AN EVALUATION OF THE MARKET AND APPLICATIONS OF BATTERIES IN PHOTOVOLTAIC SYSTEMS

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ABSTRACT

Under the sponsorship of the Department of Energy, Office of Utility Technology, the Battery Analysis and Evaluation Department and the Photovoltaic System Assistance Center of Sandia National Laboratories (SNL) initiated a US industry-wide PV Energy Storage System survey. Arizona State University (ASU) was contracted by SNL to conduct the survey and to compile the survey results.

The extrapolated data from the study show the 1995 market for PV batteries to be quite large: worldwide sales of PV batteries were 2,961,000 kWh, worldwide wholesale value for PV batteries shipped in 1995 was $302 million, and worldwide total installed capacity of batteries in PV systems was 10,519,000 kWh.

For the 21 System Integrator respondents, seventy-one percent of the dollars were spent on valve-regulated lead-acid (VRLA) batteries, and VRLA batteries cost 88 percent more than flooded-vented batteries per kWh ($128/kWh Vs $68/kWh). The use of VRLA batteries increased by 145 percent from 1991 to 1995, while the use of flooded-vented batteries increased by 117 percent in units, but decreased by about 25 percent in dollars.

INTRODUCTION

The survey included three separate segments tailored to the following groups:

A. PV system integrators
B. PV charge controller manufacturers
C. Battery manufacturers

The overall purpose of the survey was to:

1. quantify the market for batteries shipped with (or for) PV systems in 1995,
2. quantify the PV market segments by battery type and application for PV batteries,
3. characterize and quantify the charge controllers used in PV system,
4. characterize the operating environment for energy storage components in PV systems and
5. estimate the PV battery market for the year 2000

In January 1996 Survey A was sent to PV System Integrators (11 large and 18 small); Survey B was sent to 10 Battery manufacturers; Survey C was sent to 10 Charge Controller manufacturers.

Responses to the three surveys were:

Survey A	Large System Integrators	8 responses from 11 inquiries (73%)
	Small System Integrators	13 responses from 18 inquiries (72%)
Survey B	Battery Manufacturers	9 responses from 10 inquiries (90%)
Survey C	Charge Controller Mfg.	8 responses from 10 inquiries (80%)

Responses for each survey (A, B, and C) were consolidated and highlights are presented herein.

SURVEY A, SYSTEM INTEGRATORS

Survey A was segmented into four parts: 1) Battery Sales Data, 2) Battery Information Needed For PV System Design, 3) PV System Operating Conditions, and 4) Hybrid System Issues.

Part 1. Battery Sales Data

Top-Down Market Analysis

The majority of results presented in Part 1 were based solely on summary results from the 21 System Integrators that responded to the survey. These summary results are, to a large extent, representative of the worldwide market and therefore can be extrapolated. However, the summary results do not provide a means to estimate total PV battery sales for either the US market or the worldwide market. **In order to put the data from Part 1 in perspective, a Top-Down Market Analysis was developed to quantify the volume of batteries installed in PV systems.**

The top down analysis is based on a rule of thumb[1] which provides an estimate of the number of batteries used for each 50 watts (peak) of modules used. Since the number of PV watts shipped each year (both US and worldwide) is well known and published by recognized PV marketing experts, it is a straight forward process to estimate the total number of batteries installed in PV systems each year.

Worldwide PV module shipments in 1995 were approximately 78 megawatts (MW) [2], with about 67 MW being used in stand-alone applications (about 11 MW were used in grid-connected and consumer[3] applications). Water pumping, a segment of the stand-alone market, often does not use batteries, so the 67 MW will be adjusted downward to **64 MW**, which represents PV module sales in systems that included batteries. Using the rule of thumb of one 12V-100 AH battery (i.e., 1.2 kWh) for each 50 watts of PV modules, the 1995 PV battery sales can be calculated:

- **The total worldwide sales of PV batteries in 1995 was (64 MW/50W)*1.2 kWh = 1,536,000 kWh.**

Additional batteries were sold during 1995 to replace batteries that reached end-of-life in existing PV systems. Assuming a typical battery life of 5 years and that all PV system batteries installed in 1990, 1985, and 1980 were replaced (934,000+291,000+200,000 kWh), then a total of 1,425,000 kWh of batteries were replaced in 1995.

