Fabricate PHEV Type Cells for Testing & Diagnostics

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June 10th, 2010

Annual Merit Review & Peer Evaluation Meeting
2010 U.S. DOE Vehicle Technologies Program - Energy Storage

Wardman Park Marriott Hotel, Washington, DC

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Project ID #: ES030

Overview

Timeline

- Start: October 2008
- Finish: September 2014
- ~25% Complete

Budget

- Total project funding
  - 100% DOE
- $400K FY09 (ABR)
- $400K FY10 (ABR)
  - Not counting dry room and cell making equipment

Barriers

- Development of a safe cost-effective PHEV battery with a 40 mile all electric range that meets or exceeds all performance goals
  - Validation tests of newly developed battery materials are needed in cell formats with at least 0.4 Ah in capacity before larger scale industrial commitment

Partners

- Leyden Energy (Mobius Power)
- Johnson Controls-Saft
- Media Tech
- A-Pro
- Material suppliers

Objectives

- Several new battery chemistries are being proposed for PHEV batteries that must be evaluated in cell formats that are larger than a few mAh in capacity. The main objective of this task is to obtain trial cells for calendar and cycle life studies in pouch cell or rigid cell (*e.g*. 18650) formats from industrial battery vendors.
- Electrode designs must be developed that are appropriate for PHEV batteries.
- To speed the evaluation of novel battery materials, Argonne will develop the capability to fabricate in-house pouch and 18650 cells in its new dry room facility.

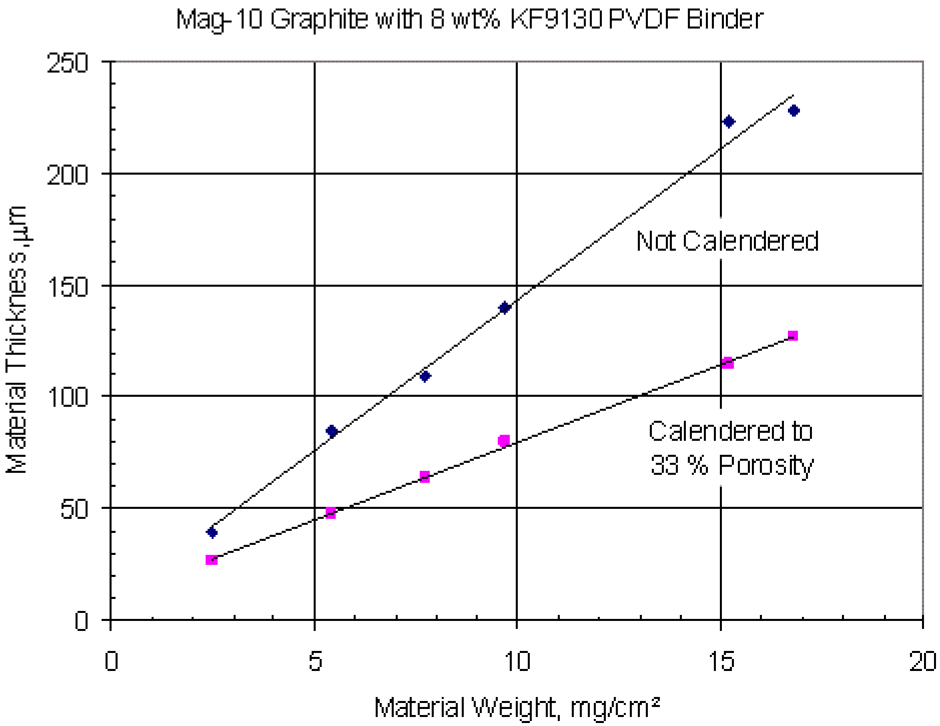
Milestones

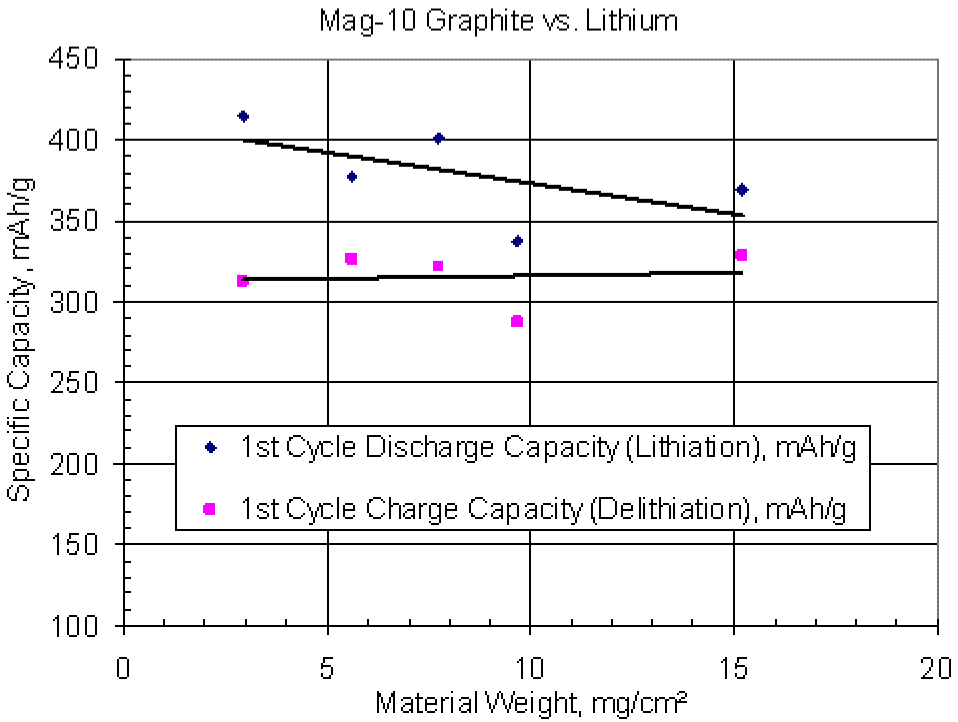
Produce graphite and NCA electrodes of varying thickness and test performance	Nov., 2008
Use thickness/performance data to design PHEV battery	Jan., 2009
Identify vendors to make electrodes and pouch/18650 cells for ABR	Jan., 2009
Finalize order of pouch/18650 cells with vendors	April, 2009
Distribute vendor cells to ABR for testing and diagnostics	Mid-summer 2009
Complete installation of pouch cell making equipment	March, 2010

