ADVANCED POWER BATTERIES FOR RENEWABLE ENERGY APPLICATIONS 3.09

Final Technical Report

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Abstract

This report describes the research that was completed under project title – Advanced Power Batteries for Renewable Energy Applications 3.09, Award Number DE-EE0001112. The report details all tasks described in the Statement of Project Objectives (SOPO). The SOPO includes purchasing of test equipment, designing tooling, building cells and batteries, testing all variables and final evaluation of results. The SOPO is included in Appendix A. There were various types of tests performed during the project, such as; gas collection, float current monitoring, initial capacity, high rate partial state of charge (HRPSoC), hybrid pulse power characterization (HPPC), high rate capacity, corrosion, software modeling and solar life cycle tests. The grant covered a period of two years starting October 1, 2009 and ending September 30, 2011.

Executive Summary

The continued research in all aspects of lead-acid batteries is of value to the enhancement of many products such as automotive, motive power, telecommunications and especially renewable energy.

Objective #1: Determine the best carbon based additive for optimal anode performance.

Result: An acetylene black type of carbon performed optimally in the AGM and Gel type batteries.

Objective #2: Determine the best lignin additive for optimal anode performance.

Result: The high temperature and high molecular weight lignin out performed all others.

A further understanding of negative plates, when additional carbons are added and variations of normal ingredients are involved, will improve the designs developed for energy storage batteries. With the results obtained in the project, engineers can focus on the proper materials for an improved renewable energy battery.

Objective #3: Construct anodes using optimized carbon and lignin material and evaluate to achieve the most advantageous life cycle performance.

Result: For the AGM battery, an acetylene black blend of carbon had the most consistent cycling performance. A high molecular weight lignin improved cycle-ability.

The standard Gel battery design was cycling at a higher state of charge than any of the other batteries built with additional carbon or different lignins. The project concluded before final results were obtained.

The capability to incorporate the preferred materials is possible in the normal production of today's batteries. The life test procedure used was IEC 61427, which is an excellent comparison of photovoltaic life between the various batteries built for the project. The results from these tests allow lead-acid batteries to be made with the optimum materials for longer life in renewable energy applications.

Objective #4: Optimize the current collector in 2-volt cells.

Result: The 95 radial design and 125 power frame design out performed the standard design at one and eight minute rates. However, at a normal fifteen minute rate the standard design was superior.

Grid designs are critical for high rate performance in lead-acid batteries. By creating new designs and testing them at high rates, we were able to determine the advantages and limitations of the new designs. The grids were manufactured using the standard production equipment and cells produced through the normal processes. This will allow battery manufacturers to proceed with improved products and limited capital costs.

Renewable energy involving energy storage applications require batteries to produce and accept power at high rates. The testing has shown, when including the newly developed designed grids, where they have advantages for use and where they do not. Also, this project will help the development of large two volt batteries in motive power and telecommunications applications.

The research from this project will help improve renewable energy systems in terms of capability and life. Energy storage systems will be enhanced, allowing quick response in applications such as wind power, solar sites, grid connections for frequency regulations, peak shifting or peak shaving, to name a few. Finally, the knowledge gained can be used in many other applications where lead-acid batteries are used today.

Background

To overcome dependency on oil imports renewable energy applications are of supreme importance. The government is investing significant amounts of money in the development of improved renewable energy sources as well as the required back-up battery systems to maximize the efficiencies of the renewable technologies. Lead-acid technology has many advantages over other systems; many years of proven reliability, excellent recyclability, low cost and availability of raw materials. Research and development in the lead-acid world continues because of new materials, designs, applications and processes which allow improvements to the product.

Carbon additions to lead-acid batteries have been a recent improvement for specific applications. The use of carbons in the anode of lead-acid batteries has been investigated for many years but the Advanced Lead Acid Battery Consortium (ALABC) discovered improvements in high rate partial state of charge applications¹. This type of operation is similar to wind farm and certain photovoltaic applications. Sandia Laboratories tested carbon enhanced batteries and found improved cycling when subjected to a HRPSoC operation². The knowledge of the effects with specific types and quantities of carbon is limited. Consequently, East Penn submitted a request for a grant to build, test and evaluate variations in the carbon additions and expander lignins in the anode of a lead-acid battery. Improved grid designs for large format cells which could improve battery capacity, life and charge acceptance for high rate applications will also be evaluated in the project.

¹ M.A. Spence, D. P. Boden, T. D. Wojcinski, "Identification of the Optimum Specification for Carbon to be Included in the Negative Active Material of a Valve-Regulated Battery in Order to Avoid Accumulation of Lead Sulfate During High-Rate Partial-State-of-Charge Operation." ALABC Research Project Designation C1.1/2.1A, Progress Report 4, October 2009.

² T. Hund, W. Caca "Large Format, Carbon-Enhanced, VRLA Battery Test Results." EESAT2009, October 4-7, 2009.

Description

The original 12 volt batteries that were built and tested are valve-regulated lead acid (VRLA) absorbed glass mat (AGM) technology types. This standard size battery, part number 8A31DT, is rated at 105 amp hours at the 20 hour rate. Since East Penn Manufacturing also builds VRLA's in the same foot print but using Gel technology, part number 8G31DT, Gel batteries were added to the project at a later date. This addition to the SOPO is documented in Appendix A.

The current collector design portion of the project involved large plate types built into two volt VRLA - AGM cells. The two plate sizes designed and produced were 95 amp hours and 125 amp hours at the eight hour rate. Finished cells were all built as seven plate designs, four negative and three positive plates.

Task 2.1 Testing Equipment: To properly test the different prototype batteries and cells requires the correct laboratory equipment. The equipment includes cycling rectifiers that charge and discharge the batteries and cells at the specified rates. Meetings were held to determine the tests to be utilized and the specifications for the equipment required. These specifications were used to secure quotes from suppliers of the equipment. Different quantities and sizes of cyclers were needed, as well as an environmental chamber for accelerated life testing, a data logger and a power supply. The equipment was purchased and installed in the Stationary Laboratory at East Penn Mfg.

Task 2.2 Carbon Based Additives in the Anode: It has been proven in previous battery tests that the addition of carbons to the anode will improve cycle life. The goal of this task is to evaluate two carbons using different loadings. Initially the project involved AGM batteries however, Gel type batteries were added during the two year project.

Subtask 2.2.1 involved the building and testing of a control group along with eight variables as shown in Table 1. Carbon X is an activated type of carbon while Y is an acetylene black type. The loadings one, two and three ranged between 0.25% and 2.0 %. The two tests performed on the 8A31DT's were HPPC and HRPSoC. The Gel versions were HRPSoC tested. The descriptions of these tests are included in Appendix B.

Subtask 2.2.2 life tested the optimum variables based on test results from Subtask 2.2.1 tests. The life test procedure is IEC-61427 Solar Life Cycle Test, which is also detailed in Appendix B.

TABLE 1

Design of Experiment			
Battery Control	Carbon Standard	Loading Standard	Lignin Standard
2A	X	1	H
2B	X	2	H
2C	Y	1	H
2D	Y	3	H
3A	X	1	N
3B	X	2	N
3C	Y	1	N
3D	Y	3	N

Task 2.3 Expander Improvements: Expander is a standard additive to the anode of a lead-acid battery. There are, however, different types. The goal of this task is to test two different lignins, which are ingredients in the expander, and determine the optimum type to use in renewable applications. The lignins are labeled H and N as variables listed in Table 1 above. Lignin N has a molecular weight greater than the control while lignin H is a high temperature, very high molecular weight version.

Subtask 2.3.1 used the same set of variables listed in Table 1. Also, 8A31DT batteries with the two lignins were HPPC and HRPSoC tested while 8G31's were HRPSoC tested.

Subtask 2.3.2 life tested the best performing variables using the IEC-61427 Solar Life Cycle Test, as in Subtask 2.2.2. An additional float test was performed on the 8A31DT types; control, 2B, 2C and 2D. The float current and gassing released during this test was recorded over thousands of hours.

Task 2.4 Current Collector Design: Current collector designs are important in the optimization of the battery operation. The most efficient use of the metal grid improves the collector's capacity, especially at high rates. Applications such as frequency regulation and UPS systems demand high current carrying efficiency.

Subtask 2.4.1 began with the development of improved current collector designs. After designing the grids, molds were purchased, grids and plates produced and cells manufactured. High rate discharge tests were performed at the one, eight and fifteen minute rates to determine the optimum grid design. During the discharges thermal imaging was done on the terminals and connectors. There was also third party software analysis of the various grid designs.

Subtask 2.4.2 was a fifteen minute life cycle test involving control cells versus cells containing the optimum, newly designed grid. Corrosion testing of the control and most efficient new grid design was also done in the Laboratory. Finally, an electrical conductivity test was performed to compare the various designs to the third party software analysis.

Results

Task 2.1 Testing Equipment: All test equipment was purchased, installed and approved by February 1, 2011. A copy of the list of equipment purchased and East Penn's identification numbers are included in TABLES 2A/2B and TABLE 3 respectively. Pictures of the installed equipment are on the following pages. Also, for a complete break-down of the equipment see Appendix C.

TABLE 2A

Equipment to Purchase	Manufacturer
Cycler, 25A charge/15A discharge, 16 circuits	Data Technologies Inc
Environmental Chamber	Espec
Cycler, 75A charge/75A discharge, 10 circuits	Data Technologies Inc
Discharger, 5000 amps	East Penn Mfg
Data Logger	Fluke
Power Supply	Hewlett Packard
Cycler, 400A charge/400A discharge, 3 circuits	Data Technologies Inc

The equipment listed above was used for the tests described in Table 2B.

