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**BATTERY RESOURCE ASSESSMENT
INTERIM REPORT #1**

**BATTERY MATERIALS
DEMAND SCENARIOS**

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I. INTRODUCTION

This report contains projections of demand for batteries and battery materials between 1980 and 2000. The estimates are based on existing predictions for the future of the electric vehicle, photovoltaic, utility load-leveling, and existing battery industry.

Battery demand was first computed as kilowatt-hours of storage for various types of batteries. Using estimates for the materials required for each battery, the maximum demand that could be expected for each battery material was determined.

The prediction of the demand for battery materials is a difficult task and subject to significant error. Future demand for batteries is highly dependent on economic conditions, battery technology, fuel availability, the state of alternate technologies, and consumer preferences. Estimates of the total battery market are highly conjectural and several different batteries have the potential to fill this market. Since different developmental batteries have significantly different material requirements, a large range of alternative materials requirements is possible. In this report, we have projected the maximum materials demands for the battery industry between 1980 and 2000.

II. FUTURE MATERIALS REQUIREMENTS FOR BATTERIES

A. Electric Vehicle Market

Electric vehicles are one of the primary applications envisioned for the advanced storage batteries under development. The future of electric vehicles is highly uncertain, and the number of vehicles actually put into operation in future years depends on a number of technological, economic, and sociopolitical factors. Specific factors that will affect the market penetration of electric vehicles include the cost and availability of oil, future electricity prices, electric vehicle range, performance, production costs, and consumer acceptance.

Despite the uncertainties of the future electric vehicle market, several estimates of future electric vehicle demand have been made. These projections range from estimates of the number of gas-driven vehicles that could be replaced by electric vehicles, given their range and performance characteristics, to the expected market penetration of electric vehicles under different technological, economic, and government policy assumptions.

ORI performed a review and summary of nine independent electric vehicle market projections (1). Market projection models were divided into three major categories:

- (1) Applicability Models - Define the size of the market for electric vehicles. The actual extent to which electric vehicles can penetrate this market is not estimated.

- (2) Plausibility Models - Formulate scenarios for electric vehicle market penetration based on assumptions of government support, manufacturing capability, and technology development.
- (3) Econometric Models - Use econometric analyses of consumer preferences to estimate electric vehicle demand. Data used in these models include relative costs of electric versus conventional vehicles, demographic factors, household income, and fuel costs.

Table II-1 lists the assumptions used in the various models. Table II-2 and Figure II-1 show the projections of the plausibility and econometric models. The estimates vary widely, with sales projections for 1995 ranging from 37,000 to 2,324,000 vehicles. Estimates of the electric vehicle stock in 1995 range from 279,000 to 7,353,000 vehicles. Market penetration projections also vary among these models, with estimates of electric vehicle sales ranging from 1 to 18 percent of all vehicle sales.

The three scenarios developed by Argonne National Laboratory (ANL) as part of the electric vehicle programmatic environmental assessment cover the range of possible vehicle futures represented in all of the market models. The ANL projections also contain estimates for different sized vehicles and different battery types. In addition, both the high and low scenarios are presented in a consistent form that simplifies any future analysis involving both scenarios. For these reasons, we have decided to use these projections as the basis for the analysis of electric vehicle battery materials demand.

TABLE II-1. KEY ASSUMPTIONS USED IN ELECTRIC VEHICLE PENETRATION STUDIES (1)

STUDY/MODEL	MODEL TYPE	THEORY/ ANALYTICAL FRAMEWORK	MARKET SEGMENTATION	STUDY RESULTS	MAJOR DATA INPUTS	EV CHARACTERISTICS							BATTERY TECHNOLOGY CONSIDERED
						Initial Cost	Range	Speed	Acceleration	Passenger Capacity	Operating Cost	Assumed Life	
Booz Allen	Applicability	Quantitative Survey of Public Awareness and Attitudes Concerning EVs	Vehicles Owned and Operated by Households	Replacement of Vehicle by EVs	Telephone Survey of 1001 Households	(000s): (1978\$) EV < ICE	Miles 40	MPH 40		2	EV < ICE	Years	Not Specified
General Research Corp. (GRC)	Applicability	Prospects for Electric Cars: Technical, Cost, Fuel Use, Pollution and Competitive Market Position	Passenger Vehicles	Projected Applicability of Electric Cars 1980-2000	Demographic, Vehicle Use and Ownership	5.2-6.7	46-140	-	Varies	2-4	Varies	12	Lead Acid Nickel Zinc Lithium/Aluminum Metal Sulfide
Brookhaven (BNL)	Applicability	Statistical Profile of Fleet Vehicles and Identification of Factors Affecting Technological Penetration Rates	Fleet Use Only	Applicable EV Market Share Based On 1976 Fleet Population	Survey of Fleet Owners and Fleet Use Driving Characteristics	Varies, but usually EV > ICE	50-150	Varies	Varies i.e. interstate capabilities	2-4	Varies	ICE	Not Specified
Argonne (ANL)	Plausibility	Market Penetration Based On Government Investment Scenarios	Total Vehicle Market	EV Market Sales and Stock for 1985, 90 and 2000	R&D Expenditures Petroleum Availability EV Technology Air Quality National Urgency	-	50-100	-	-	-	-	10	Lead Acid Nickel Zinc Lithium Metal Sulfide High Temperature
Purdue	Plausibility	Two Dominant EV R&D Scenarios Resulting in the Same EV Sales in 2005	Passenger and Commercial Vehicles	EV Sales and Stock 1980-2000 and number of EV Production Lines	EV R & D Funding Petroleum Cost Emission Standard EV Life Cycle Costs	EV > ICE	-	-	-	-	Life Cycle EV to ICE 1.70-1.00	-	Not Specified
SRI	Plausibility	Scenario of the Manufacture Use and Sale of Electric Vehicles	Passenger Cars	Sales of EV Passenger Cars by Origin and Battery Type	Participation of Major Auto Manufacturers, ICE Performance, Battery Technology, Utility Time of Day Pricing	5.2-6.7	46-140	-	Varies	2-4	Varies	12	Lead Acid Nickel Zinc High Temperature
A.D. Little (ADL)	Econometric	Acceptance by Fleet Owners and Consumers of EVs and the Effects of Government Incentives Based on a Survey of Consumers and Workshop Discussion Groups	Compact and Sub-compacts	EV Market Shares for 1990 Under Alternative Scenarios	EV Size, Acceleration, Speed, Range and Cost	2.0-7.2	50-100	85	Avg	2-4	EV > ICE	12.5	Nickel Zinc
Mathtech I DOT/TSC/OOE	Econometric	Mathtech EV Demand Model From EPRI, Wharton Automobile Demand Model	Passenger Vehicles	Vehicle Sales Based on Ten Incentive Strategies	EV Size, Battery Technology, Gasoline and Utility Costs Macroeconomic Data	5.6-7.3	31-81	50-56	Avg	2-4	EV > ICE	12	Lead Acid, Nickel Zinc
Mathtech II EPRI	Econometric	Supply Module, Demand Module, Electricity Consumption Module	Passenger Vehicles	EV Sales, Stock, Scrappage for 1985, 1990, 1995, 2000 Under Alternative Scenarios	EV Design and Cost Automobile Demand Model, Basic Economic Variables, Utility Costs	5.2-8.4	93-124	-	-	2-4	EV < ICE	12	Lead Acid, Nickel Zinc, Lithium Metal Sulfide

