NREL
NATIONAL RENEWABLE ENERGY LABORATORY

American Recovery & Reinvestment Act (ARRA)

NREL Battery Thermal and Life Test Facility

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ARRAVT079

NREL/PR-5400-50915

Outline

- Overview
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- Relevance
- Approach
- Financial Summary
- Technical Accomplishments and Progress
  - Equipment Purchased Under ARRA
  - Laboratory Modifications for ARRA Equipment
- Looking Forward – Future Equipment Development
- Collaborations and Partnerships
- Summary and Conclusions

Overview

Timeline

- Project start date: April 2010
- Project end date: June 2012
- Percent complete: 70%

Barriers – Energy Storage

- Cost
- Energy storage performance
- Safety
- Calendar and cycle life

Budget

- Funding received in
  - FY10: $2M - April
  - FY11: $0

Partners

- AeroVironment
- Arbin
- Bitrode
- Cincinnati Sub Zero
- Netzsch
- Thermal Hazard Technologies
- ThermTest

Objectives

- Acquire capital equipment to upgrade and enhance the battery thermal test facility at NREL with recovery act funds.
- Increase throughput of specialized testing, so that battery developers can more quickly obtain critical data in support of product design.
- Perform a greater number of unique tests to enhance understanding of cell thermal and lifetime performance and better guide designs for increasing performance and life.
- Support DOE/FreedomCAR, USABC and the U.S. battery industry to meet the following goals for energy storage through improved thermal design:
  - Reduce cost
  - Improve safety
  - Improve performance
  - Improve calendar and cycle life
- Validate thermal and life models to help U.S. industry accelerate product development.
- Increase the availability of equipment needed to evaluate and benchmark battery developers' prototypes.

Milestones

Month-Year	Milestone	Status
June 2010	Progress Report on the Acquisition of Equipment and Facility Modifications – for ARRA funded Battery Thermal and Life Test Facility	Completed
December 2010	• Acquire Battery Cyclers • Acquire and Install Environmental Chambers • Acquire and Install Small Cell Calorimeter • Power Point Progress Report	Completed
June 2011	• Complete Facility Modifications • Install and Calibrate All Battery Cyclers • Acquire, Install and Calibrate All Thermal Conductivity Meters • Power Point Progress Report	On Track
December 2011	• Complete Install, Shake-Down, and Calibration of All Equipment	On Track
June 2012	• Final Report	On Track

Relevance

- The U.S. has dramatically increased investment in domestic battery production plants with Recovery Act funds – for example:
  - Johnson Controls - $299 million
  - A123 Systems - $250 million
  - Dow Kokam - $161 million
  - CPI - $151 million
- Acquiring capital equipment to upgrade and enhance the battery thermal test facility at NREL will allow battery developers to improve the design of the cells produced at these plants.
- It will also allow for an independent review of the performance of batteries from the new production plants.

Equipment Acquisition/Installation

- Identify DOE/FreedomCAR, USABC, and domestic battery manufacturers' requirements with regards to NREL's test facilities.
- Identify equipment manufacturers.
- Acquire multiple quotes from vendors for each piece of equipment.
- Analyze quotes with regards to performance, cost, schedule, and quality.
- Generate purchase request.
- Receive equipment in-house and install.
- Calibrate and verify performance meets manufacturer's specifications.

