

Development of Computer-Aided Design Tools for Automotive Batteries

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Team members
GM / ANSYS / ESIM / NREL

Project ID # ES119

Overview

Timeline

- Start – June 2011
- Finish – Dec 2014
- 100% Complete

Budget

- Total project funding: \$7.1 M
 - DOE - \$ 3,540 K
 - Contractor – \$ 3,540 K
- Funding received
 - FY 14: \$ 794 K
- Funding for FY 15
 - \$0 K (project completed)

Barriers

- Barriers
 - a) Lack of validated computer-aided engineering tools for accelerating battery development cycle
 - b) Complexity of multi-scale, multi-physics interactions
- Targets -shorten time and cost for design and development of EDV and HEV battery packs

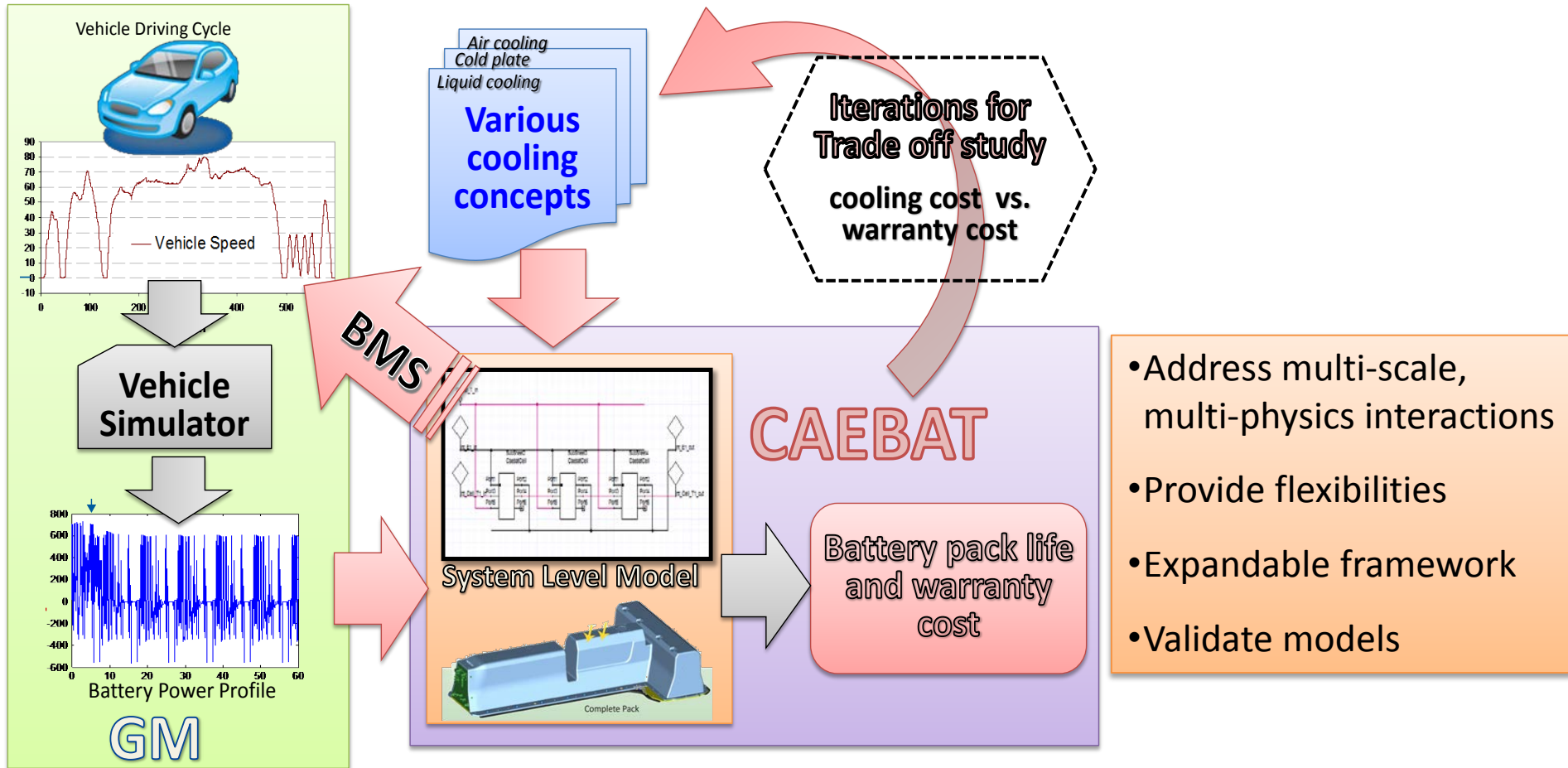
Partners

- GM : End user requirements, verification/validation, project management
- ANSYS : Software dev. and commercialization
- ESim : Cell level sub models, life model
- NREL : Technical monitor

Project Lead: GM R&D Center

***Funding provided by Dave Howell of the DOE Vehicle Technologies Program .
The activity is managed by Brian Cunningham of Vehicle Technologies.
Subcontracted by NREL, Gi-Heon Kim Technical Monitor***

Project Relevance/Objectives: faster design cycles and optimize batteries (cells and packs) for improved performance, safety, life, and low cost.

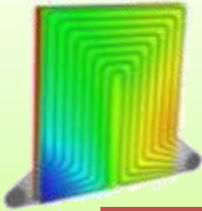
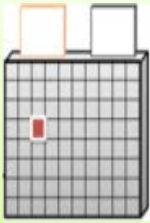


Ability to provide trade off studies between various cooling concepts and the battery pack life.

Milestones

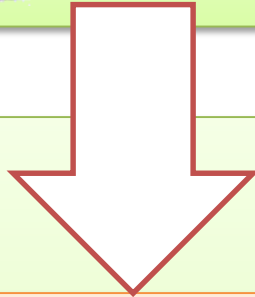
Month /Year	Milestone or Go/No-Go Decision	
Feb-2013	Go/No-Go decision: Deliver the cell level simulation tool. The cell level model includes three sub models and a scale coupling based on MSMD approach.	Complete
June-2013	Milestone: Validation of the cell level model. Deliver the first pack level model. The pack level model includes a system level capability with reduced order models (ROM).	Complete
Sept-2013	Milestone: System level simulation software tool was delivered. LTI (Linear Time Invariant) system level ROM model approach has been validated in comparison with the full field simulation results.	Complete
Dec-2013	Go/No-Go decision: Official public release of ANSYS (version 15) that includes user defined electrochemistry models that allows user to apply their own models while utilizing FLUENT's battery framework.	Complete
Jan-2014	Milestone: System level model without ROM was completed and validated compared to the full field simulation and the test data. Demonstrated System simulations for US06 drive cycle. Demonstrated LTI ROM for US06 drive cycle.	Complete
Dec -2014	Milestone: Develop CAE process automation for the pack level simulations. Complete cycle life and abuse models. Incorporate NREL's multi-particle model. Incorporate the Open Architecture Software interface. Deliver the final pack level design tools.	Complete

Project Approach



Cell Level Model (Full field simulation)

- Full field simulation based on CFD and electrochemistry model
- Cell level performance including various cooling concepts

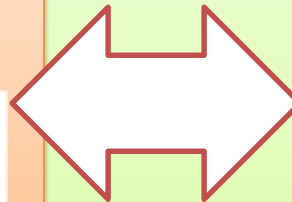
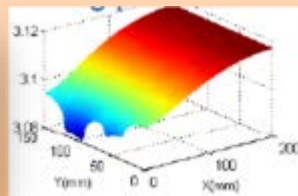
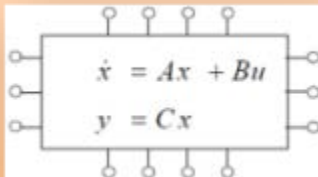