Approach

- Promising new exploratory materials are often developed in small coin cells, which may or may not scale up well in large PHEV battery designs. For this reason, pouch cells or rigid cells such as 18650's will be used for proofing of new materials in the capacity range of 0.4 to 2 Ah.
- Subcontracts will be established with battery developers to produce these cells based on screened materials from suppliers and from the ABR and BATT programs.
- The previous ATD program required cells designed for HEV applications, which used thin electrodes. The performance of thicker PHEV electrodes must be determined and verified in a baseline cell build using Gen2 System (NCA/Mag10).
- Concurrent to the fabrication of PHEV cells by battery developers, Argonne will develop the capability to fabricate pouch cells and 18650 cells in Argonne's new dry room facility.
- Once in-house cells are deemed to be reliable, the developer subcontracts will be reduced.

Negative Electrode Thickness Study



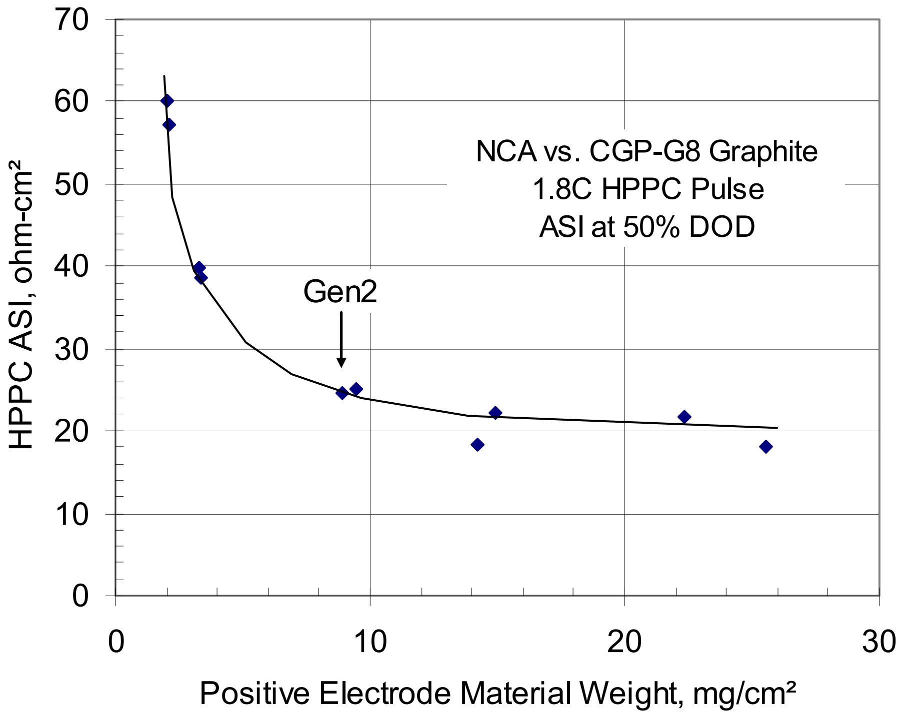


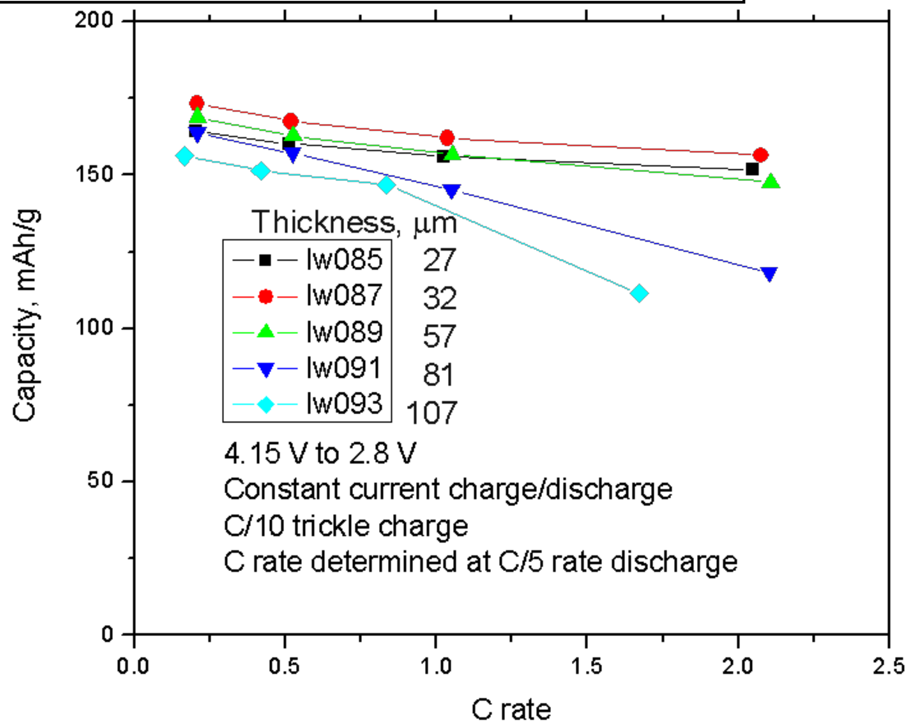
Mag-10 Graphite (Gen 2 Negative Powder)

Electrodes made with Argonne's mini-coater.
Adhesion was a concern for some of the coatings. More on this later.

