NREL National Renewable Energy Laboratory
Innovation for Our Energy Future

Motor Thermal Management

U.S. Department of Energy
Annual Merit Review

P.I. Kevin Bennion

poster presented by
Kevin Bennion
National Renewable Energy Laboratory

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APE030

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Overview

Timeline

- Project Start: FY 2010 (New Project)
- Project End: FY 2013
- Percent Complete: 5%

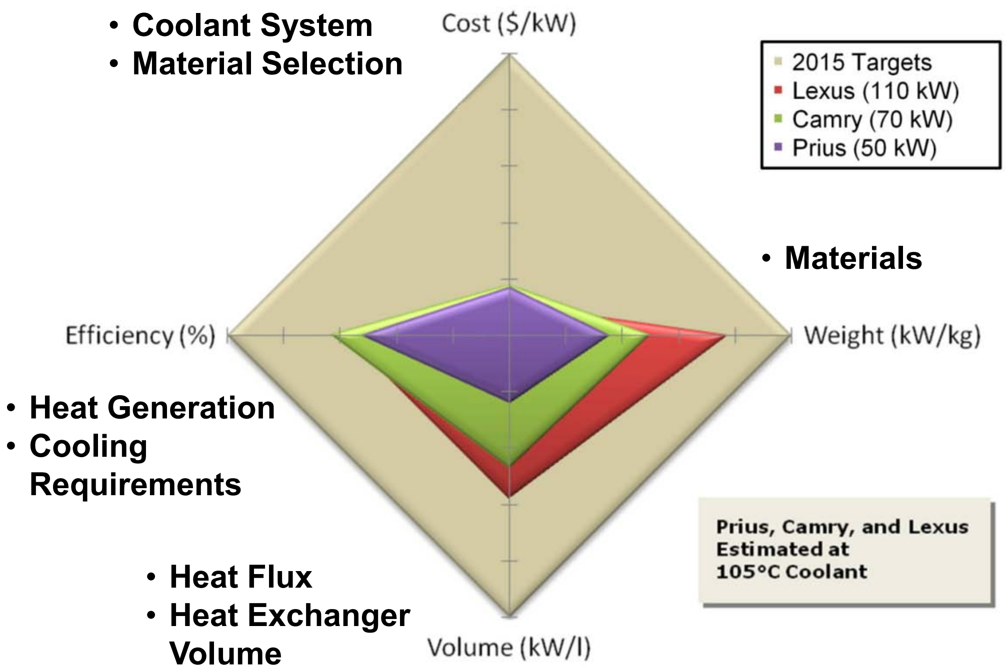
Barriers

- Cost & Performance
- Weight & Volume
- Life & Thermal Management

Budget

- Total Funding (FY10-FY13)
  - DOE: $400K
  - Contract: $0K
- Annual Funding
  - FY10: $400K

Targets



Partners/Collaboration

- Electrical and Electronics Technical Team (EETT)
- USCAR Partners
- University of Wisconsin - Madison
- Oak Ridge National Laboratory

Objectives: Relevance (1/4)

The transition to more electrically dominate propulsion systems increases the importance of thermal control for electric machines (EMs).

Problem: Heat

Over sizing the EM is one solution to improve performance of EMs within the thermal constraints [1].