Facility Modifications

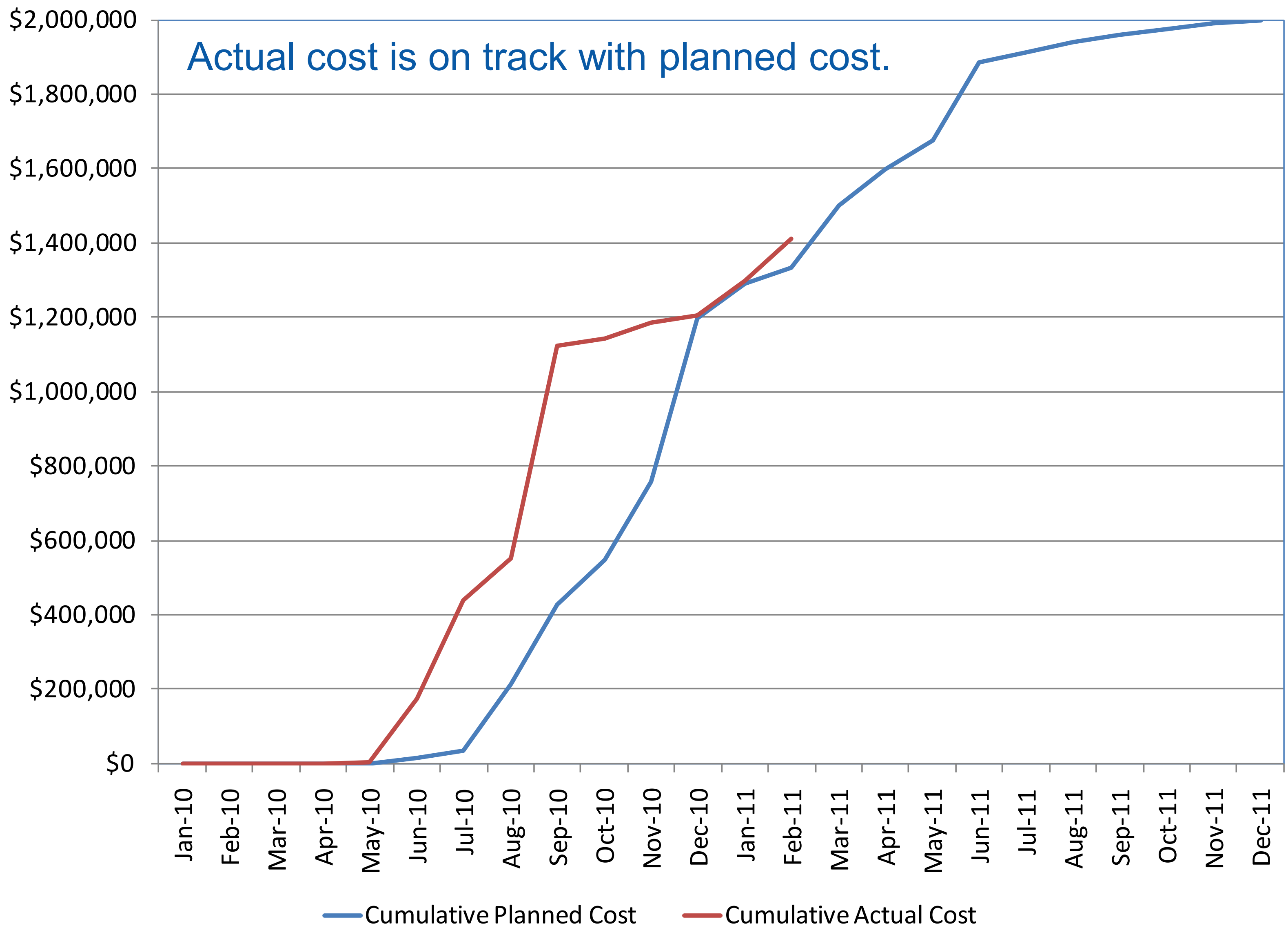
- Identify existing space and acquire new laboratory equipment.
- Perform an ES&H review on the new space to ensure a safe working environment.
- Identify necessary utility modifications—electrical, HVAC, chilled water, communication, and safety improvements.
- Complete RFPs for modifications and send out for bid.
- Evaluate bids and award contracts.
- Complete facility/utility modifications.

NREL Battery Thermal and Life Test Facility

The upgraded and enhanced facility will:

- Aid DOE, USABC, and domestic battery manufacturers in characterizing and evaluating new energy storage systems.
- Provide data for NREL's empirical models for HEV, PHEV, and EV energy storage systems.
- Validate NREL's life models, so engineers can quickly explore design trade-offs in battery usage, performance, life, and cost.
- Validate NREL's multi-scale multi-dimensional (MSMD) electrochemical/thermal model, which predicts the spatial variations in cell performance, including non-uniformities of cycling, temperature, and heat generation.
- Validate NREL's thermal abuse models.

Financials: Actual Cost vs. Planned Cost



Acquired Battery Testers – Almost 100 Channels

Technical Accomplishments

Charge/discharge energy storage systems for thermal and life cycle testing.

Cycler	Voltage Range (Volts)	Current Range (Amps)	Total Channels
5 Volt Bitrode Cycler	0-5	+/- 100	16
36 Volt Bitrode Cycler Chassis #1	0-36	+/- 300	4
36 Volt Bitrode Cycler Chassis #2	0-36	+/- 300	4
36 Volt Bitrode Cycler Chassis #3	0-36	+/- 300	4
100 Volt Bitrode Cycler Chassis #1	0-100	+/- 300	4
ABC-150 - Parallel All Channels	8-220	+/- 265	2
Arbin Battery Cyclers	0-5	+/- 2	64

Photo Credits:John Ireland/NREL

Acquired Five Environmental Chambers

Technical Accomplishments

Accurately control ambient temperature for performance and life-cycling of cells.

Photo Credit: Dirk Long/NREL

Test Parameter	Value
Volume (ft^3)	32.5
Internal Dimensions (inches)	38 x 38 x 38
Temperature Range (°C)	-45 to +190
Live Load Capacity at –18°C (Watts)	3000
Number of Units	4

Test Parameter	Value
Volume (ft^3)	64
Internal Dimensions (inches)	48 x 48 x 48
Temperature Range (°C)	-45 to +190
Live Load Capacity at –18°C (Watts)	3100
Number of Units	1

Acquired Glove Box for Destructive Physical Analysis

MBraun

Safely disassemble cells to understand their failure mechanisms.

Photo Credits: Matt Keyser/NREL

Unilab
1.95 m x 0.78 m x 0.900 m
Gas Purifier
O_2 Sensor – Control to < 5 ppm
H_2O Sensor – Control to < 5 ppm
Large Antechamber
Small Antechamber

Acquired Small Cell Calorimeter

Thermal Hazard Technology

Understanding the entropic changes with a cell and how this affects life.