Effect of Thickness on Full Cell Impedance and Rate

$LiNi_{0.85}Co_{0.15}Al_{0.05}O_2$ (NCA) vs. CGP-G8 Graphite		1.2 M $LiPF_6$ EC/EMC (3/7)
Formation cycles at C/10 rate	1.6 cm² electrode area	4.15 V to 2.8 V
Negative:Positive between 1.1 and 1.3	Porosity between 30 and 35%	





- The cell ASI decreases with increasing electrode thickness due to the increase in electrochemically active area per geometric electrode area.
- The cells with thicker electrodes deliver less capacity utilization at higher discharge rates.
- Recommend limiting positive electrode to 100 µm material thickness (32 % porosity).

Comparison of HEV and PHEV Electrode Designs

Anode	HEV (Gen 2)	PHEV - baseline
Composition	92% Mag-10 Graphite 8% PVDF Binder	95% Mag-10 Graphite 2.5% CMC Binder 2.5% SBR Binder
Electrode Thickness*, µm	34	79
Foil Thickness, µm	18 (Cu)	10 (Cu)
Electrode Loading*, mg/cm²	5.06	10.6
C/5 Capacity, mAh/cm²	1.44	3.02

Cathode	HEV (Gen 2)	PHEV - baseline
Composition	84% $LiNi_{0.8}Co_{0.15}Al_{0.05}O_2$ 8% PVDF Binder 4% Acetylene Black Carbon 4% SFG-6 Graphite	84% $LiNi_{0.8}Co_{0.15}Al_{0.05}O_2$ 8% PVDF Binder 4% Super P Carbon 4% SFG-6 Graphite
Electrode Thickness*, µm	36	65
Foil Thickness, µm	30 (Al)	22 (Al)
Electrode Loading*, mg/cm²	8.88	18.9
C/5 Capacity, mAh/cm²	1.23	2.54

*single-sided, no foil, calendered to ~33%

Status of PHEV Baseline 18650 Cells

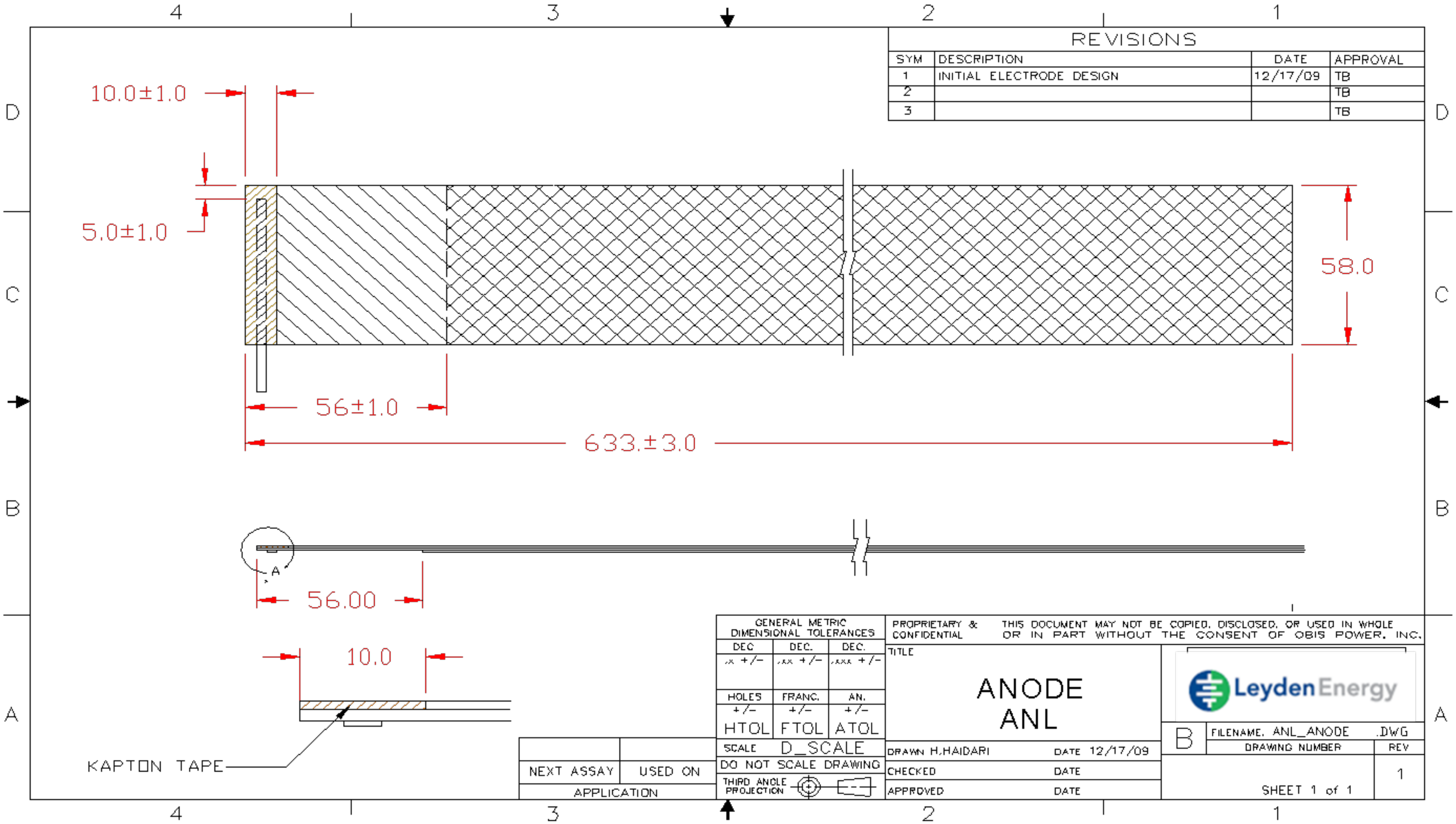
- Electrodes were coated and calendered by Johnson Controls-Saft
  - Double-sided (~80 m) and single-sided (~20 m)
- 18650 cells were made by Leyden Energy, Inc. (Mobius Power)
  - 30 cells with no additive: 1.2 M $LiPF_6$ in EC:EMC (3:7w)
  - 30 cells with 1.5 wt % vinylene carbonate (VC) added