EV technology assumptions highlighted in Table I are taken from the reports, however, when a quantitative assessment was not available an attempt was made to distinguish the key technology factors. A dash (-) means the specific technology element was not specified in the report.

TABLE II-2. ELECTRIC VEHICLE SALES ESTIMATES FOR THE
YEARS 1985, 1990, 1995, and 2000 (1)
(THOUSANDS)

MODEL/STUDY	VEHICLE POPULATION	SCENARIO	1985		1990		1995		2000	
PLAUSIBILITY			Sales	Stock	Sales	Stock	Sales	Stock	Sales	Stock
Argonne	Passenger Vehicles	Low	6	20	23	70	NA	NA	300	940
		Medium	11	30	47	125	NA	NA	1128	3060
		High	29	50	159	350	NA	NA	3763	10750
Purdue	Passenger Vehicles	Low	5	23	108	144	270	965	810	2688
		High	162	365	495	1553	693	3143	891	4892
SRI	Passenger Vehicles		10	NA	60	NA	300	NA	600	NA
ECONOMETRIC										
Mathtech I	Passenger Vehicles	Base Case	20	73	23	167	37	279	NA	NA
		\$1000 Subsidy	60	216	67	491	107	815	NA	NA
		50 Cent Gas Tax	52	160	69	457	102	791	NA	NA
		Doubling Range	56	273	70	543	114	866	NA	NA
¹ Mathtech II	Passenger Vehicles	Pessimistic	744	745	265	1900	1331	4211	1854	11019
		Optimistic	1350	1352	539	3866	2324	7353	2108	12526
	Urban Runabout	Pessimistic	621	622	150	1238	722	2480	1033	6170
		Optimistic	975	977	276	2280	1200	4122	1166	6966
	Surburban Car	Pessimistic	123	123	115	662	609	1731	821	4849
		Optimistic	375	375	276	1586	1137	3231	941	5559

NA = Not Available

¹ EV sales estimates for the optimistic scenario in the Mathtech II report are estimated by applying the ratio of sales to stock in the pessimistic scenario to the optimistic stock levels.

Figure II-1. A Comparison of Electric Vehicle Stock Levels (1)

Although the ANL scenarios include estimates of the number of each type of battery produced and total materials involved in vehicle production, several batteries, most notably the sodium-sulfur and zinc-chlorine batteries, were excluded because it was felt that safety and developmental problems would preclude their use in electric vehicles (2). Since the goal of this study is to estimate the material impacts of all the major contenders for future battery use, we have included these batteries in the analysis.

The battery types have been divided into three major categories--existing, near-term, and advanced. Only the lead-acid battery is existing. Near-term includes the nickel-iron, nickel-zinc, and zinc-chlorine batteries; advanced batteries include the sodium-sulfur (both ceramic and glass electrolytes), lithium-metal sulfide, and aluminum-air batteries. Since it is still unknown which of these batteries, if any, will achieve the necessary technological improvements to become a viable electric vehicle source, the demand for batteries was evaluated on the basis of the generic groupings rather than actual battery types. For example, under the high scenario, advanced batteries are expected to account for 15 percent of total sales for electric vehicles in 1995; however, this demand may be due to sodium-sulfur, lithium-metal sulfide, or a combination of these and other advanced battery types. Though it is assumed that some of these batteries will be developed, the specific battery design and type that will be commercialized cannot be determined at this time. The Argonne electric and hybrid vehicle projections are shown in Tables II-3 and II-4.

