Predictive Battery Management for Commercial HEVs

ARPA-E AMPED DE-AR0000279

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NREL
National Renewable Energy Laboratory

Predictive Battery Management for Commercial Hybrid Electric Vehicles

Overview

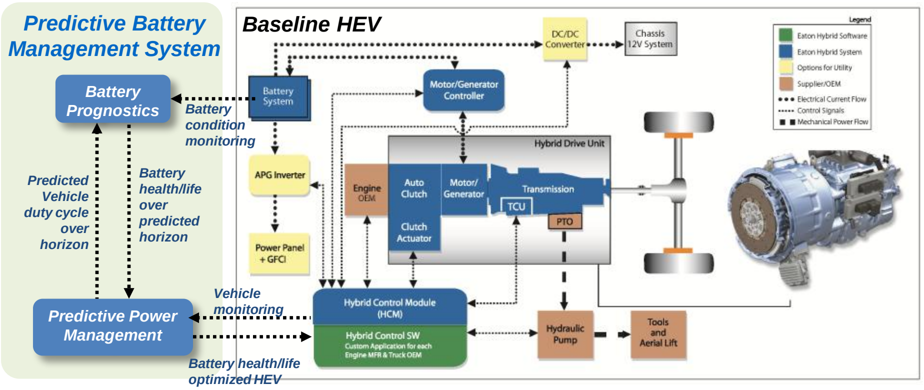
Partners: Eaton, National Renewable Energy Lab

Funding and Duration: $2.8M, 36 months

- ARPA-E: $2M, Eaton Cost Share: $0.8M

Technology

- Battery life prognostics based on electrochemical dynamics, capable of fast and accurate estimation of battery health and residual life
- Predictive Powertrain Controls with Intelligent Electric Power Management System, capable of vehicle duty cycle prediction and real-time co-optimization of fuel economy and battery life



Advantage and Differentiation

- Combines model-based battery prognostics with vehicle duty cycle prediction
- Integrates powertrain control with battery management
- Enables dynamic battery utilization to achieve required system performance from a significantly downsized battery pack with minimum impact on battery life:

1. **Lower cost and higher ROI for HEVs**
2. **Accurate residual battery life estimation for improved estimation of secondary market**

Performance Targets

Metric	State of the Art	Proposed
Battery pack cost, weight and capacity	Oversized by factor of 4	Battery downsizing by 50% while maintaining life and performance
Battery residual life prediction	Prediction uncertainty of nearly 30%	Electrochemical model capable of error of less than 10%

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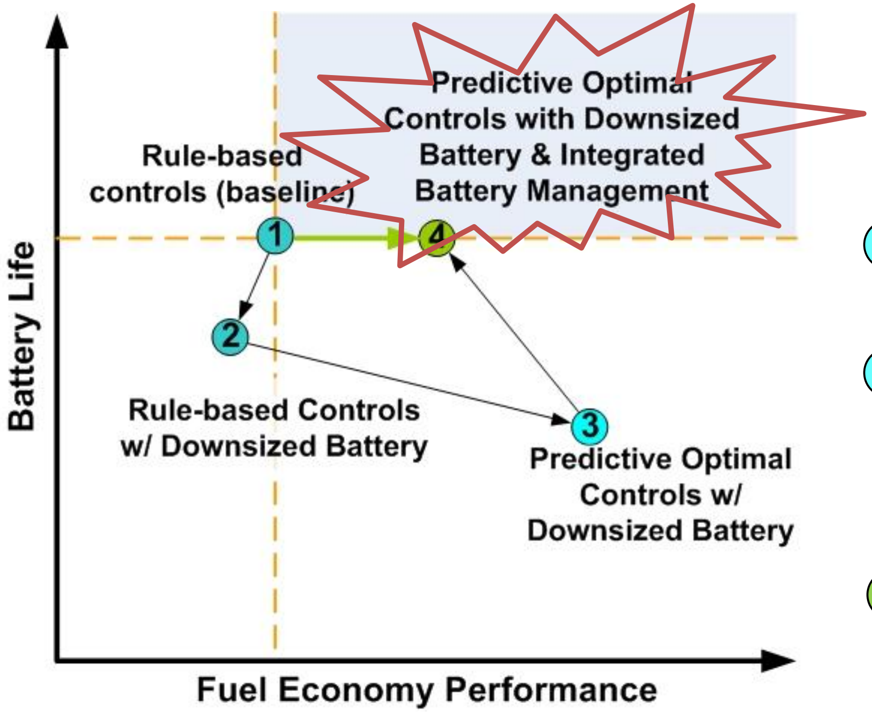
Opportunity and Challenges



1. Current HEVs design and control
   - Battery oversized due to “worse case” assumptions on environment conditions and battery usage
   - Powertrain controls forced to underutilize battery pack due to unknown battery aging and BMS limitations
2. Simply downsizing battery only will result in drop in FE performance & battery life
3. Existing study by Eaton also shows FE performance improvement even with downsized battery in one use case but with reduced battery life.
4. Proposed solution maintains baseline battery life while maintaining or improving FE performance with downsized battery.