Pack Level Model

Co-simulation

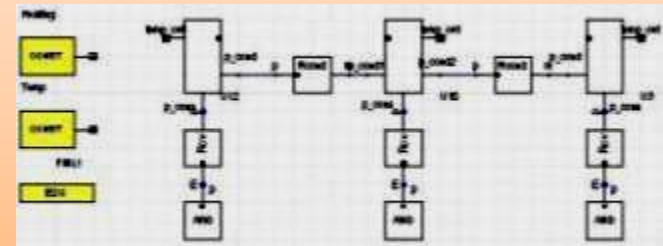
Reduced-Order Models

- Reduced order models for flow and thermal analysis at the pack level



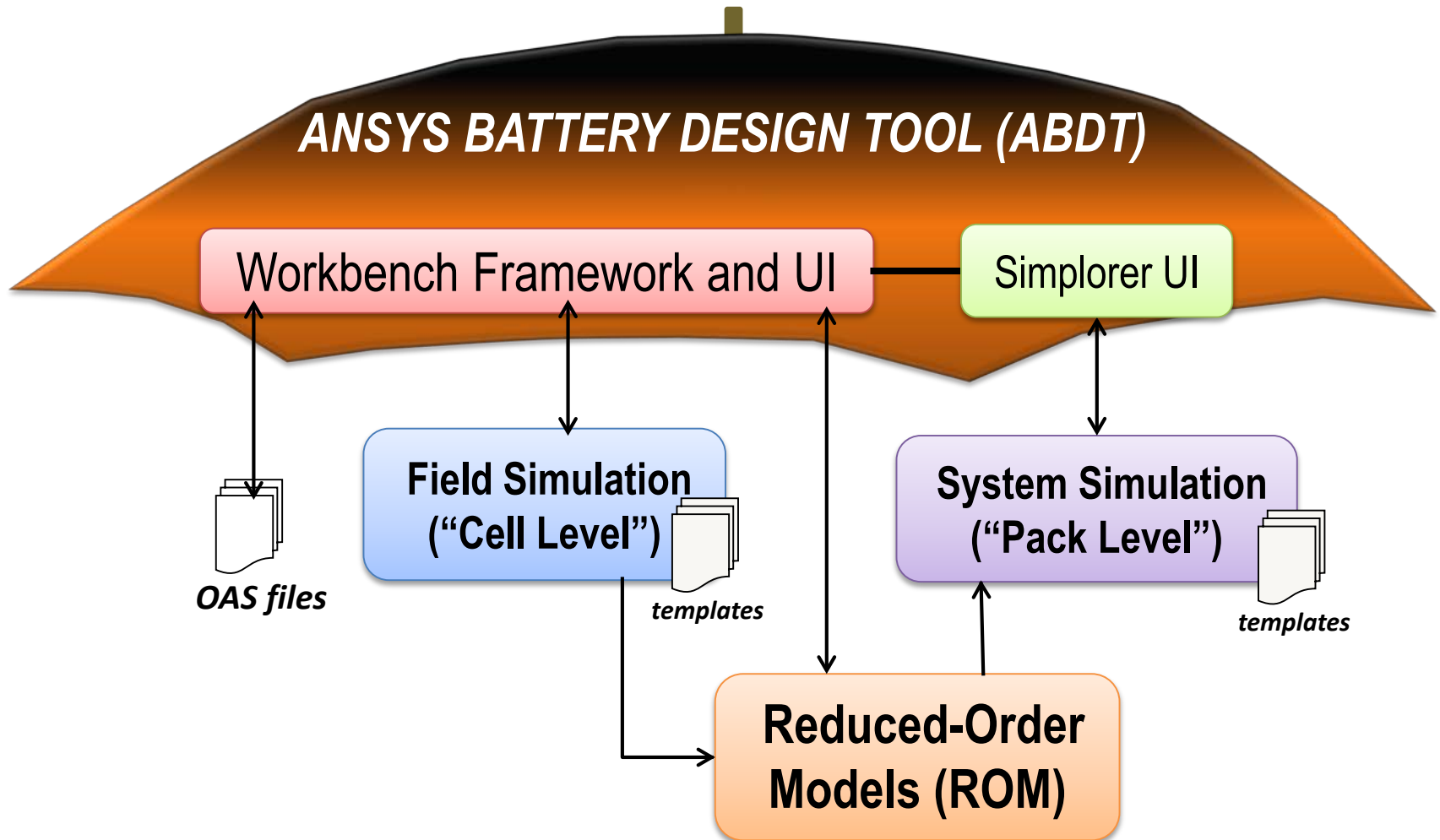
System Level Model

- Construct a “linear” or “non-linear” system simulation model from the full pack simulation model



Strategy is to offer a wide range of methods allowing analysts to trade off computational expense vs. resolution

Roadmap for Battery CAE Tools

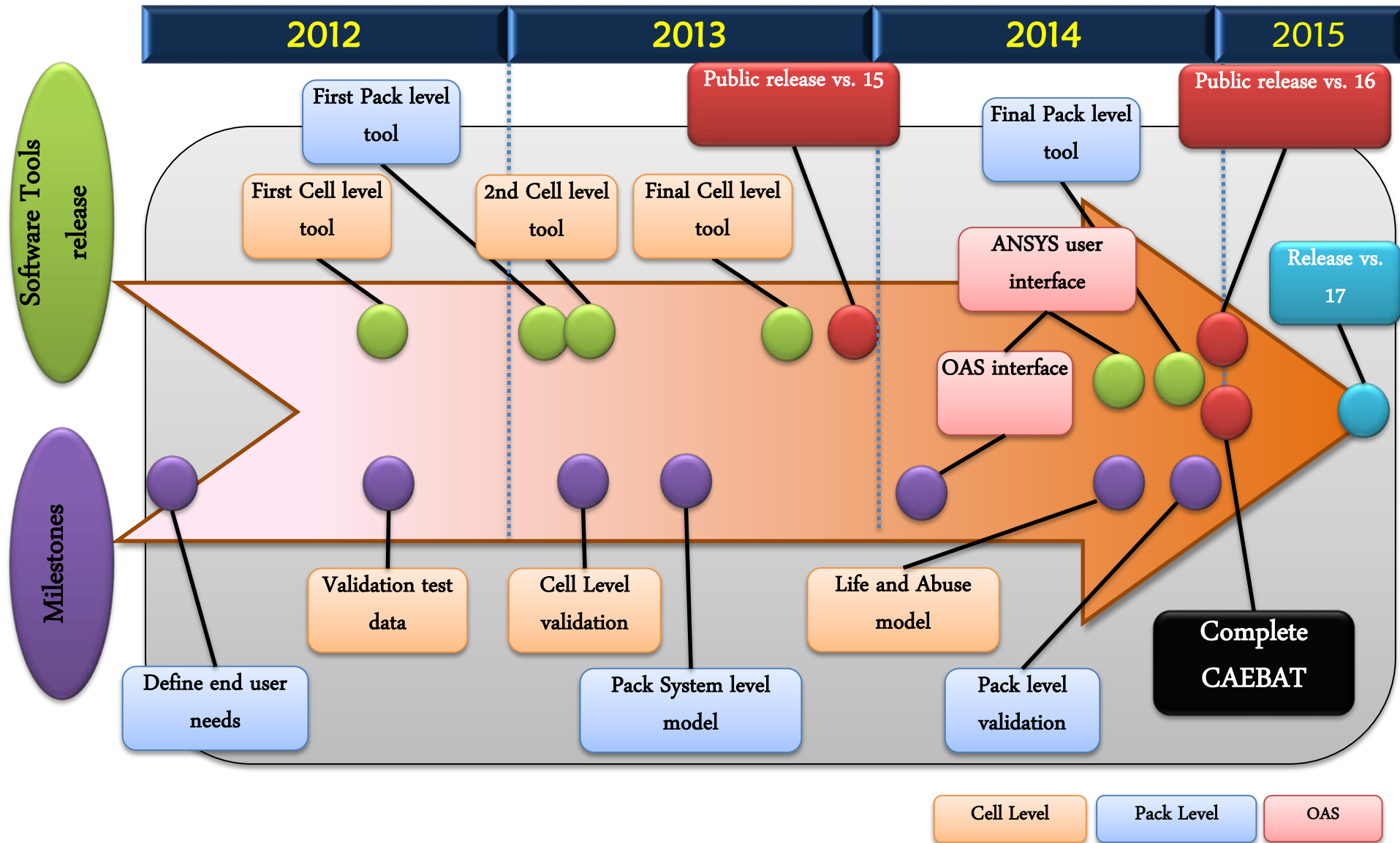


ABDT is the “umbrella” over all capabilities, including the graphical user interface (UI) that automates/customizes battery simulation workflow, leveraging ANSYS commercial products.