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[1] The widely accepted rule of thumb is that for every 50 watts (peak) of PV modules used in a PV system, approximately 1.2 kWh of battery is used (e.g., one 12V, 100 Ah battery). This industry consensus rule of thumb is sometimes used to estimate the quantity of batteries for a "typical" PV system. The authors of this report estimated that the uncertainty of this rule is +/- 20 percent.

[2] Based on averages of data from conversations with Bob Johnson of Strategies Unlimited (May 1996), and Paul Maycock of PV News, February 1996. Johnson and Maycock are two of the leading PV industry experts who have provided technology and market reports (including historical and forecasted PV sales data) for about two decades.

[3] Consumer applications: small "expendable" products such as solar powered calculators, toys, and walk lights (< five watts peak).

The total of new-system batteries in 1995 (1,536,000 kWh) plus the replacement batteries (1,425,000 kWh) equals 2,961,000 kWh of PV system battery sales. From Table 2-3, the average cost per kWh in 1995 was \$102 per kWh (wholesale).

- **The worldwide wholesale value for PV batteries shipped in 1995 was \$302 million.**

The approximations which went into this calculation will limit the accuracy to about ± 25 percent, so that an appropriate range for wholesale dollar value would be \$226 to \$378 million.

It is estimated that about 11.5 percent[4] of the total 64 MW of stand-alone PV were installed in the US in 1995. Therefore, total PV battery sales in the US were 11.5%*2,961,000 kWh or 340,515 kWh (or about 11.5%*\$302 million = \$34.7 million).

- **This indicates that the 21 System Integrators control about \$4.76 million[5]/34.7 million = 14 percent of the US PV battery market (in terms of dollar sales).**

Using the same methodology to calculate the newly installed capacity each year (not counting replacement batteries, it is estimated that:

- **Approximately 10,519,000 kWh of batteries are currently installed in PV systems worldwide.**

The approximations used for these calculations limit the accuracy to about ± 25 percent.

<u>Summary Of Results From The 21 System Integrators</u>

All battery sales reported (Tables 1, 2, and 3) were for lead-acid batteries (there were no nickel-cadmium batteries reported). The total cost of batteries purchased by the 21 System Integrators in 1995 was \$4.8 million at a unit volume of 26,308. The "top-down" market analysis showed the total worldwide PV battery shipments in 1995 to be approximately \$302 million and 2,961 MWh. This is equivalent to about 2 million 12V-100 AH batteries. The US share of this market was approximately 11.5 percent or 34.7 million dollars (340,515 kWh). The 21 System Integrators supplied about 14 percent of the 1995 US PV battery market in terms of wholesale dollars and about 13.6 percent of the worldwide kWh sales. One conclusion that may be drawn from the analysis is that many US end users buy their PV batteries directly from a battery supplier and not from a system integrator.

Seventy-one percent of the dollars were spent on valve-regulated batteries (Table 3), and valve-regulated batteries cost 88 percent more than flooded-vented batteries per kWh (\$128/kWh Vs \$68/kWh). The use of valve regulated batteries increased by 145 percent from 1991 to 1995, while the use of flooded-vented batteries increased by 117 percent in units, but decreased by about 25 percent in dollars.

The eight Large System Integrators sold 78 percent of the total units (Large plus Small Integrators) and captured 88 percent of the total dollars (Large plus Small Integrators). Small System Integrators sold 16 percent of the valve-regulated units and 33 percent of the flooded-vented units.

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[4] Based on estimates of 12.8 percent by Paul Maycock (PV News) and 10.6 percent by Bob Johnson (Strategies Unlimited) during telephone conversations November 1, 1996.

[5] see Table 3 *Totals For All Batteries*.

TABLE 1. VALVE-REGULATED BATTERIES

MANUFACTURER	1995						
	# of Units	% of #	$ (Wholesale)	% of $	kWh	%-kWh	$/kWh
GNB	3,901	23%	$2,240,352	66%	14,234	54%	$157
DEKA	6,827	41%	$645,285	19%	6,746	25%	$96
JCI	2,704	16%	$245,191	7%	3,073	12%	$80
CONCORD	1,737	10%	$156,226	5%	1,661	6%	$94
SONNENSCEIN	1,223	7%	$73,846	2%	459	2%	$161
POWERSONIC	177	1%	$15,670	0%	98	0%	$160
MISC	277	2%	$14,212	0%	253	1%	$56
TOTAL	16,846	100%	$3,390,782	100%	26,524	100%	$128

