Stand Alone Battery Thermal Management System

2014 DOE Vehicle Technologies Program Review

Principal Investigator : Erik Huyghe
Project Manager: Brad Brodie
DENSO International America, Inc.

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Project ID: ES135

Overview

Timeline	Barriers
•Start: October 1, 2011 •End: September 30, 2014 •Percent Complete: 90%	• Barriers Addressed - Cost - Reliability - Life
Budget	**Partners**
•Total Budget - Government Share: $2,610,555 - Contractor Share: $693,924 •Government Funding Received: - FY11: $37,981 - FY12: $478,710 - FY13: $314,287 • Government Funding for FY14 - $1,021,311	• National Renewable Energy Laboratory Cell Testing, Simulation Support • Chrysler Group LLC System Targets, Concept Approval

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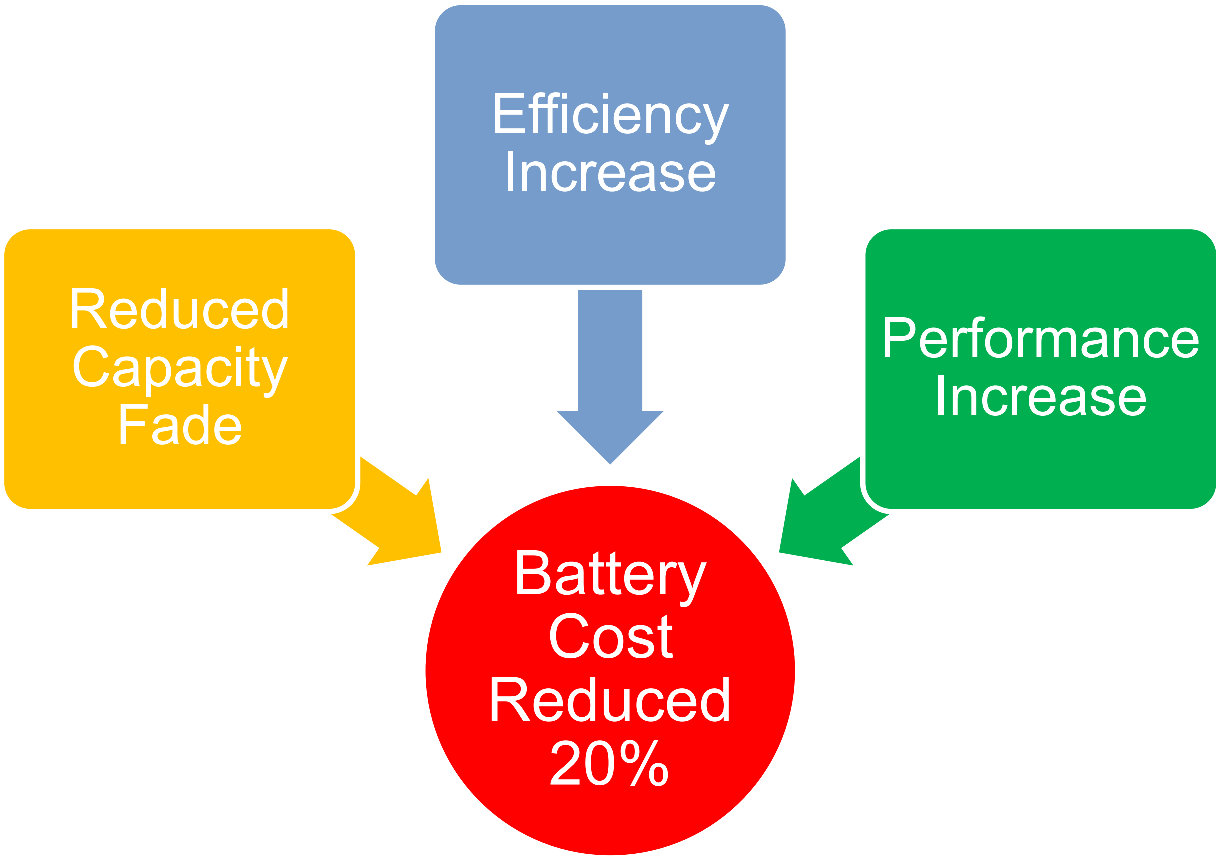
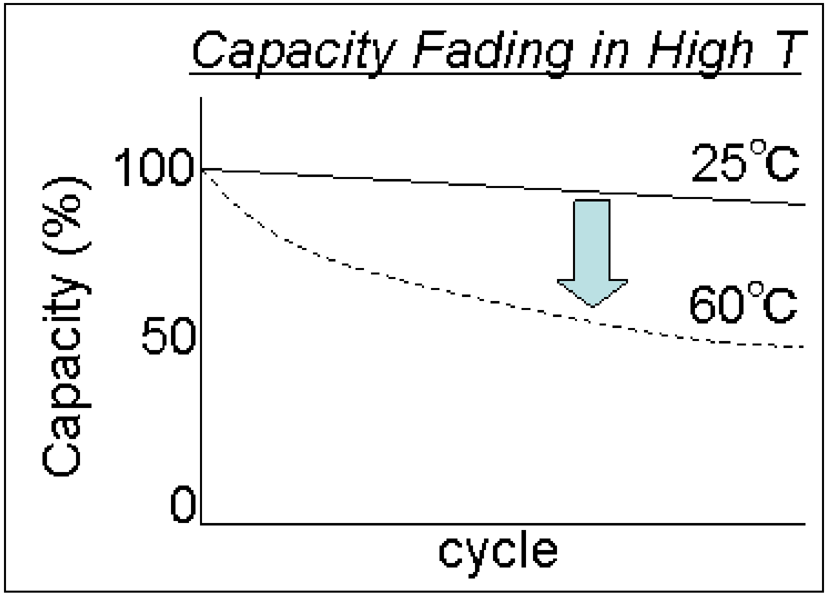
Relevance - Project Objective

Research, development, and demonstration of innovative thermal management concepts that reduce the cell or battery weight, complexity (component count), and/or cost by at least 20%.