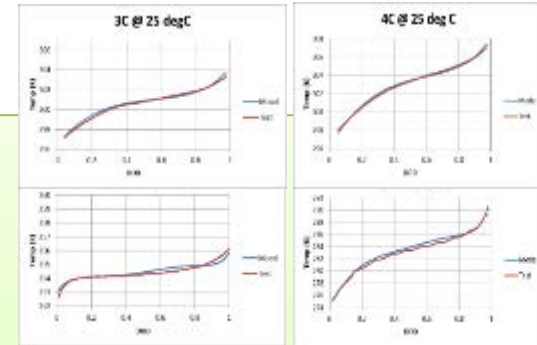
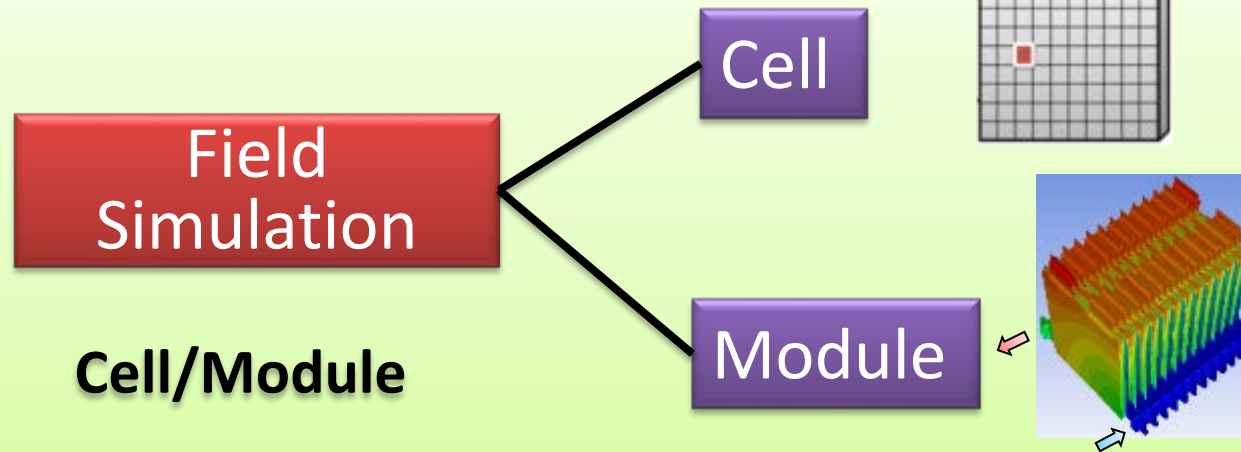
Technical accomplishments

- The ANSYS Battery Design Tool (ABDT) has been developed. ABDT facilitates the integration of existing applications with external tools to create a seamless workflow for both full field simulations and system simulations. MSMD frame work was implemented successfully.
- Model validation is completed for the cell, module/pack, and including a production pack (further production pack level validation continues).
- Semi-Physics based cycle life model was developed based on a modified equivalent-circuit model with a cell degradation circuit.
- NREL has developed a udf (user defined function) for multiple particle/multiple active material models for GM team.
- Thermal abuse/runaway model was implemented and demonstrated on a battery pack.
- Automation process for ROM construction and simulations has been completed.
- Direct ROM for the energy equation was developed and demonstrated the accuracy and the speed (will be Implemented for future ANSYS releases)