The projected mix of batteries installed in vehicles is shown in Table II-5. These percentages are based on the battery mixes included in the ANL scenarios. In addition,

TABLE II-3. TOTAL NUMBER OF ELECTRIC AND
HYBRID VEHICLES (THOUSAND VEHICLES) (2)

	<u>Low</u>			<u>High</u>		
	<u>1985</u>	<u>1990</u>	<u>2000</u>	<u>1985</u>	<u>1990</u>	<u>2000</u>
HV Trucks	12.6	59.1	1,334	0	53.4	4,220
HV Buses	0	4.6	40	0	8.2	52.5
HV Autos	7.4	31.8	626	0	53.4	2,273
EV Trucks	34	131	2,000	116	462	9,455
EV Buses	0	10	60	2	70	182
EV Autos	20	70	940	50	308	7,818
Total	74	306.5	5,000	168	955	24,000

TABLE II-4. YEARLY SALES OF ELECTRIC AND
HYBRID VEHICLES (THOUSAND VEHICLES) (3)

	<u>Low</u>			<u>High</u>		
	<u>1985</u>	<u>1990</u>	<u>2000</u>	<u>1985</u>	<u>1990</u>	<u>2000</u>
HV Trucks	4.7	25.5	509	0	28.7	2,013
HV Buses	0	2.0	15.6	0	4.4	25
HV Autos	2.7	13.7	236	0	28.7	1,084
EV Trucks	10	43	641	40	197	2,068
EV Buses	0	3	20	1	26	27
EV Autos	6	24	300	29	136	1,723
Total	23.4	111.2	1721.6	70	420.8	6,940

TABLE II-5. ESTIMATED FRACTION OF ELECTRIC VEHICLES
HAVING DIFFERENT BATTERY TYPES (PERCENT)

	<u>Existing</u> ¹	<u>Near Term</u> ²	<u>Advanced</u> ³
<u>Low</u>			
1985	95	5	0
1995	90	10	0
2000	82	18	0
<u>Medium</u>			
1985	80	20	0
1995	30	65	5
2000	15	70	15
<u>High</u>			
1985	75	25	0
1995	25	60	15
2000	10	55	35

1. Lead-acid
2. Nickel-iron, nickel-zinc, zinc-chlorine
3. Sodium-sulfur, lithium-metal sulfide, aluminum-air

Table II-6 shows the number of batteries (of approximately 30 kWh storage each) required for hybrid and electric vehicles under low and high market scenarios. Although the pure electric vehicle scenarios include low, medium, and high estimates, projections for electric and hybrid vehicles include only the low and high cases.

Table II-7 shows total projected battery capacity in kilowatt hours for electric and hybrid vehicles, assuming approximately 30 kWh per vehicle battery.

B. Load-Leveling Battery Market

The requirements for load-leveling batteries differ considerably from those for electric vehicle batteries. While electric vehicle batteries must have good specific energy characteristics and the ability to produce high power for short periods, utility load-leveling batteries must have high efficiency and low cost. Since the batteries are stationary, specific energy and specific power are of secondary importance. Total cost, reliability, and energy efficiency are the primary selection criteria for these types of batteries.

Utility load-leveling batteries are intended to replace oil- or gas-fired peak-load generators. Since peak power is required only a small portion of the time, peak load generators have a low capital cost. They operate on oil or gas and have a lower generation efficiency than baseload plants. Baseload plants have a lower operating cost due to higher operating efficiency; however, this increased efficiency is a result of higher capital costs and the use of fuels that

TABLE II-6. TOTAL NUMBER OF BATTERIES NEEDED
FOR ELECTRIC AND HYBRID VEHICLES

(thousand batteries)

	<u>Existing</u>	<u>Near Term</u>	<u>Advanced</u>	<u>Total</u>
<u>Low</u>				
1985	70	4	0	74
1995	276	31	0	307
2000	4,100	900	0	5,000
<u>High</u>				
1985	126	42	0	168
1995	239	573	143	955
2000	2,400	13,200	8,400	24,000

TABLE II-7. CAPACITY OF STORAGE BATTERIES FOR
ELECTRIC AND HYBRID USE (MWh)

(Assuming 30 kW storage per vehicle)

	<u>Existing</u>	<u>Near Term</u>	<u>Advanced</u>	<u>Total</u>
<u>Low</u>				
1985	2,100	120	0	2,220
1995	8,280	930	0	9,210
2000	123,000	27,000	0	150,000
<u>High</u>				
1985	3,780	1,260	0	5,040
1995	7,170	17,190	4,290	28,650
2000	72,000	396,000	252,000	720,000

do not allow the generator to respond to rapid fluctuations of electricity demand.

There are three primary incentives for utilities to install energy storage equipment:

- (1) Energy storage could reduce the need for gas- and oil-fired peaking plants, which use expensive, high-quality fuels.
- (2) Batteries can be used to satisfy a utility spinning reserve requirement. The spinning reserve is auxiliary generating equipment that must be kept on line in case one of the normal generating units fails.
- (3) Decentralized storage can lower current capacities of transmission lines because high peak loads would not be experienced throughout the system. Major transmission lines could be sized closer to average power levels and the storage system could match peak loads near the point of electric consumption.

The two major advantages of batteries over other types of peak-load equipment are credits due to reduced generation costs and reduced spinning reserve requirements. The third credit, for transmission line savings, is only applicable over the long run and is therefore not expected to be a major factor in initial battery commercialization stages.

Load-leveling batteries have the potential to supply all of the energy normally produced by peak load plants. It is expected, however, that batteries will supply half of this peak power. This load is estimated to be 4,050 MW by 1985 with a 5 percent per year growth rate (4). Present load-leveling batteries are designed to be discharged at a five-hour rate; thus, the total battery capacity that could be used for peaking in 1985 is 2,025 MW or 10,125 MWh.

Actual market penetration will approach this maximum value. The degree to which battery storage will be used for peak power generation depends on a variety of factors, including the cost of liquid and gaseous fuel, the price of batteries, the success of battery demonstration programs, and the degree of competition from other forms of energy storage such as pumped hydro storage and compressed air storage.

Estimates of the penetration of batteries in the load-leveling market have been developed by A.D. Little (4) based on an earlier study by Mitre Corp (5). These projections, which depend on the cost of batteries, are shown in Figure II-2. If these power figures are converted to energy (using a five-hour discharge rate), the total installed battery capacity is as shown in Table II-8.

