Evaluation of Lead-Carbon Storage Devices for Utility Applications

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Program Overview

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Phase One: *Explore possible advantages to carbon in energy storage*

- Evaluate lead based energy storage technologies
- Develop carbon for lead based technologies
  - Increase cycle life for some applications
  - Improve charging characteristics
  - Verify claims made on energy storage devices

Phase Two: *Investigate performance benefit and refine understanding*

- Focus on mechanisms that result in performance benefit
- Verify Performance

Phase Three: *Determine best technology for application needs*

- Select best technology for 1MW utility demonstration

Phase One: Battery Performance

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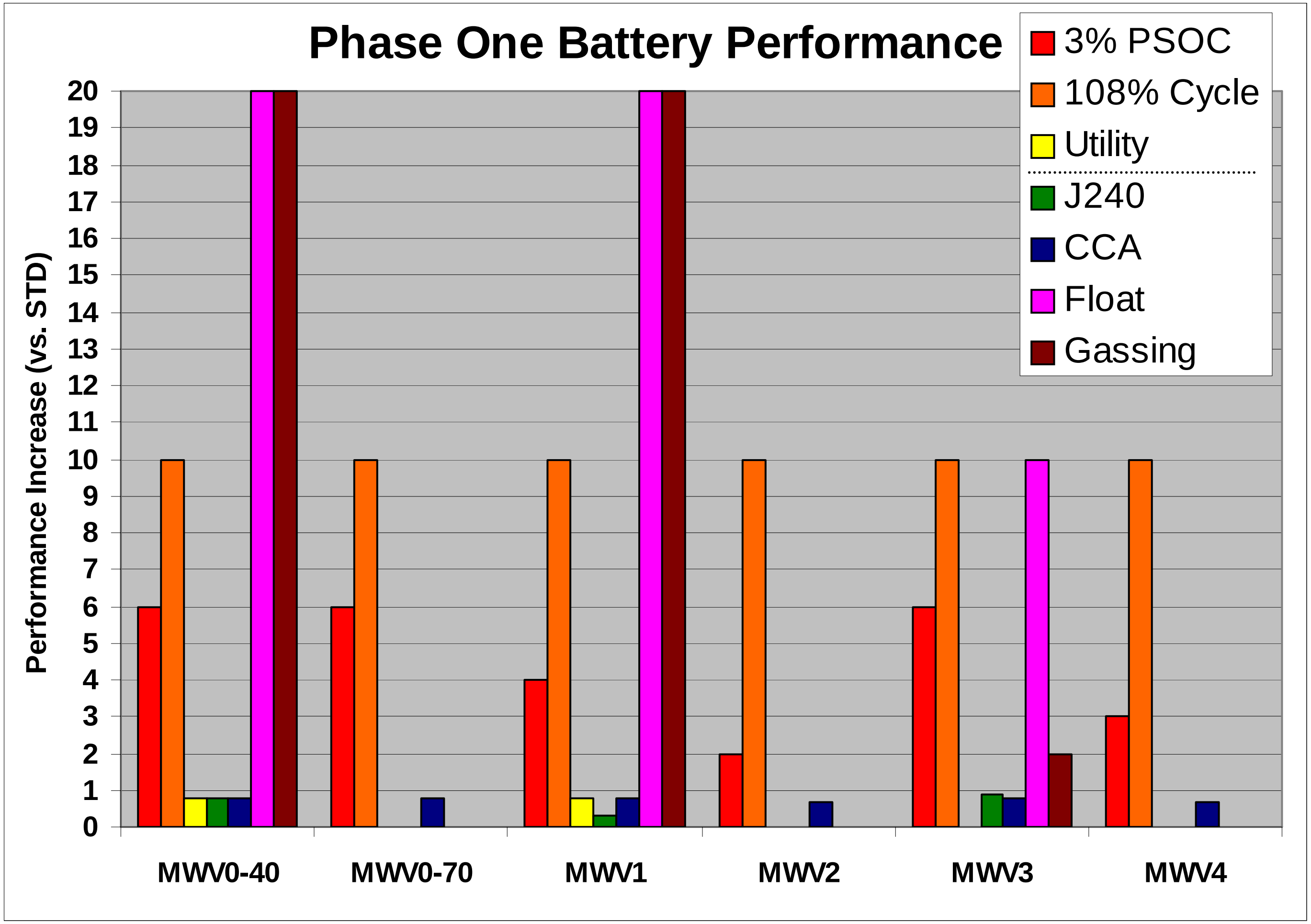

- Carbon increases life under shallow PSOC conditions
- Carbon increases charge acceptance during overcharge

Phase Two: Experimental Overview

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Questions from Phase One:

1. Are impurities interfering with performance trends?
2. Is carbon loading too high?
3. Did we evaluate the correct battery technology?
4. Can the carbon properties be optimized?

Responses included in Phase Two:

1. Acid wash activated carbon, use ultra pure carbon black
2. Lower target carbon loadings to 3% or less
3. Test carbon performance in gel electrolyte batteries vs. AGM
4. Functionalize carbons to explore optimization opportunities

Battery Builds:

NorthStar	12/06	23 Types ~6 replicates	40 AH
Hammond	4/07	23 Types ~3 replicates	~1 AH
Battery Energy	4/07	6 Types ~14x2 replicates	4 AH

Phase Two: NorthStar AGM Batteries

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Run	BaSO4	CB	AC	AC-Type	Graphite	Vanisperse	Indulin	Comments
1	STD	0.25%	1.2%	A	-	0.18%	-	Reduce H2
2	STD	0.25%	1.2%	A	-	0.37%	-	Reduce H2
3	STD	0.25%	1.2%	B	-	0.18%	-	lignin solubility
4	STD	0.25%	1.2%	C	-	-	-	lignin solubility
5	STD	0.25%	1.2%	B	-	0.18%	0.18%	lignin solubility
6	STD	0.25%	1.2%	C	-	-	0.37%	lignin solubility
7	STD	0.25%	1.2%	D	-	0.18%	-	Carbon Baseline
8	STD	0.25%	1.2%	D	-	0.37%	-	Carbon Baseline
9	STD	0.25%	3.7%	A	-	*0.18%*	-	Reduce H2
10	STD	0.25%	3.7%	A	-	*0.37%*	-	Reduce H2
11	STD	0.25%	3.7%	B	-	0.18%	-	lignin solubility
12	STD	0.25%	3.7%	C	-	-	-	lignin solubility
13	STD	0.25%	3.7%	B	-	0.18%	0.18%	lignin solubility
14	STD	0.25%	3.7%	C	-	0.00%	0.37%	lignin solubility
15	STD	0.25%	3.7%	D	-	0.18%	-	Carbon Baseline
16	STD	0.25%	3.7%	D	-	0.37%	-	Carbon Baseline
17	STD	0.25%	1.2%	E	-	0.37%	-	H2 and 02
18	STD	0.25%	3.7%	E	-	0.37%	-	H2 and 02
19	STD	0.25%	-	-	-	0.18%	-	baseline
20	STD	0.25%	-	-	-	0.37%	-	baseline
21	3X STD	0.25%	-	-	-	0.37%	-	Grain Size
22	STD	2.44%	-	-	2.44%	0.37%	-	Modifed ALABC
23	STD	0.25%	-	-	-	0.18%	-	40FT