Risks to be retired through the project

- Degrees of freedom available for predictive optimal controls (charge rate, depth of discharge) may not be able to sufficiently overcome the diminished battery life loss once the battery is downsized
- In-lab, cell-level battery prognostics performance from NREL might not be applicable to real-world duty cycles and battery packs

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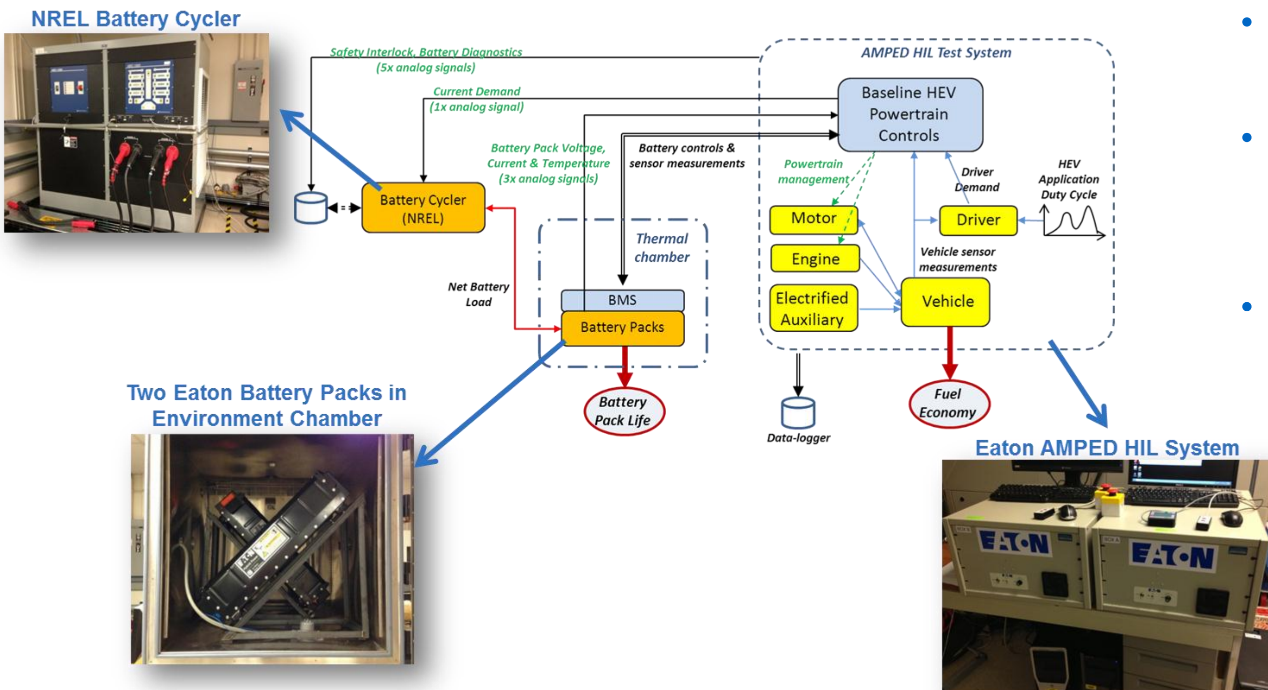
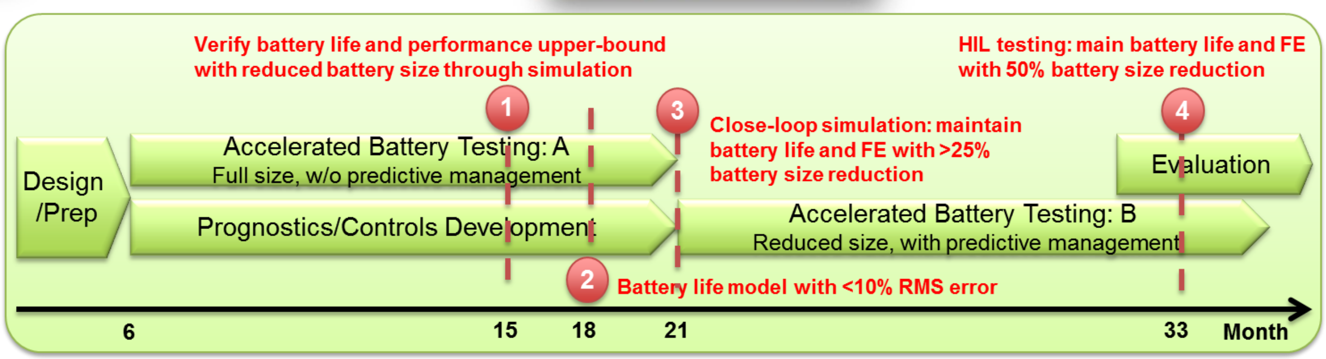
Validation Plan