The types of batteries being considered for load-leveling include lead-acid, sodium-sulfur, zinc-chlorine, Redox, zinc-bromine, and lithium-metal sulfide. Because only the lead-acid battery is currently available, installations in the period from 1985 to 1990 will rely heavily on this type of battery. As more advanced batteries are developed, they will account for an increasing amount of the total installed capacity. Load-leveling batteries, like

Figure II-2. Total Installed Battery Capacity and Oil Savings Per Year as a Function of Time (4)

TABLE II-8. TOTAL INSTALLED BATTERY
CAPACITY (MWh) FOR UTILITY LOAD LEVELING (4)

	Projected Market			
	<u>Maximum Market</u>	<u>\$350/kW</u>	<u>\$400/kW</u>	<u>\$445/kW</u>
1985	10,000	1,500	0	0
1990	50,000	20,000	5,000	0
1995	100,000	50,000	20,000	4,000
2000	150,000	100,000	50,000	20,000

vehicle batteries, have been divided into three categories--existing, near-term, and advanced batteries. The existing battery is the lead-acid, the near-term battery is the zinc-chlorine, and the advanced group includes the sodium-sulfur, zinc-bromine, Redox, and lithium-metal sulfide batteries. Nickel-iron and nickel-zinc batteries are not expected to be used for load-leveling purposes.

Estimates of fractional yearly battery sales by battery type and the cumulative fraction of battery sales are shown in Tables II-9 and II-10. While lead-acid batteries are projected to account for initial sales, the market is expected to be dominated by the sales of advanced batteries in 1995.

C. Photovoltaic Markets

Photovoltaic cells are likely to create a sizable market for storage batteries. Due to the intermittent nature of solar power, any continuous use of energy from sunlight requires some type of energy storage device.

The initial market for photovoltaic systems will be for remote power sources. These applications include communications, cathodic protection, and remote monitoring. Photovoltaic systems will also provide power for water pumping and for consumer use in foreign countries that do not have an extensive utility system.

Eventually, it may be possible to use photovoltaics to generate power in grid-connected systems, either as power sources for individual homes and factories, or for the replacement of conventional power generation systems by an electric utility.

TABLE II-9. SALES AND TOTAL INSTALLED
CAPACITY FOR LOAD-LEVELING BATTERIES BY TYPE

	Percent of Sales			Percent of Installed Battery Capacity		
	<u>Existing</u>	<u>Near Term</u>	<u>Advanced</u>	<u>Existing</u>	<u>Near Term</u>	<u>Advanced</u>
1985	90	10	0	90	10	0
1990	50	30	20	74	18	8
1995	0	40	60	45	29	26
2000	0	20	80	22.5	29.5	48

TABLE II-10. CUMULATIVE BATTERY MARKET
FOR ELECTRIC LOAD LEVELING

(High Demand Scenario)

	<u>Existing</u>	<u>Near Term</u>	<u>Advanced</u>	<u>Total</u>
1980	0	0	0	0
1985	1,350	150	0	1,500
1990	14,800	3,600	1,600	20,000
1995	22,500	14,500	13,000	50,000
2000	22,500	29,500	48,000	100,000

Battery storage requirements for various applications are shown in Table II-11 (6). This table shows that, for most uses, an energy storage requirement of approximately 30 to 50 kWh/kWp (peak kilowatts) is required. The only exceptions to this trend are the telemetry and remote-sensing applications, which use so little power that the battery tends to be larger in relation to the solar panel.

Detailed market studies for photovoltaic systems have dealt only with the near term. Results of these studies, including projections of battery storage capacity, are shown in Tables II-12 and II-13. These figures appear in a report prepared by Booz-Allen (7) which summarizes earlier projection of ITC (8), Aerospace Corp. (9), and BDM (10).

Other studies, while less detailed, have estimated the long-term potential for photovoltaic systems. Booz-Allen Corporation (6) estimates the cumulative market for photovoltaic systems to be between 11,000 and 30,000 MW in 2000 and between 900 and 3,000 MW in 1990. For this study, we have assumed that the market will grow exponentially from 1985 to 2000, reaching 1,500 MW in 1990 and 25,000 MW in 2000. The battery requirements shown in Table II-14 are for 10 kWh of storage per kilowatt of capacity. The mix between existing, near-term, and advanced systems is assumed to be the same as that for the utility load-leveling case.

D. Battery Market For Existing Applications

The primary market for storage batteries in the United States is for starting, lighting, and ignition (SLI) batteries for automobiles and trucks. This market accounted

TABLE II-11. BATTERY SIZE/PEAK WATTS FOR VARIOUS USES (6)

	<u>Array Rating</u>	<u>Battery</u>	<u>Ratio</u>
Small Radio Repeaters	0.2 kWp	6 kWh	30 $\frac{\text{kWh}}{\text{kWp}}$
Large Radio Repeaters	3.3 kWp	40 kWh	12.1 $\frac{\text{kWh}}{\text{kWp}}$
Microwave Repeaters	0.6 kWp	20 kWh	33.3 $\frac{\text{kWh}}{\text{kWp}}$
Telemetry	0.016	20 kWh	1250 $\frac{\text{kWh}}{\text{kWp}}$
Nav aids	0.15	22 kWh	147 $\frac{\text{kWh}}{\text{kWp}}$
Remote Sensing	.003	5 kWh	1,667 $\frac{\text{kWh}}{\text{kWp}}$
Rural Telephones Non-U.S.	.05	2 kWh	40 $\frac{\text{kWh}}{\text{kWp}}$
C.P. Shallow Wells, U.S.	0.18	6 kWh	33 $\frac{\text{kWh}}{\text{kWp}}$
C.P. Shallow Wells, Non-U.S.	0.3	9 kWh	30 $\frac{\text{kWh}}{\text{kWp}}$
C.P. Deep Wells, U.S.	0.6	29 kWh	48 $\frac{\text{kWh}}{\text{kWp}}$
C.P. Deep Wells, Non-U.S.	1.0	29 kWh	29 $\frac{\text{kWh}}{\text{kWp}}$
C.P. Pipeline	0.4	10 kWh	25 $\frac{\text{kWh}}{\text{kWp}}$
C.P. Bridges	0.64	13 kWh	20.3 $\frac{\text{kWh}}{\text{kWp}}$
<u>Averages</u>			
Cathodic Protection (C.P.)			30.8 (30)
Communication & Nav aids, etc.			52.4 (50)
Remote Sensing & Telemetry			1458.5 (1500)