TABLE 2B

Equipment to Use	Test
Cycler, 25A charge/15A discharge, 16 circuits	Solar Life Cycle
Environmental Chamber	HPPC
Cycler, 75A charge/75A discharge, 10 circuits	HRPSoC
Discharger, 5000 amps	1 & 8 minute discharge
Data Logger	1, 8, 15 min discharge
Power Supply	Corrosion
Cycler, 400A charge/400A discharge, 3 circuits	HPPC and 15 min cycle

TABLE 3

July 27, 2011 10:51 am

Equipment List

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* REA309

<u>Equipment ID</u>	<u>Equipment Name</u>	<u>Parent ID</u>	<u>Plant</u>	<u>Dept</u>	<u>Location</u>	<u>Group</u>	<u>Type</u>	<u>Status</u>	<u>Inactive</u>	<u>PT Xref</u>
LC-147	CYCLER, CABINET <i>Make: D.T.I.</i>	18-7320 <i>Model:</i>	18	7320	TEST LAB <i>SN:</i>	TESTER	TELC	PROCUR	No	
LC-148	CYCLER, CABINET <i>Make: D.T.I.</i>	18-7320 <i>Model: LC400X3CD</i>	18	7320	TEST LAB <i>SN: NO INFO AVAILABLE</i>	TESTER	TELC	ASSIGN	No	No
LC-149	CYCLER, CABINET <i>Make: D.T.I.</i>	18-7320 <i>Model:</i>	18	7320	TEST LAB <i>SN:</i>	TESTER	TELC	PROCUR	No	No
LC-150	CYCLER, CABINET <i>Make: D.T.I.</i>	18-7320 <i>Model: LC5000X1D</i>	18	7320	TEST LAB <i>SN: 210101</i>	TESTER	TELC	ASSIGN	No	No
OV-236	OVEN <i>Make: ESPEC</i>	18-7320 <i>Model: EGM128-4CAL</i>	18	7320	S-1 TEST LAB <i>SN: TC-00843</i>	OVEN	OV	ASSIGN	No	No
SP-038	SUPPLY, POWER CH-S1L55 <i>Make: AGILENT</i>	18-7320 <i>Model: AGI-5012B</i>	18	7320	TEST LAB <i>SN: 2524A-00685</i>	ELEC	PWSP	ASSIGN	No	
TL-203	DATA LOGGER VM-S1L13 <i>Make: FLUKE</i>	18-7320 <i>Model: 2635A</i>	18	7320	TEST LAB <i>SN: 6100002</i>	TOOLS	MAEQ	ASSIGN	No	

GRAND TOTAL: 7

25 AMP Cycler

75 AMP Cycler

400 AMP Cycler

5000 AMP Cranker

Environmental Chamber

Task 2.2 Carbon Based Additives in the Anode:

Subtask 2.2.1 began with the manufacturing of negative plates (anodes) as listed in Table 1. Following plate production batteries were assembled into two groups; 8A31DT and 8G31DT. A picture of the stacked negative plates and 8A31DT batteries is shown below.

Negative Plates

8A31DT Batteries

The first step was to collect all pertinent information on each battery. This data includes assembly and fill codes, weight, voltage, conductance and a five hour discharge. The goal is to verify all batteries are capable of proceeding with the program. The data collected has been summarized in Table 4 and Table 5. Table 5, 8G31DT, also lists leak checks that were done prior to testing.

TABLE 4 – 8A31DT

Variable	Battery #	Assembly Code		Fill Code		Weight Kg	Voltage V	Cond S	Time to 1.75 vpc	% Capacity	RCH Time
Control	4	01628BPf2E	124	0208F18	46	30.245	12.845	1689	5:09:44	103.24%	20:09:47
	5	01628BPf2E	123	0208F18	47	30.245	12.840	1702	5:06:21	102.12%	19:34:11
	8	01628BPf2E	114	0208F18	50	30.285	12.838	1702	5:08:11	102.73%	22:17:58
	9	01628BPf2E	110	0208F18	51	30.215	12.845	1689	5:08:12	102.73%	18:34:41
	11	01628BPf2E	122	0208F18	53	30.330	12.834	1708	5:05:34	101.86%	24:37:52
	14	01628BPf2E	117	0208F18	56	30.300	12.834	1708	5:09:38	103.21%	18:51:09
Min						30.215	12.834	1689	5:05:34	101.86%	18:34:41
Max						30.330	12.845	1708	5:09:44	103.24%	24:37:52
Avg						30.270	12.839	1700	5:07:57	102.65%	20:40:56
St Dev						0.042	0.005	9	0:01:42	0.57%	2:20:41

Variable	Battery #	Assembly Code		Fill Code		Weight Kg	Voltage V	Cond S	Time to 1.75 vpc	% Capacity	RCH Time
2A	1	01628BPf2E	2	0208F18	99	30.320	12.835	1776	5:13:01	104.34%	20:00:46
	2	01628BPf2E	3	0208F18	100	30.220	12.839	1745	5:11:39	103.88%	21:13:44
	5	01628BPf2E	5	0208F18	103	30.305	12.848	1770	5:13:01	104.34%	22:07:44
	7	01628BPf2E	4	0208F18	105	30.300	12.849	1764	5:12:29	104.16%	21:25:34
	11	01628BPf2E	9	0208F18	109	30.255	12.835	1745	5:13:19	104.44%	21:18:56
	12	01628BPf2E	12	0208F18	110	30.345	12.842	1788	5:12:02	104.01%	20:38:47
Min						30.220	12.835	1745	5:11:39	103.88%	20:00:46
Max						30.345	12.849	1788	5:13:19	104.44%	22:07:44
Avg						30.291	12.841	1765	5:12:35	104.20%	21:07:35
St Dev						0.046	0.006	17	0:00:39	0.22%	0:43:22

Variable	Battery #	Assembly Code		Fill Code		Weight Kg	Voltage V	Cond S	Time to 1.75 vpc	% Capacity	RCH Time
2B	4	01628BPf2E	43	0208F18	74	30.180	12.876	1764	5:15:02	105.01%	9:56:31
	5	01628BPf2E	33	0208F18	75	30.145	12.877	1751	5:15:23	105.13%	10:54:30
	9	01628BPf2E	32	0208F18	79	30.195	12.871	1689	5:16:05	105.36%	11:17:57
	11	01628BPf2E	35	0208F18	81	30.100	12.881	1727	5:17:21	105.78%	10:37:25
	12	01628BPf2E	46	0208F18	82	30.205	12.887	1708	5:17:55	105.97%	11:08:54
	13	01628BPf2E	39	0208F18	83	30.145	12.877	1751	5:15:52	105.29%	13:50:06
Min						30.100	12.871	1689	5:15:02	105.01%	9:56:31
Max						30.205	12.887	1764	5:17:55	105.97%	13:50:06
Avg						30.162	12.878	1732	5:16:16	105.42%	11:17:34
St Dev						0.039	0.005	29	0:01:08	0.38%	1:20:04

TABLE 4 - 8A31DT

	Battery	Assembly		Fill		Weight	Voltage	Cond	Time to 1.75 vpc	%	RCH
Variable	#	Code		Code		Kg	V	S		Capacity	Time
2C	1	01628BPf2E	18	0208F18	85	30.100	12.841	1727	5:09:35	103.19%	26:52:41
	2	01628BPf2E	17	0208F18	86	30.120	12.868	1720	5:15:50	105.28%	25:46:40
	3	01628BPf2E	19	0208F18	87	30.180	12.836	1702	5:12:28	104.16%	25:16:25
	4	01628BPf2E	21	0208F18	88	30.190	12.839	1727	5:07:05	102.36%	25:33:22
	5	01628BPf2E	20	0208F18	89	30.130	12.835	1733	5:10:49	103.61%	25:10:34
	7	01628BPf2E	23	0208F18	91	30.140	12.841	1689	5:14:55	104.97%	28:53:58
				Min		30.100	12.835	1689	5:07:05	102.36%	25:10:34
				Max		30.190	12.868	1733	5:15:50	105.28%	28:53:58
				Avg		30.143	12.843	1716	5:11:47	103.93%	26:15:37
				St Dev		0.035	0.012	17	0:03:18	1.10%	1:25:48

	Battery	Assembly		Fill		Weight	Voltage	Cond	Time to 1.75 vpc	%	RCH
Variable	#	Code		Code		Kg	V	S		Capacity	Time
2D	1	01628BPf2E	63	0208F18	141	30.390	12.832	1856	5:10:44	103.58%	33:08:43
	2	01628BPf2E	59	0208F18	142	30.425	12.833	1844	5:10:08	103.38%	31:53:08
	3	01628BPf2E	62	0208F18	143	30.420	12.836	1844	5:12:58	104.32%	29:38:36
	6	01628BPf2E	61	0208F18	146	30.480	12.836	1838	5:12:02	104.01%	31:41:53
	7	01628BPf2E	57	0208F18	147	30.425	12.830	1844	5:08:27	102.82%	30:45:52
	12	01628BPf2E	49	0208F18	152	30.430	12.838	1844	5:10:17	103.43%	34:23:29
				Min		30.390	12.830	1838	5:08:27	102.82%	29:38:36
				Max		30.480	12.838	1856	5:12:58	104.32%	34:23:29
				Avg		30.428	12.834	1845	5:10:46	103.59%	31:55:17
				St Dev		0.029	0.003	6	0:01:35	0.53%	1:41:02

	Battery	Assembly		Fill		Weight	Voltage	Cond	Time to 1.75 vpc	%	RCH
Variable	#	Code		Code		Kg	V	S		Capacity	Time
3A	3	01628BPf2E	91	0208F18	115	30.250	12.852	1776	5:10:51	103.62%	22:45:51
	6	01628BPf2E	84	0208F18	118	30.210	12.859	1770	5:08:39	102.88%	24:50:00
	8	01628BPf2E	87	0208F18	120	30.230	12.865	1770	5:07:25	102.47%	20:49:01
	11	01628BPf2E	88	0208F18	123	30.240	12.859	1776	5:09:28	103.16%	20:04:16
	13	01628BPf2E	82	0208F18	125	30.210	12.850	1801	5:08:20	102.78%	24:20:28
	14	01628BPf2E	81	0208F18	126	30.310	12.862	1795	5:08:51	102.95%	21:11:59
				Min		30.210	12.850	1770	5:07:25	102.47%	20:04:16
				Max		30.310	12.865	1801	5:10:51	103.62%	24:50:00
				Avg		30.242	12.858	1781	5:08:56	102.98%	22:20:16
				St Dev		0.037	0.006	13	0:01:09	0.39%	1:57:29

TABLE 4 – 8A31DT

Variable	Battery	Assembly		Fill		Weight	Voltage	Cond	Time to 1.75 vpc	%	RCH
	#	Code		Code		Kg	V	S		Capacity	Time
3B	1	01628BPf2E	104	0208F18	57	30.270	12.846	1813	5:11:07	103.71%	18:59:52
	2	01628BPf2E	103	0208F18	58	30.230	12.850	1795	5:11:23	103.79%	21:56:44
	4	01628BPf2E	101	0208F18	60	30.220	12.855	1795	5:13:09	104.38%	21:18:22
	5	01628BPf2E	111	0208F18	61	30.365	12.861	1801	5:10:11	103.39%	22:31:28
	8	01628BPf2E	99	0208F18	64	30.230	12.872	1795	5:13:43	104.57%	21:00:44
	9	01628BPf2E	107	0208F18	65	30.225	12.866	1788	5:12:14	104.08%	17:28:23
				Min		30.220	12.846	1788	5:10:11	103.39%	17:28:23
				Max		30.365	12.872	1813	5:13:43	104.57%	22:31:28
				Avg		30.257	12.858	1798	5:11:58	103.99%	20:32:35
				St Dev		0.056	0.010	8	0:01:19	0.44%	1:55:26