- Pack-level, accelerated testing with real-world duty cycles
- A and B test (with and w/o predictive management) for evaluation

AMPED HIL Test System



- Data-driven battery life modeling and validation via accelerated testing
- Simulated battery load cycle based on real-world vehicle duty cycles and validated vehicle model
- Close-loop controls simulation with real-time battery health/status



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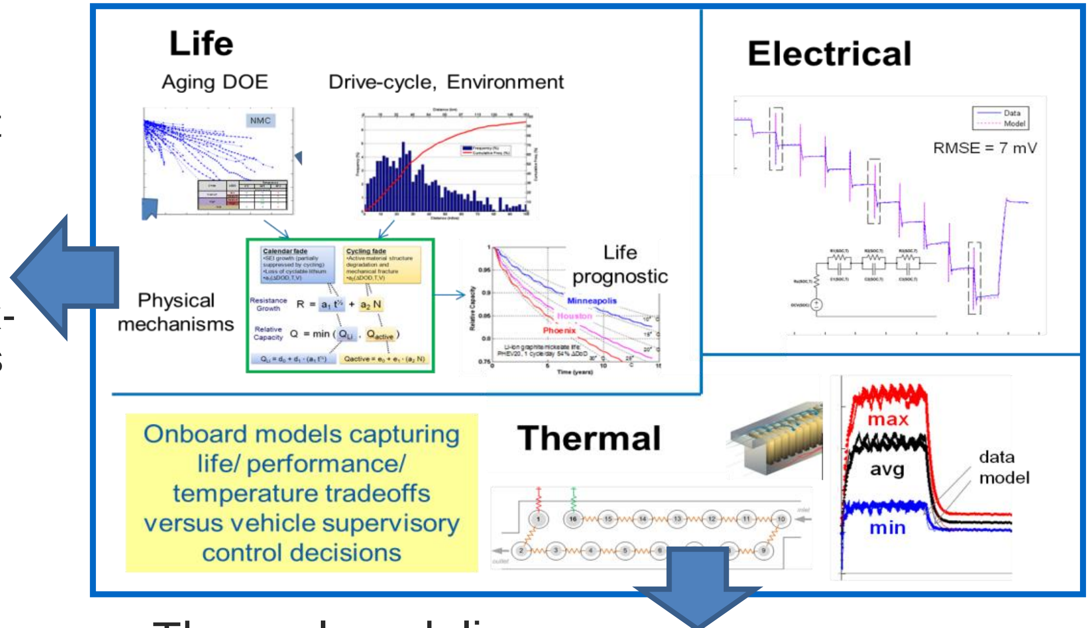
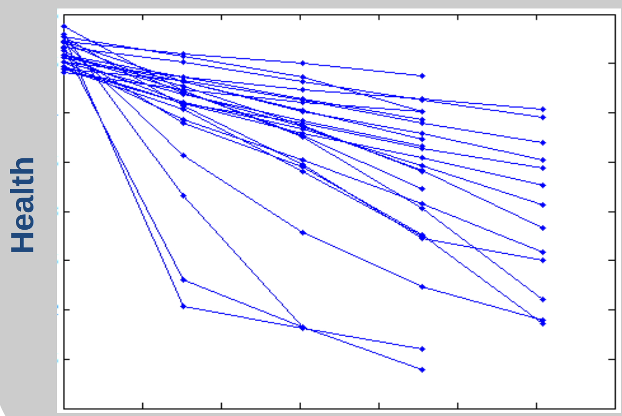
Year 1 Progress: Battery Modeling