TABLE 2. FLOODED VENTED BATTERIES

MANUFACTURER	1995						
	# of Units	% of #	$ (Wholesale)	% of $	kWh	%-kWh	$/kWh
CEAC (France) [1]	1,843	19%	$318,703	23%	4,182	21%	$76
C&D	768	8%	$271,872	20%	3,533	18%	$77
TROJAN	2,633	28%	$173,364	13%	4,174	21%	$42
GNB	182	2%	$168,119	12%	1,871	9%	$90
IBE	806	9%	$150,904	11%	1,641	8%	$92
EXIDE	1,685	18%	$116,950	9%	2,244	11%	$52
EAST PENN	628	7%	$80,448	6%	957	5%	$84
US BAT	800	8%	$71,740	5%	1,203	6%	$60
PACIFIC CHLORIDE	37	0%	$16,810	1%	187	1%	$90
MISC	80	1%	$1,150	0%	20	0%	$58
TOTAL	9,462	100%	$1,370,060	100%	20,012	100%	$68

Note 1. Compagnif Europeenne d'Accumulaturs (CEAC), France, was purchased by Exide in February 1996.

TABLE 3. TOTAL FOR ALL BATTERIES

TECHNOLOGY	1995						
	# of Units	% of #	$ (Wholesale)	% of $	kWh	%-kWh	$/kWh
VALVE-REGULATED	16,846	64%	$3,390,782	71%	26,524	57%	$128
FLOODED-VENTED	9,462	36%	$1,370,060	29%	20,012	43%	$68
TOTAL	26,308	100%	$4,760,842	100%	46,536	100%	$102

The primary applications for valve-regulated lead-acid (VRLA) batteries were telecommunications (40 %[6]), telemetry (13%), and lighting (9%)(Table 4). Approximately 85 percent of all batteries reported in the categories of telecommunications, telemetry, and lighting used VRLA batteries. Thirty percent of all flooded-vented batteries were used in hybrid systems (as opposed to 89 percent of all hybrid applications used flooded-vented batteries; see Table 5), 31 percent

[6] i.e., the percentage of kWh for all valve-regulated batteries.

TABLE 4. TOTAL FOR ALL BATTERIES; kWh BY APPLICATION[7]

TECHNOLOGY	RH	TC<	TC>	TM	L	W	H	V	UKN	TOTALS
VALVE-REGULATED	7%	6%	34%	13%	9%	2%	3%	3%	23%	100%
FLOODED-VENTED	17%	2%	29%	1%	2%	2%	30%	13%	4%	100%
TOTAL	11%	4%	32%	8%	6%	2%	15%	7%	15%	100%

TABLE 5. TOTAL (100%) BY APPLICATON; (kWh)

TECHNOLOGY	RH	TC<	TC>	TM	L	W	H	V	UKN	TOTALS
VALVE-REGULATED	35%	81%	61%	94%	85%	59%	11%	23%	89%	57%
FLOODED-VENTED	65%	19%	39%	6%	15%	41%	89%	77%	11%	43%
TOTAL	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

in telecommunications, and 17 percent in remote homes. The preference for VRLA batteries or flooded-vented batteries depended to a large extent on the market segment that the battery serves.

Valve-regulated batteries are heavily skewed toward 12 V modules (60%); 35 percent were 6 V modules, and only 5 percent were 2 V cells. Flooded batteries were skewed toward 2 V cells (45%); 42 percent were 6 V modules, and 12 percent were 12 V modules.

In terms of amp-hour size, valve-regulated batteries were grouped in the 100-400 AH bin for 6 V modules and the 0-200 AH bin for the 12 V modules. Flooded batteries were more broadly distributed in the 600-3,000 AH range at 2 V, 200-400 AH at 6 V, and 1400-1800 AH at 12V.

Part 2. Battery Information Needed For PV System Design

This part of the survey asked Integrators what information they needed from the battery manufacturer in order to properly design PV systems with optimum performance and minimum life-cycle cost. Integrators ranked 29 parameters in terms of importance (1=Essential, 2=Useful, 3=Not Important). The first 20 parameters were ranked between 1.0 and 2.0 (averages for all 21 Integrators). The parameter ranked most important was "Cost" (Table 6).

Part 3. PV System Operating Conditions

Part 3 profiles the Integrators' application of PV hardware, their approach to PV system design, and the environment into which PV systems are placed.

Integrators reported that 80 percent of their charge controllers use an ON-OFF algorithm. The ON-OFF algorithm is by far the most difficult charge management algorithm for which to define voltage set points; battery manufacturers rarely, if ever, specify voltage set points for ON-OFF algorithms. This difficulty was emphasized by a battery manufacturer:

> ...Listen to the battery industry when we tell you that we need constant voltage regulators, higher end-voltage limits, and higher limits for low-voltage disconnects.