	Battery	Assembly		Fill		Weight	Voltage	Cond	Time to 1.75 vpc	%	RCH
Variable	#	Code		Code		Kg	V	S		Capacity	Time
3C	1	01628BPf2E	79	0208F18	127	30.135	12.842	1770	5:11:03	103.68%	15:43:10
	2	01628BPf2E	75	0208F18	128	30.250	12.836	1788	5:08:17	102.76%	15:29:35
	5	01628BPf2E	78	0208F18	131	30.130	12.835	1776	5:10:39	103.55%	16:19:01
	6	01628BPf2E	71	0208F18	132	30.265	12.838	1795	5:10:19	103.44%	19:36:22
	8	01628BPf2E	70	0208F18	134	30.205	12.843	1788	5:05:49	101.94%	18:41:53
	9	01628BPf2E	67	0208F18	135	30.130	12.845	1751	5:11:43	103.91%	15:19:40
				Min		30.130	12.835	1751	5:05:49	101.94%	15:19:40
				Max		30.265	12.845	1795	5:11:43	103.91%	19:36:22
				Avg		30.186	12.840	1778	5:09:38	103.21%	16:51:37
				St Dev		0.063	0.004	16	0:02:12	0.73%	1:49:45

	Battery	Assembly		Fill		Weight	Voltage	Cond	Time to 1.75 vpc	%	RCH
Variable	#	Code		Code		Kg	V	S		Capacity	Time
3D	1	01628BPf2E	142	0208F18	29	30.145	12.838	1770	5:06:57	102.32%	35:08:15
	3	01628BPf2E	132	0208F18	31	30.040	12.867	1745	5:12:36	104.20%	23:56:25
	4	01628BPf2E	129	0208F18	32	30.060	12.865	1733	5:09:44	103.24%	21:28:04
	6	01628BPf2E	125	0208F18	34	30.145	12.836	1788	5:10:25	103.47%	29:04:12
	8	01628BPf2E	135	0208F18	36	30.060	12.845	1751	5:11:47	103.93%	24:24:48
	14	01628BPf2E	134	0208F18	42	30.110	12.864	1764	5:14:10	104.72%	26:15:56
					Min	30.040	12.836	1733	5:06:57	102.32%	21:28:04
					Max	30.145	12.867	1788	5:14:10	104.72%	35:08:15
					Avg	30.093	12.853	1759	5:10:57	103.65%	26:42:57
					St Dev	0.046	0.014	20	0:02:31	0.84%	4:50:31

TABLE 5 – 8G31DT

Variable	Battery #	Assembly Code		Fill Code		Weight Kg	Voltage V	Cond S	Leak Check	
									Bromo	Cont.
Control	7	02248CPE5E	758	1031A18	69	30.726	13.200	1250	Pass	Pass
	10	02248CPE5E	744	0305C18	1		13.163	1275	Pass	Pass
	11	02248CPE5E	742	0305C18	2		13.158	1294	Pass	Pass
5hr % Capacity 92.20						Min	30.726	13.158	1250	
						Max	30.726	13.200	1294	
						Avg	30.726	13.174	1273	
						St Dev	#DIV/0!	0.023	22	

Variable	Battery #	Assembly Code		Fill Code		Weight Kg	Voltage V	Cond S	Leak Check	
									Bromo	Cont.
2A	1	02248CPE5E	746	0305C18	3	30.673	13.147	1250	Pass	Pass
	3	02248CPE5E	747	0305C18	4	30.631	13.149	1232	Pass	Pass
	4	02248CPE5E	748	0305C18	5	30.664	13.145	1263	Pass	Pass
5hr % Capacity 91.05						Min	30.631	13.145	1232	
						Max	30.673	13.149	1263	
						Avg	30.656	13.147	1248	
						St Dev	0.022	0.002	16	

Variable	Battery #	Assembly Code		Fill Code		Weight Kg	Voltage V	Cond S	Leak Check	
									Bromo	Cont.
2B	9	02248CPE5E	725	0305C18	6	30.665	13.137	1257	Pass	Pass
	13	02248CPE5E	740	0305C18	7	30.637	13.132	1250	Pass	Pass
	14	02248CPE5E	745	0305C18	8	30.679	13.132	1250	Pass	Pass
5hr % Capacity 88.76						Min	30.637	13.132	1250	
						Max	30.679	13.137	1257	
						Avg	30.660	13.134	1252	
						St Dev	0.021	0.003	4	

Variable	Battery #	Assembly Code		Fill Code		Weight Kg	Voltage V	Cond S	Leak Check	
									Bromo	Cont.
2C	1	02248CPE5E	761	1031A18	64	30.909	13.202	1300	Pass	Pass
	13	02248CPE5E	773	1031A18	65	30.926	13.203	1306	Pass	Pass
	14	02248CPE5E	777	1031A18	63	30.887	13.205	1300	Pass	Pass
5hr % Capacity 92.59						Min	30.887	13.202	1300	
						Max	30.926	13.205	1306	
						Avg	30.907	13.203	1302	
						St Dev	0.020	0.002	3	

Variable	Battery #	Assembly Code		Fill Code		Weight Kg	Voltage V	Cond S	Leak Check	
									Bromo	Cont.
2D	4	02248CPE5E	778	1031A18	60	31.021	13.181	1331	Pass	Pass
	13	02248CPE5E	803	1031A18	62	31.047	13.186	1325	Pass	Pass
	14	02248CPE5E	804	1031A18	61	31.181	13.181	1343	Pass	Pass
5hr % Capacity 88.78						Min	31.021	13.181	1325	
						Max	31.181	13.186	1343	
						Avg	31.083	13.183	1333	
						St Dev	0.086	0.003	9	

TABLE 5 – 8G31DT

Variable	Battery #	Assembly Code		Fill Code		Weight Kg	Voltage V	Cond S	Leak Check	
									Bromo	Cont.
3A	5	02248CPE5E	809	0305C18	12	30.525	13.159	1226	Pass	Pass
	6	02248CPE5E	810	0305C18	13	30.571	13.160	1238	Pass	Pass
	7	02248CPE5E	811	0305C18	14	30.680	13.159	1232	Pass	Pass
5hr % Capacity 89.96						Min	30.525	13.159	1226	
						Max	30.680	13.160	1238	
						Avg	30.592	13.159	1232	
						St Dev	0.080	0.001	6	

Variable	Battery #	Assembly Code		Fill Code		Weight Kg	Voltage V	Cond S	Leak Check	
									Bromo	Cont.
3B	6	02248CPE5E	794	1031A18	57	30.979	13.183	1262	Pass	Pass
	7	02248CPE5E	795	1031A18	59	30.871	13.186	1244	Pass	Pass
	8	02248CPE5E	796	1031A18	58	30.942	13.187	1288	Pass	Pass
5hr % Capacity 90.09						Min	30.871	13.183	1244	
						Max	30.979	13.187	1288	
						Avg	30.931	13.185	1265	
						St Dev	0.055	0.002	22	

Variable	Battery #	Assembly Code		Fill Code		Weight Kg	Voltage V	Cond S	Leak Check	
									Bromo	Cont.
3C	11	02248CPE5E	829	1031A18	68	30.893	13.200	1300	Pass	Pass
	12	02248CPE5E	830	1031A18	66	30.830	13.200	1300	Pass	Pass
	14	02248CPE5E	831	1031A18	67	30.835	13.200	1325	Pass	Pass
5hr % Capacity 91.42						Min	30.830	13.200	1300	
						Max	30.893	13.200	1325	
						Avg	30.853	13.200	1308	
						St Dev	0.035	0.000	14	

Variable	Battery #	Assembly Code		Fill Code		Weight Kg	Voltage V	Cond S	Leak Check	
									Bromo	Cont.
3D	12	02248CPE5E	723	0305C18	9	30.675	13.074	1281	Pass	Pass
	13	02248CPE5E	727	0305C18	10	30.710	13.118	1306	Pass	Pass
	14	02248CPE5E	724	0305C18	11	30.624	13.125	1337	Pass	Pass
5hr % Capacity 87.85						Min	30.624	13.074	1281	
						Max	30.710	13.125	1337	
						Avg	30.670	13.106	1308	
						St Dev	0.043	0.028	28	

There were two tests used to determine the best designs for IEC Solar Life Cycle testing, HPPC and HRPSoC. The procedures for those tests are located in Appendix B. All variables were tested and are included in Table 6 and Table 7.

TABLE 6 – 8A31DT

HPPC Testing			
Variable	Simplified HPPC		
	100% Charge Acceptance		Optimum
	CHG % SoC	DCH % SoC	
Control	NA	50-90	NA
Control #8	NA	50-90	NA
2A	0-60	50-90	50-60
2B	0-60	50-90	50-60
2C	NA	50-90	NA
2D	NA	50-90	NA
3A	0-60	50-90	50-60
3B	0-60	50-90	50-60
3C	20-30	60-90	NA
3D	10-30	50-90	NA

HRPSoC Testing				
Variable	HRPSoC Cycles			
	Set #1	Set #2	Total	Avg
Control # 1	154	150	304	291
Control # 14	139	138	277	
2A # 5	144	123	267	286
2A # 12	158	147	305	
2B # 9	111	88	199	194
2B # 11	108	81	189	
2C # 3	156	139	295	277
2C # 7	141	118	259	
2D # 2	1000	232	1232	1616
2D # 6	1000	1000	2000	
3A # 11	121	103	224	229
3A # 14	123	111	234	
3B # 2	74	57	131	129
3B # 4	73	54	127	
3C # 1	137	119	256	251
3C # 5	131	114	245	
3D # 3	724	280	1004	1082
3D # 8	1000	159	1159	

Variable 2A, 2B, 3A and 3B performed the best in the HPPC test. In the HRPSoC test variable 2D averaged 1616 cycles which was far greater than any other variable. Variable 2D and 3D contained carbon type Y and a loading of three, resulting in the greatest HRPSoC cycles. Based on these results variables 2B, 2C, 2D, 3B, 3D and Control were included in the Solar Life Cycle testing.