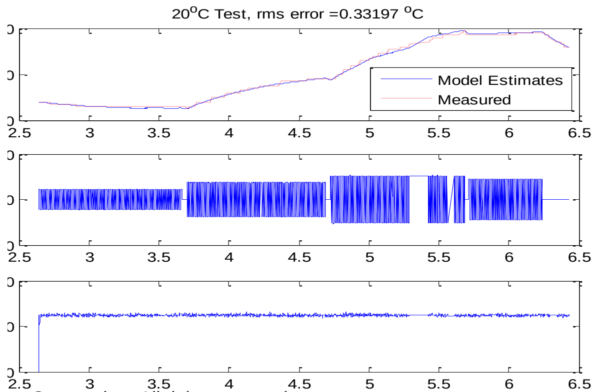
- Life Modeling
  - Physics-based mechanisms for correct separation & coupling of calendar- vs cyclic-driven fade
  - Initial model ID using cell aging tests
  - To be refined and validated using pack-level testing with real-world duty cycles and various temperature conditions

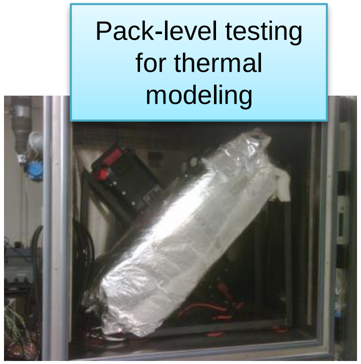


AMPED Project Cell Aging Test Campaign

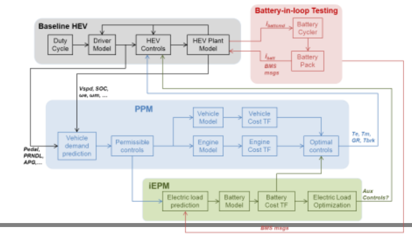


- Thermal modeling
  - Captures both pack average and worst cell behavior





Year 1 Progress: Controls



Challenges

- Slow battery life feedback vs. fast vehicle & fuel consumption dynamics
- Multiple control objectives with different time scale
- Various hard constraints on battery operation

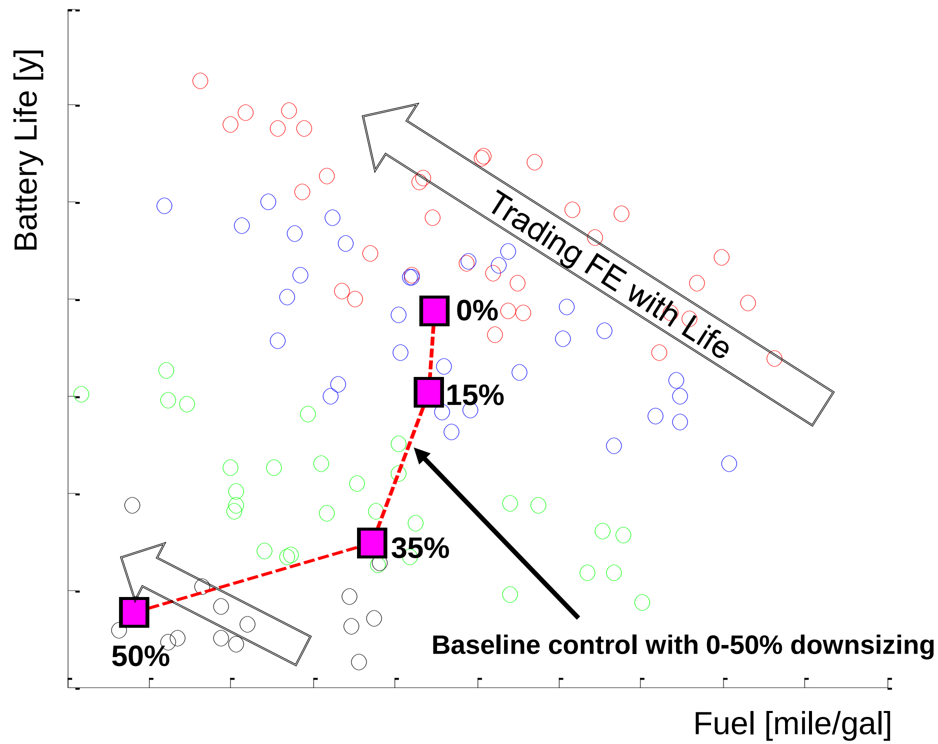
Solution

- A battery utilization cost function integrated into a predictive powertrain control strategy which dynamically adjusting the “cost” of battery usage

Year 1 progress to date

- Verify PPM’s potential through simulation

Simulation results for downsizing using various PPM strategies
0%:Red 15%:Blue 35%:Green 50%:Black



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