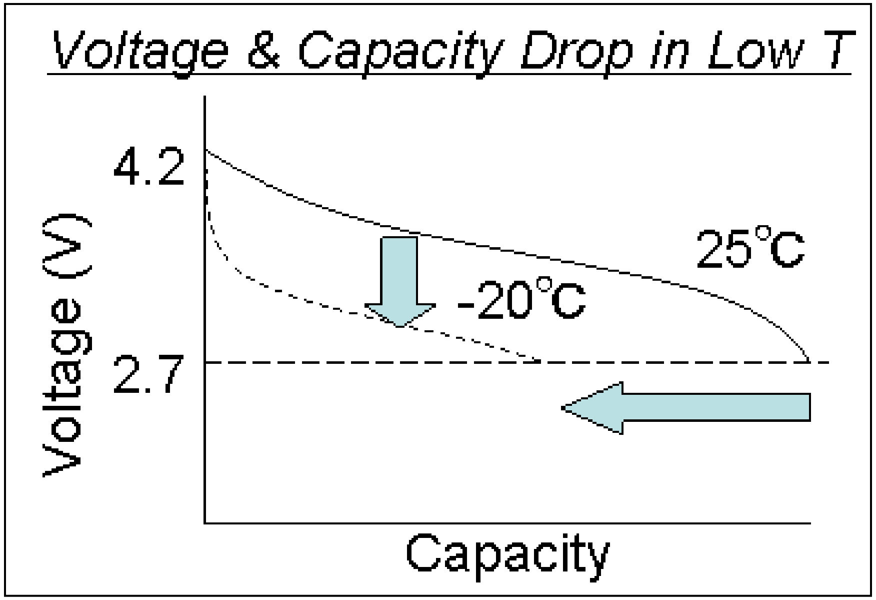
Relevance – Temperature Effect On Batteries

High Temperature Effect



The more time the battery is subjected to high temperatures, greater the capacity is reduced = reduced battery life.

Low Temperature Effect



Battery Voltage and Capacity is reduced at low temperatures = reduced driving range.

Thermal Management is Required to Enable a Reduction in Battery Size
(Prevent over-size of battery pack to overcome temperature effects)

Milestones (FY12 & FY13)

Target Completion Date	Milestone	Status
4/05/2012	Milestone 1: Testing Conditions for Simulation and Bench for Entire Project	Done
5/30/2012	Milestone 2: Thermal Characteristics of Battery Cells / Modules	Done
1/15/2013	Milestone 3, Budget Period 1 Judgment: Simulation Complete: Does it Match Vehicle Test Data? (Yes/No)	Done
04/11/2013	Milestone 4: Heat Pump System Simulation	Done
07/10/2013	Milestone 5: Gas Injection Heat Pump System Simulation	Done
10/04/2013	Milestone 6: PCM + Heat Pump System Simulation	Done
01/09/2014	Milestone 7: PTC + Vapor Compression System Simulation	Done
01/09/2014	Milestone 8, Budget Period 2 Judgment: System Design Complete: Can the Project Objective be Achieved? (Yes/No)	Done

FY14 Milestones are planned to be completed on time.

Approach – Project Strategy

Phase 1	• Study previous research and establish battery simulation model using software that can also simulate thermal systems.	10/2011→01/2013
Phase 2	• Simulation work to evaluate various thermal management concepts and study their effectiveness to enable the reduction of the battery size.	01/2013→01/2014
Phase 3	• Actual bench testing with the thermal management concepts identified in Phase 2. Validation by NREL.	01/2014→09/2014

The thermal system being developed is one that is dedicated to the battery pack which has <u>high efficiency</u> and <u>high reliability</u> for the thermal needs of the battery pack to enable the size reduction of the pack.

Approach – Phase 1 Review

Phase 1: October 2011 → January 2013

For Phase 1, the project created a battery simulation model in LMS AMESim software package.

- Simulate battery cells
- NREL helped characterize battery cell thermal characteristics
- NREL also helped in creation of the battery model
- Simulation model correlated to actual vehicle test data from Chrysler

Battery Simulation Model Was Successfully Created In Phase 1

Approach – Phase 2 Review

Phase 2: January 2013 → January 2014

For Phase 2, the project analyzed various thermal management concepts using LMS AMESim software. (Using the battery model created in Phase 1)

- This used DENSO's research into high efficiency vapor-compression cycles to be used for active battery thermal management.
- Passive thermal management technologies were also studied.
- NREL provided the battery life model and help with incorporating into the rest of the model.

Thermal system simulation models complete.