Photo Credits: John Ireland/NREL

Isothermal Battery Colorimeter		
Model	IBC-001 (Standard)	IBC-002 (High Sensitivity)
Temp Range	-20 to 80	-20 to 80
Dynamic Range	100uW to 10W	10uW to 2 Watts
Chamber Size	34.5mm ID x 61.5mm High	34.5mm ID x 61.5mm High
Battery Testing?	Yes	Yes
Cycler Capability	0-4A Chrg/1-10A disch/1mA res	0-1A Chrg/1-1A disch/1uA res

Acquired Thin Film Thermal Conductivity Meter

Netzsch

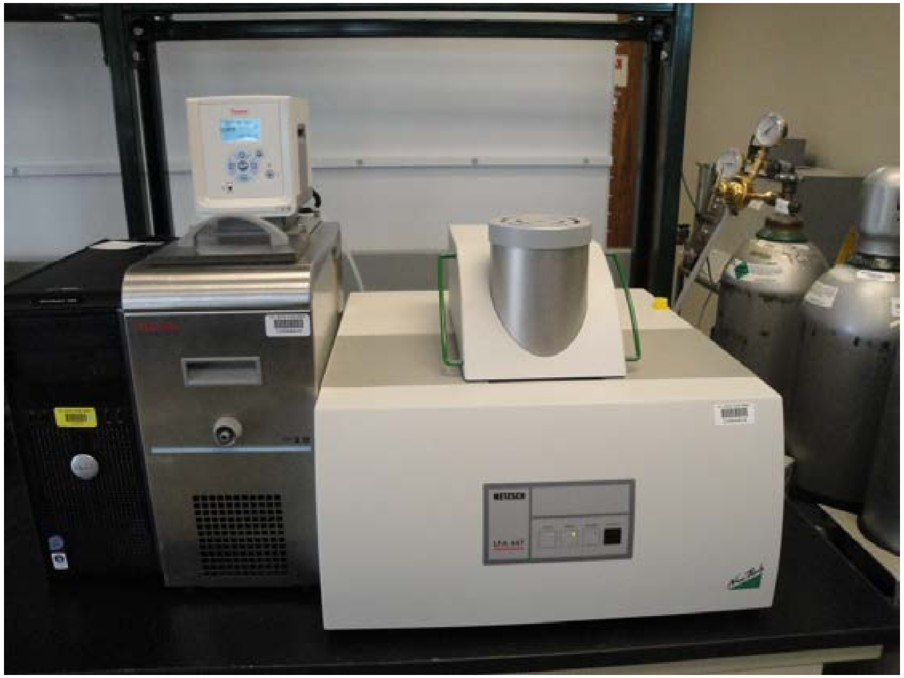


Photo Credits: John Ireland/NREL

LFA 447	
Temp Range	RT to 300
Number of Samples	4
Sample Size	25.4mm
Sample Types	Solid, Liquid, Powder, Laminated
Test Atmosphere	Pressure, Air, Inert, Oxidizing, Reducing, Static, Dynamic
Thermal Diffusivity	0.01 to 1000mm^2/s
Thermal Conductivity	0.1 to 2000W/mK
Accuracy	3%
Repeatability	2%

Developing a test procedure for accurately measuring the thermal conductivity of battery materials – thin films.