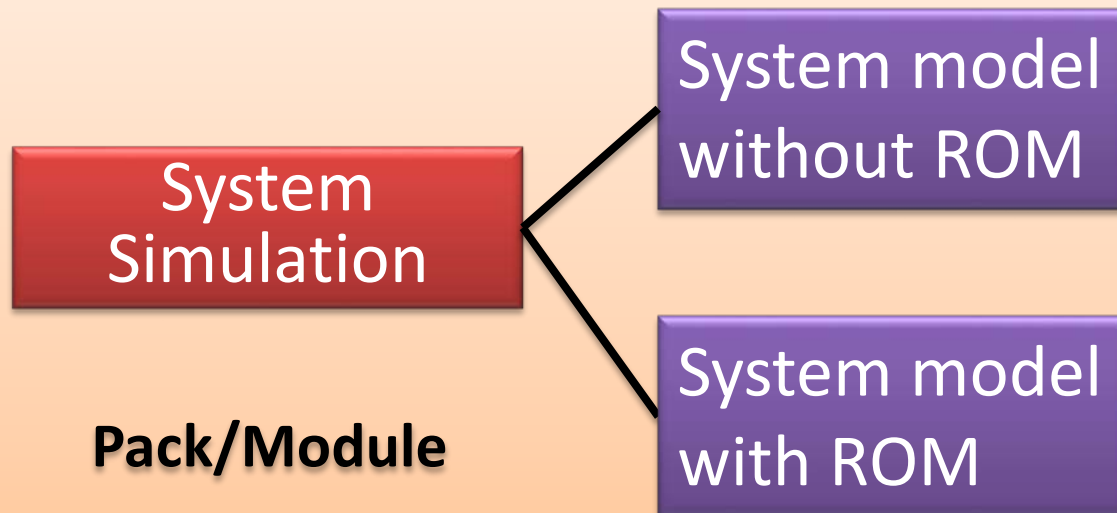
Project Timeline



Validation of CAEBAT Tools



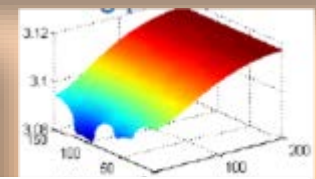
Completed for Cell and 24 cell Module



Completed with flexible & configurable module/pack



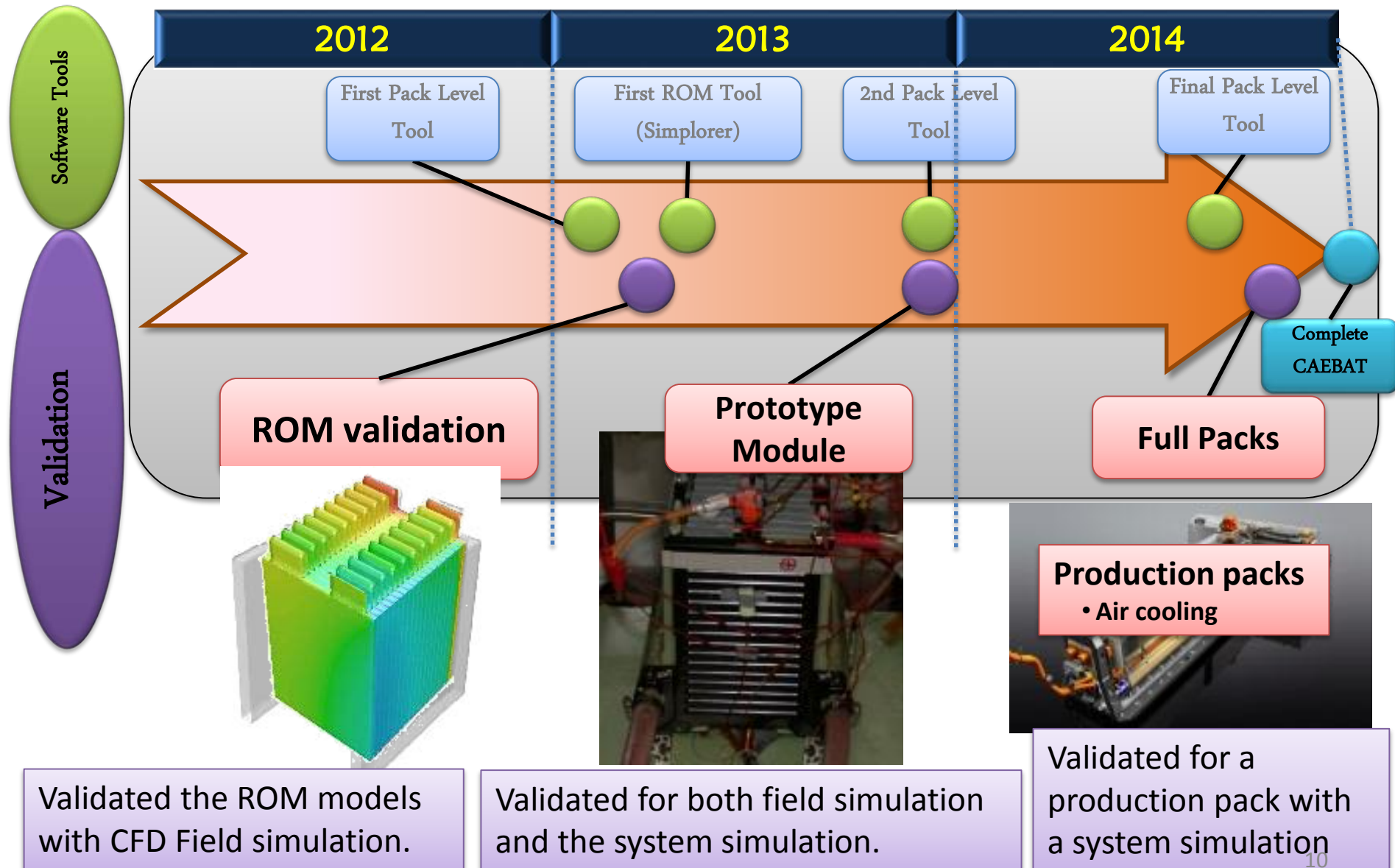
$$\begin{aligned}\dot{x} &= Ax + Bu \\ y &= Cx\end{aligned}$$



Completed with automation



Pack Level Validation Time Line

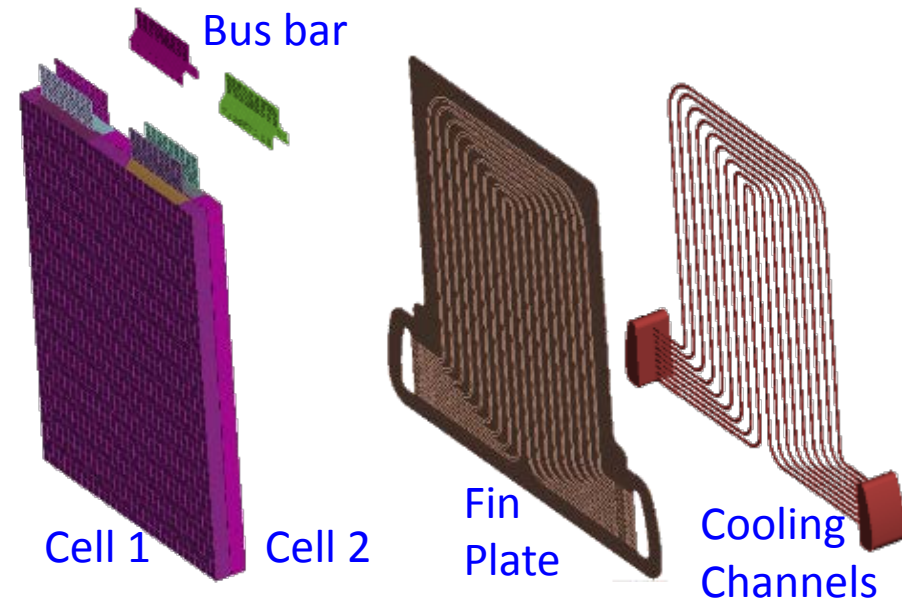
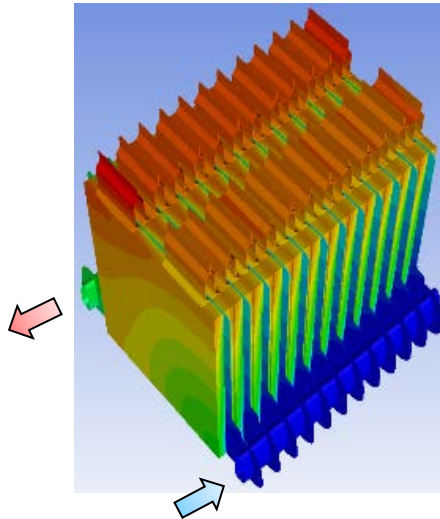


Validation of Full Field Simulation

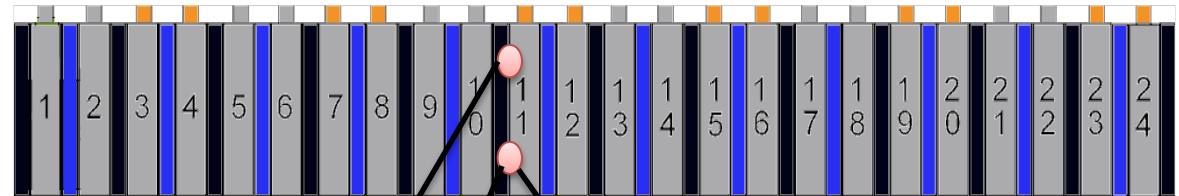
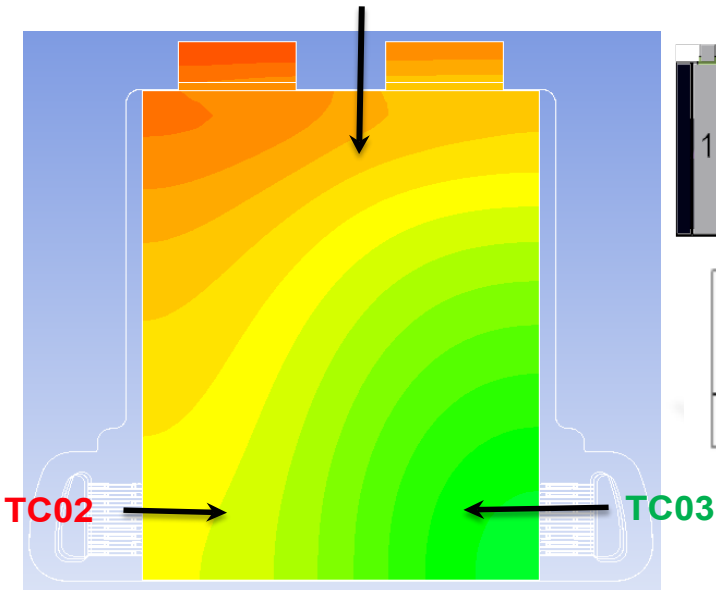
24 cell prototype



Temperature Profiles



TC01

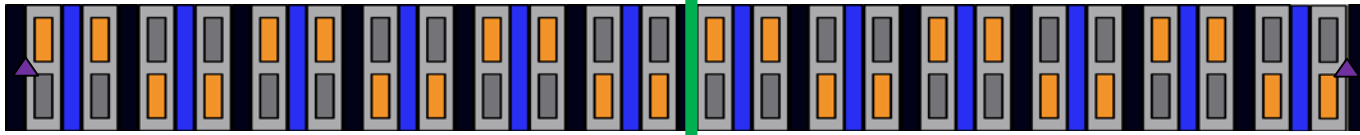


Simulation vs. Measurement @ 1800 s	TC01	TC02	TC03
$\Delta T, ^\circ\text{C}$	0.3	0.3	-0.1

