Eckroad. 1984. Economic Analysis of Specific Customer Side-of-the-Meter Applications for Battery Energy Storage, Volume I: Study Results.
15. Stolte, W. J., and S. W. Eckroad. 1985. Updated Cost Estimate and Benefit Analysis of Customer-Owned Battery Energy Storage.

qualitative check doesn't verify the ratio calculated from the Ramsay data, it does increase the confidence in this number.

On these bases, the cost estimates presented in Section 3.2.1 for the conventional lead-acid battery were increased by 13% to yield cost estimates for the sealed lead-acid battery. The nominal conventional lead-acid battery cost estimate is \$134/kWh (1988\$). The range of cost estimated is \$93 to \$143/kWh. Adding the 13% yields a nominal cost estimate for the sealed lead-acid battery of \$151/kWh and a range of \$105/kWh to \$177/kWh.

For evaluating the life-cycle costs of 50-MWh, 10-MW and 30-MWh, 10-MW systems, the unit battery purchase cost was kept equivalent to the nominal cost estimate for the 100-MWh, 20-MW.

3.2.2.2 Shipping and Installation Cost

Basically, installation of the sealed lead-acid battery is the same as the conventional lead-acid battery. One advantage of a sealed lead-acid battery system over some conventional lead-acid batteries is that acid does not need to be added to the sealed cells during installation and air agitation and automatic watering tubes do not need to be connected to sealed cells. (Note, however, that some conventional cells are shipped filled with acid.) However, These components are not the major cost drivers during installation. With respect to shipping, the lead-acid technologies with high energy densities may have a very slight advantage in shipping costs, but again, this is a minor point. Therefore, shipping and installation is assumed to be the same for both technologies at \$28.5/kWh (1988\$) with a range of \$28/kWh to \$33/kWh.

Shipping and installation costs were assumed constant on a unit-cost basis for 100-MWh, 50-MWh, and 30-MWh systems.

3.2.2.3 Energy-Related Balance-of-Plant Cost

Generally, the design of a sealed lead-acid battery energy-related BOP is the same as the BOP for conventional lead-acid plants. The difference is due to the lack of open lead-acid cells. Ventilation costs are reduced or eliminated, paint need not be acid resistant, gas detection systems are not required, nor are make-up water or air-agitation systems.

Because no large-scale sealed lead-acid battery BOP cost data were available, an estimate for a 2.01-MWh system was evaluated. The estimated cost is \$160,071 (1980\$). Comparable costs for a conventional lead-acid system are \$199,505 (1980\$). Based on this limited data, the sealed lead-acid system costs 20% less than its conventional counterpart. On this basis, the nominal and range estimates developed for the conventional lead-acid BOP cost estimate were scaled down by 20% to yield estimates for the sealed lead-acid battery energy-related BOP. Table 3.14 presents the conventional and derived sealed cost estimates.

For the sensitivity evaluation, the cost relationships developed for the conventional lead-acid battery system were applied. That is, the energy-related BOP for a 50-MWh system costs 20% more than a 100-MWh system on a unit-cost basis. For a 30-MWh system, costs are 60% more. Based on the nominal estimate, this yields cost estimates for the 50-MWh and 30-MWh sealed lead-acid battery energy-related BOP of \$43.3/kWh and \$57.8/kWh.

3.2.2.4 Power-Related Balance-of-Plant Cost

The power-related BOP for a sealed lead-acid battery storage facility is no different than that for a conventional lead-acid battery storage system. Therefore, the sealed lead-acid battery power-related BOP is estimated to cost \$121/kW with a range of \$121/kW to \$188/kW, the same as the estimates for the conventional lead-acid system. The same unit cost used for the conventional lead-acid battery cost estimates of 50-MWh, 10-MW and 30-MWh, 10-MW systems are applicable to the sealed systems. This unit cost is \$139/kW.

TABLE 3.14. Sealed Lead-Acid Battery Energy-Related
Balance-of-Plant Cost: Summary of
Normalized Estimates (mid-1988\$)

	<u>Conventional</u>	<u>Sealed</u>
Input Nominal Estimate	\$45.1/kWh	\$36.1/kWh
Input Range Estimate	\$33 - 49/kWh	\$26 - 39/kWh

3.2.2.5 Net Salvage Value

The net salvage value for the sealed lead-acid system includes battery removal cost and a scrap credit. It was assumed the net salvage value of a sealed lead-acid battery is equivalent to a conventional lead-acid battery on a dollar-per-kWh basis. Table 3.15 summarizes the salvage cost estimates. During the development of sensitivity cases, the nominal estimate of \$5.6/kWh was used.

3.2.2.6 Operating and Maintenance Cost

O&M cost estimates for load-leveling sized sealed lead-acid battery systems were not available. To develop O&M cost estimates, one of the factors considered was relative difference between O&M costs for conventional lead-acid and sealed lead-acid battery systems. The basis for estimating the relative difference was two sources: Gould, Inc. (Ramsay and Edgecomb 1982) and Bechtel (1982).

For a 2.01 MWh system Bechtel estimated annual O&M costs at \$0.54/kWh-of-capacity (mid-1988\$) for a sealed battery system and \$2.06/kWh-of-capacity for a conventional battery system. The ratio of these two costs is 3.8. For a 50-kWh system, Gould, Inc. estimated the sealed battery annual O&M costs at \$19/kWh-of-capacity (mid-1988\$) and the conventional annual O&M costs at \$66/kWh-of-capacity (mid-1988\$). The corresponding ratio between these two costs is 3.5. With only two data points for small systems, it is quite difficult to make a good determination of the appropriate annual O&M cost of load-leveling systems. Because the Gould, Inc. estimate is for such a small system, 50-kWh, it was not used. However, it does add some confidence to the overall estimate because it differs by only 10% from the other cost ratio calculated. Eliminating the Ramsay estimate leaves the 3.8 ratio factor calculated from the Bechtel data.

TABLE 3.15. Sealed Lead-Acid Battery Net Salvage Value:
Summary of Normalized Estimates (mid-1988\$)

Input Nominal Estimate: \$5.6/kWh

Input Range Estimate: \$5.6 - (-4)/kWh

To complete the cost estimate for the sealed load-leveling system, the variable cost estimates developed for the conventional lead-acid battery load-leveling system were scaled down by the factor of 3.8. Only the variable side was scaled, because it represents the portion of the plant O&M related to cell maintenance. Table 3.16 presents the conventional system O&M cost estimates, and Table 3.17 presents the derived sealed O&M cost estimates.

3.2.2.7 Cycle Life

Currently, the cycle life of the sealed battery is significantly lower than that of the conventional lead-acid cell; however, they are much more technologically immature than the conventional cells, and cycle life is expected to increase. A nominal cycle life of 1500 was chosen based on engineering judgment. Table 3.18 presents some relevant data based on the

TABLE 3.16. Conventional Lead-Acid Battery Operating and Maintenance Costs: Summary of Normalized Estimates (mid-1988\$)

System Size	Average Discharge Hours Per Cycle	O&M Cost, \$/yr	
		Fixed	Variable
100-MWh, 20-MW	5.0	\$22,000	\$40,000 - \$117,500
50-MWh, 10-MW	5.0	\$11,000	\$47,500
30-MWh, 10-MW	3.0	\$11,000	\$28,500

Input Nominal Estimate: \$117,000/yr

Input Range Estimate: \$62,000 - 137,500/yr

TABLE 3.17. Sealed Lead-Acid Battery Operating and Maintenance Costs: Summary of Normalized Estimates (mid-1988\$)

System Size	Average Discharge Hours Per Cycle	O&M Cost, \$/yr	
		Fixed	Variable
100-MWh, 20-MW	5.0	\$22,000	\$10,500 - \$30,900
50-MWh, 10-MW	5.0	\$11,000	\$12,500
30-MWh, 10-MW	3.0	\$11,900	\$7,500

Input Nominal Estimate: \$47,000/yr

Input Range Estimate: \$32,500 - 52,900/yr

TABLE 3.18. Conventional Lead-Acid Battery Cycle Life Summary

<u>Source</u>	<u>Cycle Life</u>	<u>Certainty</u>
Podder et al. (1981)	4000	Ultimate Projection
Podder et al. (1981)	1800	Achieved
Stolte (1982)	1000-3000	Expected
Ferrell et al. (1977)	2000	Expected
Bechtel (1982)	1500-2000	Expected
PSE&G (Abraham et al. 1985a)	1500-2000	Expected

conventional lead-acid battery. To evaluate life-cycle cost at a range of cycle life values, sensitivity cases were run assuming 2000, 2500, and 3000 cycles in the battery's lifetime.

3.2.2.8 System Efficiency

Cell efficiency is assumed to be 2-1/2% higher than that for the conventional lead-acid battery. This higher cell efficiency boosts the system efficiency slightly. Table 3.19 presents the data upon which the system efficiency was based.

TABLE 3.19. Conventional Lead-Acid Battery System and Component Efficiencies

<u>Source</u>	<u>Roundtrip Efficiency</u>	<u>Component</u>
Podder (1981)	0.75	cell
Bechtel (1982)	0.75 - 0.80	cell
Bechtel (Stolte 1982)	0.50 - 0.85	system
Ferrell (1977)	0.85	cell
Bechtel (SCE) (Eckroad et al. 1986)	0.90	converter
Bechtel (SCE) (Eckroad et al. 1986)	0.75	cell
Bechtel (SCE) (Eckroad et al. 1986)	0.664	system
PSE&G (GNB) (Abraham et al. 1985a)	0.70	cell
PSE&G (Abraham et al. 1985a)	0.90	converter
PSE&G (Abraham et al. 1985a)	0.98	auxiliaries
PSE&G (Abraham et al. 1985a)	0.617	system

$$\begin{aligned}
 \text{Nominal Input Conventional System Efficiency} &= (\text{cell})(\text{converter})(\text{auxiliaries}) \\
 &= (0.725)(0.9)(0.98) \\
 &= 0.64
 \end{aligned}$$

$$\begin{aligned}
 \text{Nominal Input Sealed System Efficiency} &= (\text{cell})(\text{converter})(\text{auxiliaries}) \\
 &= (0.75)(0.9)(0.98) \\
 &= 0.66
 \end{aligned}$$

ZINC-BROMINE
BATTERY

3.2.3 Zinc-Bromine Battery

The zinc-bromine battery is one of the primary candidates for load-leveling. The low estimate represents technology primarily developed by ERC, while the high estimate is based primarily on older Exxon technology. The nominal estimate represents ERC technology with some increases assessed for uncertain cost components.

O&M cost information is extremely ill-defined. Information related to cell stack replacement, in particular, is vague. It will be important to develop detailed O&M scenarios to improve zinc-bromine LCC estimates.

The complete performance characteristics and life-cycle economics of the zinc-bromine battery are presented in Table 3.20. Table 3.21 presents the results of sensitivity cases. The sources used to develop the zinc-bromine LCC estimates are listed in Table 3.22.

TABLE 3.20. Zinc-Bromine Battery System Life-Cycle Economics: Baseline Case

Cycle Life: 2500
Cell Efficiency: 0.75
System Efficiency: 0.64

Nominal Estimate (mid-1988\$)

Battery Purchase Cost (\$/kWh): 83
Battery Installation (\$/kWh): 18.8
Energy-Related Balance-of-Plant (\$/kWh): 55
Power-Related Balance-of-Plant (\$/kWe): 121
Net Salvage Value (\$/kWh): 4.9

Annual Operating & Maintenance Costs (\$/yr): 64,900

Levelized Output Cost: 20.1 cents/kWh of energy retrieved

Range of Estimates (mid-1988\$)

Battery Purchase Cost (\$/kWh): 75 - 117
Battery Installation (\$/kWh): 2.6 - 21.2
Energy-Related Balance-of-Plant (\$/kWh): 29.5 - 88
Power-Related Balance-of-Plant (\$/kWe): 116 - 188
Net Salvage Value (\$/kWh): 39.4 - 0.8

Annual Operating & Maintenance Costs (\$/yr): 64,900 - 84,700

Levelized Output Cost: 13.3 - 27.4 cents/kWh of energy retrieved

TABLE 3.21. Zinc-Bromine Battery System Life-Cycle Economics: Sensitivities

<u>Variable</u>	<u>Baseline Value</u>	<u>New Value</u>	<u>New Levelized Output Cost (cents/kWh)</u>	<u>Percent Change</u>
Discount Rate	4.2%	3%	19.2	-5%
		5%	20.8	+3%
		6%	21.7	+8%
		7%	22.7	+13%
Cycle Life	2500	1500	26.0	+29%
		2000	22.7	+13%
		3000	19.5	-3%
Charging Cost	\$0.025	\$0.01	17.8	-12%
		\$0.015	18.6	-8%
		\$0.020	19.3	-4%
		\$0.030	20.9	+4%
System Size: 50-MWh, 10-MW			21.0	+4.5%
Energy-Related BOP		\$66/kWh	--	--
Power-Related BOP		\$139/kW	--	--
Operating and Maintenance		\$32,400/yr	--	--
System Size: 30-MWh, 10-MW			23.5	+17%
Energy-Related BOP		\$88/kWh	--	--
Power-Related BOP		\$139/kW	--	--
Operating and Maintenance		\$21,800/yr	--	--
Cell Efficiency	0.75	0.73	20.8	+3%
		0.77	19.5	-3%

3.2.3.1 Battery Purchase Cost

Trying to establish a strong estimate on the zinc-bromine battery is difficult, because most of the available data is from the same developer, ERC (previously Gould, Inc.). This makes the general procedure of establishing credibility through comparison to estimates prepared by other developers difficult.

In 1986, cost estimates for three sizes of ERC-designed zinc-bromine modules became publicly available. The modules have basically the same design, but the stacks and associated components have been scaled up. All these estimates were directly escalated to mid-1988\$, because not enough

TABLE 3.22. Bibliography of Key Sources Used to Evaluate the Zinc-Bromine Battery Technology

1. Abraham, J., et al. 1985c. Technical and Economic Assessments of Electrochemical Energy Storage Systems: Topical Report on the Potential for Savings in Load-Leveling Battery and Balance-of-Plant Costs.
2. Abraham, J., et al. 1985d. Technical and Economic Assessments of Electrochemical Energy Storage Systems: Zinc-Bromine Battery Plant Description, Cost Estimate, Credible Accident and Efficiency Assessment.
3. Bechtel Group, Inc. 1982. Study of Installed and Life-Cycle Costs for Batteries in Photovoltaic Power Systems.
4. Bellows, R., et al. 1983a. Development of a Circulating Zinc-Bromine Battery: Phase II - Final Report
5. Bellows, R., et al. 1983b. Development of a Circulating Zinc-Bromine Battery: Phase I - Final Report.
6. Bellows, R., et al. 1983c. "Zinc-Bromine Batteries for Bulk Energy Storage."
7. Eckroad, S. W., et al. 1986. "Conceptual Design and Cost Estimate: 10-MW Utility Battery Facility."
8. Energy Research Corporation (ERC), Flour Engineers, Inc. 1983. Design Study of 100-kW, 500-kWh Zinc-Bromine Battery System.
9. Energy Research Corporation. 1986a. "Development of Zinc-Bromine Batteries for Utility Applications."
10. Energy Research Corporation. 1986b. Zinc Bromide Battery Development.
11. Podder, A., et al. 1981. Data Base on Batteries, Power-Conditioning Equipment, and Photovoltaic Arrays.
12. Putt, R. A., et al. 1980. Development of Zinc-Bromine Batteries for Utility Energy Storage.
13. Ramsay, G. B., and A. Edgecomb. 1982. Comparison of Prices for Conventional and Advanced Storage Batteries for Residential, Commercial and Utility Applications.

detail was available to put them in the format of the George guidelines. Table 3.23 presents the adjusted ERC cost estimates.

These are considered preliminary numbers by ERC; however, there do appear to be some particularly remarkable economies. Structural steel, for example, dropped from \$17/kWh to \$1.2/kWh over the size change from 2.0-MWh to 4.2-MWh (see Appendix B.3 for details). Some of the other economies-of-scale claimed are not so disconcerting.

PSE&G evaluated the ERC 1-MWh design and "molded" it into the form of the George Guidelines. After normalization to this study's ground rules, the resulting cost was \$176/kWh (1988\$). This estimate is 11% higher than the corresponding ERC cost estimate.

PSE&G with Solvo-Tek Associates (Abraham et al. 1985d) also evaluated a 20-kWh battery module developed by Exxon. Exxon's estimated cost was \$56/kWh (1988\$), while PSE&G deemed \$112-\$140/kWh more appropriate. Considering the self-contained nature of Exxon's module, which reduces possible economies-of-scale cost saving and ERC's cost range (\$75-\$159/kWh), PSE&G's opinion of the battery's cost was assessed as more realistic.

The low estimate was taken as the ERC estimate for the 4.2-MWh module of \$75/kWh (1988\$). The nominal estimate was prepared by adding 12% to the low estimate yielding \$83/kWh. The 11%-factor is the best quantification available of the cost difference between ERC's estimating methodology and the normalizing methodology used in this study. The high estimate was taken as the average of PSE&G's range estimate for the Exxon design, \$117/kWh. Table 3.24 summarizes the final cost estimates. The nominal unit cost was used for both of the sensitivity cases performed.

TABLE 3.23. Adjusted ERC Zinc-Bromine Module Cost Estimates (1988\$)

	<u>Stacks Per Module</u>	<u>Electrode Size</u>	<u>Module Cost \$/kWh (1988\$)</u>
4.2-MWh module	40	6 ft ²	\$ 75/kWh
2.0-MWh module	30	4 ft ²	\$102/kWh
1.0-MWh module	30	2 ft ²	\$159/kWh

3.2.3.2 Shipping and Installation Cost

There is some conflict in the zinc-bromine shipping cost estimates; however, this component is not a major cost driver. Bechtel (1982) estimated shipping costs as \$8.78/kWh (1988\$) for Gould, Inc. technology, (forerunner to ERC). A second source (ERC, Fluor 1983) estimated shipping costs for a 500-kWh ERC module to be used at the BEST facility as \$4800 (Jan. 1983\$). This is equivalent to \$11.2/kWh (1988\$). A third ERC source (1986) estimated shipping costs for its 1-MWh and 2-MWh units as \$2.2/kWh (1988\$). This third estimate is somewhat surprising, because the 1- and 2-MWh units weigh 20% less on a kWh-basis than the 500-kWh ERC BEST unit, but shipping costs are 80% lower. ERC's cost estimate for its 4.2-MWh system estimate is assumed to include shipping costs, but it is not detailed and thus could not be used for developing shipping cost estimates.

The low estimate was taken as \$2.2/kWh (1988\$), ERC's 1986 estimate. As the high estimate, the \$11.2/kWh (1988\$) BEST facility unit cost was used. This may include extra costs for this special, one-time shipment, which could cause the estimate to be high. Finally, the Bechtel estimate of \$8.80/kWh was used as the nominal cost estimate.

Installation should not be exceedingly difficult, because capacity is sold in 4.2-MWh modules. ERC estimates installation for a 1- or 2-MWh unit would be \$0.4/kWh (1988\$). This equals \$400 for a 1-MWh unit, which seems somewhat low. Typically, heavy modular objects can be craned in very quickly but require significant leveling and connecting time. Four hundred dollars is only one manday. Using Gould, Inc. technology, Bechtel (1982) estimated \$9.3B/kWh (1980\$) for a 6.24-MWh plant. This appears on the high side.

TABLE 3.24. Zinc-Bromine Battery Purchase Cost:
Summary of Normalized Estimates (1988\$)

Input Nominal Estimate: \$83/kWh

Input Range Estimate: \$75 - \$117/kWh

For the low estimate, the ERC estimate of \$0.4/kWh was used. The Bechtel estimate of \$10/kWh (1988\$) was used as both the high and nominal estimates. Table 3.25 summarizes the shipping and installation cost estimates.

3.2.3.3 Energy-Related Balance-of-Plant Cost

The energy-related BOP is another zinc-bromine system component for which cost differences exist. ERC estimates the total cost for a 100-MWh system using 20-MWh modules at \$24.4/kWh (1982\$) (\$29.5/kWh; 1988\$). Of this, \$19.7/kWh (1982\$), or 81% of the total cost, is attributed to the required enclosures, which are estimated at \$20/ft² (1982\$).

A second ERC estimate (ERC 1986b) estimates only \$9.48/kWh (1988\$) for the energy-related BOP of a 50-MWh system using 4.2-MWh modules. In this case ERC estimates \$2.28/kWh (1988\$) for buildings. Based on the 10,000 square feet of enclosure ERC designed for, the enclosure cost is \$11/ft² (1988\$). This is 50% of ERC's earlier enclosure estimate. Without an explanation (which is not given with the estimates), these numbers are classed as uncertain.

PSE&G's evaluation of the energy-related BOP paints a significantly different picture for a 100-MWh system. It estimates a cost of \$47.1/kWh (1983\$) for a plant constructed with 1-MWh modules stacked two high. Escalating to 1988-dollars yields \$55/kWh. Without stacking, BOP costs reach \$88/kWh (1988\$).

For the nominal estimate, the PSE&G stacked system cost estimate of \$55/kWh (1988\$) was used. This estimate is not based on the most recent module designs but is presented in more detail than any other zinc-bromine BOP cost estimate. The unstacked PSE&G design was used as the high-end cost estimate of \$88/kWh (1988\$). The low estimate was taken as \$29.5/kWh (1988\$) based upon ERC's estimate of a 100-MWh facility using 1-MWh modules. The

TABLE 3.25. Shipping and Installation Cost: Summary of Normalized Estimates (1988\$)

Input Nominal Estimate: \$18.8/kWh

Input Range Estimate: \$2.6 - \$21.2/kWh

second ERC estimate of \$9.48/kWh, although not used here, does deserve independent investigation. If it is a well-founded estimate, zinc-bromine systems could have a major cost advantage over some other systems in the energy-related BOP.

Although not the ideal relationships, the 20% and 60% factors developed for the lead-acid battery energy-related BOP were applied to the 100-MWh BOP unit costs to yield 50-MWh and 30-MWh BOP unit costs. These estimates were used to make sensitivity runs. Table 3.26 summarizes all the final energy-related BOP cost estimates.

3.2.3.4 Power-Related Balance-of-Plant Cost

The only data available that discussed quantitative differences between the power-related BOP for the zinc-bromine system and other systems was prepared by PSE&G (Abraham et al. 1985d). PSE&G estimated zinc-bromine BOP costs as \$116/kW (1988\$), while estimating the lead-acid battery system BOP costs as \$121/kW (1988\$). The reasons stated by PSE&G for the difference are that the zinc-bromine system can handle higher voltages (2500 Vdc versus 1000 Vdc for the lead-acid battery system) and a larger converter is used (5-MW units instead of 2-MW units). PSE&G believes that both differences give a cost advantage to the zinc-bromine battery system. There is information to the contrary, which suggests that the zinc-bromine power-related BOP should be no different than that of a lead-acid power-related BOP.

The ratio of the PSE&G estimates is 1.04. This ratio was applied to generate a low estimate. The high and sensitivity cost estimates for the zinc-bromine battery system were assumed the same as that used for the conventional lead-acid battery system. The developed estimates are summarized in Table 3.27.

TABLE 3.26. Energy-Related Balance-of-Plant Costs: Summary of Normalized Estimates (1988\$)

Input Nominal Estimate for a 100-MWh System:	\$55/kWh
Input Range Estimate:	\$29.5 - \$88/kWh
Input 50-MWh System Estimate:	\$66/kWh
Input 30-MWh System Estimate:	\$88/kWh

TABLE 3.27. Zinc-Bromine Battery Power-Related Balance-of-Plant Cost: Summary of Normalized Estimates (mid-1988\$)

Input Nominal Estimate for 100-MWh System: \$121/kWh
Input Range Estimate for 100-MWh System: \$116 - \$188/kWh
Input 50-MWh System Estimate: \$139/kWh
Input 30-MWh System Estimate: \$139/kWh

3.2.3.5 Net Salvage Value

Scrap value is the fraction of the initial battery purchase that is still of value at the end of the battery's cycle life. None of the ERC work addressed scrap value for the battery. One ERC estimate did assume that the stack is the only major replaceable component of the battery but did not estimate a scrap value for the stack.

A Bechtel (1982) salvage cost estimate assumed disposal of the entire battery module at the end of the cycle life. The scrap value estimated was 13% of original purchase cost. However, this total disposal scenario is probably not the way the battery end-of-life would be handled. More likely, only failed components would be replaced.

The most structured scrap scenario (Ramsay and Edgecomb 1982) estimated electrolyte scrap value as 60% of its original cost with 90% recovery, electrode scrap value of 80% of its original cost with 100% recovery, and all else recovered at a rate of 50% to have a scrap value of 40% of its original cost. This methodology was applied by Ramsay and Edgecomb to a Gould, Inc. battery system, and overall scrap value was determined to be 23% of the original battery cost. The recovery and credits assumed in this scenario appear somewhat optimistic.

Unfortunately, good material breakdown of the battery purchase cost is not easily determined; therefore, more simplistic overall percentages were applied to determine scrap values used to prepare the net salvage value cost estimates of the batteries. The nominal scrap percentage was set at 18%, the average of the Gould, Inc. and Bechtel estimates. The low estimate was taken as 13%, the scrap value derived from the Bechtel cost estimate. The high scrap value assumes that only the basic stack within the module would be

replaced and the remainder of the battery would be usable. The stack is assumed worth less at the end of its life. The stack itself comprises 40% of the battery cost; thus, the high scrap value is 60% of the initial battery cost.

In the salvage scenario where total disposal is assumed (13% scrap value), the nominal shipping estimate of \$8.75/kWh was applied. In the low scrap value case where only minimal components are scrapped, 50% of the nominal shipping cost estimate was applied. In the high scrap value case where only the stack is assumed to be removed, shipping is considered negligible. De-installation in all cases was assumed to be equal to 60% of the nominal installation cost estimate of \$9.38/kWh, which equals \$5.6/kWh (1988\$).

Applying the above figures and percentages, the high salvage estimate is equal to the low battery purchase cost of \$75/kWh times 60%, which equals \$45/kWh less de-installation of \$5.6/kWh. For the nominal net salvage value, 18% of the nominal battery purchase cost of \$83/kWh less \$4.4/kWh for shipping and \$5.6/kWh yields an estimate of \$4.9/kWh. To determine the low salvage value estimate, the high battery purchase cost of \$117/kWh was multiplied by 13% and \$8.8/kWh for shipping, and 5.6/kWh for de-installation was deducted, leaving \$0.8/kWh. Table 3.28 summarizes the net salvage value cost estimates. The nominal net salvage value cost estimate was used in the sensitivity cases.

3.2.3.6 Operating and Maintenance Cost

There is an extremely limited amount of O&M cost information for zinc-bromine battery designs. The interim capital replacement costs for pumps and cells/stacks is accounted for in the battery replacement calculations (see Appendix C), but labor and supplies associated with general maintenance and operations must be accounted for in this cost category.

TABLE 3.28. Zinc-Bromine Battery Net Salvage Value Costs:
Summary of Normalized Estimates (mid-1988\$)

Input Nominal Estimate: \$4.9/kWh

Input Range Estimate: \$39.4-0.8/kWh

The first cost estimate evaluated was prepared by Gould, Inc. (Ramsay and Edgecomb 1982) for a 100-MWh, 20-MW load-leveling plant constructed from 80.7 kWh modules of Gould, Inc. design. This source estimated 16 mandays per month for scheduled maintenance and 24 mandays per year for unscheduled maintenance. Assuming a \$49/hr (\$392 manday) labor rate including materials, an annual cost of \$84,700 (1988\$) is calculated. This is equivalent to 0.34 cents/kWh-of-energy-retrieved for a 100-MWh plant.

A second source (Bechtel 1982) estimated annual maintenance for a 6.21-MWh facility as requiring 29 hours per year and \$200 (1980\$) in materials. They also assessed interim costs for maintenance of the cooling pumps and refrigeration system. At \$49/hr (1988\$), the annual estimated cost is \$1700 or \$0.27/kWh-of-capacity annually. This estimate appears low and was not used.

The third and final source evaluated (ERC 1986a) estimated annual O&M as 0.2 cents/kWh plus \$0.54/kW-yr (1986\$). There was no explanation given with regard to the details of this estimate. For a 100-MWh, 20-MW system operating 250-full cycles per year, this estimate yields \$60,800 (1986\$). Escalating results in a cost of \$64,900 (1988\$).

Theoretically, O&M should be less for the ERC system than the design evaluated by Gould, Inc. (Ramsay and Edgecomb 1982), because the ERC system uses larger components as opposed to many smaller components. On this basis, the lower of the two estimates, \$64,600/yr (1988\$) was used as the nominal cost estimate as well as the low-end estimate. The other annual O&M cost estimate of \$84,700 was used as the high-end estimate. Without additional data points or a more detailed evaluation, it is not possible to place a high certainty on these estimates. For evaluating the 50-MWh, 10-MW and 30-MWh, 10-MW plants in the sensitivity analyses, the ERC (1986a) unit costs were used. Table 3.29 provides a summary of the normalized input cost estimates.

3.2.3.7 Cycle Life

Cycle life estimates vary between 2000-3000 cycles. In the nominal estimate, 2500 cycles was used. The cost impacts of cycle lives of 1500, 2000, and 3000 were examined in the sensitivity cases.

TABLE 3.29. Zinc-Bromine Battery Annual Operating and Maintenance Cost: Summary of Normalized Estimates (1988\$)

Input Nominal Estimate for 100-MWh System: \$64,900
 Input Range Estimate for 100-MWh System: \$64,900 - \$84,700
 Input Estimate for 50-MWh System: \$32,400
 Input Estimate for 30-MWh System: \$21,800

3.2.3.8 System Efficiency

There is some variance in the projection for battery efficiencies. Other system component efficiencies are fairly well established. Three sources were used to arrive at the final system efficiency input for preparing a LCC estimate. Table 3.30 presents the roundtrip efficiencies for different system components. The nominal system efficiency was taken as the PSE&G (ERC) (Abraham et al. 1985d) system efficiency. The efficiency of the converter and auxiliaries is assumed to be the same as that of the comparable components of the lead-acid system. Sensitivity cases were run with both 0.75 and 0.80 battery efficiencies.

TABLE 3.30. Zinc-Bromine Battery System and Component Efficiencies

<u>Source</u>	<u>Roundtrip Efficiency</u>	<u>Component</u>
Bechtel (SCE) (Eckroad et al. 1986)	0.90	converter
PSE&G (Abraham et al. 1985d)	0.90	converter
PSE&G (Abraham et al. 1985d)	0.98	auxiliaries
PSE&G (Abraham et al. 1985d)	0.644	system
PSE&G (ERC) (Abraham et al. 1985d)	0.73	battery
ERC (1986)	0.75 - 0.80	battery
Nominal Input System Efficiency = (battery)(converter)(auxiliaries)		
= (0.725)(0.90)(0.98)		
= 0.64		

SODIUM-SULFUR
BATTERY

3.2.4 Sodium-Sulfur Battery

Presuming that the cell reliability can be increased, the sodium-sulfur battery has good potential as a load-leveling battery. Currently, the high rate of battery cell failures early in the cell life would necessitate expensive cell replacement operations. Despite the sodium-sulfur battery system being one of the main technologies currently funded by the U.S. DOE, cost estimates are difficult to assemble. The main reasons for this are 1) CSPL, the current prime developer, prepares cost estimates with primarily internal funding, and thus detailed estimates are not publicly available, and 2) because there is only one major developer producing any cost information, it is difficult to have recent bases for comparison of cost data. This necessitates using data for sodium-sulfur technology which is five to seven years old as a comparison basis. Also, most of the O&M information available is in the form of goals or possible scenarios that have a larger confidence interval than preferred. Therefore, the O&M cost estimates used may be optimistic.

A summary of the life-cycle economics of the sodium-sulfur battery system is presented in Table 3.31. The low estimate incorporates CSPL's XPB cell with the BOP based on rectangular buildings. Recently, CSPL considered a 100-MWh, 20-MW facility design which incorporates silo-shaped buildings, but this design has subsequently been dropped. The nominal estimate accounts for some of the uncertainty associated with the low cost estimate. The high estimate is based on Ford's cell and a rectangular building configuration. In addition to these baseline cost estimates, a number of sensitivity cases were performed. The results of these cases are shown in Table 3.32. Sources used for determining the sodium-sulfur LCC estimates are listed in Table 3.33.

TABLE 3.31. Sodium-Sulfur Battery System Life-Cycle Economics:
Baseline Case

Cycle Life: 2500
Cell Efficiency: 0.80
System Efficiency: 0.64

Nominal Estimate (mid-1988\$)

Battery Purchase Cost (\$/kWh): 70
Battery Installation (\$/kWh): 3.6
Energy-Related Balance-of-Plant (\$/kWh): 27.6
Power-Related Balance-of-Plant (\$/kWe): 121
Net Salvage Value (\$/kWh): (-2.95)

Annual Operating & Maintenance Costs (\$/yr): 218,000

Levelized Output Cost: 16.8 cents/kWh of energy retrieved

Range of Estimates (mid-1988\$)

Battery Purchase Cost (\$/kWh): 67 - 118
Battery Installation (\$/kWh): 3.6 - 3.6
Energy-Related Balance-of-Plant (\$/kWh): 27.6 - 51
Power-Related Balance-of-Plant (\$/kWe): 121 - 188
Net Salvage Value (\$/kWh): (-2.95) - (-2.95)

Annual Operating & Maintenance Costs (\$/yr): 109,000 - 328,000

Levelized Output Cost: 15.8 - 25.1 cents/kWh of energy retrieved

TABLE 3.32. Sodium-Sulfur Battery System Life-Cycle Economics: Sensitivities

<u>Variable</u>	<u>Baseline Value</u>	<u>New Value</u>	<u>New Levelized Output Cost (cents/kWh)</u>	<u>Percent Change</u>
Discount Rate	4.2%	3%	16.2	-4%
		5%	17.3	+3%
		6%	17.9	+6%
		7%	18.5	+10%
Cycle Life	2500	1500	21.5	+27%
		2000	18.9	+12%
		3000	16.4	-3%
Charging Cost	\$0.025	\$0.01	14.5	-14%
		\$0.015	15.3	-9%
		\$0.020	16.1	-5%
		\$0.030	17.6	+5%
System Size: 50-MWh, 10-MW			17.5	+4%
Energy-Related BOP		\$33.1/kWh	--	--
Power-Related BOP		\$139/kW	--	--
Operating and Maintenance		\$114,000	--	--
System Size: 30-MWh, 10-MW			19.3	+14.5%
Energy-Related BOP		\$44.2/kWh	--	--
Power-Related BOP		\$139/kW	--	--
Operating and Maintenance		\$68,400	--	--
Battery Efficiency	0.73	0.70	17.4	+3%
		0.75	16.3	-3%

TABLE 3.33. Bibliography of Key Sources Used to Evaluate the Sodium-Sulfur Battery Technology

1. Abraham, J., et al. 1985b. Technical and Economic Assessments of Electrochemical Energy Storage Systems: Sodium-Sulfur Battery Plant Description, Cost Estimate, Credible Accident and Efficiency Assessment.
2. Abraham, J., et al. 1985c. Technical and Economic Assessments of Electrochemical Energy Storage Systems: Topical Report on the Potential for Savings in Load-Leveling Battery and Balance of Plant Costs.
3. Askew, B. A., and P. C. Symons. 1986. Evaluation of Sodium/Sulfur and Lithium/Metal Sulfide Battery Systems.
4. Bechtel Group, Inc. 1982. Study of Installed and Life-Cycle Costs of Photovoltaic Power Systems.
5. Ceramtec, Inc. 1986. Proceedings of the DOE/EPRI Beta (Sodium-Sulfur) Battery Workshop VI.
6. Chloride Silent Power Ltd. (CSPL). 1986a. "Sodium-Sulfur Batteries for Utilities Applications: Commercialization Planning."
7. Chloride Silent Power Ltd. (CSPL). 1986b. "Sodium-Sulfur Core Technology and Battery Engineering Program."
8. Ford Aerospace & Communications Corporation. 1980. Sodium-Sulfur Battery Development Economic Analysis, Phase IV: Topical Status Report.
9. General Electric Company. 1982. Development of Advanced Batteries for Utility Application.
10. Podder, A., et al. 1981. Data Base on Batteries, Power-Conditioning Equipment, and Photovoltaic Arrays.

3.2.4.1 Battery Purchase Cost

A number of early-1980s economic evaluations were prepared by General Electric (GE) and Ford. Since then GE and Ford have left the program, and CSPL picked up sodium-sulfur technology where GE left off. Although the older estimates are for somewhat different battery designs, they provide the only available cost data to which newer CSPL data can be compared.

One valuable study by PSE&G (Abraham et al. 1985b) evaluated a 1983 CSPL cost estimate and prepared an estimate adjusted for the cost uncertainties in materials and equipment costs. This new estimate was 9% higher than the original CSPL estimate. While not conclusive, this might indicate some

original CSPL estimate. While not conclusive, this might indicate some optimism on the part of CSPL. After normalization to this study's ground rules, the PSE&G estimate was \$102/kWh (1988\$). This is based on older GE/CSPL technology called the FII cell.

Based on more recent CSPL data (CSPL 1986a), the estimated module cost is \$53/kWh (1986\$). This cost estimate assumes a 2000-kWh module constructed using XPB cells. Normalizing to this study's ground rules and escalating to 1988 dollars yields a cost of \$67/kWh. This is considerably lower than the PSE&G estimate (\$102/kWh), even discounting the uncertainties.

One final estimate is a PSE&G evaluation of the Ford cell. In this system cells are constructed into heavy duty modules which form part of the battery buildings. The total building/battery structure was estimated to cost \$155/kWh (1988\$) after normalization to this study's ground rules. From an evaluation of some Ford data (1980), it was determined that 76% of the total cost is for cells and cell busbars. Therefore, the battery purchase cost estimate of the Ford system (\$155/kWh) was reduced to \$118/kWh (1988\$) to include only cells and cell hardware.

Considering all this information, the final nominal estimate was set at \$67/kWh (1988\$) plus 4% for possible material uncertainties. The full 9% identified by PSE&G was not added, it was known that CSPL has invested considerable resources into evaluating equipment costs. The low estimate was set equal to CSPL's estimate of \$67/kWh; the high estimate was set at \$118/kWh, the PSE&G estimate for the Ford system. Table 3.34 summarizes the nominal and range estimates. For evaluating of system costs in sensitivity cases, the nominal cost estimate was used for all system sizes.

TABLE 3.34. Sodium-Sulfur Battery Purchase Cost: Summary of Normalized Source Estimates (1988\$)

Input Nominal Estimate: \$70/kWh

Input Range Estimate: \$67 - \$118/kWh

3.2.4.2 Shipping and Installation Cost

This level of detail is not typically available in recent cost estimates made public by developers. Using the older Ford cost data (1980), installation was estimated as \$127,000 (1980\$) for a 132-MWh facility. This is equivalent to \$1.35/kWh (1988\$), which is considerably less than installation for a lead-acid system on a unit-cost basis. This is at least partly due to the sodium-sulfur cells being assembled into large factory modules, which lessens onsite installation costs.

The shipping cost estimate was extracted from an evaluation of the Ford battery system (Bechtel 1982). This estimate is \$1.56/kWh (1980\$). Adjusting to 1988\$ yields an estimate of \$2.2/kWh.

Summing the shipping and installation cost estimates yields a total cost of \$3.6/kWh (1988\$). Not enough data is available to establish a range. This same unit cost was used in all sensitivity cases.

3.2.4.3 Energy-Related Balance-of-Plant Cost

Complete and relatively recent cost data are limited to those made available by CSPL, which estimated the energy-related BOP cost as \$37.33/kWh (1986\$) for a 100-MWh facility. After adjusting for the economies associated with multiple installations and escalating to 1988\$, an estimate of \$27.6/kWh results. This value was used for both the nominal and low estimates.

Representative of Ford technology and used as the basis for the high estimate is a PSE&G cost estimate (Abraham et al. 1985b). As detailed in Appendix B.4.3, the normalized cost estimate is \$14/kWh (1983\$) plus \$35/kWh (1988\$) for buildings. Adjusting both cost estimates to 1988-dollars and totaling yields a cost estimate of \$51/kWh (1988\$).

There is no good data specifically related to sodium-sulfur batteries indicating changes in energy-related BOP costs with plant size. Therefore, economies-of-scale in the same ratios developed for the lead-acid plants were applied here. That is, for a 50-MWh sodium-sulfur plant, the unit cost of the energy-related BOP is 20% higher than for a 100-MWh BOP; for a 30-MWh, it is 60% more. This is not an ideal assumption, but it may not be too unrealistic given that this type of scaling is quite consistent with construction

industry rules-of-thumb for scaling. The energy-related BOP estimates developed for the sodium-sulfur battery system are presented in Table 3.35.

3.2.4.4 Power-Related Balance-of-Plant Cost

The power-related BOP for a sodium-sulfur lead-acid battery storage facility should be no different than for a conventional lead-acid battery storage system. Therefore, the sodium-sulfur lead-acid battery power-related BOP is estimated to cost \$121/kW with a range of \$121/kW to \$188/kW, the same as the conventional lead-acid system cost estimate. The same unit cost used for the conventional lead-acid battery cost estimates of 50-MWh, 10-MW and 30-MWh, 10-MW systems are applicable to the sodium-sulfur systems. That is, a unit cost of \$139/kW.

3.2.4.5 Net Salvage Value

There are no salvageable components in the sodium-sulfur cells; however, they must be disposed of in an appropriate manner. Salvage is estimated by summing de-installation costs with the cost of shipping cells to a disposal facility. Shipping is assumed equivalent to a Bechtel estimate of \$1.56/kWh (1980\$) (\$2.12/kWh; 1988\$). De-installation is estimated as 60% of installation, which was estimated as \$1.28/kWh (1988\$). This yields a total salvage estimate of (-\$2.95/kWh). No range was established for this value. Also, this value was used in all sensitivity cases.

3.2.4.6 Operating and Maintenance Cost

While cost estimates are far from certain, in the last few years consideration has been given to developing cost-effective maintenance approaches for the sodium-sulfur battery. This work has been conducted primarily by CSPL, with some contributions from EPRI (Askew and Symons 1986).

TABLE 3.35. Sodium-Sulfur Battery System Energy-Related Balance-of-Plant: Summary of Normalized Source Estimates (1988\$)

Input Nominal Estimate for 100-MWh System:	27.6/kWh
Input Range Estimate for 100-MWh System:	\$27.6/kWh - \$51/kWh
Input 50-MWh System Estimate:	\$33.1/kWh
Input 30-MWh System Estimate:	\$44.2/kWh

Askew and Symons' work is perhaps the most generally informative of any O&M cost data available for any load-leveling technology. While the work does not pinpoint costs (it leans toward goals or possible costs), it focuses attention specifically on what technical accomplishments must occur to meet specified O&M costs. Symons identifies a baseline 0.2 cents/kWh for general BOP maintenance in addition to cell replacement labor; 0.6 to 0.8 cents/kWh is identified as possible allowable costs for replacement labor. Symons identifies cell reliability as the key to achieving this cost range. With the development of cells with a calendar life of ten years and a cycle life of 2500 cycles with failures concentrated in later years, battery maintenance by individual module repair could conceivably be cost effective.

Based on Symons' estimates, three input estimates were prepared. At the low end 0.4 cents/kWh was used, and 0.8 cents/kWh was used for the nominal estimate. To represent the high end, 1.2 cents/kWh was used. The high end estimate was subjectively set. Based on a 100-MWh, 20-MW system, the low, nominal, and high estimates are \$100,000; \$200,000; and \$300,000, respectively, on an annual basis in 1985 dollars. Escalating to 1988\$ yields \$109,000; \$218,000; and \$328,000, respectively. For the 50-MWh, 10-MW and 30-MWh, 10-MW sensitivity cases, the nominal estimate of 0.8 cents/kWh was used. Table 3.36 summarizes the input estimates.

3.2.4.7 Cycle Life

Cycle life, and calendar life for that matter, are significant problems currently holding up commercialization of the sodium-sulfur battery system. There have, however, been consistent improvement in the cycle life of the PB cell in recent years. A nominal cycle life of 2500 was chosen. Sensitivity cases were run with cycle lives of 1000, 1500, and 2000.

TABLE 3.36. Sodium-Sulfur Battery Operating and Maintenance Cost:
Summary of Normalized Estimates (1988\$)

Input Nominal Estimate for 100-MWh System:	\$218,000
Input Range Estimate for 100-MWh System:	\$109,000 - \$328,000
Input Estimate for 50-MWh System:	\$114,000
Input Estimate for 30-MWh System:	\$68,400

3.2.4.8 System Efficiency

There is some variance in the projection for battery efficiencies. Other system component efficiencies are fairly well established. Three sources were considered to arrive at the final system efficiency input for preparing a LCC estimate. Table 3.37 presents the roundtrip efficiencies for different system components. The nominal system efficiency was taken as the PSE&G (Abraham et al. 1985b) system efficiency.

TABLE 3.37. Sodium-Sulfur Battery System and Component Efficiencies

<u>Source</u>	<u>Roundtrip Efficiency</u>	<u>Component</u>
Bechtel (SCE) (Eckroad et al. 1986)	0.90	converter
PSE&G (CSPL) (Abraham et al. 1985b)	0.73	cell
CSPL (1986a)	0.90	XPB cell
CSPL (1986a)	0.80	FII cell
CSPL (1986a)	0.70	system
PSE&G (Abraham et al. 1985b)	0.90	converter
PSE&G (Abraham et al. 1985b)	0.98	auxiliaries
PSE&G (Abraham et al. 1985b)	0.644	system
PSE&G (ERC) (Abraham et al. 1985b)	0.73	battery

$$\begin{aligned}\text{Nominal Input System Efficiency} &= (\text{battery})(\text{converter})(\text{auxiliaries}) \\ &= (0.73)(0.90)(0.98) \\ &= 0.64\end{aligned}$$

LITHIUM-IRON
SULFIDE BATTERY

3.2.5 Lithium-Iron Sulfide Battery

Cost data pertaining to current lithium-iron sulfide batteries are extremely limited. Detailed cost data have not been published for new cell designs. The basis for this LCC estimate was cost data for late-1970s-era battery design, primarily because there has not been a major lithium-iron sulfide battery program for utility applications in the last ten years. Opinions vary, but many feel that the lithium-iron battery system is better suited to electric vehicle applications. As a result, this data should be interpreted with caution. Therefore, only a nominal estimate was prepared from which limited conclusions can be drawn. To develop a good LCC estimate, the new cell designs must be evaluated in detail. Table 3.38 presents the life-cycle economics of the lithium-iron sulfide battery based on the old design. Table 3.39 presents the results of the sensitivity analysis conducted on the LCC estimate. Table 3.40 lists the sources used to arrive at these LCC estimates.

TABLE 3.38. Lithium-Iron Sulfide Battery System Life-Cycle Economics:
Baseline Case

Cycle Life: 2500
Cell Efficiency: 0.75
System Efficiency: 0.66

Nominal Estimate (mid-1988\$)

Battery Purchase Cost (\$/kWh): 108
Battery Installation (\$/kWh): 3.8
Energy-Related Balance-of-Plant (\$/kWh): 67
Power-Related Balance-of-Plant (\$/kWh): 121
Net Salvage Value (\$/kWh): (-2.4)

Annual Operating & Maintenance Costs (\$/yr): 300,000

Levelized Storage Cost: 25.0 cents/kWh of energy retrieved

TABLE 3.39. Lithium-Iron Sulfide Battery System Life-Cycle Economics: Sensitivities

Variable	Baseline Value	New Value	New Levelized Output Cost	Percent Change
Discount Rate	4.2%	3%	22.3	-4%
		5%	24.0	+3%
		6%	25.0	+7%
		7%	26.0	+12%
Cycle Life	2500	1000	39.2	+69%
		2000	26.2	+13%
		3000	22.5	-3%
Charging Cost	\$0.025	\$0.01	21.0	-10%
		\$0.015	21.7	-7%
		\$0.020	22.5	-3%
		\$0.030	24.0	+3%
System Size: 50-MWh, 10-MW			25.0	+7%
Energy-Related BOP		\$86/kWh	--	--
Power-Related BOP		\$139/kW	--	--
Operating and Maintenance		\$180,000	--	--
System Size: 30-MWh, 10-MW			27.8	+19.5%
Energy-Related BOP		\$115/kWh	--	--
Power-Related BOP		\$139/kW	--	--
Operating and Maintenance		\$109,000	--	--
Battery Efficiency	0.75	0.80	24.0	+3%
		0.825	22.6	-3%

TABLE 3.40. Bibliography of Key Sources Used to Evaluate the Lithium-Iron Sulfide Battery Technology

1. Abraham, J., et al. 1985c. Technical and Economic Assessments of Electrochemical Energy Storage Systems: Topical Report on the Potential for Savings in Load-Leveling Battery and Balance-of-Plant Costs.
2. Bechtel Group, Inc. 1982. Study of Installed and Life-Cycle Costs for Batteries in Photovoltaic Power Systems.
3. Chilenskas, A. A., et al. 1980. A Preliminary Estimate of the Manufacturing Cost for Lithium-Metal Sulfide Cells for Stationary and Mobile Applications.
4. Podder, A., et al. 1981. Data Base on Batteries, Power-Conditioning Equipment, and Photovoltaic Arrays.
5. Ramsay, G. B., and A. Edgecomb 1982. Comparison of Prices for Conventional and Advanced Storage Batteries for Residential, Commercial and Utility Applications.
6. Stolte, W. J. 1982. Feasibility Assessment of Customer-Side-of-the-Meter Applications for Battery Energy Storage.
7. Towle, T. W., et al. 1976. Cost Estimate for the Commercial Manufacture of Lithium/Iron Sulfide Cells for Load-Leveling.
8. Zivi, S. M., et al. 1980a. Reference Design of 100-MWh Lithium/Iron Sulfide Battery System for Utility Load-Leveling.
9. Zivi, S. M., et al. 1980b. Conceptual Designs for Utility Load-Leveling Battery with Li/FeS Cells.

3.2.5.1 Battery Purchase Cost

The cost estimate for the battery purchase cost of the lithium-iron sulfide battery is based on a 1976 cost estimate (Towle et al.) for the mass production of 0.92 kWh cells. The source estimate was developed prior to the introduction of the George guidelines; therefore, the appropriate data from the source estimate was input into the 1984 George guidelines to yield a cost of \$94.08/kWh (1983\$). Escalating to mid-1988\$ yields a cost of \$108/kWh, which represents the purchase cost of the cells. The cells are then assembled into submodules for shipment. These submodules are basically a

large rack which provides connecting buswork for individual cells into large battery units. Submodule costs are included with the energy-related BOP components.

3.2.5.2 Shipping and Installation Cost

Argonne National Laboratory (ANL) estimates the weight of a submodule as 6 tons for a 240-kWh unit which is equivalent to 40-kWh per ton (Zivi et al. 1980a). Based on a 1000-mile shipping distance (2000 mile roundtrip), a 1.50-per-mile charge, and a 20-ton weight-limited load, shipping is \$3.75/kWh.

Installation of the cells is included in the submodule assembly costs, which are part of the energy-related BOP.

3.2.5.3 Energy-Related Balance-of-Plant Cost

The energy-related BOP includes buildings, thermal management, busbars, submodule assembly costs, and submodule installation. The total cost of these facilities was estimated as \$80.25/kWh (1978\$) (Zivi et al. 1980a). Escalating to mid-1988\$ yields an estimate of \$134/kWh. The battery developers and BOP designers realized these costs were prohibitively high and initiated a cost-reduction program. In a second study (Zivi et al. 1980b), a cost reduction through design modification of \$20 to \$58/kWh (1978\$) was identified; however, detailed estimates breaking cell costs out of total system costs were not available. Assuming the average of the range (\$40/kWh) could be saved, total energy-related BOP costs would be \$40/kWh (1978\$). The total estimated BOP cost in mid-1988\$ would be \$67/kWh for a 100-MWh, 20-MW plant.

Developing cost estimates for the 50-MWh and 30-MWh energy-related BOP poses a difficult problem. There are no available estimates at these sizes. The problem is compounded by the fact the 100-MWh data is old and costs are uncertain.

The source estimate by Zivi et al. (1980a) was examined to identify the major components that fulfill physically different functions or are more extensively used, such as thermal management from a lead-acid energy-related BOP. These include ceramic insulation, thermal controls and insulation, T/C

wiring and connectors, and thermal controls. These items represent 12% of the total BOP. It seems that these components would not drastically differ in cost scaling from the more conventional components. On this basis, the same cost scale-up relationships developed for the lead-acid plant were used to obtain the unit cost of a 50-MWh BOP; the 100-MWh BOP estimate of \$72/kWh (1988\$) was increased by 20% to \$86/kWh. The 30-MWh BOP was calculated by scaling up the \$72/kWh by 60% to \$115/kWh. It should be noted that these estimates have a high uncertainty.

3.2.5.4 Power-Related Balance-of-Plant Cost

The power-related BOP for a lithium-iron sulfide battery system should have no major differences from a conventional lead-acid battery storage system. Therefore, the cost estimate for the lithium-iron sulfide battery power-related BOP for a 100-MWh system is \$121/kW, the same as for the conventional lead-acid system. The unit cost for the smaller, 10-MW plant was assumed to be \$139/kW, the same as for the lead-acid system.

3.2.5.5 Net Salvage Value

The net salvage value for the lithium-iron sulfide includes battery removal cost, shipping to a reclaiming facility, and scrap value for recyclable components. The materials of value in the old batteries are the lithium compounds. Towle (1976) estimated \$1.83/kWh (1975\$) as the scrap credit. This value was escalated to \$3.6/kWh (1988\$). Shipping is estimated as \$3.75/kWh, the same as initial shipping. Deinstallation is generally calculated as sixty percent of installation. It is, however, difficult to break installation out of the available source data. It is approximated by taking 60% of the submodule assembly cost of \$2.19 (1978\$). Escalating to 1988\$ yields a deinstallation estimate of \$2.2/kWh (mid-1988\$). Summing salvage credit, shipping, and deinstallation yields a net salvage value of (\$-2.4/kWh).

3.2.5.6 Operating and Maintenance Cost

General maintenance of the lithium-iron sulfide battery includes checking performance, inspecting connections, servicing the cooling-air system, and replacing defective cells (Podder et al. 1981). One estimate for a

500-kWh unit is 0.72/kWh capacity (1980\$) not including cell replacements. Another estimate (Ramsay and Edgecomb 1982), for general maintenance of a 100-MWh, 20-MW system, is \$360,000/yr plus cell replacements. This is equivalent to \$3.60 (1980\$)/kWh-of-capacity plus cell replacements. Replacement cells are accounted for in the LCC calculations.

The two general maintenance estimates are not consistent at \$0.72/kWh-of-capacity for a 500-kWh system and 3.60/kWh-of-capacity for a 100-MWh system. The estimate of \$0.72/kWh is lower than the conventional lead-acid battery system cost estimate. For lack of better information, the annual figure of \$3.60/kWh-of-capacity was averaged with the lower estimate, yielding an annual estimate of \$2.16/kWh-capacity. The estimate of \$2.18/kWh (1980\$) was escalated to 1988\$ and used as part of the nominal estimate. This yields \$3/kWh (1988\$), which is equivalent to \$300,000/yr. There is a very low confidence in this estimate. Fortunately, O&M is not a major LCC driver.

There is no good basis for generating cost estimates for use in the sensitivity calculations. Therefore, a simple linear scaling was used. This yields an annual estimate for the 50-MWh, 10-MW plant of \$150,000 and \$109,000 for the 30-MWh, 10-MW plant.

3.2.5.7 Cycle Life

Data on cycle life is also limited, as shown in Table 3.41. Looking only this limited data a cycle life of 2500 was assumed for the nominal estimate. Sensitivities at 1000, 2000, 3000, and 4000 cycle lives were performed.

TABLE 3.41. Lithium-Iron Sulfide Cycle Life Summary

<u>Source</u>	<u>Cycle Life</u>	<u>Certainty</u>
Zivi et al. (1980a)	ten-years	Projection
Podder et al. (1981)	750	Achieved

3.2.5.8 System Efficiency

ANL (Zivi et al. 1980b) estimates cell efficiency at 75% and system efficiency at 70%. To be consistent with other estimates in this evaluation, the cell efficiency of 75% was coupled with a converter efficiency of 90% and an auxiliaries efficiency of 98%. This yields a system efficiency of 66%.

PHOSPHORIC ACID
FUEL CELL

3.2.6 Phosphoric Acid Fuel Cell

The PAFC is an electricity generation technology, as opposed to a storage technology. The PAFC is designed as an intermediate load plant but could conceivably be used to provide peak power utilizing its excess capacity. It appears that the PAFC could be competitive in supplying peaking power. Because it is a generation technology, its capital cost is expressed in \$/kW. The capital cost and LCC estimates for scenarios assuming a low world oil price, nominal world oil price, and high world oil price are presented in Table 3.42 for a 20-MW unit operating in peaking mode five hours per day. Fuel cost is based on the use of natural gas. The fuel stack life is estimated as 40,000 hours (Kinetics 1984), which corresponds to 8000, 5-hour cycles. Table 3.43 presents the sensitivity cases performed on the nominal estimate for the PAFC system. The sources upon which the estimate is based are listed in Table 3.44.

TABLE 3.42. Phosphoric Acid Fuel Cell System Life-Cycle Economics:
Baseline Case

Cycle Life: 8000

Nominal World Oil Price Estimate (Fuel Esc. at 5.6%/yr, 1988\$)

Power-Related Capital Costs (\$/kWe): 955
Annual Operating & Maintenance Costs (\$/yr): 379,000
Annual Fossil Fuel Consumption (MBTU/yr): 208,750
Fossil Fuel Cost (\$/MBTU): 2.36

Levelized Output Cost: 15.3 cents/kWh of energy generated

Range of Estimates (Fossil Fuel Esc at 4.9%/yr - 6.3%, 1988\$)

Power-Related Capital Costs (\$/kWe): 955
Annual Operating & Maintenance Costs (\$/yr): 379,000
Annual Fossil Fuel Consumption (MBTU/yr): 208,750
Fossil Fuel Cost (\$/MBTU): 2.36

Levelized Storage Cost: 14.4 - 16.4 cents/kWh of energy generated

TABLE 3.43. Phosphoric Acid Fuel Cell System Life-Cycle Economics: Sensitivities

<u>Variable</u>	<u>Baseline Value</u>	<u>New Value</u>	<u>New Levelized Output Cost (cents/kWh)</u>	<u>Percent Change</u>
Discount Rate	4.2%	3%	14.7	-4%
		5%	15.8	+3%
		6%	16.4	+7%
		7%	17.1	+11.5%
System: 10-MW, 5 hrs/day			153	0%
Annual O&M	--	189,500	--	--
Annual Fuel Consumption	--	104,375	--	--
System: 10-MW, 3 hrs/day		--	207	+34%
Annual O&M	--	140,500	--	--
Annual Fuel Consumption	--	62,625	--	--

TABLE 3.44. Bibliography of Key Sources Used to Evaluate the Phosphoric Acid Fuel Cell Technology

1. Electric Power Research Institute (EPRI). 1986. Technical Assessment Guide.
2. Energy Information Administration (EIA). 1988. Annual Energy Outlook: 1987.
3. Kinetics Technology International Corporation. 1984. Assessment of Centralized Medium-Sized Fuel Cell Power Plants.
4. Krumpelt, M., et al. 1985. Fuel Cell Power Plant Designs.

COMPARISON
TECHNOLOGIES

3.2.7 Comparison Technologies

LCC estimates were prepared for three alternative peaking technologies that compete with batteries and fuel cells: two types of gas-turbine technology CAES, and conventional pumped-hydrostorage. Conventional gas-fired turbine technology represents a mature generation technology, whereas the advanced gas turbine technology is in the development phase. CAES is a storage technology at the demonstration level of development. Conventional pumped-hydro storage is a mature storage technology.

3.2.7.1 Gas-Fired Turbine

Cost for two types of turbines are presented: a conventional gas-fired turbine and an advanced gas-fired turbine. The only difference between the two units are the improved heat rate and lower capital cost of the advanced gas-fired turbine. For each technology, three estimates are presented. Each estimate corresponds to a different world-oil-price scenario (escalation 4.9%/yr, 5.6%/yr, and 6.3%/yr) (EIA 1988). Table 3.45 presents the life-cycle economics of the conventional gas-fired turbine. Table 3.46 presents comparable data for the advanced gas-fired turbine.

In addition, two other plant configurations were evaluated for each technology. These include a 10-MW gas turbine operating three and five hours per day. The selection of these plant configurations was based on providing comparative points for 50-MWh, 10-MW and 30-MWh, 10-MW battery storage systems. The costs associated with these plant configurations are presented in Tables B.47 and B.48. Table 3.49 lists the sources used to develop the gas-fired turbine estimates.

3.2.7.2 Compressed Air Energy Storage

The CAES system operates by using electricity to compress air into a storage cavern. During retrieval the air is expanded, heated, and used to drive a turbine, which generates electricity. Electrical efficiency is estimated as 0.76. Natural gas consumption is 4100 BTU/kWh retrieved. Based on data presented in TAG (EPRI 1986), the cost and energy relationships presented in Table 3.50 were developed. From this data, system estimates for CAES systems constructed in three types of geological media were prepared.