- Industrial→FT
- Mixing Calcs
- Lignin Omission
- Low Capacities

✓ Capacity
✓ Self-Discharge
✓ Float
✓ Gassing
✓ Charge Acceptance
✓ Recharge Efficiency
✓ PSOC Cycle Testing

Phase Two: NorthStar AGM Batteries

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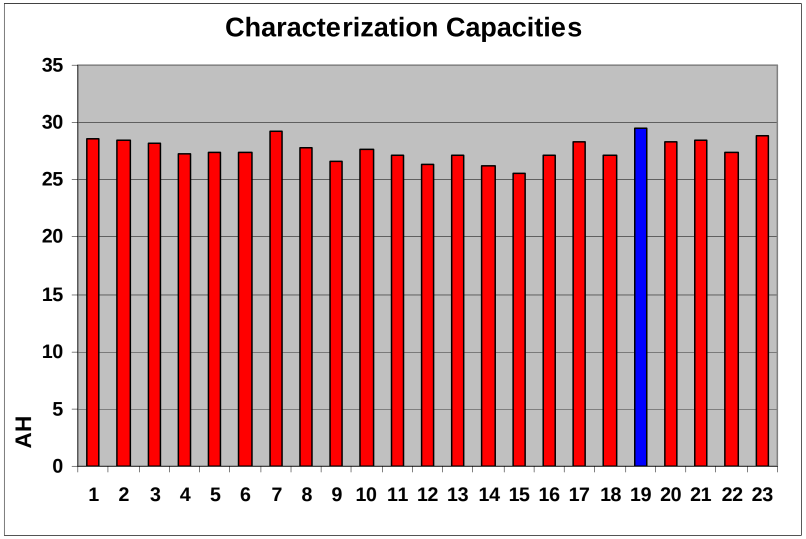
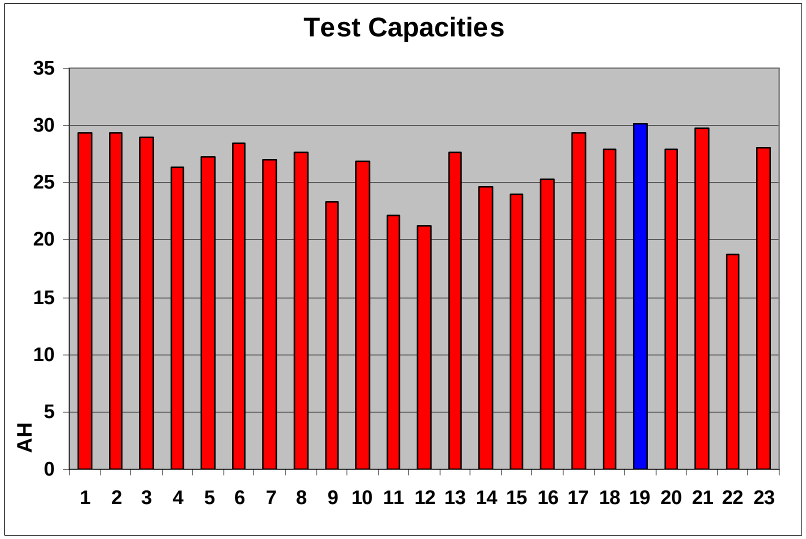
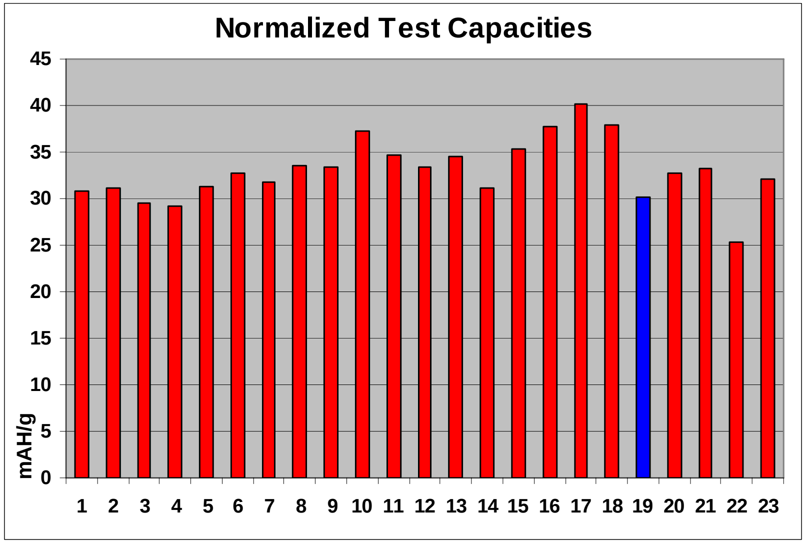




- Comparable End-of-Line capacities
- Retest shows significant capacity drop
- Normalized data = increased NAM utilization