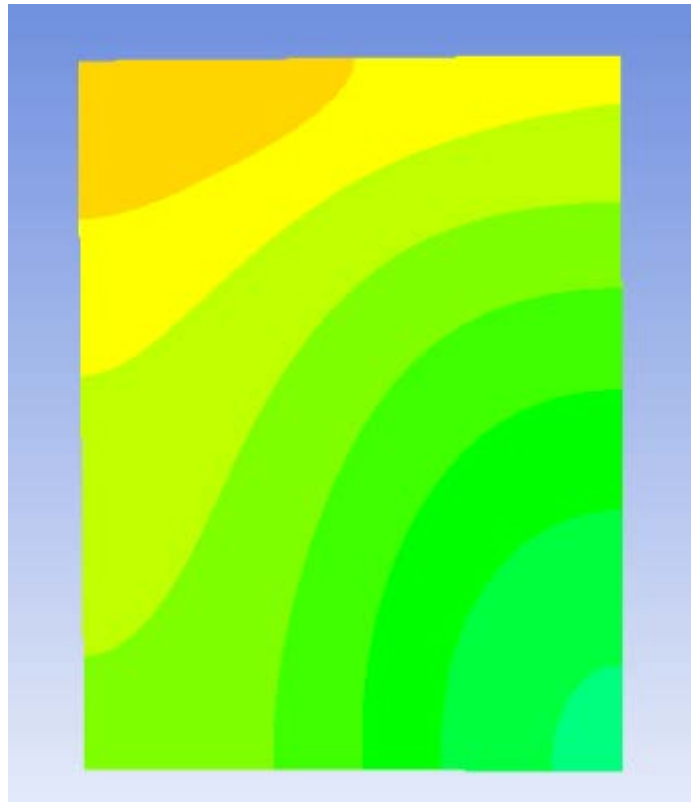
A 24 cell module validation test set up for full field simulation against test data for high-frequency pulse charge-discharge.

Validation for 24 Cell Module

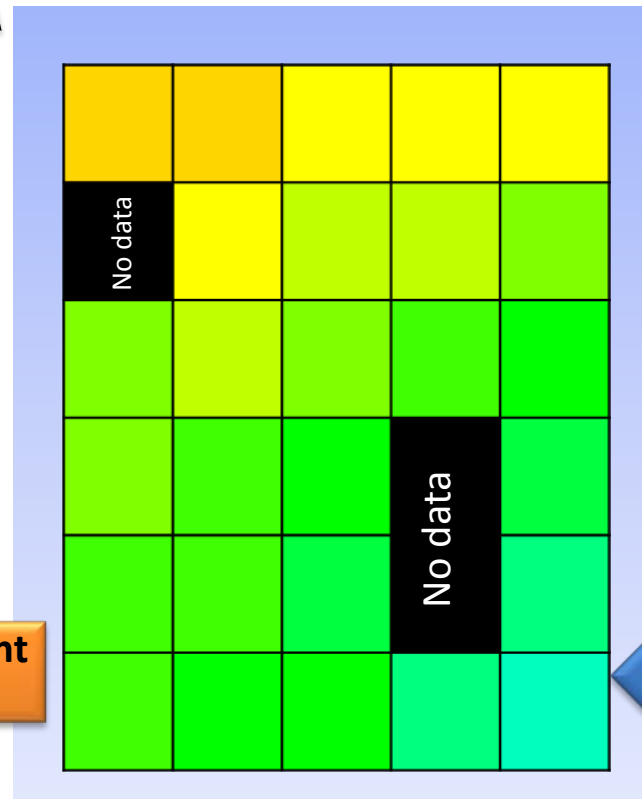
Top
View



Full Field Simulation
Prediction



Measurement



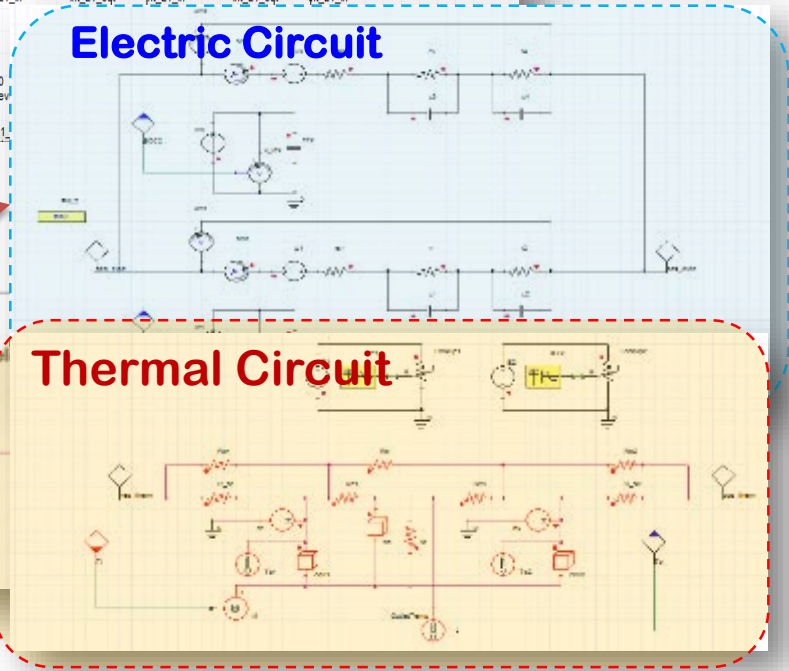
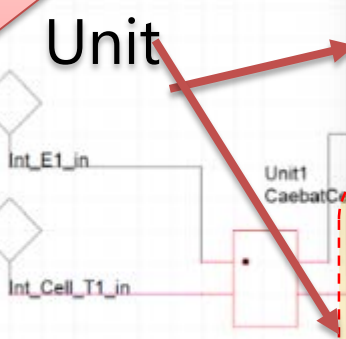
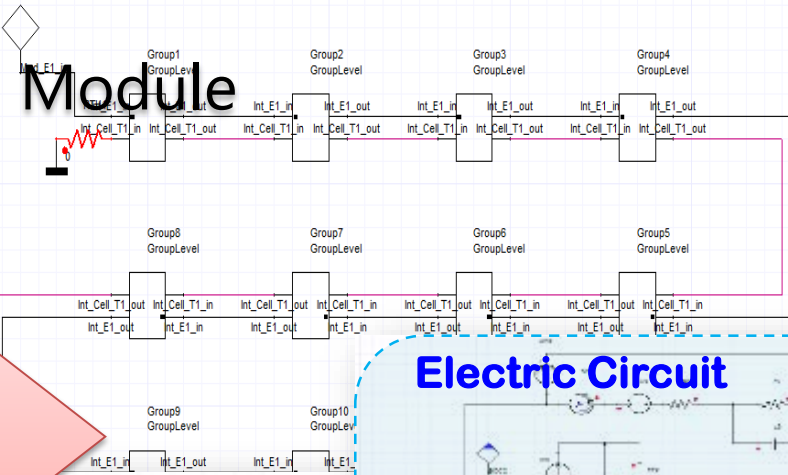
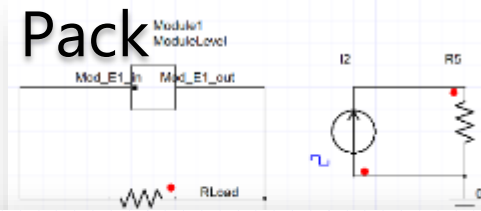
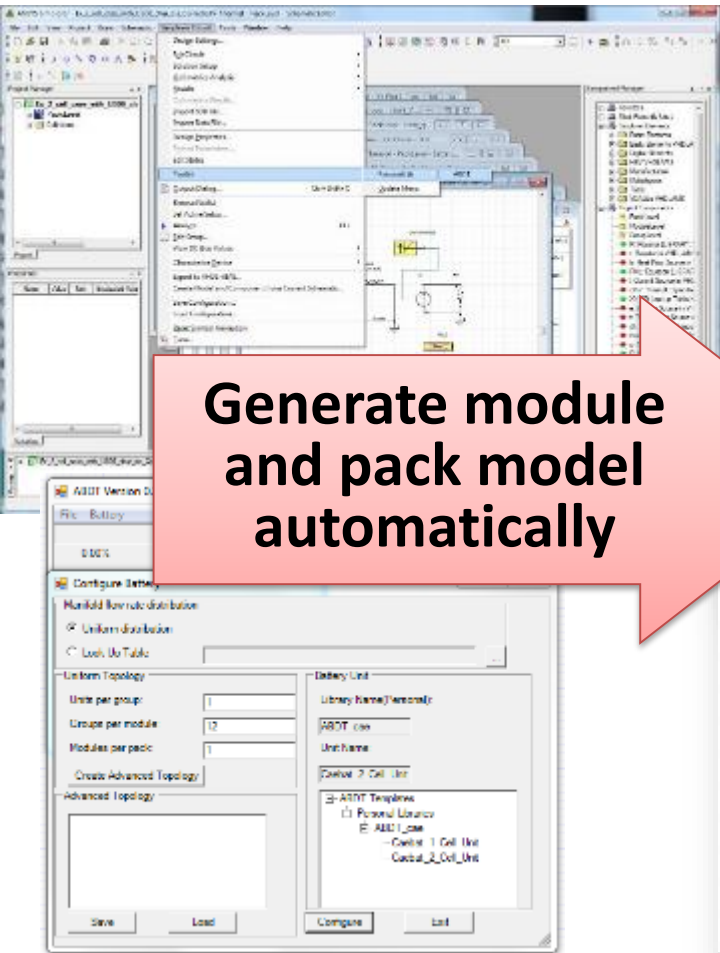
Coolant
out