PHEV Baseline 18650 Cell Design Specifications

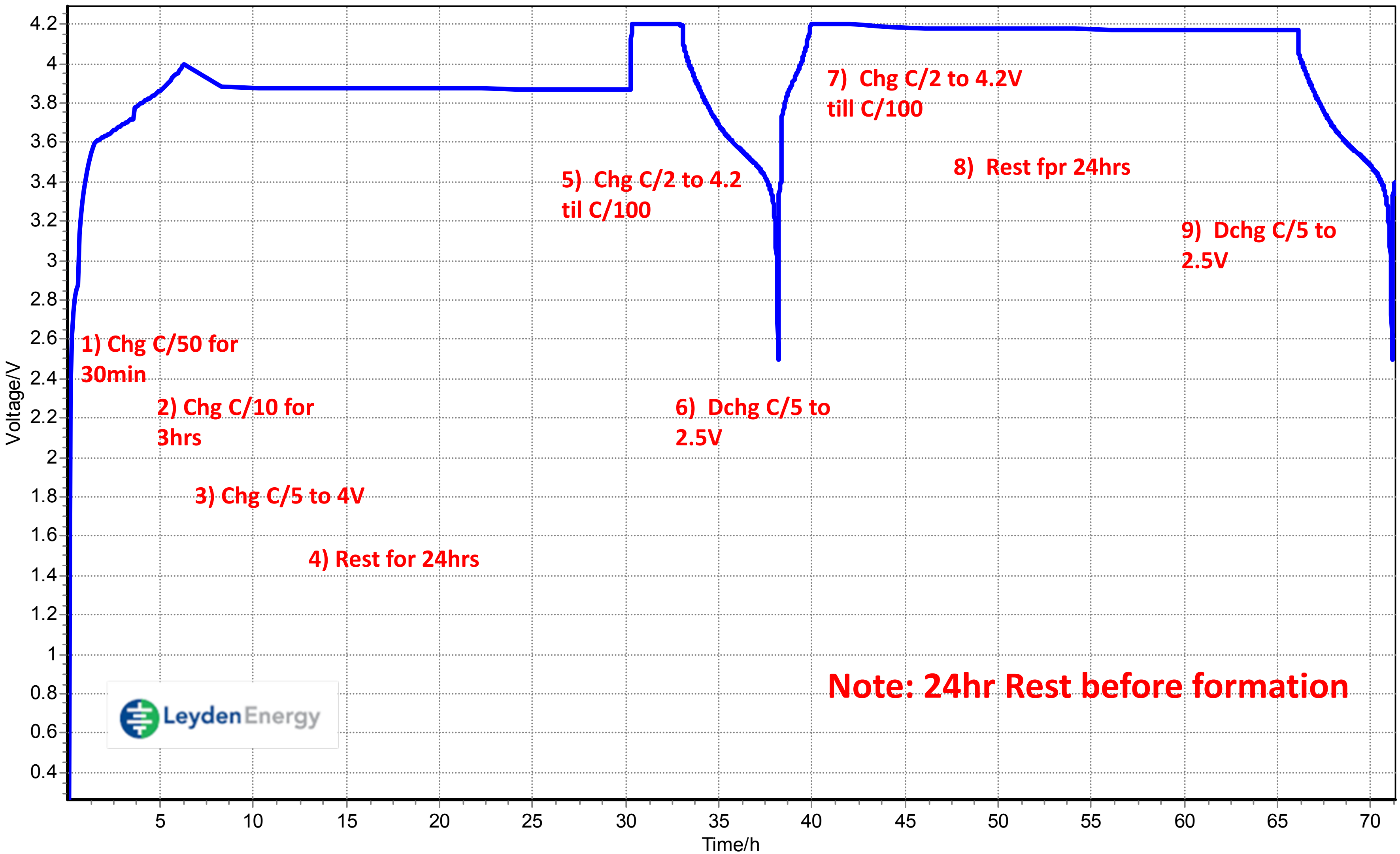
LeydenEnergy

		Target	UCL	LCL		
Cathode loading(Single)	mg/cm^2	18.9	19.467	18.333		
Cathode thickness	um	**152**	156	147	Mass Free	
cathode width	mm	56	56	56	Top	Bottom
Cathode length	mm	**578**	583	573	C5	C5
cathode mass free	mm	10.0	12.0	8.0	10	10
cathode wt incl Al foil	g	13.71	14.12	13.30		
cathode density	g/cc	2.91	3.00	2.82		
Anode Loading(Single)	mg/cm^2	10.60	10.92	10.28		
Anode thickness	um	**168**	173	163	Mass Free	
anode width	mm	58	58	58	Top	Bottom
Anode length	mm	**633**	638	628	A2-A3	A2-A4
anode mass free	mm	10	12	8	10	56
anode wt incl Cu	g	10.41	10.72	10.09		
anode density	g/cc	1.33	1.37	1.29		
Separator thickness	um	**25.0**	25.0	25.0		
separator width	mm	60	60	60		
Cathode Current collector	um	22				
jelly roll OD incl tape	mm	17.60	17.65	17.50		
Total Cell Wt	g	39.13				
Upper Charging Voltage	V	4.20				
Rated Capacity	Ah	**1.738**	Single Side	Capacity		
1st Cycle Max. Charge	Ah	1.88	Anode	3.323	mAh/cm2	
2nd + Cycles Max. Chg.	Ah	1.74	Cathode	2.778	mAh/cm2	
Energy Density	Wh/L	390	A/C=	1.20		
Energy Density	Wh/kg	167				