Phase Two: NorthStar AGM Batteries

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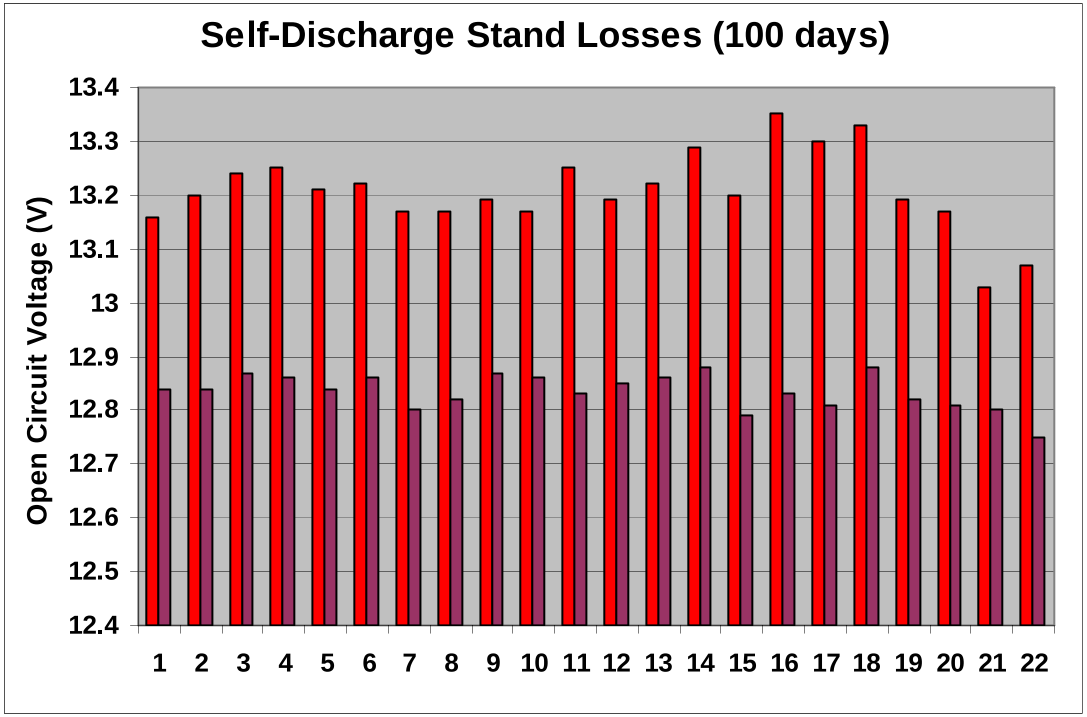

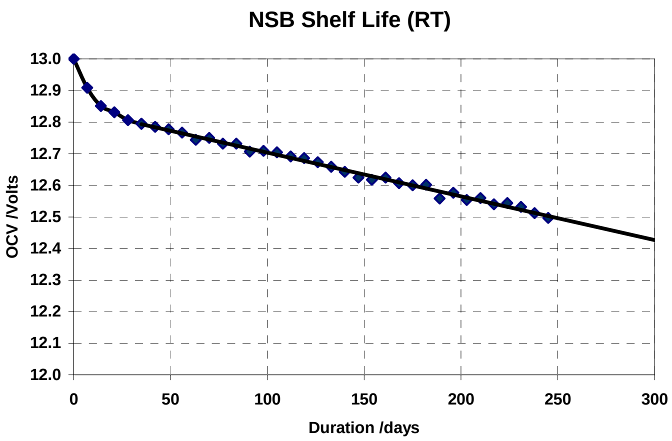

- No significant stand losses observed
- Final OCV comparable to standard and typical performance

Phase Two: NorthStar AGM Batteries

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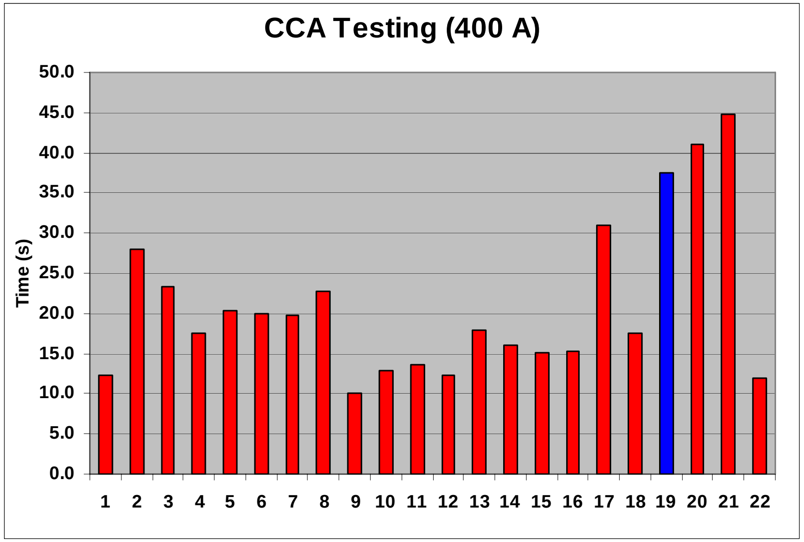

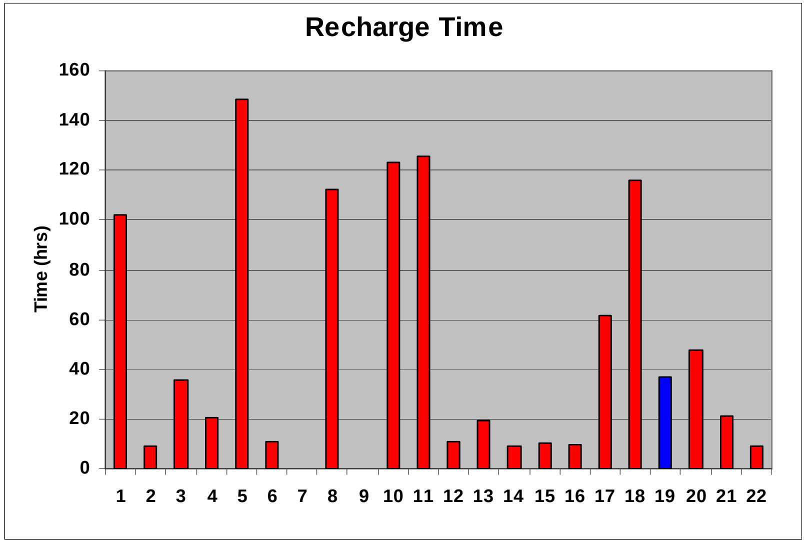

-18°C Chamber
Discharge 400A

C: 16 A, 14.7 V, 10 hrs.
Rest 2 hrs.
D: C/1
C: 2.27 vpc to 105%

- Carbon batteries show reduced CCA: not ideal for high rate, low temperature
- Recharge Time (Current Acceptance): initial capacity issues, ideal charge?