TABLE II-12. PHOTOVOLTAIC BATTERY MARKET 1976 (7)

<u>Domestic</u> <u>Commercial</u>	<u>ITC (8)</u>		<u>BDM (10)</u>	
	<u>Array</u>		<u>Array</u>	
	<u>Capacity (kWp)</u>	<u>Storage (kWh)</u>	<u>Capacity (kWp)</u>	<u>Storage (kWh)</u>
Communications	67.6	3,380	73.9	3,695
Corrosion Protection	28.1	843	70.0	2,100
Navigation Aids	20.3	1,015	44.6	2,230
Recreation	4.5	--	1.6	--
Consumer Products	7.1	--	3.4	--
Water Pumping	--	--	0.7	--
Miscellaneous	1.1	--	--	--
<u>Subtotal</u>	128.6	5,238	194.2	8,025
<u>Government & Aerospace</u>				
Commercial Satellite	14.3	--	53.1	--
DOD and NASA	31.2	1,560	0.4	20
USCG and Faa	3.0	150	46.0	2,300
DOE	60.0	--	3.1	--
Other	--	--	102.5	--
<u>Subtotal</u>	108.5	1,710	205.1	2,320
<u>Export</u> <u>Commercial</u>				
Communications	NA	--	87.0	4,350
Water Pumping	NA	--	5.2	--
<u>Subtotal</u>	40.0	2,000	92.2	4,350
<u>Government</u>				
Japan	75.0	--	NA	--
Europe	35.0	--	NA	--
<u>Subtotal</u>	110.0	--	NA	--
<u>TOTAL</u>	387.1	2,000	389.0	4,350

TABLE II-13. PHOTOVOLTAIC BATTERY MARKET 1985 (7)

<u>Domestic</u>	<u>ITC (8)</u>		<u>Aerospace (9)</u>		<u>BDM (10)</u>	
	<u>Array Capacity (kWp)</u>	<u>Battery Storage (kWh)</u>	<u>Array Capacity (kWp)</u>	<u>Battery Storage (kWh)</u>	<u>Array Capacity (kWp)</u>	<u>Battery Storage (kWh)</u>
Communications	2,100	105,000	2,100	105,000	4,900	245,000
Cathodic Protection	69	2,070	--	--	17,000	510,000
Marking and Warning	25	1,250	3,170	158,500	2,100	105,000
Monitoring and Sensing	--	--	130	195,000	33	49,500
General Power	--	--	7,900	395,000	19,000	950,000
Consumer Products	715	--	--	--	790	--
<u>Subtotal</u>	2,900	108,320	13,300	853,500	43,823	1,754,500
<u>Foreign</u>						
Communications	16,300	815,000	--	--	5,200	260,000
Cathodic Protection	35	1,050	--	--	8,000	240,000
Marking and Warning	9	450	--	--	--	--
Monitoring and Sensing	--	--	--	--	--	--
Desalinization	1,000	50,000	--	--	--	--
Lighting	254,000	12,700,000	--	--	--	--
Water Pumping	6,200	310,000	--	--	56,000	2,800,000
Rural Electrification	500	29,000	--	--	--	--
Consumer, Misc.	245	--	--	--	--	--
<u>Subtotal</u>	287,369	13,905,500	--	--	69,200	3,300,000
<u>TOTAL</u>	281,269	14,013,820	--	--	113,023	5,054,500

TABLE II-14. CUMULATIVE MARKET FOR
PHOTOVOLTAIC BATTERY SYSTEMS

<u>Year</u>	<u>Cumulative* Photovoltaic Capacity (MW)</u>	<u>Existing</u>	<u>Battery Capacity (MWh) Near Term</u>	<u>Advanced</u>	<u>Total</u>
1985	367	3,303	367	0	3,670
1990	1,500	11,100	2,700	1,200	15,000
1995	6,123	27,553	17,757	15,920	61,230
2000	25,000	50,000	80,000	80,000	120,000

*Includes residential, intermediate size (large buildings), and utility systems.

for 73.6 percent of all the storage battery units sold in 1977, and for 71.7 percent of all storage battery sales (dollar value) (11). All of these batteries are lead-acid. Nickel-cadmium batteries which have the second largest market, are used for rechargeable battery packs for calculators, electronic equipment, and consumer equipment. These batteries are normally considerably smaller than the lead-acid batteries used in vehicles. Other batteries, primarily lead-acid, are sold for miscellaneous uses such as power sources for golf carts, industrial lift trucks, and railroad applications.

A market exists for three types of storage batteries: starting, lighting, and ignition automobile and truck (SLI) batteries, other large batteries (primarily lead-acid batteries) for industrial use, and nickel-cadmium batteries for low power and storage uses.

The SLI battery market is closely tied to the market for automobiles and trucks. This market can be expected to expand somewhat, although gasoline supply problems and the impact of electric vehicles may limit its growth. To allow for these effects, we have assumed that the market for SLI batteries will grow at its historical rate until 1990 and then level off. All SLI batteries are lead-acid (Table II-15).