TABLE 3.45. Conventional Gas-Fired Turbine System Life-Cycle Economics:
Baseline Case

Nominal World Oil Price Estimate (5.6%/yr, 1988\$)

Power-Related Capital Costs (\$/kWe): 331
Annual Operating & Maintenance Costs (\$/yr): 118,800
Annual Fossil Fuel Consumption (MBTU/yr): 345,000
Fossil Fuel Cost (\$/MBTU): 2.36

Levelized Output Cost: 13.6 cents/kWh of energy generated

Range of Estimates (Fuel Esc. at 4.9%/yr - 6.3%/yr, 1988\$)

Power-Related Capital Costs (\$/kWe): 331
Annual Operating & Maintenance Costs (\$/yr): 118,800
Annual Fossil Fuel Consumption (MBTU/yr): 345,000
Fossil Fuel Cost (\$/MBTU): 2.36

Levelized Output Cost: 12.1 - 15.3 cents/kWh of energy generated

TABLE 3.46. Advanced Gas-Fired Turbine System Life-Cycle Economics:
Baseline Case

Nominal World Oil Price Estimate (5.6%/yr, 1988\$)

Power-Related Capital Costs (\$/kWe): 307
Annual Operating & Maintenance Costs (\$/yr): 118,800
Annual Fossil Fuel Consumption (MBTU/yr): 327,500
Fossil Fuel Cost (\$/MBTU): 2.36

Levelized Output Cost: 12.8 cents/kWh of energy generated

Range of Estimates (Fuel Esc. at 4.9%/yr - 6.3%/yr, 1988\$)

Power-Related Capital Costs (\$/kWe): 307
Annual Operating & Maintenance Costs (\$/yr): 118,800
Annual Fossil Fuel Consumption (MBTU/yr): 327,500
Fossil Fuel Cost (\$/MBTU): 2.36

Levelized Output Cost: 11.4 - 14.5 cents/kWh of energy generated

TABLE 3.47. Conventional Gas-Fired Turbine System Life-Cycle Economics: Sensitivities

Variable	Baseline Value	New Value	New Levelized Output Cost (cents/kWh)	Percent Change
Discount Rate	4.2%	3%	13.7	+1.5%
		5%	13.5	-1%
		6%	13.4	-1%
		7%	13.4	-1.5%
System: 10-MW, 5 hrs/day			136	+1%
Capital Cost	\$331/kW	\$331/kW	--	--
Annual O&M	--	\$63,000	--	--
Annual Fuel Consumption	--	172,500 MBTU	--	--
System: 10-MW, 3 hrs/day			153	+19.5%
Capital Cost	\$331/kW	\$331/kW	--	--
Annual O&M	--	\$33,000	--	--
Annual Fuel Consumption	--	103,500 MBTU	--	--

TABLE 3.48. Advanced Gas-Fired Turbine System Life-Cycle Economics: Sensitivities

Variable	Baseline Value	New Value	New Levelized Output Cost (cents/kWh)	Percent Change
Discount Rate	4.2%	3%	13.0	+1.5%
		5%	12.8	-1%
		6%	12.7	-1%
		7%	12.6	-1.5%
System: 10-MW, 5 hrs/day			12.9	0%
Capital Cost	\$307/kW	\$307/kW	--	--
Annual O&M	--	\$63,000	--	--
Annual Fuel Consumption	--	163,750 MBTU	--	--
System: 10-MW, 3 hrs/day			14.4	+12%
Capital Cost	\$307/kW	\$307/kW	--	--
Annual O&M	--	\$33,000	--	--
Annual Fuel Consumption	--	98,250 MBTU	--	--

TABLE 3.49. Bibliography of Key Sources Used to Evaluate the Gas-Fired Turbine

1. Energy Information Administration. 1988. Annual Energy Outlook 1987.
2. Electric Power Research Institute (EPRI). 1986. Technical Assessment Guide.

TABLE 3.50. Normalized Compressed Air Energy Storage System Costs (1988\$)

	<u>Storage Media</u>		
	<u>Rock</u>	<u>Salt</u>	<u>Aquifer</u>
Capital Cost, \$/kW	937	726	734
\$/kWh	62.0	11.6	4.5
O&M Fixed, \$/kW-yr	2.4	1.1	1.1
Variable, cents/kWh	0.19	0.09	0.09
Fossil Fuel Usage, BTU/kWh	4100	4100	4100
Electricity, kWh out/kWh in	1.32	1.32	1.32

Three system operating configurations were evaluated for each media. The nominal and range estimates for the 100-MWh, 20-MW systems for each media are presented in Tables 3.51 through 3.53. LCC estimates for the 50-MWh, 10-MW and 30-MWh, 10-MW systems in each media are presented in Tables 3.54 through 3.56. The sources used to develop these estimates are presented in Table 3.57.

TABLE 3.51. Compressed Air Energy Storage System Using a Rock Storage
Media Life-Cycle Economics: Baseline Case

Nominal World Oil Price Estimate (5.6%/yr, 1988\$)

Power-Related Capital Costs (\$/kWe): 937
Energy-Related Capital Costs (\$/kWh): 62.0
Annual Operating & Maintenance Costs (\$/yr): 84,100
Annual Fossil Fuel Consumption (MBTU/yr): 77,900
Fossil Fuel Cost (\$/MBTU): 2.36

Levelized Output Cost: 11.3 cents/kWh of energy retrieved

Range of Estimates (fuel esc. At 4.9%/yr - 6.3%/yr, 1988\$)

Power-Related Capital Costs (\$/kWe): 937
Energy-Related Capital Costs (\$/kWh): 62.0
Annual Operating & Maintenance Costs (\$/yr): 84,100
Annual Fossil Fuel Consumption (MBTU/yr): 77,900
Fossil Fuel Cost (\$/MBTU): 2.36

Levelized Output Cost: 11.1 - 11.6 cents/kWh of energy retrieved

TABLE 3.52. Compressed Air Energy Storage System Using an Aquifer
Storage Media Life-Cycle Economics: Baseline Case

Nominal World Oil Price Estimate (5.6%/yr, 1988\$)

Power-Related Capital Costs (\$/kWe): 734
Energy-Related Capital Costs (\$/kWh): 4.5
Annual Operating & Maintenance Costs (\$/yr): 39,000
Annual Fossil Fuel Consumption (MBTU/yr): 77,900
Fossil Fuel Cost (\$/MBTU): 2.36

Levelized Output Cost: 8.3 cents/kWh of energy retrieved

Range of Estimates (fuel esc. At 4.9%/yr - 6.3%/yr, 1988\$)

Power-Related Capital Costs (\$/kWe): 734
Energy-Related Capital Costs (\$/kWh): 4.5
Annual Operating & Maintenance Costs (\$/yr): 39,000
Annual Fossil Fuel Consumption (MBTU/yr): 77,900
Fossil Fuel Cost (\$/MBTU): 2.36

Levelized Output Cost: 8.0 - 8.6 cents/kWh of energy retrieved

TABLE 3.53. Compressed Air Energy Storage System Using a Salt Storage Media Life-Cycle Economics: Baseline Case

Nominal World Oil Price Estimate (5.6%/yr, 1988\$)

Power-Related Capital Costs (\$/kWe): 726
Energy-Related Capital Costs (\$/kWh): 11.6
Annual Operating & Maintenance Costs (\$/yr): 39,000
Annual Fossil Fuel Consumption (MBTU/yr): 77,900
Fossil Fuel Cost (\$/MBTU): 2.36

Levelized Output Cost: 8.6 cents/kWh of energy retrieved

Range of Estimates (fuel esc. At 4.9%/yr - 6.3%/yr, 1988\$)

Power-Related Capital Costs (\$/kWe): 726
Energy-Related Capital Costs (\$/kWh): 11.6
Annual Operating & Maintenance Costs (\$/yr): 39,000
Annual Fossil Fuel Consumption (MBTU/yr): 77,900
Fossil Fuel Cost (\$/MBTU): 2.36

Levelized Output Cost: 8.3 - 8.9 cents/kWh of energy retrieved

TABLE 3.54. Compressed Air Energy Storage System Using a Rock Storage Media Life-Cycle Economics: Sensitivities

Variable	Baseline Value	New Value	New Levelized Output Cost cents/kWh	Percent Change
Discount Rate	4.2%	3%	10.5	-7%
		5%	11.9	+5%
		6%	12.7	+12%
		7%	13.4	+19%
Charging Cost	\$0.025	\$0.01	10.2	-10%
		\$0.015	10.6	-6%
		\$0.020	11.0	-2.5%
		\$0.030	11.7	+3.5%
50-MWh, 10-MW System			11.3	+0%
Power-Related Capital	\$937/kW	\$937/kW	--	--
Energy-Related Capital	\$62.0/kWh	\$62.0/kWh	--	--
Annual O&M	--	\$42,050	--	--
Annual Fossil Fuel	--	38,950 MBTU	--	--
30-MWh, 10-MW System			15.1	+33.5%
Power-Related Capital	\$937/kW	\$937/kWh	--	--
Energy-Related Capital	\$62.0/kWh	\$62.0/kW	--	--
Annual O&M	--	\$34,830	--	--
Annual Fossil Fuel	--	23,370 MBTU	--	--

**TABLE 3.55. Compressed Air Energy Storage System Using an Aquifer
Storage Media Life-Cycle Economics: Sensitivities**

<u>Variable</u>	<u>Baseline Value</u>	<u>New Value</u>	<u>New Levelized Output Cost (cents/kWh)</u>	<u>Percent Change</u>
Discount Rate	4.2%	3% 5% 6% 7%	7.8 8.6 9.1 9.6	-5.5% +4% +9% +15%
Charging Cost	\$0.025	\$0.01 \$0.015 \$0.020 \$0.030	7.2 7.5 7.9 8.7	-13% -10% -5% +5%
50-MWh, 10-MW System			8.3	+0%
Power-Related Capital	\$734/kW	\$734/kW	--	--
Energy-Related Capital	\$4.5/kWh	\$4.5/kWh	--	--
Annual O&M	--	\$19,550	--	--
Annual Fossil Fuel	--	38,950 MBTU	--	--
30-MWh, 10-MW System			11.2	+35%
Power-Related Capital	\$734/kW	\$734/kWh	--	--
Energy-Related Capital	\$4.5/kWh	\$4.5/kW	--	--
Annual O&M	--	\$16,130	--	--
Annual Fossil Fuel	--	23,370 MBTU	--	--

TABLE 3.56. Compressed Air Energy Storage System Using a Salt Storage Media Life-Cycle Economics: Sensitivities

Variable	Baseline Value	New Value	New Levelized Output Cost (cents/kWh)	Percent Change
Discount Rate	4.2%	3%	8.1	-5.5%
		5%	8.9	+4%
		6%	9.4	+9.5%
		7%	9.9	+15%
Charging Cost	\$0.025	\$0.01	7.4	-14%
		\$0.015	7.8	-9%
		\$0.020	8.2	-4.5%
		\$0.030	9.0	+4.5%
50-MWh, 10-MW System			8.5	-1%
Energy-Related Capital	\$726/kW	\$726/kW	--	--
Power-Related Capital	\$11.6/kWh	\$11.6/kWh	--	--
Annual O&M	--	\$19,550	--	--
Annual Fossil Fuel	--	38,950 MBTU	--	--
30-MWh, 10-MW System			11.4	+33%
Energy-Related Capital	\$726/kW	\$726/kWh	--	--
Power-Related Capital	\$11.6/kWh	\$11.6/kW	--	--
Annual O&M	--	\$16,130	--	--
Annual Fossil Fuel	--	23,370 MBTU	--	--

TABLE 3.57. Bibliography of Key Sources Used to Evaluate Compressed Air Energy Storage

1. Electric Power Research Institute (EPRI). 1986. Technical Assessment Guide.
2. Energy Information Administration (EIA). 1988. Annual Energy Outlook: 1987.

3.2.7.3 Conventional Pumped-Hydro Storage

Conventional pumped-hydro storage uses electrical energy to pump water uphill to a storage pond. During discharge, the facility operates in reverse. The net electrical efficiency of this process is 73.5%. From source data presented in TAG (EPRI 1986), a cost relationship of \$990/kW plus \$15.7/kWh (mid-1988\$) was derived for the capital cost. TAG estimates O&M as

\$3.8 kW-yr and 0.38 cents/kWh (1988\$). Based on the normalized source data, the life-cycle estimates presented in Table 3.58 were developed for a 100-MWh, 20-MW plant. Table 3.59 presents the results of sensitivity cases for conventional pumped-hydro storage systems. EPRI's TAG (1986) was the only source used to evaluate the conventional pumped-hydro storage system.

TABLE 3.58. Conventional Pumped-Hydro Storage System Life-Cycle Economics: Baseline Case

Power-Related Capital Cost (\$/kWe): 990
 Energy-Related Capital Cost (\$/kWh): 15.7
 Annual Operating and Maintenance Cost (\$/yr): 169,400
 Levelized Output Cost: 15.7 cents/kWh of energy retrieved

TABLE 3.59. Conventional Pumped-Hydro Storage System Life-Cycle Economics: Sensitivities

Variable	Baseline Value	New Value	New Levelized Output Cost (cents/kWh)	Percent Change
Discount Rate	4.2%	3%	14.3	-9%
		5%	16.7	+6.5%
		6%	18.0	+14.5%
		7%	19.4	+23%
Charging Cost	\$0.01	\$0.025	13.7	-13%
		\$0.015	14.4	-8.5%
		\$0.020	15.0	-4%
		\$0.030	16.4	-4.5%
50-MWh, 10-MW System			15.7	+0%
Power-Related Capital	\$990/kW	\$990/kW	--	--
Energy-Related Capital	\$15.7/kWh	\$15.7/kWh	--	--
Annual O&M	--	\$85,900	--	--
30-MWh, 10-MW System			23.0	+46%
Power-Related Capital	\$990/kW	\$990/kW	--	--
Energy-Related Capital	\$15.7/kWh	\$15.7/kWh	--	--
Annual O&M	--	\$66,900	--	--

4.0 STAND-ALONE APPLICATION

The operating constraints under which batteries in stand-alone applications function are quite different from load-leveling applications. The stand-alone battery system is usually associated with remote residences, remote telecommunications equipment, or similar locations not connected to a utility grid. The batteries are usually charged by wind or solar power or another renewable energy source. In some specialized cases they are coupled with a diesel generator. Because some discharge usually occurs on a daily basis and charging may vary depending on wind speed, insolation, and other uncontrollable factors, the battery must have enough capacity to provide power for several discharge periods in a row with minimal or no recharging. This operating constraint can lead to complicated charge-discharge scenarios. For the purposes of simplicity and consistency with the load-leveling discharge cycle, a daily five-hour discharge period has been presumed with full recharge each day. Although this approach does not precisely model the system, complications which arise through using a more detailed treatment were beyond the scope of this summary-level evaluation of alternatives.

The Department of Energy has targeted the energy range for stand-alone applications as 1 kWh to 100 kWh (DOE 1985). For the life-cycle cost estimates, a 50-kWh system, which represents the center of DOE's defined range for stand-alone applications, was selected for evaluation. The results of the life-cycle cost estimates are graphically presented in Figure 4.1. At this level of evaluation, the figures can be somewhat misleading if taken out of context for several reasons. First, cost data for stand-alone systems are not as readily available as cost data for utility applications. This leads to final estimates with a much lower confidence level than the utility application estimates. Second, two of the stand-alone technologies presented, the hydrogen-nickel oxide and zinc-ferricyanide (zinc-REDOX) batteries, are both in early stages of development as compared with the sealed lead-acid battery. Because both systems are relatively immature, very little detailed design information has been published for the batteries in specific applications. Specifically, very little BOP design details, O&M cost details, and other system details are available. To compensate for this

FIGURE 4.1. Levelized Output Cost for Stand-Alone Systems

lack of detail, developers and system estimators tend to make generalizations, such as assuming that the hydrogen-nickel oxide BOP will be the same as the lead-acid battery system BOP. While this may be true or nearly so, it cannot be confirmed without performing a thorough systems analysis. This lack of BOP, O&M, and salvage data, along with the fact that many published estimates are goals and not the mass-production consumer costs, makes these two estimates somewhat suspect. Third, it is surprising that the BOP costs and installation costs for the lead-acid system are an order of magnitude higher than the corresponding lead-acid estimates for load-leveling systems. At this level of evaluation, the absolute validity of source estimates was not questioned. It would be appropriate to prepare additional detailed estimates for stand-alone systems to determine if these high costs are reasonable.

4.1 SPECIFIC APPROACH TO EVALUATION OF STAND-ALONE APPLICATIONS

Because of the minimal amount of data available for stand-alone applications, the approach to defining life-cycle cost estimates was slightly modified for each technology, depending on what information was available. Battery purchase cost inputs were normalized by the same method used for load-leveling estimates if detailed information that could be placed in the George format was available. In the cases of hydrogen-nickel oxide and sealed lead-acid batteries, detailed estimates were not available. Therefore, a best estimate for the battery purchase cost was made from available data. The remaining cost inputs were derived by adjusting the available cost data to mid-1988\$, for mass production cost reductions, and to a system size of 50-kWh and 10-kW peak. After the source estimates were normalized, they were used to develop the nominal and range estimates used as life-cycle cost inputs. The specific criteria used in establishing input estimates from source estimates are discussed in the sections associated with each technology. As a comparison technology, a diesel-electric generator system was evaluated on a life-cycle cost basis.

4.2 TECHNOLOGIES REVIEWED

The zinc-ferricyanide (zinc-REDOX), sealed lead-acid, and hydrogen-nickel oxide batteries were evaluated for stand-alone applications. Subsections describing the life-cycle cost estimates for each of these technologies follow. In addition, a subsection detailing diesel-electric generator costs, the comparison technology, is included. Each subsection includes a summary of the nominal and range estimates used in the life-cycle cost analysis, the system characteristics that affect the life-cycle cost model output, and the levelized output cost. As backup to each summary, a subsection is included for each major input category detailing the method for the input preparation. Appendix E presents a third layer of detail, providing sufficient data were available to warrant such a discussion.

SEALED LEAD-ACID
BATTERY

4.2.1 Sealed Lead-Acid Battery

The sealed lead-acid battery represents a technology that is presently available for stand-alone applications, although it is not yet completely mature and cost estimates are limited. Because published data that define detailed systems and project future costs are limited, the estimates presented here are based primarily on Bechtel's photovoltaic report (1982). Because data are mainly from one source, which does not account for recent developments in sealed lead-acid technology, confidence in these estimates is limited. Life-cycle cost estimates for the sealed lead-acid cell are presented in Table 4.1. The sources used to develop these estimates are listed in Table 4.2.

TABLE 4.1. Sealed Lead-Acid Battery System Life-Cycle Economics

Cycle Life: 1500
Cell Efficiency: 0.75
System Efficiency: 0.66

Nominal Estimate (mid-1988\$)

Battery Purchase Cost (\$/kWh): 203
Battery Installation (\$/kWh): 287
Energy-Related Balance-of-Plant (\$/kWh): 602
Power-Related Balance-of-Plant (\$/kWe): 604
Net Salvage Value (\$/kWh): 9

Annual Operating & Maintenance Costs (\$/yr): 640

Levelized Output Cost: \$1.86 cents/kWh of energy retrieved

Range of Estimates (mid-1988\$)

Battery Purchase Cost (\$/kWh): 155 - 250
Battery Installation (\$/kWh): 248 - 313
Energy-Related Balance-of-Plant (\$/kWh): 512 - 662
Power-Related Balance-of-Plant (\$/kWh): 519 - 761
Net Salvage Value (\$/kWh): 12 - 1

Annual Operating & Maintenance Costs (\$/kWh): 280 - 1000

Levelized Storage Cost: \$1.56 - \$2.11/kWh of Energy Retrieved

TABLE 4.2. Bibliography of Key Sources Used to Evaluate the Sealed Lead-Acid Battery Technology

1. Abraham, J., et al. 1985a. Technical and Economic Assessment of Electrochemical Energy Storage Systems: Lead-Acid Battery Plant Description, Cost Estimate, Credible Accident and Efficiency Assessment.
2. Abraham, J., et al. 1985c. Technical and Economic Assessments of Electrochemical Energy Storage Systems: Topical Report on the Potential for Savings in Load-Leveling Battery and Balance-of-Plant Costs.
3. Bechtel Group, Inc. 1982. Study of Installed and Life-Cycle Costs for Batteries in Photovoltaic Power Systems.
4. Eckroad, S. W., et al. 1986. "Conceptual Design and Cost Estimate: 10-MW Utility Battery Facility."
5. Stolte, W. J. 1982. Feasibility Assessment of Customer-Side-of-the-Meter Applications For Battery Energy Storage.
6. Stolte, W. J., and S. W. Eckroad. 1985. Updated Cost Estimate and Benefit Analysis of Customer-Owned Battery Energy Storage.

4.2.1.1 Battery Purchase Cost

The battery purchase cost for sealed, lead-acid batteries is based on only one source. The battery cell upon which the source estimate is founded differs from typical load-leveling cells in that it is designed for deep discharge over longer periods of time and is smaller in capacity. Bechtel (1982) estimated the cost of this cell at \$125 to \$193/kWh (1980\$). After normalizing this estimate to a lead price of 20 cents per pound and adjusting to 1988\$, a cost range of \$155/kWh to \$250/kWh results. The nominal estimate was designated as \$203/kWh, the center of the range.

4.2.1.2 Shipping and Installation Cost

Shipping cost data was limited to one source, Bechtel 1982. The shipping costs as estimated by Bechtel for 2.01-MWh, 642-kWh, and 16.1-kWh applications were escalated to 1988\$ to yield values of \$10.6/kWh, \$9.7/kWh, and \$36.6/kWh, respectively. As illustrated by these estimates, shipping costs increase dramatically for small shipments. Estimated shipping for the 50-kWh system evaluated in this study were generated by fitting a curve to the Bechtel data. This curve is represented by equation 4.1. Predicting

shipping costs at a system size of 50-kWh using equation 4.1 yields a value of \$25/kWh.

$$\text{Shipping Cost, \$/kWh} = 75.87 (\text{capacity, kWh})^{-0.28215} \quad (4.1)$$

Installation costs were also estimated based on the Bechtel 1982 systems cost estimates. Bechtel's 1982 estimates for a 2-MWh, 624-kWh, and 16.1-kWh were adjusted to include both direct labor and the associated indirect labor, and for price year. These adjustments resulted in normalized estimates of \$30/kWh, \$28/kWh, and \$641/kWh (mid-1988\$). The installation cost for a 50-kWh system was estimated by fitting a curve to the normalized Bechtel estimates. Equation 4.2 represents this curve. Predicting the 50-kWh system installation cost using this equation yields an estimate of \$262/kWh. High and low installation estimates were obtained by multiplying \$262/kWh by 1.1 and 0.85, respectively. Table 4.3 presents a summary of the normalized shipping and installations costs from each source.

$$\text{Installation Cost, \$/kWh} = 3859 (\text{capacity, kWh})^{-0.68713} \quad (4.2)$$

4.2.1.3 Energy-Related Balance-of-Plant Cost

Energy-related BOP includes battery auxiliaries, engineering, and other capital systems costs not included in any other input category. In general, enclosures, thermal management, ventilation, instrumentation, electrical, and safety equipment are included.

TABLE 4.3. Sealed Lead-Acid Battery Shipping and Installation Cost: Summary of Normalized Estimates (mid-1988\$)

<u>Source</u>	<u>Shipping</u>	<u>Installation Nominal</u>	<u>Range</u>
Bechtel (2-MWh) (Bechtel 1982)	\$10.6/kWh	\$30/kWh	--
Bechtel (642-kWh) (Bechtel 1982)	\$9.7/kWh	\$28/kWh	--
Bechtel (16.1-kWh) (Bechtel 1982)	\$36.7/kWh	\$641/kWh	--
Curve-fit (50 kWh)	\$25/kWh	\$262/kWh	\$223 - 288/kWh
Input nominal estimate: \$287/kWh			
Input range estimate: \$248 - 313/kWh			

The estimates for the 2.01-MWh, 643-kWh, and 16.1-kWh BOPs are \$112/kWh, \$145/kWh, and \$1094/kWh, respectively. Fitting a curve to this data yields equation 4.3. Using this equation, a nominal cost estimate of \$602/kWh for a 50-kWh system was obtained. High and low estimates were obtained by multiplying the nominal estimate of \$602/kWh by 1.1 and 0.85, as the source estimate had done. This yields high and low estimates of \$512 and \$662/kWh (1988\$).

$$\text{Energy-Related BOP Cost, \$/kWh} = 4110 (\text{capacity, kWh})^{-0.49084} \quad (4.3)$$

4.2.1.4 Power-Related Balance-of-Plant Cost

Lacking better source data, a cost curve developed by Bechtel (Stolte and Eckroad 1984) for power converters encompassing the 90-kW to 20-MW range was extrapolated 10-kW. From this curve, a range of \$300 to \$440/kW (1982\$) and a nominal estimate of \$370/kW was estimated. The costs were then escalated to 1988\$; however, these costs are only for the converter and do not include the AC/DC interface, controls, and an enclosure. To aid in estimating the cost of these components, the ratio of converter cost to total power-related BOP for a load-leveling plant was determined. The ratio as calculated from cost data presented in Section B.1.4 is 0.7. Applying this ratio to the straight converter cost yields a normalized power-related BOP cost estimate range of \$519 to 761/kWh. The nominal estimate is \$640/kW (1988\$).

4.2.1.5 Net Salvage Value

The net salvage value for the sealed lead-acid system includes battery removal cost and a scrap credit. Based on Bechtel's (1982) scrap scenario, shipping to the scrap facility was considered negligible because lead reclaiming facilities are already widespread. Based on the same Bechtel document, salvage by scrap was estimated to range from 6% to 17% of the purchase cost. The nominal scrap value was taken as the average of the range, 12%. Battery removal cost was estimated the same as for lead-acid load-leveling cells on a kWh-basis.

Using this base information, nominal and range estimates for salvage were determined as follows. The nominal salvage value is the total of the nominal scrap credit (12%) times the nominal battery purchase cost (\$203/kWh), less deinstallation (\$15/kWh). This yields a nominal salvage value of \$9/kWh (1988\$). The high range estimate (high system life-cycle cost) is the total of the low scrap credit (6%) times the high battery purchase cost (\$250/kWh), less high deinstallation cost (\$13.6/kWh). Following through the calculation, a high-end salvage value of \$1/kWh (1988\$) is obtained. The low-end (low system life-cycle cost) salvage value is estimated in a similar manner. The product of the scrap credit [high credit value (17%) time low purchase cost (\$155/kWh)], less the battery removal cost [the low deinstallation cost (\$11.3/kWh)] results in a low-end scrap value of \$12/kWh. Table 4.4 summarizes the salvage cost estimates.

4.2.1.6 Operating and Maintenance Cost

Operating and maintenance costs will vary considerably with owner attitudes toward routine maintenance and ease of access to the stand-alone location. The two sources evaluated, Gould, Inc. (Ramsay and Edgecomb 1982) and Bechtel (1982), estimated markedly different costs.

Ramsay's estimate for a 50-kWh, 10-kW system allowed for 1 manhour/month plus 8 manhours/yr for a total of \$1000/yr, assuming \$50/manhour. Bechtel's estimate was based on a 16.1-kWh, 8-kW calcium-grid lead-acid battery. Although this battery is not maintenance-free, the manufacturer suggests that for this conventional cell, watering is required only every five years. The manufacturer does suggest a 1-manhour check-out annually. Bechtel translated this information into an estimate of \$4 - 4.80/kWh-of-capacity (1980\$) plus added \$32.50 to 39/kWh-of-capacity (1980\$) in year ten of system life for ventilation fan maintenance.

TABLE 4.4. Conventional Lead-Acid Battery Net Salvage Value:
Summary of Normalized Estimates (mid-1988\$)

Input Nominal Value: 9/kWh

Input Range Estimate: 12 - 1/kWh

Because a ventilation system is not required for a sealed, maintenance-free system, Bechtel's estimate reduces to \$4 - 4.80/kWh per year or \$200 to \$240 (1980\$) (\$281 - \$338/kWh) (1988\$) for a 50-kWh system. This estimate of \$281 - \$338/yr for a conventional limited-maintenance lead-acid battery system is quite different from the \$1000/yr estimated by Ramsay. The Ramsay methodology seems reasonable, although a monthly check-out may be a conservative operating mode. Because the Bechtel estimate was based on manufacturer estimates, it is founded on a strong knowledge base; however, it is more likely low than high.

To generate the life-cycle cost estimates, both source estimates were used to define the range. The middle of the range was used as the nominal estimate. In summary, the annual O&M estimates are as follows: nominal estimate, \$640; range of estimates, \$280 - \$1000/yr.

HYDROGEN-NICKEL
OXIDE BATTERY

4.2.2 Hydrogen-Nickel Oxide Battery

The hydrogen-nickel oxide battery was originally developed for satellite applications and is currently being redesigned for terrestrial, stand-alone applications. Because it is still in the design phase, cost data is almost nonexistent. The developers have projected a consumer cost based on what they define as reasonable advances. BOP costs have been generalized by the developers as being similar to those of a sealed lead-acid battery. While this may in fact be a valid assumption, without details to support it, the certainty of the overall hydrogen-nickel oxide estimate is not as high as it might otherwise be. Also, because the BOP, O&M, shipping, and installation costs are presumed to be nearly equal, the final life-cycle cost estimates are similar. This may not be an accurate representation. The life-cycle economics of the hydrogen-nickel oxide battery are summarized in Table 4.5. The sources used to derive these estimates are listed in Table 4.6.

4.2.2.1 Battery Purchase Cost

Availability of hydrogen-nickel oxide cost data is quite limited. While many reports and papers discuss cost, they are based mainly on one estimate: Sindorf et al. 1985. Based on this source, \$992/kWh (1986\$) was taken as the nominal and high estimate. This represents the estimated cost for producing hydrogen-nickel oxide batteries on an assembly-limited production schedule using available technology. The low end of the range was taken as the \$375/kWh (\$400/kWh in 1988\$) cost goal.

4.2.2.2 Shipping and Installation Cost

Both the sealed lead-acid battery system and hydrogen-nickel oxide battery system weigh approximately the same, and neither has extraordinary shipping requirements; therefore, shipping costs for the hydrogen nickel-oxide system are estimated to be the same as for the lead-acid battery. Likewise, installation costs are assumed to be the same. Table 4.7 presents the shipping and installation costs.

TABLE 4.5. Hydrogen-Nickel Oxide Battery System Life-Cycle Economics

Cycle Life: 6000
Cell Efficiency: 0.85
System Efficiency: 0.75

Nominal Estimate (mid-1988\$)

Battery Purchase Cost (\$/kWh): 989
Battery Installation (\$/kWh): 287
Energy-Related Balance-of-Plant (\$/kWh): 602
Power-Related Balance-of-Plant (\$/kWe): 640
Net Salvage Value (\$/kWh): 56

Annual Operating & Maintenance Costs (\$/yr): 640

Levelized Storage Cost: \$1.65/kWh of energy retrieved

Range of Estimates (mid-1988\$)

Battery Purchase Cost (\$/kWh): 400 - 989
Battery Installation (\$/kWh): 248 - 313
Energy-Related Balance-of-Plant (\$/kWh): 512 - 662
Power-Related Balance-of-Plant (\$/kWe): 519 - 761
Net Salvage Value (\$/kWh): 34 - 56

Annual Operating & Maintenance Costs (\$/yr.): 280 - 1000

Levelized Storage Cost: \$1.14 - 1.77/kWh of energy retrieved

TABLE 4.6. Bibliography of Key Sources Used to Evaluate the Hydrogen-Nickel Oxide Battery Technology

1. Bechtel Group, Inc. 1982. Study of Installed and Life-Cycle Costs for Batteries in Photovoltaic Power Systems.
2. Ounlop, J. D., and R. Beauchamp. 1987. Making Space Nickel/Hydrogen Batteries Lighter and Less Expensive.
3. Sindorf, J. F., et al. 1985. "Design and Cost Study of a 15-kWh Hydrogen-Nickel Oxide Battery for Photovoltaic Applications."
4. Stolte, W. J. 1982. Feasibility Assessment of Customer-Side-of-the-Meter Applications for Battery Energy Storage.

TABLE 4.7. Hydrogen-Nickel Oxide Battery Shipping and Installation Cost:
Summary of Normalized Estimates (mid-1988\$)

<u>Source</u>	<u>Shipping</u>	<u>Installation Nominal</u>	<u>Range</u>
Bechtel (2-MWh) (Bechtel 1982)	\$10.6/kWh	\$30/kWh	--
Bechtel (642-kWh) (Bechtel 1982)	\$9.57/kWh	\$28/kWh	--
Bechtel (16.1-kWh) (Bechtel 1982)	\$36.7/kWh	\$641/kWh	--
Curve-fit (50-kWh)	\$25/kWh	\$262/kWh	\$223 - 288/kWh
Input nominal estimate: \$287/kWh			
Input range estimate: \$248 - 313/kWh			

4.2.2.3 Energy-Related Balance-of-Plant Cost

As mentioned in Section 4.2.2, BOP costs have been generalized by the developers as being similar to those of a maintenance-free lead-acid battery. Because no specifics have been published, this generalization was presumed to be true. Therefore, for details on energy-related BOP, refer to Section 4.1.2.3, which details lead-acid battery BOP costs.

4.2.2.4 Power-Related Balance-of-Plant Cost

Refer to Sections 4.2.2.3 and 4.1.2.4.

4.2.2.5 Net Salvage Value

No data sources reviewed included detailed salvage value data. The main components of value in an old hydrogen-nickel oxide battery are the electrodes. The electrode material comprises 7% of the initial cost at a production rate of 72 batteries per year. On the assumption mass-production would reduce fabrication costs more than materials, 7% was taken as the nominal value. Five percent was used as the low value to reflect handling and processing costs. Ten percent was chosen as a high value. On a percentage-basis, these scrap value estimates are somewhat lower than the corresponding lead-acid estimates (6 - 17%); however this seems justified, because there is a widespread salvage network for lead-acid batteries and the hydrogen-nickel oxide cell has other high-priced components that drive up the initial cost over that of lead-acid cells. For lack of better data, deinstallation was

presumed to be the same on a kWh-basis as for lead-acid cells. Shipping to the factory or specialized salvage facility was estimated as \$10/kWh.

Table 4.8 summarizes the salvage assumptions.

Using the above data, a nominal salvage value of \$56/kWh is estimated. The range of estimates is therefore \$34/kWh to \$56/kWh.

4.2.2.6 Operating and Maintenance Cost

Hydrogen-nickel oxide O&M data is as equally as scarce as lead-acid O&M data. It is generally assumed that hydrogen-nickel oxide batteries will require extremely minimal maintenance because they are hermetically sealed. There would, however, seem to be a very high cost of repair if something in the battery pressure vessel failed. It would be prudent to check the system at least occasionally in the same manner presumed for the lead-acid battery system. Consequently, the nominal and range cost estimates were assumed the same at \$640 and \$280 - \$1000, respectively.

TABLE 4.8. Salvage Value Assumptions for the Hydrogen-Nickel Oxide Battery

	<u>High</u>	<u>Nominal</u>	<u>Low</u>
Deinstallation	\$15/kWh	\$13.6/kWh	\$11.3/kWh
Scrap of % of initial cost	5%	7%	10%
Initial Cost	\$989/kWh	\$989/kWh	\$400/kWh
Shipping	\$10/kWh	\$10/kWh	\$10/kWh

ZINC-FERRICYANIDE
(ZINC-REDOX)
BATTERY

4.2.3 Zinc-Ferricyanide (Zinc-REDOX) Battery

Data on the zinc-ferricyanide (zinc-REDOX) battery is limited, but several cost studies, albeit minimal in detail, have been performed. One difficulty encountered in arriving at a good nominal cost estimate was that estimates for 50-kWh, 10-kW systems could not be located. The input estimates are based primarily on a REDOX battery for a 50-kWh, 1-kW battery with a 5-kW peak (Hollandsworth et al. 1987). BOP and O&M data were derived from a cost estimate for an iron-chromium REDOX battery presented in Bechtel's photovoltaic report (1982). The life-cycle economics of the zinc-REDOX battery are presented in Table 4.9. The sources upon which these estimates are based are listed in Table 4.10. It should be noted that this technology is not currently under development because of difficulties encountered in some previous efforts. Should the difficulties be solvable, this technology could become competitive.

4.2.3.1 Battery Purchase Cost

Because the source cost estimate was based on a smaller battery than the 50-kWh, 10-kW standard system size used in this study, the source cost estimate was broken into two cost components: energy-related and power-related. The power-related side was then scaled to meet the 10-kW power rating used in this comparison. The normalized estimate, as prepared in Appendix E.3.1, for a 50-kWh, 10-kW battery is \$349/kWh (1988\$).

TABLE 4.9. Zinc-Ferricyanide Battery System Life-Cycle Economics

Cycle Life: 1000

System Efficiency: 0.72

Nominal Estimate (mid-1988\$)

Battery Purchase Cost (\$/kWh): 349

Battery Installation (\$/kWh): 287

Energy-Related Balance-of-Plant (\$/kWh): 196

Power-Related Balance-of-Plant (\$/kWe): 640

Net Salvage Value (\$/kWh): 0

Annual Operating & Maintenance Costs (\$/yr): 1330

Levelized Storage Cost: \$1.50/kWh of energy retrieved

TABLE 4.10. Bibliography of Key Sources Used to Evaluate the Zinc-Ferricyanide Battery Technology

1. Adams, G. B., et al. 1983. Rechargeable Alkaline Zinc/Ferricyanide Battery Phase III.
2. Bechtel Group, Inc. 1982. Study of Installed and Life-Cycle Costs for Batteries in Photovoltaic Power Systems.
3. Hollandsworth, R. P., et al. 1987. Zinc-REDOX Battery Development: Phase V.
4. Stedman, J. K., et al. 1980. Cost Projections for REDOX Energy Storage Systems.
5. Stolte, W. J. 1982. Feasibility Assessment of Customer-Side-of-the Meter Applications for Battery Energy Storage.

4.2.3.2 Shipping and Installation Cost

Shipping and installation cost information for the zinc-REDOX battery are unavailable. It was assumed that shipping and installation costs are comparable to those of the lead-acid stand-alone system. Table 4.11 summarizes these assumptions.

4.2.3.3 Energy-Related Balance-of-Plant Cost

Bechtel presented four estimates for the energy-related BOP for an iron-chromium REDOX system. It is assumed the zinc-REDOX system is similar.

From an examination of the source estimate, which is presented in Appendix E.3.3, the BOP for the 160-kWh, 8-kW system should be about the same as for a 50-kWh, 10-kW system. Therefore the 160-kWh, 8-kW system cost of \$6993 (1980\$) was used as the nominal estimate for the 50-kWh, 10-kW evaluated here. After escalating to 1988\$, a cost of \$9790 (\$196/kWh) results.

4.2.3.4 Power-Related Balance-of-Plant Cost

Power-related BOP costs are assumed equivalent to those for the lead-acid system.

TABLE 4.11. Shipping and Installation Assumptions for the Zinc-Ferricyanide Battery System (1988\$)

Input Nominal Estimate: \$287/kWh

Input Range Estimate: \$248 - 313/kWh

4.2.3.5 Net Salvage Value

Bechtel estimated scrap value of an iron-chromium stack at \$25/kW when initial materials were estimated as roughly \$500/kW. Deinstallation was estimated to cost \$25/kW and electrolyte was recovered with a value of 30% of its initial cost. Applying this same method to the zinc-REDOX system would result in a net salvage value of approximately zero, as credits equal deinstallation charges.

4.2.3.6 Operating and Maintenance Cost

Maintenance is relatively minimal. Routine inspection and pump repair are all that is required. For an 8-kW iron-chromium REDOX system, Bechtel estimated \$292 to \$409/yr for routine maintenance and an average of \$600 per year for pump replacement every five years. The total average cost is \$950/yr (1980\$). Escalating to mid-1988\$, a cost of \$1330 results.

CONVENTIONAL DIESEL-
ELECTRIC GENERATOR

4.2.4 Conventional Diesel-Electric Generator

As a comparison technology, a 10-kW diesel generator operating 5 hours per day was evaluated. The generator system includes the generator itself, foundations and enclosures, large capacity fuel storage tank, and controller to start and stop the unit. Engine life is estimated at 5000 hours. Table 4.12 presents the life-cycle cost estimates for the electric generator system. The sources used to develop these estimates are listed in Table 4.13.

TABLE 4.12. Diesel-Power Electric Generator Life-Cycle Economics

Cycle life: 1000

Nominal World Oil Price Estimate (fuel esc. at 3.8%/yr, 1988\$)

Power-Related Capital Costs (\$/kW): 375
Operating and Maintenance Costs (cents/kWh): 2^(a)
Annual Fossil Fuel Consumption (MBTU/yr): 190^(b)
Fossil Fuel Cost (\$/MBTU): 21.76

Levelized Output Cost: 74.1 cents/kWh of energy generated

Range of Estimates

Power-Related Capital Costs (\$/kW): 375
Operating and Maintenance Costs (cents/kWh/yr): 2^(a)
Annual Fossil Fuel Consumption (MBTU/yr): 190^(b)
Fossil Fuel Cost (\$/MBTU): 4.86 - 72.54

Levelized Output Cost: \$0.271/kWh - \$2.15/kWh of energy generated

-
- (a) Rounded from 1.7 cents/kWh for 300-kW unit.
(b) (25.5 gal/hr) (10 kW/350 kW) (365 days/yr) (24 hrs/day)
(0.1387 MBTU/gal).

TABLE 4.13. Bibliography of Key Sources Used to Evaluate the Diesel-Electric Generator Technology

1. Energy Information Administration (EIA). 1988. Annual Energy Outlook: 1987.
2. Rotgans, E. A. 1987. "Diesel Power Generation at Coast Guard's Mountain-Top VHF Repeater Sites."

Perhaps the most volatile factor in a generalized estimate for diesel-electric generators is the fuel cost. Fuel cost can vary from the average cost to the commercial sector of 4.86/MBTU (1988\$) (EIA 1988), which is roughly \$0.67/gallon for an easily accessible site, to \$10/gallon for sites requiring airlift of fuel. Rotgans (1987) estimates 15.0 - 30.0 cents/kWh for fuel used in his Coast Guard district, which is approximately \$2 - 4/gallon for diesel-electrics. As the low estimate \$0.67/gallon was used. This is representative of a lowest achievable cost. The center of Rotgans' range, \$3 per gallon, was used as the nominal estimate. The high estimate was based on \$10/gallon, the cost of airlifted fuel. Converting the low, nominal, and high estimates to dollars-per-MBTU yields estimates of \$4.86/MBTU, \$21.76/MBTU, and \$72.54/MBTU, respectively. EIA (1988) estimates escalation until the year 2000 to range from 3.3 - 4.5%/yr. EIA's nominal estimate of 3.8%/yr was used in all estimates.

5.0 ELECTRIC VEHICLE APPLICATION

5.0 ELECTRIC VEHICLE APPLICATION

The electric vehicle life-cycle cost estimates are presented in the form of levelized cost per kilometer traveled. Comparison on a kilometer-traveled basis normalizes the technologies for differences in initial vehicle cost, salvage value, and maintenance costs over the assumed ten-year vehicle life. Operating costs include the cost of input electricity (or fossil fuel in the case of fuel cell-powered vehicles), replacement batteries and tires, insurance, storage, parking, tolls, title, registration and license. As a baseline for comparison, a levelized cost per kilometer for an internal combustion engine (ICE)-powered vehicle was developed. At their current level of development, operating and maintenance (O&M) cost estimates for electric vehicles are based mostly on conjecture. For this reason, although O&M estimates are presented in absolute dollars, the figure of merit is the relative difference in cost.

Figure 5.1 presents the life-cycle cost estimates generated for five battery technologies used to power vans over a 96-km duty cycle. The bars in Figure 5.1 marked by asterisks indicate battery-powered vans approximately equivalent in performance to a gasoline-fueled, ICE-powered van. The unmarked bars represent life-cycle cost estimates associated with light-duty vans, roughly equivalent to a diesel-fueled ICE-powered van. As illustrated in Figure 5.1, most of the light-duty vans fall within 25% of the life-cycle cost estimate for an ICE-powered van. This indicates that, developed to its full potential, one or more of these technologies could be quite competitive in duties that require only limited performance over a short distance. The full-performance and light-duty sodium-sulfur systems are considerably more expensive (35% to 50%) than traditional ICE-powered vans. It will require more than high fossil fuel costs to facilitate the introduction and acceptance of these vehicles. The value of differential benefits, such as low noise and emission levels, may play a major role.

Figure 5.2 presents life-cycle cost estimates for full-performance five-passenger vehicles using four different battery and fuel cell technologies. As shown, the full-performance battery and fuel cell-powered vehicles range

FIGURE 5.1. Levelized Cost per Kilometer-Traveled for Electric Vans

FIGURE 5.2. Levelized Cost per Kilometer-Traveled for Electric Cars

from 50% to 100% more expensive than comparable ICE-powered vehicles operating over a 400-kilometer duty cycle. This information reinforces the notion that differential benefits will be of major importance in determining the acceptance of many electric vehicles.

5.1 SPECIFIC APPROACH TO ELECTRIC VEHICLES

Generating technically and economically consistent life-cycle cost estimates for electric vehicles from a number of studies is extremely difficult. While individual comparative studies generally maintain consistency within the study, each study includes unique basic assumptions that make direct comparison of summary results between sources difficult and in some cases totally incorrect. Generally, the basic assumptions are "imbedded" so deeply in the systems analysis that it is difficult and sometimes impossible to convert data from different sources to the same basis without the resources to completely understand the procedure used in each study. Common

assumptions that differ among studies are the mission requirements, such as vehicle range, acceleration capability, gradability; and other performance characteristics, such as specific power, specific energy, and average depth of discharge required to meet the assumed mission.

To circumvent the difficulty of equitable comparison, source cost estimates were normalized to the same financial assumptions, and for each estimate underlying assumptions as identified by the respective source study are stated. Electric vehicle costs are primarily based on data in the 1985 Jet Propulsion Laboratory (JPL) electric vehicle comparison study entitled, Advanced Vehicle Systems Assessment (Hardy et al. 1985). The exhaustive effort conducted by JPL and independent contributors is one of the most authoritative documents for electric vehicle costs. A number of additional electric vehicle studies were reviewed, and in cases where more recent or more complete data existed, the new data replaced the corresponding element of the JPL study. Details of the JPL study, the corresponding changes made to this data, additional source data, and life-cycle cost calculations are presented in Appendices G through I.

Life-cycle costs for the electric vehicle applications are based on three types of vehicles: 1) light-duty vans, 2) full-performance vans, and 3) full-performance five-passenger cars. The batteries and fuel cells evaluated for each of these applications are presented in Table 5.1. The determination of which battery or fuel cell systems were evaluated for a particular vehicle type and respective mission requirements was based on availability of data only. It is not intended to imply that a system not evaluated for a particular vehicle could not be sized to power that vehicle.

5.1.1 Electric Van Mission Requirements

Life-cycle cost estimates were based on two sets of electric van performance requirements. The first set was the basis used in JPL's evaluation, and the second set was the basis of an EPRI evaluation (Consiglio and Symons 1985) of battery systems used in full performance vans. Life-cycle cost estimates for a full-performance internal combustion engine-powered van burning methanol was developed for comparative purposes.

TABLE 5.1. Electric Vehicle/Propulsion System Combinations Evaluated

	Full- Performance Van	Light- Duty Van	Full- Performance Five- Passenger Car
Internal Combustion Engine	x	--	x
Conventional Lead-Acid	x	--	--
Sealed Lead-Acid	--	x	--
Zinc-Bromine	--	x	--
Lithium-Iron Sulfide	x	x	x
Sodium-Sulfur	x	x	x
Aluminum-Air	--	--	x
Proton Exchange Membrane	--	--	x

The mission requirements that are the basis for the JPL-based cost estimates are not as demanding as those required by general-purpose applications. Acceleration to 88 km/hr is assumed to require 27 seconds, which is approximately equivalent to a diesel vehicle. The gradability requirement is 3% for 5 km at 88 km/hr on the Federal Urban Driving Schedule. Average payload is 295 kg, including the driver. The required vehicle range is 96 km (60 miles).

The mission requirements for the EPRI-based cost estimates are much more stringent. The required vehicle range is 96 km (60 miles) on the Society of Automotive Engineers J227a(D) driving schedule. Acceleration and gradability characteristics are similar to those of ICE-powered vehicles in the same service. Range and acceleration characteristics are stipulated to be attainable at any temperature from 0° to 120°F throughout vehicle life. Payload capacity is 1000 lbs excluding the driver, and cargo volume is at least 100 ft³ (Consiglio and Symons 1985). To distinguish the estimates in the text from each other if they have different bases, estimates using the EPRI-basis are referred to as full-performance vans, while estimates for vehicles adhering to the JPL-based mission requirements are referred to as light-duty vans.

5.1.2 Five-Passenger Car Mission Requirements

The mission requirements for the full-performance five-passenger car are taken from the JPL study. Acceleration to 88 km/hr is assumed to occur in 20 seconds. Gradability is 7% for 5 km at 88 km/hr on the Federal Urban Driving Schedule. Average payload is 136 kg, including a passenger. The required vehicle range is 400 km.

5.2 TECHNOLOGIES REVIEWED

Seven battery and fuel cell technologies, including the zinc-bromine battery, the sodium-sulfur battery, the conventional lead-acid battery, the sealed lead-acid battery, the lithium-iron sulfide battery, the aluminum-air battery, and the proton exchange membrane fuel cell, were evaluated for the electric vehicle application. Subsections 5.2.1 through 5.2.8 summarize the life-cycle cost inputs for each of the technologies reviewed, plus the internal combustion engine-powered vehicle, the comparison technology.

CONVENTIONAL
LEAD-ACID BATTERY

5.2.1 Conventional Lead-Acid Battery

For current electric vehicle applications, the lead-acid battery is used almost exclusively. Its role as an electric vehicle power source will probably continue until superior technologies are developed. It is doubtful that it could take over a significant market due to its low theoretical specific energy (energy per unit mass). The life-cycle economics of the conventional lead-acid battery for two electric vehicle applications are presented in Tables 5.2 and 5.3. Sources used as the basis for the conventional lead-acid battery estimates are listed in Table 5.4.

TABLE 5.2. Conventional Lead-Acid Battery System Life-Cycle Economics for Light-Duty Vans

Cycle Life @ 80% DoD:	750
Average Daily DoD:	0.319
System Efficiency:	0.648
System Size:	61.2 kW, 18.6 kWh
Annual Electricity Usage:	3075 kWh
Annual Distance Traveled:	12848 km
Battery Purchase Cost (\$/kWh) +	70.9
(\$/kW) +	14.4
(\$)	<u>660</u>
Total Battery Cost (\$)	2,860
Basic Vehicle Cost	10,004
Motor Cost	853
Controller Cost	2,243
EV Transmission Cost	<u>232</u>
Total Vehicle (exclude battery)	13,332
Repairs and Maintenance (annual)	276
Replacement Tires (yr 5)	411
Insurance (annual)	421
Garaging, Parking Tolls (annual)	94
Title, Registration, License (yr 0)	810
Registration, License (annual)	24
Vehicle Salvage Value	1619
Levelized Cost:	31.5 cents/km-traveled

TABLE 5.3. Conventional Lead-Acid Battery System Life-Cycle Economics for Full-Performance Vans

Cycle Life @ 80% DoD:	800
System Efficiency:	0.65
System Size:	43 kWh
Annual Electricity Usage:	5175 kWh
Annual Distance Traveled:	12848 km
Battery Purchase Cost (\$/kWh) +	--
(\$/kW) +	--
(\$)	5,203
Basic Vehicle Cost	10,208
Motor Cost	1,208
Controller Cost	3,175
EV Transmission Cost	<u>328</u>
Total Vehicle Cost (excl. Battery)	14,919
Repairs and Maintenance (annual)	307
Replacement Tires (yr 5)	480
Insurance (annual)	421
Garaging, Parking Tolls (annual)	94
Title, Registration, License (yr 0)	1006
Registration, License (annual)	24
Vehicle Salvage Value	2012
Levelized Cost:	39.6 cents/km-traveled

TABLE 5.4. Bibliography of Key Sources Used to Evaluate the Conventional Lead-Acid Battery Technology

1. Consiglio, J. A., and P. C. Symons. 1985. Evaluation of Developmental Battery Cost Estimates.
2. Jet Propulsion Laboratory. 1982. Advanced Vehicle Subsystem Technology Assessment.
3. Jet Propulsion Laboratory. 1984. The Advanced Vehicle Assessment. Presentation Document.
4. Hardy, K. S., et al. 1985. Advanced Vehicle Systems Assessment.

Development assumptions associated with the estimates presented in Table 5.2 and 5.3 as identified in the JPL study are as follows:

1. improved active material utilization, especially at high rates of discharge
2. significant reduction in grid weight (e.g., through the use of composite grids)
3. improved specific power toward the end of discharge
4. reduction in battery volume, achieved through specific energy improvements
5. cycle-life improvements with regard to capacity, maintenance, and power capability; reduced shedding; and positive grid corrosion
6. successful demonstration of reliable pumps, central point-watering, and thermal management systems.

These assumptions are based on the Globe-Union ISOA (pulsed electrolyte) battery technology.

SEALED LEAD-ACID
BATTERY

5.2.2 Sealed Lead-Acid Battery

The sealed lead-acid battery is a variation of conventional lead-acid batteries. JPL projects that the sealed lead-acid battery will have improved power and energy densities as compared with the conventional technology. An additional advantage of the sealed technology is that maintenance on the battery itself is almost unnecessary. It is still questionable whether sealed lead-acid batteries can gain a significant long-run market share because of many of the same reasons the conventional battery system may not. The life-cycle economics of the sealed lead-acid battery system for a light-duty van are presented in Table 5.5. The sources upon which these estimates are based are listed in Table 5.6.

Development assumptions associated with the estimates presented in Table 5.5, as presented in the JPL study, are as follows:

1. high-conductivity, corrosion-resistant bipolar membrane
2. development of reliable intra-cell sealing
3. improved active material use
4. demonstration of adequate cycle life in bipolar configuration
5. demonstration of effective heat dissipation, especially during charge.

Although the projections for the bipolar system are attractive for a lead-acid technology, the system is still at an early stage of development.

TABLE 5.5. Sealed Lead-Acid Battery System Life-Cycle Economics for Light-Duty Vans

Cycle Life @ 80% DOD:	750
Average Daily DOD:	0.355
System Efficiency:	0.65
System Size:	14.6 kWh
Annual Electricity Usage:	2393 kWh
Annual Distance Traveled:	12848 km
Battery Purchase Cost (\$/kWh) +	97
(\$/kw) +	--
(\$)	--
Total Battery Cost (\$)	1,416
Basic Vehicle Cost	9,570
Motor Cost	759
Controller Cost	1,993
EV Transmission Cost	206
Total Vehicle Cost (excl. Battery)	12,528
Repairs and Maintenance (annual)	188
Replacement Tires (yr 5)	387
Insurance (annual)	421
Garaging, Parking Tolls (annual)	94
Title, Registration, License (yr 0)	697
Registration, License (annual)	24
Vehicle Salvage Cost	1,394
Levelized Cost:	26.4 cents/km-traveled

TABLE 5.6. Bibliography of Key Sources Used to Evaluate the Sealed Lead-Acid Battery Technology

1. Hardy, K. S., et al. 1985. Advanced Vehicle Systems Assessment.
2. Jet Propulsion Laboratory. 1982. Advanced Vehicle Subsystem Technology Assessment.
3. Jet Propulsion Laboratory. 1984. Advanced Vehicle Assessment. Presentation Document.

ZINC-BROMINE
BATTERY

5.2.3 Zinc-Bromine Battery

The zinc-bromine battery estimate is based upon Exxon battery technology. This battery has the major advantages of relatively low initial capital cost and a higher energy density than the lead-acid batteries, but projected system efficiency is relatively low. Another drawback to using the zinc-bromine technology is that complete discharge is required every several cycles, which could be inconvenient to the user. JPL believes that the battery's large size is its most important disadvantage. The life-cycle economics of the zinc-bromine battery are presented in Table 5.7. The sources used to develop these estimates are listed in Table 5.8.

Key development strides identified by JPL that must be realized in order to achieve the estimates presented in Table 5.7 include the following:

1. development of electrodes and other cell-stack components that will give stable energy and power over extended periods
2. development of leak-free cell stacks and ancillary hardware
3. improved power capability, specifically during extended high-rate discharge and at low states of charge
4. improved columbic efficiency during interrupted discharge
5. improved shunt-current protection, especially in high-voltage cell stacks for electric vehicles
6. development of efficient and reliable mechanical components such as pumps and thermal and electrolyte management systems.

**TABLE 5.7. Zinc-Bromine Battery System Life-Cycle Economics
for Light-Duty Vans**

Cycle Life @ 80% DoD:	750
Average Daily DoD:	0.310
System Efficiency:	0.40
System Size:	60 kW, 21.2 kWh
Annual Electricity Usage:	5172 kWh
Annual Distance Traveled:	12848 km
Battery Purchase Cost (\$/kWh) +	33
(\$/Kw) +	16.3
(\$)	<u>1,151.6</u>
Total Battery Cost (\$)	2860
Basic Vehicle Cost	9,975
Motor Cost	848
Controller Cost	2,232
EV Transmission Cost	<u>231</u>
Total Vehicle Cost (excl. Battery)	13,286
Repairs and Maintenance (annual)	454
Replacement Tires (yr 5)	410
Insurance (annual)	421
Garaging, Parking Tolls (annual)	94
Title, Registration, License (yr 0)	807
Registration, License (annual)	24
Vehicle Salvage Value	1,614
Levelized Cost:	33.5 cents/km-traveled

TABLE 5.8. Bibliography of Key Sources Used to Evaluate the Zinc-Bromine Battery Technology

1. Bellows, R., et al. 1982. Zinc-Bromine Battery Design for Electric Vehicles.
2. Hardy, K. S., et al. 1985. Advanced Vehicle Systems Assessment.
3. Jet Propulsion Laboratory. 1982. Advanced Vehicle Subsystem Technology Assessment.
4. Jet Propulsion Laboratory. 1984. Advanced Vehicle Assessment. Presentation Document.
5. Symons, P. 1984. Design Analyses of Exxon Zinc-Bromine Batteries for Various Electric Vehicles.

SODIUM-SULFUR
BATTERY

5.2.4 Sodium-Sulfur Battery

Sodium-sulfur cells have good potential for electric vehicle applications. It is projected that the sodium-sulfur battery will be able to meet the electrical vehicle energy and power-related requirements in the laboratory, but it is less certain they can meet these requirements during the harsh electric vehicle application discharge scenario. A major problem with the sodium-sulfur battery system is its high operating temperature. Bulky insulation is required, and it is difficult to perform maintenance on the battery. The life-cycle economics for three electric vehicle applications are presented in Tables 5.9 through 5.11. Sources for the cost estimates are presented in Table 5.12.

In order for the costs presented in Table 5.9 through 5.11 to be realized, the following developments, as identified by JPL, must occur:

- 1) development of reproducible, strong, and low resistance B-alumina tubes produced from low-cost starting materials and using potentially low-cost processing methods
- 2) demonstration that the cycle lives of such tubes exhibit good Weibull-shape factors
- 3) demonstration of ability of such tubes to undergo repeated freeze-thaw cycling without cell failures
- 4) successful demonstration of low-cost, corrosion-resistant construction materials and positive electrode-current collectors
- 5) demonstration that batteries can be developed that are tolerant to on-the-road conditions without ceramic failure (safety considerations).

TABLE 5.9. Sodium-Sulfur Battery System Life-Cycle Economics for Light-Duty Vans

Cycle Life @ 80% DoD:	750
Average Daily DoD:	0.244
System Efficiency:	.57
System Size:	42.8 kW, 15.9 kWh
Annual Electricity Usage:	3035 kWh
Annual Distance Traveled:	12848
Battery Purchase Cost (\$/kWh) +	41.3
(\$/kW) +	74.3
(\$)	<u>1,650</u>
Total Battery (\$)	5,487
Basic Vehicle Cost	9,288
Motor Cost	699
Controller Cost	1,836
EV Transmission Cost	<u>190</u>
Total Vehicle Cost (excl. Battery)	12,013
Repairs and Maintenance (annual)	409
Replacement Tires (yr 5)	371
Insurance (annual)	421
Garaging, Parking Tolls (annual)	94
Title, Registration, License (yr 0)	875
Registration, License (annual)	24
Vehicle Salvage Value	1,750
Levelized Cost:	36.4 cents/km-traveled

**TABLE 5.10. Sodium-Sulfur Battery System Life-Cycle Economics
for Full-Performance Vans**

Cycle Life @ 80% DoD:	1000 - 96 km cycles
System Efficiency:	0.57
System Size:	25.8 kWh
Annual Electricity Usage:	4158 kWh
Annual Distance Traveled:	12848 km
Battery Purchase Cost (\$/kWh) + (\$/kW) + (\$)	6,413
Basic Vehicle Cost	8,996
Motor Cost	2,027
Controller Cost	1,045
EV Transmission Cost	<u>190</u>
Total Vehicle Cost (excl. Battery)	12,258
Repairs and Maintenance (annual)	426
Replacement Tires (yr 5)	386
Insurance (annual)	421
Garaging, Parking Tolls (annual)	94
Title, Registration, License (yr 0)	934
Registration, License (annual)	24
Vehicle Salvage Value	1867
Levelized Cost:	39.3 cents/km-traveled

**TABLE 5.11. Sodium-Sulfur Battery System Life-Cycle Economics
for Full-Performance, Five-Passenger Cars**

Cycle Life @ 80% DoD:	750
Average Daily DoD:	0.109
System Efficiency:	0.57
System Size:	106.6 kW, 31.9 kWh
Annual Electricity Usage:	3616 kWh
Annual Distance Traveled:	16611 km
Battery Purchase Cost (\$/kWh) +	41.3
(\$/kW) +	74.3
(\$)	<u>1,650</u>
Total Battery Cost (\$)	10,888
Basic Vehicle Cost	8,395
Motor Cost	975
Controller Cost	2,565
EV Transmission Cost	<u>265</u>
Total Vehicle Cost (excl. Battery)	12,200
Repairs and Maintenance (annual)	500
Replacement Tires (yr 5)	620
Insurance (annual)	421
Garaging, Parking Tolls (annual)	94
Title, Registration, License (yr 0)	1,154
Registration, License (annual)	24
Vehicle Salvage Value	2,309
Levelized Cost:	31.1 cents/km-traveled

TABLE 5.12. Bibliography of Key Sources Used to Evaluate the Sodium-Sulfur Battery Technology

1. Consiglio, J. A., and P. C. Symons. 1985. Evaluation of Developmental Battery Cost Estimates.
2. Chloride Silent Power Ltd. (CSPL). 1986c. "Sodium-Sulfur EV Battery Engineering Program."
3. Ford Aerospace and Communications Corporation. 1984. Battery Design Analysis.
4. Hardy, K. S., et al. 1985. Advanced Vehicle Systems Assessment.
5. Jet Propulsion Laboratory. 1982. Advanced Vehicle Subsystem Technology Assessment.
6. Jet Propulsion Laboratory. 1984. Advanced Vehicle Assessment. Presentation Document.
7. Levine, C. 1981. Development of a Sodium-Sulfur Battery Suitable for Use by Electric Utilities and for Vehicular Propulsion.