Phase Two: NorthStar AGM Batteries

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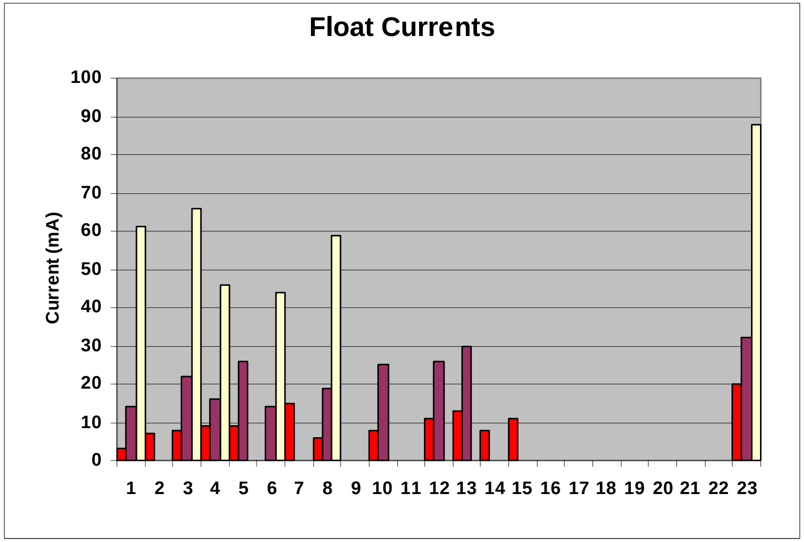

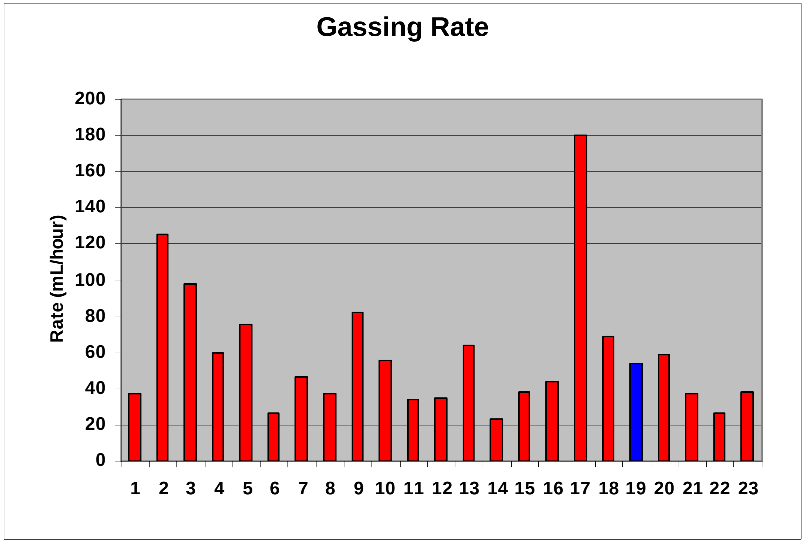

Float
2.27 vpc
2.35 vpc
2.45 vpc

Float @ 2.27 vpc
Stabilize current
Measure rate
(Water displacement)

- Float/Gassing data: variable time snap-shot; variable electrolyte saturation
- Recombination variability and matrix design = no apparent data trends

Phase Two: NorthStar AGM Batteries

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Simple PSOC
50% initial SOC [D: 26 A, **30 min**]
2C (1 min charge/discharge) [~3% SOC]
10 s rests between pulses
C test & restart cycle if EODV = **11 V**

T_{rest} = **41ºC**; wait for **35ºC**
Recharge = 6 A, 2.45 vpc, 12 hrs
Maximum TOCV = **16.5 V**

Modified Simple PSOC
50% initial SOC [D: 26 A, **11.9 V**]
2C (1 min charge/discharge) [~3% SOC]
10 s rests between pulses
C test & start subcycle at EODV = **11.5 V**

Sub-cycle
2C (1 min charge/58 s discharge) [115x]

T_{rest} = **50ºC**; wait for **49.5ºC**
Recharge = 6 A, 2.45 vpc, 12 hrs
Maximum TOCV = **17.5 V**
Maximum cycle time = **2 weeks**

- Battery design changed T behavior: T rests = polarization masking differences
- Initial capacity variation addressed via initial discharge to voltage (not time)
- SOC adjustment (“Sub-cycle”) of 15% recharge @ ~40% SOC

Phase Two: NorthStar AGM Batteries

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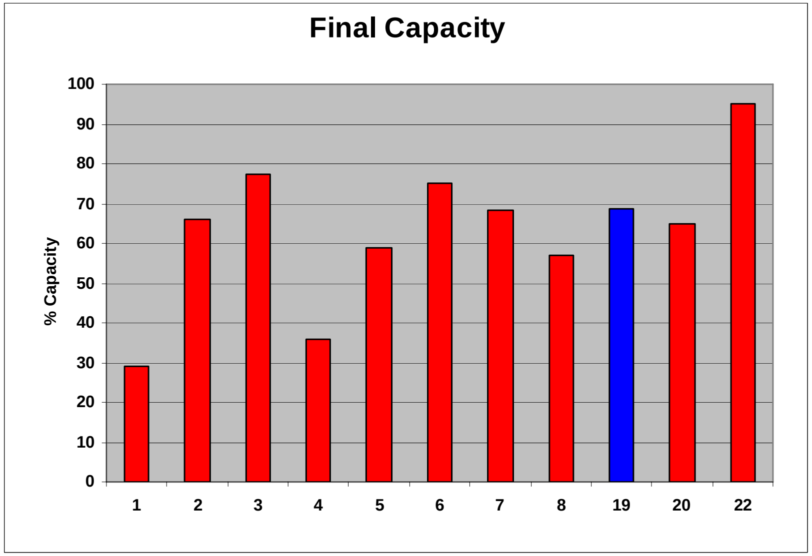

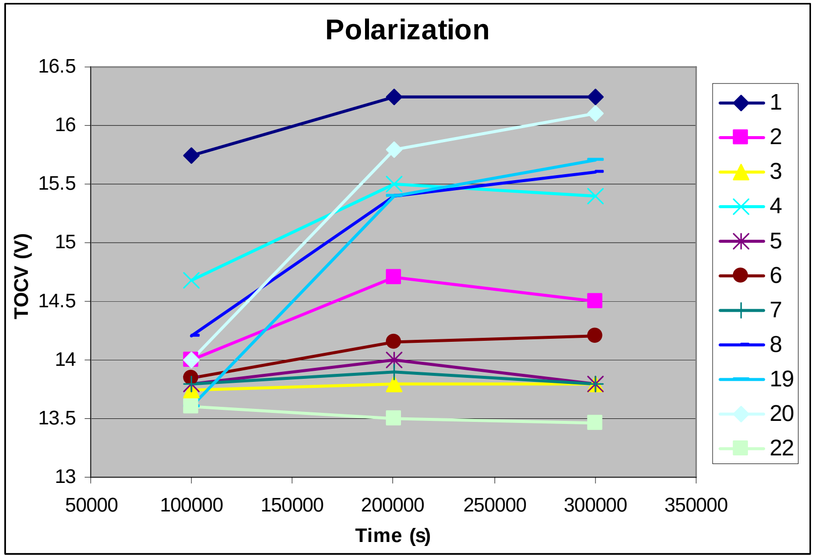

- Capacity drop typically proportional to bulk sulfate formation
- Power pulse availability demonstrated by low polarization during cycling
- Improved performance for battery types 22, 3, 7, 6, (5) (of lower loadings)
- Monitor remaining AGMs, but recognize high energy/low power limitations