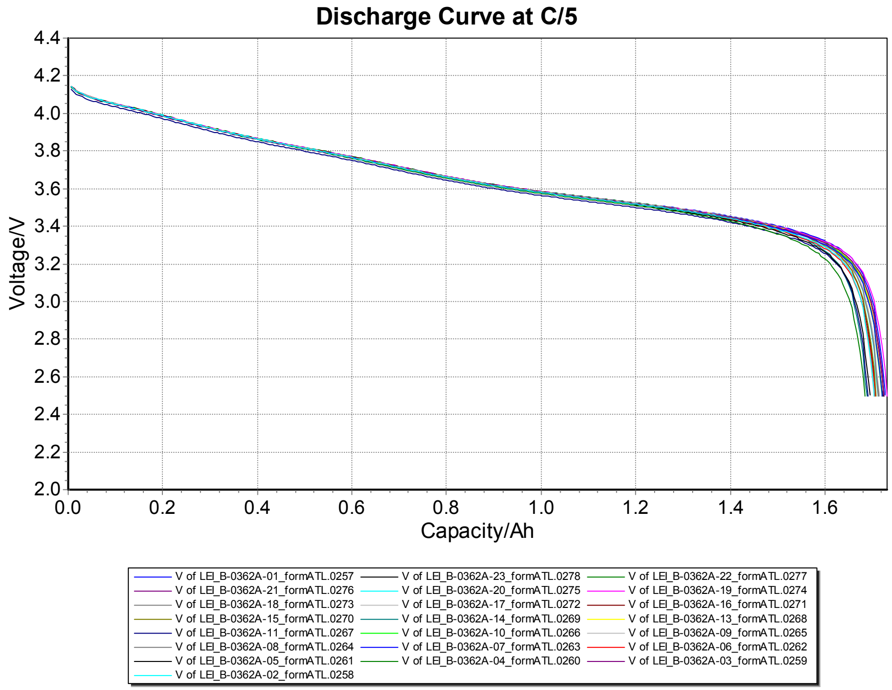
Electrodes Prepared for 18650 Assembly



Formation Procedure Used for PHEV Baseline Cells



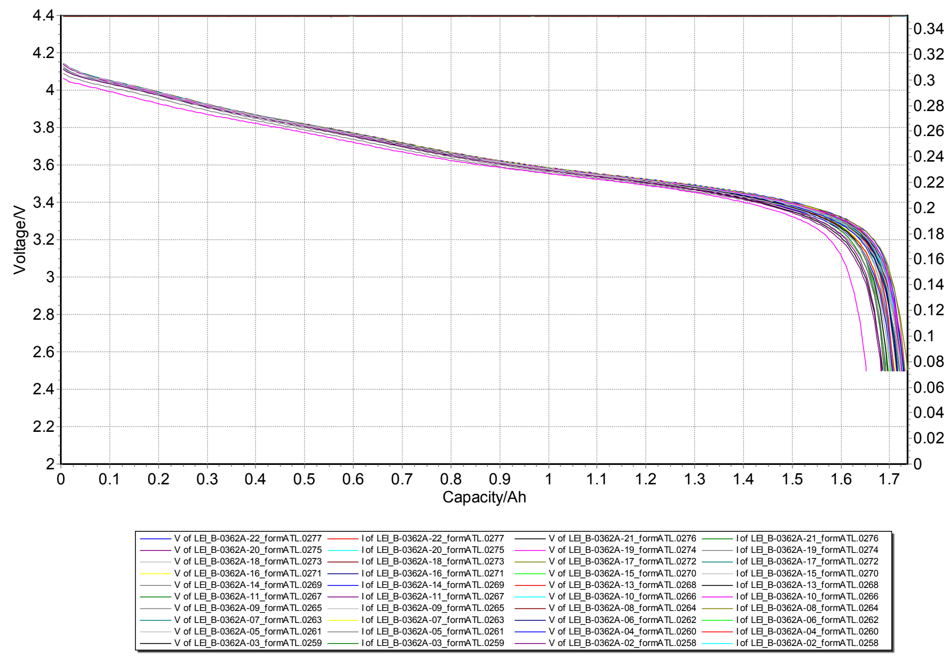
Cells Checked for Quality Before Leaving Leyden Energy



1st Discharge

Cells were tested for irreversible capacity loss and outliers were removed.

2nd Discharge



Capacity of B-362A at C/5

ABR Cell Testing at ANL, INL, and SNL

- Test plan contains tests for both HEV and PHEV cells. The HEV tests and RPTs are similar to Gen 2
- Gen2 tests will be repeated to ensure consistency with previous ATD results
- Cells are being tested in two batches of 12 cells each per lab due to channel limitations at ANL and INL
- 4 cells sent to SNL for Thermal Abuse Testing