TABLE 7 – 8G31DT**HRPSoC Testing**

Variable	HRPSoC Cycles			
	Set #1	Set #2	Total	Avg
Control # 10	45	84	129	129
Control # 11	47	82	129	
2A # 1	444	184	628	673
2A # 3	478	239	717	
2B # 9	391	231	622	596
2B # 14	409	160	569	
2C # 1	96	110	206	222
2C # 13	116	122	238	
2C # 14	225	150	375	
2D # 4	416	387	803	864
2D #13	479	445	924	
2D # 14	484		484	
3A # 5	390	140	530	491
3A # 6	462	107	569	
3A # 7	238	137	375	
3B # 6	166	193	359	396
3B # 7	197	235	432	
3B # 8	198	236	434	
3C # 11	122	131	253	249
3C # 12	125	119	244	
3C # 14	143	138	281	
3D # 12	406	495	901	773
3D # 13	433	479	912	
3D # 14	341	166	507	

The 8G31DT variable that averaged the most HRPSoC cycles was 2D followed closely by 3D. Again, 2D and 3D contained carbon Y and a loading of three. Both of these types as well as 2B and Control were included in the IEC Solar Life Cycle testing.

Task 2.3 Expander Improvements:

Subtask 2.3.1 includes the same data as Subtask 2.2.1. All data is located in the charts as previously mentioned. The two types of lignin used, H and N, did not show any obvious advantages in the HPPC or HRPSOC tests. Therefore both types of lignins were included in the IEC Solar Life Cycle testing.

Subtasks 2.2.2 and 2.3.2 Solar Life Cycle Test

Subtasks 2.2.2 and 2.3.2 involved the IEC Solar Life Cycle Test. See Appendix B for the test details. Both battery types, 8A31DT and 8G31DT, were life cycled. The graph below shows all 8A31DT batteries that were tested. The next page compares the six variables on test by graphing the life cycle data independently.

8A31DT IEC Solar Cycle Life Test.
C10 Capacity Summary (8.54A to 1.80vpc).

Examining the results of all versions tested, variables 2D and 3D were the most consistent with every battery of that type reaching 450 total cycles. Version 2D was built with carbon Y, loading 3 and lignin H while 3D was also built with carbon Y, loading 3 but lignin N.

8G31DT IEC Solar Cycle Life Test.

The 8G31DT's did not enter the project until April 2011. Therefore the testing has continued beyond the end of project date, at East Penn's expense, to determine the optimum design. As of December 15th, per the graph above, the control is outperforming every other variable. East Penn will continue to cycle these test batteries to verify the stated conclusion.

Subtasks 2.2.2 and 2.3.2 Float Current and Gassing:

Another important design criterion for VRLA batteries is low float current and minimal gassing during operation. A float gassing test was used to monitor gassing and float current on the 8A31DT's; control, variables 2B, 2C and 2D. This particular test was run for over 2000 hours at 2.25 volts per cell (vpc) and 1500 hours at 2.40 volts per cell. The following graphs reveal a lower float current, in both cases, with the control. This is to be expected because as additional carbon is added to the negative active material the voltage is suppressed requiring higher current to maintain the same voltage.

8A31DT Float Gassing Test
Float Gassing @ 2.40vpc - float current

8A31DT Float Gassing
Float Gassing @ 2.25vpc - cc's/hr per variable
7/11/2011

The gassing numbers at 2.25 vpc, as shown above, were initially higher with the control. However, over time, the control reduced the amount of gas discharged and after 2000 hours was slightly lower than variables 2C and 2D. Variable 2B was clearly gassing greater than the others.

Gassing data for the 2.40 vpc test was 50 to 100 times greater as graphed below. Variables 2C and 2D were gassing between 100 and 150 cubic centimeters (cc's) per hour while the control was at a maximum of 50 cc's/hour. The results prove that the addition of carbon to the negative active material increases the gassing rate of the battery, especially at higher temperatures and full state of charge. These gassing and float current values must be considered when designing and applying batteries to specific applications.

Subtask 2.4.1 Current Collector Design:

The design options developed were a radial, diagonal and a shear frame version for the positive 95 amp hour size. An 85 amp hour size shear frame type was used for all of the negative plates. The 125 amp hour size was limited to one variable, the power frame under lug, which was used for the positive and negative plates. The various 95 and 125 grid mold designs are shown below.

95 Standard

95 Shear Frame

95 Diagonal

95 Radial

125 Positive and Negative Power Frame

Molds were purchased to manufacture these types of grids and produce plates which were used to build all of the variable cells listed below. Table 8 describes the variables involved in the analysis. A picture of twelve cells built for the project, as connectors are being installed, is shown below.

TABLE 8

Task 2.4: Design of Experiment		
Variables	Positive Plate	Negative Plate
1	95 Control	85 Control
2	95 Power Shear Frame	85 Power Shear Frame
3	95 Diagonal Power Frame	85 Power Shear Frame
4	95 Radial Power	85 Power Shear Frame
5	125 Control	125 Control
6	125 Pwr Frame under Lug	125 Pwr Frame under Lug

Initial Data

Initial data collection included weight, open circuit voltage, conductance and an eight hour discharge to 1.75 volts per cell. Data is shown in Table 9. There are a few differences between the control and the variables but most prominent, in the 95 size, is the discharge capacity. The control out-performed all of the variables. This is expected at the eight hour rate because the control had more positive active material than any of the other cells and an eight hour discharge is more dependant on the active material than reduced resistance in the grid carrying wires.

TABLE 9

							Initial C ₈ DCH		
Cell Number	Serial Number	Assembly Code		Weight Kg	OCV V	Cond S	35.6 A to 1.75 vpc		
							Time	% Capacity	
Variable 1 <u>AVR95-7</u> Pos Grid: 95P - Control Neg Grid: 85N - Control	1	1925890	10230A1DG9507	239	19.498	2.1656	1426	8.368	104.60%
	2	1925891	10230A1DG9507	240	19.534	2.1627	1179	7.707	96.34%
	3	1925892	10230A1DG9507	241	19.575	2.1629	1449	8.418	105.22%
	4	1925893	10230A1DG9507	242	19.675	2.1654	1435	8.729	109.12%
	5	1925894	10230A1DG9507	243	19.724	2.1672	1443	8.678	108.47%
	6	1925895	10230A1DG9507	244	19.717	2.1659	1465	8.710	108.88%
	7	1925896	10230A1DG9507	245	19.718	2.1657	1440	8.752	109.41%
	8	1925897	10230A1DG9507	246	19.576	2.1657	1447	8.755	109.44%
	9	1925898	10230A1DG9507	247	19.616	2.1654	1420	8.757	109.46%
	10	1925899	10230A1DG9507	248	19.533	2.1618	1437	8.270	103.38%
	11	1925900	10230A1DG9507	249	19.685	2.1683	1399	8.978	112.22%
	12	1925901	10230A1DG9507	250	19.561	2.1629	1267	8.279	103.49%
		Min		19.498	2.1618	1179	7.707	96.34%	
		Max		19.724	2.1683	1465	8.978	112.22%	
		Avg		19.618	2.1650	1401	8.533	106.67%	
		St Dev		0.082	0.0020	87	0.343	4.29%	

							Initial C ₈ DCH		
	Cell Number	Serial Number	Assembly Code		Weight Kg	OCV V	Cond S	35.6 A to 1.75 vpc	
								Time	% Capacity
<div>Variable 2</div> <div>AVR95-7</div> <div>Pos Grid: 95P w/ Power Shear Frame</div> <div>Neg Grid: 85N w/ power Shear Frame</div>	1	1925902	10230B1AB9507	249	20.466	2.1679	1621	7.165	89.57%
	2	1925903	10230B1AB9507	250	20.417	2.1617	1650	6.921	86.51%
	3	1925904	10230B1AB9507	251	20.363	2.1625	1654	7.024	87.80%
	4	1925905	10230B1AB9507	252	20.502	2.1624	1677	7.100	88.75%
	5	1925906	10230B1AB9507	253	20.531	2.1661	1647	7.200	90.00%
	6	1925907	10230B1AB9507	254	20.796	2.1648	1665	7.563	94.54%
	7	1925908	10230B1AB9507	255	20.426	2.1657	1630	7.160	89.50%
	8	1925909	10230B1AB9507	256	20.491	2.1655	1641	7.295	91.18%
	9	1925910	10230B1AB9507	257	20.270	2.1617	1630	6.868	85.85%
	10	1925911	10230B1AB9507	258	20.344	2.1595	1640	7.073	88.41%
	11	1925912	10230B1AB9507	259	20.391	2.1587	1659	6.958	86.98%
	12	1925913	10230B1AB9507	260	20.359	2.1622	1629	7.008	87.59%
			Min		20.270	2.1587	1621	6.868	85.85%
			Max		20.796	2.1679	1677	7.563	94.54%
			Avg		20.446	2.1632	1645	7.111	88.89%
			St Dev		0.133	0.0028	17	0.188	2.35%

	Cell Number	Serial Number	Assembly Code		Weight Kg	OCV V	Cond S	35.6 A to 1.75 vpc	
								Time	% Capacity
Variable 3 AVR95-7 Pos Grid: 95P w/ Diagonal Power Frame Neg Grid: 85N w/ power Shear Frame	1	1925914	10230A1DG9507	251	20.267	2.1650	1604	7.262	90.78%
	2	1925915	10230A1DG9507	252	20.230	2.1622	1622	6.925	86.57%
	3	1925916	10230A1DG9507	253	20.288	2.1666	1613	7.094	88.67%
	4	1925917	10230A1DG9507	254	20.348	2.1619	1625	7.364	92.05%
	5	1925918	10230A1DG9507	255	20.351	2.1633	1625	7.259	90.74%
	6	1925919	10230A1DG9507	256	20.442	2.1657	1622	7.486	93.58%
	7	1925920	10230A1DG9507	257	20.417	2.1654	1625	7.448	93.10%
	8	1925921	10230A1DG9507	258	20.310	2.1636	1606	7.356	91.95%
	9	1925922	10230A1DG9507	259	20.250	2.1608	1635	7.219	90.24%
	10	1925923	10230A1DG9507	260	20.386	2.1638	1633	7.460	93.25%
	11	1925924	10230A1DG9507	261	20.236	2.1637	1595	7.528	94.10%
	12	1925925	10230A1DG9507	262	20.201	2.1685	1578	7.603	95.04%
Min					20.201	2.1608	1578	6.925	86.57%
Max					20.442	2.1685	1635	7.603	95.04%
Avg					20.311	2.1642	1615	7.334	91.67%
St Dev					0.078	0.0022	17	0.194	2.42%