Acquired Bulk Thermal Conductivity Meter

ThermTest

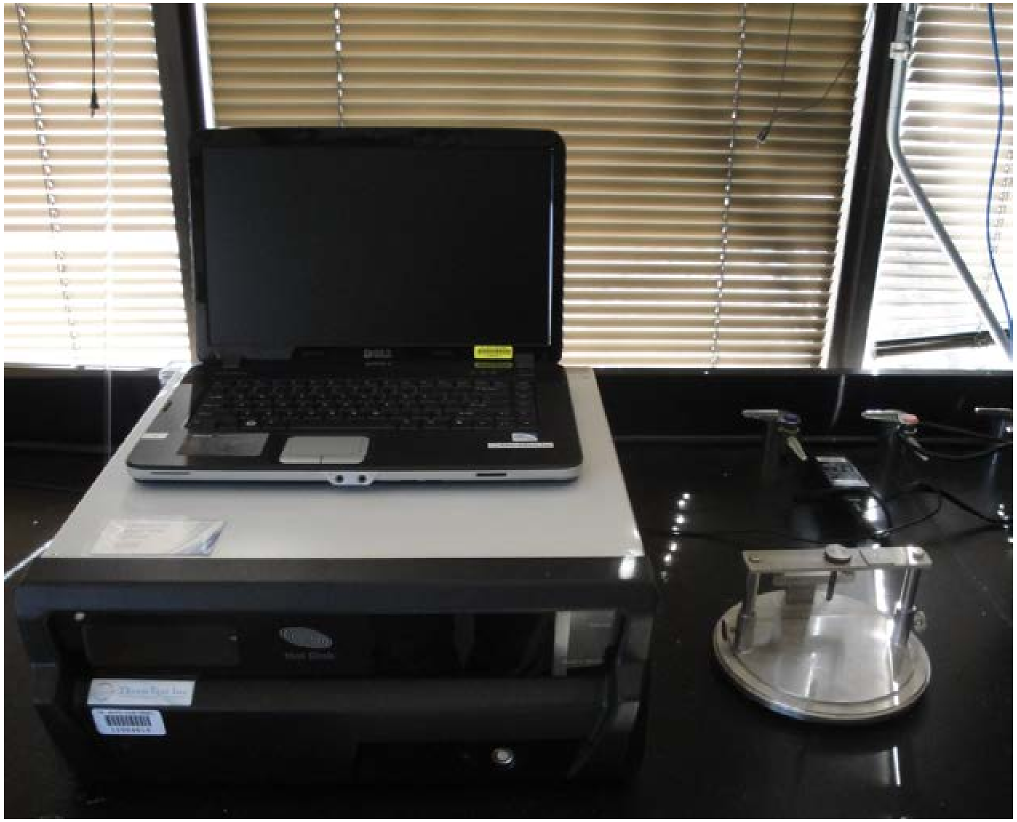


Photo Credits: John Ireland/NREL

TPS 500	
Temperature Range	-100°C to 200°C
Number of Samples	1
Sample Size (ϕ)	13mm to unlimited
Sample Thickness	3mm to unlimited
Sample Types	Solid, Liquid, Powder, Paste
Test Atmosphere	Air
Thermal Diffusivity	0.02 to 40mm^2/s
Thermal Conductivity	0.03 to 100W/mK
Accuracy	<5%
Repeatability	2%

Developing a test procedure for accurately measuring the thermal conductivity of battery materials – bulk materials.