Phase Two: Hammond Research Cells

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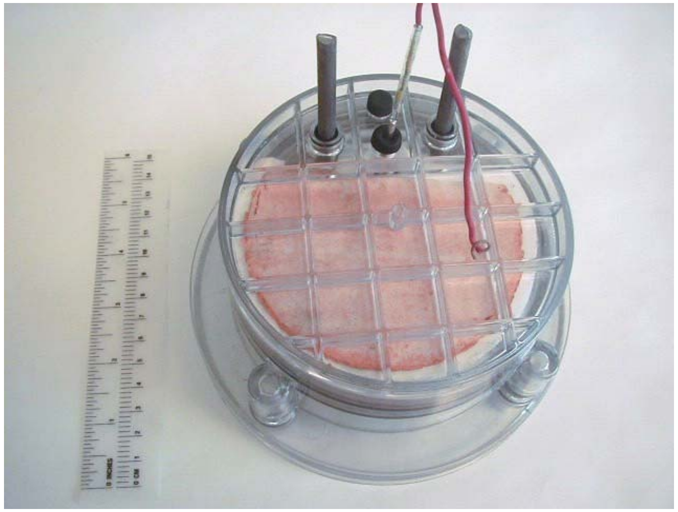
Group #	Loading	Carbon Type
21	0%	STD
1	1%	
2	2%	Type A X070200
3	5%	
5	1%	
6	2%	Type A X070198
7	5%	
8	1%	
9	2%	APH 2939
10	5%	
11	1%	
12	2%	Type B X070702
13	5%	
14	1%	
15	2%	Type B X070701
16	5%	
17	2%	2-2
18	1%	
19	2%	Type A1 X070202
20	5%	
22	1%	
23	2%	ABG1010
24	5%	
25	6%	Type A1 X070202 - 5% ABG1010 - 1%

Research Cells

- 3-Plate (2P:1N)
- Type/Loading
- Simple PSOC



Phase Two: Hammond Research Cells

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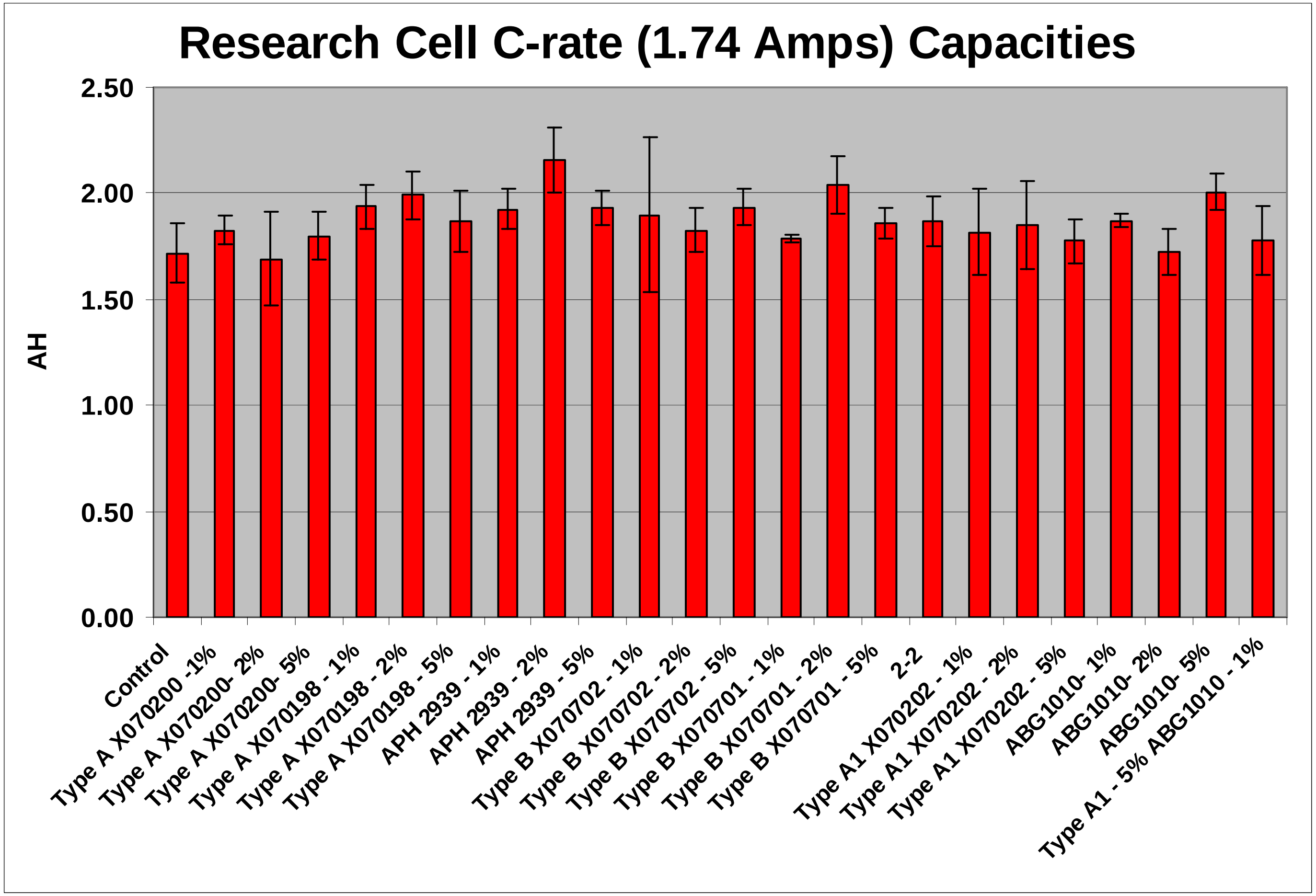