Large lead-acid batteries can be used as emergency power sources and as a power source for telephone and communications, industrial lift trucks, trains, farm equipment, and electric golf carts. The market for large lead-acid batteries should remain relatively stable and grow at its historical rate (Table II-16).

TABLE II-15. DEMAND FOR AUTOMOTIVE (SLI) BATTERIES

	<u>Units</u>	<u>Cumulative</u>	<u>Storage Capacity/Unit</u>	<u>Cumulative Capacity</u>
1980	70.2	70.2	.6 kWh	42,100
1985	85.4	465.8	.6 kWh	279,000
1990	85.4	892	.6 kWh	535,000
1995	85.4	1,319	.6 kWh	791,400
2000	85.4	1,746	.6 kWh	1,047,600

TABLE II-16. DEMAND FOR OTHER LEAD-ACID BATTERIES

	<u>Units</u>	<u>Cumulative Units</u>	<u>Storage Capacity/Unit</u>	<u>Cumulative Storage Capacity (MWh)</u>
1980	5.8	5.8	1.0 kWh	5.8
1985	7.1	38.5	1.0 kWh	38.5
1990	8.6	78.2	1.0 kWh	78.2
1995	10.4	126.6	1.0 kWh	126.6
2000	12.7	185.4	1.0 kWh	185.4

The market for nickel-cadmium batteries has grown considerably over the past 15 years. The market for sealed nickel-cadmium batteries doubled between 1972 and 1977, and has increased over 5 times since 1967. Since nickel-cadmium batteries are a relatively new product, it is expected that this high rate of growth will slacken as this battery achieves market saturation. Due to the small size of nickel-cadmium batteries, they do not account for a significant portion of the battery market in terms of storage capacity. For this reason, they have not been included in the market projections.

E. Total Battery Market to 2000

The total battery market can be estimated by adding together the estimates for batteries of different uses. Because this study is concerned with potential impacts of battery production, the high scenarios of battery production have been used where there are more than one scenario to choose from. Tables II-17 through II-19 show the markets for the different classes of batteries: lead-acid batteries, near-term vehicle batteries, near-term stationary batteries, advanced vehicle batteries, and advanced stationary batteries. Table II-20 shows total projected demand for all batteries.

F. Materials Impact

The materials requirements for batteries have been computed on the basis of the maximum demands for the batteries. Not only have high demand scenarios been used, but in cases

TABLE II-17. CUMULATIVE DEMAND FOR LEAD-ACID BATTERIES (MWh) 1980-2000

<u>Year</u>	<u>Electric Vehicle</u>	<u>Load Leveling</u>	<u>Photovoltaic</u>	<u>SLI</u>	<u>Other</u>	<u>Total Stationary</u>	<u>Total E.V. & SLI and Other</u>
1980	0	0	0	42,100	6	0	42,106
1985	3,780	1,350	3,303	279,000	39	4,653	282,819
1990	5,475	14,800	11,100	535,000	78	25,900	540,553
1995	7,170	22,500	27,553	791,400	127	50,053	798,697
2000	72,000	22,500	50,000	1,047,600	185	72,500	1,119,785

TABLE II-18. CUMULATIVE DEMAND FOR NEAR-TERM ELECTRIC VEHICLE* BATTERIES AND STATIONARY BATTERIES (MWh)

<u>Year</u>	<u>Electric Vehicle*</u>	<u>Load Leveling</u>	<u>Photovoltaic</u>	<u>Total Stationary**</u>
1980	0	0	0	0
1985	1,260	150	367	517
1990	9,225	3,600	2,700	6,300
1995	17,190	14,500	17,757	32,257
2000	396,000	29,500	80,000	109,500

*Zinc-chlorine, nickel-zinc, nickel-iron

**Zinc-chlorine

TABLE II-19. CUMULATIVE MARKET FOR ADVANCED
VEHICLE* AND STATIONARY** BATTERIES (MWh)

<u>Year</u>	<u>Electric Vehicle*</u>	<u>Load Leveling</u>	<u>Photovoltaic</u>	<u>Total Stationary**</u>
1980	0	0	0	0
1985	0	0	0	0
1990	2,145	1,600	1,200	1,800
1995	4,290	13,000	15,920	28,920
2000	252,000	48,000	120,000	168,000

*Sodium-sulfur, lithium-metal sulfide, aluminum-air

**Sodium-sulfur, Redox, lithium-metal sulfide, zinc-bromine

TABLE II-20. CUMULATIVE DEMAND FOR ALL BATTERIES (MWh)

<u>Year</u>	<u>Lead-Acid</u>		<u>Near Term</u>		<u>Advanced</u>		<u>Total</u>
	<u>Electric Vehicle, SLI, & Other</u>	<u>Stationary</u>	<u>Electric Vehicle</u>	<u>Stationary</u>	<u>Electric Vehicle</u>	<u>Stationary</u>	
1980	42,106	0	0	0	0	0	42,106
1985	282,819	4,653	1,260	517	0	0	289,249
1990	540,553	25,900	9,225	2,700	2,145	1,600	582,123
1995	798,697	50,053	17,190	17,757	4,290	13,000	900,987
2000	1,119,785	72,500	396,000	80,000	252,000	48,000	1,968,285

in which more than one battery can fulfill a certain role, both batteries are assumed to fill the entire market. This assumption allows for the fact that only one of the designs in each group may, in fact, be developed. Tables II-21 through II-34 show the amount of material per kWh storage and the cumulative amount of each material required between 1980 and 2000 under these assumptions.

In order to determine the maximum demand for each battery material, the largest material use for each major battery grouping (e.g., existing vehicle, near-term, and load-leveling) was determined. The maximum values for each group were then summed to give the maximum resource use for all batteries (Table II-35). It should be remembered that the values in Table II-35 are the maximum amounts of resources consumed for all scenarios and that if more than one battery from each group achieves significant market penetration, less materials will be used. Also, if battery commercialization proceeds more slowly than these maximum rates, resource demands will be lower.