Thermal Test Facility (TTF) Laboratory Space Modifications

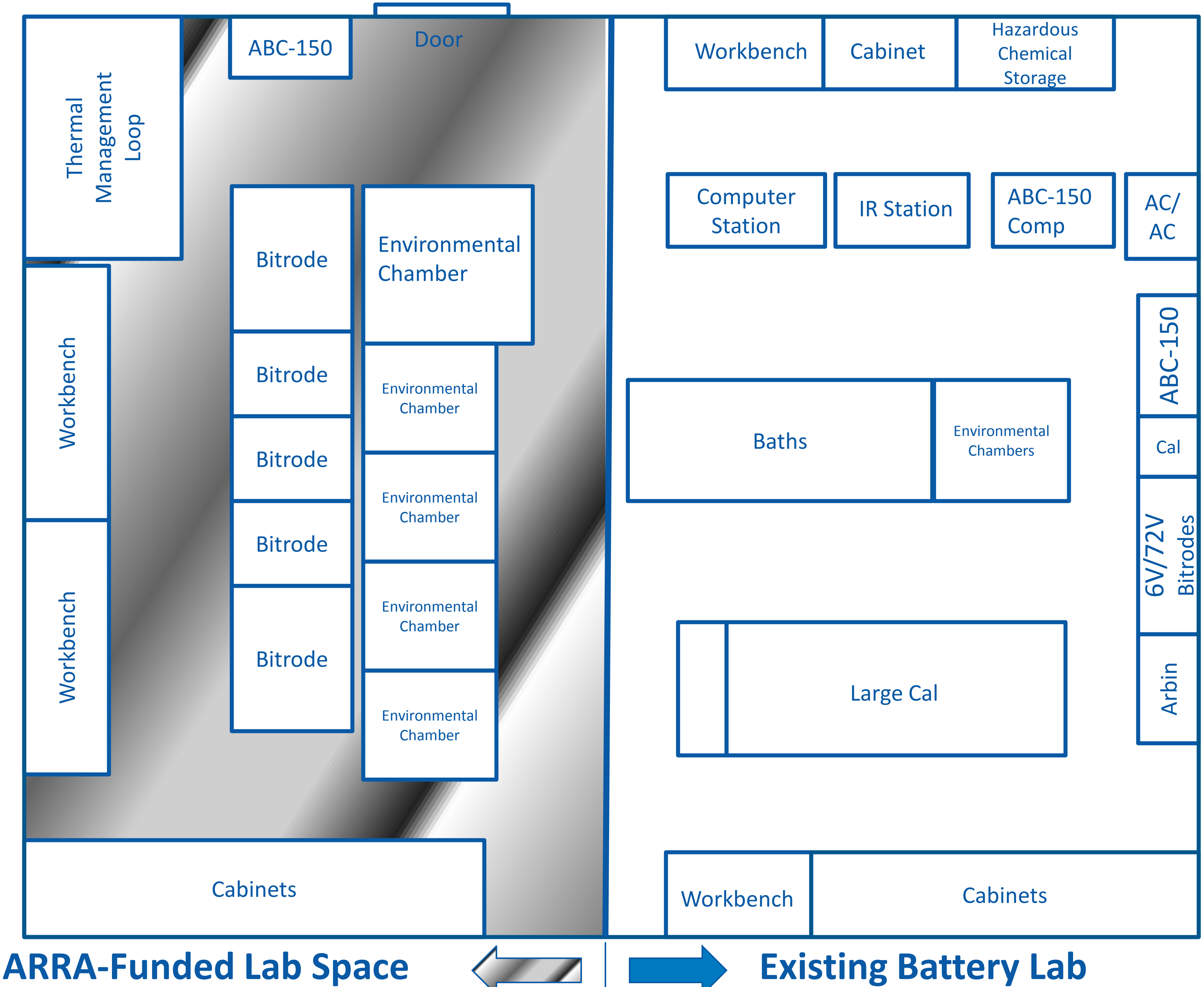
Technical Accomplishments

Before

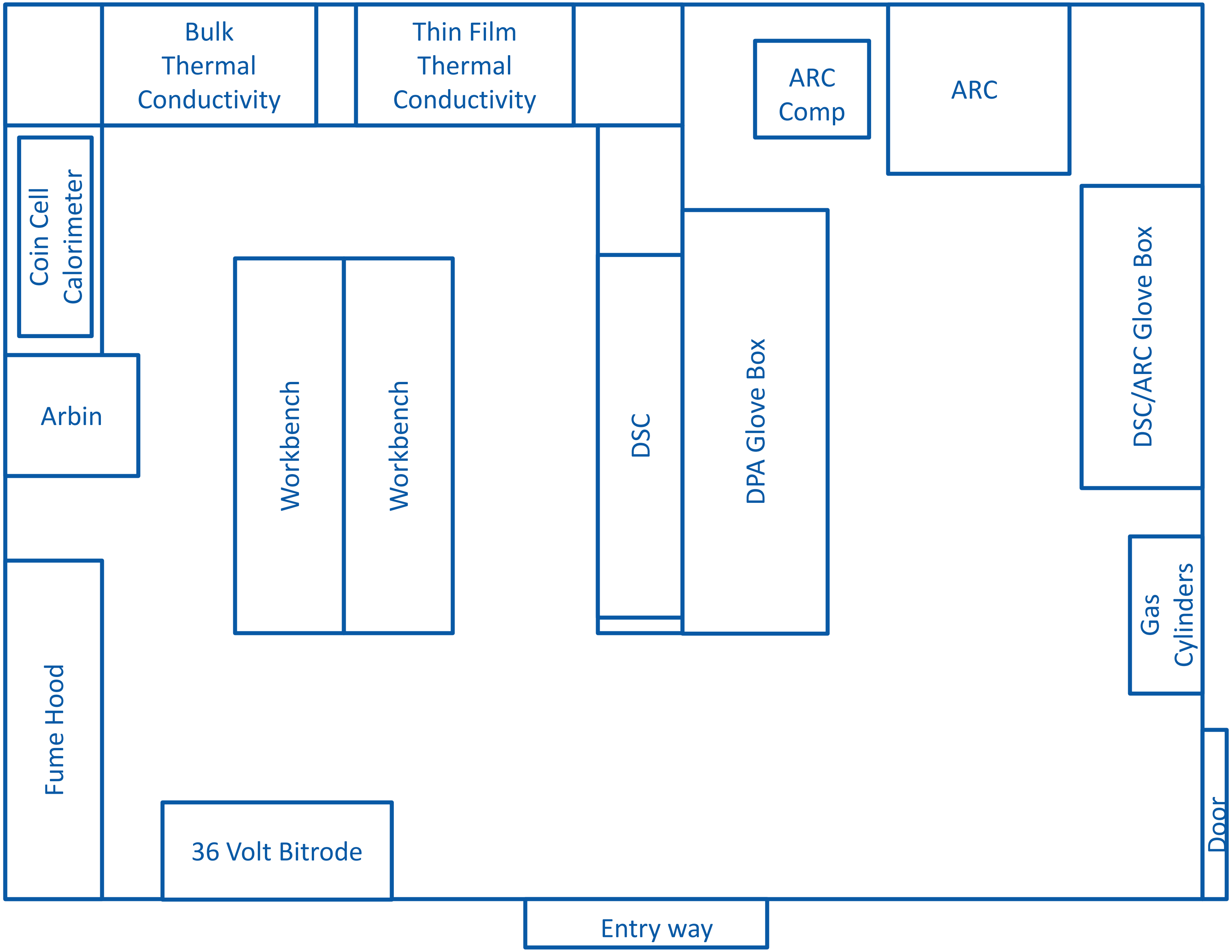
After

Photo Credits: Dirk Long/NREL

TTF Laboratory Layout - Schematic



16/216 Laboratory Layout with ARRA Equipment



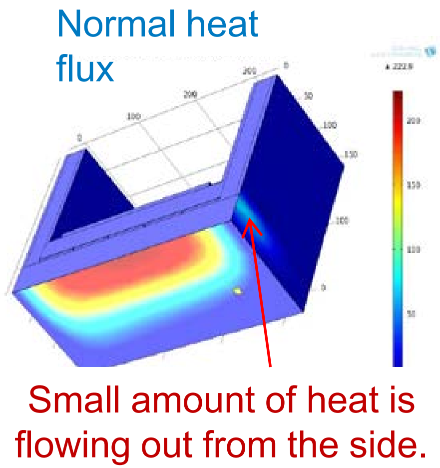
NREL is Designing/Fabricating a Custom Cell Calorimeter