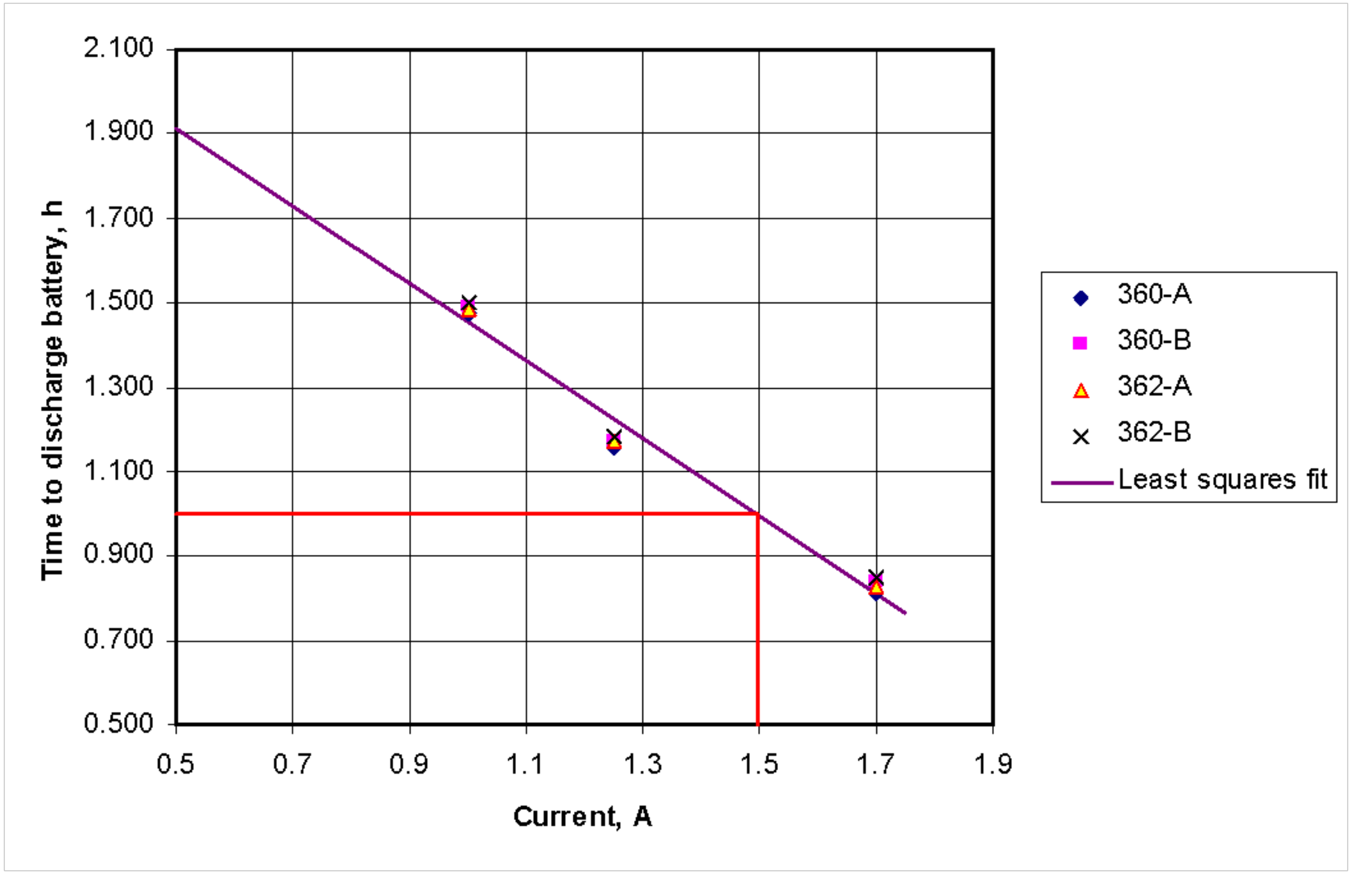
Cell Distribution Matrix

ABRT label[1]	Cell designation	Calendar life at 45°C and 60%SOC[2]	PHEV combined cycling[3]			PHEV Deep CD cycling[4]	HEV cycle at 45°C and 60% SOC[2]
			30°C	45°C	55°C		
G4A[5]	EC-B	5 cells	6	6	6	5	
G4B[5]	EC-C	5	6	6	6	5	
G4C	LE-360-A	3		3			3
G4D	LE-360-B	4		4			4
G4E	LE-362-A	3		3			3
G4F	LE-362-B	2		2			2

Notes:
1. G4A=bare cathode; G4B=Alumina-coated cathode; G4C=ANL electrolyte; G4D=ANL electrolyte + VC; G4E=LE electrolyte; G4F=LE electrolyte + VC
2. Calendar life at 45°C and 60% SOC and the HEV cycling are being performed to compare to the earlier Gen2 results. The SOC will be defined by C/25 voltage at 40% DOD.
3. A PHEV combined cycle is defined as removing the scaled 3.4-kWh of energy using the charge-depleting profile, followed by 50 charge-sustaining profiles.
4. PHEV deep charge-depleting cycling is defined as discharging the battery using the CD profile until 15% SOC, as defined by initial C/1 discharge voltage measurements.
5. These cells will not be tested with the others. They will be held until after channels have opened up after the other cells are taken off test.

Determination of Rated C/1 Capacity

- Cells were discharged at different rates
- The results of a rate experiment indicate the measured C/1 capacity is 1.5 Ah. Allow about 10% capacity margin; rate the cells at 1.4 Ah