TABLE II-21. MATERIALS REQUIRED FOR LEAD-ACID
VEHICLE* BATTERIES 1980-2000

<u>Material</u>	<u>kg/kWh (12)</u>	<u>Cumulative Demand (10⁶ kg)</u>	
		<u>1990</u>	<u>2000</u>
Lead	12.0	6,487	13,437
Sulfuric Acid	2.2	1,189	2,464
Antimony	0.1	54	112
Plastic	0.8	432	896
Water & Other	4.9	-	-
Total	20.0	-	-

*Includes SLI and industrial batteries.

**TABLE II-22. MATERIALS REQUIRED FOR NICKEL-
ZINC VEHICLE BATTERIES 1980-2000**

<u>Material</u>	<u>kg/kWh (12)</u>	<u>Cumulative Requirement (10⁶kg)</u>	
		<u>1990</u>	<u>2000</u>
Nickel	4.3	40	1,703
Zinc	3.3	30	1,307
Potassium Hydroxide	0.8	7	317
Plastic	1.1	10	436
Copper	0.5	5	198
Steel	0.5	5	198
Water, Oxygen in Oxides, Other	3.8	-	-
Total	14.3	-	-

TABLE II-23. MATERIALS REQUIRED FOR NICKEL-IRON
VEHICLE BATTERIES 1980-2000

<u>Material</u>	<u>kg/kWh (12)</u>	<u>Cumulative Requirement (10⁶kg)</u>	
		<u>1990</u>	<u>2000</u>
Nickel	2.7	25	1,069
Iron	2.2	20	871
Steel	4.9	45	1,940
Copper	0.6	6	238
Plastic	0.7	6	277
Potassium Hydroxide	1.0	9	396
Lithium Hydroxide	0.2	2	79
Water, Hydrogen & Oxygen Bound in Active Material, Other	4.4	-	-
Total	16.7	-	-

TABLE II-24. MATERIALS REQUIRED FOR ZINC-
CHLORINE VEHICLE BATTERIES 1980-2000

<u>Material</u>	<u>kg/kWh (12)</u>	<u>Cumulative Requirement (10⁶kg)</u>	
		<u>1990</u>	<u>2000</u>
Graphite	1.3	12	515
Plastic	2.0	18	792
Titanium	0.1	1	40
Steel	0.1	1	40
Zinc	0.8	7	317
Chlorine	0.4	4	158
Water	4.5	-	-
Total	9.2	-	-

**TABLE II-25. MATERIAL REQUIREMENTS FOR SODIUM-SULFUR
(GLASS) VEHICLE BATTERIES 1980-2000**

(Includes Battery Insulation & Support Equipment)

<u>Material</u>	<u>kg/kWh (12)</u>	<u>Cumulative Requirement (10⁶kg)</u>	
		<u>1990</u>	<u>2000</u>
Sodium	0.87	1.9	219
Sulfur	1.87	4.0	471
Glass	0.46	1.0	116
Aluminum	2.32	5.0	585
Steel	0.77	1.7	194
Plastic	0.55	1.2	139
Copper	0.30	0.6	76
Total	7.14	-	-

TABLE II-26. MATERIALS REQUIREMENTS FOR SODIUM-SULFUR (CERAMIC) VEHICLE BATTERIES 1980-2000

<u>Material</u>	<u>kg/kWh (12)</u>	<u>Cumulative Requirement (10⁶kg)</u>	
		<u>1990</u>	<u>2000</u>
Sulfur	2.83	6.1	713
Sodium	1.72	3.7	433
Alumina	0.84	7.8	212
Steel	1.25	2.7	315
Aluminum	1.47	3.2	370
Graphite	0.24	0.5	60
Copper	0.40	0.9	101
Plastic	0.74	1.6	186
Glass	0.13	0.3	33
Total	9.62	-	-

TABLE II-27. MATERIALS REQUIRED FOR LITHIUM-METAL
SULFIDE VEHICLE BATTERIES 1980-2000

<u>Material</u>	<u>kg/kWh (12)</u>	<u>Cumulative Requirement (10⁶kg)</u>	
		<u>1990</u>	<u>2000</u>
Steel	3.50	7.5	882
Lithium	0.45	1.0	113
Sulfur	0.67	1.5	169
Aluminum	1.10	2.4	277
Iron	0.97	2.1	244
Potassium Chloride	1.23	2.6	310
Chlorine	0.80	1.7	202
Boron Nitride	0.14	0.3	35
Molybdenum	0.02	-	5
Copper	0.36	0.8	91
Asbestos	0.22	0.5	55
Insulation	0.74	1.6	186
Total	10.20	-	-

TABLE II-28. MATERIALS REQUIREMENTS FOR
ALUMINUM-AIR VEHICLE BATTERIES 1980-2000

<u>Material</u>	<u>kg/kWh (12)</u>	<u>Cumulative Requirement (10⁶kg)</u>	
		<u>1990</u>	<u>2000</u>
Aluminum	0.91	2.0	229
Plastic	0.57	1.2	144
Steel	0.26	0.6	66
Sodium Hydroxide	0.08	0.2	20
Alumina	0.21	0.5	53
Copper	0.21	0.5	53
Water & Other	1.01	2.2	255
Total	3.25	-	-

TABLE II-29: MATERIALS REQUIREMENTS FOR
LEAD-ACID STATIONARY BATTERIES 1980-2000

<u>Material</u>	<u>kg/kWh (13)</u>	<u>Cumulative Requirement (10⁶ kg)</u>	
		<u>1990</u>	<u>2000</u>
Lead	27.0	699	1,958
Sulfuric Acid	3.0	78	218
Plastics	6.8	176	493
Steel	3.0	78	218
Copper	0.1	3	7
Antimony	0.1	3	7
Water & Other	5.8	-	-
Total	45.8	-	-