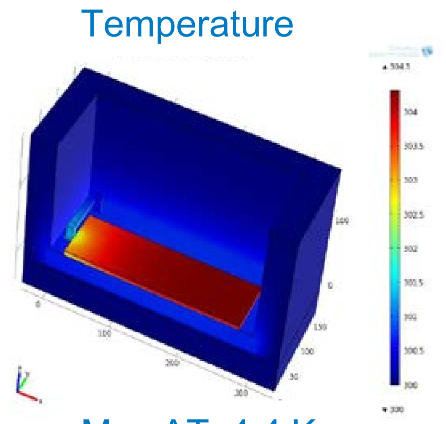
Early Design Questions

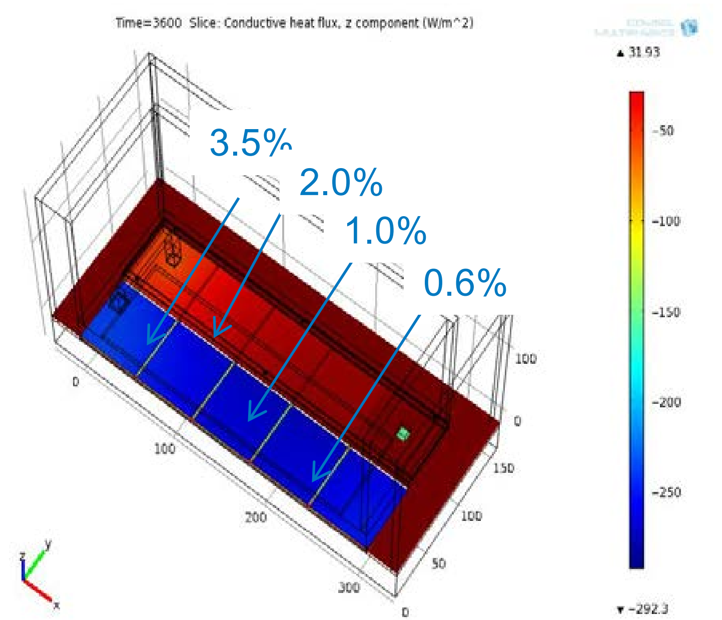
- NREL already has two calorimeters (module and pack), why the need for another calorimeter?
  - Existing USABC activities require NREL's calorimeters 100% of the time. With the addition of U.S.-sponsored cell production facilities, the number of cells received for testing at NREL will only increase.
- Why build a cell calorimeter?
  - While NREL has two calorimeters that can test cells, the time constant between tests is large due to the thermal mass of the calorimeters. NREL's present calorimeters were designed for modules and packs.
  - In order to increase throughput, NREL approached DOE about the design of a cell calorimeter with minimal thermal mass—reducing the time between tests and increasing the number of test points per day.
- Why design a custom cell calorimeter?
  - After extensive research, NREL was unable to find a calorimeter company that would build the unit for HEV, PHEV, and EV cells.
  - Most calorimeters on the market have minimal current ratings (less than 10 amps).
  - The cell calorimeter must be rated at several hundred amps for energy storage systems in advanced vehicle applications.

NREL Plans to Build Its Custom Cell Calorimeter by Scaling Down NREL's Existing Large Calorimeter

- NREL designed a large calorimeter able to handle modules, sub-modules and packs and accurate enough to test individual cells.
  - How can the large calorimeter design be scaled to test individual cells?
- In order to simplify the large calorimeter design, it was necessary to understand several design aspects as they relate to cell calorimeter design.
  - Bus bars are required due to the high currents seen by HEV, PHEV, and EV cells, but where should they be located in a cell calorimeter?
  - How can the number of heat flux gauges (HFGs) be minimized?







Future Work

- Finish electrical and chilled water modifications to the existing laboratories.
- Shake-down and calibrate all instrumentation received under the ARRA task.
- Complete fabrication of custom cell isothermal calorimeter.
- The battery thermal management test loop could not be designed until facility services (water, power, etc.) installations were designed/in place. NREL has collected enough information on these services, and design is underway. NREL anticipates that the purchase of the test loop will also meet the scheduled milestone date.

Summary

- NREL is on track to meet the original spending dates/milestones.
- NREL anticipates costing 80% of the $2M by May—one year after receiving funding—and 95% of the funds by September 30th.
- The two items that are not yet purchased are ones that are not off-the-shelf, but require design by NREL researchers/engineers:
  - The custom cell isothermal calorimeter design has been complex, but is complete. The instrument is currently being built and is on schedule.
  - The battery thermal management test loop is on schedule.
- We purchased 7 battery testers (~100 channels), a small cell isothermal calorimeter, two thermal conductivity meters, 5 environmental chambers, and a glove box.
- Secured laboratory space for new equipment.
- Updated electrical and chilled water supply to new laboratory space.