Approach – Phase 3 Overview

Phase 3: January 2014 → September 2014

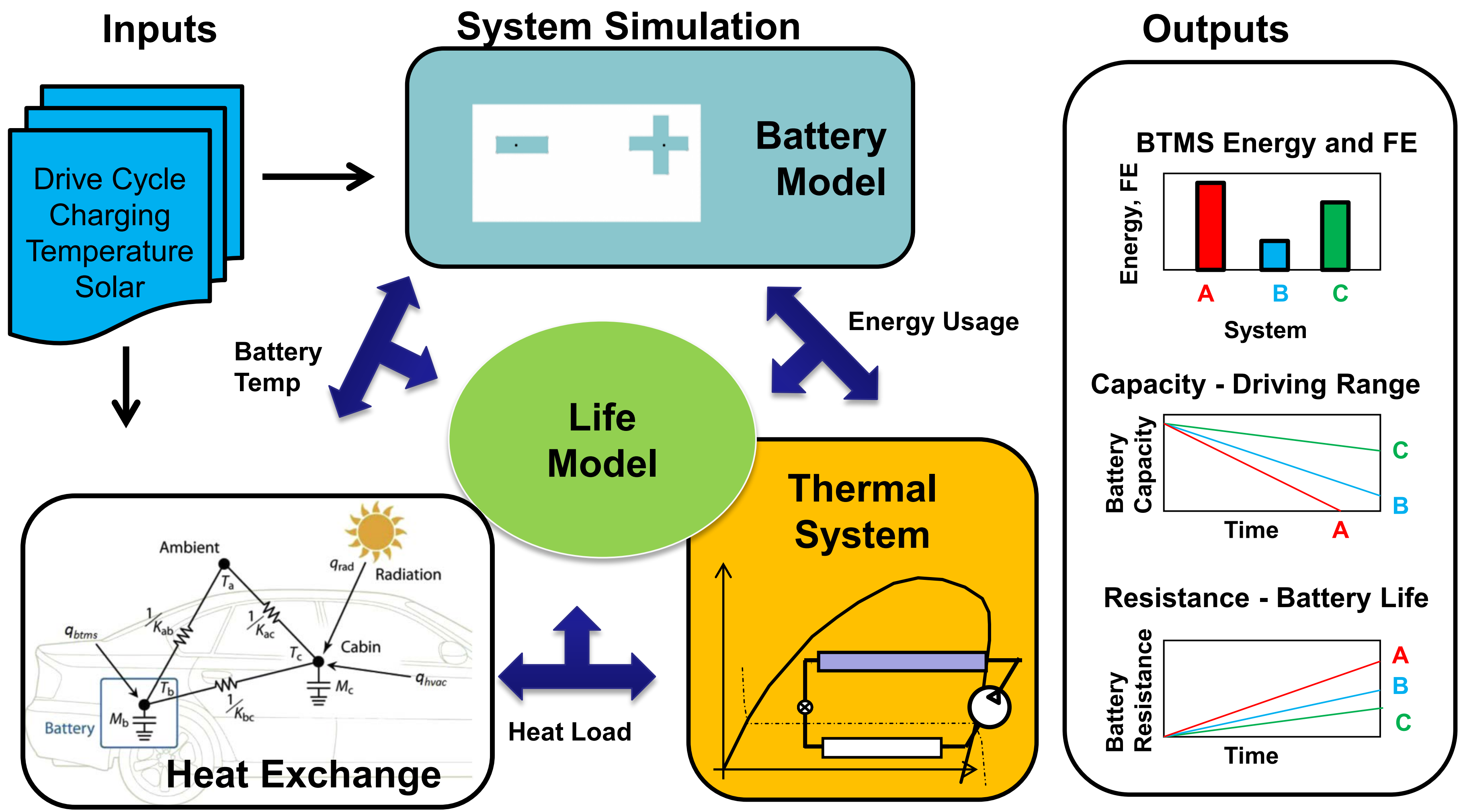
For Phase 3, the project will create prototype samples of the technologies identified in Phase 2, and do actual bench testing.

Bench testing will be done at DENSO in Southfield, MI in a new EV thermal system test bench.

Validation thermal testing of the system will be performed at NREL.

This testing will show with actual samples that the thermal and battery models are accurate. NREL will provide independent evaluation.

Approach - Battery Simulation Model



Model vehicle usage and ambient, battery heat generation and thermal system to determine battery life, fuel economy and energy effects of thermal system.

Technical Accomplishments: Milestones 4 → 8
Thermal Systems Studied

System under consideration:

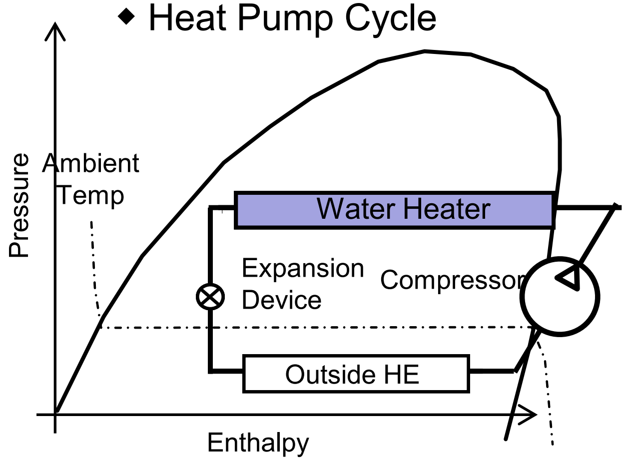
- Battery electric vehicle
- Liquid cooling / heating
- Pack mounted to floor

Study impact of each thermal system to battery and vehicle.