Coolant
in

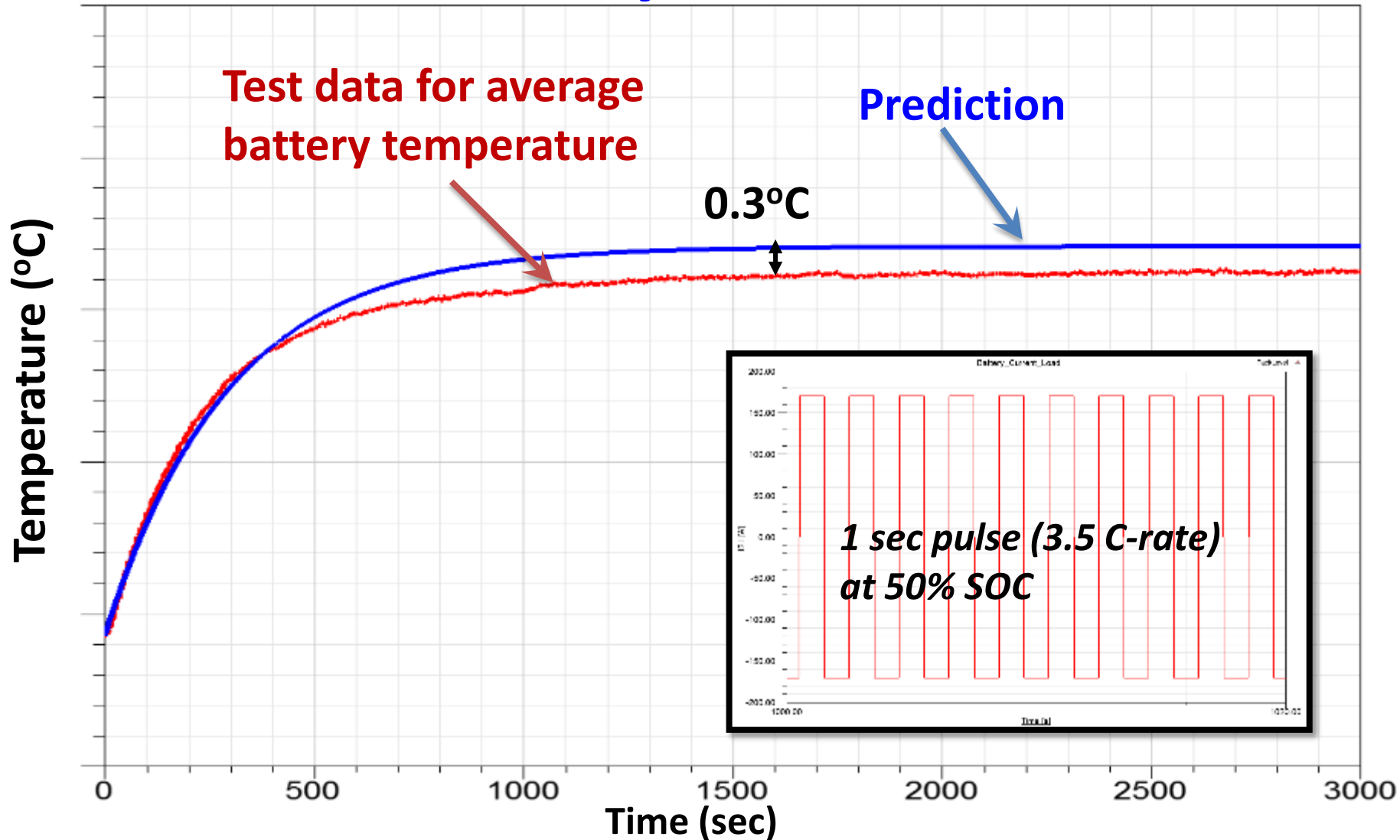
Maximum difference between the prediction and the measurement is within 1 °C.