Collaborations and Partnerships

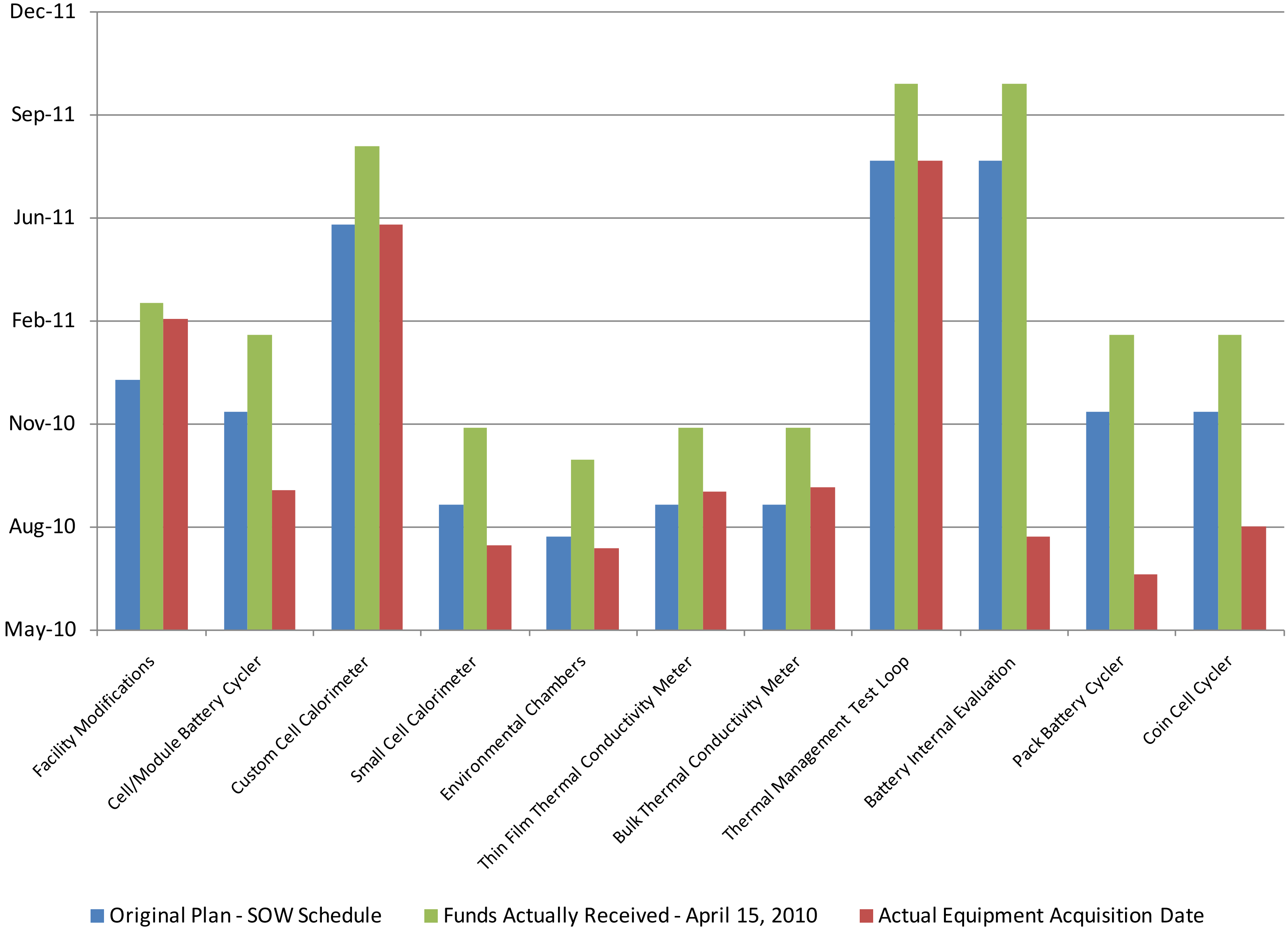
- Acquired equipment from the following manufacturers:
  - AeroVironment
  - Arbin
  - Bitrode
  - Cincinnati Sub Zero
  - Netzsch
  - Thermal Hazard Technologies
  - ThermTest

Technical Back-Up Slides

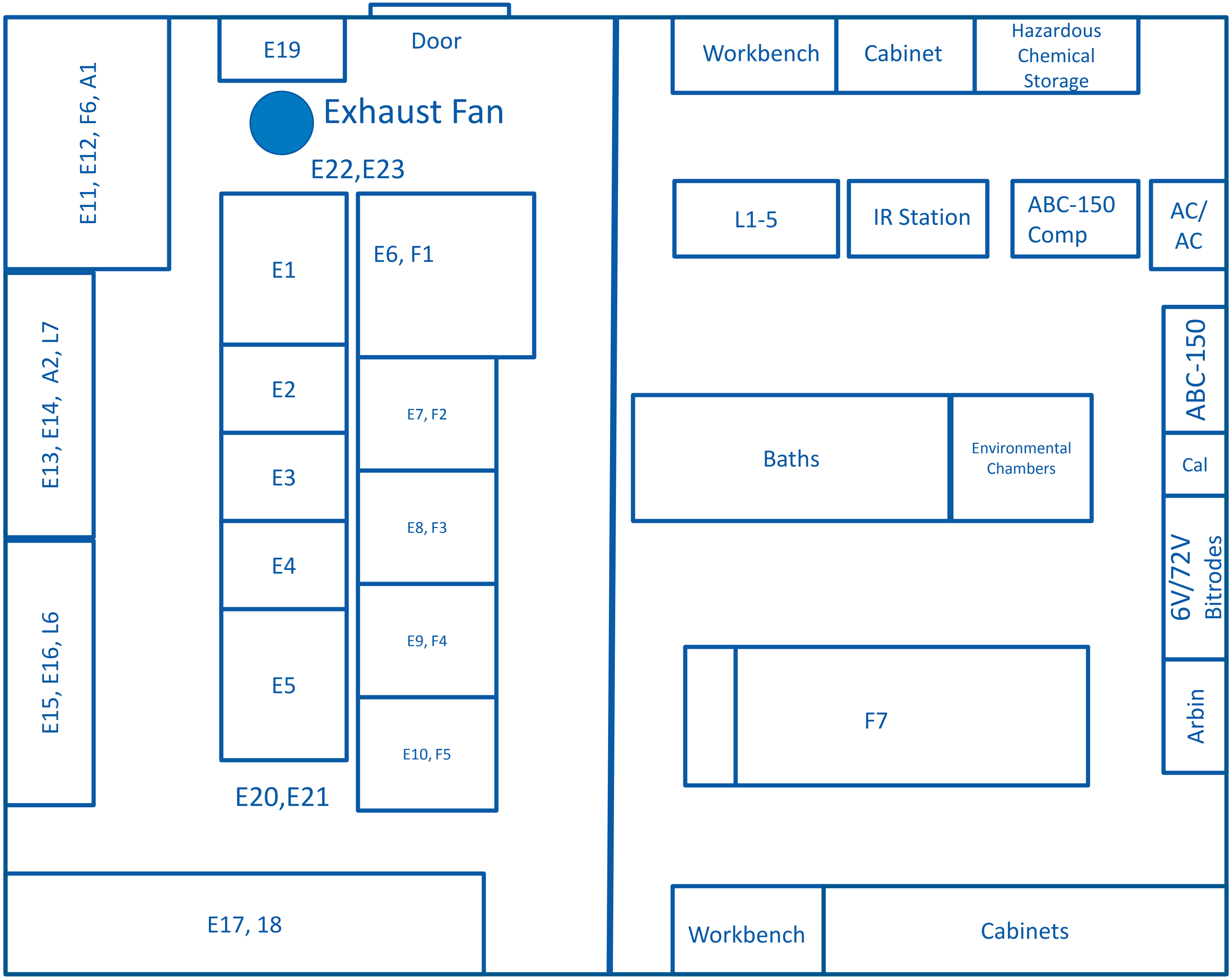
Financials: ARRA Battery Upgrade Financial Summary