								Initial C ₈ DCH	
								35.6 A to 1.75 vpc	
<div>Variable 4</div> <div>AVR95-7</div> <div>Pos Grid: 95P w/ Radial Power Design</div> <div>Neg Grid: 85N w/ power Shear Frame</div>	Cell Number	Serial Number	Assembly Code		Weight Kg	OCV V	Cond S	Time	% Capacity
	1	1925926	10230A1DG9507	263	20.556	2.1588	1584	7.532	94.15%
	2	1925927	10230A1DG9507	264	20.465	2.1549	1587	6.777	84.71%
	3	1925928	10230A1DG9507	265	20.518	2.1597	1592	7.439	92.99%
	4	1925929	10230A1DG9507	266	20.429	2.1599	1560	7.488	93.60%
	5	1925930	10230A1DG9507	267	20.590	2.1602	1592	7.530	94.13%
	6	1925931	10230A1DG9507	268	20.632	2.1580	1600	7.495	93.68%
	7	1925932	10230A1DG9507	269	20.687	2.1596	1617	7.528	94.10%
	8	1925933	10230A1DG9507	270	20.748	2.1599	1610	7.534	94.18%
	9	1925934	10230A1DG9507	271	20.800	2.1604	1622	7.683	96.04%
	10	1925935	10230A1DG9507	272	20.559	2.1641	1581	7.613	95.17%
	11	1925936	10230A1DG9507	273	20.586	2.1564	1570	6.428	80.35%
	12	1925937	10230A1DG9507	274	20.674	2.1610	1615	7.544	94.29%
			Min		20.429	2.1549	1560	6.428	80.35%
			Max		20.800	2.1641	1622	7.683	96.04%
			Avg		20.604	2.1594	1594	7.383	92.28%
			St Dev		0.110	0.0023	19	0.377	4.71%

								Initial C ₈ DCH	
								47.2 A to 1.75 vpc	
								Time	% Capacity
Cell Number	Serial Number	Assembly Code		Weight Kg	OCV V	Cond S			
Variable 5 AVR125-7 Pos Grid: 125P - Control Neg Grid: 125N - Control	1	1931436	10239B1GA12507	31	28.206	2.1500	1978	8.714	108.92%
	2	1931437	10239B1GA12507	32	28.170	2.1486	1930	8.681	108.51%
	3	1931438	10239B1GA12507	33	28.090	2.1492	1975	8.743	109.28%
	4	1931439	10239B1GA12507	34	28.050	2.1477	1944	8.759	109.49%
	5	1931440	10239B1GA12507	35	28.226	2.1474	1982	8.610	107.62%
	6	1931441	10239B1GA12507	36	28.320	2.1489	1951	8.668	108.35%
	7	1931442	10239B1GA12507	37	28.306	2.1481	1961	8.766	109.57%
	8	1931443	10239B1GA12507	38	28.061	2.1481	1964	8.617	107.71%
	9	1931444	10239B1GA12507	39	28.151	2.1470	1985	8.816	110.20%
	10	1931445	10239B1GA12507	40	28.222	2.1542	1966	8.725	109.07%
	11	1931446	10239B1GA12507	41	28.375	2.1487	1970	8.810	110.13%
	12	1931447	10239B1GA12507	42	28.314	2.1486	1996	8.752	109.40%
Min					28.050	2.1470	1930	8.610	107.62%
Max					28.375	2.1542	1996	8.816	110.20%
Avg					28.208	2.1489	1967	8.722	109.02%
St Dev					0.107	0.0019	19	0.067	0.84%

								Initial C ₈ DCH	
								47.2 A to 1.75 vpc	
								Time	% Capacity
Cell Number	Serial Number	Assembly Code		Weight Kg	OCV V	Cond S			
Variable 6 AVR125-7 Pos Grid: 125P w/ Power Frame under Lug Neg Grid: 125N w/ Power Frame under Lug	1	1931448	10239B1GA12507	43	28.481	2.1497	2130	8.664	108.30%
	2	1931449	10239B1GA12507	44	28.528	2.1493	2108	8.824	110.30%
	3	1931450	10239B1GA12507	45	28.630	2.1536	2103	8.884	111.05%
	4	1931651	10239B1GA12507	46	28.392	2.1455	2145	8.703	108.79%
	5	1931451	10239B1GA12507	47	28.406	2.1492	2130	8.757	109.46%
	6	1931452	10239B1GA12507	48	28.511	2.1453	2128	8.580	107.25%
	7	1931453	10239B1GA12507	49	28.529	2.1486	2125	8.901	111.26%
	8	1931454	10239B1GA12507	50	28.416	2.1495	2140	8.737	109.22%
	9	1931455	10239B1GA12507	51	28.396	2.1477	2131	8.758	109.48%
	10	1931456	10239B1GA12507	52	28.660	2.1508	2079	9.235	115.44%
	11	1931457	10239B1GA12507	53	28.569	2.1482	2104	9.548	119.35%
	12	1931458	10239B1GA12507	54	28.545	2.1510	2097	9.757	121.96%
Min					28.392	2.1453	2079	8.580	107.25%
Max					28.660	2.1536	2145	9.757	121.96%
Avg					28.505	2.1490	2118	8.946	111.82%
St Dev					0.090	0.0023	20	0.371	4.63%

Cells were then subjected to a one minute, eight minute and fifteen minute high rate discharge at the control cell's specification. The discharge curves for these tests are below.

As seen above the 95 control had a greater capacity during the fifteen minute discharge which correlates to the larger amount of positive active material in each plate compared to the variable designs. During the eight minute test the 95 control had a lower initial voltage which could be related to the higher resistance in the grid design. By the end of the test the 95 control lasted as long as variables two and three, while variable four out-performed all others. In the final one minute test which is done at the highest rates, the 95 control performed the poorest with a lower initial voltage and a shorter run time. The efficiencies for the different cells are pictured in the following bar graphs.

95-7 Test Data

95-7Test Data

The above bar graphs depict the improvement seen with the new 95 grid designs when discharging at the one and eight minute rates. The efficiencies, when discharging at the eight hour rate are all the same.

Unigy II AVR125-07 Cell
15 min DCH (835wpc to 1.67vpc; 500A max)
6/6/2011

Unigy II AVR125-07 Cell
8 min DCH (932wpc to 1.67vpc; 558A max)
5/20/2011

Unigy II AVR125-07 Cell
1 min DCH (1175wpc to 1.67vpc; 647.9A max)
7/25/2011

The 125 discharge data was similar to the 95 discharge results. The 125 control performed the best during the 15 minute test however the poorest when discharged at the highest, one minute rate. During the eight minute test the 125 control cells maintained a higher voltage for the first 90 seconds however the power frame version overcame the 125 control and lasted two minutes longer. The larger amount of positive active material in the 125 control plates allows it to outperform the new design at the lower, longer running rates. As the rates increase the reduced resistance in the grid design allows the new power frame version to operate longer.

Software Analysis

While the laboratory was testing the various cells the grid designs were sent to an outside firm to do a software analysis. A summary of the results is shown below in Table 10. A partial set of software simulation pictures is located in Appendix D.

TABLE 10

Kx Simulation Summary Results							
95AH				15 Min Rate 105Amps			
Drawing	Grid Spec. Wt. grams	Grid Wt. Actual grams	PAM Wt. grams	Voltage contour V	Total Power W	Avg Power W/m^3	Avg Current Density A/m^2
8100317 Std.	960	990	1368	0.025517	2.1126	24697	156698
8100392 Shear	1223	1245	1249	0.023317	1.9666	17953	148207
8100393 Diag.	1169	1212	1224	0.02222	1.8715	17725	148408
8100395 Radial	1254	1287	1282	0.019306	1.7074	15712	120520
8 Hr Rate 11 Amps							
Drawing	Grid Wt. grams	Grid Wt. Actual grams	PAM Wt. grams	Voltage contour V	Total Power W	Avg Power W/m^3	Avg Current Density A/m^2
Std.	960	990	1368	0.0027	0.0232	271	16416
8100392 Shear	1223	1245	1249	0.002443	0.0216	197	15526
8100393 Diag.	1169	1212	1224	0.002328	0.0205	195	15547
8100395 Radial	1254	1287	1282	0.002023	0.0187	172	12626
125AH				15 Min Rate 122 Amps			
Drawing	Grid Spec. Wt.	Grid Wt. Actual	PAM Wt.	Voltage contour	Total Power	Avg Power	Avg Current Density
8100278 Std S125	1691	NA	NA	0.022104	2.0513	13737	118677
8100394 Center Power Frame	1758	NA	NA	0.021015	1.965	12420	119933

Voltage Contour: This is the voltage drop seen across the grid. The edge of the lug is grounded to zero therefore all other voltages are measured from this point.

Total Power: This is the power that is lost to joule heating, which generates the temperature increase. The power loss is computed in each element based on the current in the elements and the resistance the current encounters in each element. Therefore the lower the Total Power value the better the design.

Average Power Density: This is computed by taking the sum of the power in element multiplied by the volume of element divided by total volume of model.

Average Current Density: This is computed similar to the power density.

Total Power is the most significant value and based on it, the best 95 grid design is the Radial version. Also the new 125 grid design is superior to the control. A summary of grid weights, active material weights and Total Power are shown in Table 11.

TABLE 11

Resistance Simulation Analysis

95AH Collector 15 minute rate - 105 amps	Grid Wt. Actual grams	PAM Wt. grams	Total Power W
Control	990	1368	2.1126
Shear	1245	1249	1.9666
Diagonal	1212	1224	1.8715
Radial	1287	1282	1.7074

95AH Collector 8 hour rate - 11 amps	Grid Wt. Actual grams	PAM Wt. grams	Total Power W
Control	990	1368	0.0232
Shear	1245	1249	0.0216
Diagonal	1212	1224	0.0205
Radial	1287	1282	0.0187

125AH Collector 15 minute rate - 122 amps	Grid Wt. Actual grams	PAM Wt. grams	Total Power W
Control	1749	1609	2.0513
Power Frame	1794	1572	1.965

Subtask 2.4.2 High Rate Cycle Life Test:

Based on the above analyses, high rate cycle life testing was completed on 95 control and radial designs. The radial design lasted 5% longer than the control during the 15 minute discharge cycling test. A graph of the fifteen, eight and one minute cycling tests are below. Although the capacity of the radial design is 8% less than the control, the cycle life is greater. This is seen on the graph where the curves cross at approximately 60 cycles.

Unigy II AVR95-07 High Rate Cycle Life Test
15 Minute Rate

Unigy II AVR95-07 High Rate Cycle Life Test 8-min Dch Cycles Every 25th Cycle

Unigy II AVR95-07 High Rate Cycle Life Test 1-min Dch Cycles Every 25th Cycle

Thermal Imaging:

Thermal imaging of the cell posts and connections was done to evaluate any differences between variables. Temperatures were collected and noted on the images for; #1- cell to cell connector across air gap, #2-top of terminal post and #3-cell to cell connector. The critical location for the evaluation is the top of terminal post. As shown below, the 95 control has the greatest post temperature of 112°F versus a maximum of 107°F for the other 95 variables. To determine if five degrees Fahrenheit is significant additional life testing is necessary. The 125's are almost identical at 121°F and 122°F.