LITHIUM-IRON
SULFIDE BATTERY

5.2.5 Lithium-Iron Sulfide Battery

Like the sodium-sulfur battery, the lithium-iron sulfide battery is a high-temperature battery. The battery has high projected specific power and energy, but these advantages may be offset by its high initial cost and need for a specialized charger. Also, operating and maintenance costs are expected to be high. The life-cycle economics for the three lithium-iron sulfide battery-powered vehicle applications are presented in Tables 5.13 through 5.15. The sources used to develop these estimates are listed in Table 5.16.

TABLE 5.13. Lithium-Iron Sulfide Battery System Life-Cycle Economics for Light-Duty Vans

Cycle Life @ 80% DoD:	750
Average Daily DoD:	0.244
System Efficiency:	
System Size:	37.3 kW, 13.5 kWh
Annual Electricity Usage:	3581 kWh
Annual Distance Traveled:	12848 km
Battery Purchase Cost (\$/kWh) +	33.0
(\$/kW) +	16.5
(\$)	<u>1,156</u>
Total Battery Cost	2,217
Basic Vehicle Cost	9,524
Motor Cost	748
Controller Cost	1,971
EV Transmission Cost	<u>203</u>
Total Vehicle Cost (excl. Battery)	12,446
Repairs and Maintenance (annual)	321
Replacement Tires (yr 5)	384
Insurance (annual)	421
Garaging, Parking Tolls (annual)	94
Title, Registration, License (yr 0)	733
Registration, License (annual)	24
Vehicle Salvage Value	1,466
Levelized Cost:	29.4 cents/km-traveled

TABLE 5.14. Lithium-Iron Sulfide Battery System Life-Cycle Economics
for Full-Performance Vans

Cycle Life @ 80% DoD:	1000 - 96 km cycles
System Efficiency:	0.52
System Size:	29 kWh @ C/3
Annual Electricity Usage:	4752 kWh
Annual Distance Traveled:	12848 km
Battery Purchase Cost (\$/kWh) +	--
(\$/kW) +	--
(\$)	5,445
Basic Vehicle Cost	9,265
Motor Cost	926
Controller Cost	2,027
EV Transmission Cost	<u>169</u>
Total Vehicle Cost (excl. Battery)	12,387
Repairs and Maintenance (annual)	334
Replacement Tires (yr 5)	394
Insurance (annual)	421
Garaging, Parking Tolls (annual)	94
Title, Registration, License (yr 0)	892
Registration, License (annual)	24
Vehicle Salvage Value	1784
Levelized Cost:	36.3 cents/km-traveled

**TABLE 5.15. Lithium-Iron Sulfide Battery System Life-Cycle Economics
for Full-Performance, Five-Passenger Cars**

Cycle Life @ 80% DoD:	750
Average Daily DoD:	0.244
System Efficiency:	0.52
System Size:	101 kW, 49.8 kWh
Annual Electricity Usage:	4481 kWh
Annual Distance Traveled:	12848 km
Battery Purchase Cost (\$/kWh) +	115.6
(\$/Kw) +	16.6
(\$)	<u>1,237.5</u>
Total Battery (\$)	8,671
Basic Vehicle Cost	8,897
Motor Cost	1,124
Controller Cost	2,957
EV Transmission Cost	<u>306</u>
Total Vehicle Cost (excl. Battery)	13,284
Repairs and Maintenance (annual)	385
Replacement Tires (yr 5)	664
Insurance (annual)	421
Garaging, Parking Tolls (annual)	94
Title, Registration, License (yr 0)	1098
Registration, License (annual)	24
Vehicle Salvage Value	2196
Levelized Cost:	29.5 cents/km-traveled

TABLE 5.16. Bibliography of Key Sources Used to Evaluate the Lithium-Iron Sulfide Battery Technology

1. Chilenskas, A. A., et al. 1980. A Preliminary Estimate of the Manufacturing Cost for Lithium-Metal Sulfide Cells for Stationary and Mobile Applications.
2. Consiglio, J. A., and P. C. Symons. 1985. Evaluation of Developmental Battery Cost Estimates.
3. Hardy, K. S., et al. 1985. Advanced Vehicle Systems Assessment.
4. Jet Propulsion Laboratory. 1982. Advanced Vehicle Subsystem Technology Assessment.
5. Jet Propulsion Laboratory. 1984. Advanced Vehicle Assessment. Presentation Document.

As identified by JPL, the following technical barriers must be broken in order to achieve the life-cycle costs projected in Tables 5.13 through 5.15:

1. improvement in power density, especially toward the end of discharge
2. optimized cell and battery hardware to give a higher specific energy
3. demonstration that cells can be integrated into full-size batteries without significant loss of performance or reduction in life
4. replacement of present nickel current collectors with lower-cost materials
5. proof that low-cost, active materials (e.g., by assembly in discharged state) can be used to produce practical batteries
6. demonstration of low-cost, high-performance insulation.

ALUMINUM-AIR
BATTERY

5.2.6 Aluminum-Air Battery

The aluminum-air battery works like a fuel cell, in that it consumes water, air, and aluminum to generate electricity and make by-product precipitate. Unlike other battery systems, the aluminum-air cell can be rapidly refueled by adding water and aluminum plates. Although the current projected cost is relatively high, the air cathode cost can potentially be reduced. This would improve the life-cycle economics. A summary of the life-cycle economics is presented in Table 5.17 for a five-passenger vehicle. The sources used to develop the aluminum-air economics are listed in Table 5.18.

Technical barriers which must be overcome for the life-cycle cost presented in Table 5.17 to be realized include the following:

1. development of inexpensive aluminum alloys that do not require high-purity aluminum base-metal
2. development of an aluminum alloy with reduced self discharge while maintaining electrochemical and system performance
3. demonstration of cathode life under realistic operating conditions
4. demonstration of lightweight, reliable, and low-cost device to separate hydrargillite
5. design, development, and life testing of high-performance, manufacturable cell stacks that minimize shunt currents throughout battery use
6. design, fabrication, and testing of a full-size battery system, including low-cost, reliable, and efficient auxiliaries.

**TABLE 5.17. Aluminum-Air Battery System Life-Cycle Economics
for Full-Performance, Five-Passenger Cars**

Cycle Life @ 80% DoD:	NA
System Size:	117 kW
Annual Aluminum Usage:	1177 kg
Annual Distance Traveled:	16611 km
Battery Purchase Cost (\$/kWh) +	--
(\$/kW) +	69.3
(\$)	<u>--</u>
Total battery (\$)	8,108
Basic Vehicle Cost	9,270
Motor Cost	1,234
Controller Cost	3,251
EV Transmission Cost	<u>336</u>
Total Vehicle Cost (excl. Battery)	14,091
Repairs and Maintenance	307
Replacement Tires (yr 5)	697
Insurance (annual)	421
Garaging, Parking Tolls (annual)	94
Title, Registration, License (yr 0)	836
Registration, License (annual)	24
Vehicle Salvage Value	1,672
Levelized Cost:	47.1 cents/km-traveled

TABLE 5.18. Bibliography of Key Sources Used to Evaluate the Aluminum-Air Battery Technology

1. Cooper, J. F. 1980. "Estimates of the Cost and Energy Consumption of Aluminum-Air Electric Vehicles."
2. Hardy, K. S., et al. 1985. Advanced Vehicle Systems Assessment.
3. Hudson, C. L., and E. S. Putnam. 1980. Preliminary Energy Use and Economic Analysis of the Aluminum-Air Battery for Automotive Propulsion.
4. Humphreys, K. K., and D. R. Brown. 1990. Cost and Energy Consumption Estimates for the Aluminum-Air Battery Anode Fuel Cycle.
5. Jet Propulsion Laboratory. 1982. Advanced Vehicle Subsystem Technology Assessment.
6. Jet Propulsion Laboratory. 1984. Advanced Vehicle Assessment. Presentation Document.
7. Salisbury, J. D., and E. Behrin. 1980. "An Analysis of Aluminum-Air Battery Propulsion Systems for Passenger Vehicles."

PROTON EXCHANGE MEMBRANE
FUEL CELL

5.2.7 Proton Exchange Membrane Fuel Cell

The proton exchange membrane (PEM) fuel cell, frequently referred to as the Solid Polymer Electrolyte (SPE) fuel cell,^(a) is highly efficient and has few moving parts; however, it has a long start-up period and high capital cost, and it is heavy. While the PEM cell is high in initial capital cost, it contains a large percentage of platinum which is recoverable at the end of cell life. Based on a methanol fuel and three world oil price scenarios, the life-cycle economics of the PEM fuel cell are presented in Table 5.19. The sources used to prepare the economics are listed in Table 5.20.

(a) Solid Polymer Electrolyte is a trade name of the General Electric Company.

TABLE 5.19. PEM Fuel Cell System Life-Cycle Economics
for Full-Performance, Five-Passenger Cars

System Size:	40 kW
Fossil Fuel Annual Electricity Usage:	1353 liters
Annual Distance Traveled:	16610 km
Fuel Cell Purchase Cost (\$/kWh) + (\$/kW)	<u>223</u>
Total Fuel Cell Cost (\$)	8,920
Basic Vehicle Cost	9,126
Motor Cost	828
Controller Cost	2,178
EV Transmission Cost	<u>223</u>
Total Vehicle Cost (excl. Battery)	12,355
Repairs and Maintenance (annual)	557
Replacement Tires (yr 5)	561
Insurance (annual)	421
Garaging, Parking Tolls (annual)	94
Title, Registration, License (yr 0)	1064
Registration, License (annual)	24
Vehicle Salvage Value	2,128
Levelized Cost:	24.6 cents/km-traveled

TABLE 5.20. Bibliography of Key Sources Used to Evaluate the Proton Exchange Membrane Fuel Cell Technology

1. Energy Information Administration (EIA). 1988. Annual Energy Outlook: 1987.
2. General Electric Company. 1982. "Feasibility Study of Solid Polymer Electrolyte (SPE) Fuel Cell Power Plants for Automotive Applications."
3. Hardy, K. S., et al. 1985. Advanced Vehicle Systems Assessment.
4. Jet Propulsion Laboratory. 1982. Advanced Vehicle Subsystem Technology Assessment.
5. Jet Propulsion Laboratory. 1984. Advanced Vehicle Assessment. Presentation Document.

INTERNAL COMBUSTION
ENGINE

5.2.8 Internal Combustion Engine

As a comparison case, life-cycle economics presented in Tables 5.21 and 5.22 were prepared for an internal combustion engine-powered van and five-passenger vehicle. Sources upon which the economics are based are listed in Table 5.23.

TABLE 5.21. Internal-Combustion-Engine-Powered Van Life-Cycle Economics

Annual Fossil Fuel Consumption (MBTU/yr)	53.31
Basic Vehicle Cost	\$8,236
Engine Cost	1,487
Ice Transmission Cost	<u>558</u>
Total Vehicle Cost	\$10,281
Repairs and Maintenance	\$560
Replacement Tires (yr 5)	340
Insurance (annual)	421
Garaging, Parking Tolls (annual)	94
Title, Registration, License (yr 0)	514
Registration, License (annual)	24
Vehicle Salvage Cost	1028
Fossil Fuel Cost (\$/MBTU)	7.82
Levelized Cost (nominal world oil price scenario; fuel escalated at 2.8%/yr):	26.9 cents/km-traveled
Levelized Cost (low world oil price scenario; fuel escalated at 1.8%/yr):	26.4 cents/km-traveled
Levelized Cost (high world oil price scenario; fuel escalated at 4.2%/yr):	27.7 cents/km-traveled

TABLE 5.22. Internal-Combustion-Engine-Powered Five-Passenger Vehicle Life-Cycle Economics

Annual Fossil Fuel Consumption (MBTU/yr)	53.31
Basic Vehicle Cost	\$6,953
Engine Cost	1,353
Ice Transmission Cost	<u>419</u>
Total Vehicle Cost	\$8,725
Repairs and Maintenance	647
Replacement Tires (yr 5)	507
Insurance (annual)	421
Garaging, Parking Tolls (annual)	94
Title, Registration, License (yr 0)	436
Registration, License (annual)	24
Vehicle Salvage Value	872
Fossil Fuel Cost (\$/MBTU):	5.67
Levelized Cost (nominal world oil price scenario; fuel escalated at 2.8%/yr):	19.9 cents/km-traveled
Levelized Cost (low world oil price scenario; fuel escalated at 1.8%/yr):	19.5 cents/km-traveled
Levelized Cost (high world oil price scenario; fuel escalated at 4.2%/yr):	20.5 cents/km-traveled

TABLE 5.23. Bibliography of Key Sources Used to Evaluate the Internal Combustion Engine Technology

1. Energy Information Administration (EIA). 1988. Annual Energy Outlook: 1987.
2. Hardy, K. S., et al. 1985. Advanced Vehicle Systems Assessment.
3. Jet Propulsion Laboratory. 1982. Advanced Vehicle Subsystem Technology Assessment.
4. Jet Propulsion Laboratory. 1984. Advanced Vehicle Assessment. Presentation Document.

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APPENDIX A

NORMALIZATION GUIDELINES FOR LOAD-LEVELING SYSTEMS

APPENDIX A

NORMALIZATION GUIDELINES FOR LOAD-LEVELING SYSTEMS

GEORGE GUIDELINES

The George guidelines [sometimes referred to as the Standard Costing Methodology (SCM), the ADL guidelines, the ADL/George guidelines, and the EPRI/James H. B. George/ADL guidelines (EPRI/JHBG/ADL)] provide a structured format for estimating the F.O.B. cost of battery modules produced by a manufacturer with a production level of 2500 MWh/year. The George guidelines were first published in 1976 and have undergone two revisions, in 1979 and 1984. Table A.1 presents the basic assumptions for each of the three versions of the guidelines. The assumptions for all the versions are presented, because many of the source cost estimates used in this study were based on the 1976 or 1979 versions. During the normalization process, the estimates were converted to conform, to the extent possible, with the 1984 guidelines. The step-by-step method for normalization to the 1984 George guidelines is presented in Table A.2.

TABLE A.1. Three Versions of the George Guidelines

1976 Version ^(a)	1979 Version ^(b)	1984 Version ^(c)
<u>Assumptions</u>	<u>Assumptions</u>	<u>Assumptions</u>
1. Direct labor is estimated at \$7.50/hour (1976\$).	1. Direct labor is estimated at \$10/hour (1980\$).	1. Direct labor is estimated at \$13/hour (Dec. 1983\$).
2. Rent is estimated at \$3.75/square foot/year.	2. Rent is estimated at \$5/square foot/year.	2. Rent is estimated at \$6/square foot/year.
3. Not Applicable.	3. Energy is identified as a direct cost item if energy costs exceed 5% of the cost of purchased components and materials.	3. Energy is identified as a direct cost item if energy costs exceed 5% of the cost of purchased components and materials.
4. Not Applicable.	4. Marketing, engineering, warranty, service, and misc. costs are estimated at \$5/kWh.	4. Marketing, engineering, warranty, service, and misc. costs are estimated at \$6/kWh.
5. Overheads are 150% on direct labor and 10% on materials, purchased components, and energy.	5. Overheads are 150% on direct labor and 10% on materials, purchased components, and energy.	5. Overheads are 150% on direct labor and 10% on materials, purchased components, and energy.
6. Depreciation is based on a 10-year linear scenario.	6. Depreciation is based on a 10-year linear scenario.	6. Depreciation is based on a 10-year linear scenario.
<u>Method</u>	<u>Method</u>	<u>Method</u>
Factory Cost = Labor Cost Materials and Purchased Components Cost Overhead Cost Rent <u>Equipment Depreciation (one year's)</u> SUBTOTAL	Factory Cost = Labor Cost Materials and Purchased Components Cost Energy Cost (if appropriate) Overhead Cost Rent <u>Equipment Depreciation (one year's)</u> SUBTOTAL	Factory Cost = Labor Cost Materials and Purchased Components Cost Energy Cost (if appropriate) Overhead Cost Rent <u>Equipment Depreciation (one year's)</u> SUBTOTAL
Working Capital = 0.3(Factory Cost)	Working Capital = 0.3(Factory Cost)	Working Capital = 0.3(Factory Cost)
Taxes and ROI @ 30% = 0.3(Working Capital plus Equipment Capital)	Taxes and ROI @ 30% = 0.3(Working Capital plus Equipment Capital)	Taxes and ROI @ 30% = 0.3(Working Capital plus Equipment Capital)
Warranty and Misc. = Not Applicable	Warranty and Misc. = \$5.00/kWh	Warranty and Misc. = \$6.00/kWh
F.O.B. Cost = (Factory Cost, and Taxes & ROI)	F.O.B. Cost = (Factory Cost, Taxes and ROI, and Warranty)	F.O.B. Cost = (Factory Cost, Taxes and ROI, and Warranty)

(a) From "Proposed Criteria for Estimating the Capital Costs of Advanced Battery Systems for Utility Energy Storage" (George 1976).

(b) From "Revised Guidelines for Estimating the Capital Costs of Advanced Battery Systems for Utility Energy Storage" (George 1979).

(c) From "Guidelines for Estimating the Capital Costs of Battery-Based Energy Storage Systems" (George 1984).

TABLE A.2. Method For Normalization to 1984 George Guidelines

1. Determine what method and associated ground rules were used in the source cost estimate in question.
- 2a. If the source cost estimator did not use the current George guidelines or a previous version of the guidelines, discern what the proper inputs to the current George guidelines should be (i.e., how much should be allotted for rent, manufacturing labor hours, material and component procurements, etc.).
- 2b. Adjust the derived George inputs from the given price year to the price year specified in the current George guidelines (December 1983 dollars) using GNP implicit price deflators.
- 2c. Apply the George guidelines to the time-corrected inputs to obtain a F.O.B. cost in December 1983 dollars.
- 2d. Adjust the F.O.B. cost to mid-year 1988 dollars using GNP implicit price deflators.
- 3a. If the original estimator used a previous version of the George guidelines, proceed as follows:
 1. Adjust material costs, purchased component costs, and installed equipment costs to December 1983 dollars.
 2. Escalate direct labor rates to \$13/hr for use in the 1984 guidelines from the labor rate used in the source estimate.
 3. Escalate rent to \$6/ft² from the value used in the source estimate.
 4. Allow \$6.00 for warranty and miscellaneous expenses.
- 3b. Apply the 1984 George guidelines to the adjusted inputs to obtain a F.D.B. cost in December 1983\$.
- 3c. Adjust the F.O.B. cost to mid-year 1988\$ using GNP implicit price deflators.

BOP GUIDELINES

For use in assessments of four battery systems, PSE&G developed the BOP, INC. model (Abraham et al. 1985c). This model presumes that construction of the balance-of-plant (BOP) system for load-leveling facilities is carried out as a normal field construction project with supporting architect/engineering design and field supervision. In this life-cycle cost study, it was necessary to have a standard set of BOP guidelines to follow. The BOP, INC. model was chosen as a base from which a modified set of guidelines was adapted.

These adapted guidelines are called BOP guidelines. The specific assumptions which apply to the use of the BOP guidelines are listed in Table A.3.

Developing BOP estimates, which include cost reductions for installation by the specialized BOP contractor, is a two-stage process. First, a comprehensive BOP estimate is made for a one-time 100-MWh installation in the same manner as a normal construction project cost estimate. Second, BOP cost reduction factors are applied to each component of the BOP to allow for the use of a specialized contractor. The appropriate reduction factors are enumerated in Table A.4. The labor and material cost reduction factors presented in this table are taken directly from the PSE&G study. The composite factors were derived by weighting the labor and material factors according to the average ratio between labor and material reductions for each component in the PSE&G study. Details of the calculation method for the composite reduction factors are presented in Table A.5.

In the reconciliation process, it has been presumed that battery systems will be designed to achieve maximum cost reduction. For PSE&G's 1985 study, cost reduction factors were developed that can be applied to the BOP costs for non-stacked systems to yield the BOP cost for a two-tiered battery system. In this study, these same factors were used to convert BOP source estimates for single-tiered systems to BOP estimates for stacked systems. In cases where the batteries do not tolerate stacking, the factors were not applied. The tiering cost reduction factors are listed in Table A.6. In some locations, where seismic activity is probable, stacking may not be economical because of an increase in rack stability requirements (Bellows 1983c). However, the estimates presented here are for general cases. To determine what option is most economical for any given location, a site-specific estimate must be performed. The general method for normalizing raw BOP data is summarized in Table A.7.

TABLE A.3. BOP Assumptions

1. It is assumed that the BOP design and construction company is dedicated to installing 20 to 25, 100-MWh storage plants per year. This assumption is consistent with the 2500 MWh per year of battery production for a manufacturing plant presumed by the George guidelines.
2. The cost of land is not included.
3. Access to the site is available.
4. Minimal site preparation is required.
5. There will be no on-site facilities available for the storage of special equipment for maintenance, repair, or replacement of battery components.
6. The site is in close proximity to a utility distribution substation.
7. Acquisition of construction permits will not require special or lengthy procedures.
8. Return on investment or working capital requirements and an allowance for funds during construction have not been included because overnight construction is presumed.
9. The owner will employ a specialized architect/engineer (A/E) to make minor site-specific design modifications to a standard plant design and construct the facility.
10. Outdoor enclosures are provided for the converter and AC/DC interface equipment.
11. Battery installation is provided by the battery developer.

TABLE A.4. Factors For Conversion of Baseline Estimates to Reduced BOP Estimates

	<u>Labor</u>	<u>Materials</u>	<u>Composite</u>
Battery Buildings and Auxiliaries	0.7	0.9	0.82
Site Auxiliaries	0.7	0.9	0.82
Non-Manual	0.5	0.9	0.58
Other Distributables	0.5	0.5	0.5
Home Office A/E	0.333	0.333	0.333
Converter	0.8	0.9	0.89
Master Site Controller	0.8	0.9	0.88
AC and DC Interfaces	0.8	0.9	0.87

TABLE A.5. Details on the Calculation of Composite Reduction Factors (all costs x \$1000)

		Zn/Br						Pb/Acid						
		(a) Cost	Reduction ^(b) Factor	Reduced ^(c) Cost	Total Component ^(d) Cost Before Reduction	Total Component ^e Cost After Reduction	Total Reduction ^(f) Factor	(a) Cost	Reduction ^(b) Factor	Reduced ^(c) Cost	Total Component ^(d) Cost Before Reduction	Total Component ^e Cost After Reduction	Total Reduction ^(f) Factor	
Cost Components														
Battery Auxiliaries	MAT	2950	0.9	2655	4706	3884	0.83	MAT	1961	0.9	1765	3120	2576	0.83
	LAB	1756	0.7	1229				LAB	1159	0.7	811			
Site Auxiliaries	MAT	1146	0.9	1031	1770	1468	0.83	MAT	925	0.9	833	1778	1430	0.80
	LAB	624	0.7	437				LAB	853	0.7	597			
Non-Manual	MAT	303	0.9	273	1376	809	0.59	MAT	248	0.9	223	1319	759	0.58
	LAB	1073	0.5	537				LAB	1071	0.5	536			
Other Distributables	MAT	504	0.5	252	1356	678	0.50	MAT	433	0.5	217	1169	585	0.50
	LAB	852	0.5	426				LAB	736	0.5	368			
Home Office A/E	MAT	152	0.33	50	2326	768	0.33	MAT	152	0.33	50	2322	766	0.33
	LAB	2174	0.33	717				LAB	2170	0.33	716			
Converter	MAT	1335	0.9	1202	1429	1277	0.89	MAT	1435	0.9	1292	1529	1367	0.89
	LAB	94	0.8	75				LAB	94	0.8	75			
Master Site Controller	MAT	424	0.9	382	512	452	0.88	MAT	424	0.9	382	512	452	0.88
	LAB	88	0.8	70				LAB	88	0.8	70			
AC Interface	MAT	155	0.9	140	220	192	0.87	MAT	155	0.9	140	220	192	0.87
	LAB	65	0.8	52				LAB	65	0.8	52			
DC Interface	MAT	53	0.9	48	76	66	0.87	MAT	53	0.9	48	76	66	0.87
	LAB	23	0.8	18				LAB	23	0.8	18			
Owner Charges	MAT	25	1.0	25	867	867	1.00	MAT	25	1.0	25	867	867	1.00
	LAB	842	1.0	842				LAB	842	1.0	842			

TABLE A.5. (contd)

Zn/Cl								Na/S							
Cost Components		(a)	Reduction ^(b)	Reduced ^(c)	Total Component ^(d)	Total Component ^e	Total Reduction ^(f)			(a)	Reduction ^(b)	Reduced ^(c)	Total Component ^(d)	Total Component ^e	Total Reduction ^(f)
		Cost	Factor	Cost	Cost Before Reduction	Cost After Reduction	Factor			Cost	Factor	Cost	Cost Before Reduction	Cost After Reduction	Factor
Battery Auxiliaries	MAT	944	0.9	850	1574	1291	0.82	MAT	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	LAB	630	0.7	441				LAB	N/A	N/A	N/A				
Site Auxiliaries	MAT	737	0.9	663	1139	945	0.83	MAT	306	0.9	275	490	404	0.82	
	LAB	402	0.7	281				LAB	184	0.7	129				
Non-Manual	MAT	182	0.9	164	982	564	0.57	MAT	123	0.9	111	671	386	0.57	
	LAB	800	0.5	400				LAB	551	0.5	276				
Other Distributables	MAT	247	0.5	124	658	329	0.50	MAT	98	0.5	49	255	128	0.50	
	LAB	411	0.5	206				LAB	157	0.5	79				
Home Office A/E	MAT	114	0.33	38	1736	573	0.33	MAT	78	0.33	26	1195	394	0.33	
	LAB	1622	0.33	535				LAB	1117	0.33	369				
Converter	MAT	1335	0.9	1202	1429	1277	0.89	MAT	1435	0.9	1292	1529	1367	0.89	
	LAB	94	0.8	75				LAB	94	0.8	75				
Master Site Controller	MAT	424	0.9	382	512	452	0.88	MAT	424	0.9	382	512	452	0.88	
	LAB	88	0.8	70				LAB	88	0.8	70				
AC Interface	MAT	155	0.9	140	220	192	0.87	MAT	155	0.9	140	220	192	0.87	
	LAB	65	0.8	52				LAB	65	0.8	52				
DC Interface	MAT	53	0.9	48	76	66	0.87	MAT	53	0.9	48	76	66	0.87	
	LAB	23	0.8	18				LAB	23	0.8	18				
Owner Charges	MAT	25	1.0	25	867	867	1.00	MAT	25	1.0	25	867	867	1.00	
	LAB	842	1.0	842				LAB	842	1.0	842				

(a) Cost: Given Data (Abraham et al. 1985c).

(b) Reduction Factor: Given Data (Abraham et al. 1985c).

(c) Reduced Cost: (Cost)(Reduction Factor).

(d) Total Component Cost Before Reduction: (Component Labor Cost) + (Component Material Cost).

(e) Total Component Cost After Reduction: (Reduced Component Labor Cost) + (Reduced Component Material Cost).

(f) Total Reduction Factor: Total Component Cost After Reduction/Total Component Cost Before Reduction.

Note: The batteries auxiliaries data for the sodium-sulfur technology was not used, because they do not include battery buildings that are included in the battery auxiliary component for the other three technologies.

Primary Data Source: Abraham et al. 1985c. Technical and Economic Assessments of Electrochemical Energy Storage Systems. PSE&G

TABLE A.6. Factors to Reflect Reductions in Building and Site Size and Related Cost Elements Due to Tiering of the Batteries

Battery Building and Auxiliaries	0.585
Site Auxiliaries	0.500
Non-Manual	0.78
Other Distributables	0.78
Home Office A/E	0.78

TABLE A.7. Method For Normalization to BOP Guidelines

1. Establish what elements the source estimate does and does not include.
2. If the source estimate does not take into account the cost savings derived from the use of a specialized A/E constructing numerous similar facilities, apply the appropriate BOP cost reduction factors from Table A.4.
3. If the BOP design does not incorporate but does tolerate stacking of the battery modules, apply the cost reduction factors from Table A.6.
4. Escalate the estimate to mid-1988 dollars using GNP implicit price deflators.

APPENDIX B

DETAILS OF THE NORMALIZATION PROCESS FOR THE LOAD-LEVELING APPLICATION

APPENDIX B

DETAILS OF THE NORMALIZATION PROCESS FOR THE LOAD-LEVELING APPLICATION

This Appendix presents the evaluation and normalization process used on each data source at a calculational level-of-detail. A section is included for each utility load-leveling technology evaluated. Sections are divided into a series of subsections each of which addresses one system component (e.g., energy-related BOP, battery purchase cost, etc.). Each page within a subsection is dedicated to discussing the data evaluation and normalization process from one source. Combination of data from each source into nominal and range cost estimates is discussed in the main text.

Since the main table of contents presents the title and location of this Appendix only, the following outline should aid in the location of pertinent sections and subsections within this Appendix.

<u>Section/subsection Title</u>	<u>Number</u>	<u>Page</u>
Conventional Lead-Acid Battery	B.1	B.5
Battery Purchase Cost	B.1.1	B.5
Shipping and Installation Cost	B.1.2	B.11
Energy-Related Balance-of-Plant Cost	B.1.3	B.14
Power-Related Balance-of-Plant Cost	B.1.4	B.22
Net Salvage Value	B.1.5	B.28
Operating and Maintenance Cost	B.1.6	B.29
Sealed Lead-Acid Battery	B.2	B.31
Battery Purchase Cost	B.2.1	B.31
Shipping and Installation Cost	B.2.2	B.33
Energy-Related Balance-of-Plant Cost	B.2.3	B.34
Power-Related Balance-of-Plant Cost	B.2.4	B.35
Net Salvage Value	B.2.5	B.35
Operating and Maintenance Cost	B.2.6	B.36
Zinc-Bromine Battery	B.3	B.39
Battery Purchase Cost	B.3.1	B.39
Shipping and Installation Cost	B.3.2	B.44
Energy-Related Balance-of-Plant Cost	B.3.3	B.45
Power-Related Balance-of-Plant Cost	B.3.4	B.50
Net Salvage Value	B.3.5	B.53
Operating and Maintenance Cost	B.3.6	B.54
Sodium-Sulfur Battery	B.4	B.55
Battery Purchase Cost	B.4.1	B.55
Shipping and Installation Cost	B.4.2	B.59
Energy-Related Balance-of-Plant Cost	B.4.3	B.59
Power-Related Balance-of-Plant Cost	B.4.4	B.63
Net Salvage Value	B.4.5	B.63
Operating and Maintenance Cost	B.4.6	B.64
Lithium-Iron Sulfide Battery	B.5	B.65
Battery Purchase Cost	B.5.1	B.65
Shipping and Installation Cost	B.5.2	B.67
Energy-Related Balance-of-Plant Cost	B.5.3	B.67
Power-Related Balance-of-Plant Cost	B.5.4	B.69
Net Salvage Value	B.5.5	B.69
Operating and Maintenance Cost	B.5.6	B.70
Phosphoric Acid Fuel Cell	B.6	B.71
Comparison Technologies	B.7	B.73
Gas-Fired Turbine	B.7.1	B.73
Compressed Air Energy Storage	B.7.2	B.75
Conventional Pumped Hydro Storage	B.7.3	B.7B

B.1 CONVENTIONAL LEAD-ACID BATTERY

B.1.1 Battery Purchase Cost

SOURCE: Solva-Tek Associates Review of GNB Cost Estimate (Abraham et al. 1985a)

This cost estimate is based on a 12,000 Ah lead-acid battery cell manufactured by GNB. The cycle life of this load-leveling cell is estimated as 1500 cycles at 80% DOD. The electrochemical efficiency is 70-75%. PSE&G used data from GNB and the help of an independent investigator to prepare an estimate that adhered to the 1979 George guidelines. Table B.1 compares the source cost estimate to PNL's normalized version.

TABLE B.1. Normalized PSE&G Cost Estimate of GNB Lead-Acid Battery

<u>Cost Element</u>	<u>PSE&G (1983\$/kWh)</u>	<u>Adjustment</u>	<u>Normalized PSE&G (1983\$/kWh)</u>
Materials	32.92	-	32.92
Purchased Components	35.99	-	35.99
Matls and Comp Ovhd (10%)	6.89	-	6.89
Direct Labor	7.32	13/10(a)	9.52
Direct Labor Ovhd (150%)	10.98	-	10.98
Equipment Depreciation	1.00	-	1.00
Rent	1.25	6/5(a)	1.50
	<u>\$96.35</u>		<u>98.80</u>
ROI and Taxes (30%)	11.67	recalculate	11.89
Warranty and Misc.	23.31	set by George at	6.00
	<u>\$131.33</u>		<u>\$116.69</u>
Uninstalled F.O.B.		escalated to mid-1988\$	\$134.19

(a) Adjusted to 1984 George guidelines.

SOURCE: ESB Cost Estimate (Bechtel 1982; Ferrell, et al. 1977)

This Bechtel cost estimate is based on the projected cost of an ESB load-leveling cell. The cell is described in detail in a 1977 ESB report. To avoid adding error to the Bechtel estimate by readjusting the ESB cost projections, the numbers in ESB's original report were directly adjusted using Bechtel's adjustments as a guide to normalization. The VLL45(HSG) ESB cell is designed for use in a 100-MWh, 20-MW plant, which is consistent with this study's ground rules. The projected cycle life of the cell is 2000, and efficiency is 85%.

ESB projected the cell cost based on lead prices of 20, 30, and 40 cents per pound and production levels of 500, 1000, and 4000 MWh/yr. To comply with the normalization assumptions of this study, the estimates for the cell based on a lead price of 20 cents per pound were used as the source values. Table B.2. presents the cell cost versus production level before adjustments were made. Based on these cost estimates, a regression analysis was used to generate a parametric curve representing battery cost versus annual production level:

$$\text{unit cost, \$/kWh} = 62.77654 (\text{production level})^{-0.030885}. \quad (\text{B.1})$$

Using this equation, a unit battery cost of \$49.30/kWh (1976\$) for a production level of 2500 MWh/yr, a ground rule of this study, is calculated. Escalating this value to mid-1988\$ yields a unit cost of \$93/kWh (1988\$). Following Bechtel's logic that the ESB cost estimates represent a low-cost scenario, and the low-cost scenario would be 35% less than a high-cost scenario, a high-cost scenario estimate of \$143/kWh (1988\$) is calculated. These estimates (high and low) help bound a realistic cost-estimate range. However, because the cost estimates are based on older data that has been directly escalated, they should not be weighted heavily. It is certain that these escalated numbers do not completely adhere to the current George guidelines.

TABLE B.2. ESB F.O.B. Cost Estimate (\$0.20 Lead Cost)

<u>Estimate (1976\$)</u>	<u>Annual Production Level</u>
51.60/kWh	500 MWh
51.03/kWh	1000 MWh
48.49/kWh	4000 MWh

SOURCE: Bechtel Cost Estimate of SCE Plant (Eckroad et al. 1986)

In April 1986, Bechtel released a cost estimate for the proposed Southern California Edison Chino load-leveling facility. The estimate was based on a 50-MWh, 10-MW plant. The particular type of cell to be used had not been identified at the time of the cost estimate.

Although this estimate was prepared for a plant half the size of the baseline plant used in this study (100-MWh, 20-MW), and the estimate is based on current technology rather than advanced technology, it is valuable in helping to increase the confidence of the final nominal and range estimates for the lead-acid technology. Table B.3 enumerates the Bechtel estimates. Because the estimates are based on current technology and production levels, they can be expected to fall above the range of advanced batteries.

TABLE B.3. Bechtel's Battery Purchase Cost Estimates

<u>Scenario</u>	<u>1986\$</u>	<u>1988\$</u>
Low Cost	\$140/kwh	\$149/kWh
Likely Cost	\$170/kwh	\$181/kWh
High Cost	\$180/kwh	\$192/kWh

SOURCE: PSE&G Review of Gould, Inc., Cost Estimate (Abraham et al. 1985a)

PSE&G reviewed a Gould, Inc. battery cost estimate. PSE&G adjusted the estimate to a lead price of 20 cents per pound and a production level of 1000 MWh/yr. Table B.4 presents the adjusted Gould, Inc. cost estimate in 1983 dollars. The estimate was escalated using GNP implicit price deflators, which resulted in a 1988 cost of \$113/kWh. This is only approximate because 1) the initial assumptions upon which the source estimate was based are unknown, 2) the material and purchased component cost reflects 1980-81 prices for items other than lead, and 3) when the entire estimate was escalated, the effective lead price was raised by 3 cents per pound.

TABLE B.4. Adjusted PSE&G Evaluation of Gould, Inc. Cost Estimate

<u>Cost Element</u>	<u>PSE&G (1983\$/kWh)</u>	<u>Adjusted (mid-1988\$)</u>
Mtrls & Purchased Components	65.15(a)	
Mtrls and Comp Ovhd (10%)	6.52	
Direct Labor	3.89	
Direct Labor Ovhd (150%)	5.84	
Equipment	0.80	
Rent	<u>0.95</u>	
	\$83.15	
ROI and Taxes (30%)	9.86	
Warranty and Misc.	<u>5.00</u>	
	\$98.01	\$113/kWh

(a) Reflects 1980-81 prices other than lead.

SOURCE: PSE&G Review of C&D Eltra Cost Estimate (Abraham et al. 1985a)

PSE&G evaluated an estimate prepared by C&D Eltra Corporation for lead-acid batteries. PSE&G adjusted the estimate to a lead price of 20 cents per pound and a production level of 1000 MWh/yr. Table B.5 presents PSE&G's adjusted version of C&D Eltra's estimate. This estimate was only escalated to 1988\$, because 1) the initial assumptions upon which the source estimate was based are unknown, 2) the material and purchased component cost reflects 1980-81 prices for items other than lead, and 3) when the entire estimate was escalated, the effective lead price was raised by 3 cents per pound.

TABLE B.5. Adjusted PSE&G Evaluation of C&D Eltra Cost Estimate

<u>Cost Element</u>	<u>PSE&G (1983\$/kWh)</u>	<u>Adjusted (mid-1988\$)</u>
Mtrls & Purchased Components	66.03 ^(a)	
Mtrls and Comp Ovhd (10%)	6.60	
Direct Labor	3.89	
Direct Labor Ovhd (150%)	5.84	
Equipment	0.80	
Rent	<u>0.75</u>	
	\$83.91	
ROI and Taxes (30%)	9.95	
Warranty and Misc.	<u>5.00</u>	
Uninstalled F.O.B. Cost	\$98.86	\$114/kWh

(a) Reflects 1980-81 prices other than lead.

B.1.2 Shipping and Installation Cost

SOURCE: Bechtel (1982)

Bechtel prepared cost estimates for two systems that are greater than one MWh in capacity. These include a 6.21-MWh, 900-kW shopping center application and a 2.01-MWh, 315-kW high school application.

Shipping

The projected shipping costs by Bechtel for the 6-MWh facility are \$7.57/kWh (1980\$). Escalating this estimate to mid-1988\$ using GNP implicit price deflators yields an estimated shipping cost of \$10.6/kWh.

Installation

Bechtel estimated the installation costs for systems rated at 2.01-MWh, 315-kW and 6.21-MWh, 900-kW. These estimates are presented in Table B.6.

These estimates do not include reductions for multiple installations by a specialized contractor, as established by the normalization ground rules. A reduction factor for multiple battery installations of 0.82 was approximated, based upon the standard reduction factors presented in Table A.5. Table 8.7 presents the battery installation unit cost adjusted for price year and multiple installations.

TABLE B.6. Installation Cost Estimates (1980\$)

<u>System</u>	<u>Directs</u>	<u>Indirects</u>	<u>Total</u>	<u>Unit Cost</u>
2.01-MWh	\$27,720	\$15,246	\$42,966	\$21.38/kWh
6.21-MWh	\$85,680	\$42,840	\$128,520	\$20.70/kWh

TABLE B.7. Normalized Installation Cost Estimates

<u>System</u>	<u>Unit Cost (1980\$)</u>	<u>Unit Cost (mid-1988\$)</u>	<u>Reduction Factor</u>	<u>Normalized Unit Cost</u>
2.01-MWh	21.38/kWh	30.07/kWh	0.82	\$24.66/kWh
6.21-MWh	20.70/kWh	29.11/kWh	0.82	\$23.87/kWh

SOURCE: PSE&G (Abraham et al. 1985a)

PSE&G estimated the installation cost for conventional lead-acid batteries, an air agitation system, and an automatic watering system as \$13/kWh (1983\$). Escalating this value to mid-1988\$ using GNP implicit price deflators results in a calculated battery installation cost of \$16/kWh. PSE&G did not estimate shipping costs.

SOURCE: Bechtel Cost Estimate of SCE Plant (Eckroad et al. 1986)

This source estimate is based upon a preliminary design for a 50-MWh, 10-MW battery installation to be constructed by Southern California Edison (SCE).

Shipping

Shipping costs are estimated at \$10/kWh (1986\$). Economies-of-scale are not expected for shipping costs, so no adjustment was made to account for the SCE plant being smaller than the baseline facility evaluated in this study. Escalating yields a shipping cost of \$11/kWh (1988\$).

Installation

Bechtel estimated the cost of installation for the plant at \$22/kWh (1986\$) with a range of \$20-24/kWh. These numbers represent single installation costs. Multiple installation costs are presented in Table B.8.

TABLE B.8. Normalized Installation Cost (mid-1988\$)

	<u>Unit Cost (1986\$)</u>	<u>Multiple Installation Cost Reduction Factor</u>	<u>Normalized Cost (1988\$)</u>
Low Estimate	\$20/kWh	0.82	17/kWh
Likely Estimate	\$22/kWh	0.82	19/kWh
High Estimate	\$24/kWh	0.82	21/kWh

B.1.3 Energy-Related Balance-of-Plant Cost

SOURCE: PSE&G (Abraham et al. 1985a)

Table B.9 includes an itemized list of the energy-related balance-of-plant (BOP) components and their associated costs for one installation. Table B.10 summarizes the BOP components, the reduction factors applied for the decrease in floor and building area for stacking batteries, the reduction factors applied for multiple installation savings, and the final normalized BOP cost. Finally, the total estimate of \$38.7/kWh (1983\$) was escalated to \$45.1/kWh (1988\$).

TABLE B.9. Energy-Related Balance-of-Plant for a 100-MWh Battery Facility

	<u>Manhours</u>	<u>Labor</u>	<u>Material</u>
<u>Battery Auxiliaries</u>			
Battery Building Foundation	28,600	\$591,000	\$1,097,000
Battery Building	<u>27,500</u>	<u>568,000</u>	<u>864,000</u>
Subtotal	56,100	\$1,159,000	\$1,961,000
<u>Site Auxiliaries</u>			
Safety Systems	15,300	\$357,000	\$376,000
HVAC	3,200	75,000	145,000
Aux. Power Supply Transformer	200	6,000	15,000
Uninterruptible Power	400	10,000	30,000
Chemical Cleanup	3,000	70,000	95,000
Yard Work	12,100	250,000	156,000
Utilities	<u>3,600</u>	<u>85,000</u>	<u>108,000</u>
Subtotal	37,800	\$853,000	\$925,000
<u>Home Office (A/E)</u>			
Engineering and Design	39,300	\$785,000	
Procurement	3,300	67,000	
Construction	800	17,000	
Project Operation	400	8,000	
Quality Assurance	1,100	21,000	
Other Corp. Services	1,000	21,000	
Fringe Benefits 35%		321,000	
Burden 75%		<u>930,000</u>	
Subtotal	45,900	\$2170,000	\$152,000
<u>Non-Manual</u>			
Supervision	5,400	\$97,000	
Engineering	13,900	251,000	
Quality Control	5,200	93,000	
Cost/Schedule	2,400	42,000	
Contract Administration	1,800	33,000	
First Aid, Safety, Security	1,100	20,000	
Procurement	2,500	45,000	
Administration	4,400	80,000	
Fringe Benefits 35%		231,000	
Mark-Up 20%		<u>179,000</u>	
Subtotal	36,700	\$1,071,000	247,000
<u>Other Distributables</u>	37,100	\$736,000	\$433,000

TABLE B.10. Normalized Balance-of-Plant Estimate (1983\$)

<u>Cost Elements</u>	<u>Component</u>	<u>Cost in \$1000s</u>	<u>Stacked System Red Fctr</u>	<u>Reduced Cost \$1000s</u>	<u>Multiple Installation Red Fctr</u>	<u>Reduced Cost \$1000s</u>
Battery Auxil.	Material	1961	0.585	147	0.9	1032
	Labor	1159	0.585	678	0.7	475
Site Auxil.	Material	195	0.500	463	0.9	417
	Labor	853	0.500	427	0.7	299
Home Off. A/E	Material	152	0.78	119	0.33	39
	Labor	2170	0.78	1693	0.33	559
Non-Manual	Material	247	0.78	13	0.9	174
	Labor	1071	0.78	835	0.5	418
Other Distrib.	Material	433	0.78	338	0.5	169
	Labor	736	0.78	574	0.5	287
						<u>\$3,869,000</u>
						(\$38.69/kWh)

SOURCE: Bechtel Cost Estimate of SCE Plant (Eckroad et al. 1986)

Based on the 50-MWh, 10-MW Southern California Preliminary Plant Design, Bechtel estimated the energy-related BOP and engineering cost as presented in Table B.11. The SCE design is for a stacked battery system. Therefore, cost reductions attributed to decreased floor space from stacking are accounted for in Bechtel's cost estimate. The estimates were normalized by reducing engineering costs by two-thirds to allow for the multiple installation reductions. The remainder of the energy-related BOP was reduced by 29.7%. This is the same net reduction as calculated from the PSE&G BOP cost estimate, exclusive of engineering (see Table B.10).

TABLE B.11. Normalized Bechtel Cost Estimate of a Conventional Lead-Acid Battery Energy-Related Balance-of-Plant

	<u>BOP (1986\$)</u>	<u>Multiple Installation Reduction Factor</u>	<u>Normalized BOP (1986\$)</u>		
Low	\$33/kWh	(1 - 0.297)	\$23/kWh		
Likely	\$33/kWh	(1 - 0.297)	\$23/kWh		
High	\$53/kWh	(1 - 0.297)	\$37/kWh		

	<u>Engineering (1986\$)</u>	<u>Multiple Installation Reduction Factor</u>	<u>Normalized Engineering (1986\$)</u>	<u>Total BOP (1986\$)</u>	<u>Total BOP (1988\$)</u>
Low	\$24/kWh	0.33	\$8/KWh	\$31/kWh	\$33/kWh
Likely	\$24/kWh	0.33	\$8/KWh	\$31/kWh	\$33/kWh
High	\$26/kWh	0.33	\$9/KWh	\$46/kWh	\$49/kWh

SOURCE: Bechtel (1982)

This source includes energy-related BOP cost estimates for 6.21-MWh, 900-kW; 2.01-MWh, 315-kW; and 643-kWh, 72-kW systems that were reviewed. The three unadjusted cost estimates in 1980 dollars are presented in Tables B.12 through B.14. The estimates were evaluated in two ways. First the 6-MWh estimate was adjusted for multiple installations by reducing the engineering cost by 67%, the amount specified by the BOP normalization guidelines. The remaining BOP was scaled down by 29.7% for multiple installations. This percentage is the same as that of the net savings associated with PSE&G's BOP cost estimate, exclusive of engineering (see Table B.10). The total effective reduction is 35%. A regression was performed on the adjusted cost estimates for the 643-kWh BOP, 2-MWh BOP, and 6.21-MWh BOPs. The following resulting equation (B.2) was used to estimate a single installation cost for a 100-MWh BOP:

$$\text{Cost (1980\$)} = 8532.5 (\text{Size, MWh})^{-0.58646} \quad (\text{B.2})$$

This cost estimate was reduced by 35% (the percentage calculated above) to allow for multiple installations, which yields a unit cost of \$9/kWh (1988\$). This estimate should be lower than the true cost of a 100-MWh BOP, because it was estimated from three relatively small systems which tend to exaggerate economies-of-scale for large system sizes.

**TABLE B.12. 6.21-MWh Conventional Lead-Acid Battery Energy-Related
Balance-of-Plant Estimate (1980\$)**

	<u>Labor(a)</u>	<u>Material</u>	<u>Subtotal</u>
<u>Building</u>			
Building			\$ 63,000
Structural			15,060
Paint (Acid-Resistant)			4,620
Other			940
<u>Thermal Management</u>			
Heat Rejection	\$1,350	\$21,000	\$ 22,350
Piping, Pumps, Valves	3,180	6,660	9,840
Other	1,515	1,880	3,395
<u>Ventilation</u>			
Fans	\$ 675	\$ 1,500	\$ 2,175
Ducts	5,730	13,850	19,580
<u>Instrumentation</u>			
Fire Detection	\$ 270	\$ 130	\$ 400
Gas Detection	1,755	3,200	4,955
<u>Electrical</u>			
DC Wiring	\$5,400	\$30,500	\$ 35,900
DC Equipment	735	9,160	9,895
AC Wiring	9,075	2,490	11,565
AC Panel Requirements	375	250	625
Lighting	5,070	5,120	10,190
Other	135	750	885
<u>Auxiliaries</u>			
Make-Up Water System	\$ 705	\$1,280	\$ 1,985
Air-Lift System	2,235	3,080	5,315
Plumbing Support Trays	3,375	2,050	5,425
Fire Extinguisher		50	50
<u>Subtotal BOP</u>			\$228,150
Energy-Related BOP Contingency @ 20%			45,630
Engineering @ 15%			34,223
Engineering Contingency @ 20%			6,845
Total Engineering-Related BOP			\$ 41,068
Total Other-Related BOP			<u>273,780</u>
			\$314,848

(a) Includes apportioned indirects.

TABLE B.13. 2.01-MWh Conventional Lead-Acid Battery Energy-Related Balance-of-Plant Estimate (1980\$)

	<u>Labor(a)</u>	<u>Material</u>	<u>Subtotal</u>
<u>Building</u>			
Building			\$45,900
Structural	\$9,285	\$3,440	12,725
Paint (Acid-Resistant)	760	1,350	2,110
Other	558	350	908
<u>Thermal Management</u>			
Heat Rejection	\$1,116	\$9,330	\$10,446
Piping, Pumps, Valves	2,170	3,520	5,690
Other	1,116	1,120	2,236
<u>Ventilation</u>			
Fans	\$ 698	\$1,000	\$1,698
Ducts	2,511	5,470	7,981
<u>Instrumentation</u>			
Fire Detection	\$ 279	\$ 130	\$ 409
Gas Detection	1,814	3,200	5,014
<u>Electrical</u>			
DC Wiring	\$2,232	\$9,400	\$11,632
DC Equipment	775	9,160	9,935
AC Wiring	6,495	1,740	8,235
AC Panel Requirements	388	250	638
Lighting	5,239	5,120	10,359
Other	217	720	937
<u>Auxiliaries</u>			
Make-Up Water System	\$ 636	\$1,190	\$1,826
Air-Lift System	1,147	1,860	3,007
Plumbing Support Trays	1,783	1,050	2,833
Fire Extinguisher		50	50
Subtotal BOP			\$144,569
Energy-Related BOP Contingency @ 20%			\$28,914
Engineering @ 15%			\$21,685
Engineering Contingency @20%			\$4,337
Engineering-Related BOP			\$26,022
Other BOP			<u>\$173,483</u>
			\$199,505

(a) Includes apportioned indirects.

**TABLE B.14. 643-kWh Conventional Lead-Acid Battery Energy-Related
Balance-of-Plant Estimate (1980\$)**

	<u>Labor(a)</u>	<u>Material</u>	<u>Subtotal</u>
<u>Building</u>			
Building	--	--	\$15,360
Structural	\$6,665	\$2,800	\$9,465
Paint (Acid-Resistant)	357	640	997
Other	558	350	908
<u>Thermal Management</u>			
Heat Rejection	\$837	\$4,420	\$5,257
Piping, Pumps, Valves	1,287	1,850	3,137
Other	589	640	1,229
<u>Ventilation</u>			
Fans	\$ 698	\$ 800	\$1,498
Ducts	1,705	2,200	3,905
<u>Instrumentation</u>			
Fire Detection	\$ 279	\$ 130	\$ 409
Gas Detection	1,814	3,200	5,014
Other	419	230	649
<u>Electrical</u>			
DC Wiring	\$2,062	\$10,090	\$12,152
DC Equipment	775	9,160	9,935
AC Wiring	5,890	1,560	7,450
AC Panel Requirements	388	250	638
Lighting	3,069	3,630	6,699
Other	31	80	111
<u>Auxiliaries</u>			
Air-Lift System	\$1,054	\$1,760	\$2,814
Plumbing Support Trays	1,008	620	1,628
Fire Extinguisher	--	50	<u>50</u>
Subtotal BOP			\$89,305
Energy-Related BOP Contingency @ 20%			\$17,861
Engineering @ 15%			\$13,396
Engineering Contingency @ 20%			\$ 2,979
Engineering-Related BOP			\$16,075
Other BOP			<u>\$107,196</u>
			<u>\$123,271</u>

(a) Includes apportioned indirects.

B.1.4 Power-Related Balance-of-Plant Cost

SOURCE: PSE&G (Abraham et al. 1985a)

Presented in Table B.15 is PSE&G's power-related BOP cost estimate for a 100-MWh, 20-MW system. Table B.16 presents the normalized version of the cost estimate, adjusted for multiple installations and price year.

TABLE B.15. PSE&G Conventional Lead-Acid Battery Power-Related Balance-of-Plant Estimate (1983\$)

	<u>Manhours</u>	<u>Labor(a)</u>	<u>Material</u>
<u>AC Interface Equipment</u>			
Breaker Offsite	1,000	\$25,000	\$100,000
Monitor	100	3,000	5,000
Relays	200	6,000	10,000
Power Cable	200	5,000	20,000
Pole Lines	800	10,000	10,000
Instrumentation	<u>200</u>	<u>6,000</u>	<u>10,000</u>
Subtotal	2,500	\$65,000	\$155,000
<u>DC Interface Equipment</u>			
DC Bus	-	-	-
Foundation DC Equipment	50	\$30,000	
Isolating Switches	200	5,000	15,000
Monitor & Protection	300	8,000	15,000
instrumentation	300	7,000	10,000
Cable	<u>100</u>	<u>2,000</u>	<u>10,000</u>
Subtotal	950	\$23,000	\$53,000
<u>Converter</u>			
Converter Foundation	700	\$15,000	\$24,000
Transformer	400	9,000	11,000
Converter	<u>2,800</u>	<u>70,000</u>	<u>1,400,000</u>
Subtotal	3,900	\$94,000	\$1,435,000
<u>Master Site Controller</u>			
MSC Foundation	300	\$ 6,000	\$ 9,000
MSC Building	1,000	40,000	40,000
Remote Controller	600	21,000	100,000
Computer & Peripherals	<u>1,900</u>	<u>47,000</u>	<u>\$275,000</u>
Subtotal			\$424,000

(a) Includes apportioned indirects.

TABLE B.16. Normalized PSE&G Power-Related Balance-of-Plant

<u>Cost Elements</u>		<u>Cost in</u> <u>1,000's (1983\$)</u>	<u>Reduction</u> <u>Factor</u>	<u>Reduced Cost</u> <u>1,000's (1983\$)</u>
AC Interface	M	155	0.90	139.5
	L	65	0.80	52.0
DC Interface	M	53	0.90	47.7
	L	23	0.80	18.4
Converter	M	1435	0.90	1291.5
	L	94	0.80	75.2
Site Controller	M	424	0.90	381.6
	L	88	0.80	70.4
				<u>2076.3</u>
Escalated to 1988\$				2,420,000
Unit Cost Based on 20-MW System				\$121/kW

SOURCE: Bechtel Cost Estimate of SCE Plant (Eckroad et al. 1986)

Based on the proposed 50-MWh, 10-MW Southern California Edison preliminary Chino plant design, Bechtel estimated the power-related BOP as presented in Table B.17. These cost estimates are based on current production levels.

TABLE B.17. Bechtel Cost Estimate for a Conventional Lead-Acid Battery Balance-of-Plant

	<u>First Quarter 1986\$</u>	<u>1988\$</u>
Low Estimate	\$202/kW	\$217/kW
Likely Estimate	\$229/kW	\$247/kW
High Estimate	\$242/kW	\$261/kW

SOURCE: Bechtel (Stolte and Eckroad 1984)

This source presented two parametric curves from which estimates for a 20-MW converter of present and advanced designs were taken. Table B.18 presents the time-adjusted extracted from this source.

TABLE B.18. Normalized Power Conditioner Costs

	<u>1982\$</u>	<u>1988\$</u>
Advanced Technology	110/kW	133/kW
Current Technology	180-290/kW	218-351/kW

SOURCE: Bechtel (Stolte and Eckroad 1984)

This source presented two parametric curves developed by Bechtel for estimating total BOP costs. By evaluating these curves, the energy-related BOP for a 50-MWh BOP was estimated to be 20% more expensive on a unit-cost-basis than a 100-MWh BOP. The unit cost of a 30-MWh BOP is 60% greater than that for a 100-MWh BOP.

SOURCE: Bechtel (Eckroad 1985)

This source presented a power-related BOP cost estimate of \$170/kW (1985\$). This estimate was based on Nth plant sizes of 1.6-MWh, 2-MW and 4.7-MWh, 6-MN. Escalating this cost to 1988\$ yields a unit cost of \$188/kW.

B.1.5 Net Salvage Value

SOURCE: Bechtel (1982)

The salvage scenario in this source presumed a scrap credit for conventional lead-acid batteries ranging from 6 to 17%. Battery removal was assumed to be 60% of installation. Shipping to the scrap facility was presumed to be negligible. It was suggested that cells could possibly be rebuilt. However, details of such a scenario were not discussed.

B.1.6 Operating and Maintenance Cost

SOURCE: Bechtel Cost Estimate for SCE Plant (Eckroad et al. 1986)

Size: 50-MWh, 10-MW

Fixed: \$18/kW-yr

Variable: \$2.8 1986\$

SOURCE: TAG (EPRI 1986)

Size: 100-MWh, 20-MW

Fixed: \$1.4/kW-yr

Variable: \$0.0066/kWh retrieved from storage

SOURCE: EPRI(a)

Fixed: \$1/kW-yr

Variable: \$0.002/kWh retrieved from storage

SOURCE ESTIMATE: ERC (1986a)

Size: 5 Hours of Storage

Fixed: \$.54/kW-yr

Variable: \$0.002/kWh retrieved from storage

(a) Screening curve analysis by Robert Schanker of EPRI.

B.2 SEALED LEAD-ACID BATTERY

B.2.1 Battery Purchase Cost

SOURCE: Gould, Inc. (Ramsay and Edgecomb 1982)

This source presents cost estimates using the George guidelines for both a conventional and sealed lead-acid battery. Although somewhat dated, in combination the two estimates can be used to help establish a relative cost relationship between the sealed and conventional lead-acid battery technologies. Table B.19 presents the normalized sealed lead-acid battery cost estimate, while Table B.20 presents the conventional lead-acid battery cost estimate.

TABLE B.19. Normalized Gould, Inc. Cost Estimate of the Sealed Lead-Acid Battery Technology

<u>Cost Element</u>	<u>Gould (1980\$/kWh)</u>	<u>Adjustment</u>	<u>Gould Normalized (1983\$/kWh)</u>
Materials			
Plates and Grids	35.60	20 /lb lead	17.80
All Else	34.32	esc.	41.97
Ovhd @ 10%	6.99	recalculate	5.98
Direct Labor	3.12	13/10(a)	4.06
Direct Labor Ovhd	4.68	recalculate	6.09
Equipment Depreciation	0.63	esc.	0.77
Rent	0.75	6/5(a)	.90
	<u>\$86.09</u>		<u>\$77.57</u>
ROI plus Taxes @ 50%	9.63	recalculate	9.29
Warranty	5.00	set by George at	6.00
	<u>\$100.72</u>		<u>\$92.86</u>
Uninstalled F.O.B. cost		esc. to mid-1988\$	\$106.78

(a) Adjusted to 1984 George guidelines

TABLE B.20. Normalized Gould, Inc. Cost Estimate of the
Conventional Lead-Acid Battery

<u>Cost Element</u>	<u>Gould (1980\$/kWh)</u>	<u>Adjustment</u>	<u>Gould (1983\$/kWh)</u>
Materials			
Plates and Grids	37.49	20 /lb Pb	18.75
All else	26.09	esc.	31.91
Ovhd @ 10%	6.39	recalculate	5.07
Direct Labor	3.12	13/10(a)	4.06
Direct Labor Ovhd	4.68	recalculate	6.09
Equipment Depreciation	0.63	esc.	0.77
Rent	0.75	6/5(a)	0.90
	<u>\$79.15/kWh</u>		<u>\$67.55/kWh</u>
ROI plus Taxes @ 50%	9.00	recalculate	8.38
Warranty	5.00	set by George at	6.00
	<u>\$93.12</u>		<u>\$81.93</u>
Uninstalled F.O.B. Cost	\$93.12	esc. to mid-1988\$	\$94.22

(a) Adjusted to 1984 George guidelines.

B.2.2 Shipping and Installation Cost

No cost data specifically related to the sealed lead-acid battery could be located. Refer to Section B.1.2 for cost data pertaining to the conventional lead-acid technology. This data is largely applicable to the sealed battery system, with the exception of air agitation and water addition systems. These are unnecessary for a sealed battery system.

B.2.3 Energy-Related Balance-of-Plant Cost

SOURCE: Bechtel (1982)

This source presented the only cost estimate for a sealed lead-acid energy-related BOP for which a comparable conventional lead-acid battery technology cost estimate was also available. Comparability between the technologies was necessary to identify cost and design differences between the two respective energy-related BOPs. Table B.21 presents the source estimate, which is based on a 2.01-MWh system.

TABLE B.21. 2.01-MWh Sealed Lead-Acid Battery Energy-Related Balance-of-Plant Estimate (1980\$)

	<u>Labor</u>	<u>Material</u>	<u>Subtotal</u>
<u>Building</u>			
Building			\$45,900
Structural	\$9,285	\$3,440	12,725
<u>Thermal Management</u>			
Heat Rejection	\$1,116	\$9,330	\$10,446
Piping, Pumps, Valves	2,170	3,520	5,690
Other	1,116	1,120	2,236
<u>Instrumentation</u>			
Fire Detection	\$279	\$130	\$409
<u>Electrical</u>			
DC Wiring	\$2,232	\$9,400	\$11,632
DC Equipment	775	9,160	9,935
AC Wiring	6,495	1,740	8,235
AC Panel Requirements	388	250	638
Lighting	3,178	1,180	4,358
Other	217	720	937
<u>Auxiliaries</u>			
Plumbing Support Trays	1,783	1,050	<u>2,833</u>
<u>Subtotal BOP</u>			\$115,994
Energy-Related BOP Contingency @ 20%			\$23,198
Engineering @ 15%			\$17,399
Engineering Contingency @ 20%			\$3,480
Engineering-Related BOP			\$20,879
Other BOP			<u>139,192</u>
			\$160,071

B.2.4 Power-Related Balance-of-Plant Cost

There should be no major differences between the power-related BOP for a sealed lead-acid battery storage plant and a conventional lead-acid system. Refer to Sections 3.2.2.4 and B.1.4 for applicable data.