Goal: Lower cost, volume, and weight

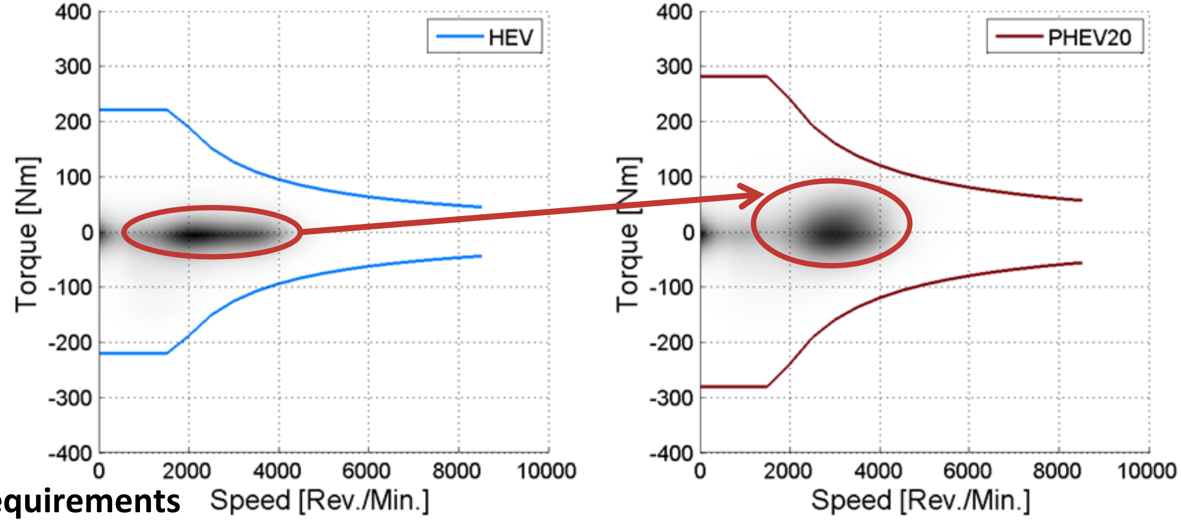
Thermal management is needed to **reduce size** and improve electric machine performance [1].

[1] Source: C. Liao, C. Chen, and T. Katcher, "Thermal Analysis for Design of High Performance Motors," ITHERM, May, 1998

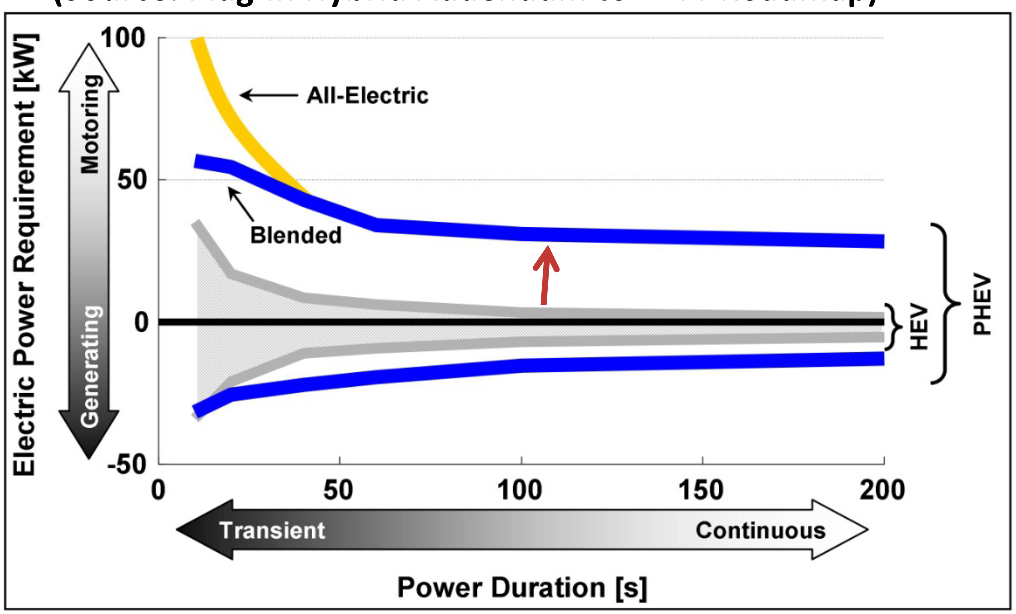
Objectives: Relevance (2/4)

Significant increase in continuous power requirements with transition from HEV to PHEV.

Cumulative operating time of 227 in-use drive cycles.