Grid Corrosion:

One of the major failure modes seen in VRLA batteries is grid corrosion. Therefore a corrosion study was included, allowing a comparison between the standard 95 and radial 95 designs. A number of grids were charged at a constant current rate of 1.39 amps, which correlates 30 days on test to five years of float charging. Every 30 days a grid of each type was removed and evaluated for weight loss, thickness change and visual examination under a microscope.

Table 12 lists the data collected throughout the 180 day test. The weight and thickness changes were slightly greater for the standard design. Considering 120 days on test is equal to 20 years in applications on float and the weight loss numbers are 6.23% versus 4.91% for the standard and radial designs respectively, there is only a minor difference between designs.

TABLE 12

		% Loss						
		Weight	Tk	Tk	Tk	Tk	Tk	Avg
		g	1	2	3	4	5	Tk
Control	29 days (#1)	-2.01%	0.25%	-0.47%	2.88%	0.00%	-2.56%	0.02%
	60 days (#2)	-3.06%	-5.53%	0.72%	0.48%	1.17%	-1.40%	-0.91%
	90 days (#6)	-5.27%	-4.15%	-0.71%	-13.41%	-2.79%	-4.11%	-5.03%
	120 days (#5)	-6.23%	-2.03%	-7.98%	-11.52%	-10.96%	-7.22%	-7.94%
	150 days (#4)	-7.50%	-3.08%	-1.65%	1.91%	-1.88%	-3.74%	-1.69%
	180 days (#3)	-10.16%	-5.56%	-1.41%	-4.09%	-2.08%	-3.46%	-3.32%

		% Loss						
		Weight	Tk	Tk	Tk	Tk	Tk	Avg
		g	1	2	3	4	5	Tk
Radial	29 days (#2)	-1.18%	-1.30%	-0.23%	-0.72%	-0.96%	-0.72%	-0.79%
	60 days (#3)	-2.20%	-2.09%	-0.95%	-2.14%	0.72%	0.97%	-0.70%
	90 days (#1)	-3.21%	0.00%	-0.95%	-1.18%	-3.07%	-0.72%	-1.18%
	120 days (#4)	-4.91%	3.13%	-3.81%	-8.02%	-4.67%	-0.96%	-2.87%
	150 days (#5)	-5.32%	-1.58%	-3.08%	-4.68%	-0.48%	2.39%	-1.49%
	180 days (#6)	-7.00%	-4.31%	-1.41%	-2.82%	-1.92%	-0.72%	-2.24%

At each 30 day interval pictures were taken for visual comparison. The 30 day and 180 day micrographs are shown below. It is obvious after 180 days on constant current charge, the grids have been corroded however there is no clear winner between the two designs.

30 Day Corrosion - Control Grid (2.01% weight loss; .02% tk. loss)

30 Day Corrosion - Radial Grid (1.18% weight loss; .79% tk. loss)

180 Day Corrosion - Control Grid (10.16% weight loss; 3.32% tk. loss)

180 Day Corrosion - Radial Grid (7.00% weight loss; 2.24% tk. loss)

Grid Resistance:

The laboratory conducted a resistance test on each of the 95 and 125 grid designs and compared them to the standard versions. A picture of the apparatus is shown below.

Each grid design was placed in a jig and clamped at the bottom frame between two copper bars. A current of 30 amps was applied to each grid design and using a meter the voltage contour was recorded from the lug to each intersection of the grid. The voltage, in millivolts, was recorded then color coded for every 5 millivolts. The following set of color coded pictures describes the results.

The 95 standard grid has a greater voltage drop than any of the new designs. The diagonal design appears to have the lowest resistance of the four types. The 125 power frame is also better, less voltage drop, than the standard design

Conclusion

The project started in October 2009 with the development of a Gantt Chart and Milestone Status Report for the entire project. These charts are located in Appendix E. Engineering then began the determination of equipment required to test the twelve volt batteries and two volt cells produced for the project. At the same time materials were purchased to build the Design of Experiment (DOE) variables to be tested. Also, the grid mold designs for the two volt cells were drawn and approved. Following production of the batteries and cells, testing was initiated. In April 2011 Gel type batteries were added to the project. After completion of the first part of each Task, the data was reviewed to filter weak variables out of the second phase of the Tasks. The life testing was the final part of each Task which ended, officially, on September 30, 2011. Because some of the batteries were still passing the life test requirements, it was decided to continue testing until all batteries failed. Therefore, the life test results include data up to December 15th. The remainder of the Conclusion will be partitioned by Task numbers.

Task 2.1

All of the equipment purchased was incorporated into the various tests performed. This equipment is located in the East Penn Stationary Laboratory.

Task 2.2 and 2.3

A Control and eight different batteries were built using two carbons, two carbon loadings and two lignins in the negative paste. The negative paste is pressed into the negative grid to produce the negative plates in the battery. These plates were used in the original 8A31DT AGM build but were also used in the latter 8G31DT Gel production.

Tasks 2.2.1 and 2.3.1 involved the HPPC and HRPSoC tests to weed out the weaker batteries. The HPPC test which was only run using 8A31DT batteries, revealed the carbon loading and lignin had little effect on the outcome. Variables 2A, 2B, 3A and 3B returned an optimum state of charge of 55 percent with carbon X. Meanwhile the HRPSoC test, which included 8A31DT's and 8G31DT's, determined carbon type Y and carbon loading number 3 were superior in number of cycles attained.

From the above data the following battery variables were picked for IEC Solar Life Cycle testing.

8A31DT – Control, 2B, 2C, 2D, 3B, 3D
8G31DT – Control, 2B, 2D, 3D

The 8A31DT life cycle data indicates an acetylene black blend of carbon with a medium loading performed more consistently to the maximum cycles attained. Also, the lignin was not a determining factor since 2D and 3D had different types of lignins.

The 8G31DT results were different. The control outperformed all other variables, maintaining 104% capacity after 600 cycles. Since all types are greater than 80% capacity testing will continue at East Penn until all batteries have failed.

Float current and gassing tests substantiated the fact that adding more carbon to the negative plates and float charging at full state of charge will increase the gassing rate and float current for those batteries. Consequently, the prime market for carbon enhanced batteries is partial state of charge applications.

Task 2.4

High rate current carrying ability of large grids can be affected by grid design. Therefore the first step was to develop optional grid designs to be tested for conductivity and performance in the high current carrying realm. Evaluations were done on a 95 and 125 amp hour size grid. There were three different positive grid molds purchased for the 95 size and one positive grid mold purchased for the 125 size. Each size had one new negative grid mold.

The Finite Element Analysis (FEA) modeling revealed a slight improvement using the radial design for the 95 amp hour size and the power frame design was better than the control in the 125 size. When high rate capacity testing was done in Task 2.4.1, the radial design was superior to the other versions. There was very little difference between the 125 control and 125 power frame at the 15 minute rate. However, at the higher one and eight minute rates the power frame was superior.

Task 2.4.2 was a life cycle test using the 95 control and radial designed cells. The radial design cycled approximately 5% longer than the control in all three rated tests. This occurred despite the reduced amount of positive active material in the radial design.

A thermal imaging study revealed terminal post temperatures 5°F higher in the 95 control cells versus the new designed grid cells. There was no difference in temperatures between the 125 cells. Without further testing it is impossible to determine if 5°F will affect the life of the cells.

Grid corrosion analysis of weights and thicknesses revealed the 95 radial loses less metal during accelerated float charging than the control design.

Grid resistance measurements supported previous data, in that the 95 and 125 control grids have greater resistance than the new designs. Of the 95 types, the order of least resistance to worst resistance was; diagonal, power shear, radial, control.

All data suggests the radial or diagonal designs are superior to the control at one to eight minute rates. However, because of positive active material requirements for 15 minute and longer rates, the control is superior. The battery manufacturers will have to decide whether to have different designs for specific applications or limit their product line to one design that performs adequately in all applications.

APPENDIX A

Statement of Project Objectives Additional Battery Type Added to SOPO

Statement of Project Objectives (SOPO)

ADVANCED POWER BATTERIES FOR RENEWABLE ENERGY APPLICATIONS

A. Objectives

The Obama Administration has called for a significant investment in next generation energy technologies. In fact, President Obama committed to investing \$150 billion over the next ten years in research and development for clean energy technology. As Secretary Chu stated, “the goal is to set America on a course for a secure and sustainable energy future.” To achieve this goal, Secretary Chu recently echoed the president’s objective of generating ten percent of the nation’s electricity from renewable energies by 2012.

However, producing clean, renewable energy is not without its challenges. Indeed, renewable energy systems such as wind farm and solar applications require storage of energy in specialized batteries designed to help balance the fluctuating generation of electricity (load leveling) with the erratic peak demand periods. These renewable energy systems also require the batteries to operate under a Partial State of Charge (PSOC) condition, which is necessary to allow the battery to accept high electrical currents for a short duration.

These energy storage challenges can be overcome, in part, through the use of certain advanced lead acid battery technologies – technologies that are domestically produced, economically viable, safe and fully recyclable. Recently through research efforts such as those performed by the Advanced Lead Acid Battery Consortium (ALABC), great advances have been realized in the performance and longevity of these batteries, especially when operating under conditions necessary for the support of renewable energy systems. Nonetheless, more research and testing is needed to further improve these technologies.

This Department of Energy funding will advance the manufacturing of advanced power batteries suitable for renewable energy applications. These evolutionary advances to the chemistry will produce revolutionary performance enhancements to these batteries. Moreover, these batteries will be a fraction of the cost of lithium-ion and nickel metal hydride batteries and are also totally recyclable.

Phase 2 Technology Development

- 2.1. Determine the best carbon based additive for optimal anode performance.
- 2.2. Determine the best lignin additive for optimal anode performance.
- 2.3. Construct anode using optimized carbon and anode material and evaluate to achieve most advantageous performance.
- 2.4. Optimize the current collector in 2-volt cells.

B. Project Scope

This project, which initially included research with Sandia National Laboratories, benefits work being conducted by DOE’s Office of Energy Efficiency and Renewable Energy as well as the Office of Electricity Delivery and Energy Reliability. Specifically, the project will focus on the engineering, design, development, prototyping and testing for field site implementation of an economically viable, recyclable advanced lead acid battery system capable of load leveling and

peak demand management of renewable energy projects, including but not limited to wind farms and solar sites.