B.2.5 Net Salvage Value

Availability of data does not warrant a third level of detail. Refer to Section 3.2.2.5 for applicable information.

B.2.6 Operating and Maintenance Cost

SOURCE: Bechtel (1982)

This source presents two O&M cost estimates for a system size of 2.01-MWh: one for a conventional lead-acid battery system and one for a sealed lead-acid battery system. From a comparison of these two estimates, an indication of the relative difference between conventional and sealed lead-acid battery O&M costs can be developed. Table B.22 and B.23 present the two cost estimates.

TABLE B.22. Operating and Maintenance Cost Estimate for a 2.01-MWh Sealed Lead-Acid Battery System

	<u>Manhours</u>	<u>Materials (1980\$)</u>	<u>Materials (1988\$)</u>	<u>Total (1988\$)(a)</u>
Cell Maintenance	20	--	--	\$ 780
Cooling System	140	2800	3940	9,400
Cooling System Pump	50	2360	3320	5,270
Cooling System Refrigeration	30	3730	5245	<u>6,420</u>
Total Cost				\$21,870
Annual Cost				\$ 1,093/yr
Unit Cost				\$ 0.54/kWh

(a) Assumes \$39/hr (1988\$) labor rate.

TABLE B.23. Operating and Maintenance Cost Estimate for a 2.01-MWh
Conventional Lead-Acid Battery System

	<u>Manhours</u>	<u>Materials (1980\$)</u>	<u>Materials (1988\$)</u>	<u>Total (1988\$) (a)</u>
Cell Maintenance	960	\$6960	\$9789	\$47,229
Cooling System	140	2000	2813	8,273
Ventilation Fan	20	--	--	780
Air-Lift	80	1000	1406	4,526
Water Pump	50	2360	3319	5,269
Refrigeration	30	3730	5246	6,416
Exhaust Fan	20	200	281	1,061
Air-Lift	75	4500	6329	<u>9,254</u>
Total Cost				\$82,808
Annual Cost				4,140/yr
Unit Cost				\$2.06/kWh

(a) Assumes \$39/hr (1988\$) labor rate.

SOURCE: Gould, Inc. (Ramsay and Edgecomb 1982)

This source presents O&M cost estimates for both conventional and sealed lead-acid battery systems. A disadvantage to using this data is that it pertains to a small system size of 50-kWh. However, the pair of estimates do provide an additional data point.

Gould, Inc. estimated annual maintenance as 20 manhours per year for the sealed lead-acid battery and 68 manhours for the conventional lead-acid battery. Gould, Inc. estimated the cost of materials and labor at \$34.50 per manhour. Table B.24 presents the estimates adjusted for price year.

TABLE B.24. Adjusted Gould, Inc. Operating and Maintenance Cost Estimates

<u>Technology</u>	<u>Manhours</u>	<u>Cost (1980\$)</u>	<u>Cost (1988\$)</u>	<u>Unit Cost (1988\$)</u>
Conventional	68	2346	3299	\$66/kWh
Sealed	20	690	970	\$19/kWh

B.3 ZINC-BROMINE BATTERY

B.3.1 Battery Purchase Cost

SOURCE: PSE&G Review of an ERC Cost Estimate (Abraham et al. 1985d)

PSE&G prepared a cost estimate based on a 1-MWh module with two square feet of electrode area. This module design is called Design C by ERC. PSE&G's estimate was adjusted to meet the 1984 George guidelines and the results escalated to 1988 dollars. Table B.25 presents the normalized cost estimate.

It is important to note that ERC has not performed any detailed, publicly available manufacturing studies, which necessitated PSE&G's developing equipment and factory floor space estimates to enable the use of the George guidelines.

TABLE B.25. Normalized PSE&G Estimate of ERC's Zinc-Bromine Battery:
Design C

<u>Cost Element</u>	<u>PSE&G (1983\$/kWh)</u>	<u>Adjustment</u>	<u>PSE&G (1983\$/kWh)</u>
Materials	60.48	--	60.48
Matls and Comp Ovhd (10%)	6.05	--	6.05
Direct Labor	18.47	13/10(a)	24.01
Direct Labor Ovhd (150%)	27.71	--	36.02
Equipment Depreciation	2.00	--	2.00
Rent	1.00	6/5(a)	1.20
	<u>\$115.71</u>		<u>\$129.76</u>
ROI and Taxes (30%)	16.40	recalculate	\$17.68
Indirects	5.00	set by George at	6.00
	<u>\$137.11</u>		<u>\$153.44</u>
Uninstalled F.O.B. Cost		esc. to 1988\$	\$176.45

(a) Adjusted to 1984 George guidelines.

SOURCE: ERC (1986b)

This source presents an ERC cost estimate for the 1-MWh Design C module, the same design evaluated by PSE&G. This estimate was examined to see how it compares to the PSE&G version. ERC's cost estimate was escalated from the presumed 1984 cost year. This was the only adjustment made to the cost estimate presented in Table B.26.

TABLE B.26. Adjusted ERC Cost Estimate of Design C

Submodule	25,000
Piping	32,000
Structural Steel	23,000
Electrical	12,000
Instruments	12,000
Equipment	21,000
Paint and Scaffolding	<u>1,200</u>
Module Cost	\$126,200
Module Cost	\$126.2/kWh (1984\$)
Electrolyte Cost	<u>15.0/kWh (1984\$)</u>
Total Cost	\$141.2/kWh (1984\$)
Adjusted Total Cost	\$158.64/kWh (1988\$)

SOURCE: ERC (1986b)

This source presents a cost estimate for a 2-MWh module with 4 square feet of electrode area. This battery design is called Design D by ERC. The Design D cost estimate was escalated to 1988 dollars. This adjusted cost estimate is presented in Table 8.27.

TABLE B.27. Adjusted ERC Cost Estimate of Design D

Submodule	34,600
Piping	35,000
Structural Steel	30,000
Electrical	14,000
Instruments	12,000
Equipment	25,000
Paint and Scaffolding	<u>1,400</u>
Module Cost	\$152,000
Module Cost	\$ 76/kWh (1984\$)
Electrolyte Cost	<u>15/kWh (1984\$)</u>
Total Cost	\$ 91/kWh (1984\$)
Adjusted Total Cost	\$102/kWh (1988\$)

SOURCE: ERC (1986a)

As shown in Table B.28, this source presents a cost estimate for a 4.2-MWh module with 6 square feet of electrode area per stack (40 stacks/module).

TABLE B.28. Adjusted ERC Cost Estimate of 4.2-MWe Module

Submodule	27.9/kWh
Piping	15.60/kWh
Structural Steel	1.11/kWh
Electrical	2.35/kWh
Instruments	7.67/kWh
Paint and Scaffolding	<u>0.05/kWh</u>
Module Cost	\$54.68/kWh (1986\$)
Electrolyte Cost	<u>15.74/kWh</u> (1986\$)
Total Cost	\$70.42/kWh (1986\$)
Adjusted Total Cost	675.14/kWh (1988\$)

SOURCE: PSE&G Review of Exxon Cost Estimate (Abraham et al. 1985d)

Presented in Table 8.29 is a cost estimate prepared by Exxon for a 20-kWh battery uninstalled. PSE&G evaluated this estimate and determined that, through a combination of factors, actual costs would be 100 to 150% higher. PSE&G and Exxon could not resolve the conflicts. Because of the extreme uncertainty that was identified in the source study, Exxon's estimate was escalated only to \$56/kWh (1988\$). The corresponding PSE&G estimate would be \$112-140/kWh.

TABLE B.29. Exxon's Estimate of 20-kWh Battery Uninstalled (1980\$)

	<u>Unit Cost (\$/kWh)</u>
1. Factory Cost	
Material and Purchased Components	8.57
Plus Overhead @ 10%	
Electrolyte Plus Overhead @ 10%	11.00
Other Equipment and Accessories	
Plus Overhead @ 10%	<u>6.54</u>
Total Material and Components	26.11
Plus Overhead	
Direct Labor Plus Overhead @ 150%	3.44
Equipment Depreciation @ 10 year	0.50
Straight-Line	
Rent @ \$5/ft ²	0.20
2. After Tax Return on Investment (ATROI)	2.11
3. Taxes (Equal to ATROI)	2.11
4. Indirect Cost @ \$5/kWh	<u>5.00</u>
OEM Estimated Selling Price	39.47

B.3.2 Shipping and Installation Cost

SOURCE: Bechtel (1982)

Bechtel estimated shipping costs associated with a Gould, Inc.-designed zinc-bromine battery to be \$6.25/kWh (1980\$) for a 6.24-MWh system. Escalating to 1988\$ yields a cost estimate of \$8.79 (1988\$) for this battery. Bechtel estimated the cost of installation at \$7.08/kWh (1980\$) (\$9.96/kWh; 1988\$).

SOURCE: ERC (1983)

In cooperation with ERC, Fluor estimated shipping for a 500-kWh system to be used at the BEST Facility as \$4800 (Jan. 1983\$). Escalating yields a cost of \$11.2/kWh (1988\$).

SOURCE: ERC (1986b)

For both the C and D battery designs, ERC estimates the cost of shipping at \$2/kWh. This estimate was escalated from the presumed 1984 price year to yield a cost of \$2.2/kWh. The C and D battery designs are approximately 20% lighter than 500-kWh BEST Facility design on a kWh basis. The cost of installation was estimated by ERC as \$0.4/kWh.

B.3.3 Energy-Related Balance-of-Plant Cost

SOURCE: ERC Cost Estimate (ERC 1986a)

For Design D, ERC estimated energy-related BOP costs as presented in Table B.30.

TABLE B.30. ERC Energy-Related Balance-of-Plant Cost Estimate

<u>Cost Element</u>	<u>Unit Cost (1982\$/kWh)</u>
System Enclosure (@ \$20/ft ²)	19.7
Drainage System	1.0
Neutralization Chemicals	1.5
Scrubber	1.4
Cooling Tower	<u>0.8</u>
Total Cost	\$24.4
Adjusted Total Cost	\$29.5/kWh (1988\$)

SOURCE: ERC (1986b)

Based on a 50-MWh system, ERC estimated auxiliary equipment and building costs at \$8.88/kWh (1986\$). Escalating to 1988\$ yields an estimate of \$9.48/kWh. Buildings comprise \$2.28/kWh of the total \$9.48/kWh. Engineering drawings for a 50-MWh plant show approximately 10,000 square feet of building. Based on \$2.28/kWh, ERC is estimating \$11/ft², which is 50% of its estimate for previous designs (ERC 1983).

SOURCE: PSE&G (Abraham et al. 1985d)

For the ERC battery system, PSE&G developed an energy-related BOP cost estimate based on module Design D (Table B.31). This estimate was generated for a 100-MWh, 20-MW plant. Table B.32 shows the adjustments made to the base estimate to allow for multiple installations. Finally, the total estimate of \$47.1/kWh (1983\$) was escalated to \$54.9/kWh (1988\$).

**TABLE B.31. PSE&G (ERC Battery) Energy-Related Balance-of-Plant
Cost Estimate (1983\$)**

	<u>Manhours</u>	<u>Labor</u>	<u>Materials</u>
<u>Battery Auxiliaries</u>			
Battery Building Foundation	42,300	\$874,000	\$1,312,000
Battery Building	42,700	882,000	1,638,000
Refrigeration	--	--	--
Racks	--	--	--
Subtotal	85,000	\$1,756,000	\$2,950,000
<u>Site Auxiliaries</u>			
Battery Thermal Management	2,550	\$60,000	\$151,000
Module Repair and Storage	--	--	--
Safety Systems	11,300	263,000	341,000
HVAC	2,400	56,000	138,000
Aux. Power Supply Transfer	200	5,000	16,000
Uninterruptable Power	400	10,000	30,000
Module Handling Crane	0	0	0
Chem. Cleanup-Scrubber	1,300	30,000	60,000
Firewalls	--	--	--
Yard Work	9,300	192,000	360,000
Utilities	350	8,000	10,000
Miscellaneous	--	--	--
Subtotal	27,800	\$624,000	\$1,146,000
<u>Non-Manual</u>			
Supervision	5,400	\$96,700	\$ --
Engineering	13,900	250,900	--
Quality Control	5,200	93,400	--
Cost/Schedule	2,400	42,400	--
Contract Administration	1,800	33,100	--
First Aid, Safety, Security	1,100	20,500	--
Procurement	2,500	45,000	--
Administration	4,500	80,000	--
Fringe Benefits 35%	--	\$232,000	--
Mark Up 20%	--	\$179,000	--
Non-manual Total	36,800	\$1,073,000	\$303,000
Other Distributables	43,300	852,000	504,000
<u>Home Office (AE)</u>			
Engineering & Design	39,300	\$786,000	--
Procurement	3,300	66,800	--
Construction	900	17,100	--
Project Operation	400	8,000	--
Quality Assurance	1,000	21,000	--
Other Corp. Services	1,100	21,100	--
Fringe Benefits 35%	--	\$322,000	--
Burden 75%	--	\$932,000	--
Subtotal AE	46,000	\$2,174,000	\$152,000

TABLE B.32. Normalized PSE&G (ERC Battery) Energy-Related Balance-of-Plant Cost Estimate (1983\$)

<u>Cost Elements</u>	<u>Component</u>	<u>Cost</u>	<u>Multiple Installation Factor</u>	<u>Stacked Factor</u>	<u>Adjusted Total</u>
Battery Auxil.	Material	\$2,950,000	0.9	0.585	1,533,000
	Labor	1,756,000	0.7	0.585	719,100
Site Auxil.	Material	1,146,000	0.9	0.5	515,700
	Labor	624,000	0.7	0.5	218,400
Non-Manual	Material	303,000	0.9	0.78	212,706
	Labor	1,073,000	0.5	0.78	418,470
Other Distributables	Material	504,000	0.5	0.78	196,600
	Labor	852,000	0.5	0.78	332,300
Home Office A/E	Material	152,000	0.3	0.78	35,600
	Labor	2,174,000	0.3	0.78	508,700
					<u>\$4,710,600</u>
					(\$47.1/kWh)

B.3.4 Power-Related Balance-of-Plant Cost

SOURCE: PSE&G (Abraham et al. 1985d)

PSE&G evaluated power-related BOP components for several battery technologies. They estimated the zinc-bromine system could be charged with several large converters (5-MW) and at a higher voltage (2500 VDC) than either the lead-acid or sodium-sulfur battery systems. Table B.33 presents an estimate of the converter cost and associated interfaces and controls for the zinc-bromine system. Table B.34 quantifies the cost reductions achieved from having multiple installations performed by a single installer. As shown in Table B.34, the total cost is \$116/kW (1983\$). The comparable estimate prepared by PSE&G for the lead-acid battery system is \$121/kW (1988\$). (See Section B.1.4 for details.)

**TABLE B.33. PSE&G Zinc-Bromine Battery Energy-Related
Balance-of-Plant (1983\$)**

	<u>Manhours</u>	<u>Labor</u>	<u>Materials</u>
<u>AC Interface Equipment</u>			
Breaker-Offsite	1,000	\$25,000	\$100,000
Monitor	120	3,000	5,000
Relays	240	6,000	10,000
Power Cable	200	5,000	20,000
Pole Lines	805	20,000	10,000
Instrumentation	235	6,000	10,000
Subtotal	2,600	\$65,000	\$155,000
<u>DC Interface Equipment</u>			
DC Bus	--	\$ --	\$ --
Foundation DC Equipment	50	1,000	3,000
Isolating Switches	200	5,000	15,000
Monitor & Protection	300	8,000	15,000
Instrumentation	275	7,000	10,000
Cable	100	2,000	10,000
Subtotal	925	\$23,000	\$ 53,000
<u>Converter</u>			
Converter Foundation	730	\$15,000	\$ 24,000
Transformer	435	9,000	11,000
Converter	2,820	70,000	1,300,000
Subtotal	3,985	\$94,000	\$1,335,000
<u>Master Site Controller</u>			
MSC Foundation	290	\$ 6,000	\$ 9,000
MSC Building	970	20,000	40,000
Remote Controller	590	15,000	100,000
Computer & Peripherals	1,840	47,000	275,000
Subtotal	3,690	\$88,000	\$424,000

TABLE B.34. Normalized PSE&G Zinc-Bromine Power-Related
Balance-of-Plant Cost Estimate

<u>Cost Elements</u>		<u>Cost in</u> <u>1,000s (1983\$)</u>	<u>Reduction</u> <u>Factor</u>	<u>Reduced Cost</u> <u>1,000s (1983\$)</u>
AC Interface	Material	155	0.90	139.5
	Labor	65	0.80	52.0
DC Interface	Material	53	0.90	47.7
	Labor	23	0.80	18.4
Converter	Material	1335	0.90	1,201.5
	Labor	94	0.80	75.2
Site Controller	Material	424	0.90	381.6
	Labor	88	0.80	70.4
				<u>1986.3</u>
Escalated to 1988\$				2,315,400
Unit Cost Based on 20-MW System				\$116/kW

B.3.5 Net Salvage Value

SOURCE: Gould, Inc. (Ramsay and Edgecomb 1982)

This source estimates scrap value as the sum of the following:

- electrolyte (90% of material)(60% of cost)
- electrodes (100% of material)(80% of cost)
- all else (50% of material)(40% of cost).

The scrap value calculations presented by Gould, Inc. were based on one of its own battery designs. In this particular case, scrap value was \$15.75/kWh (1980\$) for a battery with an initial cost of \$68.73/kWh. This is equivalent to roughly 23% on this battery system. The system in question was 100-MWh, 20-MW and comprised 80.7 kWh modules.

SOURCE: Bechtel (1982b)

This source examined a Gould, Inc. battery and assumed entire modules would be replaced at the end of the battery's cycle life. Old modules would be sold for \$12.60/kWh (1980\$) based on an original F.O.B. cost of \$95.48. This amounts to 13% of the initial capital.

SOURCE: ERC (1986b)

This source acknowledged the replacement of the battery cell stack every ten years but did not detail any credit received for the stack.

B.3.6 Operating and Maintenance Cost

SOURCE: Gould, Inc. (Ramsay and Edgecomb 1982)

This source presents cost estimates for scheduled and unscheduled maintenance, along with pump replacements and cell replacement for a 100-MWh, 20-MW system constructed of 80.7 kWh modules. Table B.35 presents the source estimate. The preface to the report did cite optimism.

TABLE B.35. Gould, Inc. Zinc-Bromine Battery Operating and Maintenance Costs (Ramsay and Edgecomb 1982)

Replacement of pump every 7 years: \$150/module plus 1 manhour

Replacement of one cell/module every 3 years: \$650/module
plus 0.5 mandays

Scheduled maintenance: 16 mandays/month

Unscheduled maintenance: 24 mandays/year

SOURCE: ERC (1986a)

This estimate assumed stack replacement every 10 years at \$25/kWh (1986\$). ERC set variable operating and maintenance costs at \$0.02/kWh-retrieved and fixed costs at \$0.54/kW-yr. Lead-acid battery O&M was presented at the same fixed and variable rates. No explanation of any of these costs was given.

SOURCE: Bechtel (1982)

For a 6.21-MWh system, Bechtel estimated annual maintenance at 29 hours/yr. Associated material costs were \$200/yr (1980\$). Twenty-five hours and \$1500 are estimated to be required for the coolant pump maintenance every 8 years. The refrigerator system requires \$9000 and 30 manhours every 12 years.

B.4 SODIUM-SULFUR BATTERY

B.4.1 Battery Purchase Cost

SOURCE: PSE&G Review of Ford Sodium-Sulfur Battery Cost Estimate
(Abraham et al. 1985b)

This PSE&G estimate is based on Ford's 211-Wh Cell. The cells are assembled into modules at the factory. The modules actually form part of the battery building structure; thus, the battery module cost is appreciable higher than CSPL's. Table B.36 compares PSE&G's cost estimate to PNL's normalized version.

In order to make this estimate consistent with others on a component basis, the building and installation costs need to be deducted from the total cost of \$152.70/kWh. The appropriate deduction was approximated by examining Ford's original cost estimate (Ford 1980) to determine the fraction of the \$152.70/kWh that should be attributed to the energy-related BOP (i.e., buildings and associated costs).

TABLE B.36. Normalized PSE&G Estimate of the Ford Sodium-Sulfur Battery

Cost Element	PSE&G (1980\$/kWh)	Adjustment	Normalized PSE&G (1983\$/kWh)
Materials	53.91	esc. to 1983\$	65.04
Matls Ovhd @ 10%	5.39	esc. to 1983\$	6.50
Direct Labor	9.56	--	9.56
Direct Labor Ovhd @ 150%	14.33	--	14.33
Energy W/10% Ovhd	2.85	esc. to 1983\$	3.44
Equipment Depreciation	3.60	esc. to 1983\$	4.34
Rent	<u>1.17</u>	--	<u>1.17</u>
	90.81		104.38
ROI and Taxes @ 30%	18.97	recalculate	22.41
Indirects	<u>5.00</u>	recalculate	<u>6.00</u>
	114.79		\$132.79
Esc. to 1983\$ @ 8%/yr	<u>30.00</u>		
	\$144.79 (1983\$)		
		esc. to 1988\$	\$152.70/kWh

Ford estimated a system cost of \$7,809,000 (1980\$), with modules costing \$7,144,000 of the total. Module cost was estimated by Ford as \$12,758, with \$9,421 associated with cells and \$1,225 associated with cell busbars. The remainder of the module cost is for structures and controls. From this information, it was determined that cells and cell busbars represent 76% of the total costs. On this basis, the estimate of \$152.70/kWh was reduced to \$116/kWh, with the balance moved to the energy-related BOP component and a small portion (\$1.35/kWh, 1980\$; \$1.90/kWh, 1988\$) to the installation component.

SOURCE: CSPL (1986a)

This cost estimate for a module constructed of XPB cells was prepared largely according to the 1984 George guidelines. The XPB cell is sized at 65 kWh-of-capacity.

The costs associated with fabrication of a 2000-kWh module are shown in Table B.37.

TABLE B.37. XPB Sodium-Sulfur Cell Module Costs (1986\$)

<u>Cost Element</u>	<u>CSPL (1986\$/kWh)</u>	<u>Adjustment</u>	<u>Normalized CSPL (1983\$)</u>
Direct Materials	49,413	de-escalate	45,230
Mtrl Ovhd @ 10%	4,941	recalculate	4,523
Direct Labor	8,773	(b)	8,773
Direct Labor Ovhd @ 150%	13,160	(b)	13,160
Equipment Depreciation	6,707	de-escalate	6,139
Rent	<u>1,657</u>	(c)	<u>1,657</u>
	\$84,651		\$79,482
ROI and Taxes (30%)			25,570
	\$10.67/kWh (a)		
Indirects			<u>12,000</u>
Cost per kWh	<u>\$53.00/kWh</u>		<u>\$58.53/kWh</u>
		esc. to 1988\$	\$67.31/kWh

(a) Includes ROI, Taxes, and Indirects.

(b) Source based on \$13/hour, as stated in 1984 George guidelines. No adjustment required.

(c) Source based on \$6/ft², as stated in 1984 George guidelines. No adjustment required.

SOURCE: PSE&G Review of GE/CSPL Sodium-Sulfur Battery Cost Estimate (Abraham et al. 1985d)

PSE&G evaluated the early-1980s cell design of GE/CSPL. It is interesting to note that at that point, GE had identified cost uncertainties in purity and cost of alumina powder, bedding for powder sinter, saggars for tube sinter, and alumina header powder, but the uncertainties were not reflected in the cost data submitted to PSE&G for evaluation. These uncertainties and manufacturing equipment uncertainties lead PSE&G to estimate manufacturing costs 9% higher than GE/CSPL. The PSE&G cost estimate normalized to this study's ground rules is presented in Table B.38.

TABLE B.38. Normalized PSE&G Estimate of the GE/CSPL Sodium-Sulfur Battery

<u>Cost Element</u>	<u>PSE&G (1983\$/kWh)</u>	<u>Adjustment</u>	<u>PSE&G (1983\$/kWh)</u>
Materials	42.55	--	42.55
Materials and Purchased Components Ovhd @ 10%	4.26	--	4.26
Direct Labor	5.63	13/10(a)	7.32
Direct Labor Ovhd @ 150%	8.45	--	12.68
Equipment Depreciation	2.26	--	2.26
Rent	0.66	6/5(a)	0.79
	<u>\$63.80</u>		<u>\$ 69.86</u>
ROI and Taxes (30%)	12.52	recalculate	\$ 13.07
Indirects	5.00	set by George at	6.00
	<u>\$81.32</u>		<u>\$ 88.93</u>
Uninstalled F.O.B. cost		esc. to mid 1988\$	\$102.26

(a) Adjusted to 1984 George guidelines.

B.4.2 Shipping and Installation Cost

The availability of data does not warrant a third layer of detail.
Refer to Section 3.2.4.2.

B.4.3 Energy-Related Balance-of-Plant Cost

SOURCE: CSPL (1986a)

This CSPL component cost estimate was adjusted to reflect cost savings from multiple installations. Table B.39 presents the normalized cost estimate of \$27.6/kWh, which was escalated to \$29.5/kWh (1988\$).

TABLE B.39. Normalized CSPL Sodium-Sulfur Energy-Related
Balance-of-Plant (1986\$)

<u>Cost Element</u>	<u>Base Cost(a)</u>	<u>Contingency(a)</u>	<u>Multiple Installation Reduction Factor</u>	<u>Total</u>
Civil/Structural/ Foundations	\$ 468,000	\$113,000	0.8	\$ 465,000
Electrical	558,000	134,000	0.8	554,000
Buildings	1600,000	385,000	0.8	1,588,000
Engineering	475,000	--	0.33	157,000
				<u>\$2,764,000</u>
				\$27.6/kWh

(a) As estimated by CSPL.

SOURCE: PSE&G (Abraham et al. 1985b)

For the Ford battery system, PSE&G developed the cost estimate presented in Table B.40. The normalized cost estimate, adjusted for multiple installations, is presented in Table B.41. The total cost of \$14/kWh (1983\$) does not include costs for buildings, which are estimated at \$35/kWh (1988\$). (See Section B.4.1 for details). Escalating the \$14/kWh (1983\$) estimate and adding \$35/kWh (1988\$) for buildings yields a total cost estimate of \$51/kWh (1988\$).

**TABLE B.40. PSE&G (Ford Battery) Energy-Related
Balance-of-Plant Cost Estimate**

	<u>Manhours</u>	<u>Labor</u>	<u>Materials</u>
<u>Battery Auxiliaries</u>			
Battery Building Foundation	\$2,900	\$ 60,000	\$ 87,000
Battery Building	--	--	--
Refrigeration	--	--	--
Racks	--	--	--
Subtotal	<u>\$2,900</u>	<u>\$ 60,000</u>	<u>\$ 87,000</u>
<u>Site Auxiliaries</u>			
Module Repair & Storage	\$ --	\$ --	\$ --
Safety Systems	1,700	39,000	60,000
HVAC	500	12,000	9,000
Aux. Power Supply Transfer	200	6,000	15,000
Uninterruptable Power	400	10,000	30,000
Module Handling Crane	--	--	--
Chem. Cleanup-Scrubber	--	--	--
Firewalls	1,000	23,000	35,000
Yard Work	3,200	65,000	120,000
Utilities	700	17,000	25,000
Miscellaneous	500	\$ 12,000	\$ 12,000
Subtotal	<u>\$8,200</u>	<u>\$184,000</u>	<u>\$306,000</u>
<u>Non-Manual</u>			
Supervision	\$2,700	\$ 50,000	
Engineering	7,200	129,000	
Quality Control	2,700	48,000	
Cost/Schedule	1,200	22,000	
Contract Administration	900	17,000	
First Aid, Safety, Security	600	10,000	
Procurement	1,300	23,000	
Administration	2,300	41,000	
Fringe Benefits 35%		\$119,000	
Mark Up 20%		\$ 92,000	
Non-manual Total	<u>\$18,900</u>	<u>\$551,000</u>	<u>\$123,000</u>
<u>Other Distributables</u>	<u>\$ 7,800</u>	<u>\$157,000</u>	<u>\$ 98,000</u>
<u>Home Office (AE)</u>			
Engineering & Design	\$20,200	\$404,000	
Procurement	700	34,000	
Construction	400	9,000	
Project Operation	200	4,000	
Quality Assurance	600	11,000	
Other Corp. Services	500	11,000	
Fringe Benefits 35%		\$ 165,000	
Burden 75%		\$ 479,000	
Subtotal AE	<u>\$23,600</u>	<u>\$1,117,000</u>	<u>\$78,000</u>

TABLE B.41. Normalized PSE&G Energy-Related Balance-of-Plant
for Ford Battery System (1983\$)

<u>Cost Elements</u>		<u>Cost in</u> <u>\$1000s</u>	<u>Multiple</u> <u>Installation</u> <u>Reduction Factor</u>	<u>Reduced Cost</u> <u>\$1000s</u>
Battery Auxiliary	Materials	87	0.9	78.3
	Labor	60	0.7	42.0
Site Auxiliary	Materials	306	0.9	275.4
	Labor	184	0.7	110.7
Non-Manual	Materials	123	0.9	128.8
	Labor	551	0.5	275.5
Other Distributables	Materials	98	0.5	49
	Labor	157	0.5	78.5
Home Office A/E	Materials	78	0.3	23.4
	Labor	1117	0.3	<u>335.1</u>
				\$14/kWh

B.4.4 Power-Related Balance-of-Plant Cost

There are no major differences between the power-related BOP for a sodium-sulfur battery storage plant and a conventional lead-acid system. Refer to Sections 3.2.4.4 and B.1.4 for applicable data.

B.4.5 Net Salvage Value

The availability of data does not warrant a third layer of detail. Refer to Section 3.2.4.5.

B.4.6 Operating and Maintenance Cost

SOURCE: Askew and Symons (1986)

This source evaluates several alternatives for maintaining the sodium-sulfur battery system. The general assumption made in this study is that replacement of failed cells is scheduled when nameplate capacity of the plant has been reduced by 20%. Such a scenario involves replacement of failed cells every year.

Askew and Symons estimated BOP maintenance costs to be 2 mills/kWh (\$0.002/kWh), with cell maintenance labor extra. One maintenance scenario suggested by the manufacturer (CSPL) is to repair modules which have a significant number of failures degrading capacity. The authors estimate this strategy would require every plant module to be replaced and repaired each year. They do not believe slightly larger cells will improve the situation. It was suggested that a cell size of greater than 10 kWh, rather than the 65 Wh of the XPB cell, is required before this maintenance scenario is economically viable, and 10-kWh cells are impractical. Thus, this maintenance scenario is unlikely ever to be economically feasible.

This study also briefly examined automated cell replacement. This method reduces labor costs but increases capital costs. The author identified both reliability and cost concerns.

The authors estimated O&M costs to be possibly as high as 8-10 mills/kWh, with a cost goal of 4 mills/kWh. Achieving such costs will require development of cells with a calendar life of 10 years and cycle life of 2500 cycles, with cell failures concentrated in later years rather than evenly distributed.

B.5 LITHIUM-IRON SULFIDE BATTERY

B.5.1 Battery Purchase Cost

SOURCE: Argonne National Laboratory Cost Estimate (Towle et al. 1976)

This source presents a detailed manufacturing cost analysis based on a 0.92 kWh cell. Annual production rate is assumed to be 1.15×10^6 kWh. The cells are shipped to the load-leveling facility in modules of 24 cells.

Subsequent to this study, in 1979 a lithium-iron sulfide battery cost estimate using the George guidelines was prepared (Chilenskas et al. 1980). However, it is primarily an escalation of the cost data presented in this source. Because both sources are based on the same information, the older, original estimate by Towle was used as the basis for the normalized estimate.

This source was published before the first George guidelines were developed, and therefore, input data for the guidelines was assembled from the raw source data. Table B.42 presents the key cost data from the source report.

Included in these costs are cell manufacturing costs and assembly into submodules. The BOP design used to develop the overall normalized cost estimate incorporates larger cells and, consequently, larger submodules. To work around this difference, submodule costs were deducted to allow the normalized source estimate (Towle et al. 1976) to include only cell costs. Submodule cost contributors included \$75,000 (1975\$) of capital equipment, 11 of the 90 mandays of daily manufacturing labor during plant operations, and \$2.13/kWh of material costs. The key cost data shown in Table B.42 was adjusted to reflect the deductions for these submodule costs. The adjusted estimates are shown in Table B.43.

Towle allowed 200% of the capital equipment cost for buildings, land, and installation. Because the George guidelines require only installed equipment cost, only 100% was added to the capital cost estimate. In addition, labor was adjusted to the 1984 George guidelines labor rate of \$13/hr (Dec. 1983\$). Table B.44 presents the normalized cost estimate for the lithium-iron sulfide battery.

TABLE B.42. Key Cost Data for the Lithium-Iron Sulfide Battery (1975\$)

Submodule Materials Cost (100% yield)	19.02/kWh
Direct Labor at \$6/hr	\$1,080,000
Factory Floor Space	50,000 ft ²
Capital Equipment (uninstalled)	\$3,204,000

TABLE B.43. Adjusted Key Cost Data for the Lithium-Iron Sulfide Battery (1975\$)

Cell Materials Cost (100% yield)	16.89/kWh
Direct Labor at \$6/hr	\$948,000
Factory Floor Space	48,000 ft ²
Capital Equipment (uninstalled)	3,129,000

TABLE B.44. Normalized Cost Estimate for the Lithium Iron Sulfide Battery

<u>Cost Element</u>	<u>\$/kWh</u>	<u>Adjustment</u>	<u>\$/kWh (1983\$)</u>
Materials (90% yield)	18.77 (1975\$)	esc.	32.56
Mtrls Ovhd @ 10%	1.88 (1975\$)	recalculate	3.26
Direct Labor	1.79 (1983\$)	--	1.79
Direct Labor Ovhd @ 150%	2.68 (1983\$)	--	2.68
Equipment Depreciation	6.26 (1975\$)	recalculate	10.72
Rent	0.29 (1983\$)	--	0.29
Subtotal			\$51.30
ROI and Taxes (30%)		recalculate	36.78
Indirects		recalculate	6.00
			\$94.08
Uninstalled F.O.B. Cost \$94.08/kWh		esc. to 1988\$	108/kWh

B.5.2 Shipping and Installation Cost

The availability of data does not warrant a third layer of detail. Refer to Section 3.2.5.2.

B.5.3 Energy-Related Balance-of-Plant Cost

SOURCE: Argonne National Laboratory Cost Estimate (Zivi et al. 1980a)

This energy-related BOP cost estimate is based on a 100-MWh design. Construction is assumed to be performed in a mature market when 25 facilities are constructed per year. On this basis, it appears unnecessary to further reduce costs for multiple construction savings. The source estimate is shown in Table B.45.

The total cost of 80.25/kWh (\$134/kWh, 1988\$) does not include land acquisition or site-specific engineering costs. It was recognized by the developers that these BOP costs were unacceptably high. Therefore, a program was undertaken to reduce costs. In a second report (Zivi et al. 1980b), a cost reduction of \$20 to \$58 kWh (1978\$) was identified; however, detailed estimates breaking out cell costs from BOP costs are not available. Assuming the average of \$40/kWh saved could be achieved, total BOP costs would be \$40/kWh (67/kWh, 1988\$).

TABLE B.45. Lithium-Iron Sulfide Energy-Related

Item	Description	Material Cost, \$/kWh	Labor Cost, \$/kWh	Subtotal, \$/kWh	Contractor Overhead, \$/kWh	Contractor Profit, \$/kWh	Total Price, \$/kWh
1	<u>Submodules</u>						
	Structural Steel	6.96	0.56	7.52	1.70	1.03	10.25
	Copper Components	13.96	1.13	15.09	3.41	2.07	20.57
	Ceramic Insulation	5.08	0.41	5.49	1.24	0.75	7.48
	Miscellaneous	0.98	0.08	1.06	0.24	0.14	1.44
2	<u>Modules</u>						
	Structural Steel and Sheet Metal	3.80	2.86	6.66	0.67	0.73	8.06
	Thermal Control (subcontract)	2.14	--	2.14	0.21	0.24	2.59
	Thermal Insulation	0.50	0.38	0.88	0.09	0.10	1.07
	Equalization and T/C/ Wiring and Connectors	8.85	1.36	10.20	1.02	1.12	12.34
3	<u>Control and Instrumentation</u>						
	Site Controller	1.50	--	1.50	0.15	0.16	1.82
	Thermal Controllers	0.12	--	0.12	0.01	0.01	0.14
	Circuit Protectors	2.79	--	2.79	0.28	0.30	3.38
	Instrumentation (T/C)	0.36	--	0.36	0.04	0.04	0.44
	Equalization Pallets	1.60	0.54	2.14	0.21	0.24	2.59
4	<u>Ancillary Equipment</u>						
	Shelter (hanger)	0.12	0.23	0.35	0.03	0.04	0.42
	Gantry	0.97	--	0.97	0.10	0.11	1.17
	Special Tools and Rack	0.11	0.12	0.23	0.02	0.03	0.28
	Facility Lighting and Power	1.15	0.06	1.21	0.12	0.13	1.46
	Bus Ducts	0.35	0.03	0.38	0.04	0.04	0.46
5	<u>Field Installations</u>						
	Foundations	0.11	0.31	0.42	0.04	0.05	0.51
	Mechanical Assembly	--	1.53	1.53	0.15	0.17	1.85
	Electrical	--	0.67	0.69	0.07	0.08	0.83
	Startup	--	0.28	0.28	0.03	0.03	0.34
	Equalization Electrical	--	0.63	0.63	0.06	0.07	0.76
6	Total Plant	51.44	11.18	62.64	9.95	7.68	80.25

B.5.4 Power-Related Balance-of-Plant Cost

There are no major differences between the power-related BOP for a lithium-iron sulfide battery storage plant and a conventional lead-acid system. Refer to Sections 3.2.5.4 and B.1.4 for applicable data.

B.5.5 Net Salvage Value

The availability of data does not warrant a third layer of detail. Refer to Section 3.2.5.5.

B.5.6 Operating and Maintenance Cost

SOURCE: Podder et al. (1981)

This source presents one estimate for a relatively small system. The estimated O&M cost does not include cell replacements. The data as presented in the source document is:

System size: 500-kWh

Annual O&M cost: \$0.72/kWh (1980\$; 1.01/kWh 1988\$)

SOURCE: Gould, Inc. (Ramsay and Edgecomb 1982)

Gould, Inc. presented the following O&M cost estimate for a 100-MWh, 20-MW system with 45,000 cells:

2.5% Annual Cell Failure Rate

Individual Cell Replacement: 2 manhours

Bulk Cell Replacements: 0.5 manhours

Scheduled Maintenance: 94 mandays/mo

Unscheduled Maintenance: 24 mandays/yr

Based on the cell failure rate, 2 manhours for replacements, 45,000 cells, and a \$39/hour labor rate (1988\$), cell replacement labor is \$87,750 (1988\$). General maintenance would be \$360,000/yr (1988\$), assuming the same labor rate.

B.6 PHOSPHORIC ACID FUEL CELL

SOURCE: EPRI (1986)

The estimate presented in this source is for first generation phosphoric acid fuel cells produced at a production level of 1500 MW/yr. Stack replacement costs are included in the operating cost, and there is no salvage credit with respect to stack replacement. The expected life, based on use as a baseload or intermediate load plant, is 40,000 hours. It is not known how peaking applications would affect stack life.^(a) Table B.46 presents the source estimate and associated design data as excerpted from EPRI's Technical Assessment Guide (TAG). The source estimate does include land costs, which are excluded in the battery system cost estimates. However, in the case of a phosphoric acid fuel cell, land costs are less than \$0.50/kWh and are, therefore, ignored.

TABLE B.46. Phosphoric Acid Fuel Cell System Cost and Design Data

	<u>Dec. 1984\$</u>	<u>mid-1988\$</u>
Unit Size	10-MW	10-MW
Capital Cost	\$797/kW	--
Startup Capital	\$53/kW	--
Total Capital Cost	\$850/kW	\$955/kW
Operating and Maintenance		
Fixed	\$6/kW-yr	\$6.7/kW-yr
Variable	\$0.0087/kWh	\$0.0098/kWh
Heat Rate	8350 BTU/kWh	8350 BTU/kWh

(a) Personal communication with John Sholes, Director of Fuel Cell Branch, U.S. Department of Energy (December 1986).

B.7 COMPARISON TECHNOLOGIES

B.7.1 Gas-Fired Turbine

SOURCE: EPRI (1986)

Cost estimates for two peaking turbines are presented in this source: one for a 75-MW conventional unit and one for a 130-MW advanced unit. Based on the 75-MW distillate/gas fuel turbine, EPRI estimated a plant capital cost of \$269/kW (Dec. 1984\$) plus \$26/kW for startup, inventory, and land, yielding a total of \$295/kW (1984\$). Operating and maintenance costs were estimated at \$0.40/kW-yr plus \$0.004/kWh. Heat rate at average annual load is estimated at 13800 BTU/kWh in a peaking application. Accuracy on the estimates was identified as $\pm 15\%$. Table B.47 presents the cost and design data.

The capital cost of the 130-MW advanced unit is \$273 (Dec. 1984\$), including startup, inventory, and land. Maintenance is estimated the same as the conventional turbine, but the heat rate is lower at 13100 BTU/kWh in a peaking application. This technology is in the pilot-plant stage of development, and accuracy of the estimate is projected as -30 to +80%. Table B.48 presents the cost and design data normalized to mid-1988 dollars.

TABLE B.47. Cost and Design Data for a Conventional Gas-Fired Turbine (1988\$)

Unit Size: 75-MWe
Capital Cost: \$331/kWe
O&M: \$0.44/kW-yr plus \$0.0044/kWh
Heat Rate: 13800 BTU/kWh

TABLE B.48. Cost and Design Data for an Advanced Gas-Fired Turbine (1988\$)

Unit Size: 130-MWe
Capital Cost: \$307
O&M: \$0.44/kW-yr plus \$0.0044/kWh
Heat Rate: 13100 BTU/kWh

Based on the unit O&M costs presented in Table B.46, O&M costs would be \$113,400 (1988\$) for a 20-MW conventional gas-fired turbine operating 5 hours a day, 250 days a year. At a heat rate of 13800 BTU/kWh, fuel consumption would be 345,000 MBTU annually. The O&M, fuel consumption, and capital cost for a 10-MW gas-fired turbine operating 3 and 5 hours a day, based on the same unit costs, are presented in Table B.49. Table B.50 presents cost data for the advanced gas-fired turbine in three plant configurations. These additional plant configurations were examined as a baseline for comparison of the battery energy storage system sensitivity cases.

TABLE B.49. Cost and Operational Data for Three Conventional Gas-Fired Turbine System Configurations (1988\$)

<u>Unit Size</u>	<u>Hrs/day</u>	<u>Capital Cost</u>	<u>Annual O&M</u>	<u>Annual Fuel Consumption</u>
20-MWe	5	\$331/kW	\$118,800	345,000 MBTU
10-MWe	5	\$331/kW	\$63,000	172,500 MBTU
10-MWe	3	\$331/kW	\$33,000	103,500 MBTU

TABLE B.50. Cost and Design Data for Advanced Gas-Fired Turbines (mid-1988\$)

<u>Unit Size</u>	<u>Hrs/day</u>	<u>Capital Cost</u>	<u>Annual O&M</u>	<u>Annual Fuel Consumption</u>
20-MWe	5	\$307/kW	\$118,800	327,500 MBTU
10-MWe	5	\$307/kW	\$63,000	163,750 MBTU
10-MWe	3	\$307/kW	\$33,000	98,250 MBTU

B.7.2 Compressed Air Energy Storage

SOURCE: EPRI (1986)

This source presents estimates for a 25-MW compressed air energy storage (CAES) system, with underground storage constructed in three media (rock, salt, and aquifer). All the estimates have projected error bands of less than $\pm 15\%$. However, CAES does rely on highly restrictive geologic conditions, which in some locations, results in much higher costs than presented. Costs and related data as summarized from TAG (EPRI 1986) are presented in Table B.51.

To develop comparison costs for a number of plant configurations, several assumptions regarding these costs were made. It was assumed the power/charging side cost would scale as a function of power rating. The storage side cost was assumed to scale with storage hours. Interest during construction was included with storage costs, because it would be driven primarily by those costs. Finally, startup, inventory, and land were grouped with the power/charging side of the system. Making these cost distributions and escalating to mid-1988\$ yields the values shown in Table B.52 for a 100-MWh, 20-MW system.

TABLE B.51. CAES System Costs (December 1984\$/kW)

	Storage Media		
	Rock	Salt	Aquifer
Storage Size	10 hrs	10 hrs	10 hrs
Capital Cost			
Power/Charging Side, \$/kW	801	627	634
Storage Side, \$/kW	408	62	3
AFDC, \$/kW	144	41	37
Startup, Inventory Land, \$/kW	33	19	19
Total, \$/kW	1386	749	693
O&M			
Fixed, \$/kW-yr	2.1	1.0	1.0
Variable, \$/kWh	0.0017	0.0008	0.0008

TABLE B.52. Normalized CAES System Costs (1988\$)

	Storage Media		
	Rock	Salt	Aquifer
Capital Cost, \$/kW	937	726	734
\$/kWh	62.0	11.6	4.5
O&M, Fixed, \$/kW-yr	2.4	1.1	1.1
Variable, \$/kWh	0.0019	0.0009	0.0009
Fossil Fuel Usage, BTU/kWh	4100(a)	4100(a)	4100(a)
Electricity, kWh out/kWh in	1.32	1.32	1.32

(a) TAG (EPRI 1986) estimated 4040 BTU/kWh at 75% load and 4160 BTU/kWh at 50% load. Peaking unit operates in the 60-65% load rate; therefore, 4100 BTU/kWh was selected.

Based on the normalized CAES system costs, the estimates for three system configurations were developed. These estimates are presented in Tables B.53 through B.55.

TABLE B.53. Cost and Operating Data for CAES Plants Constructed in Rock (1988\$)

System Size	Capital Cost		Annual Fuel RQTS.	Annual
	(\$/kWh)	(\$/kW)	(MBTU)	O&M Cost (\$)
100-MWh, 20-MW	62	937	77,900	84,100
50-MWh, 10-MW	62	937	38,950	42,050
30-MWh, 10-MW	62	937	23,370	34,830

TABLE B.54. Cost and Operating Data for CAES Plants Constructed in Salt (1988\$)

System Size	Capital Cost		Annual Fuel RQTS.	Annual
	(\$/kWh)	(\$/kW)	(MBTU)	O&M Cost (\$)
100-MWh, 20-MW	11.6	726	77,900	39,000
50-MWh, 10-MW	11.6	726	38,950	19,550
30-MWh, 10-MW	11.6	726	23,370	16,130

TABLE B.55. Cost and Operating Data for CAES Plants
Constructed in Aquifer (1988\$)

<u>System Size</u>	<u>Capital Cost</u>		<u>Annual</u>	<u>Annual</u>
	<u>(\$/kWh)</u>	<u>(\$/kW)</u>	<u>Fuel RQTS.</u>	<u>O&M Cost (\$)</u>
100-MWh, 20-MW	4.5	734	77,900	39,000
50-MWh, 10-MW	4.5	734	38,950	19,550
30-MWh, 10-MW	4.5	734	23,370	16,130

B.7.3 Conventional Pumped Hydro Storage

SOURCE: EPRI (1986)

The estimates presented here are for a 350-MWe system at a favorable site, as presented in TAG. The costs of pumped-hydro systems can vary 40% or more, depending on site-specific conditions. Table B.56 presents key data from the source document.

Making the assumptions AFDC can be distributed proportionally to the power generation and storage sides of the plant and that startup scales with the power generation side of the plant, power generation-related costs are \$881/kW (1984\$) and storage-related costs are \$14/kWh. These costs are equivalent to \$990/kW and \$15.7/kWh (1988\$), respectively. Based upon these unit costs, Table B.57 presents cost and operational data for the three system sizes.

TABLE B.56. Cost and Design Data for a Conventional Pumped-Hydro Storage Facility (December 1984\$)

Unit Size:	350-MWe
Efficiency:	0.735
Plant Capital	
Power Generation	\$622/kW
Storage (10 hrs)	\$104/kW
AFDC	\$260/kW
Startup	\$ 35/kW
O&M, Fixed	\$ 3.4/kW-yr
O&M, Variable	\$0.0034

TABLE B.57. Cost and Operational Data for Three Pumped-Hydro Storage Plants Configurations (1988\$)

<u>Configuration</u>	<u>Capital Cost</u>	<u>O&M</u>
100-MWh, 20-MW	\$990/kW, \$15.7/kWh	\$171,893
50-MWh, 10-MW	\$990/kW, \$15.7/kWh	\$ 85,946
30-MWh, 10-MW	\$990/kW, \$15.7/kWh	\$ 66,847

APPENDIX C

LIFE-CYCLE COST CALCULATIONS FOR LOAD-LEVELING APPLICATION

APPENDIX C

LIFE-CYCLE COST CALCULATIONS FOR LOAD-LEVELING APPLICATION

This Appendix presents a summary of the pertinent input and output to the life-cycle cost calculations presented in the main text. They would prove most useful for identifying what specific components drive total cost. The following table should provide a guide to locating information in this Appendix.

<u>Technology</u>	<u>Page</u>
Conventional Lead-Acid Battery System	C.3
Sealed Lead-Acid Battery System	C.9
Zinc-Bromine Battery System	C.15
Sodium-Sulfur Battery System	C.21
Lithium-Iron Sulfide Battery System	C.27
Phosphoric Acid Fuel Cell System	C.29
Conventional Gas-Fired Turbine	C.35
Advanced Gas-Fired Turbine	C.41
Rock Media Compressed Air Energy Storage	C.47
Aquifer Media Compressed Air Energy Storage	C.53
Salt Media Compressed Air Energy Storage	C.59
Conventional Pumped Hydro Storage	C.65

CONVENTIONAL LEAD-ACID BATTERY SYSTEM: LOW ESTIMATE

BATTERY STORAGE ECONOMIC ANALYSIS MODEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	Conv. Lead-Acid	CYCLE LIFE (#)	2000
APPLICATION	Utility	CYCLES/YEAR	250
SYSTEM SIZE (KWH)	100,000	ROUND TRIP EFFICIENCY	0.64
SYSTEM SIZE (KWE)	20,000		

AUXILARY ELECTRICITY CONSUMPTION (KWH/YR)	0
AUXILARY FOSSIL FUEL CONSUMPTION (MBTU/YR)	0

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	93 (\$/KWH)
BATTERY INSTALLATION	28 (\$/KWH)
ENERGY RELATED BOS	33 (\$/KWH)
POWER RELATED BOS	121 (\$/KWE)
NET SALVAGE VALUE	5.6 (\$/KWH)

-----OPERATING AND MAINTENANCE COST INPUTS-----

COST OF ELECTRICITY, \$/KWH	0.025	ANNUAL O&M COST, \$	62000
COST OF FOSSIL FUEL, \$/MBTU	0		

*****EQUAL INTERVAL PERIODIC O&M*****

PERIODIC MAINTENANCE INTERVAL	1 (YEARS)
PERIODIC MAINTENANCE COST	0 (\$)

*****VARIED INTERVAL PERIODIC O&M*****

YEAR	COST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.042
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	30	TAX CREDIT	0.000
CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	PLANT TAX LIFE	20
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR PLANT	0.485
DEPRECIATION FACTOR FOR BATTERIES	0.851
CAPITAL RECOVERY FACTOR	0.059242
FIXED CHARGE RATE FOR PLANT	0.097929
FIXED CHARGE RATE FOR BATTERIES	0.084658

OVERNIGHT CONSTRUCTION COST	17820000
1st YEAR OPERATING & MAINT. COST	62,000
1st YEAR EFFICIENCY ELECTRICITY COST	225,000
1st YEAR STORED ELECTRICITY COST	400000
1st YEAR AUXILARY ELECTRICITY COST	0
1st YEAR AUXILARY FOSSIL FUEL COST	0

ANNUAL ENERGY STORED (KWH)	25000000
ANNUAL ENERGY RETRIEVED (KWH)	16000000

PRESENT VALUE OF INITIAL CAPITAL	17820000
PRESENT VALUE OF NET REPLACEMENT CAPITAL	18577469
PRESENT VALUE OF ANNUAL O&M	1046544.
PRESENT VALUE OF PERIODIC O&M	0
PRESENT VALUE OF EFFICIENCY LOSS ENERGY	3797943.
PRESENT VALUE OF STORED ENERGY	6751899.
PRESENT VALUE OF AUXILARY ELECTRIC ENERGY	0
PRESENT VALUE OF AUXILARY FOSSIL FUEL ENERGY	0
PRESENT VALUE OF FINAL SALVAGE	-156418.

-----SUMMARY RESULTS-----

COMPONENT LIFE-CYCLE COST CONTRIBUTORS

INITIAL BATTERY COST	64
BALANCE-OF-PLANT	35
REPLACEMENTS	98
OPERATING AND MAINTENANCE	4
ENERGY	39
SALVAGE	-1
TOTAL	239 MILLS/KWH

TOTAL PRESENT WORTH	47837438
TOTAL ANNUALIZED COST	3831019.
LEVELIZED STORAGE COST	0.239439 \$/KWH OF ENERGY RETRIEVED

XX

CONVENTIONAL LEAD-ACID BATTERY SYSTEM: NOMINAL ESTIMATE

BATTERY STORAGE ECONOMIC ANALYSIS MODEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	Conv. Lead-Acid	CYCLE LIFE (#)	2000
APPLICATION	Utility	CYCLES/YEAR	250
SYSTEM SIZE (KWH)	100,000	ROUND TRIP EFFICIENCY	0.64
SYSTEM SIZE (KWE)	20,000		

AUXILARY ELECTRICITY CONSUMPTION (KWH/YR)	0
AUXILARY FOSSIL FUEL CONSUMPTION (MBTU/YR)	0

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	134 (\$/KWH)
BATTERY INSTALLATION	28.5 (\$/KWH)
ENERGY RELATED BOS	45.1 (\$/KWH)
POWER RELATED BOS	121 (\$/KWE)
NET SALVAGE VALUE	5.6 (\$/KWH)

-----OPERATING AND MAINTENANCE COST INPUTS-----

COST OF ELECTRICITY, \$/KWH	0.025	ANNUAL O&M COST, \$	117000
COST OF FOSSIL FUEL, \$/MBTU	0		

*****EQUAL INTERVAL PERIODIC O&M*****

PERIODIC MAINTENANCE INTERVAL	1 (YEARS)
PERIODIC MAINTENANCE COST	0 (\$)

*****VARIED INTERVAL PERIODIC O&M*****

YEAR	COST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.042
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	30	TAX CREDIT	0.000
CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	PLANT TAX LIFE	20
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR PLANT	0.485
DEPRECIATION FACTOR FOR BATTERIES	0.851
CAPITAL RECOVERY FACTOR	0.059242
FIXED CHARGE RATE FOR PLANT	0.097929
FIXED CHARGE RATE FOR BATTERIES	0.084658

OVERNIGHT CONSTRUCTION COST	23180000
1st YEAR OPERATING & MAINT. COST	117,000
1st YEAR EFFICIENCY ELECTRICITY COST	225,000
1st YEAR STORED ELECTRICITY COST	400000
1st YEAR AUXILARY ELECTRICITY COST	0
1st YEAR AUXILARY FOSSIL FUEL COST	0

ANNUAL ENERGY STORED (KWH)	25000000
ANNUAL ENERGY RETRIEVED (KWH)	16000000

PRESENT VALUE OF INITIAL CAPITAL	23180000
PRESENT VALUE OF NET REPLACEMENT CAPITAL	25258275
PRESENT VALUE OF ANNUAL O&M	1974930.
PRESENT VALUE OF PERIODIC O&M	0
PRESENT VALUE OF EFFICIENCY LOSS ENERGY	3797943.
PRESENT VALUE OF STORED ENERGY	6751899.
PRESENT VALUE OF AUXILARY ELECTRIC ENERGY	0
PRESENT VALUE OF AUXILARY FOSSIL FUEL ENERGY	0
PRESENT VALUE OF FINAL SALVAGE	-156418.

-----SUMMARY RESULTS-----

COMPONENT LIFE-CYCLE COST CONTRIBUTORS

INITIAL BATTERY COST	86
BALANCE-OF-PLANT	42
REPLACEMENTS	134
OPERATING AND MAINTENANCE	7
ENERGY	39
SALVAGE	-1
TOTAL	308 MILLS/KWH

TOTAL PRESENT WORTH	60806630
TOTAL ANNUALIZED COST	4921432.
LEVELIZED STORAGE COST	0.307590 \$/KWH OF ENERGY RETRIEVED

XX

CONVENTIONAL LEAD-ACID BATTERY SYSTEM: HIGH ESTIMATE

BATTERY STORAGE ECONOMIC ANALYSIS MODEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	Conv. Lead-Acid	CYCLE LIFE (#)	2000
APPLICATION	Utility	CYCLES/YEAR	250
SYSTEM SIZE (KWH)	100,000	ROUND TRIP EFFICIENCY	0.64
SYSTEM SIZE (KWE)	20,000		
AUXILIARY ELECTRICITY CONSUMPTION (KWH/YR)		0	
AUXILIARY FOSSIL FUEL CONSUMPTION (MBTU/YR)		0	

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	143 (\$/KWH)
BATTERY INSTALLATION	33 (\$/KWH)
ENERGY RELATED BOS	49 (\$/KWH)
POWER RELATED BOS	188 (\$/KWE)
NET SALVAGE VALUE	-4 (\$/KWH)

-----OPERATING AND MAINTENANCE COST INPUTS-----

COST OF ELECTRICITY, \$/KWH	0.025	ANNUAL O&M COST, \$	137500
COST OF FOSSIL FUEL, \$/MBTU	0		

*****EQUAL INTERVAL PERIODIC O&M*****

PERIODIC MAINTENANCE INTERVAL	1 (YEARS)
PERIODIC MAINTENANCE COST	0 (\$)

*****VARIED INTERVAL PERIODIC O&M*****

YEAR	COST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.042
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	30	TAX CREDIT	0.000
CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	PLANT TAX LIFE	20
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR PLANT	0.485
DEPRECIATION FACTOR FOR BATTERIES	0.851
CAPITAL RECOVERY FACTOR	0.059242
FIXED CHARGE RATE FOR PLANT	0.097929
FIXED CHARGE RATE FOR BATTERIES	0.084658

OVERNIGHT CONSTRUCTION COST	26260000
1st YEAR OPERATING & MAINT. COST	137,500
1st YEAR EFFICIENCY ELECTRICITY COST	225,000
1st YEAR STORED ELECTRICITY COST	400000
1st YEAR AUXILARY ELECTRICITY COST	0
1st YEAR AUXILARY FOSSIL FUEL COST	0

ANNUAL ENERGY STORED (KWH)	25000000
ANNUAL ENERGY RETRIEVED (KWH)	16000000

PRESENT VALUE OF INITIAL CAPITAL	26260000
PRESENT VALUE OF NET REPLACEMENT CAPITAL	28976989
PRESENT VALUE OF ANNUAL O&M	2320965.
PRESENT VALUE OF PERIODIC O&M	0
PRESENT VALUE OF EFFICIENCY LOSS ENERGY	3797943.
PRESENT VALUE OF STORED ENERGY	6751899.
PRESENT VALUE OF AUXILARY ELECTRIC ENERGY	0
PRESENT VALUE OF AUXILARY FOSSIL FUEL ENERGY	0
PRESENT VALUE OF FINAL SALVAGE	111727.6

-----SUMMARY RESULTS-----

COMPONENT LIFE-CYCLE COST CONTRIBUTORS

INITIAL BATTERY COST	93
BALANCE-OF-PLANT	53
REPLACEMENTS	153
OPERATING AND MAINTENANCE	9
ENERGY	39
SALVAGE	1
TOTAL	348 MILLS/KWH

TOTAL PRESENT WORTH	68219525
TOTAL ANNUALIZED COST	5563160.

LEVELIZED STORAGE COST	0.347698 \$/KWH OF ENERGY RETRIEVED
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SEALED LEAD-ACID BATTERY SYSTEM: LOW ESTIMATE

BATTERY STORAGE ECONOMIC ANALYSIS MODEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	Sealed Lead-Acid	CYCLE LIFE (#)	1500
APPLICATION	Utility	CYCLES/YEAR	250
SYSTEM SIZE (KWH)	100,000	ROUND TRIP EFFICIENCY	0.66
SYSTEM SIZE (KWE)	20,000		

AUXILARY ELECTRICITY CONSUMPTION (KWH/YR)	0
AUXILARY FOSSIL FUEL CONSUMPTION (MBTU/YR)	0

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	105 (\$/KWH)
BATTERY INSTALLATION	28 (\$/KWH)
ENERGY RELATED BOS	26 (\$/KWH)
POWER RELATED BOS	121 (\$/KWE)
NET SALVAGE VALUE	5.6 (\$/KWH)

-----OPERATING AND MAINTENANCE COST INPUTS-----

COST OF ELECTRICITY, \$/KWH	0.025	ANNUAL O&M COST, \$	32500
COST OF FOSSIL FUEL, \$/MBTU	0		

*****EQUAL INTERVAL PERIODIC O&M*****

PERIODIC MAINTENANCE INTERVAL	1 (YEARS)
PERIODIC MAINTENANCE COST	0 (\$)

*****VARIED INTERVAL PERIODIC O&M*****

YEAR	COST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.042
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	30	TAX CREDIT	0.000
CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	PLANT TAX LIFE	20
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR PLANT 0.485
DEPRECIATION FACTOR FOR BATTERIES 0.851
CAPITAL RECOVERY FACTOR 0.059242
FIXED CHARGE RATE FOR PLANT 0.097929
FIXED CHARGE RATE FOR BATTERIES 0.084658

OVERNIGHT CONSTRUCTION COST 18320000
1st YEAR OPERATING & MAINT. COST 32,500
1st YEAR EFFICIENCY ELECTRICITY COST 212,500
1st YEAR STORED ELECTRICITY CDST 412500
1st YEAR AUXILARY ELECTRICITY COST 0
1st YEAR AUXILARY FOSSIL FUEL COST 0

ANNUAL ENERGY STORED (KWH) 25000000
ANNUAL ENERGY RETRIEVED (KWH) 16500000

PRESENT VALUE OF INITIAL CAPITAL 18320000
PRESENT VALUE OF NET REPLACEMENT CAPITAL 28550457
PRESENT VALUE OF ANNUAL O&M 548591.8
PRESENT VALUE OF PERIODIC O&M 0
PRESENT VALUE OF EFFICIENCY LOSS ENERGY 3586946.
PRESENT VALUE OF STORED ENERGY 6962896.
PRESENT VALUE OF AUXILARY ELECTRIC ENERGY 0
PRESENT VALUE OF AUXILARY FOSSIL FUEL ENERGY 0
PRESENT VALUE DF FINAL SALVAGE -156418.