Description	Purpose	Estimated Cost	Cost to Date	Estimated Total Cost
Module Battery Cycler	Thermal and life cycle testing of cells	**$490,977**	$ 486,850.00	$ 486,850.00
Pack Battery Cycler	Thermal and life cycle testing of cells	**$159,553**	$ 158,360.00	$ 158,360.00
Cell Battery Cycler	Thermal and life cycle testing of cells	**$54,548**	$ 51,360.00	$ 51,360.00
Custom Cell Calorimeter	Evaluates heat generation and efficiency of cells	**$201,933**	$ 30,000.00	$ 201,933.00
Small Cell Calorimeter	Evaluates heat generation and efficiency of cells	**$105,057**	$ 49,950.00	$ 49,950.00
Module Environmental Chamber - 32 ft3	Controls temperature of cells under test	**$115,390**	$ 113,420.00	$ 113,420.00
Pack Environmental Chamber - 64 ft3	Controls temperature of cells under test	**$46,156**	$ 41,195.00	$ 41,195.00
Thermal Conductivity - Bulk Materials	Measure thermal conductivity of materials	**$57,695**	$ 20,000.00	$ 20,000.00
Xenon Flash Thermal Conductivity Instrument - Thin Films	Measure thermal conductivity thin films	**$70,808**	$ 79,173.00	$ 79,173.00
Thermal management in the loop testing apparatus	thermal management in the loop testing apparatus	**$125,880**	$ 9,800.00	$ 125,800.00
Battery Internal Evaulation	Disassemble batteries to understand failure mechanisms in cells.	**$62,940**	$ 38,520.00	$ 62,940.00
Additional Equipment - Due to Cost Underrun - Isothermal Baths, Dilatometer, Scales, etc…	Controls temperature of cells under test		$ -	$ 75,000.00
Miscellaneous - Connectors, Materials, etc.	-	**$26,225**	$ 21,500.00	$ 26,225.00
Laboratory Modifications		$150,000	$ 151,000.00	$ 176,450.00
Labor		$332,839	$ 158,460.00	$331,344
Total		**$2,000,000**	**1,409,588**	**$2,000,000**
	POs Completed	Evaluating Technologies	On-Going	Long Term

Financials: Planned Purchase Date vs. Actual Purchase Date



TTF Laboratory Layout – ARRA Infrastructure Modifications



TTF Electrical Circuits and Chilled Water

Circuit	Voltage	Current	Phase	Comments
E1	480	210	3	No De-rating - Equipment Maximum Power Draw
E2	480	115	3	No De-rating - Equipment Maximum Power Draw
E3	480	115	3	No De-rating - Equipment Maximum Power Draw
E4	480	115	3	No De-rating - Equipment Maximum Power Draw
E5	480	38	3	No De-rating - Equipment Maximum Power Draw
E6	480	25	3	Circuit Rating
E7	208	40	3	Circuit Rating
E8	208	40	3	Circuit Rating
E9	208	40	3	Circuit Rating
E10	208	40	3	Circuit Rating
E11	120	20	1	Circuit Rating
E12	208	30	1	Circuit Rating
E13	120	20	1	Circuit Rating
E14	208	30	1	Circuit Rating
E15	120	20	1	Circuit Rating
E16	208	30	1	Circuit Rating
E17	120	20	1	Circuit Rating
E18	208	30	1	Circuit Rating
E19	480	150 kVA	3	Transformer Rating
E20	120	20	1	Circuit Rating
E21	120	20	1	Circuit Rating
E22	120	20	1	Circuit Rating
E23	120	20	1	Circuit Rating

Circuit	Flow (GPM)
F1	6.5
F2	3.9
F3	3.9
F4	3.9
F5	3.9
F6	10
F7	15
Total	47.1

Previous slide shows locations