Phase 2 Technology Development

- 2.1. Purchase, install and test all new equipment specifically related to this project.
- 2.2. Testing that involves adding various carbons at different percentages to the anode material.
- 2.3. Optimize the capacity and life of 12-volt batteries by testing various lignins.
- 2.4. Develop and test new current collector designs for improved performance.

C. Tasks to be Performed

Phase 2 Technology Development

Task 2.1: Testing Equipment

- Subtask 2.1.1: Install and Commission Equipment: Specify, purchase, install and test all equipment required for completion of the project.

Task 2.2: Carbon Based Additives in the Anode

- Subtask 2.2.1: Experimental Carbon Based Additives: Evaluating the addition of various carbons to the anode at different percentages.
- Subtask 2.2.2: Final Performance Evaluation: Performance and life testing of 12-volt batteries.

Task 2.3: Expander Improvements

- Subtask 2.3.1: Experimental Lignin in Anode Material: Evaluate the addition of various lignins to the anode material.
- Subtask 2.3.2: Final Performance Evaluation: Performance and life testing of 12-volt batteries.

Task 2.4: Current Collector Design

- Subtask 2.4.1: Experimental Current Collector Designs: Develop and test new current collector design for improved performance.
- Subtask 2.4.2: Final Performance Evaluation: Performance and testing in 2-volt cells.

Task 2.5: Project Management & Planning

- Subtask 2.5.1: DOE Milestone and Budget Period Reporting: A brief milestone report shall be submitted to document the completion of the milestone. Future milestones shall be reviewed and documented as part of the program requirements.
- Subtask 2.5.2: Update Project Management Plan: Updates applied for preparation of subsequent phases.
- Subtask 2.5.3: Phase 2 Summary Topical Reporting and Continuation Application for Phase 3.
- Subtask 2.5.4: Project Management Coordination: Coordinate project information acquired from Phase 2.
- Subtask 2.5.5: Project Finance, Invoicing and Contract Management

Advanced Batteries for Renewable Energy Applications DE-EE0001112

East Penn is requesting the approval to add more batteries to the initial test plan. Originally the plan was to compare various 12 volt AGM VRLA batteries. At the same time East Penn made similar batteries using Gel electrolyte. The Gel batteries were not included initially because of the fear of exceeding the project budget. Since there is money available, East Penn would like to add them to the testing. Gel type batteries are used in Solar applications today and may be improved based on the testing being conducted.

APPENDIX B

Test Procedures

HPPC – Hybrid Pulse Power Characterization Test*

Step	Description
1	Charge at 2.45 vpc (C_1 rate) until charge amps change by < 0.1 A for 45 minutes
	↓
2	Discharge @ C_1 rate to an end voltage of 1.75 vpc
	↓
3	Recharge to 108% Ah (C_1 rate)
	↓
4	Discharge @ C_1 rate to remove 10% Ah (from discharge in step 2)
	↓
5	Rest for 1 Hour
	↓
6	1.75 vpc CV Discharge @ $6 \times C_1$ for 10 seconds
	↓
7	Rest for 40 seconds
	↓
8	Charge at 2.45 vpc @ $4 \times C_1$ for 10 seconds
	↓
9	Repeat steps 4 - 8 for 10 cycles
	↓
10	Charge at 2.45 vpc (C_1 rate) for 4 hours
	↓
11	Repeat step 1

* Based on FreedomCAR Battery Test Manual for Power-Assist Hybrid Electric Vehicles (DOE/ID-11069)

HRPSoC - High Rate Partial State of Charge Test*

* Based on Sandia National Laboratories' Utility PSOC Cycle-Life Test

IEC 61427 Solar Cycling Test

Test Temp = 40°C (104°F)

Step	Description
------	-------------

Part A (shallow cycling @ low SOC)

1	Discharge @ $I_{10}^{1.80\text{vpc}}$ (8.54A) for 9 hrs
	↓
2	Recharge @ $1.03I_{10}^{1.80\text{vpc}}$ (8.8A) for 3 hrs
	↓
3	Discharge @ $I_{10}^{1.80\text{vpc}}$ (8.54A) for 3 hrs
	↓
4	Repeat steps 2 & 3 50 times (failure is 1.50vpc)
	↓
5	Recharge to a fully charged condition

Part B (shallow cycling @ high SOC)

6	Discharge @ $1.25I_{10}^{1.80\text{vpc}}$ (10.68A) for 2 hrs
	↓
7	Recharge @ $I_{10}^{1.80\text{vpc}}$ (8.54A) for 6 hrs @ 2.40vpc
	↓
8	Repeat steps 6 & 7 100 times
	↓
9	Check capacity - discharge @ $I_{10}^{1.80\text{vpc}}$ (8.54A)
	↓
10	Repeat parts A & B until step 9 capacity < 80%

APPENDIX C

Equipment Lists

Equipment List

REA309										
Equipment ID	Equipment Name	Parent ID	Plant	Dept	Location	Group	Type	Status	Inactive	PT Xref
LC-147	CYCLER, CABINET <i>Make: D.T.I.</i>	18-7320 <i>Model:</i>	18	7320	TEST LAB <i>S/N:</i>	TESTER	TELC	PROCUR	No	
LC-148	CYCLER, CABINET <i>Make: D.T.I.</i>	18-7320 <i>Model: LC400X3CD</i>	18	7320	TEST LAB <i>S/N: NO INFO AVAILABLE</i>	TESTER	TELC	ASSIGN	No	No
LC-149	CYCLER, CABINET <i>Make: D.T.I.</i>	18-7320 <i>Model:</i>	18	7320	TEST LAB <i>S/N:</i>	TESTER	TELC	PROCUR	No	No
LC-150	CYCLER, CABINET <i>Make: D.T.I.</i>	18-7320 <i>Model: LC500X3JD</i>	18	7320	TEST LAB <i>S/N: 210101</i>	TESTER	TELC	ASSIGN	No	No
LE-872	CYCLER, CIRCUIT <i>Make: D.T.I.</i>	LC-147 <i>Model:</i>	18	7320	TEST LAB <i>S/N:</i>	TESTER	TELC	PROCUR	No	
LE-873	CYCLER, CIRCUIT <i>Make: D.T.I.</i>	LC-147 <i>Model:</i>	18	7320	TEST LAB <i>S/N:</i>	TESTER	TELC	PROCUR	No	No
LE-874	CYCLER, CIRCUIT <i>Make: D.T.I.</i>	LC-147 <i>Model:</i>	18	7320	TEST LAB <i>S/N:</i>	TESTER	TELC	PROCUR	No	No
LE-875	CYCLER, CIRCUIT <i>Make: D.T.I.</i>	LC-147 <i>Model:</i>	18	7320	TEST LAB <i>S/N:</i>	TESTER	TELC	PROCUR	No	No
LE-876	CYCLER, CIRCUIT <i>Make: D.T.I.</i>	LC-147 <i>Model:</i>	18	7320	TEST LAB <i>S/N:</i>	TESTER	TELC	PROCUR	No	No
LE-877	CYCLER, CIRCUIT <i>Make: D.T.I.</i>	LC-147 <i>Model:</i>	18	7320	TEST LAB <i>S/N:</i>	TESTER	TELC	PROCUR	No	No
LE-878	CYCLER, CIRCUIT <i>Make: D.T.I.</i>	LC-147 <i>Model:</i>	18	7320	TEST LAB <i>S/N:</i>	TESTER	TELC	PROCUR	No	No
LE-879	CYCLER, CIRCUIT <i>Make: D.T.I.</i>	LC-147 <i>Model:</i>	18	7320	TEST LAB <i>S/N:</i>	TESTER	TELC	PROCUR	No	No
LE-880	CYCLER, CIRCUIT <i>Make: D.T.I.</i>	LC-147 <i>Model:</i>	18	7320	TEST LAB <i>S/N:</i>	TESTER	TELC	PROCUR	No	No
LE-881	CYCLER, CIRCUIT <i>Make: D.T.I.</i>	LC-147 <i>Model:</i>	18	7320	TEST LAB <i>S/N:</i>	TESTER	TELC	PROCUR	No	No
LE-882	CYCLER, CIRCUIT <i>Make: D.T.I.</i>	LC-148 <i>Model: LC400X3CD</i>	18	7320	TEST LAB <i>S/N: CY-S1L0227</i>	TESTER	TELC	ASSIGN	No	No
LE-883	CYCLER, CIRCUIT <i>Make: D.T.I.</i>	LC-148 <i>Model: LC400X3CD</i>	18	7320	TEST LAB <i>S/N: CY-S1L0228</i>	TESTER	TELC	ASSIGN	No	No
LE-884	CYCLER, CIRCUIT <i>Make: D.T.I.</i>	LC-148 <i>Model: LC400X3CD</i>	18	7320	TEST LAB <i>S/N: SY-S1L0229</i>	TESTER	TELC	ASSIGN	No	No
LE-885	CYCLER, CIRCUIT <i>Make: D.T.I.</i>	LC-149 <i>Model:</i>	18	7320	TEST LAB <i>S/N:</i>	TESTER	TELC	PROCUR	No	No
LE-886	CYCLER, CIRCUIT <i>Make: D.T.I.</i>	LC-149 <i>Model:</i>	18	7320	TEST LAB <i>S/N:</i>	TESTER	TELC	PROCUR	No	No
LE-887	CYCLER, CIRCUIT <i>Make: D.T.I.</i>	LC-149 <i>Model:</i>	18	7320	TEST LAB <i>S/N:</i>	TESTER	TELC	PROCUR	No	No
LE-888	CYCLER, CIRCUIT <i>Make: D.T.I.</i>	LC-149 <i>Model:</i>	18	7320	TEST LAB <i>S/N:</i>	TESTER	TELC	PROCUR	No	No
LE-889	CYCLER, CIRCUIT <i>Make: D.T.I.</i>	LC-149 <i>Model:</i>	18	7320	TEST LAB <i>S/N:</i>	TESTER	TELC	PROCUR	No	No
LE-890	CYCLER, CIRCUIT <i>Make: D.T.I.</i>	LC-149 <i>Model:</i>	18	7320	TEST LAB <i>S/N:</i>	TESTER	TELC	PROCUR	No	No
LE-891	CYCLER, CIRCUIT <i>Make: D.T.I.</i>	LC-149 <i>Model:</i>	18	7320	TEST LAB <i>S/N:</i>	TESTER	TELC	PROCUR	No	No
LE-892	CYCLER, CIRCUIT	LC-149	18	7320	TEST LAB	TESTER	TELC	PROCUR	No	No