-----SUMMARY RESULTS-----

COMPONENT LIFE-CYCLE COST CONTRIBUTORS

INITIAL BATTERY COST	68
BALANCE-OF-PLANT	30
REPLACEMENTS	146
OPERATING AND MAINTENANCE	2
ENERGY	38
SALVAGE	-1
TOTAL	284 MILLS/KWH

TOTAL PRESENT WORTH 57812473
TOTAL ANNUALIZED COST 4678855.

LEVELIZED STORAGE COST 0.283567 \$/KWH OF ENERGY RETRIEVED

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SEALED LEAD-ACID BATTERY SYSTEM: NOMINAL ESTIMATE

BATTERY STORAGE ECONOMIC ANALYSIS MODEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	Sealed Lead-Acid	CYCLE LIFE (#)	1500
APPLICATION	Utility	CYCLES/YEAR	250
SYSTEM SIZE (KWH)	100,000	ROUND TRIP EFFICIENCY	0.66
SYSTEM SIZE (KWE)	20,000		

AUXILARY ELECTRICITY CONSUMPTION (KWH/YR)	0
AUXILARY FOSSIL FUEL CONSUMPTION (MBTU/YR)	0

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	151 (\$/KWH)
BATTERY INSTALLATION	28.5 (\$/KWH)
ENERGY RELATED BOS	36.1 (\$/KWH)
POWER RELATED BOS	121 (\$/KWE)
NET SALVAGE VALUE	5.6 (\$/KWH)

-----OPERATING AND MAINTENANCE COST INPUTS-----

COST OF ELECTRICITY, \$/KWH	0.025	ANNUAL O&M COST, \$	47000
COST OF FOSSIL FUEL, \$/MBTU	0		

*****EQUAL INTERVAL PERIODIC O&M*****

PERIODIC MAINTENANCE INTERVAL	1 (YEARS)
PERIODIC MAINTENANCE COST	0 (\$)

*****VARIED INTERVAL PERIODIC O&M*****

YEAR	COST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.042
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	30	TAX CREDIT	0.000
CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	PLANT TAX LIFE	20
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR PLANT	0.485
DEPRECIATION FACTOR FOR BATTERIES	0.851
CAPITAL RECOVERY FACTOR	0.059242
FIXED CHARGE RATE FOR PLANT	0.097929
FIXED CHARGE RATE FOR BATTERIES	0.084658

OVERNIGHT CONSTRUCTION COST	23980000
1st YEAR OPERATING & MAINT. COST	47,000
1st YEAR EFFICIENCY ELECTRICITY COST	212,500
1st YEAR STORED ELECTRICITY COST	412500
1st YEAR AUXILARY ELECTRICITY COST	0
1st YEAR AUXILARY FOSSIL FUEL COST	0

ANNUAL ENERGY STORED (KWH)	25000000
ANNUAL ENERGY RETRIEVED (KWH)	16500000

PRESENT VALUE OF INITIAL CAPITAL	23980000
PRESENT VALUE OF NET REPLACEMENT CAPITAL	38971149
PRESENT VALUE OF ANNUAL O&M	793348.1
PRESENT VALUE OF PERIODIC O&M	0
PRESENT VALUE OF EFFICIENCY LOSS ENERGY	3586946.
PRESENT VALUE OF STORED ENERGY	6962896.
PRESENT VALUE OF AUXILARY ELECTRIC ENERGY	0
PRESENT VALUE OF AUXILARY FOSSIL FUEL ENERGY	0
PRESENT VALUE OF FINAL SALVAGE	-156418.

-----SUMMARY RESULTS-----

COMPONENT LIFE-CYCLE COST CONTRIBUTORS

INITIAL BATTERY COST	92
BALANCE-OF-PLANT	36
REPLACEMENTS	200
OPERATING AND MAINTENANCE	3
ENERGY	38
SALVAGE	-1
TOTAL	368 MILLS/KWH

TOTAL PRESENT WORTH	74137922
TOTAL ANNUALIZED COST	6068124.

LEVELIZED STORAGE COST	0.367765 \$/KWH OF ENERGY RETRIEVED
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SEALED LEAD-ACID BATTERY SYSTEM: HIGH ESTIMATE

BATTERY STORAGE ECONOMIC ANALYSIS MODEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	Sealed Lead-Acid	CYCLE LIFE (#)	1500
APPLICATION	Utility	CYCLES/YEAR	250
SYSTEM SIZE (KWH)	100,000	ROUND TRIP EFFICIENCY	0.66
SYSTEM SIZE (KWE)	20,000		

AUXILARY ELECTRICITY CONSUMPTION (KWH/YR)	0
AUXILARY FOSSIL FUEL CONSUMPTION (MBTU/YR)	0

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	177 (\$/KWH)
BATTERY INSTALLATION	33 (\$/KWH)
ENERGY RELATED BOS	39 (\$/KWH)
POWER RELATED BOS	188 (\$/KWE)
NET SALVAGE VALUE	-4 (\$/KWH)

-----OPERATING AND MAINTENANCE COST INPUTS-----

COST OF ELECTRICITY, \$/KWH	0.025	ANNUAL O&M COST, \$	52900
COST OF FOSSIL FUEL, \$/MBTU	0		

*****EQUAL INTERVAL PERIODIC O&M*****

PERIODIC MAINTENANCE INTERVAL	1 (YEARS)
PERIODIC MAINTENANCE COST	0 (\$)

*****VARIED INTERVAL PERIODIC O&M*****

YEAR	COST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.042
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	30	TAX CREDIT	0.000
CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	PLANT TAX LIFE	20
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR PLANT	0.485
DEPRECIATION FACTOR FOR BATTERIES	0.851
CAPITAL RECOVERY FACTOR	0.059242
FIXED CHARGE RATE FOR PLANT	0.097929
FIXED CHARGE RATE FOR BATTERIES	0.084658

OVERNIGHT CONSTRUCTION COST	28660000
1st YEAR OPERATING & MAINT. COST	52,900
1st YEAR EFFICIENCY ELECTRICITY COST	212,500
1st YEAR STORED ELECTRICITY COST	412500
1st YEAR AUXILARY ELECTRICITY COST	0
1st YEAR AUXILARY FOSSIL FUEL COST	0

ANNUAL ENERGY STORED (KWH)	25000000
ANNUAL ENERGY RETRIEVED (KWH)	16500000

PRESENT VALUE OF INITIAL CAPITAL	28660000
PRESENT VALUE OF NET REPLACEMENT CAPITAL	47957596
PRESENT VALUE OF ANNUAL O&M	892938.7
PRESENT VALUE OF PERIODIC O&M	0
PRESENT VALUE OF EFFICIENCY LOSS ENERGY	3586946.
PRESENT VALUE OF STORED ENERGY	6962896.
PRESENT VALUE OF AUXILARY ELECTRIC ENERGY	0
PRESENT VALUE OF AUXILARY FOSSIL FUEL ENERGY	0
PRESENT VALUE OF FINAL SALVAGE	111727.6

-----SUMMARY RESULTS-----

COMPONENT LIFE-CYCLE COST CONTRIBUTORS

INITIAL BATTERY COST	108
BALANCE-OF-PLANT	45
REPLACEMENTS	246
OPERATING AND MAINTENANCE	3
ENERGY	38
SALVAGE	1
TOTAL	441 MILLS/KWH

TOTAL PRESENT WORTH	88172105
TOTAL ANNUALIZED COST	7275336.

LEVELIZED STORAGE COST	0.440929 \$/KWH OF ENERGY RETRIEVED
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ZINC-BROMINE BATTERY SYSTEM: LOW ESTIMATE

BATTERY STORAGE ECONOMIC ANALYSIS MODEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	Zinc-Bromine	CYCLE LIFE (#)	2500
APPLICATION	Utility	CYCLES/YEAR	250
SYSTEM SIZE (KWH)	100,000	ROUND TRIP EFFICIENCY	0.64
SYSTEM SIZE (KWE)	20,000		

AUXILARY ELECTRICITY CONSUMPTION (KWH/YR)	0
AUXILARY FOSSIL FUEL CONSUMPTION (MBTU/YR)	0

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	75 (\$/KWH)
BATTERY INSTALLATION	2.6 (\$/KWH)
ENERGY RELATED BOS	29.5 (\$/KWH)
POWER RELATED BOS	116 (\$/KWE)
NET SALVAGE VALUE	39.4 (\$/KWH)

-----OPERATING AND MAINTENANCE COST INPUTS-----

COST OF ELECTRICITY, \$/KWH	0.025	ANNUAL O&M COST, \$	64900
COST OF FOSSIL FUEL, \$/MBTU	0		

*****EQUAL INTERVAL PERIODIC O&M*****

PERIODIC MAINTENANCE INTERVAL	1 (YEARS)
PERIODIC MAINTENANCE COST	0 (\$)

*****VARIED INTERVAL PERIODIC O&M*****

YEAR	COST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.042
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	30	TAX CREDIT	0.000
CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	PLANT TAX LIFE	20
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR PLANT	0.485
DEPRECIATION FACTOR FOR BATTERIES	0.851
CAPITAL RECOVERY FACTOR	0.059242
FIXED CHARGE RATE FOR PLANT	0.097929
FIXED CHARGE RATE FOR BATTERIES	0.084658

OVERNIGHT CONSTRUCTION COST	13030000
1st YEAR OPERATING & MAINT. COST	64,900
1st YEAR EFFICIENCY ELECTRICITY COST	225,000
1st YEAR STORED ELECTRICITY COST	400000
1st YEAR AUXILARY ELECTRICITY COST	0
1st YEAR AUXILARY FOSSIL FUEL COST	0

ANNUAL ENERGY STORED (KWH)	25000000
ANNUAL ENERGY RETRIEVED (KWH)	16000000

PRESENT VALUE OF INITIAL CAPITAL	13030000
PRESENT VALUE OF NET REPLACEMENT CAPITAL	4209227.
PRESENT VALUE OF ANNUAL O&M	1095495.
PRESENT VALUE OF PERIODIC O&M	0
PRESENT VALUE OF EFFICIENCY LOSS ENERGY	3797943.
PRESENT VALUE OF STORED ENERGY	6751899.
PRESENT VALUE OF AUXILARY ELECTRIC ENERGY	0
PRESENT VALUE OF AUXILARY FOSSIL FUEL ENERGY	0
PRESENT VALUE OF FINAL SALVAGE	-1100517

-----SUMMARY RESULTS-----

COMPONENT LIFE-CYCLE COST CONTRIBUTORS

INITIAL BATTERY COST	41
BALANCE-OF-PLANT	32
REPLACEMENTS	22
OPERATING AND MAINTENANCE	4
ENERGY	39
SALVAGE	-6
TOTAL	133 MILLS/KWH

TOTAL PRESENT WORTH	27784048
TOTAL ANNUALIZED COST	2126116.

LEVELIZED STORAGE COST	0.132882 \$/KWH OF ENERGY RETRIEVED
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ZINC-BROMINE BATTERY SYSTEM: NOMINAL ESTIMATE

BATTERY STORAGE ECONOMIC ANALYSIS MODEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	Zinc-Bromine	CYCLE LIFE (#)	2500
APPLICATION	Utility	CYCLES/YEAR	250
SYSTEM SIZE (KWH)	100,000	ROUND TRIP EFFICIENCY	0.64
SYSTEM SIZE (KWE)	20,000		

AUXILARY ELECTRICITY CONSUMPTION (KWH/YR)	0
AUXILARY FOSSIL FUEL CONSUMPTION (MBTU/YR)	0

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	83 (\$/KWH)
BATTERY INSTALLATION	18.8 (\$/KWH)
ENERGY RELATED BOS	55 (\$/KWH)
POWER RELATED BOS	121 (\$/KWE)
NET SALVAGE VALUE	4.9 (\$/KWH)

-----OPERATING AND MAINTENANCE COST INPUTS-----

COST OF ELECTRICITY, \$/KWH	0.025	ANNUAL O&M COST, \$	64900
COST OF FOSSIL FUEL, \$/MBTU	0		

*****EQUAL INTERVAL PERIODIC O&M*****

PERIODIC MAINTENANCE INTERVAL	1 (YEARS)
PERIODIC MAINTENANCE COST	0 (\$)

*****VARIED INTERVAL PERIODIC O&M*****

YEAR	COST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.042
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	30	TAX CREDIT	0.000
CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	PLANT TAX LIFE	20
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR PLANT	0.485
DEPRECIATION FACTOR FOR BATTERIES	0.851
CAPITAL RECOVERY FACTOR	0.059242
FIXED CHARGE RATE FOR PLANT	0.097929
FIXED CHARGE RATE FOR BATTERIES	0.084658

OVERNIGHT CONSTRUCTION COST	18100000
1st YEAR OPERATING & MAINT. COST	64,900
1st YEAR EFFICIENCY ELECTRICITY COST	225,000
1st YEAR STORED ELECTRICITY COST	400000
1st YEAR AUXILARY ELECTRICITY COST	0
1st YEAR AUXILARY FOSSIL FUEL COST	0

ANNUAL ENERGY STORED (KWH)	25000000
ANNUAL ENERGY RETRIEVED (KWH)	16000000

PRESENT VALUE OF INITIAL CAPITAL	18100000
PRESENT VALUE OF NET REPLACEMENT CAPITAL	10677333
PRESENT VALUE OF ANNUAL O&M	1095495.
PRESENT VALUE OF PERIODIC O&M	0
PRESENT VALUE OF EFFICIENCY LOSS ENERGY	3797943.
PRESENT VALUE OF STORED ENERGY	6751899.
PRESENT VALUE OF AUXILARY ELECTRIC ENERGY	0
PRESENT VALUE OF AUXILARY FOSSIL FUEL ENERGY	0
PRESENT VALUE OF FINAL SALVAGE	-136866.

-----SUMMARY RESULTS-----

COMPONENT LIFE-CYCLE COST CONTRIBUTORS

INITIAL BATTERY COST	54
BALANCE-OF-PLANT	48
REPLACEMENTS	56
OPERATING AND MAINTENANCE	4
ENERGY	39
SALVAGE	-1
TOTAL	201 MILLS/KWH

TOTAL PRESENT WORTH	40285805
TOTAL ANNUALIZED COST	3219663.

LEVELIZED STORAGE COST	0.201229 \$/KWH OF ENERGY RETRIEVED
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ZINC-BROMINE BATTERY SYSTEM: HIGH ESTIMATE

BATTERY STORAGE ECONOMIC ANALYSIS MODEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	Zinc-Bromine	CYCLE LIFE (#)	2500
APPLICATION	Utility	CYCLES/YEAR	250
SYSTEM SIZE (KWH)	100,000	ROUND TRIP EFFICIENCY	0.64
SYSTEM SIZE (KWE)	20,000		

AUXILARY ELECTRICITY CONSUMPTION (KWH/YR)	0
AUXILARY FOSSIL FUEL CONSUMPTION (MBTU/YR)	0

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	117 (\$/KWH)
BATTERY INSTALLATION	21.2 (\$/KWH)
ENERGY RELATED BOS	88 (\$/KWH)
POWER RELATED BOS	188 (\$/KWE)
NET SALVAGE VALUE	0.8 (\$/KWH)

-----OPERATING AND MAINTENANCE COST INPUTS-----

CDST OF ELECTRICITY, \$/KWH	0.025	ANNUAL O&M COST, \$	84700
COST OF FOSSIL FUEL, \$/MBTU	0		

*****EQUAL INTERVAL PERIODIC O&M*****

PERIODIC MAINTENANCE INTERVAL	1 (YEARS)
PERIODIC MAINTENANCE COST	0 (\$)

*****VARIED INTERVAL PERIODIC D&M*****

YEAR	COST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.042
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	30	TAX CREDIT	0.000
CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	PLANT TAX LIFE	20
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR PLANT	0.485
DEPRECIATION FACTOR FOR BATTERIES	0.851
CAPITAL RECOVERY FACTOR	0.059242
FIXED CHARGE RATE FOR PLANT	0.097929
FIXED CHARGE RATE FOR BATTERIES	0.084658

OVERNIGHT CONSTRUCTION COST	26380000
1st YEAR OPERATING & MAINT. COST	84,700
1st YEAR EFFICIENCY ELECTRICITY COST	225,000
1st YEAR STORED ELECTRICITY COST	400000
1st YEAR AUXILARY ELECTRICITY COST	0
1st YEAR AUXILARY FOSSIL FUEL COST	0

ANNUAL ENERGY STORED (KWH)	25000000
ANNUAL ENERGY RETRIEVED (KWH)	16000000

PRESENT VALUE OF INITIAL CAPITAL	26380000
PRESENT VALUE OF NET REPLACEMENT CAPITAL	15139996
PRESENT VALUE OF ANNUAL O&M	1429714.
PRESENT VALUE OF PERIODIC O&M	0
PRESENT VALUE OF EFFICIENCY LOSS ENERGY	3797943.
PRESENT VALUE OF STORED ENERGY	6751899.
PRESENT VALUE OF AUXILARY ELECTRIC ENERGY	0
PRESENT VALUE OF AUXILARY FOSSIL FUEL ENERGY	0
PRESENT VALUE OF FINAL SALVAGE	-22345.5

-----SUMMARY RESULTS-----

COMPONENT LIFE-CYCLE COST CONTRIBUTORS

INITIAL BATTERY COST	73
BALANCE-OF-PLANT	77
REPLACEMENTS	80
OPERATING AND MAINTENANCE	5
ENERGY	39
SALVAGE	-0
TOTAL	274 MILLS/KWH

TOTAL PRESENT WORTH	53477208
TOTAL ANNUALIZED COST	4389510.
LEVELIZED STORAGE COST	0.274344 \$/KWH OF ENERGY RETRIEVED

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SODIUM-SULFUR BATTERY SYSTEM: LDW ESTIMATE

BATTERY STORAGE ECONOMIC ANALYSIS MODEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	Sodium-Sulfur	CYCLE LIFE (#)	2500
APPLICATION	Utility	CYCLES/YEAR	250
SYSTEM SIZE (KWH)	100,000	ROUND TRIP EFFICIENCY	0.64
SYSTEM SIZE (KWE)	20,000		

AUXILARY ELECTRICITY CONSUMPTION (KWH/YR)	0
AUXILARY FOSSIL FUEL CONSUMPTION (MBTU/YR)	0

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	67 (\$/KWH)
BATTERY INSTALLATION	3.6 (\$/KWH)
ENERGY RELATED BOS	27.6 (\$/KWH)
POWER RELATED BOS	121 (\$/KWE)
NET SALVAGE VALUE	-2.95 (\$/KWH)

-----OPERATING AND MAINTENANCE COST INPUTS-----

COST OF ELECTRICITY, \$/KWH	0.025	ANNUAL O&M COST, \$	109000
COST OF FOSSIL FUEL, \$/MBTU	0		

*****EQUAL INTERVAL PERIODIC O&M*****

PERIODIC MAINTENANCE INTERVAL	1 (YEARS)
PERIODIC MAINTENANCE COST	0 (\$)

*****VARIED INTERVAL PERIODIC O&M*****

YEAR	COST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.042
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	30	TAX CREDIT	0.000
CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	PLANT TAX LIFE	20
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR PLANT	0.485
DEPRECIATION FACTOR FOR BATTERIES	0.851
CAPITAL RECOVERY FACTOR	0.059242
FIXED CHARGE RATE FOR PLANT	0.097929
FIXED CHARGE RATE FOR BATTERIES	0.08465B

OVERNIGHT CONSTRUCTION COST	12240000
1st YEAR OPERATING & MAINT. COST	109,000
1st YEAR EFFICIENCY ELECTRICITY COST	225,000
1st YEAR STORED ELECTRICITY COST	400000
1st YEAR AUXILARY ELECTRICITY COST	0
1st YEAR AUXILARY FOSSIL FUEL COST	0

ANNUAL ENERGY STORED (KWH)	25000000
ANNUAL ENERGY RETRIEVED (KWH)	16000000

PRESENT VALUE OF INITIAL CAPITAL	12240000
PRESENT VALUE OF NET REPLACEMENT CAPITAL	8104415.
PRESENT VALUE OF ANNUAL O&M	1839892.
PRESENT VALUE OF PERIODIC O&M	0
PRESENT VALUE OF EFFICIENCY LOSS ENERGY	3797943.
PRESENT VALUE OF STORED ENERGY	6751899.
PRESENT VALUE OF AUXILARY ELECTRIC ENERGY	0
PRESENT VALUE OF AUXILARY FOSSIL FUEL ENERGY	0
PRESENT VALUE OF FINAL SALVAGE	82399.14

-----SUMMARY RESULTS-----

COMPONENT LIFE-CYCLE COST CONTRIBUTORS

INITIAL BATTERY COST	37
BALANCE-OF-PLANT	32
REPLACEMENTS	43
OPERATING AND MAINTENANCE	7
ENERGY	39
SALVAGE	0
TOTAL	158 MILLS/KWH

TOTAL PRESENT WORTH	32816550
TOTAL ANNUALIZED COST	2532045.

LEVELIZED STORAGE COST	0.158253 \$/KWH OF ENERGY RETRIEVED
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SODIUM-SULFUR BATTERY SYSTEM: NOMINAL ESTIMATE

BATTERY STORAGE ECONOMIC ANALYSIS MODEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	Sodium-Sulfur	CYCLE LIFE (#)	2500
APPLICATION	Utility	CYCLES/YEAR	250
SYSTEM SIZE (KWH)	100,000	ROUND TRIP EFFICIENCY	0.64
SYSTEM SIZE (KWE)	20,000		
AUXILARY ELECTRICITY CONSUMPTION (KWH/YR)			0
AUXILARY FOSSIL FUEL CONSUMPTION (MBTU/YR)			0

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	70 (\$/KWH)
BATTERY INSTALLATION	3.6 (\$/KWH)
ENERGY RELATED BOS	27.6 (\$/KWH)
POWER RELATED BOS	121 (\$/KWE)
NET SALVAGE VALUE	-2.95 (\$/KWH)

-----OPERATING AND MAINTENANCE COST INPUTS-----

COST OF ELECTRICITY, \$/KWH	0.025	ANNUAL O&M COST, \$	218000
COST OF FOSSIL FUEL, \$/MBTU	0		

*****EQUAL INTERVAL PERIODIC O&M*****

PERIODIC MAINTENANCE INTERVAL	1 (YEARS)
PERIODIC MAINTENANCE COST	0 (\$)

*****VARIED INTERVAL PERIODIC O&M*****

YEAR	COST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.042
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	30	TAX CREDIT	0.000
CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	PLANT TAX LIFE	20
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR PLANT	0.485
DEPRECIATION FACTOR FOR BATTERIES	0.851
CAPITAL RECOVERY FACTOR	0.059242
FIXED CHARGE RATE FOR PLANT	0.097929
FIXED CHARGE RATE FOR BATTERIES	0.084658

OVERNIGHT CONSTRUCTION COST	12540000
1st YEAR OPERATING & MAINT. COST	218,000
1st YEAR EFFICIENCY ELECTRICITY COST	225,000
1st YEAR STORED ELECTRICITY COST	400000
1st YEAR AUXILARY ELECTRICITY COST	0
1st YEAR AUXILARY FOSSIL FUEL COST	0

ANNUAL ENERGY STORED (KWH)	25000000
ANNUAL ENERGY RETRIEVED (KWH)	16000000

PRESENT VALUE OF INITIAL CAPITAL	12540000
PRESENT VALUE OF NET REPLACEMENT CAPITAL	8434983.
PRESENT VALUE OF ANNUAL O&M	3679785.
PRESENT VALUE OF PERIODIC O&M	0
PRESENT VALUE OF EFFICIENCY LOSS ENERGY	3797943.
PRESENT VALUE OF STORED ENERGY	6751899.
PRESENT VALUE OF AUXILARY ELECTRIC ENERGY	0
PRESENT VALUE OF AUXILARY FOSSIL FUEL ENERGY	0
PRESENT VALUE OF FINAL SALVAGE	82399.14

-----SUMMARY RESULTS-----

COMPONENT LIFE-CYCLE COST CONTRIBUTORS

INITIAL BATTERY COST	39
BALANCE-OF-PLANT	32
REPLACEMENTS	45
OPERATING AND MAINTENANCE	14
ENERGY	39
SALVAGE	0
TOTAL	168 MILLS/KWH

TOTAL PRESENT WORTH	35287010
TOTAL ANNUALIZED COST	2694428.

LEVELIZED STORAGE COST	0.168402 \$/KWH OF ENERGY RETRIEVED
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SODIUM-SULFUR BATTERY SYSTEM: HIGH ESTIMATE

BATTERY STORAGE ECONOMIC ANALYSIS MODEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	Sodium-Sulfur	CYCLE LIFE (#)	2500
APPLICATION	Utility	CYCLES/YEAR	250
SYSTEM SIZE (KWH)	100,000	ROUND TRIP EFFICIENCY	0.64
SYSTEM SIZE (KWE)	20,000		

AUXILARY ELECTRICITY CONSUMPTION (KWH/YR)	0
AUXILARY FOSSIL FUEL CONSUMPTION (MBTU/YR)	0

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	118 (\$/KWH)
BATTERY INSTALLATION	3.6 (\$/KWH)
ENERGY RELATED BOS	51 (\$/KWH)
POWER RELATED BOS	188 (\$/KWE)
NET SALVAGE VALUE	-2.95 (\$/KWH)

-----OPERATING AND MAINTENANCE COST INPUTS-----

COST OF ELECTRICITY, \$/KWH	0.025	ANNUAL O&M COST, \$	328000
COST OF FOSSIL FUEL, \$/MBTU	0		

*****EQUAL INTERVAL PERIODIC O&M*****

PERIODIC MAINTENANCE INTERVAL	1 (YEARS)
PERIODIC MAINTENANCE COST	0 (\$)

*****VARIED INTERVAL PERIODIC O&M*****

YEAR	COST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.042
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	30	TAX CREDIT	0.000

CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	PLANT TAX LIFE	20
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR PLANT	0.485
DEPRECIATION FACTOR FOR BATTERIES	0.851
CAPITAL RECOVERY FACTOR	0.059242
FIXED CHARGE RATE FOR PLANT	0.097929
FIXED CHARGE RATE FOR BATTERIES	0.084658

OVERNIGHT CONSTRUCTION COST	21020000
1st YEAR OPERATING & MAINT. COST	328,000
1st YEAR EFFICIENCY ELECTRICITY COST	225,000
1st YEAR STORED ELECTRICITY COST	400000
1st YEAR AUXILARY ELECTRICITY COST	0
1st YEAR AUXILARY FOSSIL FUEL COST	0

ANNUAL ENERGY STORED (KWH)	25000000
ANNUAL ENERGY RETRIEVED (KWH)	16000000

PRESENT VALUE OF INITIAL CAPITAL	21020000
PRESENT VALUE OF NET REPLACEMENT CAPITAL	13724065
PRESENT VALUE OF ANNUAL O&M	5536557.
PRESENT VALUE OF PERIODIC O&M	0
PRESENT VALUE OF EFFICIENCY LOSS ENERGY	3797943.
PRESENT VALUE OF STORED ENERGY	6751899.
PRESENT VALUE OF AUXILARY ELECTRIC ENERGY	0
PRESENT VALUE OF AUXILARY FOSSIL FUEL ENERGY	0
PRESENT VALUE OF FINAL SALVAGE	82399.14

-----SUMMARY RESULTS-----

COMPONENT LIFE-CYCLE COST CONTRIBUTORS

INITIAL BATTERY COST	64
BALANCE-OF-PLANT	54
REPLACEMENTS	73
OPERATING AND MAINTENANCE	21
ENERGY	39
SALVAGE	0
 TOTAL	 251 MILLS/KWH

TOTAL PRESENT WORTH	50912864
TOTAL ANNUALIZED COST	4018934.
LEVELIZED STORAGE COST	0.251183 \$/KWH OF ENERGY RETRIEVED

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LITHIUM-IRON SULFIDE BATTERY SYSTEM: NOMINAL ESTIMATE

BATTERY STORAGE ECONOMIC ANALYSIS MODEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	Lithium	CYCLE LIFE (#)	2500
APPLICATION	Utility	CYCLES/YEAR	250
SYSTEM SIZE (KWH)	100,000	ROUND TRIP EFFICIENCY	0.66
SYSTEM SIZE (KWE)	20,000		

AUXILARY ELECTRICITY CONSUMPTION (KWH/YR)	0
AUXILARY FOSSIL FUEL CONSUMPTION (MBTU/YR)	0

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	108 (\$/KWH)
BATTERY INSTALLATION	3.8 (\$/KWH)
ENERGY RELATED BOS	67 (\$/KWH)
POWER RELATED BOS	121 (\$/KWE)
NET SALVAGE VALUE	-2.4 (\$/KWH)

-----OPERATING AND MAINTENANCE COST INPUTS-----

COST OF ELECTRICITY, \$/KWH	0.025	ANNUAL O&M COST, \$	300000
COST OF FOSSIL FUEL, \$/MBTU	0		

*****EQUAL INTERVAL PERIODIC O&M*****

PERIODIC MAINTENANCE INTERVAL	1 (YEARS)
PERIODIC MAINTENANCE COST	0 (\$)

*****VARIED INTERVAL PERIODIC O&M*****

YEAR	COST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.042
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	30	TAX CREDIT	0.000
CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	PLANT TAX LIFE	20
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR PLANT	0.485
DEPRECIATION FACTOR FOR BATTERIES	0.851
CAPITAL RECOVERY FACTOR	0.059242
FIXED CHARGE RATE FOR PLANT	0.097929
FIXED CHARGE RATE FOR BATTERIES	0.084658

OVERNIGHT CONSTRUCTION COST	20300000
1st YEAR OPERATING & MAINT. COST	300,000
1st YEAR EFFICIENCY ELECTRICITY COST	212,500
1st YEAR STORED ELECTRICITY COST	412500
1st YEAR AUXILARY ELECTRICITY COST	0
1st YEAR AUXILARY FOSSIL FUEL COST	0

ANNUAL ENERGY STORED (KWH)	25000000
ANNUAL ENERGY RETRIEVED (KWH)	16500000

PRESENT VALUE OF INITIAL CAPITAL	20300000
PRESENT VALUE OF NET REPLACEMENT CAPITAL	12583606
PRESENT VALUE OF ANNUAL O&M	5063924.
PRESENT VALUE OF PERIODIC O&M	0
PRESENT VALUE OF EFFICIENCY LOSS ENERGY	3586946.
PRESENT VALUE OF STORED ENERGY	6962896.
PRESENT VALUE OF AUXILARY ELECTRIC ENERGY	0
PRESENT VALUE OF AUXILARY FOSSIL FUEL ENERGY	0
PRESENT VALUE OF FINAL SALVAGE	67036.59

-----SUMMARY RESULTS-----

COMPONENT LIFE-CYCLE COST CONTRIBUTORS

INITIAL BATTERY COST	57
BALANCE-OF-PLANT	54
REPLACEMENTS	65
OPERATING AND MAINTENANCE	18
ENERGY	38
SALVAGE	0
TOTAL	232 MILLS/KWH

TOTAL PRESENT WORTH	48564410
TOTAL ANNUALIZED COST	3835581.

LEVELIZED STORAGE COST	0.232459 \$/KWH OF ENERGY RETRIEVED
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PHOSPHORIC ACID FUEL CELL SYSTEM: LOW WORLD OIL PRICE

BATTERY STORAGE ECONOMIC ANALYSIS MODEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	PAFC	CYCLE LIFE (#)	8000
APPLICATION	Utility	CYCLES/YEAR	250
SYSTEM SIZE (KWH)	100,000	ROUND TRIP EFFICIENCY	I
SYSTEM SIZE (KWE)	20,000		

AUXILARY ELECTRICITY CONSUMPTION (KWH/YR)	0
AUXILARY FOSSIL FUEL CONSUMPTION (MBTU/YR)	208750

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	0 (\$/KWH)
BATTERY INSTALLATION	0 (\$/KWH)
ENERGY RELATED COSTS	0 (\$/KWH)
POWER RELATED COSTS	955 (\$/KWE)
NET SALVAGE VALUE	0 (\$/KWH)

-----OPERATING AND MAINTENANCE COST INPUTS-----

COST OF ELECTRICITY, \$/KWH	0.000	ANNUAL O&M COST, \$	379000
COST OF FOSSIL FUEL, \$/MBTU	2.36		

*****EQUAL INTERVAL PERIODIC O&M*****

PERIODIC MAINTENANCE INTERVAL	1 (YEARS)
PERIODIC MAINTENANCE COST	0 (\$)

*****VARIED INTERVAL PERIODIC O&M*****

YEAR	COST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.042
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	30	TAX CREDIT	0.000
CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	PLANT TAX LIFE	20
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0.049		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR PLANT	0.485
DEPRECIATION FACTOR FOR BATTERIES	0.851
CAPITAL RECOVERY FACTOR	0.059242
FIXED CHARGE RATE FOR PLANT	0.097929
FIXED CHARGE RATE FOR BATTERIES	0.084658

OVERNIGHT CONSTRUCTION COST	19100000
1st YEAR OPERATING & MAINT. COST	379,000
1st YEAR EFFICIENCY ELECTRICITY COST	0
1st YEAR STORED ELECTRICITY COST	0
1st YEAR AUXILARY ELECTRICITY COST	0
1st YEAR AUXILARY FOSSIL FUEL COST	688599.8

ANNUAL ENERGY GENERATED (KWH)	25000000
ANNUAL ENERGY GENERATED (KWH)	25000000

PRESENT VALUE OF INITIAL CAPITAL	19100000
PRESENT VALUE OF NET REPLACEMENT CAPITAL	0
PRESENT VALUE OF ANNUAL O&M	6397424.
PRESENT VALUE OF PERIODIC O&M	0
PRESENT VALUE OF EFFICIENCY LOSS ENERGY	0
PRESENT VALUE OF STORED ENERGY	0
PRESENT VALUE OF AUXILARY ELECTRIC ENERGY	0
PRESENT VALUE OF AUXILARY FOSSIL FUEL ENERGY	22955544
PRESENT VALUE OF FINAL SALVAGE	0

-----SUMMARY RESULTS-----

COMPONENT LIFE-CYCLE COST CONTRIBUTORS

INITIAL BATTERY COST	0
BALANCE-OF-PLANT	75
REPLACEMENTS	0
OPERATING AND MAINTENANCE	15
ENERGY	54
SALVAGE	0
TOTAL	144 MILLS/KWH

TOTAL PRESENT WORTH	48452969
TOTAL ANNUALIZED COST	3609402.
LEVELIZED STORAGE COST	0.144376 \$/KWH OF ENERGY GENERATED

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PHOSPHORIC ACID FUEL CELL SYSTEM: NOMINAL WORLD OIL PRICE

BATTERY STORAGE ECONOMIC ANALYSIS MODEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	PAFC	CYCLE LIFE (#)	B000
APPLICATION	Utility	CYCLES/YEAR	250
SYSTEM SIZE (KWH)	100,000	ROUND TRIP EFFICIENCY	1
SYSTEM SIZE (KWE)	20,000		

AUXILARY ELECTRICITY CONSUMPTION (KWH/YR)	0
AUXILARY FOSSIL FUEL CONSUMPTION (MBTU/YR)	208750

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	0 (\$/KWH)
BATTERY INSTALLATION	0 (\$/KWH)
ENERGY RELATED COSTS	0 (\$/KWH)
POWER RELATED COSTS	955 (\$/KWE)
NET SALVAGE VALUE	0 (\$/KWH)

-----OPERATING AND MAINTENANCE COST INPUTS-----

COST OF ELECTRICITY, \$/KWH	0.000	ANNUAL O&M COST, \$	379000
COST OF FOSSIL FUEL, \$/MBTU	2.36		

*****EQUAL INTERVAL PERIODIC O&M*****

PERIODIC MAINTENANCE INTERVAL	1 (YEARS)
PERIODIC MAINTENANCE COST	0 (\$)

*****VARIED INTERVAL PERIODIC O&M*****

YEAR	COST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.042
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	30	TAX CREDIT	0.000
CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	PLANT TAX LIFE	20
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0.056		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR PLANT	0.485
DEPRECIATION FACTOR FOR BATTERIES	0.851
CAPITAL RECOVERY FACTOR	0.059242
FIXED CHARGE RATE FOR PLANT	0.097929
FIXED CHARGE RATE FOR BATTERIES	0.084658

OVERNIGHT CONSTRUCTION COST	19100000
1st YEAR OPERATING & MAINT. COST	379,000
1st YEAR EFFICIENCY ELECTRICITY COST	0
1st YEAR STORED ELECTRICITY COST	0
1st YEAR AUXILARY ELECTRICITY COST	0
1st YEAR AUXILARY FOSSIL FUEL COST	721416.2

ANNUAL ENERGY GENERATED (KWH)	25000000
ANNUAL ENERGY GENERATED (KWH)	25000000

PRESENT VALUE OF INITIAL CAPITAL	19100000
PRESENT VALUE OF NET REPLACEMENT CAPITAL	0
PRESENT VALUE OF ANNUAL O&M	6397424.
PRESENT VALUE OF PERIODIC O&M	0
PRESENT VALUE OF EFFICIENCY LOSS ENERGY	0
PRESENT VALUE OF STORED ENERGY	0
PRESENT VALUE OF AUXILARY ELECTRIC ENERGY	0
PRESENT VALUE OF AUXILARY FOSSIL FUEL ENERGY	26794278
PRESENT VALUE OF FINAL SALVAGE	0

-----SUMMARY RESULTS-----

COMPONENT LIFE-CYCLE COST CONTRIBUTORS

INITIAL BATTERY COST	0
BALANCE-OF-PLANT	75
REPLACEMENTS	0
OPERATING AND MAINTENANCE	15
ENERGY	63
SALVAGE	0
TOTAL	153 MILLS/KWH

TOTAL PRESENT WORTH	52291703
TOTAL ANNUALIZED COST	3836819.
LEVELIZED STORAGE COST	0.153473 \$/KWH OF ENERGY GENERATED

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PHOSPHORIC ACID FUEL CELL SYSTEM: HIGH WORLD OIL PRICE

BATTERY STORAGE ECONOMIC ANALYSIS MODEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	PAFC	CYCLE LIFE (#)	8000
APPLICATION	Utility	CYCLES/YEAR	250
SYSTEM SIZE (KWH)	100,000	ROUND TRIP EFFICIENCY	1
SYSTEM SIZE (KWE)	20,000		

AUXILARY ELECTRICITY CONSUMPTION (KWH/YR)	0
AUXILARY FOSSIL FUEL CONSUMPTION (MBTU/YR)	208750

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	0 (\$/KWH)
BATTERY INSTALLATION	0 (\$/KWH)
ENERGY RELATED COSTS	0 (\$/KWH)
POWER RELATED COSTS	955 (\$/KWE)
NET SALVAGE VALUE	0 (\$/KWH)

-----OPERATING AND MAINTENANCE COST INPUTS-----

COST OF ELECTRICITY, \$/KWH	0.000	ANNUAL O&M COST, \$	379000
COST OF FOSSIL FUEL, \$/MBTU	2.36		

*****EQUAL INTERVAL PERIODIC O&M*****

PERIODIC MAINTENANCE INTERVAL	1 (YEARS)
PERIODIC MAINTENANCE COST	0 (\$)

*****VARIED INTERVAL PERIODIC O&M*****

YEAR	COST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.042
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	30	TAX CREDIT	0.000
CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	PLANT TAX LIFE	20
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0.063		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR PLANT	0.485
DEPRECIATION FACTOR FOR BATTERIES	0.851
CAPITAL RECOVERY FACTOR	0.059242
FIXED CHARGE RATE FOR PLANT	0.097929
FIXED CHARGE RATE FOR BATTERIES	0.084658

OVERNIGHT CONSTRUCTION COST	19100000
1st YEAR OPERATING & MAINT. COST	379,000
1st YEAR EFFICIENCY ELECTRICITY COST	0
1st YEAR STORED ELECTRICITY COST	0
1st YEAR AUXILARY ELECTRICITY COST	0
1st YEAR AUXILARY FOSSIL FUEL COST	755564.1

ANNUAL ENERGY GENERATED (KWH)	25000000
ANNUAL ENERGY GENERATED (KWH)	25000000

PRESENT VALUE OF INITIAL CAPITAL	19100000
PRESENT VALUE OF NET REPLACEMENT CAPITAL	0
PRESENT VALUE OF ANNUAL O&M	6397424.
PRESENT VALUE OF PERIODIC O&M	0
PRESENT VALUE OF EFFICIENCY LOSS ENERGY	0
PRESENT VALUE OF STORED ENERGY	0
PRESENT VALUE OF AUXILARY ELECTRIC ENERGY	0
PRESENT VALUE OF AUXILARY FOSSIL FUEL ENERGY	31344838
PRESENT VALUE OF FINAL SALVAGE	0

-----SUMMARY RESULTS-----

COMPONENT LIFE-CYCLE COST CONTRIBUTORS

INITIAL BATTERY COST	0
BALANCE-OF-PLANT	75
REPLACEMENTS	0
OPERATING AND MAINTENANCE	15
ENERGY	74
SALVAGE	0
TOTAL	164 MILLS/KWH

TOTAL PRESENT WORTH	56842262
TOTAL ANNUALIZED COST	4106406.
LEVELIZED STORAGE COST	0.164256 \$/KWH OF ENERGY GENERATED

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CONVENTIONAL GAS-FIRED TURBINE: LOW WORLD OIL PRICE

BATTERY STORAGE ECONOMIC ANALYSIS MODEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	Gas Turbine (C)	CYCLE LIFE (#)	8000
APPLICATION	Utility	CYCLES/YEAR	250
SYSTEM SIZE (KWH)	100,000	ROUND TRIP EFFICIENCY	1
SYSTEM SIZE (KWE)	20,000		

AUXILARY ELECTRICITY CONSUMPTION (KWH/YR)	0
AUXILARY FOSSIL FUEL CONSUMPTION (MBTU/YR)	345000

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	0 (\$/KWH)
BATTERY INSTALLATION	0 (\$/KWH)
ENERGY RELATED COSTS	0 (\$/KWH)
POWER RELATED COSTS	331 (\$/KWE)
NET SALVAGE VALUE	0 (\$/KWH)

-----OPERATING AND MAINTENANCE COST INPUTS-----

COST OF ELECTRICITY, \$/KWH	0.000	ANNUAL O&M COST, \$	118800
COST OF FOSSIL FUEL, \$/MBTU	2.36		

*****EQUAL INTERVAL PERIODIC O&M*****

PERIODIC MAINTENANCE INTERVAL	1 (YEARS)
PERIODIC MAINTENANCE COST	0 (\$)

*****VARIED INTERVAL PERIODIC O&M*****

YEAR	COST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.042
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	30	TAX CREDIT	0.000
CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	PLANT TAX LIFE	20
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0.049		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR PLANT	0.485
DEPRECIATION FACTOR FOR BATTERIES	0.851
CAPITAL RECOVERY FACTOR	0.059242
FIXED CHARGE RATE FOR PLANT	0.097929
FIXED CHARGE RATE FOR BATTERIES	0.084658

OVERNIGHT CONSTRUCTION COST	6620000
1st YEAR OPERATING & MAINT. COST	118,800
1st YEAR EFFICIENCY ELECTRICITY COST	0
1st YEAR STORED ELECTRICITY COST	0
1st YEAR AUXILARY ELECTRICITY COST	0
1st YEAR AUXILARY FOSSIL FUEL COST	1138045.

ANNUAL ENERGY GENERATED (KWH)	25000000
ANNUAL ENERGY GENERATED (KWH)	25000000

PRESENT VALUE OF INITIAL CAPITAL	6620000
PRESENT VALUE OF NET REPLACEMENT CAPITAL	0
PRESENT VALUE OF ANNUAL O&M	2005314.
PRESENT VALUE OF PERIODIC O&M	0
PRESENT VALUE OF EFFICIENCY LOSS ENERGY	0
PRESENT VALUE OF STORED ENERGY	0
PRESENT VALUE OF AUXILARY ELECTRIC ENERGY	0
PRESENT VALUE OF AUXILARY FOSSIL FUEL ENERGY	37938504
PRESENT VALUE OF FINAL SALVAGE	0

-----SUMMARY RESULTS-----

COMPONENT LIFE-CYCLE COST CONTRIBUTORS

INITIAL BATTERY COST	0
BALANCE-OF-PLANT	26
REPLACEMENTS	0
OPERATING AND MAINTENANCE	5
ENERGY	90
SALVAGE	0
TOTAL	121 MILLS/KWH

TOTAL PRESENT WORTH	46563818
TOTAL ANNUALIZED COST	3014669.

LEVELIZED STORAGE COST	0.120587 \$/KWH OF ENERGY GENERATED
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CONVENTIONAL GAS-FIRED TURBINE: NOMINAL WORLD OIL PRICE

BATTERY STORAGE ECONOMIC ANALYSIS MODEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	Gas Turbine (C)	CYCLE LIFE (#)	8000
APPLICATION	Utility	CYCLES/YEAR	250
SYSTEM SIZE (KWH)	100,000	ROUND TRIP EFFICIENCY	1
SYSTEM SIZE (KWE)	20,000		

AUXILARY ELECTRICITY CONSUMPTION (KWH/YR)	0
AUXILARY FOSSIL FUEL CONSUMPTION (MBTU/YR)	345000

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	0 (\$/KWH)
BATTERY INSTALLATION	0 (\$/KWH)
ENERGY RELATED COSTS	0 (\$/KWH)
POWER RELATED COSTS	331 (\$/KWE)
NET SALVAGE VALUE	0 (\$/KWH)

-----OPERATING AND MAINTENANCE COST INPUTS-----

COST OF ELECTRICITY, \$/KWH	0.000	ANNUAL O&M COST, \$	118800
COST OF FOSSIL FUEL, \$/MBTU	2.36		

*****EQUAL INTERVAL PERIODIC D&M*****

PERIODIC MAINTENANCE INTERVAL	1 (YEARS)
PERIODIC MAINTENANCE COST	0 (\$)

*****VARIED INTERVAL PERIODIC O&M*****

YEAR	COST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.042
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	30	TAX CREDIT	0.000
CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	PLANT TAX LIFE	20
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0.056		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR PLANT	0.485
DEPRECIATION FACTOR FOR BATTERIES	0.851
CAPITAL RECOVERY FACTOR	0.059242
FIXED CHARGE RATE FOR PLANT	0.097929
FIXED CHARGE RATE FOR BATTERIES	0.084658

OVERNIGHT CONSTRUCTION COST	6620000
1st YEAR OPERATING & MAINT. COST	118,800
1st YEAR EFFICIENCY ELECTRICITY COST	0
1st YEAR STORED ELECTRICITY COST	0
1st YEAR AUXILARY ELECTRICITY COST	0
1st YEAR AUXILARY FOSSIL FUEL COST	1192280.

ANNUAL ENERGY GENERATED (KWH)	25000000
ANNUAL ENERGY GENERATED (KWH)	25000000

PRESENT VALUE OF INITIAL CAPITAL	6620000
PRESENT VALUE OF NET REPLACEMENT CAPITAL	0
PRESENT VALUE OF ANNUAL O&M	2005314.
PRESENT VALUE OF PERIODIC O&M	0
PRESENT VALUE OF EFFICIENCY LOSS ENERGY	0
PRESENT VALUE OF STORED ENERGY	0
PRESENT VALUE OF AUXILARY ELECTRIC ENERGY	0
PRESENT VALUE OF AUXILARY FOSSIL FUEL ENERGY	44282760
PRESENT VALUE OF FINAL SALVAGE	0

-----SUMMARY RESULTS-----

COMPONENT LIFE-CYCLE COST CONTRIBUTORS

INITIAL BATTERY COST	0
BALANCE-OF-PLANT	26
REPLACEMENTS	0
OPERATING AND MAINTENANCE	5
ENERGY	105
SALVAGE	0
TOTAL	136 MILLS/KWH

TOTAL PRESENT WORTH	52908074
TOTAL ANNUALIZED COST	3390519.

LEVELIZED STORAGE COST	0.135621 \$/KWH OF ENERGY GENERATED
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CONVENTIONAL GAS-FIRED TURBINE: HIGH WORLD OIL PRICE

BATTERY STORAGE ECONOMIC ANALYSIS MODEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	Gas Turbine (C)	CYCLE LIFE (#)	8000
APPLICATION	Utility	CYCLES/YEAR	250
SYSTEM SIZE (KWH)	100,000	ROUND TRIP EFFICIENCY	1
SYSTEM SIZE (KWE)	20,000		

AUXILARY ELECTRICITY CONSUMPTION (KWH/YR)	0
AUXILARY FOSSIL FUEL CONSUMPTION (MBTU/YR)	345000

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	0 (\$/KWH)
BATTERY INSTALLATION	0 (\$/KWH)
ENERGY RELATED COSTS	0 (\$/KWH)
POWER RELATED COSTS	331 (\$/KWE)
NET SALVAGE VALUE	0 (\$/KWH)

-----OPERATING AND MAINTENANCE COST INPUTS-----

COST OF ELECTRICITY, \$/KWH	0.000	ANNUAL O&M COST, \$	118800
COST OF FOSSIL FUEL, \$/MBTU	2.36		

*****EQUAL INTERVAL PERIODIC O&M*****

PERIODIC MAINTENANCE INTERVAL	1 (YEARS)
PERIODIC MAINTENANCE COST	0 (\$)

*****VARIED INTERVAL PERIODIC O&M*****

YEAR	COST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.042
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	30	TAX CREDIT	0.000
CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	PLANT TAX LIFE	20
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0.063		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR PLANT	0.485
DEPRECIATION FACTOR FOR BATTERIES	0.851
CAPITAL RECOVERY FACTOR	0.059242
FIXED CHARGE RATE FOR PLANT	0.097929
FIXED CHARGE RATE FOR BATTERIES	0.084658

OVERNIGHT CONSTRUCTION COST	6620000
1st YEAR OPERATING & MAINT. COST	118,800
1st YEAR EFFICIENCY ELECTRICITY COST	0
1st YEAR STORED ELECTRICITY COST	0
1st YEAR AUXILARY ELECTRICITY COST	0
1st YEAR AUXILARY FOSSIL FUEL COST	1248716.

ANNUAL ENERGY GENERATED (KWH)	25000000
ANNUAL ENERGY GENERATED (KWH)	25000000

PRESENT VALUE OF INITIAL CAPITAL	6620000
PRESENT VALUE OF NET REPLACEMENT CAPITAL	0
PRESENT VALUE OF ANNUAL O&M	2005314.
PRESENT VALUE OF PERIODIC O&M	0
PRESENT VALUE OF EFFICIENCY LOSS ENERGY	0
PRESENT VALUE OF STORED ENERGY	0
PRESENT VALUE OF AUXILARY ELECTRIC ENERGY	0
PRESENT VALUE OF AUXILARY FOSSIL FUEL ENERGY	51803444
PRESENT VALUE OF FINAL SALVAGE	0

-----SUMMARY RESULTS-----

COMPONENT LIFE-CYCLE COST CONTRIBUTORS

INITIAL BATTERY COST	0
BALANCE-OF-PLANT	26
REPLACEMENTS	0
OPERATING AND MAINTENANCE	5
ENERGY	123
SALVAGE	0
TOTAL	153 MILLS/KWH

TOTAL PRESENT WORTH	60428759
TOTAL ANNUALIZED COST	3836064.
LEVELIZED STORAGE COST	0.153443 \$/KWH OF ENERGY GENERATED

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ADVANCED GAS-FIRED TURBINE: LOW WORLD OIL PRICE

BATTERY STORAGE ECONOMIC ANALYSIS MODEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	Gas Turbine (A)	CYCLE LIFE (#)	8000
APPLICATION	Utility	CYCLES/YEAR	250
SYSTEM SIZE (KWH)	100,000	ROUND TRIP EFFICIENCY	1
SYSTEM SIZE (KWE)	20,000		

AUXILARY ELECTRICITY CONSUMPTION (KWH/YR)	0
AUXILARY FOSSIL FUEL CONSUMPTION (MBTU/YR)	327500

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	0 (\$/KWH)
BATTERY INSTALLATION	0 (\$/KWH)
ENERGY RELATED COSTS	0 (\$/KWH)
POWER RELATED COSTS	307 (\$/KWE)
NET SALVAGE VALUE	0 (\$/KWH)

-----OPERATING AND MAINTENANCE COST INPUTS-----

COST OF ELECTRICITY, \$/KWH	0.000	ANNUAL O&M COST, \$	118800
COST OF FOSSIL FUEL, \$/MBTU	2.36		

*****EQUAL INTERVAL PERIODIC O&M*****

PERIODIC MAINTENANCE INTERVAL	1 (YEARS)
PERIODIC MAINTENANCE COST	0 (\$)

*****VARIED INTERVAL PERIODIC O&M*****

YEAR	COST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.042
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	30	TAX CREDIT	0.000
CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	PLANT TAX LIFE	20
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0.049		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR PLANT	0.485
DEPRECIATION FACTOR FOR BATTERIES	0.851
CAPITAL RECOVERY FACTOR	0.059242
FIXED CHARGE RATE FOR PLANT	0.097929
FIXED CHARGE RATE FOR BATTERIES	0.084658

OVERNIGHT CONSTRUCTION COST	6140000
1st YEAR OPERATING & MAINT. COST	118,800
1st YEAR EFFICIENCY ELECTRICITY COST	0
1st YEAR STORED ELECTRICITY COST	0
1st YEAR AUXILARY ELECTRICITY COST	0
1st YEAR AUXILARY FOSSIL FUEL COST	1080318.

ANNUAL ENERGY GENERATED (KWH)	25000000
ANNUAL ENERGY GENERATED (KWH)	25000000

PRESENT VALUE OF INITIAL CAPITAL	6140000
PRESENT VALUE OF NET REPLACEMENT CAPITAL	0
PRESENT VALUE OF ANNUAL O&M	2005314.
PRESENT VALUE OF PERIODIC O&M	0
PRESENT VALUE OF EFFICIENCY LOSS ENERGY	0
PRESENT VALUE OF STORED ENERGY	0
PRESENT VALUE OF AUXILARY ELECTRIC ENERGY	0
PRESENT VALUE OF AUXILARY FOSSIL FUEL ENERGY	36014087
PRESENT VALUE OF FINAL SALVAGE	0

-----SUMMARY RESULTS-----

COMPONENT LIFE-CYCLE COST CONTRIBUTORS

INITIAL BATTERY COST	0
BALANCE-OF-PLANT	24
REPLACEMENTS	0
OPERATING AND MAINTENANCE	5
ENERGY	85
SALVAGE	0
TOTAL	114 MILLS/KWH

TOTAL PRESENT WORTH	44159402
TOTAL ANNUALIZED COST	2853655.
LEVELIZED STORAGE COST	0.114146 \$/KWH OF ENERGY GENERATED
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ADVANCED GAS-FIRED TURBINE: NOMINAL WORLD OIL PRICE

BATTERY STORAGE ECONOMIC ANALYSIS MODEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	Gas Turbine (A)	CYCLE LIFE (#)	8000
APPLICATION	Utility	CYCLES/YEAR	250
SYSTEM SIZE (KWH)	100,000	ROUND TRIP EFFICIENCY	1
SYSTEM SIZE (KWE)	20,000		

AUXILARY ELECTRICITY CONSUMPTION (KWH/YR)	0
AUXILARY FOSSIL FUEL CONSUMPTION (MBTU/YR)	327500

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	0 (\$/KWH)
BATTERY INSTALLATION	0 (\$/KWH)
ENERGY RELATED COSTS	0 (\$/KWH)
POWER RELATED COSTS	307 (\$/KWE)
NET SALVAGE VALUE	0 (\$/KWH)

-----OPERATING AND MAINTENANCE COST INPUTS-----

COST OF ELECTRICITY, \$/KWH	0.000	ANNUAL O&M COST, \$	118800
COST OF FOSSIL FUEL, \$/MBTU	2.36		

*****EQUAL INTERVAL PERIODIC O&M*****

PERIODIC MAINTENANCE INTERVAL	1 (YEARS)
PERIODIC MAINTENANCE COST	0 (\$)

*****VARIED INTERVAL PERIODIC O&M*****

YEAR	COST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.042
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	30	TAX CREDIT	0.000
CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	PLANT TAX LIFE	20
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0.056		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR PLANT	0.485
DEPRECIATION FACTOR FOR BATTERIES	0.851
CAPITAL RECOVERY FACTOR	0.059242
FIXED CHARGE RATE FOR PLANT	0.097929
FIXED CHARGE RATE FOR BATTERIES	0.084658

OVERNIGHT CONSTRUCTION COST	6140000
1st YEAR OPERATING & MAINT. COST	118,800
1st YEAR EFFICIENCY ELECTRICITY COST	0
1st YEAR STORED ELECTRICITY COST	0
1st YEAR AUXILARY ELECTRICITY COST	0
1st YEAR AUXILARY FOSSIL FUEL COST	1131802.

ANNUAL ENERGY GENERATED (KWH)	25000000
ANNUAL ENERGY GENERATED (KWH)	25000000

PRESENT VALUE OF INITIAL CAPITAL	6140000
PRESENT VALUE OF NET REPLACEMENT CAPITAL	0
PRESENT VALUE OF ANNUAL O&M	2005314.
PRESENT VALUE OF PERIODIC O&M	0
PRESENT VALUE OF EFFICIENCY LOSS ENERGY	0
PRESENT VALUE OF STORED ENERGY	0
PRESENT VALUE OF AUXILARY ELECTRIC ENERGY	0
PRESENT VALUE OF AUXILARY FOSSIL FUEL ENERGY	42036533
PRESENT VALUE OF FINAL SALVAGE	0

-----SUMMARY RESULTS-----

COMPONENT LIFE-CYCLE COST CONTRIBUTORS

INITIAL BATTERY COST	0
BALANCE-OF-PLANT	24
REPLACEMENTS	0
OPERATING AND MAINTENANCE	5
ENERGY	100
SALVAGE	0
TOTAL	128 MILLS/KWH

TOTAL PRESENT WORTH	50181847
TOTAL ANNUALIZED COST	3210441.

LEVELIZED STORAGE COST	0.128418 \$/KWH OF ENERGY GENERATED
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ADVANCED GAS-FIRED TURBINE: HIGH WORLD OIL PRICE

BATTERY STORAGE ECONOMIC ANALYSIS MODEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	Gas Turbine (A)	CYCLE LIFE (#)	8000
APPLICATION	Utility	CYCLES/YEAR	250
SYSTEM SIZE (KWH)	100,000	ROUND TRIP EFFICIENCY	1
SYSTEM SIZE (KWE)	20,000		

AUXILARY ELECTRICITY CONSUMPTION (KWH/YR)	0
AUXILARY FOSSIL FUEL CONSUMPTION (MBTU/YR)	327500

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	0 (\$/KWH)
BATTERY INSTALLATION	0 (\$/KWH)
ENERGY RELATED COSTS	0 (\$/KWH)
POWER RELATED COSTS	307 (\$/KWE)
NET SALVAGE VALUE	0 (\$/KWH)

-----OPERATING AND MAINTENANCE COST INPUTS-----

COST OF ELECTRICITY, \$/KWH	0.000	ANNUAL O&M COST, \$	118800
COST OF FOSSIL FUEL, \$/MBTU	2.36		

*****EQUAL INTERVAL PERIODIC O&M*****

PERIODIC MAINTENANCE INTERVAL	1 (YEARS)
PERIODIC MAINTENANCE COST	0 (\$)

*****VARIED INTERVAL PERIODIC O&M*****

YEAR	COST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.042
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	30	TAX CREDIT	0.000
CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	PLANT TAX LIFE	20
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0.063		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR PLANT	0.485
DEPRECIATION FACTOR FOR BATTERIES	0.851
CAPITAL RECOVERY FACTOR	0.059242
FIXED CHARGE RATE FOR PLANT	0.097929
FIXED CHARGE RATE FOR BATTERIES	0.084658

OVERNIGHT CONSTRUCTION COST	6140000
1st YEAR OPERATING & MAINT. COST	118,800
1st YEAR EFFICIENCY ELECTRICITY COST	0
1st YEAR STORED ELECTRICITY COST	0
1st YEAR AUXILARY ELECTRICITY COST	0
1st YEAR AUXILARY FOSSIL FUEL COST	1185376.

ANNUAL ENERGY GENERATED (KWH)	25000000
ANNUAL ENERGY GENERATED (KWH)	25000000

PRESENT VALUE OF INITIAL CAPITAL	6140000
PRESENT VALUE OF NET REPLACEMENT CAPITAL	0
PRESENT VALUE OF ANNUAL O&M	2005314.
PRESENT VALUE OF PERIODIC O&M	0
PRESENT VALUE OF EFFICIENCY LOSS ENERGY	0
PRESENT VALUE OF STORED ENERGY	0
PRESENT VALUE OF AUXILARY ELECTRIC ENERGY	0
PRESENT VALUE OF AUXILARY FOSSIL FUEL ENERGY	49175733
PRESENT VALUE OF FINAL SALVAGE	0

-----SUMMARY RESULTS-----

COMPONENT LIFE-CYCLE COST CONTRIBUTORS

INITIAL BATTERY COST	0
BALANCE-OF-PLANT	24
REPLACEMENTS	0
OPERATING AND MAINTENANCE	5
ENERGY	117
SALVAGE	0
TOTAL	145 MILLS/KWH

TOTAL PRESENT WORTH	57321048
TOTAL ANNUALIZED COST	3633385.