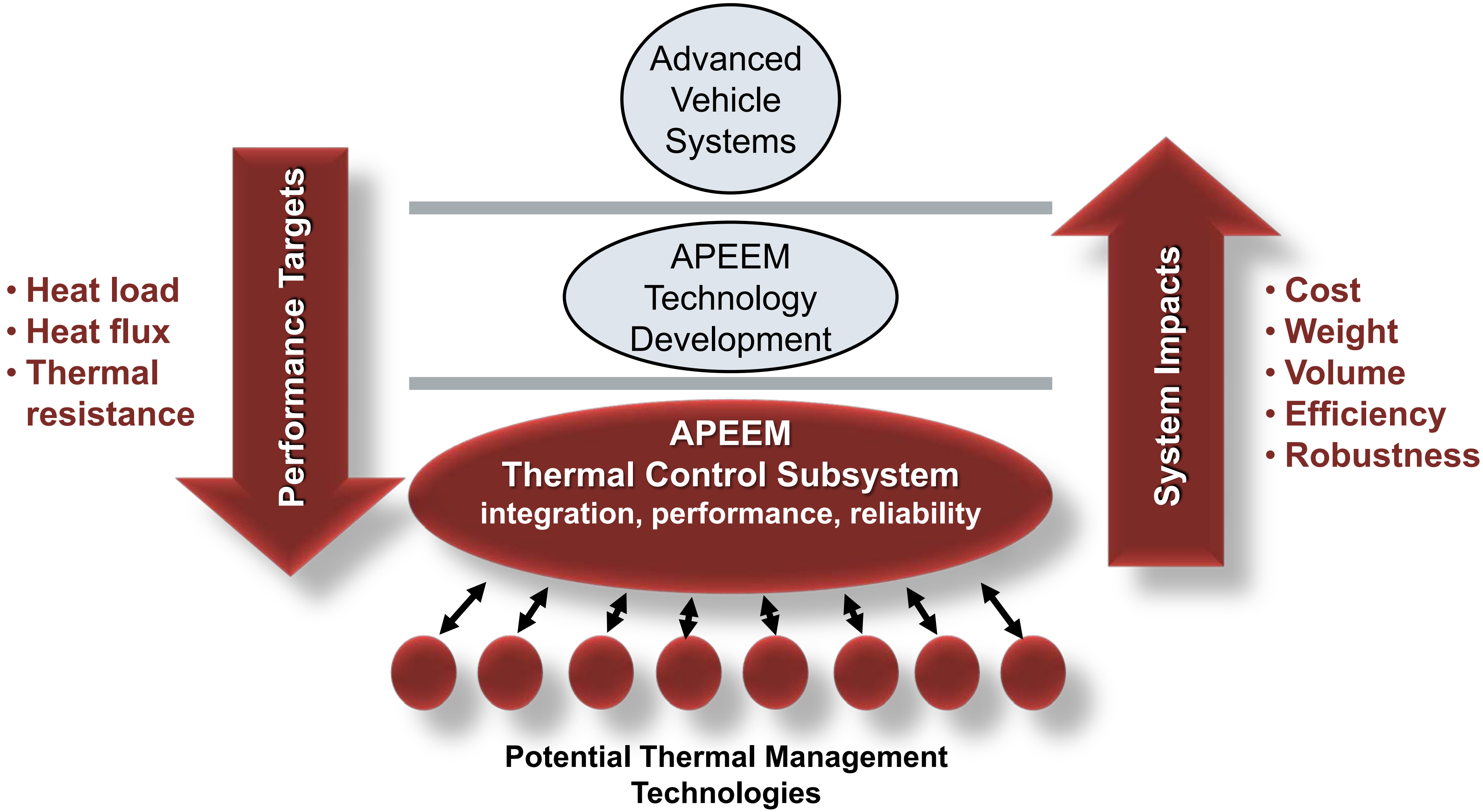
Midsize parallel hybrid electric power requirements (Source: Plug-In Hybrid Addendum to EETT Roadmap)



- Results based on Vehicle Systems Analysis activity simulated vehicle data and in-use drive cycles.
  - Parallel hybrid electric configuration.
  - Blended PHEV energy management strategy.