- Carbon addition shows some degree of increased utilization

Phase Two: Hammond Research Cells

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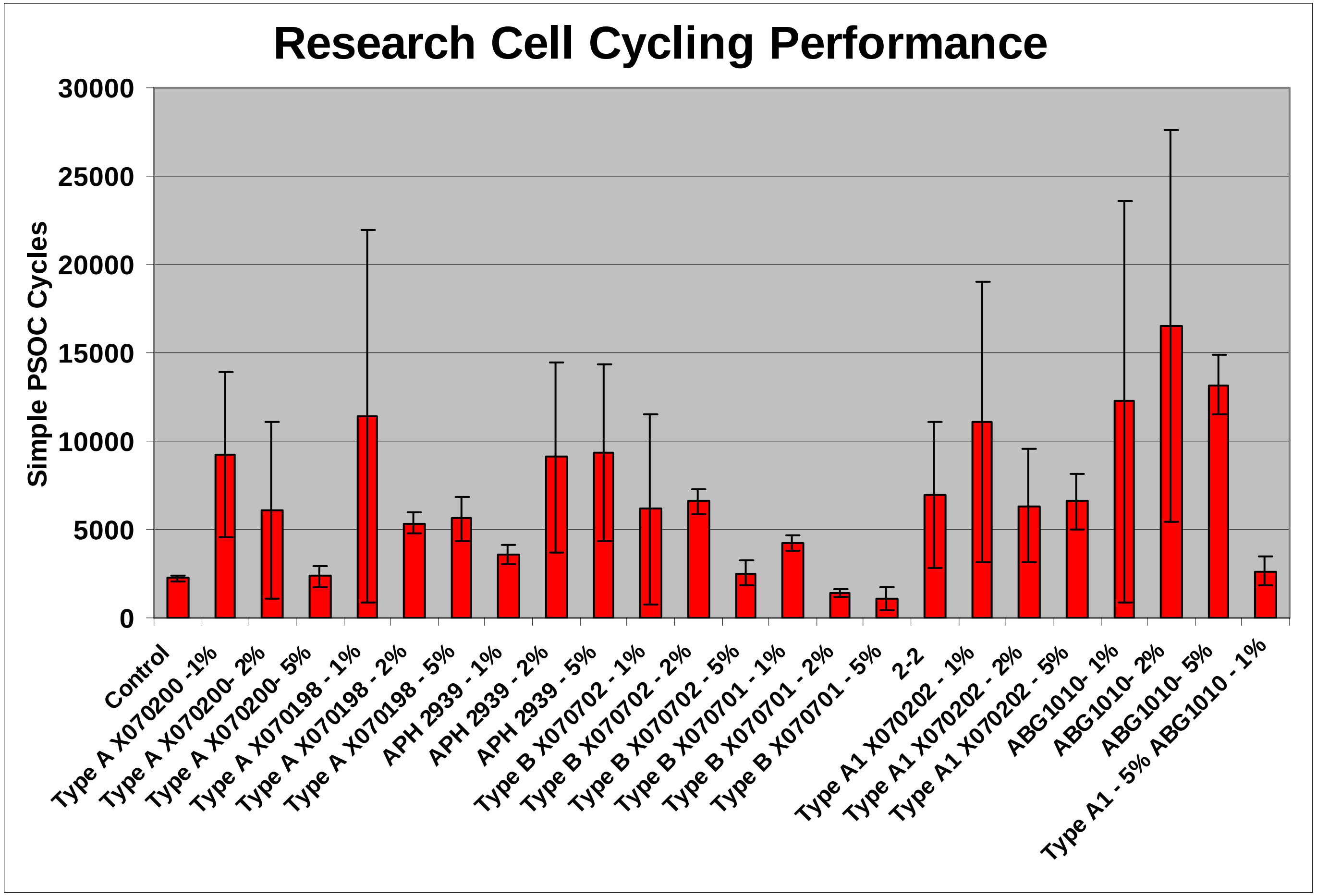

- Two sets of cycling completed – variation in test cells (compression?)
- ABG, A-198, A1-202, (APH) showing improved average screening cycle life

Phase Two: Battery Energy Gel Batteries

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Battery Description	Carbon	Type
MWV-STD	0.25	CB
BE-STD	1%	CB
MWV-A	1%	MWV
MWV-B	2%	MWV
MWV-C	3%	MWV
MWV-D	1%	Graphite

Gel VRLA Batteries
(Silica/Acid Electrolyte)
✓ Increased Cycle Life
✓ Improved Charge Efficiency
✓ Improved Heat Dissipation
✓ No Acid Stratification
Ideal for Wide PSOC Cycling

- Five units at JBI 7/23 [Characterization]
- Remaining units at MWV 9/1 (Sandia, ETA)
- ETA Testing to begin In October [Cycling]

Cycling Options
PSOC: Advanced PSOC
Utility: Koontz / "Karner" / New Cycle

Phase Two: Battery Energy Gel Batteries

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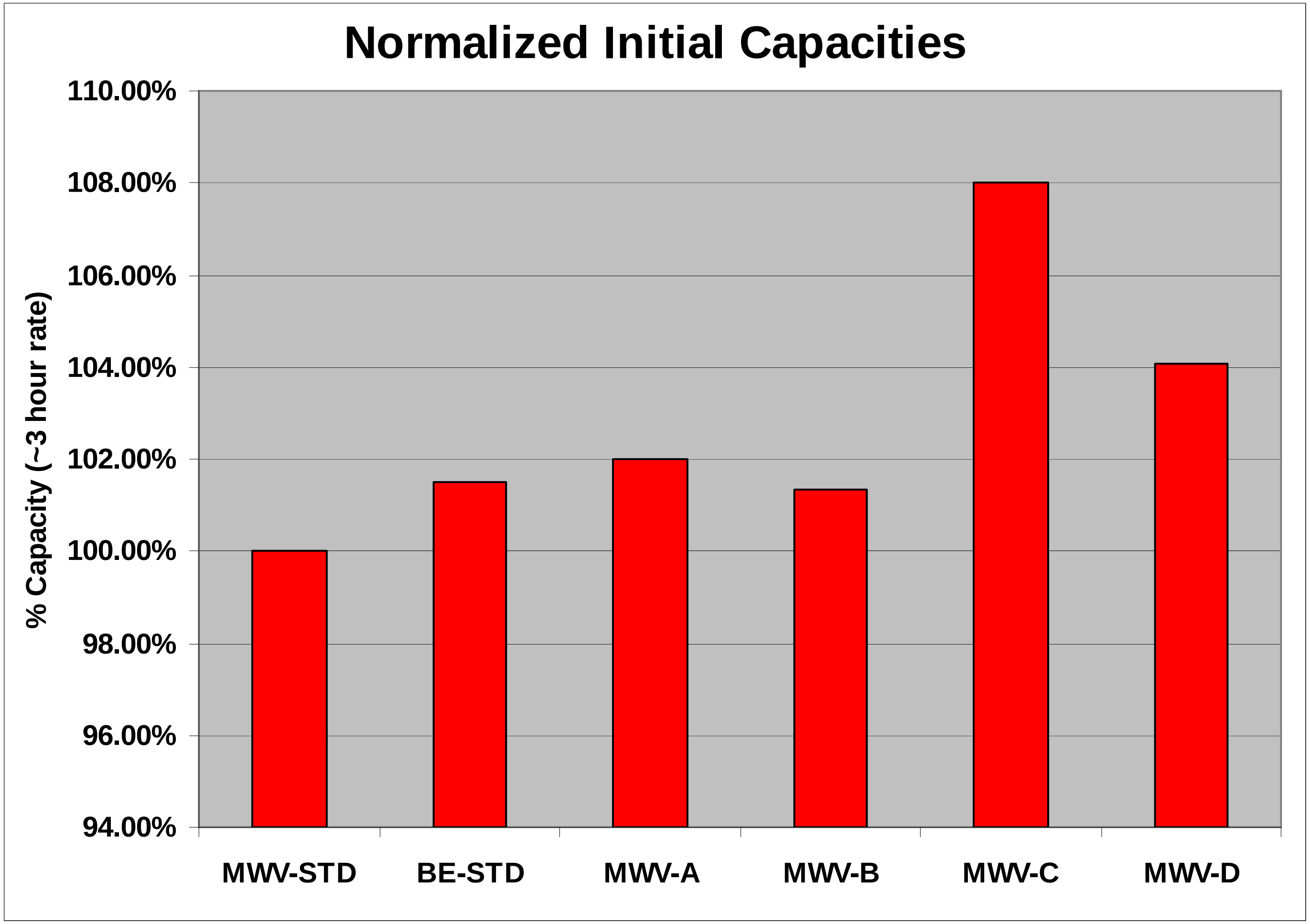