LEVELIZED STORAGE COST	0.145335 \$/KWH OF ENERGY GENERATED
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ROCK MEDIA COMPRESSED AIR ENERGY STORAGE: LOW WORLD OIL PRICE

BATTERY STORAGE ECONOMIC ANALYSIS MODEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	CAES(Rock)	CYCLE LIFE (#)	8000
APPLICATION	Utility	CYCLES/YEAR	250
SYSTEM SIZE (KWH)	100,000	ROUND TRIP EFFICIENCY	1.32
SYSTEM SIZE (KWE)	20,000		

AUXILARY ELECTRICITY CONSUMPTION (KWH/YR)	0
AUXILARY FOSSIL FUEL CONSUMPTION (MBTU/YR)	77900

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	0 (\$/KWH)
BATTERY INSTALLATION	0 (\$/KWH)
ENERGY RELATED COSTS	62 (\$/KWH)
POWER RELATED COSTS	937 (\$/KWE)
NET SALVAGE VALUE	0 (\$/KWH)

-----OPERATING AND MAINTENANCE COST INPUTS-----

COST OF ELECTRICITY, \$/KWH	0.025	ANNUAL O&M COST, \$	84100
COST OF FOSSIL FUEL, \$/MBTU	2.36		

*****EQUAL INTERVAL PERIODIC O&M*****

PERIODIC MAINTENANCE INTERVAL	1 (YEARS)
PERIODIC MAINTENANCE COST	0 (\$)

*****VARIED INTERVAL PERIODIC O&M*****

YEAR	COST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.042
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	30	TAX CREDIT	0.000
CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	PLANT TAX LIFE	20
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0.049		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR PLANT	0.485
DEPRECIATION FACTOR FOR BATTERIES	0.851
CAPITAL RECOVERY FACTOR	0.059242
FIXED CHARGE RATE FOR PLANT	0.097929
FIXED CHARGE RATE FOR BATTERIES	0.084658

OVERNIGHT CONSTRUCTION COST	24940000
1st YEAR OPERATING & MAINT. COST	84,100
1st YEAR EFFICIENCY ELECTRICITY COST(200,000)	
1st YEAR STORED ELECTRICITY COST	825000
1st YEAR AUXILARY ELECTRICITY COST	0
1st YEAR AUXILARY FOSSIL FUEL COST	256967.3

ANNUAL ENERGY GENERATED (KWH)	25000000
ANNUAL ENERGY GENERATED (KWH)	33000000

PRESENT VALUE OF INITIAL CAPITAL	24940000
PRESENT VALUE OF NET REPLACEMENT CAPITAL	0
PRESENT VALUE OF ANNUAL O&M	1419586.
PRESENT VALUE OF PERIODIC O&M	0
PRESENT VALUE OF EFFICIENCY LOSS ENERGY	-3375949
PRESENT VALUE OF STORED ENERGY	13925792
PRESENT VALUE OF AUXILARY ELECTRIC ENERGY	0
PRESENT VALUE OF AUXILARY FOSSIL FUEL ENERGY	8566404.
PRESENT VALUE OF FINAL SALVAGE	0

-----SUMMARY RESULTS-----

COMPONENT LIFE-CYCLE COST CONTRIBUTORS

INITIAL BATTERY COST	0
BALANCE-OF-PLANT	74
REPLACEMENTS	0
OPERATING AND MAINTENANCE	3
ENERGY	34
SALVAGE	0
TOTAL	111 MILLS/KWH

TOTAL PRESENT WORTH	45475834
TOTAL ANNUALIZED COST	3658961.
LEVELIZED STORAGE COST	0.110878 \$/KWH OF ENERGY GENERATED

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ROCK MEDIA COMPRESSED AIR ENERGY STORAGE: NOMINAL WORLD OIL PRICE

BATTERY STORAGE ECONOMIC ANALYSIS MODEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	CAES(Rock)	CYCLE LIFE (#)	8000
APPLICATION	Utility	CYCLES/YEAR	250
SYSTEM SIZE (KWH)	100,000	ROUND TRIP EFFICIENCY	1.32
SYSTEM SIZE (KWE)	20,000		

AUXILARY ELECTRICITY CONSUMPTION (KWH/YR)	0
AUXILARY FOSSIL FUEL CONSUMPTION (MBTU/YR)	77900

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	0 (\$/KWH)
BATTERY INSTALLATION	0 (\$/KWH)
ENERGY RELATED COSTS	62 (\$/KWH)
POWER RELATED COSTS	937 (\$/KWE)
NET SALVAGE VALUE	0 (\$/KWH)

-----OPERATING AND MAINTENANCE COST INPUTS-----

COST OF ELECTRICITY, \$/KWH	0.025	ANNUAL O&M COST, \$	84100
COST OF FOSSIL FUEL, \$/MBTU	2.36		

*****EQUAL INTERVAL PERIODIC O&M*****

PERIODIC MAINTENANCE INTERVAL	1 (YEARS)
PERIODIC MAINTENANCE COST	0 (\$)

*****VARIED INTERVAL PERIODIC O&M*****

YEAR	COST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.042
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	30	TAX CREDIT	0.000
CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	PLANT TAX LIFE	20
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0.056		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR PLANT	0.485
DEPRECIATION FACTOR FOR BATTERIES	0.851
CAPITAL RECOVERY FACTOR	0.059242
FIXED CHARGE RATE FOR PLANT	0.097929
FIXED CHARGE RATE FOR BATTERIES	0.084658

OVERNIGHT CONSTRUCTION COST	24940000
1st YEAR OPERATING & MAINT. COST	84,100
1st YEAR EFFICIENCY ELECTRICITY COST(200,000)	
1st YEAR STORED ELECTRICITY COST	825000
1st YEAR AUXILARY ELECTRICITY COST	0
1st YEAR AUXILARY FOSSIL FUEL COST	269213.5

ANNUAL ENERGY GENERATED (KWH)	25000000
ANNUAL ENERGY GENERATED (KWH)	33000000

PRESENT VALUE OF INITIAL CAPITAL	24940000
PRESENT VALUE OF NET REPLACEMENT CAPITAL	0
PRESENT VALUE OF ANNUAL O&M	1419586.
PRESENT VALUE OF PERIODIC O&M	0
PRESENT VALUE OF EFFICIENCY LOSS ENERGY	-3375949
PRESENT VALUE OF STORED ENERGY	13925792
PRESENT VALUE OF AUXILARY ELECTRIC ENERGY	0
PRESENT VALUE OF AUXILARY FOSSIL FUEL ENERGY	9998918.
PRESENT VALUE OF FINAL SALVAGE	0

-----SUMMARY RESULTS-----

COMPONENT LIFE-CYCLE COST CONTRIBUTORS

INITIAL BATTERY COST	0
BALANCE-OF-PLANT	74
REPLACEMENTS	0
OPERATING AND MAINTENANCE	3
ENERGY	37
SALVAGE	0
TOTAL	113 MILLS/KWH

TOTAL PRESENT WORTH	46908348
TOTAL ANNUALIZED COST	3743827.

LEVELIZED STORAGE COST	0.113449 \$/KWH OF ENERGY GENERATED
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ROCK MEDIA COMPRESSED AIR ENERGY STORAGE: HIGH WORLD OIL PRICE

BATTERY STORAGE ECONOMIC ANALYSIS MODEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	CAES(Rock)	CYCLE LIFE (#)	8000
APPLICATION	Utility	CYCLES/YEAR	250
SYSTEM SIZE (KWH)	100,000	ROUND TRIP EFFICIENCY	1.32
SYSTEM SIZE (KWE)	20,000		
AUXILARY ELECTRICITY CONSUMPTION (KWH/YR)		0	
AUXILARY FOSSIL FUEL CONSUMPTION (MBTU/YR)		77900	

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	0 (\$/KWH)
BATTERY INSTALLATION	0 (\$/KWH)
ENERGY RELATED COSTS	62 (\$/KWH)
POWER RELATED COSTS	937 (\$/KWE)
NET SALVAGE VALUE	0 (\$/KWH)

-----OPERATING AND MAINTENANCE COST INPUTS-----

COST OF ELECTRICITY, \$/KWH	0.025	ANNUAL O&M COST, \$	84100
COST OF FOSSIL FUEL, \$/MBTU	2.36		

*****EQUAL INTERVAL PERIODIC O&M*****

PERIODIC MAINTENANCE INTERVAL	1 (YEARS)
PERIODIC MAINTENANCE COST	0 (\$)

*****VARIED INTERVAL PERIODIC O&M*****

YEAR	COST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.042
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	30	TAX CREDIT	0.000
CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	PLANT TAX LIFE	20
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0.063		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR PLANT	0.485
DEPRECIATION FACTOR FOR BATTERIES	0.851
CAPITAL RECOVERY FACTOR	0.059242
FIXED CHARGE RATE FOR PLANT	0.097929
FIXED CHARGE RATE FOR BATTERIES	0.084658

OVERNIGHT CONSTRUCTION COST	24940000
1st YEAR OPERATING & MAINT. COST	84,100
1st YEAR EFFICIENCY ELECTRICITY COST(200,000)	
1st YEAR STORED ELECTRICITY COST	825000
1st YEAR AUXILARY ELECTRICITY COST	0
1st YEAR AUXILARY FOSSIL FUEL COST	281956.6

ANNUAL ENERGY GENERATED (KWH)	25000000
ANNUAL ENERGY GENERATED (KWH)	33000000

PRESENT VALUE OF INITIAL CAPITAL	24940000
PRESENT VALUE OF NET REPLACEMENT CAPITAL	0
PRESENT VALUE OF ANNUAL O&M	1419586.
PRESENT VALUE OF PERIODIC O&M	0
PRESENT VALUE OF EFFICIENCY LOSS ENERGY	-3375949
PRESENT VALUE OF STORED ENERGY	13925792
PRESENT VALUE OF AUXILARY ELECTRIC ENERGY	0
PRESENT VALUE OF AUXILARY FOSSIL FUEL ENERGY	11697067
PRESENT VALUE OF FINAL SALVAGE	0

-----SUMMARY RESULTS-----

COMPONENT LIFE-CYCLE COST CONTRIBUTORS

INITIAL BATTERY COST	0
BALANCE-OF-PLANT	74
REPLACEMENTS	0
OPERATING AND MAINTENANCE	3
ENERGY	40
SALVAGE	0
TOTAL	116 MILLS/KWH

TOTAL PRESENT WORTH	48606497
TOTAL ANNUALIZED COST	3844430.
LEVELIZED STORAGE COST	0.116498 \$/KWH OF ENERGY GENERATED

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AQUIFER MEDIA COMPRESSED AIR ENERGY STORAGE: LOW WORLD OIL PRICE

BATTERY STORAGE ECONOMIC ANALYSIS MODEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	CAES(Aquifer)	CYCLE LIFE (#)	8000
APPLICATION	Utility	CYCLES/YEAR	250
SYSTEM SIZE (KWH)	100,000	ROUND TRIP EFFICIENCY	1.32
SYSTEM SIZE (KWE)	20,000		

AUXILARY ELECTRICITY CONSUMPTION (KWH/YR)	0
AUXILARY FOSSIL FUEL CONSUMPTION (MBTU/YR)	77900

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	0 (\$/KWH)
BATTERY INSTALLATION	0 (\$/KWH)
ENERGY RELATED COSTS	4.5 (\$/KWH)
POWER RELATED COSTS	734 (\$/KWE)
NET SALVAGE VALUE	0 (\$/KWH)

-----OPERATING AND MAINTENANCE COST INPUTS-----

COST OF ELECTRICITY, \$/KWH	0.025	ANNUAL O&M COST, \$	39000
COST OF FOSSIL FUEL, \$/MBTU	2.36		

*****EQUAL INTERVAL PERIODIC O&M*****

PERIODIC MAINTENANCE INTERVAL	1 (YEARS)
PERIODIC MAINTENANCE COST	0 (\$)

*****VARIED INTERVAL PERIODIC O&M*****

YEAR	COST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.042
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	30	TAX CREDIT	0.000
CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	PLANT TAX LIFE	20
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0.049		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR PLANT	0.485
DEPRECIATION FACTOR FOR BATTERIES	0.851
CAPITAL RECOVERY FACTOR	0.059242
FIXED CHARGE RATE FOR PLANT	0.097929
FIXED CHARGE RATE FOR BATTERIES	0.084658

OVERNIGHT CONSTRUCTION COST	15130000
1st YEAR OPERATING & MAINT. COST	39,000
1st YEAR EFFICIENCY ELECTRICITY COST(200,000)	
1st YEAR STORED ELECTRICITY COST	825000
1st YEAR AUXILARY ELECTRICITY COST	0
1st YEAR AUXILARY FOSSIL FUEL COST	256967.3

ANNUAL ENERGY GENERATED (KWH)	25000000
ANNUAL ENERGY GENERATED (KWH)	33000000

PRESENT VALUE OF INITIAL CAPITAL	15130000
PRESENT VALUE OF NET REPLACEMENT CAPITAL	0
PRESENT VALUE OF ANNUAL O&M	658310.1
PRESENT VALUE OF PERIODIC O&M	0
PRESENT VALUE OF EFFICIENCY LOSS ENERGY	-3375949
PRESENT VALUE OF STORED ENERGY	13925792
PRESENT VALUE OF AUXILARY ELECTRIC ENERGY	0
PRESENT VALUE OF AUXILARY FOSSIL FUEL ENERGY	8566404.
PRESENT VALUE OF FINAL SALVAGE	0

-----SUMMARY RESULTS-----

COMPONENT LIFE-CYCLE COST CONTRIBUTORS

INITIAL BATTERY COST	0
BALANCE-OF-PLANT	45
REPLACEMENTS	0
OPERATING AND MAINTENANCE	1
ENERGY	34
SALVAGE	0
TOTAL	80 MILLS/KWH

TOTAL PRESENT WORTH	34904557
TOTAL ANNUALIZED COST	2653171.

LEVELIZED STORAGE COST	0.080399 \$/KWH OF ENERGY GENERATED
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AQUIFER MEDIA COMPRESSED AIR ENERGY STORAGE: NOMINAL WORLD OIL PRICE

BATTERY STORAGE ECONOMIC ANALYSIS MODEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	CAES(Aquifer)	CYCLE LIFE (#)	8000
APPLICATION	Utility	CYCLES/YEAR	250
SYSTEM SIZE (KWH)	100,000	ROUND TRIP EFFICIENCY	1.32
SYSTEM SIZE (KWE)	20,000		

AUXILARY ELECTRICITY CONSUMPTION (KWH/YR)	0
AUXILARY FOSSIL FUEL CONSUMPTION (MBTU/YR)	77900

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	0 (\$/KWH)
BATTERY INSTALLATION	0 (\$/KWH)
ENERGY RELATED COSTS	4.5 (\$/KWH)
POWER RELATED COSTS	734 (\$/KWE)
NET SALVAGE VALUE	0 (\$/KWH)

-----OPERATING AND MAINTENANCE COST INPUTS-----

COST OF ELECTRICITY, \$/KWH	0.025	ANNUAL O&M COST, \$	39000
COST OF FOSSIL FUEL, \$/MBTU	2.36		

*****EQUAL INTERVAL PERIODIC O&M*****

PERIODIC MAINTENANCE INTERVAL	1 (YEARS)
PERIODIC MAINTENANCE COST	0 (\$)

*****VARIED INTERVAL PERIODIC O&M*****

YEAR	COST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.042
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	30	TAX CREDIT	0.000
CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	PLANT TAX LIFE	20
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0.056		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR PLANT	0.485
DEPRECIATION FACTOR FOR BATTERIES	0.851
CAPITAL RECOVERY FACTOR	0.059242
FIXED CHARGE RATE FOR PLANT	0.097929
FIXED CHARGE RATE FOR BATTERIES	0.084658

OVERNIGHT CONSTRUCTION COST	15130000
1st YEAR OPERATING & MAINT. COST	39,000
1st YEAR EFFICIENCY ELECTRICITY COST(200,000)	
1st YEAR STORED ELECTRICITY COST	825000
1st YEAR AUXILARY ELECTRICITY COST	0
1st YEAR AUXILARY FOSSIL FUEL COST	269213.5

ANNUAL ENERGY GENERATED (KWH)	25000000
ANNUAL ENERGY GENERATEO (KWH)	33000000

PRESENT VALUE OF INITIAL CAPITAL	15130000
PRESENT VALUE OF NET REPLACEMENT CAPITAL	0
PRESENT VALUE OF ANNUAL O&M	658310.1
PRESENT VALUE OF PERIOOIC O&M	0
PRESENT VALUE OF EFFICIENCY LOSS ENERGY	-3375949
PRESENT VALUE OF STORED ENERGY	13925792
PRESENT VALUE OF AUXILARY ELECTRIC ENERGY	0
PRESENT VALUE OF AUXILARY FOSSIL FUEL ENERGY	9998918.
PRESENT VALUE OF FINAL SALVAGE	0

-----SUMMARY RESULTS-----

COMPONENT LIFE-CYCLE COST CONTRIBUTORS

INITIAL BATTERY COST	0
BALANCE-OF-PLANT	45
REPLACEMENTS	0
OPERATING AND MAINTENANCE	1
ENERGY	37
SALVAGE	0
TOTAL	83 MILLS/KWH

TOTAL PRESENT WORTH	36337072
TOTAL ANNUALIZED COST	2738037.
LEVELIZED STORAGE COST	0.082971 \$/KWH OF ENERGY GENERATED

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AQUIFER MEDIA COMPRESSED AIR ENERGY STORAGE: HIGH WORLD OIL PRICE

BATTERY STORAGE ECONOMIC ANALYSIS MODEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	CAES(Aquifer)	CYCLE LIFE (#)	8000
APPLICATION	Utility	CYCLES/YEAR	250
SYSTEM SIZE (KWH)	100,000	ROUND TRIP EFFICIENCY	1.32
SYSTEM SIZE (KWE)	20,000		

AUXILARY ELECTRICITY CONSUMPTION (KWH/YR)	0
AUXILARY FOSSIL FUEL CONSUMPTION (MBTU/YR)	77900

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	0 (\$/KWH)
BATTERY INSTALLATION	0 (\$/KWH)
ENERGY RELATED COSTS	4.5 (\$/KWH)
POWER RELATED COSTS	734 (\$/KWE)
NET SALVAGE VALUE	0 (\$/KWH)

-----OPERATING AND MAINTENANCE COST INPUTS-----

COST OF ELECTRICITY, \$/KWH	0.025	ANNUAL O&M COST, \$	39000
COST OF FOSSIL FUEL, \$/MBTU	2.36		

*****EQUAL INTERVAL PERIODIC O&M*****

PERIODIC MAINTENANCE INTERVAL	1 (YEARS)
PERIODIC MAINTENANCE COST	0 (\$)

*****VARIED INTERVAL PERIODIC O&M*****

YEAR	COST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.042
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	30	TAX CREDIT	0.000
CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	PLANT TAX LIFE	20
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0.063		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR PLANT	0.485
DEPRECIATION FACTOR FOR BATTERIES	0.851
CAPITAL RECOVERY FACTOR	0.059242
FIXED CHARGE RATE FOR PLANT	0.097929
FIXED CHARGE RATE FOR BATTERIES	0.084658

OVERNIGHT CONSTRUCTION COST	15130000
1st YEAR OPERATING & MAINT. COST	39,000
1st YEAR EFFICIENCY ELECTRICITY COST(200,000)	
1st YEAR STORED ELECTRICITY COST	825000
1st YEAR AUXILARY ELECTRICITY COST	0
1st YEAR AUXILARY FOSSIL FUEL COST	281956.6

ANNUAL ENERGY GENERATED (KWH)	25000000
ANNUAL ENERGY GENERATED (KWH)	33000000

PRESENT VALUE OF INITIAL CAPITAL	15130000
PRESENT VALUE OF NET REPLACEMENT CAPITAL	0
PRESENT VALUE OF ANNUAL O&M	658310.1
PRESENT VALUE OF PERIODIC O&M	0
PRESENT VALUE OF EFFICIENCY LOSS ENERGY	-3375949
PRESENT VALUE OF STORED ENERGY	13925792
PRESENT VALUE OF AUXILARY ELECTRIC ENERGY	0
PRESENT VALUE OF AUXILARY FOSSIL FUEL ENERGY	11697067
PRESENT VALUE OF FINAL SALVAGE	0

-----SUMMARY RESULTS-----

COMPONENT LIFE-CYCLE COST CONTRIBUTORS

INITIAL BATTERY COST	0
BALANCE-OF-PLANT	45
REPLACEMENTS	0
OPERATING AND MAINTENANCE	1
ENERGY	40
SALVAGE	0
TOTAL	86 MILLS/KWH

TOTAL PRESENT WORTH	38035220
TOTAL ANNUALIZED COST	2838640.

LEVELIZED STORAGE COST	0.086019 \$/KWH OF ENERGY GENERATED
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SALT MEDIA COMPRESSED AIR ENERGY STORAGE: LOW WORLD OIL PRICE

BATTERY STORAGE ECONOMIC ANALYSIS MODEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	CAES(Salt)	CYCLE LIFE (#)	8000
APPLICATION	Utility	CYCLES/YEAR	250
SYSTEM SIZE (KWH)	100,000	ROUND TRIP EFFICIENCY	1.32
SYSTEM SIZE (KWE)	20,000		
AUXILARY ELECTRICITY CONSUMPTION (KWH/YR)		0	
AUXILARY FOSSIL FUEL CONSUMPTION (MBTU/YR)		77900	

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	0 (\$/KWH)
BATTERY INSTALLATION	0 (\$/KWH)
ENERGY RELATED COSTS	11.6 (\$/KWH)
POWER RELATED COSTS	726 (\$/KWE)
NET SALVAGE VALUE	0 (\$/KWH)

-----OPERATING AND MAINTENANCE COST INPUTS-----

COST OF ELECTRICITY, \$/KWH	0.025	ANNUAL O&M COST, \$	77900
COST OF FOSSIL FUEL, \$/MBTU	2.36		

*****EQUAL INTERVAL PERIODIC O&M*****

PERIODIC MAINTENANCE INTERVAL	1 (YEARS)
PERIODIC MAINTENANCE COST	0 (\$)

*****VARIED INTERVAL PERIODIC O&M*****

YEAR	COST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.042
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	30	TAX CREDIT	0.000
CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	PLANT TAX LIFE	20
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0.049		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR PLANT	0.485
DEPRECIATION FACTOR FOR BATTERIES	0.851
CAPITAL RECOVERY FACTOR	0.059242
FIXED CHARGE RATE FOR PLANT	0.097929
FIXED CHARGE RATE FOR BATTERIES	0.084658

OVERNIGHT CONSTRUCTION COST	15680000
1st YEAR OPERATING & MAINT. COST	77,900
1st YEAR EFFICIENCY ELECTRICITY COST(200,000)	
1st YEAR STORED ELECTRICITY COST	825000
1st YEAR AUXILARY ELECTRICITY COST	0
1st YEAR AUXILARY FOSSIL FUEL COST	256967.3

ANNUAL ENERGY GENERATED (KWH)	25000000
ANNUAL ENERGY GENERATED (KWH)	33000000

PRESENT VALUE OF INITIAL CAPITAL	15680000
PRESENT VALUE OF NET REPLACEMENT CAPITAL	0
PRESENT VALUE OF ANNUAL O&M	1314932.
PRESENT VALUE OF PERIODIC O&M	0
PRESENT VALUE OF EFFICIENCY LOSS ENERGY	-3375949
PRESENT VALUE OF STORED ENERGY	13925792
PRESENT VALUE OF AUXILARY ELECTRIC ENERGY	0
PRESENT VALUE OF AUXILARY FOSSIL FUEL ENERGY	8566404.
PRESENT VALUE OF FINAL SALVAGE	0

-----SUMMARY RESULTS-----

COMPONENT LIFE-CYCLE COST CONTRIBUTORS

INITIAL BATTERY COST	0
BALANCE-OF-PLANT	47
REPLACEMENTS	0
OPERATING AND MAINTENANCE	2
ENERGY	34
SALVAGE	0
TOTAL	83 MILLS/KWH

TOTAL PRESENT WORTH	36111179
TOTAL ANNUALIZED COST	2745933.

LEVELIZED STORAGE COST	0.083210 \$/KWH OF ENERGY GENERATED
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SALT MEDIA COMPRESSED AIR ENERGY STORAGE: NOMINAL WORLD OIL PRICE

BATTERY STORAGE ECONOMIC ANALYSIS MODEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	CAES(Salt)	CYCLE LIFE (#)	8000
APPLICATION	Utility	CYCLES/YEAR	250
SYSTEM SIZE (KWH)	100,000	ROUND TRIP EFFICIENCY	1.32
SYSTEM SIZE (KWE)	20,000		

AUXILARY ELECTRICITY CONSUMPTION (KWH/YR)	0
AUXILARY FOSSIL FUEL CONSUMPTION (MBTU/YR)	77900

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	0 (\$/KWH)
BATTERY INSTALLATION	0 (\$/KWH)
ENERGY RELATED COSTS	11.6 (\$/KWH)
POWER RELATED COSTS	726 (\$/KWE)
NET SALVAGE VALUE	0 (\$/KWH)

-----OPERATING AND MAINTENANCE COST INPUTS-----

COST OF ELECTRICITY, \$/KWH	0.025	ANNUAL O&M COST, \$	77900
COST OF FOSSIL FUEL, \$/MBTU	2.36		

*****EQUAL INTERVAL PERIODIC O&M*****

PERIODIC MAINTENANCE INTERVAL	1 (YEARS)
PERIODIC MAINTENANCE COST	0 (\$)

*****VARIED INTERVAL PERIODIC O&M*****

YEAR	COST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.042
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	30	TAX CREDIT	0.000
CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	PLANT TAX LIFE	20
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0.056		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR PLANT	0.485
DEPRECIATION FACTOR FOR BATTERIES	0.851
CAPITAL RECOVERY FACTOR	0.059242
FIXED CHARGE RATE FOR PLANT	0.097929
FIXED CHARGE RATE FOR BATTERIES	0.084658

OVERNIGHT CONSTRUCTION COST	15680000
1st YEAR OPERATING & MAINT. COST	77,900
1st YEAR EFFICIENCY ELECTRICITY COST(200,000)	
1st YEAR STORED ELECTRICITY COST	825000
1st YEAR AUXILARY ELECTRICITY COST	0
1st YEAR AUXILARY FOSSIL FUEL COST	269213.5

ANNUAL ENERGY GENERATED (KWH)	25000000
ANNUAL ENERGY GENERATED (KWH)	33000000

PRESENT VALUE OF INITIAL CAPITAL	15680000
PRESENT VALUE OF NET REPLACEMENT CAPITAL	0
PRESENT VALUE OF ANNUAL O&M	1314932.
PRESENT VALUE OF PERIODIC O&M	0
PRESENT VALUE OF EFFICIENCY LOSS ENERGY	-3375949
PRESENT VALUE OF STORED ENERGY	13925792
PRESENT VALUE OF AUXILARY ELECTRIC ENERGY	0
PRESENT VALUE OF AUXILARY FOSSIL FUEL ENERGY	9998918.
PRESENT VALUE OF FINAL SALVAGE	0

-----SUMMARY RESULTS-----

COMPONENT LIFE-CYCLE COST CONTRIBUTORS

INITIAL BATTERY COST	0
BALANCE-OF-PLANT	47
REPLACEMENTS	0
OPERATING AND MAINTENANCE	2
ENERGY	37
SALVAGE	0
TOTAL	86 MILLS/KWH

TOTAL PRESENT WORTH	37543694
TOTAL ANNUALIZED COST	2830799.
LEVELIZED STORAGE COST	0.085782 \$/KWH OF ENERGY GENERATED

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SALT MEDIA COMPRESSED AIR ENERGY STORAGE: HIGH WORLD OIL PRICE

BATTERY STORAGE ECONOMIC ANALYSIS MODEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	CAES(Salt)	CYCLE LIFE (#)	8000
APPLICATION	Utility	CYCLES/YEAR	250
SYSTEM SIZE (KWH)	100,000	ROUND TRIP EFFICIENCY	1.32
SYSTEM SIZE (KWE)	20,000		
AUXILIARY ELECTRICITY CONSUMPTION (KWH/YR)		0	
AUXILIARY FOSSIL FUEL CONSUMPTION (MBTU/YR)		77900	

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	0 (\$/KWH)
BATTERY INSTALLATION	0 (\$/KWH)
ENERGY RELATED COSTS	11.6 (\$/KWH)
POWER RELATED COSTS	726 (\$/KWE)
NET SALVAGE VALUE	0 (\$/KWH)

-----OPERATING AND MAINTENANCE COST INPUTS-----

COST OF ELECTRICITY, \$/KWH	0.025	ANNUAL O&M COST, \$	77900
COST OF FOSSIL FUEL, \$/MBTU	2.36		

*****EQUAL INTERVAL PERIODIC O&M*****

PERIODIC MAINTENANCE INTERVAL	1 (YEARS)
PERIODIC MAINTENANCE COST	0 (\$)

*****VARIED INTERVAL PERIODIC O&M*****

YEAR	COST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.042
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	30	TAX CREDIT	0.000
CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	PLANT TAX LIFE	20
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0.063		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR PLANT	0.485
DEPRECIATION FACTOR FOR BATTERIES	0.851
CAPITAL RECOVERY FACTOR	0.059242
FIXED CHARGE RATE FOR PLANT	0.097929
FIXED CHARGE RATE FOR BATTERIES	0.084658

OVERNIGHT CONSTRUCTION COST	15680000
1st YEAR OPERATING & MAINT. COST	77,900
1st YEAR EFFICIENCY ELECTRICITY COST(200,000)	
1st YEAR STORED ELECTRICITY COST	825000
1st YEAR AUXILARY ELECTRICITY COST	0
1st YEAR AUXILARY FOSSIL FUEL COST	281956.6

ANNUAL ENERGY GENERATED (KWH)	25000000
ANNUAL ENERGY GENERATED (KWH)	33000000

PRESENT VALUE OF INITIAL CAPITAL	15680000
PRESENT VALUE OF NET REPLACEMENT CAPITAL	0
PRESENT VALUE OF ANNUAL O&M	1314932.
PRESENT VALUE OF PERIODIC O&M	0
PRESENT VALUE OF EFFICIENCY LOSS ENERGY	-3375949
PRESENT VALUE OF STORED ENERGY	13925792
PRESENT VALUE OF AUXILARY ELECTRIC ENERGY	0
PRESENT VALUE OF AUXILARY FOSSIL FUEL ENERGY	11697067
PRESENT VALUE OF FINAL SALVAGE	0

-----SUMMARY RESULTS-----

COMPONENT LIFE-CYCLE COST CONTRIBUTORS

INITIAL BATTERY COST	0
BALANCE-OF-PLANT	47
REPLACEMENTS	0
OPERATING AND MAINTENANCE	2
ENERGY	40
SALVAGE	0
TOTAL	89 MILLS/KWH

TOTAL PRESENT WORTH	39241843
TOTAL ANNUALIZED COST	2931401.

LEVELIZED STORAGE COST	0.088830 \$/KWH OF ENERGY GENERATED
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CONVENTIONAL PUMPED HYDRO STORAGE: NOMINAL ESTIMATE

BATTERY STORAGE ECONOMIC ANALYSIS MODEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	Pumped-Hydro	CYCLE LIFE (#)	8000
APPLICATION	Utility	CYCLES/YEAR	250
SYSTEM SIZE (KWH)	100,000	ROUND TRIP EFFICIENCY	0.735
SYSTEM SIZE (KWE)	20,000		

AUXILARY ELECTRICITY CONSUMPTION (KWH/YR)	0
AUXILARY FOSSIL FUEL CONSUMPTION (MBTU/YR)	0

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	0 (\$/KWH)
BATTERY INSTALLATION	0 (\$/KWH)
ENERGY RELATED BOS	15.7 (\$/KWH)
POWER RELATED BOS	990 (\$/KWE)
NET SALVAGE VALUE	0 (\$/KWH)

-----OPERATING AND MAINTENANCE COST INPUTS-----

COST OF ELECTRICITY, \$/KWH	0.025	ANNUAL O&M COST, \$	169400
COST OF FOSSIL FUEL, \$/MBTU	0		

*****EQUAL INTERVAL PERIODIC O&M*****

PERIODIC MAINTENANCE INTERVAL	1 (YEARS)
PERIODIC MAINTENANCE COST	0 (\$)

*****VARIED INTERVAL PERIODIC O&M*****

YEAR	COST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.042
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	30	TAX CREDIT	0.000
CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	PLANT TAX LIFE	20
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR PLANT	0.485
DEPRECIATION FACTOR FOR BATTERIES	0.851
CAPITAL RECOVERY FACTOR	0.059242
FIXED CHARGE RATE FOR PLANT	0.097929
FIXED CHARGE RATE FOR BATTERIES	0.084658

OVERNIGHT CONSTRUCTION COST	21370000
1st YEAR OPERATING & MAINT. COST	169,400
1st YEAR EFFICIENCY ELECTRICITY COST	165,625
1st YEAR STORED ELECTRICITY COST	459375
1st YEAR AUXILARY ELECTRICITY COST	0
1st YEAR AUXILARY FOSSIL FUEL COST	0

ANNUAL ENERGY STORED (KWH)	25000000
ANNUAL ENERGY RETRIEVED (KWH)	18375000

PRESENT VALUE OF INITIAL CAPITAL	21370000
PRESENT VALUE OF NET REPLACEMENT CAPITAL	0
PRESENT VALUE OF ANNUAL O&M	2859429.
PRESENT VALUE OF PERIODIC O&M	0
PRESENT VALUE OF EFFICIENCY LOSS ENERGY	2795708.
PRESENT VALUE OF STORED ENERGY	7754134.
PRESENT VALUE OF AUXILARY ELECTRIC ENERGY	0
PRESENT VALUE OF AUXILARY FOSSIL FUEL ENERGY	0
PRESENT VALUE OF FINAL SALVAGE	0

-----SUMMARY RESULTS-----

COMPONENT LIFE-CYCLE COST CONTRIBUTORS

INITIAL BATTERY COST	0
BALANCE-OF-PLANT	114
REPLACEMENTS	0
OPERATING AND MAINTENANCE	9
ENERGY	34
SALVAGE	0
TOTAL	157 MILLS/KWH

TOTAL PRESENT WORTH	34779272
TOTAL ANNUALIZED COST	2887157.
LEVELIZED STORAGE COST	0.157124 \$/KWH OF ENERGY RETRIEVED

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APPENDIX D

NORMALIZATION GUIDELINES FOR STAND-ALONE SYSTEMS

APPENDIX D

NORMALIZATION GUIDELINES FOR STAND-ALONE SYSTEMS

Normalization of the stand-alone battery system cost estimates was accomplished using much of the same procedure as was used for the load-leveling systems. The battery costs were normalized to the 1984 George guidelines using the methodology discussed in Appendix A. After adjustment to the 1984 guidelines, the cost estimates were escalated to mid-1988\$ using GNP Implicit Price Deflators.

The balance-of-plant (BOP) for the stand-alone systems would not be subject to all the cost savings from construction efficiency improvements and quantity discounts that large load-leveling systems would. Stand-alone systems represent a small purchase from major manufacturers and/or distributors, which reduces the purchaser's ability to command discounts. Also, installers would incur a larger percentage of fixed costs than in installation of a load-leveling system. These higher fixed costs would be passed along to the consumer. The final BOP estimates were determined by identifying the necessary components associated with the BOP and reviewing source documents to determine their estimated cost. All estimates were adjusted to mid-1988\$ using GNP Implicit Price Deflators.

APPENDIX E

DETAILS OF THE NORMALIZATION PROCESS FOR STAND-ALONE SYSTEMS

APPENDIX E

DETAILS OF THE NORMALIZATION PROCESS FOR STAND-ALONE SYSTEMS

This Appendix presents the evaluation and normalization process used on each data source at a calculational level-of-detail. A section is included for each stand-alone technology evaluated. Sections are divided into a series of subsections each of which addresses one system component (e.g., energy-related BOP, battery purchase cost, etc.). Each page within a subsection is dedicated to discussing the data evaluation and normalization process from one source. Combination of data from each source into nominal and range cost estimates is discussed in the main text.

Since the main table of contents presents the title and location of this appendix, only the following outline should aid in the location of pertinent section and subsections within this appendix.

<u>Section/subsection Title</u>	<u>Number</u>	<u>Page</u>
Sealed Lead-Acid Battery	E.1	E.3
Battery Purchase Cost	E.1.1	E.3
Shipping and Installation Cost	E.1.2	E.4
Energy-Related Balance-of-Plant Cost	E.1.3	E.5
Power-Related Balance-of-Plant Cost	E.1.4	E.8
Net Salvage Value	E.1.5	E.9
Operating and Maintenance Cost	E.1.6	E.9
Hydrogen-Nickel Oxide Battery(a)	E.2	E.11
Battery Purchase Cost	E.2.1	E.11
Net Salvage Value	E.2.2	E.12
Zinc-Ferricyanide Battery(a)	E.3	E.13
Battery Purchase Cost	E.3.1	E.13
Energy-Related Balance-of-Plant Cost	E.3.2	E.16
Comparison Technology	E.4	E.21
Diesel-Electric Generator	E.4.1	E.21

(a) Availability of data does not warrant a third level of detail for this technology. Refer to main text for applicable information.

E.1 SEALED LEAD-ACID BATTERY

E.1.1 Battery Purchase Cost

SOURCE: Bechtel (1980)

Bechtel suggests the use of a deep-cycle renewable energy cell, such as those produced by Exide. Detailed estimates using the George guidelines were not prepared by Bechtel, because versions of these cells are currently available. For an 11-hour discharge scenario, Bechtel estimated the F.O.B. battery cost as \$125-193/kWh (1980\$) based on a lead price of 35 cents per pound. Bechtel estimated that a one-cent change in lead price would change the battery cell price by roughly \$1/kWh. On this basis, the F.O.B. battery cost was reduced to \$110/kWh-178/kWh (1980\$) to reflect the 20 cents per pound lead price that is a ground rule for this study. After escalating, a battery cost of \$155 to \$250/kWh (1988\$) results.

E.1.2 Shipping and Installation Cost

SOURCE: Bechtel (1982)

Bechtel prepared cost estimates for two systems with less than one MWh-of-capacity. These systems include a 642-kWh, 72-kW multiple residence application and a 16.1-kWh, 8-kW single residence application. Also evaluated was a larger 2.01 MWh, 315-kW system for a high school application.

Shipping

The battery shipping costs projected by Bechtel for the 2.01-MWh, 642-kWh, and 16.1-kWh systems are \$7.54/kWh, \$6.87/kWh, \$26/kWh (1980\$), respectively. Escalating these cost estimates to mid-1988\$ using GNP implicit price deflators yields shipping costs of \$10.6/kWh, \$9.7/kWh, and \$36.6/kWh, respectively.

Installation

Bechtel estimated the installation costs for systems rated at 2.01-MWh, 642-kWh and 16.1-kWh. These estimates are presented in Table E.1. Using GNP implicit price deflators, the estimates were escalated to 1988\$, as shown in Table E.2.

TABLE E.1. Installation Cost Estimates (1980\$)

<u>System Size</u>	<u>Directs</u>	<u>Indirects</u>	<u>Total</u>	<u>Unit Cost</u>
2.01 MWh	\$27,720	\$15,246	\$42,966	\$21.38/kWh
642 kWh	8,320	4,576	12,896	\$20.09/kWh
16.1 kWh	4,450	2,893	7,343	\$456/kWh

TABLE E.2. Normalized Installation Cost Estimates

<u>System Size</u>	<u>Unit Cost (1980\$)</u>	<u>Unit Cost (1988\$)</u>
2.01 MWh	21.38/kWh	30/kWh
642 kWh	20.09/kWh	28/kWh
16.1 kWh	456/kWh	641/kWh

E.1.3 Energy-Related Balance-of-Plant Cost

SOURCE: Bechtel (1982)

Three estimates of energy-related balance-of-plants (BOPs) from this source were reviewed. These estimates included BOPs for 2.01-MWh, 315-kW; 643-kWh, 72-kWh; and 16.1-kWh, 8-kW systems. The three unadjusted cost estimates in 1980\$ are presented in Table E.3 through E.5. Table E.6 presents these cost estimates summarized in 1980 dollars, mid-1988 dollars, and dollars per kilowatt-hour.

TABLE E.3. 2.01-MWh Sealed Lead-Acid Battery System Energy-Related Balance-of-Plant Estimate (1980\$)

	<u>Labor</u>	<u>Material</u>	<u>Subtotal</u>
<u>Building</u>			
Building	--	--	\$45,900
Structural	\$9,285	\$3,440	12,725
<u>Thermal Management</u>			
Heat Rejection	\$1,116	\$9,330	\$10,446
Piping, Pumps, Valves	2,170	3,520	5,690
Other	1,116	1,120	2,236
<u>Instrumentation</u>			
Fire Detection	\$ 279	\$ 130	\$ 409
<u>Electrical</u>			
DC Wiring	\$2,232	\$9,400	\$11,632
DC Equipment	775	9,160	9,935
AC Wiring	6,495	1,740	8,235
AC Panel Requirements	388	250	638
Lighting	3,178	1,180	4,358
Other	217	720	937
<u>Auxiliaries</u>			
Plumbing Support Trays	<u>\$1,783</u>	<u>\$1,050</u>	<u>\$2,833</u>
Subtotal BOP			\$115,974
Energy-Related BOP Contingency @ 20%			23,195
Engineering @ 15%			17,396
Engineering Contingency @ 20%			3,479
Engineering-Related BOP			20,875
Other BOP			<u>139,169</u>
			\$160,044

**TABLE E.4. 643-kWh Sealed Lead-Acid Battery System Energy-Related
Balance-of-Plant Estimate (1980\$)**

	<u>Labor</u>	<u>Material</u>	<u>Subtotal</u>
<u>Building</u>			
Building	--	--	\$19,200
Structural	\$7,177	\$2,800	\$10,057
<u>Thermal Management</u>			
Heat Rejection	\$ 698	\$ 800	\$ 1,498
<u>Instrumentation</u>			
Fire Detection	\$ 279	\$ 130	\$ 409
Other	419	230	649
<u>Electrical</u>			
DC Wiring	\$ 977	\$2,800	\$3,777
DC Equipment	389	2,580	2,969
AC Wiring	5,084	1,340	6,424
AC Panel Requirements	389	250	639
Lighting	1,705	640	2,345
Other	31	80	<u>111</u>
Subtotal BOP			\$48,078
Energy-Related BOP Contingency @ 20%			9,616
Engineering @ 15%			7,212
Engineering Contingency @ 20%			1,442
Engineering-Related BOP			8,654
Other BOP			<u>57,694</u>
			\$66,348

TABLE E.5. 16.1-kWh Sealed Lead-Acid Battery System Energy-Related Balance-of-Plant Estimate (1980\$)

	<u>Labor</u>	<u>Material</u>	<u>Subtotal</u>
<u>Building</u>			
Building	--	--	\$2,450
Structural	\$1,700	\$860	\$2,560
<u>Thermal Management</u>			
Heat Rejection	\$ 594	\$ 500	\$1,094
<u>Electrical</u>			
DC Wiring	\$ 33	\$ 10	\$ 43
DC Equipment	264	600	864
AC Wiring	776	190	966
AC Panel Requirements	149	30	179
Lighting	297	100	397
Battery Voltage Penalty	--	--	460
Other	33	30	63
Subtotal BOP			\$9,076
Energy-Related BOP Contingency @ 20%			1,815
Engineering @ 15%			1,361
Engineering Contingency @ 20%			272
Engineering-Related BOP			1,633
Other BOP			<u>10,891</u>
			\$12,524

TABLE E.6. Sealed Lead-Acid Battery Balance-of-Plant

<u>System Size</u>	<u>1980\$</u>	<u>1988\$</u>	<u>\$/kWh (1988\$)</u>
2010-MWh	160,044	225,086	112
643-kWh	66,348	93,312	145
16.1-kWh	12,524	17,614	1,094

E.1.4 Power-Related Balance-of-Plant Cost

SOURCE: Bechtel (Stolte & Eckroad 1985)

This source presented two parametric curves from which estimates for a 50 kWh converter of advanced designs were extrapolated. Table E.7 presents the time-adjusted estimates generated with the curves. These estimates are only for the power conditioner. The remaining components of the power-related BOP could not be separated from the total BOP cost estimates presented in the source.

TABLE E.7. Normalized Power Conditioner Costs

	<u>1982\$</u>	<u>1988\$</u>
Conservative Advanced Technology	400/kW	\$484/kW
Nominal Advanced Technology	300/kW	\$363/kW

E.1.5 Net Salvage Value

SOURCE: Bechtel (1982)

The salvage scenario taken from this source presumed a scrap credit for the batteries ranging from 6 to 17%. Battery removal was assumed to be 60% of installation, with shipping to the scrap facility negligible.

E.1.6 Operating and Maintenance Cost

SOURCE: Gould, Inc. (Ramsay and Edgecomb 1982)

Size: 50-kWh, 10-kW

Scheduled Maintenance: 1 manhour/month

Unscheduled Maintenance: 8 manhours/yr

This estimate is based on a 2-1/2% cell failure rate and individual cell replacement requiring 4 manhours. Assuming a \$50/hr fully-burdened labor rate (1988\$), maintenance would cost \$1000 per year exclusive of materials, which should be minor. This results in an annual maintenance cost estimate of \$20/kWh-of-capacity.

SOURCE: Bechtel (1982)

This cost estimate is for a conventional calcium-plate lead-acid battery and would therefore be expected to be slightly higher than a corresponding cost estimate for a sealed lead-acid battery.

Size: 16.1-kWh, 8-kW

Annual Maintenance: \$4.00-4.80/kWh-of-capacity (1980\$)

Infrequent (yr 10): \$32.50-39.00/kWh-of-capacity (1980\$)

This estimate is based on 1 manhour/year, plus ventilation fan replacement at year ten. The 1 manhour annual estimate is based on a manufacturer's recommendation.

E.2 HYDROGEN-NICKEL OXIDE BATTERY

E.2.1 Battery Purchase Cost

SOURCE: Sindorf et al. (1985)

This source based its estimates on hydrogen-nickel oxide technology as it existed on May 1986. Estimated costs for a 15-kWh battery system are presented for three production levels in Table E.8.

The long-term cost goal was defined as \$375/kWh (1984\$) (\$400/kWh, 1988\$). The highest production level presented, 1024, is based on production being assembly-limited.

TABLE E.8. Hydrogen-Nickel Oxide Battery Cost:
Cost Versus Production Level

<u>Units per Year</u>	<u>Cost per kWh (1984\$)</u>	<u>Cost per kWh (1988\$)</u>
1	5900	95
72	1451	1548
270	1022	1090
1024	930	992

E.2.2 Net Salvage Value

SOURCE: Sindorf et al. (1985)

While this source makes no explicit mention of salvage value, there is a breakdown of initial material and fabrication costs for the battery at a production level of 72 units per year. The nickel electrode materials, which are anticipated to be the main recoverable component, are estimated to cost \$263 of the initial cell cost of \$3650 (1984\$). This represents 7% of the initial capital cost.

E.3 ZINC-FERRICYANIDE BATTERY

E.3.1 Battery Purchase Cost

SOURCE: Hollandsworth et al. 1987.

This source presents an estimate of a 56-kWh, 1-kW (average discharge) zinc-REDOX battery system. Peak discharge power is 5-kW. Complete BOP installation and operating costs were not assessed in this source.

To normalize the source estimate, battery costs were divided into two cost categories: energy-related and power-related. Consistent with the approach used by Bechtel (1982) for the development of an iron-chromium REDOX cost estimate, pumps, power stacks, plumbing, and related items were classified as power-related. Electrolyte, tanks, and related items are classified as energy-related. Table E.9 presents the source estimate divided in power and energy-related categories.

As shown in Table E.9, power-related costs are \$1269.61 or \$254/peak-kW and energy-related costs are \$809.52 or \$14.5/kWh. Using these unit costs, the materials cost for a 50-kWh, 10-kW battery is \$3,265.

Calculation of the F.O.B. battery cost as presented in the source document and the corresponding adjustments made to the source estimate are shown in Table E.10.

TABLE E.9. Zinc-REDOX Cost Estimate Based on Symons (1985\$)

<u>Item</u>	<u>Cost (\$)</u>
<u>Power-Related Components</u>	
Positive End Block	7.93
Positive Terminals	20.00
End Current Collector	13.46
Positive Current Collector	5.25
Positive Electrode	155.05
Positive Frame	33.04
Membrane	310.10
Membrane Frame	19.82
Negative Cavity Spacer	70.48
Negative Electrode	15.25
Negative Frame	52.86
Bipolar Partition	76.23
Negative Current Collector	13.46
Negative Terminals	22.00
Negative End Block	7.93
Shunt Protection	20.00
Stack Hardware	10.00
Stack Case	0.00
Stack Subtotal	862.84
Positive Pump	62.00
Positive Sump	20.00
Negative Pump	62.00
Plumbing	10.00
Filter	33.68
Pump P3	52.40
Wiped Heat Exchanger	111.09
Piping	55.60
Total	1269.61
<u>Energy-Related Components</u>	
Negative Tank	57.68
Ferricyanide Tank	168.42
Valves	15.00
Air Fan	50.00
Controls	50.00
Recombiner	50.00
Sodium Ferricyanide	249.73
Zinc Oxide	41.99
Solutions	26.70
Hardware	100.00
Total	809.52
Grand Total	2,079.13

TABLE E.10. Normalized Zinc-REDOX Cost Estimate

<u>Cost Element</u>	<u>56-kWh, 1-kW Symons (1985\$/Battery)</u>	<u>Adjustment</u>	<u>50-kWh, 10-kW Normalized Symons (1983\$/kWh)</u>
Materials	2709.12	(a)	62.13
Purchased Components	--		
Materials and Components			
Ovhd @ 10%	170.91	recalculate	6.21
Direct Labor	268.94	(b)	48.00
Direct Labor Ovhd @ 150%	403.42	recalculate	72.00
Equipment Depreciation	112.06	(c)	21.00
Tooling Depreciation	18.68	--	
Rent	<u>33.62</u>		<u>6.00</u>
	3123.74		215.34
ROI and Taxes (30%)	634.13	recalculate	82.40
Indirects	<u>280.15</u>	(d)	<u>6.00</u>
	4038.02		303.72
Uninstalled F.O.B. cost		esc. to mid 1988\$	\$349.26/kWh

- (a) Adjusted to reflect a 50-kWh, 10-kW system, changed to a \$/kWh-basis, and de-escalated to 1983\$.
- (b) Adjusted from a \$12/hr labor rate to a \$13/hr labor rate and changed to a \$/kWh-basis.
- (c) The source estimate itemized tooling separately. Although this is probably a more accurate accounting method, it is inconsistent with other estimates. Therefore, equipment depreciation was placed in one 10-year category.
- (d) Adjusted to 1984 George guidelines.

E.3.2 Energy Related Balance-of-Plant Cost

SOURCE: Bechtel (1982)

Four estimates of energy-related BOPs from this source were reviewed. These estimates are system sizes of 2000-kWh, 314-kW; 640-kWh, 73-kW; 395-kWh, 32.4-kW; and 160-kWh, 8.1-kW. The four unadjusted estimates in 1980 dollars are presented in Tables E.11 through E.14. Although the estimates were originally developed for an iron-chromium REDOX battery system, the BOP requirements for a zinc-REDOX system appear relatively equal.

TABLE E.11. 2000-kWh REDOX Energy-Related Balance-of-Plant Cost Estimate

	<u>Labor</u>	<u>Material</u>	<u>Subtotal</u>
<u>Building</u>			
Land	--	--	\$ 3,000
Building	--	--	40,800
Structural	11,377	3,400	14,777
Other	1,116	1,400	2,516
<u>Thermal Management</u>			
Heat Rejection	\$2,232	\$14,000	\$16,232
Other	109	60	169
<u>Instrumentation</u>			
Fire Detection	279	130	409
<u>Electrical</u>			
DC Wiring	1,783	10,000	11,783
DC Equipment	558	7,120	7,678
AC Wiring	4,077	1,120	5,197
AC Panel Requirements	837	600	1,437
Lighting	2,093	980	3,073
Other	<u>62</u>	<u>250</u>	<u>312</u>
Subtotal BOP			\$104,383
Energy-Related BOP Contingency @ 20%			20,877
Engineering-Related BOP @ 15%			15,657
Engineering Contingency @ 20%			3,131
Engineering-Related BOP			18,788
Other BOP			<u>125,260</u>
			\$144,048

TABLE E.12. 640-kWh REDOX Energy-Related Balance-of-Plant Cost Estimate

	<u>Labor</u>	<u>Material</u>	<u>Subtotal</u>
<u>Building</u>			
Building	--	--	12,000
Structural	\$7,177	\$2,600	9,777
Other	837	1,050	1,887
<u>Thermal Management</u>			
Heat Rejection	\$2,232	\$8,000	\$10,232
Other	62	20	82
<u>Instrumentation</u>			
Fire Detection	279	130	409
Other	419	230	649
<u>Electrical</u>			
DC Wiring	341	300	641
DC Equipment	341	1,200	1,541
AC Wiring	1,674	460	2,134
AC Panel Requirements	837	580	1,417
Lighting	1,039	440	1,479
Other	<u>31</u>	<u>60</u>	<u>91</u>
Subtotal BOP			\$42,339
Energy-Related BOP Contingency @ 20%			8,468
Engineering @ 15%			6,351
Engineering Contingency @ 20%			1,271
Engineering-Related BOP			7,621
Other BOP			<u>50,807</u>
			\$ 58,428

TABLE E.13. 395-kWh REDOX Energy-Related Balance-of-Plant Cost Estimate

	<u>Labor</u>	<u>Material</u>	<u>Subtotal</u>
<u>Building</u>			
Building	--	--	8,400
Structural	5,410	2,280	7,690
Other	558	700	1,258
<u>Thermal Management</u>			
Heat Rejection	\$1,116	\$4,000	\$ 5,116
Other	31	10	41
<u>Instrumentation</u>			
Fire Detection	279	130	409
Other	419	230	649
<u>Electrical</u>			
DC Wiring	109	100	209
DC Equipment	341	1,500	1,841
AC Wiring	868	320	1,188
AC Panel Requirements	698	500	1,198
Lighting	977	410	1,387
Dther	<u>31</u>	<u>60</u>	<u>91</u>
Subtotal BOP			\$29,477
Energy-Related BOP Contingency @ 20%			5,895
Engineering @ 15%			4,422
Engineering Contingency @ 20%			884
Engineering-Related BOP			5,306
Other BOP			<u>35,372</u>
			\$40,678

TABLE E.14. 160-kWh REDOX Energy-Related Balance-of-Plant Cost Estimate

	<u>Labor</u>	<u>Material</u>	<u>Subtotal</u>
<u>Building</u>			
Structural	\$ 363	\$ 630	993
Other	594	700	1,294
<u>Electrical</u>			
DC Wiring	\$ 479	\$ 50	\$ 529
DC Equipment	215	900	1,115
AC Wiring	528	130	658
AC Panel Requirements	594	400	994
Other	<u>33</u>	<u>50</u>	<u>83</u>
Subtotal BOP			\$5,666
Energy-Related BOP Contingency 20%			1,133
Engineering @ 15%			850
Engineering Contingency @ 20%			227
Engineering-Related BOP			1,077
Other BOP			<u>6,799</u>
			\$7,876

E.4 COMPARISON TECHNOLOGY

E.4.1 Diesel-Electric Generator

SOURCE: Power Generation in Remote Location Conference 1987(a)

The cost of diesel-electric was identified as \$300/kW, with a fuel cost 15 - 30 cents/kWh.

SOURCE: Rotgans (1987)

This source related experience with 0.5-kW continuously operating mini-diesel. Life expectancy was rated at one year. No operating cost data were given.

(a) Personal communication with moderator, October 1987.

APPENDIX F

LIFE-CYCLE COST CALCULATIONS FOR THE STAND-ALONE APPLICATION

APPENDIX F

LIFE-CYCLE COST CALCULATIONS FOR THE STAND-ALONE APPLICATION

This Appendix presents a summary of the pertinent input and output to the life-cycle cost calculations presented in the main text. They would prove most useful for identifying what specific components drive total cost. The following table should provide a guide to locating information in this Appendix.