System Simulation for 24 Cell Module

ABDT User Interface

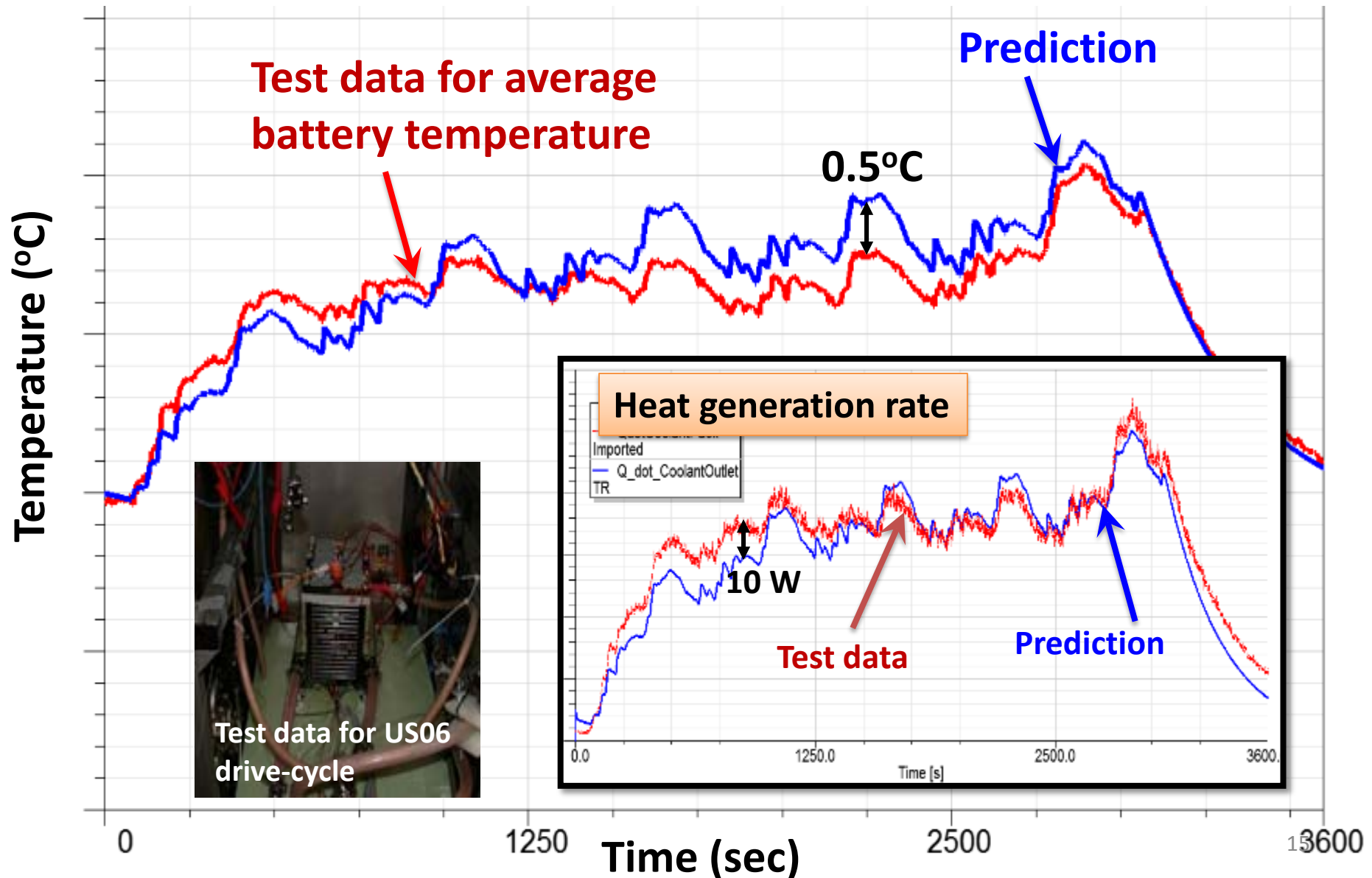


Validation of System Simulation



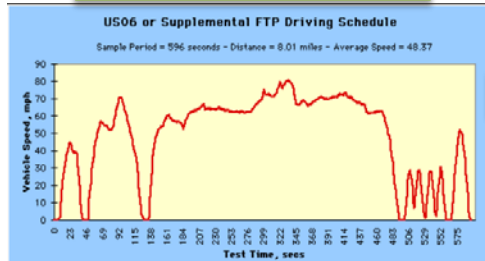
System simulation without ROM reproduced electric and thermal characteristics which are comparable to the test data

Validation of System Simulation for USO6 drive cycle

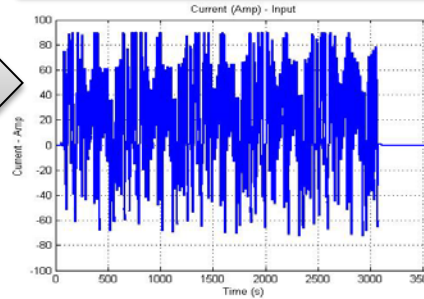


LTI ROM System-Modeling approach for Battery Thermal Simulation

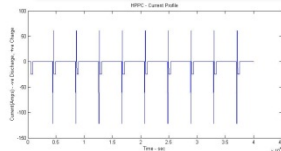
US06 drive cycle



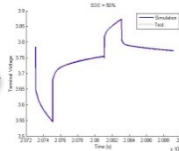
Current profile for US06



HPPC Data

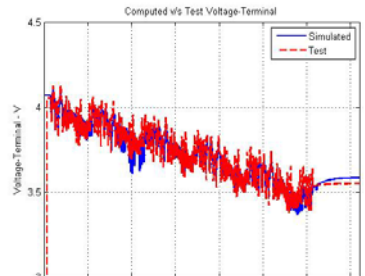


ECM Fitting

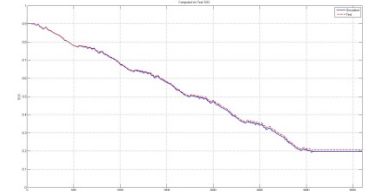


hybrid pulse power characterization

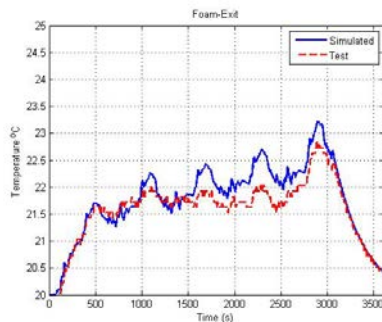
Battery Model



Terminal Voltage

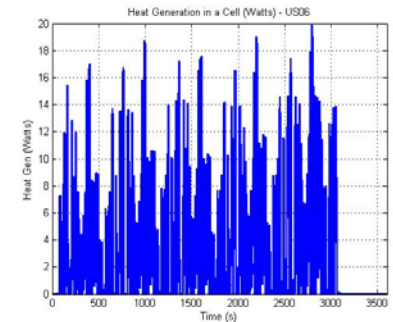


SOC



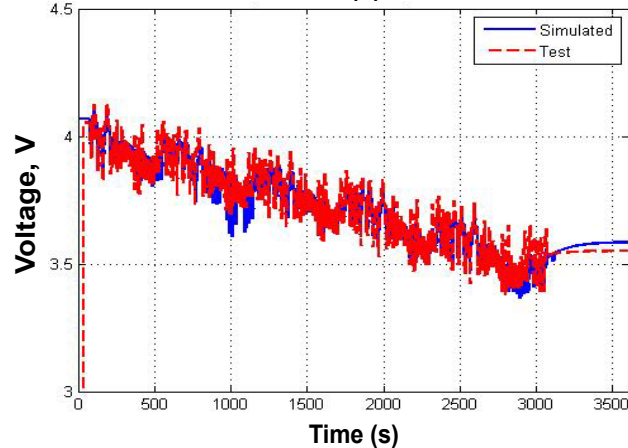
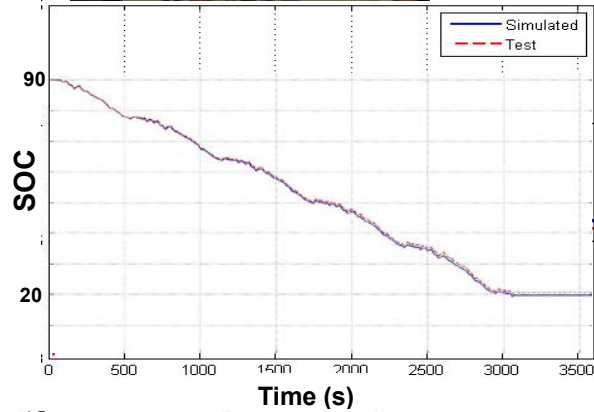
Cell Temperature