About 60 percent of integrator respondents use temperature compensated voltage regulators in their charge controller systems. By comparison, 88 percent of charge controller respondents felt that temperature compensation was either vital or important.

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[7] H=Hybrid; L=Lighting; RH=Remote Home; TM=Telemetry; TC<=telecommunication systems less than 200 W(peak) of PV; TC>=telecommunication systems greater than 200 W(peak) of PV; UKN=Unknown; V=Village Power; W=Water Pumping

TABLE 6. BATTERY INFORMATION NEEDED FOR SYSTEM DESIGN (TOP 5)

	1 = Essential, 2 = Useful, 3 = Not Important				
	1991	1995			
	7 Large	Small	Large	Average	PARAMETER(S)
1	1.00	1.23	**1.00**	1.12	Cost
2	1.00	1.08	**1.00**	1.04	Nominal battery voltage
3	1.00	1.77	**1.14**	1.46	Amp-hour capacity at C/100
4	1.14	1.31	**1.14**	1.23	Recommended charging voltage vs. temperature vs. charge rate
5	1.14	1.15	**1.29**	1.22	Physical characteristics; dimensions, terminal size, weight

Part 4. Hybrid System Issues

Hybrid systems are stand-alone systems with two or more types of power generating sources, one of which is photovoltaics. The purpose of Part 4 was to identify unique characteristics and requirements of hybrid systems.

Forty-eight percent of the Small Integrators' business was hybrid systems, compared to 16 percent for Large Integrators. This may be due to the fact that Small Integrators provide many PV systems for remote homes, which often use a backup generator.

The majority (52%) of hybrid systems batteries are flooded-vented lead-acid with antimony additive to the plates. None of the Integrators used flooded-vented batteries with calcium additive to the plates. Forty-eight percent of the batteries were VRLA.

SURVEY B. BATTERY MANUFACTURER SURVEY

This survey was designed to a) collect information regarding contacts and products that would be of interest to the PV industry and b) to determine what information that battery manufacturers needed from the PV industry. Nine of the ten battery manufacturers that received the three page questionnaire responded.

None of the nine respondents indicated that they had an "Application Guide for PV Customers" available at the time that the survey was submitted. However, four indicated that they will have an application guide available by the end of 1996.

SURVEY C. CHARGE CONTROLLER MANUFACTURERS

Two of the eight respondents had about 55 percent of the US unit and dollar volume in 1995 (Table 7). On the other end of the scale, two manufacturers had less than 2 percent of the market. A 203 percent growth rate in unit volume was projected for 1996 by the respondents (Table 7).

Manufacturers answered with one YES and seven NOs to the question "Do you receive adequate information from battery manufacturers regarding the performance of batteries in PV Systems?"

TABLE 7. CHARGE CONTROLLER SALES AND PROJECTIONS

	Units, 1995		Dollar Sales, 1995		Projected Units	
Mfg.	**Units**	**% of Total**	**$**	**% of Total**	**1996**	**96/95**
A	75	0%	$13,925	0%	200	267%
B	285	1%	$54,150	1%	1,590	558%
C	1,054	3%	$330,362	6%	1,270	120%
D	5,375	13%	$512,250	10%	6,335	118%
E	7,000	17%	$717,500	14%	17,550	251%
F	4,734	11%	$800,790	15%	25,000	528%
G	1,230	3%	$1,019,850	20%	4,950	402%
H	21,431	52%	$1,758,300	34%	26,780	125%
TOTALS	**41,184**	**100%**	**$5,207,127**	**100%**	**83,675**	**203%**

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GENERAL CONCLUSIONS AND RECOMMENDATIONS

The Survey

The survey provided: a) quantification and characterization of batteries and charge controllers used in PV systems, b) characterization of the operating environment in which batteries and charge controllers are used, and c) feedback from PV system integrators, battery manufacturers, and charge controller manufacturers defining what information each needed to optimize PV energy storage systems.

Sandia National Laboratories Assistance

Survey respondents identified areas of focus by each of the three industries (PV System Integrators, Battery Manufacturers, and Charge Controller Manufacturers) in which they would like Sandia National Laboratories' (SNL) assistance. The high priority areas identified were: a) assist in the development of application guides or notes, b) assist in the characterization of batteries for PV data sheet values, c) provide technical liaison between the PV and battery industries and, d) perform surveys to define the market.