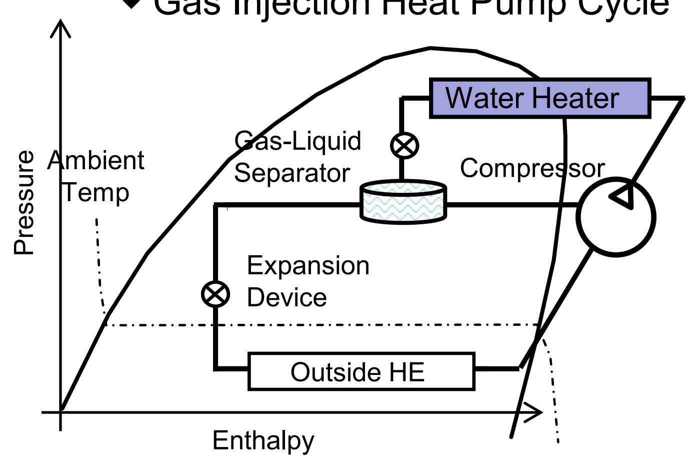
Cooling System	Heating System	Comment
Chiller	Water PTC	PTC has low COP
Chiller	HP	Improve COP
Chiller	GIHP	Improve low ambient temperature performance
Chiller + PCM	HP	Add passive heat adsorption

PTC = Positive Temperature Coefficient (resistance heater)
(GI) HP = vapor compression (Gas Injection) Heat Pump
PCM = Phase Change Material (latent heat of fusion)

- Heat Pump Cycle



- Gas Injection Heat Pump Cycle



Gas injection heat pump provides greater performance at cold ambient.

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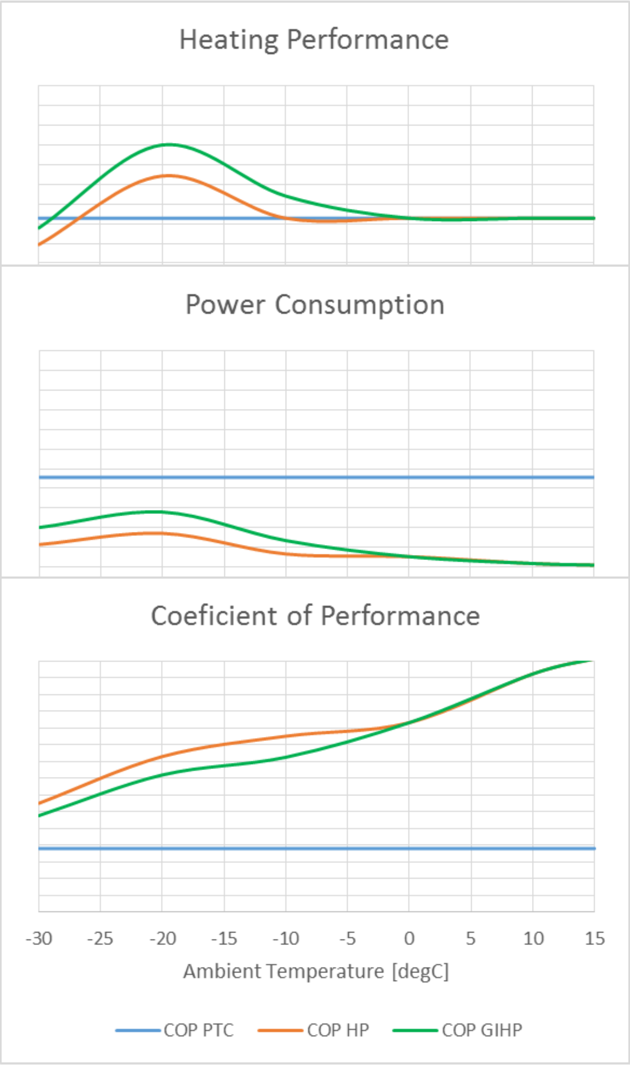
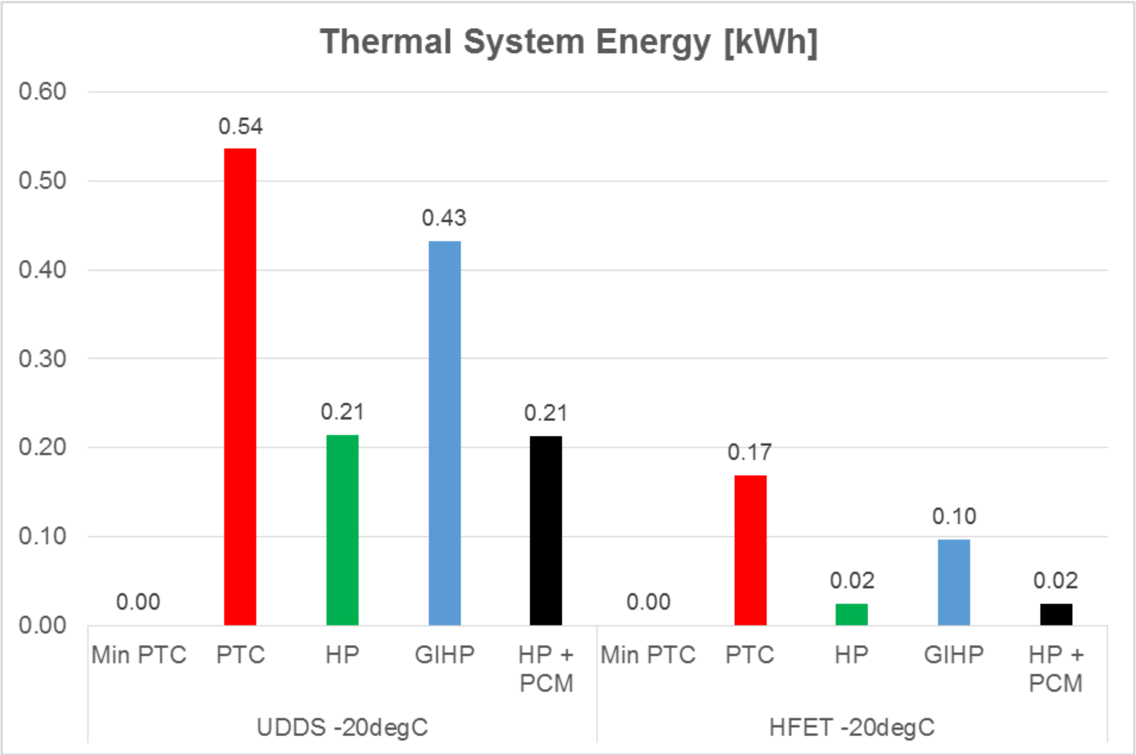
Technical Accomplishments: Milestones 4 → 8
Thermal Systems Performance