**TABLE II-30. MATERIALS REQUIREMENTS FOR
ZINC-CHLORINE STATIONARY BATTERIES 1980-2000**

<u>Material</u>	<u>kWh (13)</u>	<u>Cumulative Requirement (10⁶kg)</u>	
		<u>1990</u>	<u>2000</u>
Graphite	1.37	8.6	150
Plastic	2.16	13.6	237
Titanium	0.14	0.9	15
Zinc	0.88	5.5	96
Chlorine	0.48	3.0	53
Water	4.81	30.3	527
Steel	3.00	18.9	329
Copper	0.10	-	-
TOTAL	13.03	-	-

TABLE II-31. MATERIALS REQUIREMENTS FOR SODIUM-SULFUR (GLASS) STATIONARY BATTERIES

<u>Materials</u>	<u>kg/kWh (13)</u>	<u>Cumulative Requirement (10⁶kg)</u>	
		<u>1990</u>	<u>2000</u>
Steel	7.22	13.0	1,213
Aluminum	2.56	4.6	430
Sulfur	1.88	3.4	316
Sodium	0.74	1.3	124
Glass	0.77	1.4	129
Plastic	0.03	0.1	5
Insulation	1.02	1.8	171
Copper	0.16	0.3	27
TOTAL	14.38	-	-

TABLE II-32. MATERIALS REQUIREMENTS FOR SODIUM-SULFUR (CERAMIC ELECTROLYTE) STATIONARY BATTERIES 1980-2000

<u>Material</u>	<u>kg/kWh (13)</u>	<u>Cumulative Requirement (10⁶ kg)</u>	
		<u>1990</u>	<u>2000</u>
Steel	7.13	12.8	1,198
Aluminum	1.98	3.6	333
Sulfur	1.73	3.1	291
Sodium	1.12	2.0	188
Alumina	1.99	3.6	334
Sodium Carbonate	0.23	0.4	39
Lithium Oxylate	0.04	0.1	7
Plastic	0.03	0.1	5
Insulation	1.02	1.8	171
Chromic Acid	0.36	0.6	60
Copper	0.15	0.3	25
Graphite	0.15	0.3	25
TOTAL	16.35	-	-

TABLE II-33. MATERIALS REQUIREMENTS FOR LITHIUM-METAL SULFIDE STATIONARY BATTERIES 1980-2000

<u>Material</u>	<u>kg/kWh (13)</u>	<u>Cumulative Requirement (10⁶kg)</u>	
		<u>1990</u>	<u>2000</u>
Lithium	0.46	0.8	77
Sulfur	0.71	1.3	119
Aluminum	1.14	2.1	192
Iron	1.00	1.8	168
Chlorine	0.83	1.5	139
Potassium Chloride	1.27	2.3	213
Magnesium Oxide	0.88	1.6	148
Steel	7.73	13.9	1,299
Molybdenum	0.02	-	3
Copper	0.47	0.8	79
Asbestos	0.23	0.4	39
Glass Insulation	0.77	1.4	129
TOTAL	15.51	-	-

**TABLE II-34. MATERIALS REQUIREMENTS FOR
ZINC-BROMINE STATIONARY BATTERIES 1980-2000**

<u>Material</u>	<u>kg/kWh (13)</u>	<u>Cumulative Requirement (10⁶kg)</u>	
		<u>1990</u>	<u>2000</u>
Zinc	0.68	1.4	114
Bromine	1.02	1.8	171
Polypropylene	4.50	8.1	756
Steel	3.79	6.8	637
Potassium Chloride	2.24	4.0	376
Chlorine	0.88	1.6	148
Quaternary Ammonium Bromide	0.89	1.6	150
Titanium	0.66	1.2	111
Copper	0.56	1.0	94
Carbon	0.43	0.8	72
Glass-Filled Polypropylene	0.27	0.5	45
Water	6.62	-	-
Total	22.54	-	-

TABLE II-35. MAXIMUM RESOURCE USE CUMULATIVE TOTAL
FOR ALL BATTERIES (10^6 kg) (1980-2000)

	1990			2000		
	EV	Stationary	Total	EV	Stationary	Total
Lead	6,487	699	7,186	13,437	1,958	15,395
Sulfuric Acid	1,189	78	1,267	2,464	218	2,682
Antimony	54	3	57	112	7	119
Plastic	452	198	650	1,874	1,211	3,085
Nickel	40	0	40	1,703	0	1,703
Zinc	30	7	37	1,307	210	1,517
Potassium Hydroxide	9	0	9	396	0	396
Copper	7	5	12	339	112	451
Steel	53	33	86	927	1,846	2,773
Iron	22	2	24	1,115	168	1,283
Lithium Hydroxide	2	0	2	79	0	79
Graphite	13	9	22	575	222	797
Titanium	1	2	3	40	126	166
Chlorine	6	5	11	360	201	561
Sodium	4	2	6	433	188	621
Sulfur	6	3	9	713	316	1,029
Glass	1	1	2	116	129	140
Aluminum	5	5	10	585	430	1,015
Alumina	2	4	6	212	334	546
Lithium	1	1	2	113	77	190
Potassium Chloride	3	4	7	310	376	686
Boron Nitride	0	0	0	35	0	35
Molybdenum	0	0	0	5	3	8
Asbestos	1	0	1	55	39	94
Sodium Hydroxide	0	0	0	20	0	20
Sodium Carbonate	0	0	0	0	39	39
Lithium Oxylate	0	0	0	0	7	7
Chromic Acid	0	1	1	0	60	60
Magnesium Oxide	0	2	2	0	148	148
Bromine	0	2	2	0	171	171
Quaternary						
Ammonium Bromide	0	2	2	0	150	150

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