Results of C/1 Capacity Verification

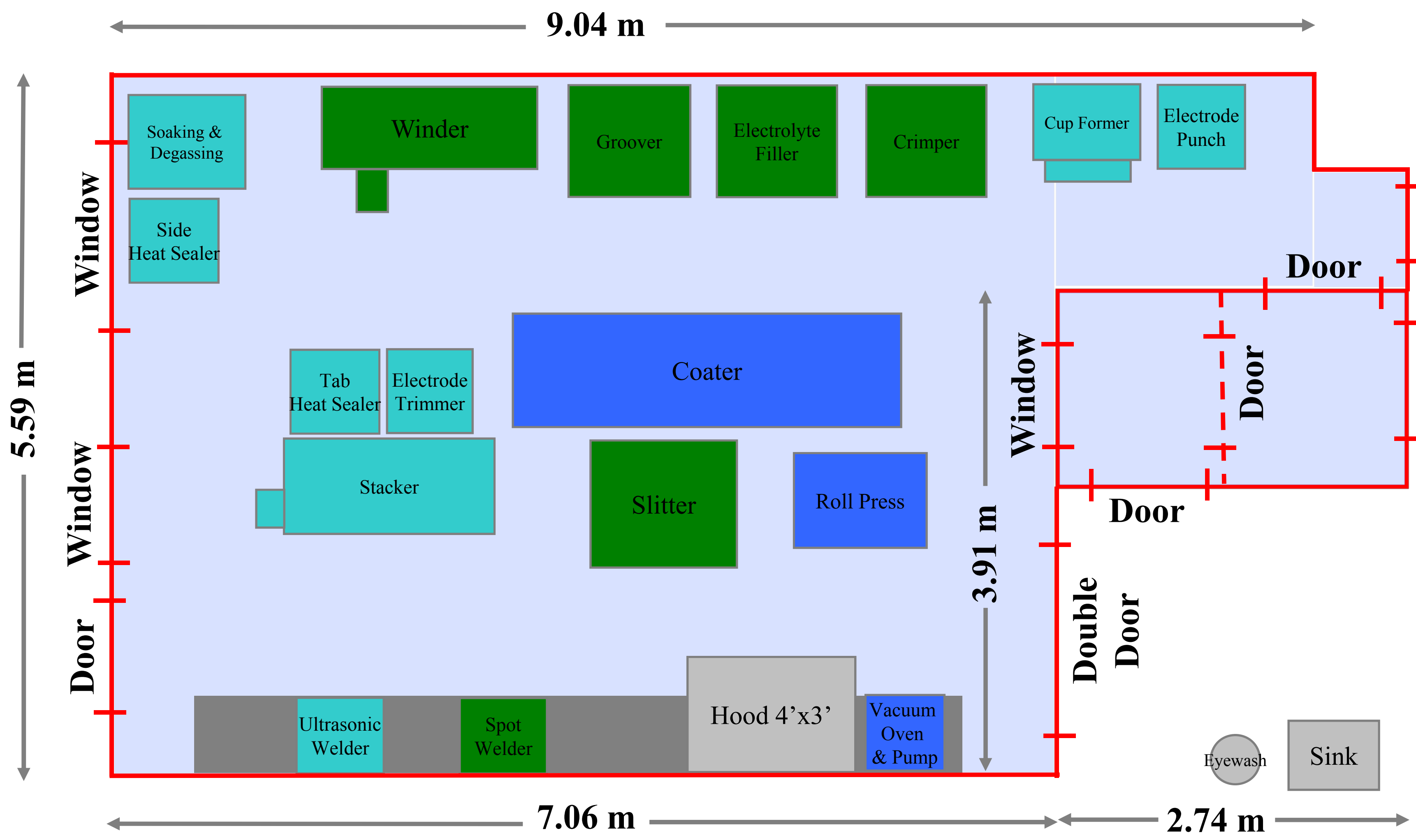
- Five measurements of the C/1 capacity were made on each cell
- The values reported are the average of the last three measurements
- Cells were placed on calendar and cycle life tests

ABRT label	Cell designation	Battery potential, V	Impedence at 1 kHz, mohms	Initial C/1 capacity, Ah @ 1.4-A rate	St. Dev., Ah
G4CH.60C45.A201.30.CC.NA.G	LE-360-A	3.625	46.1	1.417	0.002
G4CH.60C45.A202.30.CC.NA.G		3.615	45.0	1.436	0.000
G4CH.60C45.A203.30.CC.NA.G		3.619	44.2	1.440	0.001
G4DH.60C45.A204.30.CC.NA.G	LE-360-B	3.615	47.5	1.487	0.000
G4DH.60C45.A205.30.CC.NA.G		3.617	45.7	1.467	0.002
G4DH.60C45.A206.30.CC.NA.G		3.621	46.9	1.425	0.002
G4DH.60C45.A207.30.CC.NA.G		3.622	50.8	1.439	0.001
G4EH.60C45.A208.30.CC.NA.G	LE-362-A	3.622	45.9	1.415	0.001
G4EH.60C45.A209.30.CC.NA.G		3.612	46.3	1.442	0.001
G4EH.60C45.A210.30.CC.NA.G		3.614	45.0	1.458	0.002
G4FH.60C45.A211.30.CC.NA.G	LE-362-B	3.616	42.9	1.457	0.001
G4FH.60C45.A212.30.CC.NA.G		3.621	46.3	1.459	0.002

Status of Sealed Cell Fabrication Facility

- Dry room installation completed September 2009
  - by Scientific Climate Systems LTD
  - $\leq$100 PPMv (-42°C dew point), ~500 ft^2 area, 6 persons, 750 SCFM exhaust capability, and >8 kW heat load
- Lithium-ion pouch cell making equipment
  - made by Media-Tech
  - uses XX3450 format
  - installed
- Lithium-ion 18650 cell making equipment
  - made by Media-Tech
  - installed
- Electrode coater and hot roll press
  - bid awarded to A-Pro
  - installation and training expected in late summer
- Hired a new process engineer (Bryant Polzin)