Equipment List

REA309									
Equipment ID	Equipment Name	Parent ID	Plant	Dept	Location	Group	Type	Status	Inactive PT Xref
	Make: D.T.I.	Model:			S/N:		Misc Ref: REA309		
LE-893	CYCLER, CIRCUIT	LC-149	18	7320	TEST LAB	TESTER	TELC	PROCUR	No No
	Make: D.T.I.	Model:			S/N:		Misc Ref: REA309		
LE-894	CYCLER, CIRCUIT	LC-149	18	7320	TEST LAB	TESTER	TELC	PROCUR	No No
	Make: D.T.I.	Model:			S/N:		Misc Ref: REA309		
LE-895	CYCLER, CIRCUIT	LC-149	18	7320	TEST LAB	TESTER	TELC	PROCUR	No No
	Make: D.T.I.	Model:			S/N:		Misc Ref: REA309		
LE-896	CYCLER, CIRCUIT	LC-149	18	7320	TEST LAB	TESTER	TELC	PROCUR	No No
	Make: D.T.I.	Model:			S/N:		Misc Ref: REA309		
LE-897	CYCLER, CIRCUIT	LC-149	18	7320	TEST LAB	TESTER	TELC	PROCUR	No No
	Make: D.T.I.	Model:			S/N:		Misc Ref: REA309		
LE-898	CYCLER, CIRCUIT	LC-149	18	7320	TEST LAB	TESTER	TELC	PROCUR	No No
	Make: D.T.I.	Model:			S/N:		Misc Ref: REA309		
LE-899	CYCLER, CIRCUIT	LC-149	18	7320	TEST LAB	TESTER	TELC	PROCUR	No No
	Make: D.T.I.	Model:			S/N:		Misc Ref: REA309		
LE-900	CYCLER, CIRCUIT	LC-149	18	7320	TEST LAB	TESTER	TELC	PROCUR	No No
	Make: D.T.I.	Model:			S/N:		Misc Ref: REA309		
M-1114	MOLD, GRID	15-0011	15	0011	IND GRID CASTING	MOLD	GRIDM	PROCUR	No
	Make:	Model:			S/N:		Misc Ref: REA309		
M-1115	MOLD, GRID	15-0011	15	0011	IND GRID CASTING	MOLD	GRIDM	PROCUR	No No
	Make:	Model:			S/N:		Misc Ref: REA309		
M-1116	MOLD, GRID	15-0011	15	0011	IND GRID CASTING	MOLD	GRIDM	PROCUR	No No
	Make:	Model:			S/N:		Misc Ref: REA309		
M-1117	MOLD, GRID	15-0011	15	0011	IND GRID CASTING	MOLD	GRIDM	PROCUR	No No
	Make:	Model:			S/N:		Misc Ref: REA309		
M-1118	MOLD, GRID	15-0011	15	0011	IND GRID CASTING	MOLD	GRIDM	PROCUR	No No
	Make:	Model:			S/N:		Misc Ref: REA309		
OV-236	OVEN	18-7320	18	7320	S-1 TEST LAB	OVEN	OV	ASSIGN	No No
	Make: ESPEC	Model: EGNL28-4CAL			S/N: TC-00843		Misc Ref: REA309		
SP-038	SUPPLY, POWER CH-SIL55	18-7320	18	7320	TEST LAB	ELEC	PWSP	ASSIGN	No
	Make: AGILENT	Model: AGI-6012B			S/N: 2524A-00685		Misc Ref: REA309		
TL-203	DATA LOGGER VM-SIL13	18-7320	18	7320	TEST LAB	TOOLS	MAEQ	ASSIGN	No
	Make: FLUKE	Model: 2635A			S/N: 6100002		Misc Ref: REA309		

GRAND TOTAL: 41

APPENDIX D

Software Analyses of Grid Designs

95 Standard

Detailed view of the model

Current density (A/m²)

Voltage contour (V)

95 Radial

Voltage contour (V) for 105 Amps

Current density (A/m²) for 105 Amps

Current density (A/m²) for 105 Amps

The contour values were adjusted to show the localized increases at the edges

Power density (W/m³) for 105 Amps

95 Diagonal

Voltage contour (V) for 105 Amps

Current density (A/m²) for 105 Amps

Power density for 105 Amps (W/m³)

125 Power Frame

Voltage contour (V) @ 122 Amps

Current density (A/m²) @ 122 Amps

Power density (W/m³)

125 Control

Voltage contour (V) @ 122 Amps

Current density (A/m²) @ 122 Amps

Power density (W/m³)

APPENDIX E

Gantt Chart Milestone Status Chart

Gantt Chart

ID	Task Name	Duration	Start	Finish	2, 2009	Half 1, 2010	Half 2, 2010	Half 1, 2011	Half 2, 2011
					S O N D	J F M A M J	J A S O N D	J F M A M J	J A S O N
22	Subtask 2.2.1 - Various Types and Amounts	256 days	Wed 2/3/10	Sun 10/17/10					
23	✓ Plan DOE	30 days	Wed 2/3/10	Fri 3/5/10					
24	✓ Obtain Carbon Samples	26 days	Wed 3/10/10	Mon 4/5/10					
25	✓ Mfg Plates (grid casting - formation)	31 days	Tue 3/16/10	Fri 4/16/10					
26	Build Batteries (COS - assembly)	14 days	Fri 4/16/10	Fri 4/30/10					
27	Fill & Activate Batteries	18 days	Mon 7/12/10	Fri 7/30/10					
28	Test Variables	76 days	Mon 8/2/10	Sun 10/17/10					
29	Subtask 2.2.2 - Final Performance Evaluation	367 days	Sun 10/17/10	Wed 10/19/11					
30	Select Variable to Test	1 day	Sun 10/17/10	Mon 10/18/10					
31	Life Cycle Test	365 days	Mon 10/18/10	Tue 10/18/11					
32	Analyze Results	1 day	Tue 10/18/11	Wed 10/19/11					
33									
34	Task 2.3 - Expander Improvements	623 days	Wed 2/3/10	Wed 10/19/11					
35	Subtask 2.3.1 - Various Types of Lignins	256 days	Wed 2/3/10	Sun 10/17/10					
36	✓ Plan DOE	30 days	Wed 2/3/10	Fri 3/5/10					
37	✓ Obtain Expander Samples	26 days	Wed 3/10/10	Mon 4/5/10					
38	✓ Mfg Plates (grid casting - formation)	31 days	Tue 3/16/10	Fri 4/16/10					
39	Build Batteries (COS - assembly)	14 days	Fri 4/16/10	Fri 4/30/10					
40	Fill & Activate Batteries	18 days	Mon 7/12/10	Fri 7/30/10					
41	Test Variables	76 days	Mon 8/2/10	Sun 10/17/10					
42	Subtask 2.3.2 - Final Performance Evaluation	367 days	Sun 10/17/10	Wed 10/19/11					

Project: REA 3-09, 24-7 Rev 6.mpp
Date: 7/21/10
Rod, Barry, Eric, Rich, Gary, Scott

Task		Milestone		External Tasks
Split		Summary		External Milestone
Progress		Project Summary		Deadline

ID		Task Name	Duration	Start	Finish	2, 2009	Half 1, 2010	Half 2, 2010	Half 1, 2011	Half 2, 2011																						
						S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N
43		Select Variable to Test	1 day	Sun 10/17/10	Mon 10/18/10																											
44		Life Cycle Test	365 days	Mon 10/18/10	Tue 10/18/11																											
45		Analyze Results	1 day	Tue 10/18/11	Wed 10/19/11																											
46																																
47		Task 2.4 - Current Collector Design	717 days	Wed 10/28/09	Sat 10/15/11																											
48		Subtask 2.4.1 - Optimize Design	369 days	Wed 10/28/09	Mon 11/1/10																											
49	✓	Determine/Draw Various Designs	86 days	Wed 10/28/09	Fri 1/22/10																											
50	✓	Plan DOE	65 days	Wed 12/23/09	Fri 2/26/10																											
51	✓	Obtain Tooling Quotes	4 days	Mon 1/25/10	Fri 1/29/10																											
52	✓	Submit Capital Budgets	3 days	Mon 2/1/10	Thu 2/4/10																											
53	✓	Place Purchase Orders	5 days	Fri 2/5/10	Wed 2/10/10																											
54	✓	Receive Tooling	100 days	Wed 2/10/10	Fri 5/21/10																											
55	✓	Run/Approve Molds	42 days	Fri 5/21/10	Fri 7/2/10																											
56	✓	Mfg Grids	42 days	Fri 5/21/10	Fri 7/2/10																											
57	📅	Build Cells	42 days	Fri 7/2/10	Fri 8/13/10																											
58	📅	Test Cells	77 days	Mon 8/16/10	Mon 11/1/10																											
59		Subtask 2.4.2 - Final Performance Evaluation	373 days	Thu 10/7/10	Sat 10/15/11																											
60	📅	Select Variable to Test	1 day	Thu 10/7/10	Fri 10/8/10																											
61	📅	Life Cycle Test	365 days	Sat 10/9/10	Sun 10/9/11																											
62	📅	Analyze Results	4 days	Tue 10/11/11	Sat 10/15/11																											

Project: REA 3-09, 24-7 Rev 8.mpp
Date: 7/21/10
Rod, Barry, Eric, Rich, Gary, Scott

Task

Split

Progress

Milestone

Summary

Project Summary

External Tasks

External Milestone

Deadline

Milestone Status Report

September 30, 2011	Project Duration - Start: October 1, 2009 End: September 30, 2011								Planned Start Date	Planned End Date	Actual Start Date	Actual End Date
	Project Year (PY) 1				PY 2							
Project Milestone Description	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8				
Task 2.1: Testing Equipment									10/1/2009	6/30/2010	10/15/2009	1/24/2011
Task 2.2: Carbon Based Additives in the Anode									2/1/2010	9/30/2011	2/3/2010	9/30/2011
Subtask 2.2.1: Various Types and Amounts									2/1/2010	10/17/2010	2/3/2010	10/14/2010
Subtask 2.2.2: Final Performance Evaluation									9/27/2010	9/30/2011	11/2/2010	9/30/2011
Task 2.3: Expander Improvements									2/1/2010	9/30/2011	2/3/2010	9/30/2011
Subtask 2.3.1: Various Types of Lignins									2/1/2010	10/17/2010	2/3/2010	10/14/2010
Subtask 2.3.2: Final Performance Evaluation									9/27/2010	9/30/2011	11/2/2010	9/30/2011
Task 2.4: Current Collector Design									10/1/2009	10/15/2011	10/28/2009	9/30/2011
Subtask 2.4.1: Optimize Design									10/1/2009	10/13/2010	10/28/2009	12/20/2010
Subtask 2.4.2: Final Performance Evaluation									10/14/2010	10/15/2011	1/31/2011	9/30/2011