- Matrix shows promise for conclusive results

System Design and Cost Estimates

Electric Transportation Applications

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Work Scope

Task 1 - Overall system design

Task 2 - Power inverter design/cost

Task 3 - BMS design/cost

Task 4 - Overall system cost

Task 1: System Design

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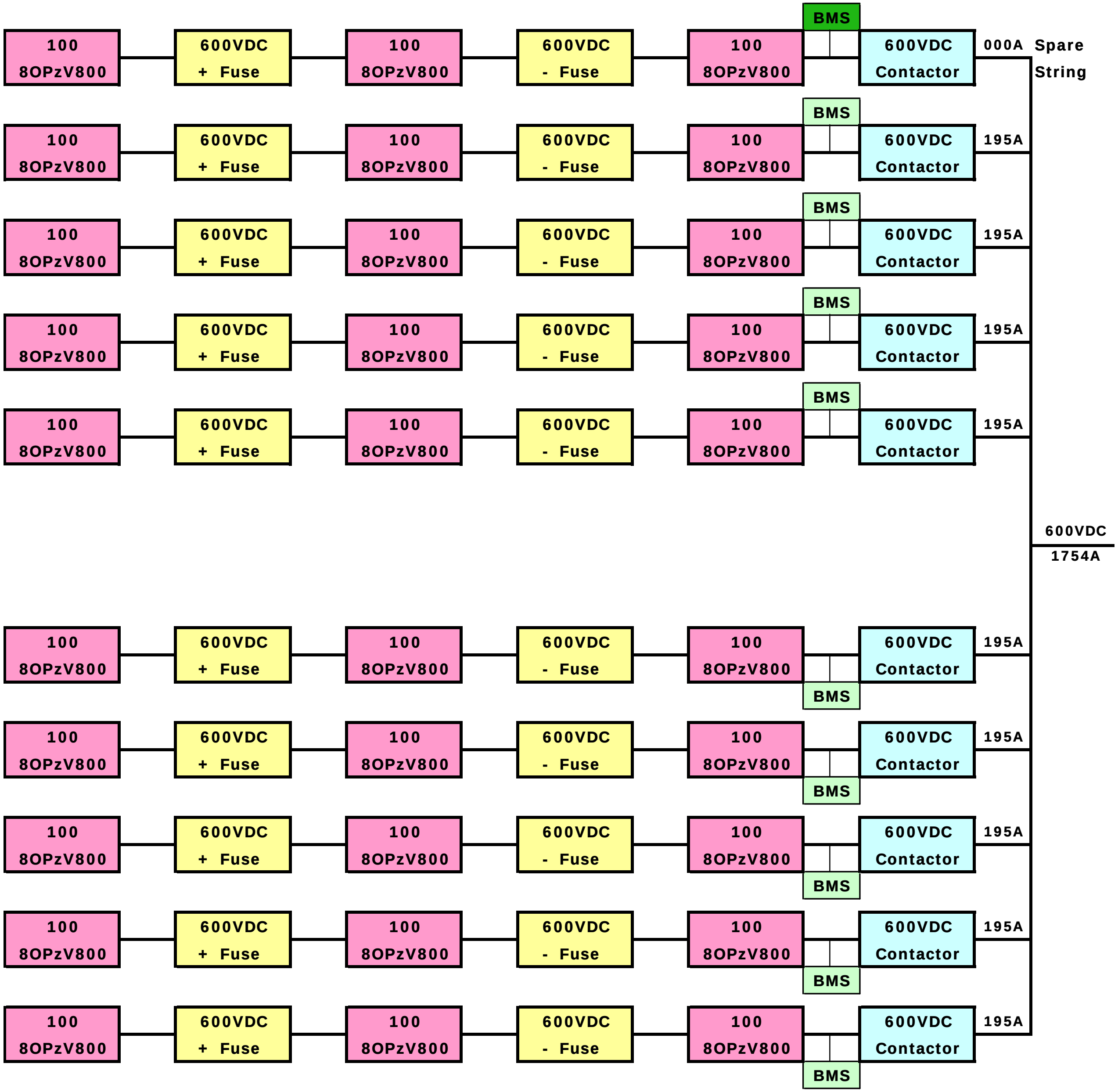

Task 1: Battery Cost

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Sizing Assumptions

Reserve Strings	10%	(0 = no reserve)	
End of Life Derate	80%	(100 = no derate)	
Module Manufacturer	Northstar	Sonnenschein	Battery Energy
Module Model	170FT	8OPzV800WE	2SG875
Module Voltage	12	2	2
Module Cost	$220.00	$450.00	$350.00
Module Capacity (Ah @ C/10)	170	800	875