<u>Technology</u>	<u>Page</u>
Sealed Lead-Acid Battery System	F.3
Hydrogen Nickel-Oxide Battery System	F.9
Zinc-Ferricyanide Battery System	F.15
Diesel-Electric Generating System	F.17

SEALED LEAD-ACID BATTERY SYSTEM: LOW ESTIMATE

BATTERY STORAGE ECONOMIC ANALYSIS MODEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	Sealed Lead-Acid	CYCLE LIFE (#)	1500
APPLICATION	Stand-Alone	CYCLES/YEAR	250
SYSTEM SIZE (KWH)	50	ROUND TRIP EFFICIENCY	0.66
SYSTEM SIZE (KWE)	10		

AUXILARY ELECTRICITY CONSUMPTION (KWH/YR)	0
AUXILARY FOSSIL FUEL CONSUMPTION (MBTU/YR)	0

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	155 (\$/KWH)
BATTERY INSTALLATION	248 (\$/KWH)
ENERGY RELATED BOS	512 (\$/KWH)
POWER RELATED BOS	519 (\$/KWE)
NET SALVAGE VALUE	12 (\$/KWH)

-----OPERATING AND MAINTENANCE COST INPUTS-----

COST OF ELECTRICITY, \$/KWH	0.200	ANNUAL O&M COST, \$	280
COST OF FOSSIL FUEL, \$/MBTU	0		

*****EQUAL INTERVAL PERIODIC O&M*****

PERIODIC MAINTENANCE INTERVAL	1 (YEARS)
PERIODIC MAINTENANCE COST	0 (\$)

*****VARIED INTERVAL PERIODIC O&M*****

YEAR	COST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.060
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	20	TAX CREDIT	0.000
CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	PLANT TAX LIFE	20
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR PLANT	0.440
DEPRECIATION FACTOR FOR BATTERIES	0.829
CAPITAL RECOVERY FACTOR	0.087184
FIXED CHARGE RATE FOR PLANT	0.137091
FIXED CHARGE RATE FOR BATTERIES	0.116328

OVERNIGHT CONSTRUCTION COST	50940
1st YEAR OPERATING & MAINT. COST	280
1st YEAR EFFICIENCY ELECTRICITY COST	850
1st YEAR STORED ELECTRICITY COST	1650
1st YEAR AUXILARY ELECTRICITY COST	0
1st YEAR AUXILARY FOSSIL FUEL COST	0

ANNUAL ENERGY STORED (KWH)	12500
ANNUAL ENERGY RETRIEVED (KWH)	8250

PRESENT VALUE OF INITIAL CAPITAL	50940
PRESENT VALUE OF NET REPLACEMENT CAPITAL	30346.95
PRESENT VALUE OF ANNUAL O&M	3211.577
PRESENT VALUE OF PERIODIC O&M	0
PRESENT VALUE OF EFFICIENCY LOSS ENERGY	9749.433
PRESENT VALUE OF STORED ENERGY	18925.37
PRESENT VALUE OF AUXILARY ELECTRIC ENERGY	0
PRESENT VALUE OF AUXILARY FOSSIL FUEL ENERGY	0
PRESENT VALUE OF FINAL SALVAGE	-176.493

-----SUMMARY RESULTS-----

COMPONENT LIFE-CYCLE COST CONTRIBUTORS

INITIAL BATTERY COST	284
BALANCE-OF-PLANT	512
REPLACEMENTS	428
OPERATING AND MAINTENANCE	34
ENERGY	303
SALVAGE	-2
TOTAL	1558 MILLS/KWH

TOTAL PRESENT WORTH	112996.8
TOTAL ANNUALIZED COST	12854.75

LEVELIZED STORAGE COST	1.558152 \$/KWH OF ENERGY RETRIEVED
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SEALED LEAD-ACID BATTERY SYSTEM: NOMINAL ESTIMATE

BATTERY STORAGE ECONOMIC ANALYSIS MODEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	Sealed Lead-Acid	CYCLE LIFE (#)	1500
APPLICATION	Stand-Alone	CYCLES/YEAR	250
SYSTEM SIZE (KWH)	50	ROUND-TRIP EFFICIENCY	0.66
SYSTEM SIZE (KWE)	10		
AUXILARY ELECTRICITY CONSUMPTION (KWH/YR)		0	
AUXILARY FOSSIL FUEL CONSUMPTION (MBTU/YR)		0	

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	203 (\$/KWH)
BATTERY INSTALLATION	287 (\$/KWH)
ENERGY RELATED BOS	602 (\$/KWH)
POWER RELATED BOS	640 (\$/KWE)
NET SALVAGE VALUE	9 (\$/KWH)

-----OPERATING AND MAINTENANCE COST INPUTS-----

COST OF ELECTRICITY, \$/KWH	0.200	ANNUAL O&M COST, \$	640
COST OF FOSSIL FUEL, \$/MBTU	0		

*****EQUAL INTERVAL PERIODIC O&M*****

PERIODIC MAINTENANCE INTERVAL	1 (YEARS)
PERIODIC MAINTENANCE COST	0 (\$)

*****VARIED INTERVAL PERIODIC O&M*****

YEAR	COST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.060
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	20	TAX CREDIT	0.000
CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	PLANT TAX LIFE	20
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR PLANT	0.440
DEPRECIATION FACTOR FOR BATTERIES	0.829
CAPITAL RECOVERY FACTOR	0.087184
FIXED CHARGE RATE FOR PLANT	0.137091
FIXED CHARGE RATE FOR BATTERIES	0.116328

OVERNIGHT CONSTRUCTION COST	61000
1st YEAR OPERATING & MAINT. COST	640
1st YEAR EFFICIENCY ELECTRICITY COST	850
1st YEAR STORED ELECTRICITY COST	1650
1st YEAR AUXILARY ELECTRICITY COST	0
1st YEAR AUXILARY FOSSIL FUEL COST	0

ANNUAL ENERGY STORED (KWH)	12500
ANNUAL ENERGY RETRIEVED (KWH)	8250

PRESENT VALUE OF INITIAL CAPITAL	61000
PRESENT VALUE OF NET REPLACEMENT CAPITAL	37332.18
PRESENT VALUE OF ANNUAL O&M	7340.749
PRESENT VALUE OF PERIODIC O&M	0
PRESENT VALUE OF EFFICIENCY LOSS ENERGY	9749.433
PRESENT VALUE OF STORED ENERGY	18925.37
PRESENT VALUE OF AUXILARY ELECTRIC ENERGY	0
PRESENT VALUE OF AUXILARY FOSSIL FUEL ENERGY	0
PRESENT VALUE OF FINAL SALVAGE	-132.369

-----SUMMARY RESULTS-----

COMPONENT LIFE-CYCLE COST CONTRIBUTORS

INITIAL BATTERY COST	345
BALANCE-OF-PLANT	607
REPLACEMENTS	526
OPERATING AND MAINTENANCE	78
ENERGY	303
SALVAGE	-2
TOTAL	1857 MILLS/KWH

TOTAL PRESENT WORTH	134215.3
TOTAL ANNUALIZED COST	15321.29

LEVELIZED STORAGE COST	1.857127 \$/KWH OF ENERGY RETRIEVED
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SEALED LEAD-ACID BATTERY SYSTEM: HIGH ESTIMATE

BATTERY STORAGE ECONOMIC ANALYSIS MODEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	Sealed Lead-Acid	CYCLE LIFE (#)	1500
APPLICATION	Stand-Alone	CYCLES/YEAR	250
SYSTEM SIZE (KWH)	50	ROUND TRIP EFFICIENCY	0.66
SYSTEM SIZE (KWE)	10		
AUXILARY ELECTRICITY CONSUMPTION (KWH/YR)		0	
AUXILARY FOSSIL FUEL CONSUMPTION (MBTU/YR)		0	

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	250 (\$/KWH)
BATTERY INSTALLATION	313 (\$/KWH)
ENERGY RELATED BOS	662 (\$/KWH)
POWER RELATED BOS	761 (\$/KWE)
NET SALVAGE VALUE	1 (\$/KWH)

-----OPERATING AND MAINTENANCE COST INPUTS-----

COST OF ELECTRICITY, \$/KWH	0.200	ANNUAL O&M COST, \$	1000
COST OF FOSSIL FUEL, \$/MBTU	0		

*****EQUAL INTERVAL PERIODIC O&M*****

PERIODIC MAINTENANCE INTERVAL	1 (YEARS)
PERIODIC MAINTENANCE COST	0 (\$)

*****VARIED INTERVAL PERIODIC O&M*****

YEAR	COST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.060
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	20	TAX CREDIT	0.000
CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	PLANT TAX LIFE	20
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR PLANT	0.440
DEPRECIATION FACTOR FOR BATTERIES	0.829
CAPITAL RECOVERY FACTOR	0.087184
FIXED CHARGE RATE FOR PLANT	0.137091
FIXED CHARGE RATE FOR BATTERIES	0.116328

OVERNIGHT CONSTRUCTION COST	68860
1st YEAR OPERATING & MAINT. COST	1,000
1st YEAR EFFICIENCY ELECTRICITY COST	850
1st YEAR STORED ELECTRICITY COST	1650
1st YEAR AUXILARY ELECTRICITY COST	0
1st YEAR AUXILARY FOSSIL FUEL COST	0

ANNUAL ENERGY STORED (KWH)	12500
ANNUAL ENERGY RETRIEVED (KWH)	8250

PRESENT VALUE OF INITIAL CAPITAL	68860
PRESENT VALUE OF NET REPLACEMENT CAPITAL	43618.89
PRESENT VALUE OF ANNUAL D&M	11469.92
PRESENT VALUE OF PERIODIC O&M	0
PRESENT VALUE OF EFFICIENCY LOSS ENERGY	9749.433
PRESENT VALUE OF STORED ENERGY	18925.37
PRESENT VALUE OF AUXILARY ELECTRIC ENERGY	0
PRESENT VALUE OF AUXILARY FOSSIL FUEL ENERGY	0
PRESENT VALUE OF FINAL SALVAGE	-14.7077

-----SUMMARY RESULTS-----

COMPONENT LIFE-CYCLE COST CONTRIBUTORS

INITIAL BATTERY COST	397
BALANCE-OF-PLANT	676
REPLACEMENTS	615
OPERATING AND MAINTENANCE	121
ENERGY	303
SALVAGE	-0
 TOTAL	 2112 MILLS/KWH

TOTAL PRESENT WORTH	152608.9
TOTAL ANNUALIZED COST	17428.06

LEVELIZED STORAGE COST	2.112492 \$/KWH OF ENERGY RETRIEVED
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HYDROGEN NICKEL-OXIDE BATTERY SYSTEM: LOW ESTIMATE

BATTERY STORAGE ECONOMIC ANALYSIS MODEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	Nickel-Hydrogen	CYCLE LIFE (#)	6000
APPLICATION	Stand-Alone	CYCLES/YEAR	250
SYSTEM SIZE (KWH)	50	ROUND TRIP EFFICIENCY	0.75
SYSTEM SIZE (KWE)	10		
AUXILARY ELECTRICITY CONSUMPTION (KWH/YR)		0	
AUXILARY FOSSIL FUEL CONSUMPTION (MBTU/YR)		0	

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	400 (\$/KWH)
BATTERY INSTALLATION	248 (\$/KWH)
ENERGY RELATED BOS	512 (\$/KWH)
POWER RELATED BOS	519 (\$/KWE)
NET SALVAGE VALUE	34 (\$/KWH)

-----OPERATING AND MAINTENANCE COST INPUTS-----

COST OF ELECTRICITY, \$/KWH	0.200	ANNUAL O&M COST, \$	280
COST OF FOSSIL FUEL, \$/MBTU	0		

*****EQUAL INTERVAL PERIODIC O&M*****

PERIODIC MAINTENANCE INTERVAL	1 (YEARS)
PERIODIC MAINTENANCE COST	0 (\$)

*****VARIED INTERVAL PERIODIC O&M*****

YEAR	COST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.060
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	20	TAX CREDIT	0.000
CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	PLANT TAX LIFE	20
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR PLANT	0.440
DEPRECIATION FACTOR FOR BATTERIES	0.829
CAPITAL RECOVERY FACTOR	0.087184
FIXED CHARGE RATE FOR PLANT	0.137091
FIXED CHARGE RATE FOR BATTERIES	0.116328

OVERNIGHT CONSTRUCTION COST	63190
1st YEAR OPERATING & MAINT. COST	280
1st YEAR EFFICIENCY ELECTRICITY COST	625
1st YEAR STORED ELECTRICITY COST	1875
1st YEAR AUXILARY ELECTRICITY COST	0
1st YEAR AUXILARY FOSSIL FUEL COST	0

ANNUAL ENERGY STORED (KWH)	12500
ANNUAL ENERGY RETRIEVED (KWH)	9375

PRESENT VALUE OF INITIAL CAPITAL	63190
PRESENT VALUE OF NET REPLACEMENT CAPITAL	0
PRESENT VALUE OF ANNUAL O&M	3211.577
PRESENT VALUE OF PERIODIC O&M	0
PRESENT VALUE OF EFFICIENCY LOSS ENERGY	7168.700
PRESENT VALUE OF STORED ENERGY	21506.10
PRESENT VALUE OF AUXILARY ELECTRIC ENERGY	0
PRESENT VALUE OF AUXILARY FOSSIL FUEL ENERGY	0
PRESENT VALUE OF FINAL SALVAGE	-500.064

-----SUMMARY RESULTS-----

COMPONENT LIFE-CYCLE COST CONTRIBUTORS

INITIAL BATTERY COST	402
BALANCE-OF-PLANT	450
REPLACEMENTS	0
OPERATING AND MAINTENANCE	30
ENERGY	267
SALVAGE	-6
TOTAL	1143 MILLS/KWH

TOTAL PRESENT WORTH	94576.31
TOTAL ANNUALIZED COST	10711.92

LEVELIZED STORAGE COST	1.142605 \$/KWH OF ENERGY RETRIEVED
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HYDROGEN NICKEL-OXIDE BATTERY SYSTEM: NOMINAL ESTIMATE

BATTERY STORAGE ECONOMIC ANALYSIS MODEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	Nickel-Hydrogen	CYCLE LIFE (#)	6000
APPLICATION	Stand-Alone	CYCLES/YEAR	250
SYSTEM SIZE (KWH)	50	ROUND TRIP EFFICIENCY	0.75
SYSTEM SIZE (KWE)	10		
AUXILARY ELECTRICITY CONSUMPTION (KWH/YR)		0	
AUXILARY FOSSIL FUEL CONSUMPTION (MBTU/YR)		0	

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	989 (\$/KWH)
BATTERY INSTALLATION	287 (\$/KWH)
ENERGY RELATED BOS	602 (\$/KWH)
POWER RELATED BOS	640 (\$/KWE)
NET SALVAGE VALUE	56 (\$/KWH)

-----OPERATING AND MAINTENANCE COST INPUTS-----

COST OF ELECTRICITY, \$/KWH	0.200	ANNUAL O&M COST, \$	640
COST OF FOSSIL FUEL, \$/MBTU	0		

*****EQUAL INTERVAL PERIODIC O&M*****

PERIODIC MAINTENANCE INTERVAL	1 (YEARS)
PERIODIC MAINTENANCE COST	0 (\$)

*****VARIED INTERVAL PERIODIC O&M*****

YEAR	COST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.060
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	20	TAX CREDIT	0.000
CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	PLANT TAX LIFE	20
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR PLANT	0.440
DEPRECIATION FACTOR FOR BATTERIES	0.829
CAPITAL RECOVERY FACTOR	0.087184
FIXED CHARGE RATE FOR PLANT	0.137091
FIXED CHARGE RATE FOR BATTERIES	0.116328

OVERNIGHT CONSTRUCTION COST	100300
1st YEAR OPERATING & MAINT. COST	640
1st YEAR EFFICIENCY ELECTRICITY COST	625
1st YEAR STORED ELECTRICITY COST	1875
1st YEAR AUXILARY ELECTRICITY COST	0
1st YEAR AUXILARY FOSSIL FUEL COST	0

ANNUAL ENERGY STORED (KWH)	12500
ANNUAL ENERGY RETRIEVED (KWH)	9375

PRESENT VALUE OF INITIAL CAPITAL	100300
PRESENT VALUE OF NET REPLACEMENT CAPITAL	0
PRESENT VALUE OF ANNUAL O&M	7340.749
PRESENT VALUE OF PERIODIC O&M	0
PRESENT VALUE OF EFFICIENCY LOSS ENERGY	7168.700
PRESENT VALUE OF STORED ENERGY	21506.10
PRESENT VALUE OF AUXILARY ELECTRIC ENERGY	0
PRESENT VALUE OF AUXILARY FOSSIL FUEL ENERGY	0
PRESENT VALUE OF FINAL SALVAGE	-823.635

-----SUMMARY RESULTS-----

COMPONENT LIFE-CYCLE COST CONTRIBUTORS

INITIAL BATTERY COST	792
BALANCE-OF-PLANT	534
REPLACEMENTS	0
OPERATING AND MAINTENANCE	68
ENERGY	267
SALVAGE	-10
TOTAL	1650 MILLS/KWH

TOTAL PRESENT WORTH	135491.9
TOTAL ANNUALIZED COST	15469.79

LEVELIZED STORAGE COST	1.650111 \$/KWH OF ENERGY RETRIEVED
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HYDROGEN NICKEL-OXIDE BATTERY SYSTEM: HIGH ESTIMATE

BATTERY STORAGE ECONOMIC ANALYSIS MODEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	Nickel-Hydrogen	CYCLE LIFE (#)	6000
APPLICATION	Stand-Alone	CYCLES/YEAR	250
SYSTEM SIZE (KWH)	50	ROUND TRIP EFFICIENCY	0.75
SYSTEM SIZE (KWE)	10		
AUXILARY ELECTRICITY CONSUMPTION (KWH/YR)		0	
AUXILARY FOSSIL FUEL CONSUMPTION (MBTU/YR)		0	

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	989 (\$/KWH)
BATTERY INSTALLATION	313 (\$/KWH)
ENERGY RELATED BOS	662 (\$/KWH)
POWER RELATED BOS	761 (\$/KWE)
NET SALVAGE VALUE	56 (\$/KWH)

-----OPERATING AND MAINTENANCE COST INPUTS-----

COST OF ELECTRICITY, \$/KWH	0.200	ANNUAL O&M COST, \$	1000
COST OF FOSSIL FUEL, \$/MBTU	0		

*****EQUAL INTERVAL PERIODIC O&M*****

PERIODIC MAINTENANCE INTERVAL	1 (YEARS)
PERIODIC MAINTENANCE COST	0 (\$)

*****VARIED INTERVAL PERIODIC O&M*****

YEAR	COST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.060
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	20	TAX CREDIT	0.000
CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	PLANT TAX LIFE	20
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR PLANT	0.440
DEPRECIATION FACTOR FOR BATTERIES	0.829
CAPITAL RECOVERY FACTOR	0.087184
FIXED CHARGE RATE FOR PLANT	0.137091
FIXED CHARGE RATE FOR BATTERIES	0.116328

OVERNIGHT CONSTRUCTION COST	105810
1st YEAR OPERATING & MAINT. COST	1,000
1st YEAR EFFICIENCY ELECTRICITY COST	625
1st YEAR STORED ELECTRICITY COST	1875
1st YEAR AUXILARY ELECTRICITY COST	0
1st YEAR AUXILARY FOSSIL FUEL COST	0

ANNUAL ENERGY STORED (KWH)	12500
ANNUAL ENERGY RETRIEVED (KWH)	9375

PRESENT VALUE OF INITIAL CAPITAL	105810
PRESENT VALUE OF NET REPLACEMENT CAPITAL	0
PRESENT VALUE OF ANNUAL O&M	11469.92
PRESENT VALUE OF PERIODIC O&M	0
PRESENT VALUE OF EFFICIENCY LOSS ENERGY	7168.700
PRESENT VALUE OF STORED ENERGY	21506.10
PRESENT VALUE OF AUXILARY ELECTRIC ENERGY	0
PRESENT VALUE OF AUXILARY FOSSIL FUEL ENERGY	0
PRESENT VALUE OF FINAL SALVAGE	-823.635

-----SUMMARY RESULTS-----

COMPONENT LIFE-CYCLE COST CONTRIBUTORS

INITIAL BATTERY COST	808
BALANCE-OF-PLANT	595
REPLACEMENTS	0
OPERATING AND MAINTENANCE	107
ENERGY	267
SALVAGE	-10
TOTAL	1766 MILLS/KWH

TOTAL PRESENT WORTH	145131.0
TOTAL ANNUALIZED COST	16558.17

LEVELIZED STORAGE COST	1.766206 \$/KWH OF ENERGY RETRIEVED
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ZINC-FERRICYANIDE BATTERY SYSTEM: NOMINAL ESTIMATE

BATTERY STORAGE ECONOMIC ANALYSIS MODEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	Zinc-REDOX	CYCLE LIFE (#)	2000
APPLICATION	Stand-Alone	CYCLES/YEAR	250
SYSTEM SIZE (KWH)	50	ROUND TRIP EFFICIENCY	0.72
SYSTEM SIZE (KWE)	10		

AUXILARY ELECTRICITY CONSUMPTION (KWH/YR)	0
AUXILARY FOSSIL FUEL CONSUMPTION (MBTU/YR)	0

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	349 (\$/KWH)
BATTERY INSTALLATION	287 (\$/KWH)
ENERGY RELATED BOS	196 (\$/KWH)
POWER RELATED BOS	640 (\$/KWE)
NET SALVAGE VALUE	0 (\$/KWH)

-----OPERATING AND MAINTENANCE COST INPUTS-----

COST OF ELECTRICITY, \$/KWH	0.200	ANNUAL O&M COST, \$	1330
COST OF FOSSIL FUEL, \$/MBTU	0		

*****EQUAL INTERVAL PERIODIC O&M*****

PERIODIC MAINTENANCE INTERVAL	1 (YEARS)
PERIODIC MAINTENANCE COST	0 (\$)

*****VARIED INTERVAL PERIODIC O&M*****

YEAR	COST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.060
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	20	TAX CREDIT	0.000
CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	PLANT TAX LIFE	20
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR PLANT	0.440
DEPRECIATION FACTOR FOR BATTERIES	0.829
CAPITAL RECOVERY FACTOR	0.087184
FIXED CHARGE RATE FOR PLANT	0.137091
FIXED CHARGE RATE FOR BATTERIES	0.116328

OVERNIGHT CONSTRUCTION COST	48000
1st YEAR OPERATING & MAINT. COST	1,330
1st YEAR EFFICIENCY ELECTRICITY COST	700
1st YEAR STORED ELECTRICITY COST	1800
1st YEAR AUXILARY ELECTRICITY COST	0
1st YEAR AUXILARY FOSSIL FUEL COST	0

ANNUAL ENERGY STORED (KWH)	12500
ANNUAL ENERGY RETRIEVED (KWH)	9000

PRESENT VALUE OF INITIAL CAPITAL	48000
PRESENT VALUE OF NET REPLACEMENT CAPITAL	32469.66
PRESENT VALUE OF ANNUAL O&M	15254.99
PRESENT VALUE OF PERIODIC O&M	0
PRESENT VALUE OF EFFICIENCY LOSS ENERGY	8028.944
PRESENT VALUE OF STORED ENERGY	20645.85
PRESENT VALUE OF AUXILARY ELECTRIC ENERGY	0
PRESENT VALUE OF AUXILARY FOSSIL FUEL ENERGY	0
PRESENT VALUE OF FINAL SALVAGE	0

-----SUMMARY RESULTS-----

COMPONENT LIFE-CYCLE COST CONTRIBUTORS

INITIAL BATTERY COST	411
BALANCE-OF-PLANT	247
REPLACEMENTS	420
OPERATING AND MAINTENANCE	148
ENERGY	278
SALVAGE	0
 TOTAL	 1503 MILLS/KWH

TOTAL PRESENT WORTH	124399.4
TOTAL ANNUALIZED COST	13527.28

LEVELIZED STORAGE COST	1.503031 \$/KWH OF ENERGY RETRIEVED
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DIESEL-ELECTRIC GENERATING SYSTEM: LOW FUEL PRICE

BATTERY STORAGE ECONOMIC ANALYSIS MOOEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	Diesel	CYCLE LIFE (#)	1000
APPLICATION	Stand-Alone	CYCLES/YEAR	250
SYSTEM SIZE (KWH)	50	ROUND TRIP EFFICIENCY	1
SYSTEM SIZE (KWE)	10		
AUXILARY ELECTRICITY CONSUMPTION (KWH/YR)		0	
AUXILARY FOSSIL FUEL CONSUMPTION (MBTU/YR)		190	

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	75 (\$/KWH)
BATTERY INSTALLATION	0 (\$/KWH)
ENERGY RELATED BOS	0 (\$/KWH)
POWER RELATED BOS	0 (\$/KWE)
NET SALVAGE VALUE	0 (\$/KWH)

-----OPERATING AND MAINTENANCE COST INPUTS-----

COST OF ELECTRICITY, \$/KWH	0.000	ANNUAL O&M COST, \$	250
COST OF FOSSIL FUEL, \$/MBTU	4.86		

*****EQUAL INTERVAL PERIODIC O&M*****

PERIODIC MAINTENANCE INTERVAL	1 (YEARS)
PERIODIC MAINTENANCE COST	0 (\$)

*****VARIED INTERVAL PERIODIC O&M*****

YEAR	COST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.060
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	20	TAX CREDIT	0.000
CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	PLANT TAX LIFE	20
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0.038		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR PLANT	0.440
DEPRECIATION FACTOR FOR BATTERIES	0.829
CAPITAL RECOVERY FACTOR	0.087184
FIXED CHARGE RATE FOR PLANT	0.137091
FIXED CHARGE RATE FOR BATTERIES	0.116328

OVERNIGHT CONSTRUCTION COST	3750
1st YEAR OPERATING & MAINT. COST	250
1st YEAR EFFICIENCY ELECTRICITY COST	0
1st YEAR STORED ELECTRICITY COST	0
1st YEAR AUXILARY ELECTRICITY COST	0
1st YEAR AUXILARY FOSSIL FUEL COST	1198.867

ANNUAL ENERGY STORED (KWH)	12500
ANNUAL ENERGY RETRIEVED (KWH)	12500

PRESENT VALUE OF INITIAL CAPITAL	3750
PRESENT VALUE OF NET REPLACEMENT CAPITAL	8662.956
PRESENT VALUE OF ANNUAL O&M	2867.480
PRESENT VALUE OF PERIODIC O&M	0
PRESENT VALUE OF EFFICIENCY LOSS ENERGY	0
PRESENT VALUE OF STORED ENERGY	0
PRESENT VALUE OF AUXILARY ELECTRIC ENERGY	0
PRESENT VALUE OF AUXILARY FOSSIL FUEL ENERGY	19379.08
PRESENT VALUE OF FINAL SALVAGE	0

-----SUMMARY RESULTS-----

COMPONENT LIFE-CYCLE COST CONTRIBUTORS

INITIAL BATTERY COST	35
BALANCE-OF-PLANT	0
REPLACEMENTS	81
OPERATING AND MAINTENANCE	20
ENERGY	135
SALVAGE	0
TOTAL	271 MILLS/KWH

TOTAL PRESENT WORTH	34659.52
TOTAL ANNUALIZED COST	3383.538

LEVELIZED STORAGE COST	0.270683 \$/KWH OF ENERGY RETRIEVED
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DIESEL-ELECTRIC GENERATING SYSTEM: NOMINAL FUEL PRICE

BATTERY STORAGE ECONOMIC ANALYSIS MODEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	Diesel	CYCLE LIFE (#)	1000
APPLICATION	Stand-Alone	CYCLES/YEAR	250
SYSTEM SIZE (KWH)	50	ROUND TRIP EFFICIENCY	1
SYSTEM SIZE (KWE)	10		
AUXILARY ELECTRICITY CONSUMPTION (KWH/YR)		0	
AUXILARY FOSSIL FUEL CONSUMPTION (MBTU/YR)		190	

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	75 (\$/KWH)
BATTERY INSTALLATION	0 (\$/KWH)
ENERGY RELATED BOS	0 (\$/KWH)
POWER RELATED BOS	0 (\$/KWE)
NET SALVAGE VALUE	0 (\$/KWH)

-----OPERATING AND MAINTENANCE COST INPUTS-----

COST OF ELECTRICITY, \$/KWH	0.000	ANNUAL O&M COST, \$	250
COST OF FOSSIL FUEL, \$/MBTU	21.76		

*****EQUAL INTERVAL PERIODIC O&M*****

PERIODIC MAINTENANCE INTERVAL	1 (YEARS)
PERIODIC MAINTENANCE COST	0 (\$)

*****VARIED INTERVAL PERIODIC O&M*****

YEAR	COST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.060
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	20	TAX CREDIT	0.000
CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	PLANT TAX LIFE	20
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0.038		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR PLANT	0.440
DEPRECIATION FACTOR FOR BATTERIES	0.829
CAPITAL RECOVERY FACTOR	0.087184
FIXED CHARGE RATE FOR PLANT	0.137091
FIXED CHARGE RATE FOR BATTERIES	0.116328

OVERNIGHT CONSTRUCTION COST	3750
1st YEAR OPERATING & MAINT. COST	250
1st YEAR EFFICIENCY ELECTRICITY COST	0
1st YEAR STORED ELECTRICITY COST	0
1st YEAR AUXILARY ELECTRICITY COST	0
1st YEAR AUXILARY FOSSIL FUEL COST	5367.770

ANNUAL ENERGY STORED (KWH)	12500
ANNUAL ENERGY RETRIEVED (KWH)	12500

PRESENT VALUE OF INITIAL CAPITAL	3750
PRESENT VALUE OF NET REPLACEMENT CAPITAL	8662.956
PRESENT VALUE OF ANNUAL O&M	2867.480
PRESENT VALUE OF PERIODIC O&M	0
PRESENT VALUE OF EFFICIENCY LOSS ENERGY	0
PRESENT VALUE OF STORED ENERGY	0
PRESENT VALUE OF AUXILARY ELECTRIC ENERGY	0
PRESENT VALUE OF AUXILARY FOSSIL FUEL ENERGY	86767.25
PRESENT VALUE OF FINAL SALVAGE	0

-----SUMMARY RESULTS-----

COMPONENT LIFE-CYCLE COST CONTRIBUTORS

INITIAL BATTERY COST	35
BALANCE-OF-PLANT	0
REPLACEMENTS	81
OPERATING AND MAINTENANCE	20
ENERGY	605
SALVAGE	0
TOTAL	741 MILLS/KWH

TOTAL PRESENT WORTH	102047.6
TOTAL ANNUALIZED COST	9258.746

LEVELIZED STORAGE COST	0.740700 \$/KWH OF ENERGY RETRIEVED
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DIESEL-ELECTRIC GENERATING SYSTEM: HIGH FUEL PRICE

BATTERY STORAGE ECONOMIC ANALYSIS MODEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	Diesel	CYCLE LIFE (#)	1000
APPLICATION	Stand-Alone	CYCLES/YEAR	250
SYSTEM SIZE (KWH)	50	ROUND TRIP EFFICIENCY	1
SYSTEM SIZE (KWE)	10		

AUXILARY ELECTRICITY CONSUMPTION (KWH/YR)	0
AUXILARY FOSSIL FUEL CONSUMPTION (MBTU/YR)	190

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	75 (\$/KWH)
BATTERY INSTALLATION	0 (\$/KWH)
ENERGY RELATED BOS	0 (\$/KWH)
POWER RELATED BOS	0 (\$/KWE)
NET SALVAGE VALUE	0 (\$/KWH)

-----OPERATING AND MAINTENANCE COST INPUTS-----

COST OF ELECTRICITY, \$/KWH	0.000	ANNUAL O&M COST, \$	250
COST OF FOSSIL FUEL, \$/MBTU	72.54		

*****EQUAL INTERVAL PERIODIC O&M*****

PERIODIC MAINTENANCE INTERVAL	1 (YEARS)
PERIODIC MAINTENANCE COST	0 (\$)

*****VARIED INTERVAL PERIODIC O&M*****

YEAR	COST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.060
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	20	TAX CREDIT	0.000
CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	PLANT TAX LIFE	20
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0.038		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR PLANT	0.440
DEPRECIATION FACTOR FOR BATTERIES	0.829
CAPITAL RECOVERY FACTOR	0.087184
FIXED CHARGE RATE FOR PLANT	0.137091
FIXED CHARGE RATE FOR BATTERIES	0.116328

OVERNIGHT CONSTRUCTION COST	3750
1st YEAR OPERATING & MAINT. COST	250
1st YEAR EFFICIENCY ELECTRICITY COST	0
1st YEAR STORED ELECTRICITY COST	0
1st YEAR AUXILARY ELECTRICITY COST	0
1st YEAR AUXILARY FOSSIL FUEL COST	17894.21

ANNUAL ENERGY STORED (KWH)	12500
ANNUAL ENERGY RETRIEVED (KWH)	12500

PRESENT VALUE OF INITIAL CAPITAL	3750
PRESENT VALUE OF NET REPLACEMENT CAPITAL	8662.956
PRESENT VALUE OF ANNUAL O&M	2867.480
PRESENT VALUE OF PERIODIC O&M	0
PRESENT VALUE OF EFFICIENCY LOSS ENERGY	0
PRESENT VALUE OF STORED ENERGY	0
PRESENT VALUE OF AUXILARY ELECTRIC ENERGY	0
PRESENT VALUE OF AUXILARY FOSSIL FUEL ENERGY	289250.7
PRESENT VALUE OF FINAL SALVAGE	0

-----SUMMARY RESULTS-----

COMPONENT LIFE-CYCLE COST CONTRIBUTORS

INITIAL BATTERY COST	35
BALANCE-OF-PLANT	0
REPLACEMENTS	81
OPERATING AND MAINTENANCE	20
ENERGY	2017
SALVAGE	0
TOTAL	2153 MILLS/KWH

TOTAL PRESENT WORTH	304531.2
TOTAL ANNUALIZED COST	26912.18

LEVELIZED STORAGE COST	2.152975 \$/KWH OF ENERGY RETRIEVED
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APPENDIX G

NORMALIZATION GUIDELINES FOR ELECTRIC VEHICLE APPLICATIONS

APPENDIX G

NORMALIZATION GUIDELINES FOR ELECTRIC VEHICLE APPLICATIONS

The capital and operating costs for electric vehicles, exclusive of the battery or fuel cell system costs, were normalized to the cost methodology from AVCOST. AVCOST is a computer program developed by the Jet Propulsion Laboratory (JPL) for the Electric and Hybrid Vehicle Division of the Department of Energy. The battery and fuel cell system costs were escalated to 1988 dollars. No other adjustments were made. Because the battery and fuel cell system costs were taken from studies that emphasized independent evaluation, developer biases, if any, should be minimized.

The costing methodology, as adapted to this study from JPL's AVCOST documentation, follows. All costs are given in 1982 dollars.

1. Initial Cost

Initial cost is defined as the cost to the consumer. It is made up of the following costs: basic vehicle, engine, transmission, motor, controller, and battery or fuel cell costs.

Basic Vehicle Cost. This cost is computed as the product of the weight of the basic vehicle and a cost per unit weight for a standard vehicle. The basic-vehicle weight is obtained by removing the battery, motor, engine, controller, and transmission from the vehicle curb weight. Thus,

$$\begin{aligned} \text{basic vehicle weight} &= \text{curb weight (excludes driver and payload)} & (G.1) \\ &- \text{battery weight} \\ &- \text{motor weight} \\ &- \text{engine weight} \\ &- \text{controller weight} \\ &- \text{transmission weight} \end{aligned}$$

Curb weight and battery weight are as estimated in the source studies. The other weights are calculated as functions of the rated power, as follows:

$$\text{motor weight, kg} = \frac{\text{motor power, kW}}{0.49} \quad (\text{G.2})$$

where motor size, kW, is estimated as 90% of peak battery or fuel cell system output. A specific weight of 490 W/kg is assumed for AC motors.

$$\text{engine weight, kg} = \frac{\text{engine power, kW}}{0.45} \quad (\text{G.3})$$

A specific weight of 450 W/kg is assumed for the engines.

$$\text{controller weight, kg} = \frac{\text{controller power, kW}}{2.5} \quad (\text{G.4})$$

where controller power is equal to the maximum power of the battery or fuel cell system. A specific weight of 2500 W/kg is assumed for AC controllers.

$$\text{transmission weight, kg} = \frac{\text{peak power, kW}}{1.42} \quad (\text{G.5})$$

where transmission power is estimated as 90% of peak battery or fuel cell system output. A specific weight of 1420 W/kg is assumed for fixed-gear reduction transmissioning.

Engine Cost. Engine cost is given by the following:

$$\text{engine cost} = 1.5 \times 240 \times (\text{engine power, kW})^{0.33} \quad (\text{G.6})$$

where engine maximum-rated power is an input. One and one-half represents the mark-up from original equipment manufacturer (OEM) cost to sale price.

Transmission Cost. Transmission cost is related to the rated power by the following equation:

$$\text{transmission cost} = 1.5 \times 3.1 \times \text{power, kW} \quad (\text{G.7})$$

The figure of 1.5 accounts for an OEM mark-up of 50%.

Motor Cost. Motor cost is given by the following:

$$\text{motor cost} = 1.5 \times 12.7 \times \text{motor power} \quad (\text{G.8})$$

The equation includes the OEM mark-up multiplier of 1.5.

Controller Cost. Controller cost is related to controller power by the following:

$$\text{controller cost} = 30 \times 1.5 \times \text{AC controller power, kW} \quad (\text{G.9})$$

The OEM cost for the controller is \$30/kW (1982\$) and is marked up by 50%.

2. Operating Cost

Operating costs include replacement batteries, replacement tires, repairs and maintenance, insurance, garaging, parking, tolls, title, registration, license, fuel and oil, electricity, and equivalent road tax. Replacement batteries, fuel, electricity, and oil are discussed in Section 5.0.

Repairs and Maintenance. For light-duty electric vans, repairs and maintenance costs are given by the following:

$$81.73 + (0.0114)(\text{kilometers traveled per year})(\text{maintenance factor}) \quad (\text{G.10})$$

For ICE-powered vehicles, repair and maintenance costs are given by the following:

$$81.73 + (0.0191)(\text{kilometers per year traveled}) \quad (\text{G.11})$$

For full-performance vans, repair and maintenance costs are given by the following:

$$[81.73 + (0.0114)(\text{kilometers traveled per year})(\text{maintenance factor})] \quad (\text{G.12})$$

$$*[0.5 (\text{initial cost of full-performance van/initial cost of light-duty van})]$$

For five-passenger vehicles, repair and maintenance costs are given by the following:

$$[78.67 + (0.0123)(\text{kilometers per year})(\text{maintenance factor})] \quad (\text{G.13})$$

The maintenance factor included in these equations is a subjective measure of relative maintenance. The factors used in the normalization process are shown in Table G.1.

Replacement Tires. The cost of replacement tires is given by the following:

$$\text{cost} = [(\text{lifetime km-traveled} - 64374) * (368.74 + (0.18086 * \text{curb weight})/128748)] \quad (\text{G.14})$$

TABLE G.1. Maintenance Factors for Battery, Fuel Cell, and ICE-Powered Vehicles

<u>Vehicle Power System</u>	<u>Factor</u>
Conventional Lead-Acid Battery System	1
Sealed Lead-Acid Battery System	0.5
Sodium-Sulfur Battery System	1.75
Zinc-Bromine Battery System	2
Aluminum-Air Battery System	1.125(a)
Lithium-Iron Sulfide Battery System	1.25
Solid Polymer Electrolyte Fuel Cell System	2
Internal Combustion Engine Vehicle	1.675(b)

- (a) The portion of vehicle maintenance cost associated with refueling is included the fuel cost.
- (b) This factor is presented as a basis for relative comparison of the battery system values presented in this table. It is not required for generating maintenance cost estimates.

Insurance. Insurance is estimated as \$348/yr.

Garaging, Parking, and Tolls. Garaging, parking, and tolls are estimated at \$78/yr.

Title, Registration, and License. Title, registration, and license are estimated at 5% of initial cost plus \$20/yr.

APPENDIX H

DETAILS OF THE NORMALIZATION PROCESS FOR THE ELECTRIC VEHICLE APPLICATION

APPENDIX H

DETAILS OF THE NORMALIZATION PROCESS FOR THE ELECTRIC VEHICLE APPLICATION

This Appendix presents the evaluation and normalization process used on each data source at a calculational level-of-detail. A section is included for each electric vehicle technology evaluated. Each page within a section is dedicated to discussing the data evaluation and normalization process from one source.

The following outline should aid in the location of pertinent sections of this appendix.

<u>Section Title</u>	<u>Number</u>	<u>Page</u>
Conventional Lead-Acid Battery	H.1	H.3
Sealed Lead-Acid Battery	H.2	H.7
Zinc-Bromine Battery	H.3	H.9
Sodium-Sulfur Battery	H.4	H.11
Lithium-Iron Sulfide Battery	H.5	H.15
Aluminum-Air Battery	H.6	H.19
Proton Exchange Membrane Fuel Cell	H.7	H.21
Internal Combustion Engine	H.8	H.23

H.1 CONVENTIONAL LEAD-ACID BATTERY

SOURCE: Jet Propulsion Laboratory Evaluation of Light-Duty Van (Hardy et al. 1985)

Based on the results of JPL's systems analysis, a 61.2-kW, 18.6-kWh battery system was determined to meet the light-duty van requirements. This optimized size was based on 41 Wh/kg and 135 W/kg for the battery's specific energy and specific power, respectively. Estimated average daily depth of discharge (DoD) is 0.319, and annual electricity consumption is 3075 kWh. Table H.1 presents the capital and operating cost estimate for a light-duty van powered by a lead-acid battery system.

**TABLE H.1. Conventional Lead-Acid Battery System Cost
Estimate for the Light-Duty Van**

	<u>1982\$</u>	<u>1988\$</u>
Basic Vehicle Cost	8,268	10,004
Motor Cost	705	853
Controller Cost	1,854	2,243
EV Transmission Cost	192	<u>232</u>
Total Vehicle Cost (excl. battery)	11,019	13,332
Battery Variable Cost (\$/kWh)	58.6(a)	70.9
Battery Variable Cost (\$/kW)	11.9	14.4
Battery Fixed Cost (\$)	545.5	<u>660</u>
Total Battery Cost (\$)	--	2,860
Repairs and Maintenance (annual)	228(b)	276
Replacement Tires (yr 5)	340(b)	411
Insurance (annual)	348(b)	421
Garaging, Parking, Toll	78(b)	94
Title, Registration, License (yr 0)	5%(b)	810
(annual)	20(b)	24
Vehicle Salvage Value:		1,619

- (a) The JPL estimate in 1982\$ was presented as \$2360.03. This estimate was calculated from the following equation: $[43 \text{ (kWh)} + 8.7 \text{ (kW)} + (400)](1.5/1.1)$. The factor of 1.5 allows for battery manufacturer's and distributor's profit. The divisor of 1.1 reduces the cost year of the equation from 1983\$ to 1982\$.
- (b) Calculated based on the cost relationships presented in Appendix G.

SOURCE: Consiglio and Symons Evaluation of a Full-Performance Van
(1985)

This source estimate included only the battery system capital cost. Using this estimate and accompanying vehicle performance requirements, a life-cycle cost estimate was prepared. The methodology for the estimate preparation is included in Appendix G. Table H.2 presents the pertinent source data. From this data a total vehicle weight, including driver and payload, of 2914 kg was estimated. The controller and transmission were each estimated to be rated at 58.5 kW. Cell efficiency was assumed to be 75%. Using these calculated values, the cost estimate in Table H.3 was prepared.

TABLE H.2. Battery Cost and Performance Source Data for the Conventional Lead-Acid Battery-Powered Full-Performance Van

Nominal System Size	43 kWh
System Cost	\$4300(a)
System Life	800-96 km cycles
Energy Delivered	29 kWh per 96 per km-cycle
Base Vehicle Weight (incl. driver)	1193 kg
Battery Weight	1014 kg
Weight Propagation Factor	0.25
Required Power	20 W/kg

(a) Based on 20,000 units/yr and a 20 cents/pound lead cost (1983 dollars).

TABLE H.3. Conventional Lead-Acid Battery System Cost Estimate for the Full-Performance Van

	<u>1982\$</u>	<u>1988\$</u>
Basic Vehicle Cost	8,436	10,208
Motor Cost	998	1,208
Controller Cost	2,624	3,175
EV Transmission Cost	<u>271</u>	<u>328</u>
Total Vehicle Cost (excl. battery)	12,329	14,919
Battery	4,300 ^(a)	5,203
Repairs and Maintenance (annual)	254 ^(b)	307
Replacement Tires (yr 5)	397 ^(b)	480
Insurance (annual)	348 ^(b)	421
Garaging, Parking, Toll (annual)	78 ^(b)	94
Title, Registration, License (yr 0)	5% ^(b)	1,006
(annual)	20 ^(b)	24
Vehicle Salvage Value		2,012

(a) 1983 dollars.

(b) Calculated from the cost relationships presented in Appendix G.

H.2 SEALED LEAD-ACID BATTERY

SOURCE: Jet Propulsion Laboratory Evaluation of a Light-Duty Van
(Hardy et al. 1985)

At the time of the JPL study, the design characteristics of the sealed lead-acid battery were nebulous. Based on a specific energy of 50 wh/kg and an unspecified specific power, a battery size of 14.6 kWh was estimated to be required to fulfill the light-duty van requirements. Although the specific power was unspecified, it would definitely be above 135 W/kg, the value for the conventional lead-acid battery. The estimated average daily DoD is 0.355 and annual electricity consumption is 2393 kWh. Table H.4 presents the capital and operating cost estimate for a light-duty van powered by a sealed lead-acid battery system.

**TABLE H.4. Sealed Lead-Acid Battery System Cost
Estimate for the Light-Duty Van**

	<u>1982\$</u>	<u>1988\$</u>
Basic Vehicle Cost	7,909	9,570
Motor Cost	627	759
Controller Cost	1,647	1,993
EV Transmission Cost	170	<u>206</u>
Total Vehicle Cost (excl. battery)		12,528
Battery Variable Cost (\$/kWh)	80(a)	97
Battery Variable Cost (\$/kW)	--	--
Battery Fixed Cost (\$)	--	--
Total Battery Cost (\$)		<u>1,416</u>
Repairs and Maintenance (annual)	155(b)	188
Replacement Tires (yr 5)	320(b)	387
Insurance (annual)	348(b)	421
Garaging, Parking, Toll	78(b)	94
Title, Registration, License (yr 0)	5%(b)	697
(annual)	20(b)	24
Vehicle Salvage Cost		1,394

- (a) The JPL estimate in 1982\$ was presented as \$1598.18. This estimate was calculated from the following equation: $(80 \text{ (kWh)})(1.5/1.1)$, which reduces to 109/kWh. The factor of 1.5 allows for battery manufacturer's, vehicle manufacturer's, and distributor's profit. The divisor of 1.1 reduces the cost year of the equation from 1983\$ to 1982\$.
- (b) Calculated from the cost relationships presented in Appendix G.

H.3 ZINC-BROMINE BATTERY

SOURCE: Jet Propulsion Laboratory Evaluation of a Light-Duty Van
(Hardy et al. 1985)

The optimized size for the zinc-bromine battery system based on a specific energy of 49 kWh/kg and a specific power of 135 kW/kg is 60 kW, 21.76 kWh. The estimated average DoD is 0.310, and annual electricity consumption is 5172 kWh. Table H.5 presents the capital and operating cost estimate for the light-duty van powered by the zinc-bromine battery system.

TABLE H.5. Zinc-Bromine Battery System Cost Estimate for the Light-Duty Van

	<u>1982\$</u>	<u>1988\$</u>
Basic Vehicle Cost	8,244	9,975
Motor Cost	701	848
Controller Cost	1,845	2,232
EV Transmission Cost	191	231
Total Vehicle Cost (excl. battery)		<u>13,286</u>
Battery Variable Cost (\$/kWh)	27.3	33.0
Battery Variable Cost (\$/kW)	13.6	16.5
Battery Fixed Cost (\$)	955	<u>1,151.6</u>
Total Battery Cost (\$)		<u>2,860</u>
Repairs and Maintenance (annual)	375 ^(b)	454
Replacement Tires (yr 5)	339 ^(b)	410
Insurance (annual)	348 ^(b)	421
Garaging, Parking, Toll	78 ^(b)	94
Title, Registration, License (yr 0)	5% ^(b)	807
(annual)	20 ^(b)	24
Vehicle Salvage Cost		1,614

- (a) The JPL estimate in 1982\$ was presented as \$2365.25. This estimate was calculated from the following equation: $(20 \text{ (kWh)} + 10 \text{ (kW)} + 700)(1.5/1.1)$ which reduces to $27.3 \text{ (kWh)} + 13.6 \text{ (kW)} + 955$. The factor of 1.5 allows for battery manufacturer's, vehicle manufacturer's, and distributor's profit. The divisor of 1.1 reduces the cost year of the equation from 1983\$ to 1982\$.
- (b) Calculated from the cost relationships presented in Appendix G.

H.4 SODIUM-SULFUR BATTERY

SOURCE: Jet Propulsion Laboratory Evaluation of a Light-Duty Van
(Hardy et al. 1985)

Based on the results of JPL's system analysis, a 42.8-kW, 15.9-kWh battery system was determined to meet the light-duty van requirements. This optimized size was based on 83 Wh/kg and 224 W/kg for the battery's specific energy and specific power, respectively. Estimated average daily DoD is 0.244, and annual electricity consumption is 3035 kWh. Table H.6 presents the capital and operating cost estimate for the light-duty van powered by the sodium-sulfur battery system.

TABLE H.6. Sodium-Sulfur Battery System Cost Estimate for the Light-Duty Van

	<u>1982\$</u>	<u>1988\$</u>
Basic Vehicle Cost	7,676	9,288
Motor Cost	578	699
Controller Cost	1,517	1,836
EV Transmission Cost	157	<u>190</u>
Total Vehicle Cost (excl. battery)		12,013
Battery Variable Cost (\$/kWh)	34.1 ^(a)	41.3
Battery Variable Cost (\$/kW)	61.4	74.3
Battery Variable Cost (\$)	1,364	<u>1,650</u>
Total Battery Cost (\$)		5,487
Repairs and Maintenance (annual)	338 ^(b)	409
Replacement Tires (yr 5)	307 ^(b)	371
Insurance (annual)	348 ^(b)	421
Garaging, Parking, Toll	78 ^(b)	94
Title, Registration, License (yr 0)	5% ^(b)	875
(annual)	20 ^(b)	24
Vehicle Salvage Value		1,750

- (a) The JPL estimate in 1982\$ was presented as \$4302.99. This estimate was calculated from the following equation: $(25 \text{ (kWh)} + 45 \text{ (kW)} + 1000)(1.5/1.1)$ which reduces to $34.1 \text{ (kWh)} + 61.4 \text{ (kW)} + 1364$.
- (b) Calculated from the cost relationships presented in Appendix G.

SOURCE: Consiglio and Symons Evaluation of a Full-Performance Van
(1985)

This estimate included only the battery system capital cost. Using the estimate and accompanying vehicle performance requirements, a life-cycle cost estimate was prepared. The methodology for estimate preparation is included in Appendix G. Table H.7 presents the pertinent source data. From this data a total vehicle weight, including driver and payload, of 2042 kg was estimated. The controller and transmission were each estimated to be rated at 43.2 kW. Battery efficiency was assumed to be 66%. Using these calculated values the cost estimate in Table H.8 was prepared.

TABLE H.7. Battery Cost and Performance Source Data for the Sodium-Sulfur Battery-Powered Full-Performance Van

Nominal System Size	25.8 kWh
System Cost	\$5300(a)
System Life	1000-96 km cycles
Energy Delivered	20.5 kWh/cycle
Base Vehicle Weight (inc. driver)	1193 kg
Battery Weight	316 kg
Propagation Factor	0.25
Required Power	20 W/kg

(a) Based on 20,000 units/yr and a 20 cents/pound lead cost (1983 dollars).

TABLE H.8. Sodium-Sulfur Battery System Cost Estimate for the Full-Performance Van

	<u>1982\$</u>	<u>1988\$</u>
Basic Vehicle Cost	7,435	8,996
Motor Cost	1,675	2,027
Controller Cost	864	1,045
EV Transmission Cost	157	<u>190</u>
Total Vehicle Cost (excl. battery)		12,258
Battery	5,300(a)	6,413
Repairs and Maintenance (annual)	352(b)	426
Replacement Tires (yr 5)	319(b)	386
Insurance (annual)	348(b)	421
Garaging, Parking, Toll (annual)	78(b)	94
Title, Registration, License (yr 0)	5%(b)	934
(annual)	20(b)	24
Vehicle Salvage Value		1,867

(a) 1983 dollars.

(b) Calculated from the cost relationships presented in Appendix G.

SOURCE: Jet Propulsion Laboratory Evaluation of a Five-Passenger Car
(Hardy et al. 1985)

To meet the five-passenger requirements, a 106.6 kW, 31.9 kWh battery system was selected by JPL. This optimized size was based on 73 wh/kg and 244 w/kg for the battery's specific energy and specific power, respectively. The estimated average daily DoD is 0.109, and annual electricity consumption is 3616 kWh. Table H.9 presents the capital and operating cost estimates for the five-passenger vehicle powered by a sodium-sulfur battery system.

TABLE H.9. Sodium-Sulfur Battery System Cost Estimate for the Full-Performance Five-Passenger Vehicle

	<u>1982\$</u>	<u>1988\$</u>
Basic Vehicle Cost	6,938	8,395
Motor Cost	806	975
Controller Cost	2,120	2,565
EV Transmission Cost	219	265
Total Vehicle Cost (excl. battery)		12,200
Battery Variable Cost (\$/kWh)	34.1(a)	41.3
Battery Variable Cost (\$/kW)	61.4	74.3
Battery Variable Cost(\$)	1,363.6	1,650
Total Battery Cost (\$)		10,888
Repairs and Maintenance (annual)	413(b)	500
Replacement Tires (yr 5)	512(b)	620
Insurance (annual)	348(b)	421
Garaging, Parking, Toll	78(b)	94
Title, Registration, License (yr 0)	5%(b)	1,154
(annual)	20(b)	24
Vehicle Salvage Value		2,309

- (a) The JPL estimate in 1982\$ was presented as \$8184.77. This estimate was calculated from the following equation: $(25 \text{ (kWh)} + 45 \text{ (kW)} + 1000)(1.5/1.1)$, which reduces to $34.1 \text{ (kWh)} + 61.4 \text{ (kW)} + 1363.6$. The factor of 1.5 allows for battery manufacturer's, vehicle manufacturer's, and distributor's profit. The divisor of 1.1 reduces the cost year of the equation from 1983\$ to 1982\$.
- (b) Calculated from the cost relationships presented in Appendix G.

H.5 LITHIUM-IRON SULFIDE BATTERY

SOURCE: Jet Propulsion Laboratory Evaluation of a Light-Duty Van (Hardy et al. 1985)

Based on the results of systems analysis, a 37.3-kW, 13.5-kWh battery system was determined to meet the requirements of a light-duty van. This optimized size was based on 135 Wh/kg and 4.9 W/kg for the battery's specific energy and specific power, respectively. Estimated average daily DoD is 0.244, and annual electricity consumption is 3581 kWh. Table H.10 presents the capital and operating cost estimate for the light-duty van powered by the lithium-iron sulfide battery system.

TABLE H.10. Lithium-Iron Sulfide Battery System Cost Estimate for the Light-Duty Van

	<u>1982\$</u>	<u>1988\$</u>
Basic Vehicle Cost	7,871	9,524
Motor Cost	618	748
Controller Cost	1,629	1,971
EV Transmission Cost	168	203
Total Vehicle Cost (excl. battery)		12,446
Battery Variable Cost (\$/kWh)	27.3(a)	33.0
Battery Variable Cost (\$/kW)	13.6	16.5
Battery Variable Cost (\$)	955	1,156
Total Battery Cost		2,217
Repairs and Maintenance (annual)	265(b)	321
Replacement Tires (yr 5)	317(b)	384
Insurance (annual)	348(b)	421
Garaging, Parking, Toll	78(b)	94
Title, Registration, License (yr 0)	5%(b)	733
(annual)	20(b)	24
Vehicle Salvage Cost		1,466

(a) The JPL estimate in 1982\$ was presented as \$3514.25. This estimate was calculated from the following equation: $(20 \text{ (kWh)} + 10 \text{ (kW)} + 700)(1.5/1.1)$, which reduces to $27.3 \text{ (kWh)} + 13.6 \text{ (kW)} + 955$. The factor of 1.5 allows for battery manufacturer's, vehicle manufacturer's, and distributor's profit. The divisor of 1.1 reduces the cost year of the equation from 1983\$ to 1982\$.

(b) Calculated from the cost relationships presented in Appendix G.

SOURCE: Consiglio and Symons Evaluation of a Full-Performance Van (1985)

This source estimate included only the battery system capital cost. Using the estimate and accompanying vehicle performance requirements, a life-cycle cost estimate was prepared. The methodology for estimate preparation is included in Appendix G. Table H.11 presents the pertinent source data. From this data a total vehicle weight, including driver and payload, of 2122 kg was estimated. The controller and transmission were each estimated to be rated at 42.4 kW, while the motor was rated at 38.2. Battery efficiency is assumed to be 60%. Using these calculated values, the cost estimate in Table H.12 was prepared.

TABLE H.11. Battery Cost and Performance Source Data for the Lithium-Iron Sulfide Battery-Powered Full-Performance Van

Nominal System Size	29 kWh
System Cost	\$4500(a)
System Life	1000-96 km cycles
Energy Delivered	21.3 kWh/cycle
Base Vehicle Weight (inc. driver)	1193 kg
Battery Weight	380 kg
Propagation Factor	0.25
Required Power	20 W/kg

(a) Based on 20,000 units/yr and a 20 cents/pound lead cost (1983 dollars).

TABLE H.12. Lithium-Iron Sulfide System Cost Estimate for the Full-Performance Van

	<u>1982\$</u>	<u>1988\$</u>
Basic Vehicle Cost	7,657	9,265
Motor Cost	765	926
Controller Cost	1,675	2,027
EV Transmission Cost	140	<u>169</u>
Total Vehicle Cost (excl. battery)		12,387
Battery Cost	4,500(a)	5,445
Repairs and Maintenance (annual)	276(b)	334
Replacement Tires (yr 5)	326(b)	394
Insurance (annual)	348(b)	421
Garaging, Parking, Toll (annual)	78(b)	94
Title, Registration, License (yr 0)	5%(b)	892
(annual)	20(b)	24
Vehicle Salvage Value		1,784

(a) 1983 dollars.

(b) Calculated from the cost relationships presented in Appendix G.

SOURCE: Jet Propulsion Laboratory Evaluation of a Five-Passenger Car
(Hardy et al. 1985)

To meet the five-passenger vehicle requirements, a 101-kW, 49.8-kWh battery system was selected by JPL. This optimized size was based on 81 wh/kg and 165 w/kg for the battery's specific energy and specific power, respectively. The estimated average daily DoD is 0.101, and annual electricity consumption is 4481 kWh. Table H.13 presents the capital and operating cost estimate for the five-passenger vehicle powered by a lithium-iron sulfide battery system.

TABLE H.13. Lithium-Iron Sulfide Battery System Cost Estimate for the Full-Performance Five-Passenger Vehicle

	<u>1982\$</u>	<u>1988\$</u>
Basic Vehicle Cost	7,353	8,897
Motor Cost	929	1,124
Controller Cost	2,444	2,957
EV Transmission Cost	253	306
Total Vehicle Cost (excl. battery)		13,284
Battery (\$/kWh)	95.5(a)	115.6
(\$/kW)	13.6	16.6
(\$)	1,022.7	1,237.5
Total Battery (\$)		8,671
Repairs and Maintenance (annual)	318(b)	385
Replacement Tires (yr 5)	549(b)	664
Insurance (annual)	348(b)	421
Garaging, Parking, Toll	78(b)	94
Title, Registration, License (yr 0)	5%(b)	1,098
(annual)	20(b)	24
Vehicle Salvage Cost		2,196

(a) The JPL estimate in 1982\$ was presented as \$8360.80. This estimate was calculated from the following equation: $(70 \text{ (kWh)} + 10 \text{ (kW)} + 750)(1.5/1.1)$, which reduces to $95.5 \text{ (kWh)} + 13.6 \text{ (kW)} + 1022.7$. The factor of 1.5 allows for battery manufacturer's, vehicle manufacturer's, and distributor's profit. The divisor of 1.1 reduces the cost year of the equation from 1983\$ to 1982\$.

(b) Calculated from the cost relationships presented in Appendix G.

H.6 ALUMINUM-AIR BATTERY

SOURCE: Jet Propulsion Laboratory Evaluation of a Five-Passenger Car
(Hardy et al. 1985)

To meet the five-passenger requirements, a 38-kW battery system was selected by JPL. This optimized size was based on a specific power of 157 W/kg. Annual electric consumption is estimated as 24,842 kWh based on an 18% battery system efficiency. From this estimate of energy consumption and efficiency, a battery output of 4472 kWh per year is calculated. Using an aluminum to electricity conversion efficiency of 3.8 kWh/kg, the calculated aluminum consumption is 1177 kg/yr.

JPL estimates 1.5 kWh per kilometer traveled. Adjusting for the 18% efficiency, 0.27 kWh of battery output per vehicle-kilometer traveled is required. This is equivalent to 14.1 kilometer per kilogram of aluminum. For a vehicle of this aluminum-to-road efficiency, the cost of aluminum including taxes, installation, manufacturer's and distributor's profit is estimated as \$2.11 to \$3.05 (1987 dollars) per kilogram, depending on the taxation and profit margin assumed (Humphreys and Brown 1989). For developing the life-cycle cost estimate, the average of the range in 1987 dollars, \$2.58 (\$2.64 in 1988 dollars), was used. Presented in Table H.14 is the capital and operating cost estimate for a five-passenger vehicle powered by an aluminum-air battery system.

TABLE H.14. Aluminum-Air Battery System Cost Estimate for the Full-Performance Five-Passenger Vehicle

	<u>1982\$</u>	<u>1988\$</u>
Basic Vehicle Cost	7,661	9,270
Motor Cost	1,020	1,234
Controller Cost	2,687	3,251
EV Transmission Cost	278	<u>336</u>
Total Vehicle Cost (excl. battery)		14,091
Battery (\$/kW)	57.3(a)	69.3
Repairs and Maintenance (annual)	254(b)	307
Replacement Tires (yr 5)	576(b)	697
Insurance (annual)	348(b)	421
Garaging, Parking, Toll	78(b)	94
Title, Registration, License (yr 0)	5%(b)	836
(annual)	20(b)	24
Vehicle Salvage Value		1,672

- (a) The JPL estimate in 1982\$ was presented as \$2164.30. This estimate was calculated from the following equation: $(42 \text{ (kW)})(1.5/1.1)$, which reduces to 57. The factor of 1.5 allows for battery manufacturer's, vehicle manufacturer's, and distributor's profit. The divisor of 1.1 reduces the cost year of the equation from 1983\$ to 1982\$.
- (b) Calculated from the cost relationships presented in Appendix G.

H.7 PROTON EXCHANGE MEMBRANE FUEL CELL

SOURCE: Jet Propulsion Laboratory Evaluation of a Five-Passenger Car (Hardy et al. 1985)

This source presented a systems cost estimate for a 40-kW proton exchange membrane fuel cell-powered electric vehicle. Estimated annual fuel usage is 1353 l of methanol. Table H.15 presents the capital and operating cost estimate for the full-performance, five-passenger electric vehicle powered by the PEM fuel cell.

TABLE H.15. Proton Exchange Membrane Fuel Cell System Cost Estimate for the Full-Performance Five-Passenger Vehicle

	<u>1982\$</u>	<u>1988\$</u>
Basic Vehicle Cost	7,542	9,126
Motor Cost	684	828
Controller Cost	1,800	2,178
EV Transmission Cost	184	223
Total Vehicle Cost (excl. fuel cell)		12,355
Fuel Cell Variable Cost (\$/kWh)	--	--
Fuel Cell Variable Cost (\$/kW)	184	223
Total Fuel Cell (\$)		8,920
Repairs and Maintenance (annual)	460(b)	557
Replacement Tires (yr 5)	464(b)	561
Insurance (annual)	348(b)	421
Garaging, Parking, Toll	78(b)	94
Title, Registration, License (yr 0)	5%(b)	1,064
(annual)	20(b)	24
Vehicle Salvage Value		2,128

- (a) The JPL estimate in 1982\$ was presented as \$8184.77. This estimate was calculated from the following equation: $(25 \text{ (kWh)} + 45 \text{ (kW)} + 1000)(1.5/1.1)$, which reduces to $34.1 \text{ (kWh)} + 61.4 \text{ (kW)} + 1363.6$. The factor of 1.5 allows for battery manufacturer's, vehicle manufacturer's, and distributor's profit. The divisor of 1.1 reduces the cost year of the equation from 1983\$ to 1982\$.
- (b) Calculated from the cost relationships presented in Appendix G.

H.8 INTERNAL COMBUSTION ENGINE

SOURCE: Jet Propulsion Laboratory Evaluation of a Full-Performance Van (Hardy et al. 1985)

As a baseline for comparison, JPL estimated the life-cycle costs associated with a methanol-fueled internal combustion engine (ICE)-powered van. Table H.16 presents the capital and operating cost estimate for the methanol-fueled ICE-powered van. Annual fuel use was estimated as 2034 liters.

TABLE H.16. Methanol-Fueled Internal Combustion Engine System Cost Estimate for the Full-Performance Van

	<u>1982\$</u>	<u>1988\$</u>
Basic Vehicle Cost	6,807	8,236
Engine Cost	1,229	1,487
ICE Transmission Cost	461	<u>558</u>
Total Vehicle Cost		10,281
Repairs and Maintenance (annual)	463(b)	560
Replacement Tires (yr 5)	281(b)	340
Insurance (annual)	348(b)	421
Garaging, Parking, Toll	78(b)	94
Title, Registration, License (yr 0)	5%(b)	514
(annual)		24
Vehicle Salvage Value		1,028

- (a) The JPL estimate in 1982\$ was presented as \$4633.00 in 1982 dollars. Expenses are assumed linearly distributed over vehicle life.
- (b) Calculated from the cost relationships presented in Appendix G.

SOURCE: Jet Propulsion Laboratory Evaluation of a Five-Passenger Car
(Hardy et al. 1985)

As a baseline for comparison, JPL estimated the life-cycle costs associated with a methanol-fueled, ICE-powered car. Table H.17 presents the capital and operating cost estimate for the methanol-fueled, ICE-powered five-passenger vehicle. Annual fuel use was estimated as 1610 liters.

TABLE H.17. Methanol-Fueled Internal Combustion Engine System Cost Estimate for the Full-Performance Five-Passenger Vehicle

	<u>1982\$</u>	<u>1988\$</u>
Basic Vehicle Cost	5,746	6,953
Engine Cost	1,118	1,353
ICE Transmission Cost	346	419
Total Vehicle Cost		8,725
Repairs and Maintenance (annual)	535(a)	647
Replacement Tires (yr 5)	419(b)	507
Insurance (annual)	348(b)	421
Garaging, Parking, Toll	78(b)	94
Title, Registration, License (yr 0)	5%(b)	436
(annual)	20(b)	24
Vehicle Salvage Value		872

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- (a) The JPL estimate in 1982\$ was presented as \$5352.00 in 1982 dollars. Expenses are assumed linearly distributed over vehicle life.
- (b) Calculated from the cost relationships presented in Appendix G.

APPENDIX I

LIFE-CYCLE COST CALCULATIONS ELECTRIC VEHICLE APPLICATIONS

APPENDIX I

LIFE-CYCLE COST CALCULATIONS FOR ELECTRIC VEHICLE APPLICATIONS

This Appendix presents a summary of the pertinent input and output to the life-cycle cost calculations presented in the main text. They would prove most useful for identifying what specific components drive total cost. The following table should provide a guide to locating information in this Appendix.