ROM Model

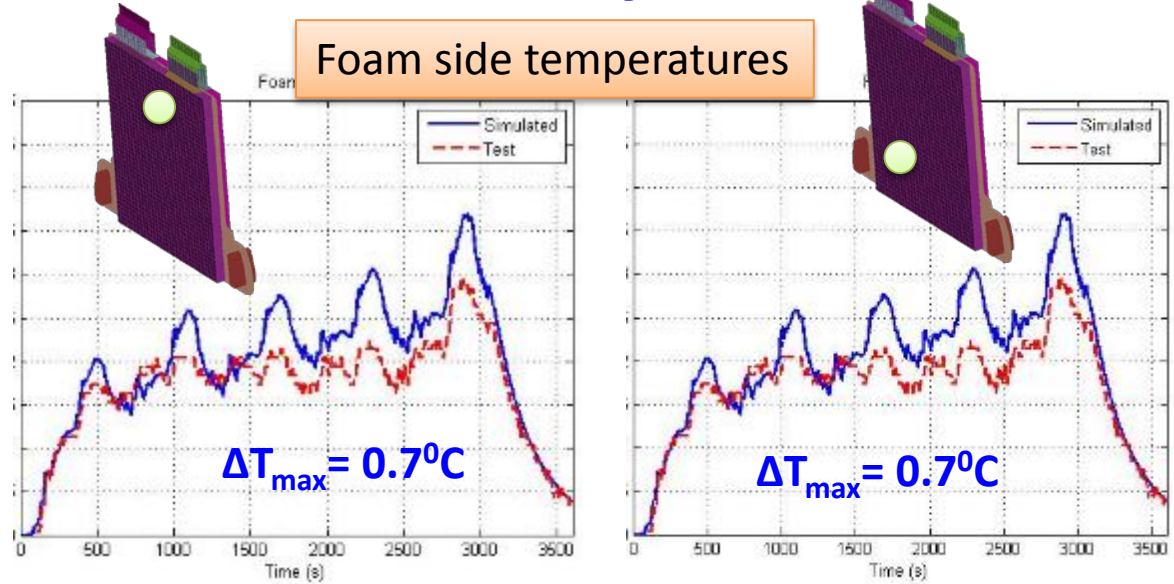


Heat Generation

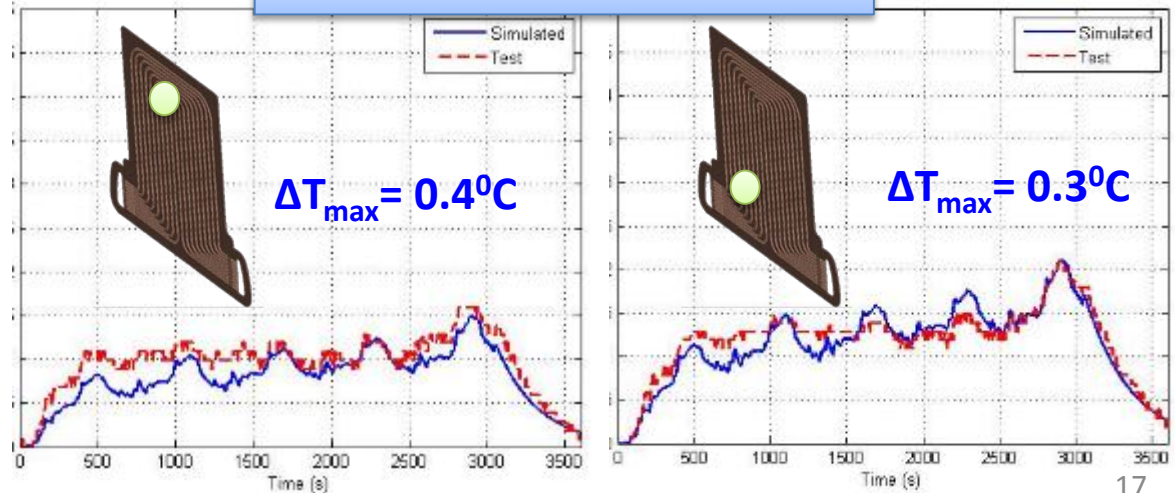
Comparison between the model and the test data for US06 Drive-Cycle



Foam side temperatures



Cooling fin side temperatures



Collaborations

GM (Project Lead)

- Provided requirements for cell and pack level designs.
- Performed cell level test for performance and cell cycle life.
- Performed math model verification and validation.
- Performed Pack level validation under various driving cycles.

ANSYS

- Implemented MSMD frame work for multi-physics models
- Integrated cell/pack level simulation capabilities.
- Process automation & OAS.

Esim

- ECM based cell aging model for capacity fade and cell life.

NREL (Tech Monitor)

- Provided MSMD frame work.
- Provided multiple particle/active material models.

ORNL

- Open Architecture Software.

Sustainable Software Tool (CAEBAT)

Support of DOE CAEBAT

The automotive industry requires CAE design tools that include the following capabilities.

•Modular:

—Integrate physics and chemistry in a computationally efficient manner.

•Provide Flexibilities:

—Provide a platform to enable various simulation strategies.

•Provide Expandable Framework:

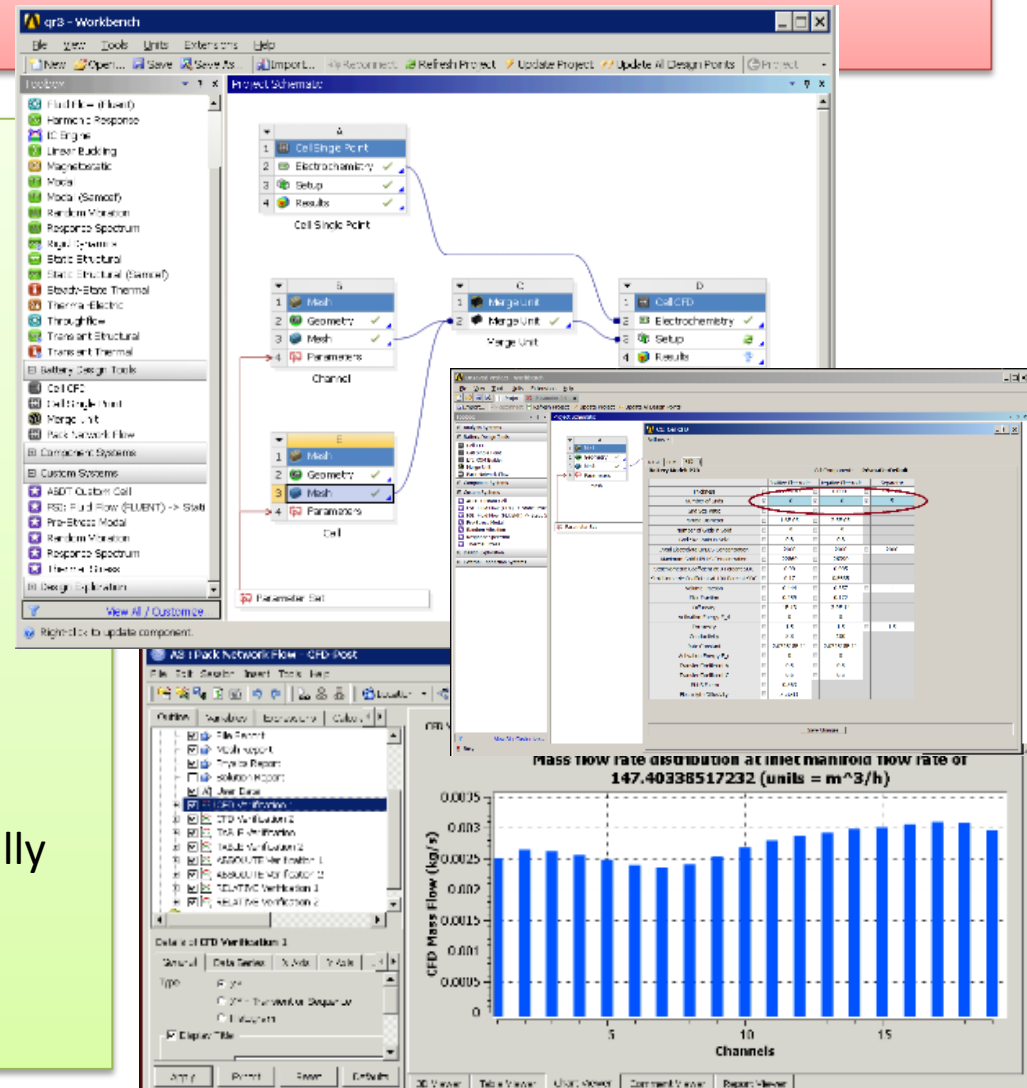
—Enable future users to easily add new physics of interest.

—OAS-compatible.

•Validated :

—Ensure model predictions agree with experimental data by performing carefully designed experiments.

•Easy to use



Summary

- ANSYS, ESIM, GM, and NREL have collaborated well to deliver all the tasks working as a single team.
- Technical monitor and guidance from NREL were very effective and valuable.
- First two years, FY 2012, 2013, we had weekly progress meetings with team members. FY 2014, we had bi-weekly meetings.
- GM team has provided 4 Quarterly reviews each year to NREL and DOE. Many technical presentations and Webcast seminars including reviews at USCAR. Three Annual Merit Reviews at DC.
- A final report was completed with technical details and validations (total 150 pages, March 11, 2015).