First cycle impact on fuel consumption vs. minimal heating by PTC.

HP saves energy versus PTC
GIHP has more performance, but is less efficient
PCM has no effect since it is chosen for cooling.

Heat pump system can reduce battery heating energy more than 50%

Technical Accomplishments: Milestones 4 → 8
Vehicle Usage Inputs to Model

5 Climates

Seattle
New York
Los Angeles
Minneapolis
Miami

✕

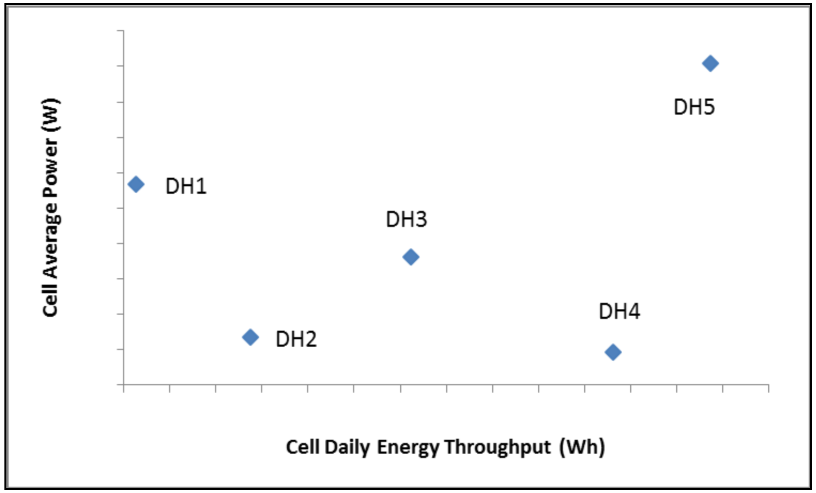
5 Drive Habits

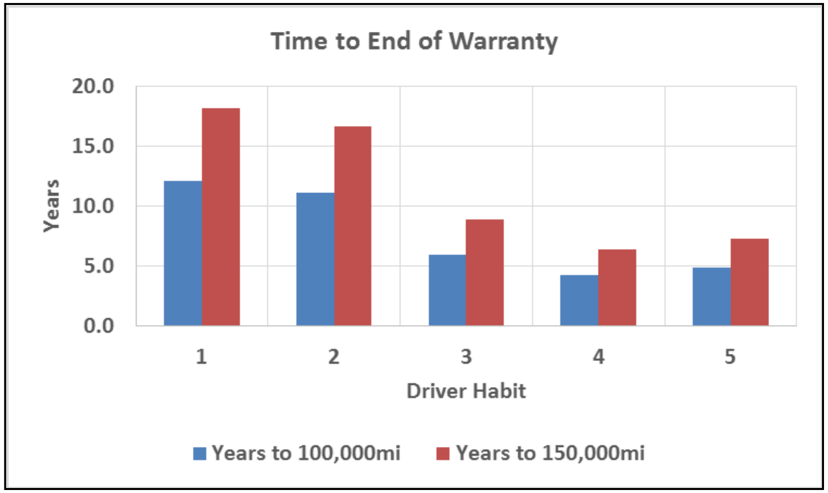
Combinations of:
HFET, US06, UDDS
Distance Driven
Idling time
Departure times