<u>Technology</u>	<u>Page</u>
Conventional Lead-Acid Battery-Powered Light-Duty Van	I.3
Conventional Lead-Acid Battery-Powered Full-Performance Van	I.5
Sealed Lead-Acid Battery-Powered Light-Duty Van	I.7
Zinc-Bromine Battery-Powered Light-Duty Van	I.9
Sodium-Sulfur Battery-Powered Light-Duty Van	I.11
Sodium-Sulfur Battery-Powered Full-Performance Van	I.13
Sodium-Sulfur Battery-Powered Five-Passenger Car	I.15
Lithium-Iron Sulfide Battery-Powered Light-Duty Van	I.17
Lithium-Iron Sulfide Battery-Powered Full-Performance Van	I.19
Lithium-Iron Sulfide Battery-Powered Five-Passenger Car	I.21
Aluminum-Air Battery-Powered Five-Passenger Car	I.23
Proton Exchange Membrane Fuel Cell-Powered Five-Passenger Car	I.25
Internal Combustion Engine-Powered Van: Low World Oil Price	I.27
Internal Combustion Engine-Powered Van: Nominal World Oil Price	I.29
Internal Combustion Engine-Powered Van: High World Oil Price	I.31
Internal Combustion Engine-Powered Five-Passenger Car: Low World Oil Price	I.33
Internal Combustion Engine-Powered Five-Passenger Car: Nominal World Oil Price	I.35
Internal Combustion Engine-Powered Five-Passenger Car:	

CONVENTIONAL LEAD-ACID BATTERY-POWERED LIGHT-DUTY VAN

BATTERY STORAGE ECONOMIC ANALYSIS MODEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	Conv Pb-Acid	CYCLE LIFE (#)	750
APPLICATION	1-van	CYCLES/YEAR	130
SYSTEM SIZE (KWH)	1	ROUND TRIP EFFICIENCY	1
SYSTEM SIZE (KWE)	1		

ANNUAL ELECTRICITY CONSUMPTION (KWH/YR)	3075
ANNUAL FOSSIL FUEL CONSUMPTION (MBTU/YR)	0

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	2860 (\$/KWH)
BATTERY INSTALLATION	0 (\$/KWH)
ENERGY RELATED BOS	14142 (\$/KWH)
POWER RELATED BOS	0 (\$/KWE)
NET SALVAGE VALUE	286 (\$/KWH)
FINAL SALVAGE	1619 (\$)

-----OPERATING AND MAINTENANCE COST INPUTS-----

COST OF ELECTRICITY, \$/KWH	0.043	ANNUAL O&M COST, \$	815
COST OF FOSSIL FUEL, \$/MBTU	0		

*****EQUAL INTERVAL PERIODIC O&M*****

PERIODIC MAINTENANCE INTERVAL	6 (YEARS)
PERIODIC MAINTENANCE COST	411 (\$)

*****VARIED INTERVAL PERIODIC O&M*****

YEAR	COST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.060
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	10	TAX CREDIT	0.000
CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	VEHICLE TAX LIFE	5
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR VEHICLE	0.829
DEPRECIATION FACTOR FOR BATTERIES	0.829
CAPITAL RECOVERY FACTOR	0.135867
FIXED CHARGE RATE FOR VEHICLE	0.170117
FIXED CHARGE RATE FOR BATTERIES	0.170117

OVERNIGHT CONSTRUCTION COST	17002
1st YEAR OPERATING & MAINT. COST	815
1st YEAR EFFICIENCY ELECTRICITY COST	0
1st YEAR ANNUAL ELECTRICITY COST	132
1st YEAR ANNUAL FOSSIL FUEL COST	0

ANNUAL ENERGY STORED (KWH)	3075
ANNUAL KILOMETERS	12848

PRESENT VALUE OF INITIAL CAPITAL	17002
PRESENT VALUE OF NET REPLACEMENT CAPITAL	1814.568
PRESENT VALUE OF ANNUAL O&M	5998.470
PRESENT VALUE OF PERIODIC O&M	289.7387
PRESENT VALUE OF EFFICIENCY LOSS ENERGY	0
PRESENT VALUE OF ANNUAL ELECTRIC ENERGY	973.1875
PRESENT VALUE OF ANNUAL FOSSIL FUEL ENERGY	0
PRESENT VALUE OF FINAL SALVAGE	-852.869

-----SUMMARY RESULTS-----

TOTAL PRESENT WORTH	25225.09
TOTAL ANNUALIZED COST	4042.538

PRESENT WORTH/INSTALLED CAPACITY	25,225 \$/KWH OF CAPACITY INSTALLED
LEVELIZED STORAGE COST	0.315 \$/KILOMETER-TRAVELED

CONVENTIONAL LEAD-ACID BATTERY-POWERED
FULL-PERFORMANCE VAN

BATTERY STORAGE ECONOMIC ANALYSIS MODEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	Conv Pb-Acid	CYCLE LIFE (#)	800
APPLICATION	f-van	CYCLES/YEAR	130
SYSTEM SIZE (KWH)	1	ROUND TRIP EFFICIENCY	1
SYSTEM SIZE (KWE)	1		
ANNUAL ELECTRICITY CONSUMPTION (KWH/YR)		5175	
ANNUAL FOSSIL FUEL CONSUMPTION (MBTU/YR)		0	

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	5203 (\$/KWH)
BATTERY INSTALLATION	0 (\$/KWH)
ENERGY RELATED BOS	15925 (\$/KWH)
POWER RELATED BOS	0 (\$/KWE)
NET SALVAGE VALUE	520 (\$/KWH)
FINAL SALVAGE	2012 (\$)

-----OPERATING AND MAINTENANCE COST INPUTS-----

COST OF ELECTRICITY, \$/KWH	0.043	ANNUAL O&M COST, \$	846
COST OF FOSSIL FUEL, \$/MBTU	0		

*****EQUAL INTERVAL PERIODIC O&M*****

PERIODIC MAINTENANCE INTERVAL	6 (YEARS)
PERIODIC MAINTENANCE COST	480 (\$)

*****VARIED INTERVAL PERIODIC O&M*****

YEAR	COST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.060
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	10	TAX CREDIT	0.000
CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	VEHICLE TAX LIFE	5
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR VEHICLE	0.829
DEPRECIATION FACTOR FOR BATTERIES	0.829
CAPITAL RECOVERY FACTOR	0.135867
FIXED CHARGE RATE FOR VEHICLE	0.170117
FIXED CHARGE RATE FOR BATTERIES	0.170117

OVERNIGHT CONSTRUCTION COST	21128
1st YEAR OPERATING & MAINT. COST	846
1st YEAR EFFICIENCY ELECTRICITY COST	0
1st YEAR ANNUAL ELECTRICITY COST	223
1st YEAR ANNUAL FOSSIL FUEL COST	0

ANNUAL ENERGY STORED (KWH)	5175
ANNUAL KILOMETERS	12848

PRESENT VALUE OF INITIAL CAPITAL	21128
PRESENT VALUE OF NET REPLACEMENT CAPITAL	3301.330
PRESENT VALUE OF ANNUAL O&M	6226.633
PRESENT VALUE OF PERIODIC O&M	338.3810
PRESENT VALUE OF EFFICIENCY LOSS ENERGY	0
PRESENT VALUE OF ANNUAL ELECTRIC ENERGY	1637.803
PRESENT VALUE OF ANNUAL FOSSIL FUEL ENERGY	0
PRESENT VALUE OF FINAL SALVAGE	-1059.89

-----SUMMARY RESULTS-----

TOTAL PRESENT WORTH	31572.25
TOTAL ANNUALIZED COST	5090.059

PRESENT WORTH/INSTALLED CAPACITY	31,572 \$/KWH OF CAPACITY INSTALLED
LEVELIZED STORAGE COST	0.396 \$/KILOMETER-TRAVELED

XX

SEALED LEAD-ACID BATTERY-POWERED LIGHT-DUTY VAN

BATTERY STORAGE ECONOMIC ANALYSIS MODEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	Seal Pb-Acid	CYCLE LIFE (#)	750
APPLICATION	1-van	CYCLES/YEAR	130
SYSTEM SIZE (KWH)	1	ROUND TRIP EFFICIENCY	1
SYSTEM SIZE (KWE)	1		
ANNUAL ELECTRICITY CONSUMPTION (KWH/YR)		2393	
ANNUAL FOSSIL FUEL CONSUMPTION (MBTU/YR)		0	

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	1416 (\$/KWH)
BATTERY INSTALLATION	0 (\$/KWH)
ENERGY RELATED BOS	13225 (\$/KWH)
POWER RELATED BOS	0 (\$/KWE)
NET SALVAGE VALUE	142 (\$/KWH)
FINAL SALVAGE	1394 (\$)

-----OPERATING AND MAINTENANCE COST INPUTS-----

COST OF ELECTRICITY, \$/KWH	0.043	ANNUAL O&M COST, \$	727
COST OF FOSSIL FUEL, \$/MBTU	0		

*****EQUAL INTERVAL PERIODIC O&M*****

PERIODIC MAINTENANCE INTERVAL	6 (YEARS)
PERIODIC MAINTENANCE COST	387 (\$)

*****VARIED INTERVAL PERIODIC O&M*****

YEAR	COST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.060
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	10	TAX CREDIT	0.000
CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	VEHICLE TAX LIFE	5
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR VEHICLE	0.829
DEPRECIATION FACTOR FOR BATTERIES	0.829
CAPITAL RECOVERY FACTOR	0.135867
FIXED CHARGE RATE FOR VEHICLE	0.170117
FIXED CHARGE RATE FOR BATTERIES	0.170117

OVERNIGHT CONSTRUCTION COST	14641
1st YEAR OPERATING & MAINT. COST	727
1st YEAR EFFICIENCY ELECTRICITY COST	0
1st YEAR ANNUAL ELECTRICITY COST	103
1st YEAR ANNUAL FOSSIL FUEL COST	0

ANNUAL ENERGY STORED (KWH)	2393
ANNUAL KILOMETERS	12848

PRESENT VALUE OF INITIAL CAPITAL	14641
PRESENT VALUE OF NET REPLACEMENT CAPITAL	898.1197
PRESENT VALUE OF ANNUAL O&M	5350.783
PRESENT VALUE OF PERIODIC O&M	272.8197
PRESENT VALUE OF EFFICIENCY LOSS ENERGY	0
PRESENT VALUE OF ANNUAL ELECTRIC ENERGY	757.3455
PRESENT VALUE OF ANNUAL FOSSIL FUEL ENERGY	0
PRESENT VALUE OF FINAL SALVAGE	-734.341

-----SUMMARY RESULTS-----

TOTAL PRESENT WORTH	21185.72
TOTAL ANNUALIZED COST	3385.524

PRESENT WORTH/INSTALLED CAPACITY	21,186 \$/KWH OF CAPACITY INSTALLED
LEVELIZED STORAGE COST	0.264 \$/KILOMETER-TRAVELED

XX

ZINC-BROMINE BATTERY-POWERED LIGHT-DUTY VAN

BATTERY STORAGE ECONOMIC ANALYSIS MODEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	Zinc-Bromine	CYCLE LIFE (#)	750
APPLICATION	1-van	CYCLES/YEAR	130
SYSTEM SIZE (KWH)	1	ROUND TRIP EFFICIENCY	1
SYSTEM SIZE (KWE)	1		
ANNUAL ELECTRICITY CONSUMPTION (KWH/YR)		5172	
ANNUAL FOSSIL FUEL CONSUMPTION (MBTU/YR)		0	

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	2860 (\$/KWH)
BATTERY INSTALLATION	0 (\$/KWH)
ENERGY RELATED BOS	14093 (\$/KWH)
POWER RELATED BOS	0 (\$/KWE)
NET SALVAGE VALUE	286 (\$/KWH)
FINAL SALVAGE	1614 (\$)

-----OPERATING AND MAINTENANCE COST INPUTS-----

COST OF ELECTRICITY, \$/KWH	0.043	ANNUAL O&M COST, \$	993
COST OF FOSSIL FUEL, \$/MBTU	0		

*****EQUAL INTERVAL PERIODIC O&M*****

PERIODIC MAINTENANCE INTERVAL	6 (YEARS)
PERIODIC MAINTENANCE COST	410 (\$)

*****VARIED INTERVAL PERIODIC O&M*****

YEAR	COST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.060
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	10	TAX CREDIT	0.000
CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	VEHICLE TAX LIFE	5
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR VEHICLE	0.829
DEPRECIATION FACTOR FOR BATTERIES	0.829
CAPITAL RECOVERY FACTOR	0.135867
FIXED CHARGE RATE FOR VEHICLE	0.170117
FIXED CHARGE RATE FOR BATTERIES	0.170117

OVERNIGHT CONSTRUCTION COST	16953
1st YEAR OPERATING & MAINT. COST	993
1st YEAR EFFICIENCY ELECTRICITY COST	0
1st YEAR ANNUAL ELECTRICITY COST	222
1st YEAR ANNUAL FOSSIL FUEL COST	0

ANNUAL ENERGY STORED (KWH)	5172
ANNUAL KILOMETERS	12848

PRESENT VALUE OF INITIAL CAPITAL	16953
PRESENT VALUE OF NET REPLACEMENT CAPITAL	1814.568
PRESENT VALUE OF ANNUAL O&M	7308.566
PRESENT VALUE OF PERIODIC O&M	289.0338
PRESENT VALUE OF EFFICIENCY LOSS ENERGY	0
PRESENT VALUE OF ANNUAL ELECTRIC ENERGY	1636.853
PRESENT VALUE OF ANNUAL FOSSIL FUEL ENERGY	0
PRESENT VALUE OF FINAL SALVAGE	-850.235

-----SUMMARY RESULTS-----

TOTAL PRESENT WORTH	27151.78
TOTAL ANNUALIZED COST	4302.725

PRESENT WORTH/INSTALLED CAPACITY	27,152 \$/KWH OF CAPACITY INSTALLED
LEVELIZED STORAGE COST	0.335 \$/KILOMETER-TRAVELED

XX

SODIUM-SULFUR BATTERY-POWERED LIGHT-DUTY VAN

BATTERY STORAGE ECONOMIC ANALYSIS MODEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	Sodium-Sulfur	CYCLE LIFE (#)	750
APPLICATION	1-van	CYCLES/YEAR	130
SYSTEM SIZE (KWH)	1	ROUND TRIP EFFICIENCY	1
SYSTEM SIZE (KWE)	1		

ANNUAL ELECTRICITY CONSUMPTION (KWH/YR)	3035
ANNUAL FOSSIL FUEL CONSUMPTION (MBTU/YR)	0

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	5487 (\$/KWH)
BATTERY INSTALLATION	0 (\$/KWH)
ENERGY RELATED BOS	12888 (\$/KWH)
POWER RELATED BOS	0 (\$/KWE)
NET SALVAGE VALUE	549 (\$/KWH)
FINAL SALVAGE	1750 (\$)

-----OPERATING AND MAINTENANCE COST INPUTS-----

COST OF ELECTRICITY, \$/KWH	0.043	ANNUAL O&M COST, \$	948
COST OF FOSSIL FUEL, \$/MBTU	0		

*****EQUAL INTERVAL PERIODIC O&M*****

PERIODIC MAINTENANCE INTERVAL	6 (YEARS)
PERIODIC MAINTENANCE COST	371 (\$)

*****VARIED INTERVAL PERIODIC O&M*****

YEAR	COST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.060
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	10	TAX CREDIT	0.000
CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	VEHICLE TAX LIFE	5
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR VEHICLE	0.829
DEPRECIATION FACTOR FOR BATTERIES	0.829
CAPITAL RECOVERY FACTOR	0.135867
FIXED CHARGE RATE FOR VEHICLE	0.170117
FIXED CHARGE RATE FOR BATTERIES	0.170117

OVERNIGHT CONSTRUCTION COST	18375
1st YEAR OPERATING & MAINT. COST	948
1st YEAR EFFICIENCY ELECTRICITY COST	0
1st YEAR ANNUAL ELECTRICITY COST	131
1st YEAR ANNUAL FOSSIL FUEL COST	0

ANNUAL ENERGY STORED (KWH)	3035
ANNUAL KILOMETERS	12848

PRESENT VALUE OF INITIAL CAPITAL	18375
PRESENT VALUE OF NET REPLACEMENT CAPITAL	3481.095
PRESENT VALUE OF ANNUAL O&M	6977.362
PRESENT VALUE OF PERIODIC O&M	261.5403
PRESENT VALUE OF EFFICIENCY LOSS ENERGY	0
PRESENT VALUE OF ANNUAL ELECTRIC ENERGY	960.5281
PRESENT VALUE OF ANNUAL FOSSIL FUEL ENERGY	0
PRESENT VALUE OF FINAL SALVAGE	-921.878

-----SUMMARY RESULTS-----

TOTAL PRESENT WORTH	29133.64
TOTAL ANNUALIZED COST	4675.325

PRESENT WORTH/INSTALLED CAPACITY	29,134 \$/KWH OF CAPACITY INSTALLED
LEVELIZED STORAGE COST	0.364 \$/KILOMETER-TRAVELED

XX

SODIUM-SULFUR BATTERY-POWERED FULL-PERFORMANCE VAN

BATTERY STORAGE ECONOMIC ANALYSIS MODEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	Sodium-Sulfur	CYCLE LIFE (#)	750
APPLICATION	f-van	CYCLES/YEAR	130
SYSTEM SIZE (KWH)	1	ROUND TRIP EFFICIENCY	1
SYSTEM SIZE (KWE)	1		

ANNUAL ELECTRICITY CONSUMPTION (KWH/YR)	4158
ANNUAL FOSSIL FUEL CONSUMPTION (MBTU/YR)	0

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	6413 (\$/KWH)
BATTERY INSTALLATION	0 (\$/KWH)
ENERGY RELATED BOS	13192 (\$/KWH)
POWER RELATED BOS	0 (\$/KWE)
NET SALVAGE VALUE	641 (\$/KWH)
FINAL SALVAGE	1867 (\$)

-----OPERATING AND MAINTENANCE COST INPUTS-----

COST OF ELECTRICITY, \$/KWH	0.043	ANNUAL O&M COST, \$	969
COST OF FOSSIL FUEL, \$/MBTU	0		

*****EQUAL INTERVAL PERIODIC O&M*****

PERIODIC MAINTENANCE INTERVAL	6 (YEARS)
PERIODIC MAINTENANCE COST	386 (\$)

*****VARIED INTERVAL PERIODIC O&M*****

YEAR	CDST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.060
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	10	TAX CREDIT	0.000
CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	VEHICLE TAX LIFE	5
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR VEHICLE	0.829
DEPRECIATION FACTOR FOR BATTERIES	0.829
CAPITAL RECOVERY FACTOR	0.135867
FIXED CHARGE RATE FOR VEHICLE	0.170117
FIXED CHARGE RATE FOR BATTERIES	0.170117

OVERNIGHT CONSTRUCTION COST	19605
1st YEAR OPERATING & MAINT. COST	969
1st YEAR EFFICIENCY ELECTRICITY COST	0
1st YEAR ANNUAL ELECTRICITY COST	179
1st YEAR ANNUAL FOSSIL FUEL COST	0

ANNUAL ENERGY STORED (KWH)	4158
ANNUAL KILOMETERS	12848

PRESENT VALUE OF INITIAL CAPITAL	19605
PRESENT VALUE OF NET REPLACEMENT CAPITAL	4069.032
PRESENT VALUE OF ANNUAL O&M	7131.924
PRESENT VALUE OF PERIODIC O&M	272.1147
PRESENT VALUE OF EFFICIENCY LOSS ENERGY	0
PRESENT VALUE OF ANNUAL ELECTRIC ENERGY	1315.939
PRESENT VALUE OF ANNUAL FOSSIL FUEL ENERGY	0
PRESENT VALUE OF FINAL SALVAGE	-983.512

-----SUMMARY RESULTS-----

TOTAL PRESENT WORTH	31410.49
TOTAL ANNUALIZED COST	5044.829

PRESENT WORTH/INSTALLED CAPACITY	31,410 \$/KWH OF CAPACITY INSTALLED
LEVELIZED STORAGE COST	0.393 \$/KILOMETER-TRAVELED

XX

SODIUM-SULFUR BATTERY-POWERED FIVE-PASSENGER CAR

BATTERY STORAGE ECONOMIC ANALYSIS MODEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	Sodium-Sulfur	CYCLE LIFE (#)	750
APPLICATION	car	CYCLES/YEAR	42
SYSTEM SIZE (KWH)	1	ROUND TRIP EFFICIENCY	1
SYSTEM SIZE (KWE)	1		

ANNUAL ELECTRICITY CONSUMPTION (KWH/YR)	3616
ANNUAL FOSSIL FUEL CONSUMPTION (MBTU/YR)	0

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	10888 (\$/KWH)
BATTERY INSTALLATION	0 (\$/KWH)
ENERGY RELATED BOS	13354 (\$/KWH)
POWER RELATED BOS	0 (\$/KWE)
NET SALVAGE VALUE	1088 (\$/KWH)
FINAL SALVAGE	2309 (\$)

-----OPERATING AND MAINTENANCE COST INPUTS-----

COST OF ELECTRICITY, \$/KWH	0.043	ANNUAL O&M COST, \$	1039
COST OF FOSSIL FUEL, \$/MBTU	0		

*****EQUAL INTERVAL PERIODIC O&M*****

PERIODIC MAINTENANCE INTERVAL	6 (YEARS)
PERIODIC MAINTENANCE COST	620 (\$)

*****VARIED INTERVAL PERIODIC O&M*****

YEAR	COST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.060
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	10	TAX CREDIT	0.000
CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	VEHICLE TAX LIFE	5
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR VEHICLE	0.829
DEPRECIATION FACTOR FOR BATTERIES	0.829
CAPITAL RECOVERY FACTOR	0.135867
FIXED CHARGE RATE FOR VEHICLE	0.170117
FIXED CHARGE RATE FOR BATTERIES	0.170117

OVERNIGHT CONSTRUCTION COST	24242
1st YEAR OPERATING & MAINT. COST	1,039
1st YEAR EFFICIENCY ELECTRICITY COST	0
1st YEAR ANNUAL ELECTRICITY COST	155
1st YEAR ANNUAL FOSSIL FUEL COST	0

ANNUAL ENERGY STORED (KWH)	3616
ANNUAL KILOMETERS	16610

PRESENT VALUE OF INITIAL CAPITAL	24242
PRESENT VALUE OF NET REPLACEMENT CAPITAL	0
PRESENT VALUE OF ANNUAL O&M	7647.130
PRESENT VALUE OF PERIODIC O&M	437.0755
PRESENT VALUE OF EFFICIENCY LOSS ENERGY	0
PRESENT VALUE OF ANNUAL ELECTRIC ENERGY	1144.405
PRESENT VALUE OF ANNUAL FOSSIL FUEL ENERGY	0
PRESENT VALUE OF FINAL SALVAGE	-1216.35

-----SUMMARY RESULTS-----

TOTAL PRESENT WORTH	32254.25
TOTAL ANNUALIZED COST	5170.947

PRESENT WORTH/INSTALLED CAPACITY	32,254 \$/KWH OF CAPACITY INSTALLED
LEVELIZED STORAGE COST	0.311 \$/KILOMETER-TRAVELED

XX

LITHIUM-IRON SULFIDE BATTERY-POWERED LIGHT-DUTY VAN

BATTERY STORAGE ECONOMIC ANALYSIS MODEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	Lithium	CYCLE LIFE (#)	750
APPLICATION	1-van	CYCLES/YEAR	130
SYSTEM SIZE (KWH)	1	ROUND TRIP EFFICIENCY	1
SYSTEM SIZE (KWE)	1		
ANNUAL ELECTRICITY CONSUMPTION (KWH/YR)		3581	
ANNUAL FOSSIL FUEL CONSUMPTION (MBTU/YR)		0	

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	2217 (\$/KWH)
BATTERY INSTALLATION	0 (\$/KWH)
ENERGY RELATED BOS	13179 (\$/KWH)
POWER RELATED BOS	0 (\$/KWE)
NET SALVAGE VALUE	222 (\$/KWH)
FINAL SALVAGE	1466 (\$)

-----OPERATING AND MAINTENANCE COST INPUTS-----

COST OF ELECTRICITY, \$/KWH	0.043	ANNUAL O&M COST, \$	860
COST OF FOSSIL FUEL, \$/MBTU	0		

*****EQUAL INTERVAL PERIODIC O&M*****

PERIODIC MAINTENANCE INTERVAL	6 (YEARS)
PERIODIC MAINTENANCE COST	384 (\$)

*****VARIED INTERVAL PERIODIC O&M*****

YEAR	COST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.060
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	10	TAX CREDIT	0.000
CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	VEHICLE TAX LIFE	5
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR VEHICLE	0.829
DEPRECIATION FACTOR FOR BATTERIES	0.829
CAPITAL RECOVERY FACTOR	0.135867
FIXED CHARGE RATE FOR VEHICLE	0.170117
FIXED CHARGE RATE FOR BATTERIES	0.170117

OVERNIGHT CONSTRUCTION COST	15396
1st YEAR OPERATING & MAINT. COST	860
1st YEAR EFFICIENCY ELECTRICITY COST	0
1st YEAR ANNUAL ELECTRICITY COST	154
1st YEAR ANNUAL FOSSIL FUEL COST	0

ANNUAL ENERGY STORED (KWH)	3581
ANNUAL KILOMETERS	12848

PRESENT VALUE OF INITIAL CAPITAL	15396
PRESENT VALUE OF NET REPLACEMENT CAPITAL	1406.396
PRESENT VALUE OF ANNUAL O&M	6329.674
PRESENT VALUE OF PERIODIC O&M	270.7048
PRESENT VALUE OF EFFICIENCY LOSS ENERGY	0
PRESENT VALUE OF ANNUAL ELECTRIC ENERGY	1133.328
PRESENT VALUE OF ANNUAL FOSSIL FUEL ENERGY	0
PRESENT VALUE OF FINAL SALVAGE	-772.270

-----SUMMARY RESULTS-----

TOTAL PRESENT WORTH	23763.83
TOTAL ANNUALIZED COST	3777.774

PRESENT WORTH/INSTALLED CAPACITY	23,764 \$/KWH OF CAPACITY INSTALLED
LEVELIZED STORAGE COST	0.294 \$/KILOMETER-TRAVELED

XX

LITHIUM-IRON SULFIDE BATTERY-POWERED FULL-PERFORMANCE VAN

BATTERY STORAGE ECONOMIC ANALYSIS MODEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	Lithium	CYCLE LIFE (#)	1000
APPLICATION	f-van	CYCLES/YEAR	130
SYSTEM SIZE (KWH)	1	ROUND TRIP EFFICIENCY	1
SYSTEM SIZE (KWE)	1		

ANNUAL ELECTRICITY CONSUMPTION (KWH/YR)	4752
ANNUAL FOSSIL FUEL CONSUMPTION (MBTU/YR)	0

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	5445 (\$/KWH)
BATTERY INSTALLATION	0 (\$/KWH)
ENERGY RELATED BOS	13279 (\$/KWH)
POWER RELATED BOS	0 (\$/KWE)
NET SALVAGE VALUE	545 (\$/KWH)
FINAL SALVAGE	1784 (\$)

-----OPERATING AND MAINTENANCE COST INPUTS-----

COST OF ELECTRICITY, \$/KWH	0.043	ANNUAL O&M COST, \$	873
COST OF FOSSIL FUEL, \$/MBTU	0		

*****EQUAL INTERVAL PERIODIC O&M*****

PERIODIC MAINTENANCE INTERVAL	6 (YEARS)
PERIODIC MAINTENANCE COST	394 (\$)

*****VARIED INTERVAL PERIODIC O&M*****

YEAR	COST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.060
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	10	TAX CREDIT	0.000
CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	VEHICLE TAX LIFE	5
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR VEHICLE	0.829
DEPRECIATION FACTOR FOR BATTERIES	0.829
CAPITAL RECOVERY FACTOR	0.135867
FIXED CHARGE RATE FOR VEHICLE	0.170117
FIXED CHARGE RATE FOR BATTERIES	0.170117

OVERNIGHT CONSTRUCTION COST	18724
1st YEAR OPERATING & MAINT. COST	873
1st YEAR EFFICIENCY ELECTRICITY COST	0
1st YEAR ANNUAL ELECTRICITY COST	204
1st YEAR ANNUAL FOSSIL FUEL COST	0

ANNUAL ENERGY STORED (KWH)	4752
ANNUAL KILOMETERS	12848

PRESENT VALUE OF INITIAL CAPITAL	18724
PRESENT VALUE OF NET REPLACEMENT CAPITAL	3074.320
PRESENT VALUE OF ANNUAL O&M	6425.355
PRESENT VALUE OF PERIODIC O&M	277.7544
PRESENT VALUE OF EFFICIENCY LOSS ENERGY	0
PRESENT VALUE OF ANNUAL ELECTRIC ENERGY	1503.930
PRESENT VALUE OF ANNUAL FOSSIL FUEL ENERGY	0
PRESENT VALUE OF FINAL SALVAGE	-939.788

-----SUMMARY RESULTS-----

TOTAL PRESENT WORTH	29065.57
TOTAL ANNUALIZED COST	4663.483

PRESENT WORTH/INSTALLED CAPACITY	29,066 \$/KWH OF CAPACITY INSTALLED
LEVELIZED STORAGE COST	0.363 \$/KILOMETER-TRAVELED

XX

LITHIUM-IRON SULFIDE BATTERY-POWERED FIVE-PASSENGER CAR

BATTERY STORAGE ECONOMIC ANALYSIS MODEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	Lithium	CYCLE LIFE (#)	750
APPLICATION	car	CYCLES/YEAR	42
SYSTEM SIZE (KWH)	1	ROUND TRIP EFFICIENCY	1
SYSTEM SIZE (KWE)	1		

ANNUAL ELECTRICITY CONSUMPTION (KWH/YR)	4481
ANNUAL FOSSIL FUEL CONSUMPTION (MBTU/YR)	0

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	8671 (\$/KWH)
BATTERY INSTALLATION	0 (\$/KWH)
ENERGY RELATED BOS	14382 (\$/KWH)
POWER RELATED BOS	0 (\$/KWE)
NET SALVAGE VALUE	867 (\$/KWH)
FINAL SALVAGE	2169 (\$)

-----OPERATING AND MAINTENANCE COST INPUTS-----

COST OF ELECTRICITY, \$/KWH	0.043	ANNUAL O&M COST, \$	924
COST OF FOSSIL FUEL, \$/MBTU	0		

*****EQUAL INTERVAL PERIODIC O&M*****

PERIODIC MAINTENANCE INTERVAL	6 (YEARS)
PERIODIC MAINTENANCE COST	664 (\$)

*****VARIED INTERVAL PERIODIC O&M*****

YEAR	COST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.060
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	10	TAX CREDIT	0.000
CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	VEHICLE TAX LIFE	5
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR VEHICLE	0.829
DEPRECIATION FACTOR FOR BATTERIES	0.829
CAPITAL RECOVERY FACTOR	0.135867
FIXED CHARGE RATE FOR VEHICLE	0.170117
FIXED CHARGE RATE FOR BATTERIES	0.170117

OVERNIGHT CONSTRUCTION COST	23053
1st YEAR OPERATING & MAINT. COST	924
1st YEAR EFFICIENCY ELECTRICITY COST	0
1st YEAR ANNUAL ELECTRICITY COST	193
1st YEAR ANNUAL FOSSIL FUEL COST	0

ANNUAL ENERGY STORED (KWH)	4481
ANNUAL KILOMETERS	16610

PRESENT VALUE OF INITIAL CAPITAL	23053
PRESENT VALUE OF NET REPLACEMENT CAPITAL	0
PRESENT VALUE OF ANNUAL O&M	6800.720
PRESENT VALUE OF PERIODIC O&M	468.0937
PRESENT VALUE OF EFFICIENCY LOSS ENERGY	0
PRESENT VALUE OF ANNUAL ELECTRIC ENERGY	1418.163
PRESENT VALUE OF ANNUAL FOSSIL FUEL ENERGY	0
PRESENT VALUE OF FINAL SALVAGE	-1142.60

-----SUMMARY RESULTS-----

TOTAL PRESENT WORTH	30597.37
TOTAL ANNUALIZED COST	4907.633

PRESENT WORTH/INSTALLED CAPACITY	30,597 \$/KWH OF CAPACITY INSTALLED
LEVELIZED STORAGE COST	0.295 \$/KILOMETER-TRAVELED

XX

ALUMINUM-AIR BATTERY-POWERED FIVE-PASSENGER CAR

BATTERY STORAGE ECONOMIC ANALYSIS MODEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	Al-Air	CYCLE LIFE (#)	1000
APPLICATION	car	CYCLES/YEAR	42
SYSTEM SIZE (KWH)	1	ROUND TRIP EFFICIENCY	1
SYSTEM SIZE (KWE)	1		

ANNUAL ELECTRICITY CONSUMPTION (KWH/YR)	0
ANNUAL FOSSIL FUEL CONSUMPTION (MBTU/YR)	1177

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	8108 (\$/KWH)
BATTERY INSTALLATION	0 (\$/KWH)
ENERGY RELATED BOS	14927 (\$/KWH)
POWER RELATED BOS	0 (\$/KWE)
NET SALVAGE VALUE	B11 (\$/KWH)
FINAL SALVAGE	1672 (\$)

-----OPERATING AND MAINTENANCE COST INPUTS-----

COST OF ELECTRICITY, \$/KWH	0.043	ANNUAL O&M COST, \$	846
COST OF FOSSIL FUEL, \$/MBTU	2.64		

*****EQUAL INTERVAL PERIODIC O&M*****

PERIODIC MAINTENANCE INTERVAL	6 (YEARS)
PERIODIC MAINTENANCE COST	697 (\$)

*****VARIED INTERVAL PERIODIC O&M*****

YEAR	COST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.060
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	10	TAX CREDIT	0.000
CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	VEHICLE TAX LIFE	5
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR VEHICLE	0.829
DEPRECIATION FACTOR FOR BATTERIES	0.829
CAPITAL RECOVERY FACTOR	0.135867
FIXED CHARGE RATE FOR VEHICLE	0.170117
FIXED CHARGE RATE FOR BATTERIES	0.170117

OVERNIGHT CONSTRUCTION COST	23035
1st YEAR OPERATING & MAINT. COST	846
1st YEAR EFFICIENCY ELECTRICITY COST	0
1st YEAR ANNUAL ELECTRICITY COST	0
1st YEAR ANNUAL FOSSIL FUEL COST	3107.28

ANNUAL ENERGY STORED (KWH)	0
ANNUAL KILOMETERS	16610

PRESENT VALUE OF INITIAL CAPITAL	23035
PRESENT VALUE OF NET REPLACEMENT CAPITAL	0
PRESENT VALUE OF ANNUAL O&M	6226.633
PRESENT VALUE OF PERIODIC O&M	491.3574
PRESENT VALUE OF EFFICIENCY LOSS ENERGY	0
PRESENT VALUE OF ANNUAL ELECTRIC ENERGY	0
PRESENT VALUE OF ANNUAL FOSSIL FUEL ENERGY	22869.85
PRESENT VALUE OF FINAL SALVAGE	-880.788

-----SUMMARY RESULTS-----

TOTAL PRESENT WORTH	51742.05
TOTAL ANNUALIZED COST	7818.99

PRESENT WORTH/INSTALLED CAPACITY	51,742 \$/KWH OF CAPACITY INSTALLED
LEVELIZED STORAGE COST	0.471 \$/KILOMETER-TRAVELED

XX

PROTON EXCHANGE MEMBRANE FUEL CELL-POWERED FIVE-PASSENGER CAR

BATTERY STORAGE ECONOMIC ANALYSIS MODEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	PEM	CYCLE LIFE (#)	1000
APPLICATION	car	CYCLES/YEAR	42
SYSTEM SIZE (KWH)	1	ROUND TRIP EFFICIENCY	1
SYSTEM SIZE (KWE)	1		
ANNUAL ELECTRICITY CONSUMPTION (KWH/YR)		0	
ANNUAL FOSSIL FUEL CONSUMPTION (MBTU/YR)		1353	

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	0 (\$/KWH)
BATTERY INSTALLATION	0 (\$/KWH)
ENERGY RELATED BOS	13419 (\$/KWH)
POWER RELATED BOS	0 (\$/KWE)
NET SALVAGE VALUE	0 (\$/KWH)
FINAL SALVAGE	2128 (\$)

-----OPERATING AND MAINTENANCE COST INPUTS-----

COST OF ELECTRICITY, \$/KWH	0.043	ANNUAL O&M COST, \$	1096
COST OF FOSSIL FUEL, \$/MBTU	0.45		

*****EQUAL INTERVAL PERIODIC O&M*****

PERIODIC MAINTENANCE INTERVAL	6 (YEARS)
PERIODIC MAINTENANCE COST	561 (\$)

*****VARIED INTERVAL PERIODIC O&M*****

YEAR	COST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.060
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	10	TAX CREDIT	0.000
CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	VEHICLE TAX LIFE	5
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0.028		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR VEHICLE	0.829
DEPRECIATION FACTOR FOR BATTERIES	0.829
CAPITAL RECOVERY FACTOR	0.135867
FIXED CHARGE RATE FOR VEHICLE	0.170117
FIXED CHARGE RATE FOR BATTERIES	0.170117

OVERNIGHT CONSTRUCTION COST	13419
1st YEAR OPERATING & MAINT. COST	1,096
1st YEAR EFFICIENCY ELECTRICITY COST	0
1st YEAR ANNUAL ELECTRICITY COST	0
1st YEAR ANNUAL FOSSIL FUEL COST	738.6898

ANNUAL ENERGY STORED (KWH)	0
ANNUAL KILOMETERS	16610

PRESENT VALUE OF INITIAL CAPITAL	13419
PRESENT VALUE OF NET REPLACEMENT CAPITAL	0
PRESENT VALUE OF ANNUAL O&M	8066.655
PRESENT VALUE OF PERIODIC O&M	395.4828
PRESENT VALUE OF EFFICIENCY LOSS ENERGY	0
PRESENT VALUE OF ANNUAL ELECTRIC ENERGY	0
PRESENT VALUE OF ANNUAL FOSSIL FUEL ENERGY	6265.042
PRESENT VALUE OF FINAL SALVAGE	-1121.00

-----SUMMARY RESULTS-----

TOTAL PRESENT WORTH	27025.17
TOTAL ANNUALIZED COST	4093.061

PRESENT WORTH/INSTALLED CAPACITY	27,025 \$/KWH OF CAPACITY INSTALLED
LEVELIZED STORAGE COST	0.246 \$/KILOMETER-TRAVELED

XX

INTERNAL COMBUSTION ENGINE-POWERED VAN: LOW WORLD OIL PRICE

BATTERY STORAGE ECONOMIC ANALYSIS MODEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	ICE	CYCLE LIFE (#)	1500
APPLICATION	van	CYCLES/YEAR	130
SYSTEM SIZE (KWH)	1	ROUND TRIP EFFICIENCY	1
SYSTEM SIZE (KWE)	1		
ANNUAL ELECTRICITY CONSUMPTION (KWH/YR)		0	
ANNUAL FOSSIL FUEL CONSUMPTION (MBTU/YR)		53.31	

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	0 (\$/KWH)
BATTERY INSTALLATION	0 (\$/KWH)
ENERGY RELATED BOS	10795 (\$/KWH)
POWER RELATED BOS	0 (\$/KWE)
NET SALVAGE VALUE	0 (\$/KWH)
FINAL SALVAGE	1028 (\$)

-----OPERATING AND MAINTENANCE COST INPUTS-----

COST OF ELECTRICITY, \$/KWH	0.043	ANNUAL O&M COST, \$	1099
COST OF FOSSIL FUEL, \$/MBTU	7.82		

*****EQUAL INTERVAL PERIODIC O&M*****

PERIODIC MAINTENANCE INTERVAL	6 (YEARS)
PERIODIC MAINTENANCE COST	340 (\$)

*****VARIED INTERVAL PERIODIC O&M*****

YEAR	COST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.060
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	10	TAX CREDIT	0.000
CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	VEHICLE TAX LIFE	5
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0.018		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR VEHICLE	0.829
DEPRECIATION FACTOR FOR BATTERIES	0.829
CAPITAL RECOVERY FACTOR	0.135867
FIXED CHARGE RATE FOR VEHICLE	0.170117
FIXED CHARGE RATE FOR BATTERIES	0.170117

OVERNIGHT CONSTRUCTION COST	10795
1st YEAR OPERATING & MAINT. COST	1,099
1st YEAR EFFICIENCY ELECTRICITY COST	0
1st YEAR ANNUAL ELECTRICITY COST	0
1st YEAR ANNUAL FOSSIL FUEL COST	472.3347

ANNUAL ENERGY STORED (KWH)	0
ANNUAL KILOMETERS	12848

PRESENT VALUE OF INITIAL CAPITAL	10795
PRESENT VALUE OF NET REPLACEMENT CAPITAL	0
PRESENT VALUE OF ANNUAL O&M	8088.735
PRESENT VALUE OF PERIODIC O&M	239.6865
PRESENT VALUE OF EFFICIENCY LOSS ENERGY	0
PRESENT VALUE OF ANNUAL ELECTRIC ENERGY	0
PRESENT VALUE OF ANNUAL FOSSIL FUEL ENERGY	3807.189
PRESENT VALUE OF FINAL SALVAGE	-541.537

-----SUMMARY RESULTS-----

TOTAL PRESENT WORTH	22389.07
TOTAL ANNUALIZED COST	3393.138

PRESENT WORTH/INSTALLED CAPACITY	22,389 \$/KWH OF CAPACITY INSTALLED
LEVELIZED STORAGE COST	0.264 \$/KILOMETER-TRAVELED

XX

INTERNAL COMBUSTION ENGINE-POWERED VAN: NOMINAL WORLD OIL PRICE

BATTERY STORAGE ECONOMIC ANALYSIS MODEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	ICE	CYCLE LIFE (#)	1500
APPLICATION	van	CYCLES/YEAR	130
SYSTEM SIZE (KWH)	1	ROUND TRIP EFFICIENCY	1
SYSTEM SIZE (KWE)	1		

ANNUAL ELECTRICITY CONSUMPTION (KWH/YR)	0
ANNUAL FOSSIL FUEL CONSUMPTION (MBTU/YR)	53.31

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	0 (\$/KWH)
BATTERY INSTALLATION	0 (\$/KWH)
ENERGY RELATED BOS	10795 (\$/KWH)
POWER RELATED BOS	0 (\$/KWE)
NET SALVAGE VALUE	0 (\$/KWH)
FINAL SALVAGE	1028 (\$)

-----OPERATING AND MAINTENANCE COST INPUTS-----

COST OF ELECTRICITY, \$/KWH	0.043	ANNUAL O&M COST, \$	1099
COST OF FOSSIL FUEL, \$/MBTU	7.82		

*****EQUAL INTERVAL PERIODIC O&M*****

PERIODIC MAINTENANCE INTERVAL	6 (YEARS)
PERIODIC MAINTENANCE COST	340 (\$)

*****VARIED INTERVAL PERIODIC O&M*****

YEAR	COST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.060
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	10	TAX CREDIT	0.000
CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	VEHICLE TAX LIFE	5
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0.028		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR VEHICLE	0.829
DEPRECIATION FACTOR FOR BATTERIES	0.829
CAPITAL RECOVERY FACTOR	0.135867
FIXED CHARGE RATE FOR VEHICLE	0.170117
FIXED CHARGE RATE FOR BATTERIES	0.170117

OVERNIGHT CONSTRUCTION COST	10795
1st YEAR OPERATING & MAINT. COST	1,099
1st YEAR EFFICIENCY ELECTRICITY COST	0
1st YEAR ANNUAL ELECTRICITY COST	0
1st YEAR ANNUAL FOSSIL FUEL COST	505.7865

ANNUAL ENERGY STORED (KWH)	0
ANNUAL KILOMETERS	12848

PRESENT VALUE OF INITIAL CAPITAL	10795
PRESENT VALUE OF NET REPLACEMENT CAPITAL	0
PRESENT VALUE OF ANNUAL O&M	8088.735
PRESENT VALUE OF PERIODIC O&M	239.6865
PRESENT VALUE OF EFFICIENCY LOSS ENERGY	0
PRESENT VALUE OF ANNUAL ELECTRIC ENERGY	0
PRESENT VALUE OF ANNUAL FOSSIL FUEL ENERGY	4289.721
PRESENT VALUE OF FINAL SALVAGE	-541.537

-----SUMMARY RESULTS-----

TOTAL PRESENT WORTH	22871.60
TOTAL ANNUALIZED COST	3458.699

PRESENT WORTH/INSTALLED CAPACITY	22,872 \$/KWH OF CAPACITY INSTALLED
LEVELIZED STORAGE COST	0.269 \$/KILOMETER-TRAVELED

XX

INTERNAL COMBUSTION ENGINE-POWERED VAN: HIGH WORLD OIL PRICE

BATTERY STORAGE ECONOMIC ANALYSIS MODEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	ICE	CYCLE LIFE (#)	1500
APPLICATION	van	CYCLES/YEAR	130
SYSTEM SIZE (KWH)	1	ROUND TRIP EFFICIENCY	1
SYSTEM SIZE (KWE)	1		

ANNUAL ELECTRICITY CONSUMPTION (KWH/YR)	0
ANNUAL FOSSIL FUEL CONSUMPTION (MBTU/YR)	53.31

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	0 (\$/KWH)
BATTERY INSTALLATION	0 (\$/KWH)
ENERGY RELATED BOS	10795 (\$/KWH)
POWER RELATED BOS	0 (\$/KWE)
NET SALVAGE VALUE	0 (\$/KWH)
FINAL SALVAGE	1028 (\$)

-----OPERATING AND MAINTENANCE COST INPUTS-----

COST OF ELECTRICITY, \$/KWH	0.043	ANNUAL O&M COST, \$	1099
COST OF FOSSIL FUEL, \$/MBTU	7.82		

*****EQUAL INTERVAL PERIODIC O&M*****

PERIODIC MAINTENANCE INTERVAL	6 (YEARS)
PERIODIC MAINTENANCE COST	340 (\$)

*****VARIED INTERVAL PERIODIC O&M*****

YEAR	COST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.060
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	10	TAX CREDIT	0.000
CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	VEHICLE TAX LIFE	5
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0.042		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR VEHICLE	0.829
DEPRECIATION FACTOR FOR BATTERIES	0.829
CAPITAL RECOVERY FACTOR	0.135867
FIXED CHARGE RATE FOR VEHICLE	0.170117
FIXED CHARGE RATE FOR BATTERIES	0.170117

OVERNIGHT CONSTRUCTION COST	10795
1st YEAR OPERATING & MAINT. COST	1,099
1st YEAR EFFICIENCY ELECTRICITY COST	0
1st YEAR ANNUAL ELECTRICITY COST	0
1st YEAR ANNUAL FOSSIL FUEL COST	556.0187

ANNUAL ENERGY STORED (KWH)	0
ANNUAL KILOMETERS	12848

PRESENT VALUE OF INITIAL CAPITAL	10795
PRESENT VALUE OF NET REPLACEMENT CAPITAL	0
PRESENT VALUE OF ANNUAL O&M	8088.735
PRESENT VALUE OF PERIODIC O&M	239.6865
PRESENT VALUE OF EFFICIENCY LOSS ENERGY	0
PRESENT VALUE OF ANNUAL ELECTRIC ENERGY	0
PRESENT VALUE OF ANNUAL FOSSIL FUEL ENERGY	5066.464
PRESENT VALUE OF FINAL SALVAGE	-541.537

-----SUMMARY RESULTS-----

TOTAL PRESENT WORTH	23648.34
TOTAL ANNUALIZED COST	3564.233

PRESENT WORTH/INSTALLED CAPACITY	23,648 \$/KWH OF CAPACITY INSTALLED
LEVELIZED STORAGE COST	0.277 \$/KILOMETER-TRAVELED

XX

INTERNAL COMBUSTION ENGINE-POWERED FIVE-PASSENGER CAR: LOW WORLD OIL PRICE

BATTERY STORAGE ECONOMIC ANALYSIS MODEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	ICE	CYCLE LIFE (#)	1000
APPLICATION	car	CYCLES/YEAR	42
SYSTEM SIZE (KWH)	1	ROUND TRIP EFFICIENCY	1
SYSTEM SIZE (KWE)	1		

ANNUAL ELECTRICITY CONSUMPTION (KWH/YR)	0
ANNUAL FOSSIL FUEL CONSUMPTION (MBTU/YR)	53.31

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	0 (\$/KWH)
BATTERY INSTALLATION	0 (\$/KWH)
ENERGY RELATED BOS	9161 (\$/KWH)
POWER RELATED BOS	0 (\$/KWE)
NET SALVAGE VALUE	0 (\$/KWH)
FINAL SALVAGE	872 (\$)

-----OPERATING AND MAINTENANCE COST INPUTS-----

COST OF ELECTRICITY, \$/KWH	0.043	ANNUAL O&M COST, \$	1186
COST OF FOSSIL FUEL, \$/MBTU	7.82		

*****EQUAL INTERVAL PERIODIC O&M*****

PERIODIC MAINTENANCE INTERVAL	6 (YEARS)
PERIODIC MAINTENANCE COST	507 (\$)

*****VARIED INTERVAL PERIODIC O&M*****

YEAR	COST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.060
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	10	TAX CREDIT	0.000
CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	VEHICLE TAX LIFE	5
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0.018		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR VEHICLE	0.829
DEPRECIATION FACTOR FOR BATTERIES	0.829
CAPITAL RECOVERY FACTOR	0.135867
FIXED CHARGE RATE FOR VEHICLE	0.170117
FIXED CHARGE RATE FOR BATTERIES	0.170117

OVERNIGHT CONSTRUCTION COST	9161
1st YEAR OPERATING & MAINT. COST	1,186
1st YEAR EFFICIENCY ELECTRICITY COST	0
1st YEAR ANNUAL ELECTRICITY COST	0
1st YEAR ANNUAL FOSSIL FUEL COST	472.3347

ANNUAL ENERGY STORED (KWH)	0
ANNUAL KILOMETERS	16610

PRESENT VALUE OF INITIAL CAPITAL	9161
PRESENT VALUE OF NET REPLACEMENT CAPITAL	0
PRESENT VALUE OF ANNUAL O&M	8729.063
PRESENT VALUE OF PERIODIC O&M	357.4149
PRESENT VALUE OF EFFICIENCY LOSS ENERGY	0
PRESENT VALUE OF ANNUAL ELECTRIC ENERGY	0
PRESENT VALUE OF ANNUAL FOSSIL FUEL ENERGY	3807.189
PRESENT VALUE OF FINAL SALVAGE	-459.358

-----SUMMARY RESULTS-----

TOTAL PRESENT WORTH	21595.30
TOTAL ANNUALIZED COST	3232.141

PRESENT WORTH/INSTALLED CAPACITY	21,595 \$/KWH OF CAPACITY INSTALLED
LEVELIZED STORAGE COST	0.195 \$/KILOMETER-TRAVELED

XX

INTERNAL COMBUSTION ENGINE-POWERED FIVE-PASSENGER CAR: NOMINAL WORLD OIL PRICE

BATTERY STORAGE ECONOMIC ANALYSIS MODEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	ICE	CYCLE LIFE (#)	1000
APPLICATION	car	CYCLES/YEAR	42
SYSTEM SIZE (KWH)	1	ROUND TRIP EFFICIENCY	1
SYSTEM SIZE (KWE)	1		
ANNUAL ELECTRICITY CONSUMPTION (KWH/YR)		0	
ANNUAL FOSSIL FUEL CONSUMPTION (MBTU/YR)		53.31	

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	0 (\$/KWH)
BATTERY INSTALLATION	0 (\$/KWH)
ENERGY RELATED BOS	9161 (\$/KWH)
POWER RELATED BOS	0 (\$/KWE)
NET SALVAGE VALUE	0 (\$/KWH)
FINAL SALVAGE	872 (\$)

-----OPERATING AND MAINTENANCE COST INPUTS-----

COST OF ELECTRICITY, \$/KWH	0.043	ANNUAL O&M COST, \$	1186
COST OF FOSSIL FUEL, \$/MBTU	7.82		

*****EQUAL INTERVAL PERIODIC O&M*****

PERIODIC MAINTENANCE INTERVAL	6 (YEARS)
PERIODIC MAINTENANCE COST	507 (\$)

*****VARIED INTERVAL PERIODIC O&M*****

YEAR	COST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.060
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	10	TAX CREDIT	0.000
CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	VEHICLE TAX LIFE	5
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0.028		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR VEHICLE	0.829
DEPRECIATION FACTOR FOR BATTERIES	0.829
CAPITAL RECOVERY FACTOR	0.135867
FIXED CHARGE RATE FOR VEHICLE	0.170117
FIXED CHARGE RATE FOR BATTERIES	0.170117

OVERNIGHT CONSTRUCTION COST	9161
1st YEAR OPERATING & MAINT. COST	1,186
1st YEAR EFFICIENCY ELECTRICITY COST	0
1st YEAR ANNUAL ELECTRICITY COST	0
1st YEAR ANNUAL FOSSIL FUEL COST	505.7865

ANNUAL ENERGY STORED (KWH)	0
ANNUAL KILOMETERS	16610

PRESENT VALUE OF INITIAL CAPITAL	9161
PRESENT VALUE OF NET REPLACEMENT CAPITAL	0
PRESENT VALUE OF ANNUAL O&M	8729.063
PRESENT VALUE OF PERIODIC O&M	357.4149
PRESENT VALUE OF EFFICIENCY LOSS ENERGY	0
PRESENT VALUE OF ANNUAL ELECTRIC ENERGY	0
PRESENT VALUE OF ANNUAL FOSSIL FUEL ENERGY	4289.721
PRESENT VALUE OF FINAL SALVAGE	-459.358

-----SUMMARY RESULTS-----

TOTAL PRESENT WORTH	22077.84
TOTAL ANNUALIZED COST	3297.702

PRESENT WORTH/INSTALLED CAPACITY	22,078 \$/KWH OF CAPACITY INSTALLED
LEVELIZED STORAGE COST	0.199 \$/KILOMETER-TRAVELED

XX

INTERNAL COMBUSTION ENGINE-POWERED FIVE-PASSENGER CAR: HIGH WORLD OIL PRICE

BATTERY STORAGE ECONOMIC ANALYSIS MODEL

-----SYSTEM DESCRIPTION INPUTS-----

BATTERY TYPE	ICE	CYCLE LIFE (#)	1000
APPLICATION	car	CYCLES/YEAR	42
SYSTEM SIZE (KWH)	1	ROUND TRIP EFFICIENCY	1
SYSTEM SIZE (KWE)	1		
ANNUAL ELECTRICITY CONSUMPTION (KWH/YR)		0	
ANNUAL FOSSIL FUEL CONSUMPTION (MBTU/YR)		53.31	

-----CAPITAL COST INPUTS-----

BATTERY PURCHASE	0 (\$/KWH)
BATTERY INSTALLATION	0 (\$/KWH)
ENERGY RELATED BOS	9161 (\$/KWH)
POWER RELATED BOS	0 (\$/KWE)
NET SALVAGE VALUE	0 (\$/KWH)
FINAL SALVAGE	872 (\$)

-----OPERATING AND MAINTENANCE COST INPUTS-----

COST OF ELECTRICITY, \$/KWH	0.043	ANNUAL O&M COST, \$	1186
COST OF FOSSIL FUEL, \$/MBTU	7.82		

*****EQUAL INTERVAL PERIODIC O&M*****

PERIODIC MAINTENANCE INTERVAL	6 (YEARS)
PERIODIC MAINTENANCE COST	507 (\$)

*****VARIED INTERVAL PERIODIC O&M*****

YEAR	COST, \$	YEAR	COST, \$	YEAR	COST, \$
1	0	8	0	15	0
2	0	9	0	16	0
3	0	10	0	17	0
4	0	11	0	18	0
5	0	12	0	19	0
6	0	13	0	20	0
7	0	14	0		

-----FINANCIAL INPUTS-----

PRICE YEAR	1988	DISCOUNT RATE	0.060
1st OPERATIONAL YEAR	1995	TAX RATE	0.380
SYSTEM LIFE (YRS)	10	TAX CREDIT	0.000
CAPITAL ESCALATION RATE	0	BATTERY TAX LIFE	5
O&M ESCALATION RATE	0	VEHICLE TAX LIFE	5
ELECTRICITY ESCALATION RATE	0	OTHER TAX RATE	0.020
FOSSIL FUEL ESCALATION RATE	0.042		
GENERAL INFLATION RATE	0.06		

-----INTERMEDIATE OUTPUTS-----

DEPRECIATION FACTOR FOR VEHICLE	0.829
DEPRECIATION FACTOR FOR BATTERIES	0.829
CAPITAL RECOVERY FACTOR	0.135867
FIXED CHARGE RATE FOR VEHICLE	0.170117
FIXED CHARGE RATE FOR BATTERIES	0.170117

OVERNIGHT CONSTRUCTION COST	9161
1st YEAR OPERATING & MAINT. COST	1,186
1st YEAR EFFICIENCY ELECTRICITY COST	0
1st YEAR ANNUAL ELECTRICITY COST	0
1st YEAR ANNUAL FOSSIL FUEL COST	556.0187

ANNUAL ENERGY STORED (KWH)	0
ANNUAL KILOMETERS	16610

PRESENT VALUE OF INITIAL CAPITAL	9161
PRESENT VALUE OF NET REPLACEMENT CAPITAL	0
PRESENT VALUE OF ANNUAL O&M	8729.063
PRESENT VALUE OF PERIODIC O&M	357.4149
PRESENT VALUE OF EFFICIENCY LOSS ENERGY	0
PRESENT VALUE OF ANNUAL ELECTRIC ENERGY	0
PRESENT VALUE OF ANNUAL FOSSIL FUEL ENERGY	5066.464
PRESENT VALUE OF FINAL SALVAGE	-459.358

-----SUMMARY RESULTS-----

TOTAL PRESENT WORTH	22854.58
TOTAL ANNUALIZED COST	3403.236

PRESENT WORTH/INSTALLED CAPACITY	22,855 \$/KWH OF CAPACITY INSTALLED
LEVELIZED STORAGE COST	0.205 \$/KILOMETER-TRAVELED

XX

APPENDIX J

ECONOMIC ANALYSIS METHODOLOGY

APPENDIX J

ECONOMIC ANALYSIS METHODOLOGY

The economic methodology used for the determination of levelized output cost, either cents/kWh or cents/km-traveled is based on a real-1988-dollar analysis, as opposed to a nominal-dollar analysis. The basic formula for calculating the unit output cost per kWh for the load-leveling and stand-alone applications is as follows:

$$(P_{pw})(FCR_p) + (B_{pw})(FCR_b) + (CRF)(OC_{pw}) = AC \quad (J.1)$$

where P_{pw} = the present worth of the plant capital cost, excluding batteries

FCR_p = the annualized fixed charge rate for plant capital

B_{pw} = the present worth of initial and replacement battery purchase and installation, along with all lifetime salvage

FCR_b = the annualized fixed charge rate for batteries

CRF = the capital recovery factor

OC_{pw} = the present worth of all annual and intermittent operating costs, efficiency loss electricity, stored electricity, auxiliary electricity, and fossil fuel

AC = the total annualized cost of electricity produced.

The total annualized cost is then divided by the number of annual kWh retrieved from storage to yield a levelized output cost per kWh. The levelized cost per kilometer-traveled is calculated in a similar manner. The difference is both batteries and the vehicle are multiplied by the same fixed charge rate (FCR), and the total annualized cost is divided by the number of kilometers traveled annually to generate the levelized cost per kilometer-traveled.

The values for P_{pw} , B_{pw} , and OC_{pw} depend on the costs associated with the particular technologies and applications discussed in the technology/

application sections of this document. The FCR is the factor which, when multiplied by the present value of the capital investment, determines the contribution of the capital investment toward the annualized plant cost. The formula for the FCR is as follows:

$$CRF((1 - \tau(DPF) - ITC) / (1 - \tau)) + \beta \quad (J.2)$$

where CRF = the capital recovery factor

τ = the income tax rate

DPF = the real depreciation factor

ITC = the investment tax credits

β = the additional tax rate and insurance (Doane et al. 1976).

The 1986 Tax Reform Act eliminated investment tax credits; therefore, ITC is equal to zero. The term is included in the formula because at some future time, investment tax credits may be reintroduced. The combined state and federal income tax rate (τ) is assumed to be 38%. Additional taxes and insurance (β) are estimated as 2% (Doane et al. 1976 and Brown et al. 1987). The FCR equation incorporates an implicit assumption that taxes and insurance (β) are paid with before-tax dollars, while the return on capital is paid with after-tax dollars. The CRF is calculated as follows:

$$k / (1 - (1 + k)^{-N}) \quad (J.3)$$

where k = the real discount rate

N = the project life.

The discount rate used in the estimates developed in this study is 6.0% for the electric vehicle and stand-alone applications, which is the real after-tax discount rate for general industry (Brown et al. 1987). A discount rate of 4.2% was used for the load-leveling application, which is the average real after-tax discount rate for utilities (Brown et al. 1987). A project life of 30 years was used for the utility load-leveling application, and 20 years was used for the stand-alone application.

The depreciation factor (DPF) represents the present value of future depreciation credits. It is determined by summing the deflated nominal depreciation credits established by IRS for each depreciable project year. Determination of the DPF requires the determination of the appropriate IRS depreciation schedule and an inflation rate.

For determining depreciation credits, a modified ACRS depreciation schedule of 5 years was assumed for batteries and vehicles, while 20 years was used for the battery plant in the utility load-leveling and stand-alone applications. The 5-year depreciation schedule is presented in Table J.1. The depreciation schedule is in nominal dollars at initial investment time; therefore, the values in the schedule must be deflated to allow for the devaluation of the dollar between the initial investment time and the tax year of recovery. This deflating was performed using an inflation rate of 3.1% (Brown et al. 1987). Table J.2 presents the deflated depreciation schedule. The total as presented in Table J.2 is the DPF. Comparable data for a 20-year depreciation schedule are presented in Tables J.3 and J.4.

TABLE J.1. Modified 5-Year ACRS Depreciation Table
for 1987 and Beyond

<u>Year</u>	<u>Depreciation Percentage</u>
1	20
2	32
3	19
4	15
5	<u>14</u>
Sum	100

Source: Brown et al. 1987.

TABLE J.2. Discounted and Modified 5-Year ACRS Depreciation Table for 1987 and Beyond

<u>Year</u>	<u>Depreciation Percentage</u>
1	20.0
2	30.2
3	16.9
4	12.6
5	<u>11.1</u>
Sum	90.8

TABLE J.3. Modified 20-Year ACRS Depreciation Table for 1987 and Beyond

<u>Year</u>	<u>Depreciation Percentage</u>
1	4
2	7
3	7
4	6
5	6
6	5
7	5
8	5
9	5
10	5
11	5
12	5
13	5
14	5
15	4
16	4
17	4
18	4
19	4
20	<u>4</u>
Sum	100

Source: Brown et al. 1987.

TABLE J.4. Discounted and Modified 20-Year ACRS Depreciation
Table for 1987 and Beyond

<u>Year</u>	<u>Depreciation Percentage</u>
1	4
2	6.6
3	6.2
4	5.0
5	4.8
6	3.7
7	3.5
8	3.3
9	3.1
10	3.0
11	2.8
12	2.6
13	2.5
14	2.3
15	2.2
16	1.7
17	1.6
18	1.5
19	1.4
20	<u>1.3</u>
Sum	48.5

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