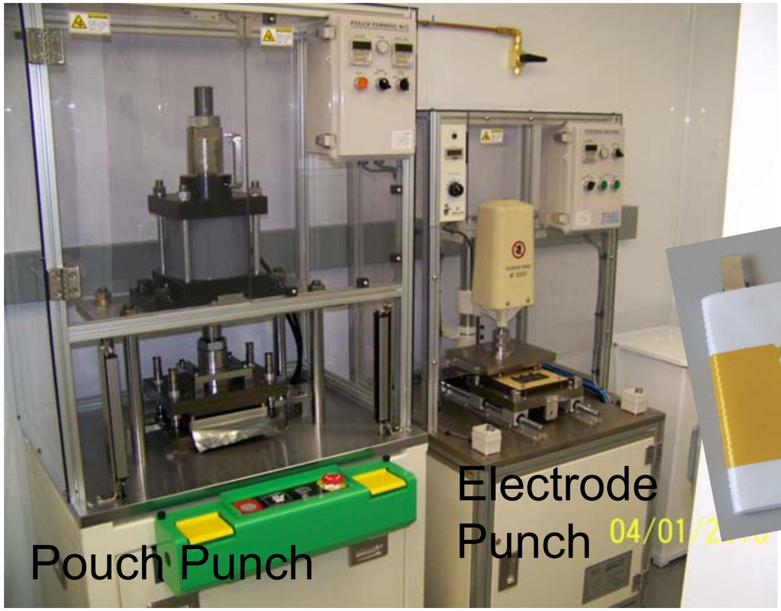
Layout of New Dry Room Cell Making Facility

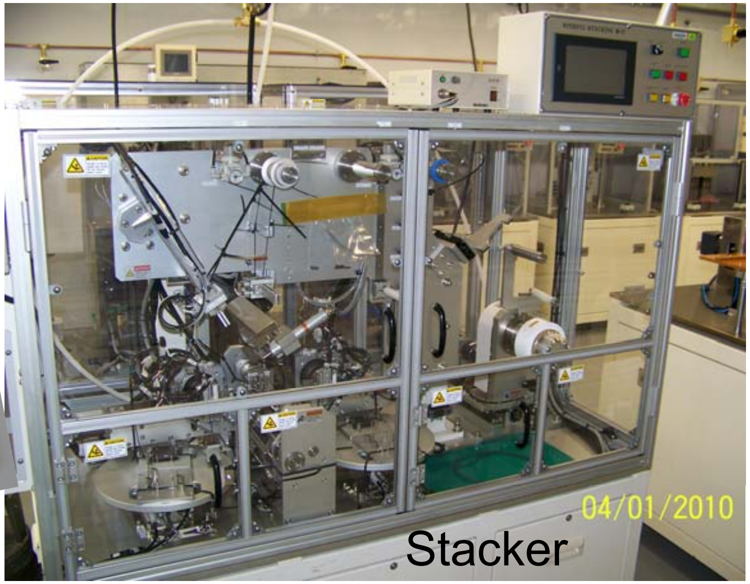


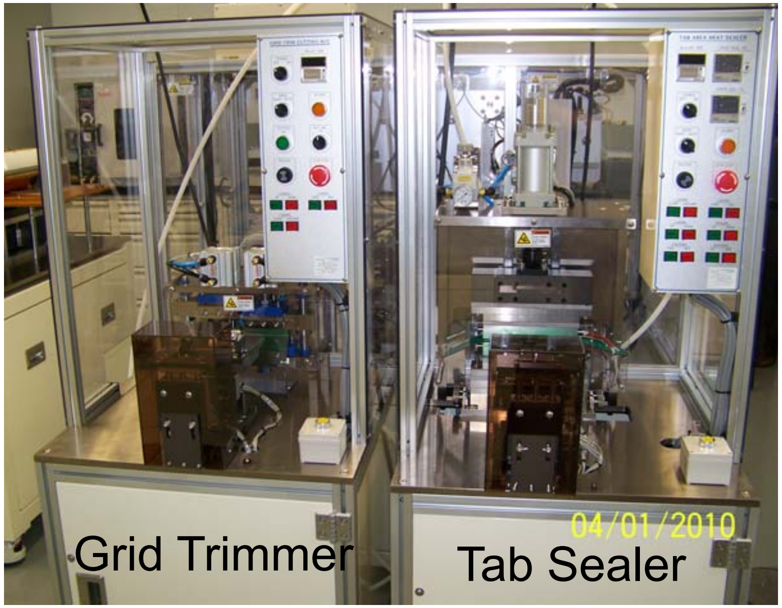
Argonne’s Dry Room Cell Fabrication Facility

(Interior Dimensions)

Pouch Cell Making Equipment Installed in Dry Room







18650 Cell Making Equipment Installed in Dry Room

Ultrasonic Welder

Resistance Welder

Summary

- Baseline PHEV electrodes have been designed and fabricated by vendor
- 18650 cells were made and are under calendar and cycle life test at ANL and INL
- Dry room installation completed
- Pouch and 18650 cell making equipment installed at Argonne
  - Completed training from Media Tech engineers
- Coater and hot roll press are being made by A-Pro

Future Plans

- Install coater and hot press when they arrive and complete training
- Complete break-in process on new cell making equipment
  - Safety inspection and modification
- Fabricate PHEV baseline electrodes and cells in-house for quality assurance check
- Fabricate 18650 and pouch cells in-house with exploratory materials

Contributors and Acknowledgments

- Sun-Ho Kang (Argonne)
- Dennis Dees (Argonne)
- Ira Bloom (Argonne)
- Kevin Gering (INL)
- Jon Christophersen (INL)
- Bryant Polzin (Argonne)
- Wenquan Lu (Argonne)
- Pete Roth (SNL)
- Khalil Amine (Argonne)
- Paul Nelson (Argonne)
- Gary Henriksen (Argonne)
- Dan Preuss (Argonne)
- Nick Veselka (Argonne)
- Chris Joyce (Argonne)
- Leyden Energy (Mobius Power)
- Johnson Controls-Saft
- Media-Tech
- A-Pro
- Ecopro

Support from David Howell of the U.S. Department of Energy's Office of Vehicle Technologies is gratefully acknowledged.