=

25 Total Scenarios

Cover wide spectrum of usage cases

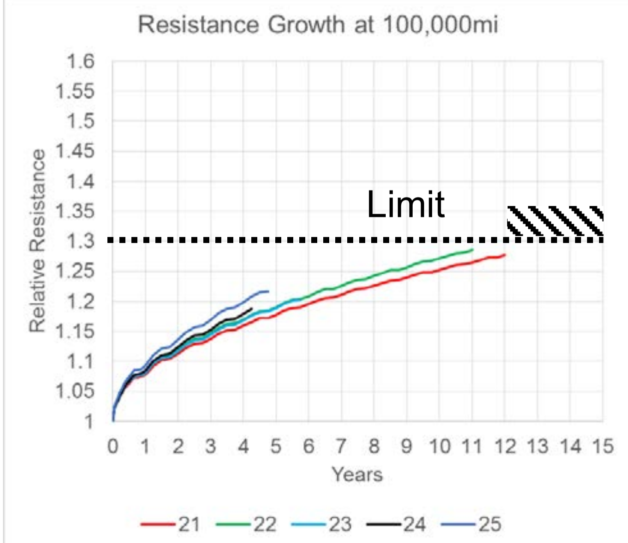


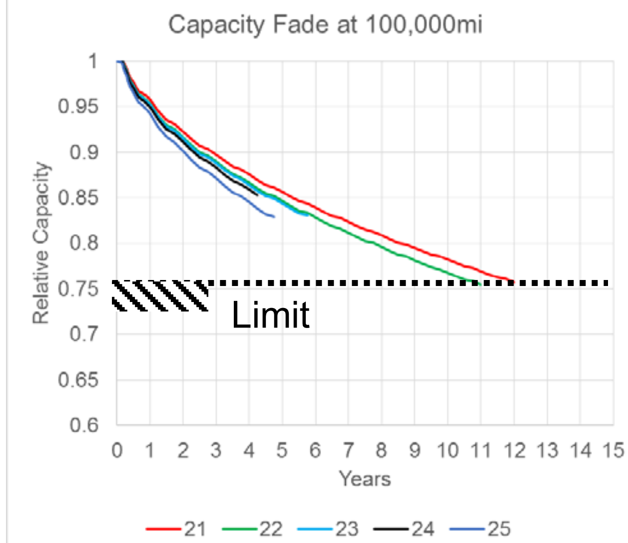


Hottest = Miami, aggressive city driving during hottest part of day
Coldest = Minneapolis, short driving during cooler parts of day

Examine various usage scenarios for life and energy savings

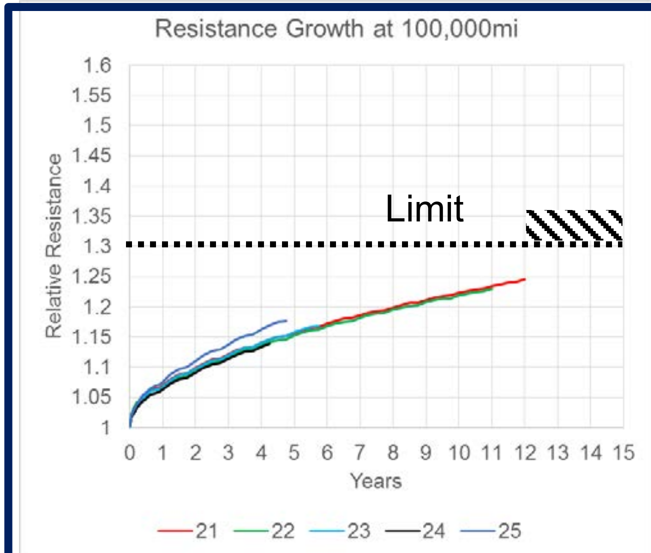
Technical Accomplishments: Milestones 4 → 8
Life Simulation Results

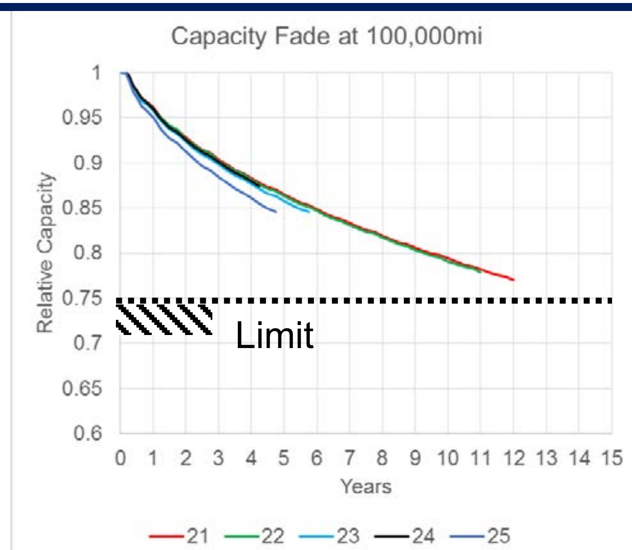




Battery life with minimal thermal management

Miami climate (scenarios 21-25) are harshest.





Battery life with more aggressive thermal management

Aggressive thermal management can improve life.