Information Exchange

Survey respondents indicated an on-going need for data collection and dissemination. Information exchange and information dissemination is most effective when done on a regular basis. There is a significant benefit to SNL continue to serve as the focal point for PV Energy System information and generation, collection, and distribution by: a) expanding the contact list developed by the survey, b) creating an internet web site for easy access to existing battery storage information and as a means for industry to ask questions and contribute information, c) distribute a quarterly "news letter" of summary information to the LIST via e-mail, d) distributing an *annual report* via e-mail to the LIST plus a hard copy to the Department of Energy and other selected individuals and e) present relevant information at conferences such as BATTCON.

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3 GROUPS

A. PV system integrators
B. PV charge controller manufacturers
C. Battery manufacturers

PURPOSE

QUANTIFY and/or CHARACTERIZE

- batteries shipped in 1995
- battery type and application
- charge controllers used in PV system
- operating environment for energy storage components in PV systems and
- the PV battery market for the year 2000

TOP DOWN MARKET ANALYSIS
1995

1. Worldwide sales of PV batteries = 2,961,000 kWh
2. Worldwide wholesale $ for PV batteries shipped in: $302 million
3. Worldwide total installed capacity of PV batteries: 10,519,000 kWh
4. US sales of PV batteries: 340,515 kWh
5. US sales of PV batteries: $34.7 million
6. the 21 System Integrators supplied about 14 percent ($)of the US PV battery

TABLE 1. VALVE-REGULATED BATTERIES: 1995

MANUFACTURER	# of Units	% of #	$ (Wholesale)	% of $	kWh	%-kWh	$/kWh
GNB	3,901	23%	$2,240,352	66%	14,234	54%	$157
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TOTAL	16,846	100%	$3,390,782	100%	26,524	100%	$128

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TOTAL	9,462	100%	$1,370,060	100%	20,012	100%	$68
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TABLE 4. kWh BY APPLICATION

TECH-NOLOGY	RH	TC<	TC>	TM	L	W	H	V	UKN	TOTAL
VALVE-REGULATED	7%	6%	34%	13%	9%	2%	3%	3%	23%	100%
FLOODED-VENTED	17%	2%	29%	1%	2%	2%	30%	13%	4%	100%
TOTAL	11%	4%	32%	8%	6%	2%	15%	7%	15%	100%

H= Hybrid	L = Lighting	TC< = Telecommunications less than 200 W(peak) PV
RH = Remote Home	TM = Telemetry	TC> = Telecommunications greater than 200 W(peak) PV
UKN = Unknown	V = Village Power	W = Water Pumping

TABLE 5. TOTALS (100%) BY APPLICATION (kWh)

TECH-NOLOGY	RH	TC<	TC>	TM	L	W	H	V	UKN	TOTAL
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TOTAL	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

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TABEL 6
BATTERY INFORMATION NEEDED FOR SYSTEM DESIGN (TOP 5)

1 = Essential, 2 = Useful, 3 = Not Important			
	1991	1995	PARAMETER(S)
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4	1.14	1.14	Recommended charging voltage vs. temperature vs. charge rate
5	1.14	1.29	Physical characteristics; dimensions, terminal size, weight

TABLE 7
CHARGE CONTROLLER
SALES & PROJECTIONS

	Units, 1995		$, 1995		Projected Units	
Mfg.	Units	% of Total	$	% of Total	1996	96/95
A	75	0%	$13,925	0%	200	267%
B	285	1%	$54,150	1%	1,590	558%
C	1,054	3%	$330,362	6%	1,270	120%
D	5,375	13%	$512,250	10%	6,335	118%
E	7,000	17%	$717,500	14%	17,550	251%
F	4,734	11%	$800,790	15%	25,000	528%
G	1,230	3%	$1,019,850	20%	4,950	402%
H	21,431	52%	$1,758,300	34%	26,780	125%
TOTALS	41,184	100%	$5,207,127	100%	83,675	203%

CONCLUSIONS

1. PV BATTERY MARKET IS MUCH LARGER THAN MOST PEOPLE REALIZED
2. VRLA BATTERIES DOMINATE THE MARKET
3. CONSTANT VOLTAGE REGULATORS DESIRED
4. SNL: SUPPORT APPLICATION NOTES, BATTERY CHARACTERIZATION, LIAISON, MARKET DEFINITION
5. PV INDUSTRY NEEDS SOURCE OF BATTERY INFORMATION