Electric Transportation Applications

Task 1: Battery Cost

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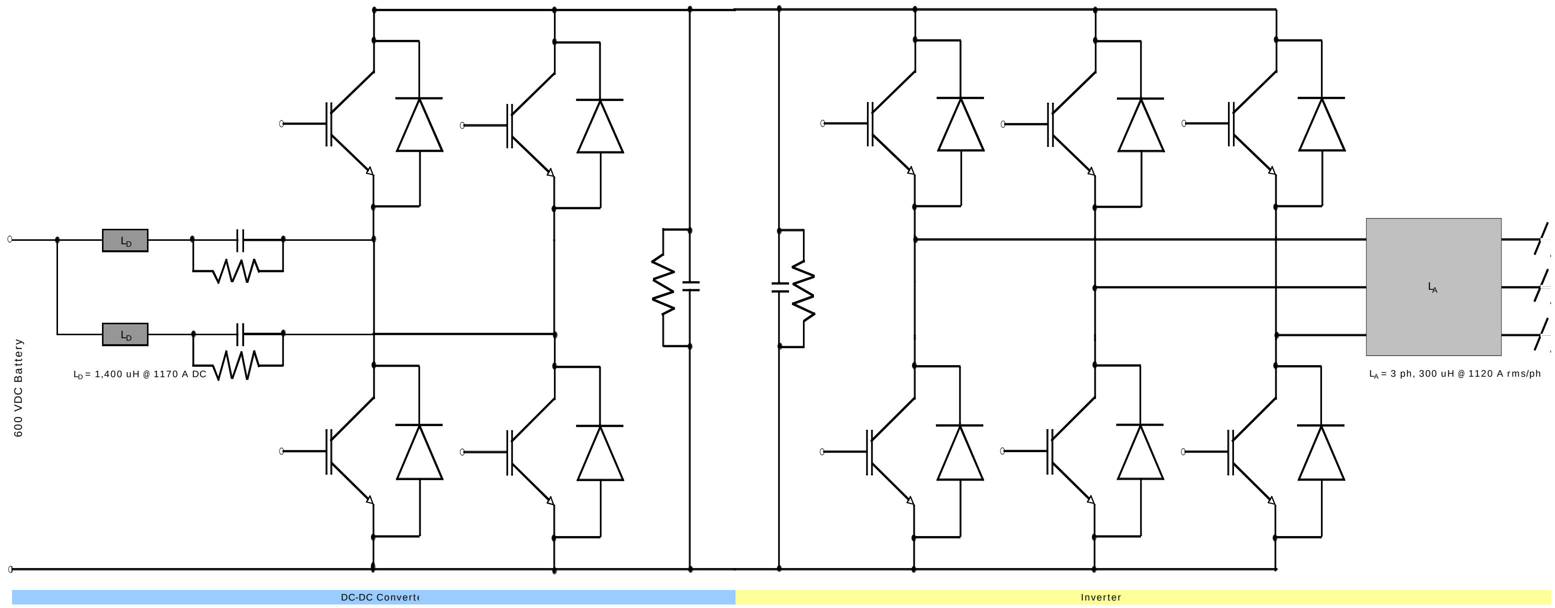
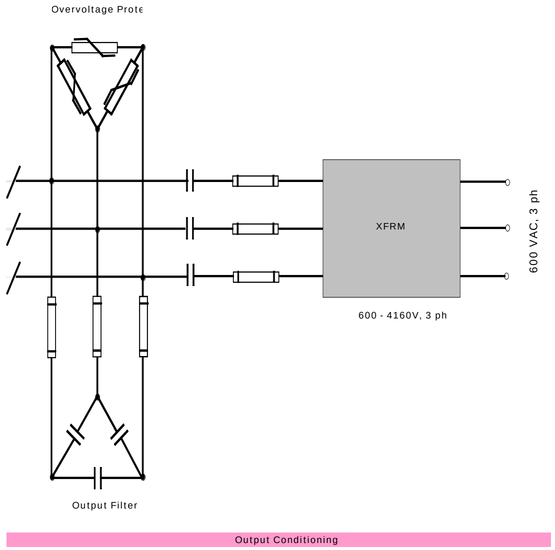
PSoC Window [%]	Discharge Rate [C]	Cycle Life			Single String - Energy (to 1.8 vpc)		
		Northstar [N]	Sonnenschein [N]	Battery Energy [N]	Northstar (kWh)	Sonnenschein (kWh)	Battery Energy (kWh)
10	C/10	10,000	15,000	16,000	102.29	432.0	333.0
20	C/5.0	8,000	12,000	14,000	85.21	372.6	267.0
30	3/3.3	6,000	10,000	12,000	81.61	324.0	240.0
40	C/2.5	5,000	8,000	10,000	78.75	302.4	214.2
50	C/2.0	3,000	5,000	7,500	76.34	274.3	198.6
60	C/1.7	1,000	3,000	5,000	74.21	266.2	182.4

PSoC Window [%]	Parallel Strings			Modules		
	Northstar (N)	Sonnenschein (N)	Battery Energy (N)	Northstar (N)	Sonnenschein (N)	Battery Energy (N)
10	117	28	45	5850	8400	13500
20	70	16	28	3500	4800	8400
30	49	12	21	2450	3600	6300
40	38	10	17	1900	3000	5100
50	31	9	15	1550	2700	4500
60	27	7	14	1350	2100	4200

PSoC Window [%]	Battery Cost			Battery Cost/Cycle		
	Northstar ($)	Sonnenschein ($)	Battery Energy ($)	Northstar ($)	Sonnenschein ($)	Battery Energy ($)
10	$ 1,287,000	$ 3,780,000	$ 4,725,000	$ 129	$ 252	$ 295
20	$ 770,000	$ 2,160,000	$ 2,940,000	$ 96	$ 180	$ 210
30	$ 539,000	$ 1,620,000	$ 2,205,000	$ 90	$ 162	$ 184
40	$ 418,000	$ 1,350,000	$ 1,785,000	$ 84	$ 169	$ 179
50	$ 341,000	$ 1,215,000	$ 1,575,000	$ 114	$ 243	$ 210
60	$ 297,000	$ 945,000	$ 1,470,000	$ 297	$ 315	$ 294

Task 2: Inverter Design





Task 2: Inverter Cost

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Non-recurring cost

Engineering	$ 218,800
Contingency	$ 43,760

Recurring cost

Production	$ 132,272
Contingency	$ 13,227

Tasks 3/4: Status

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- Battery cycling to confirm battery sizing needs
- BMS conceptual design complete
- Overall system requirements defined
- Preliminary cost analysis underway

Conclusions

- Inverter cost an order of magnitude less than battery cost
- Regulator power/energy ratio requires optimization
- Battery cycle life and capacity requires validation

Discussion

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