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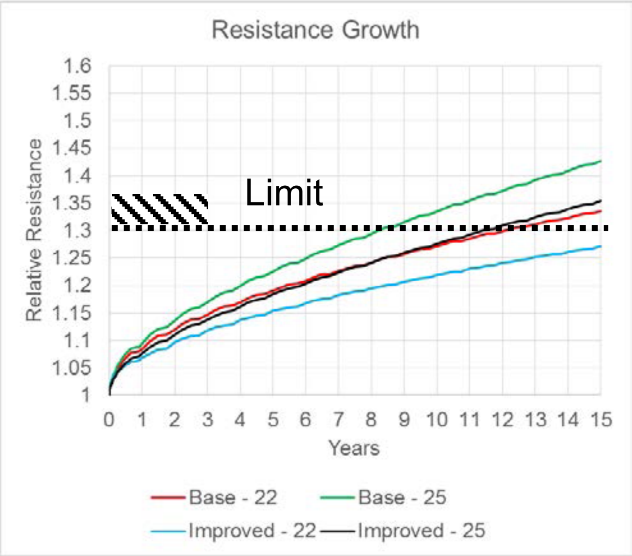
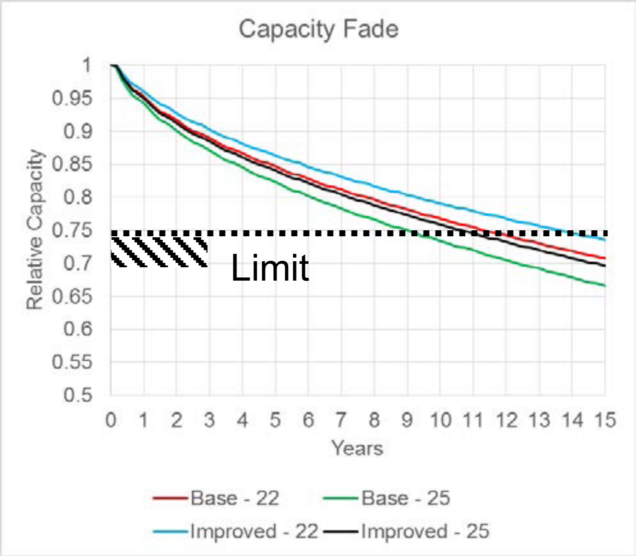
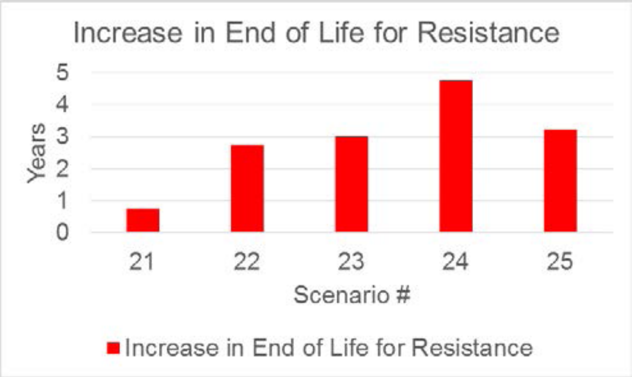
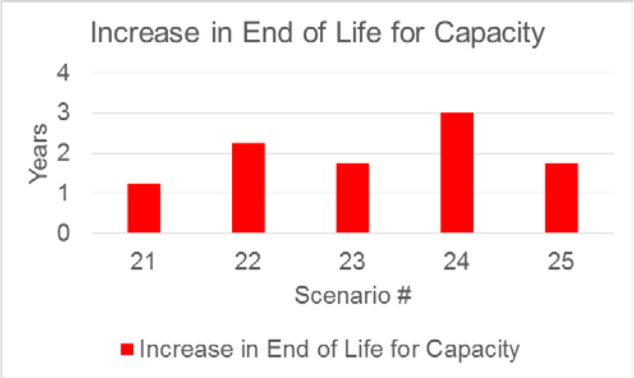
Technical Accomplishments: Milestones 4 → 8
Comparison of Minimal vs Aggressive Thermal Management



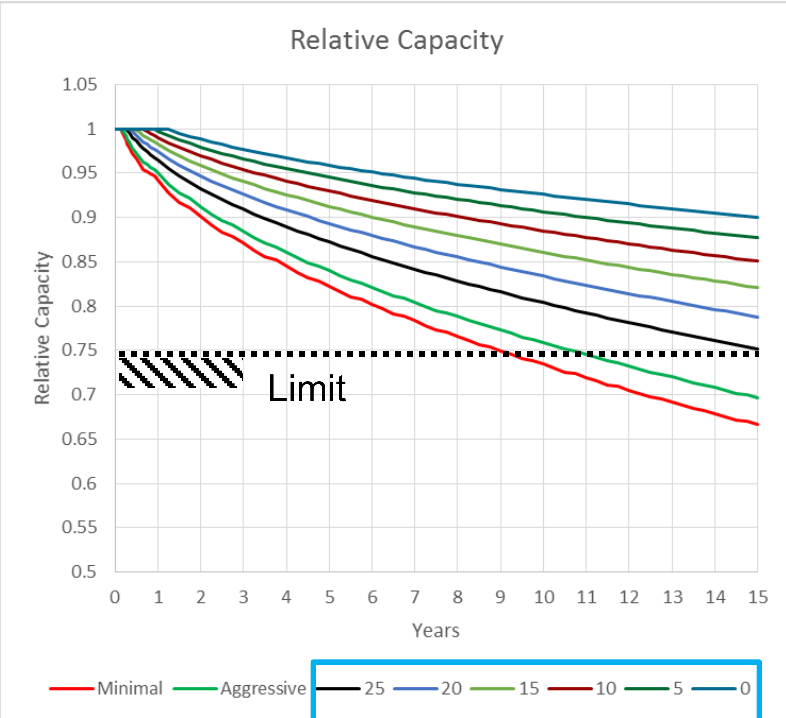


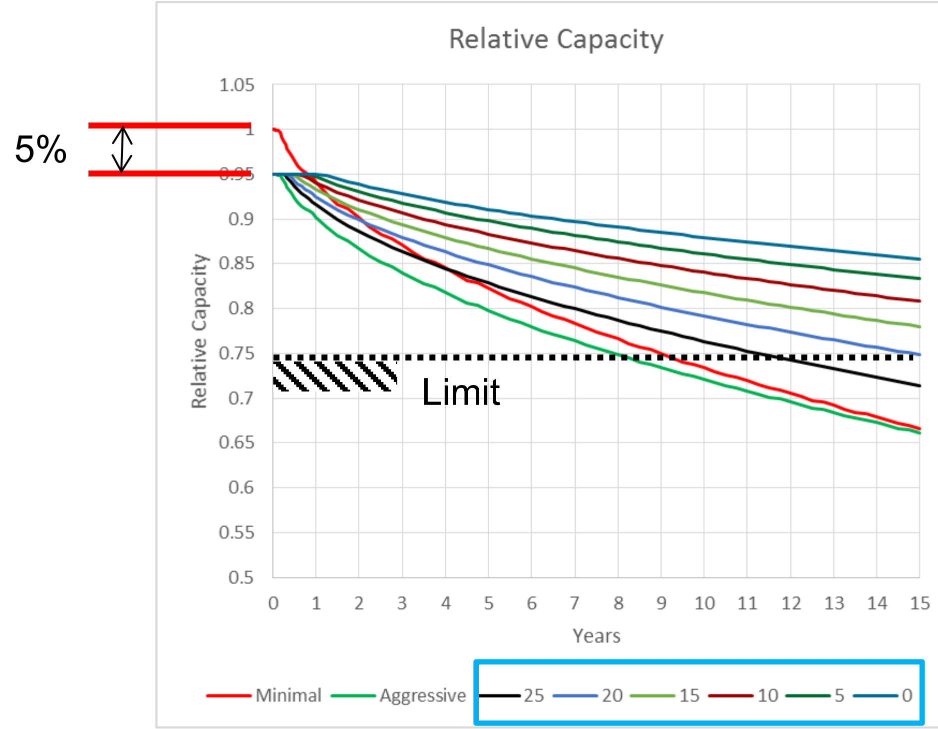




Aggressive thermal management can increase time to end of life.
End of life can increase by up to 3 years in the worst climate.

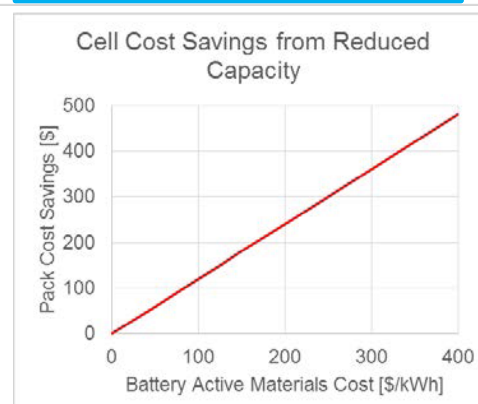
Technical Accomplishments: Milestones 4 → 8
Life Model Results





Assumed constant battery temperature throughout life.

Aggressive thermal management can enable reducing pack capacity. For an 8 year target, the battery active material can be reduced by 5%.



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Response to Previous Year Reviewer Comments

Comment 1: The reviewer stated that the authors have managed to simulate the drive profile current and voltage response. It will be of great interest to do something similar with different battery chemistries to understand the limitations of the computer program.

Comment 2: The reviewer felt that the authors may find that their model is not applicable for every cathode and anode chemistry. That should be clearly stated. The approach of comparing all results and choosing the one that meets the project objective appears reasonable and practical.

> Response to 1 and 2: The thermal and electrical models are fully configurable, so they are adaptable to other chemistries with appropriate input data. The main challenge is if a new life model must be developed for a new chemistry, since that requires large amounts of test data.

Comment 3: The reviewer stated that the accomplishments have been very good. In the future the project team should indicate with additional details which are the assumptions the team has to introduce in their model and how those assumptions may change based on the different cathode chemistries, for example.

> Response to 3: The assumptions are that the car is opportunity charged at level 2, the user takes the same trip each day and the car is parked in outside.

Collaborations

National Renewable Energy Laboratory :

- During FY12, NREL performed testing and provided data for battery cell characteristics which were used in the battery model. NREL also gave guidance for developing the model.
- During FY13, NREL provided the battery life model and help with incorporating it into the rest of the model.
- During FY14, NREL will conduct thermal testing of the new EV thermal system to validate and confirm DENSO's results.

Chrysler:

- During FY12, Chrysler provided target battery temperatures, drive cycle data and testing conditions. Also gave guidance for overall design choices.
- During FY13, Chrysler provided user drive profiles and cities of interest. They also provided information on design choices and priorities, which influenced the results. Chrysler provided a battery pack for testing in FY14.

Proposed Future Work

FY14

- Create prototype samples of the thermal system components identified in the simulation work during FY13.
- Perform bench testing in the EV thermal system test bench to demonstrate the effectiveness of the thermal system. Bench testing is planned to be done at DENSO and NREL for final validation.

Summary

- A simulation model was developed and used to evaluate the impact of various thermal system technologies on performance, energy consumption and battery life.
- Heat pump system used for battery heating was shown to have a large impact to thermal system energy consumption, improving vehicle fuel consumption in cold ambient.
- With aggressive thermal management, the battery capacity could be reduced by 5%.
- Increased battery life and reduced impact of cold temperatures on vehicle range can increase consumer confidence and satisfaction (alleviate range anxiety).