Objectives: Relevance (3/4)

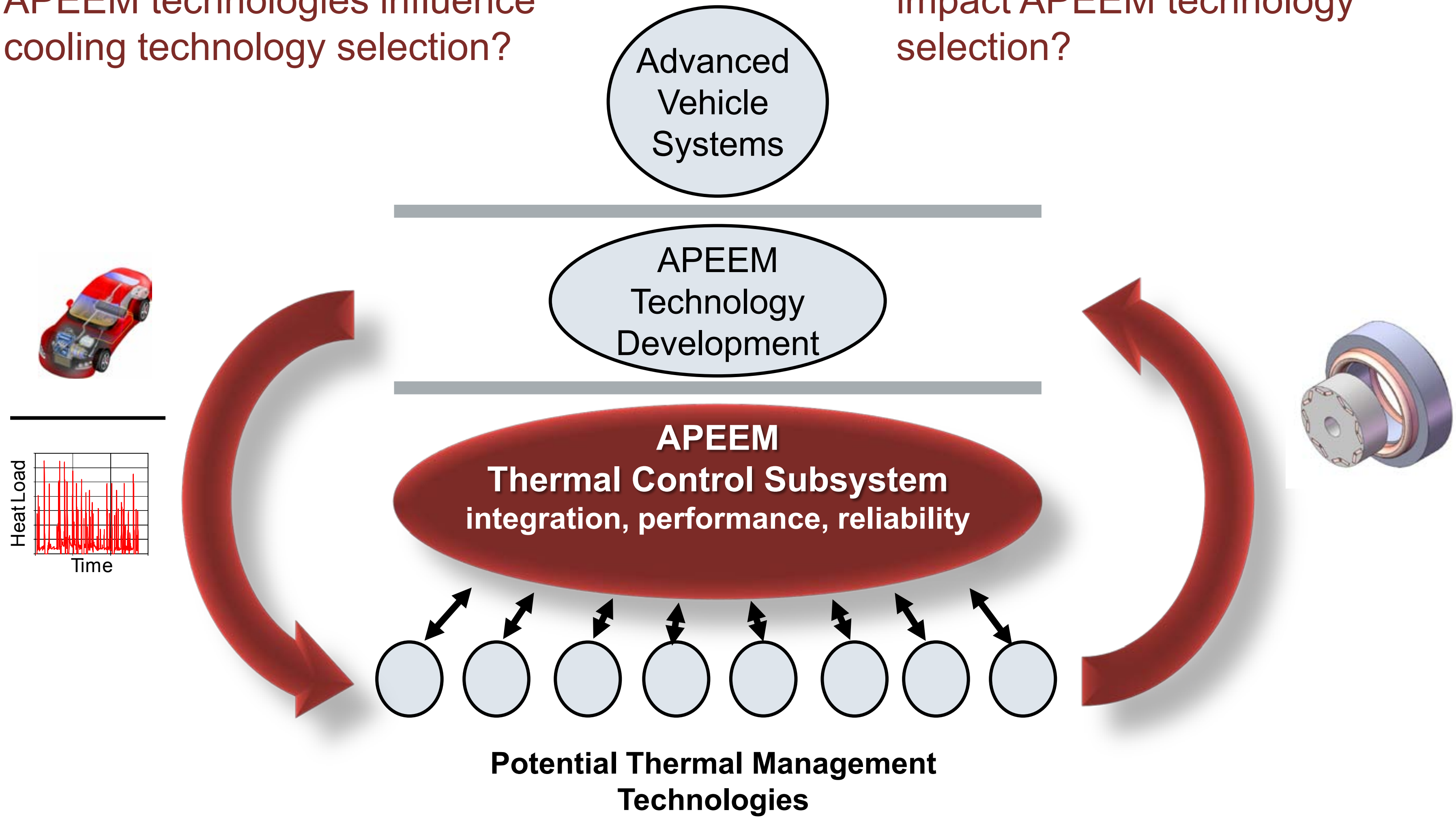
- Facilitate the integration of APEEM thermal management technologies into commercially viable advanced automotive systems including hybrid electric, plug-in hybrid electric, and fuel cell vehicles.



Objectives: Relevance (4/4)

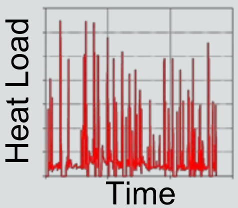
How do developments in APEEM technologies influence cooling technology selection?

How do developments in cooling impact APEEM technology selection?



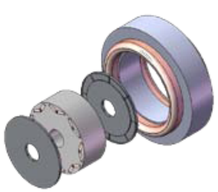
Approach/Strategy (1/3)

Vehicle Type
HEV, PHEV, EV, FCV, …



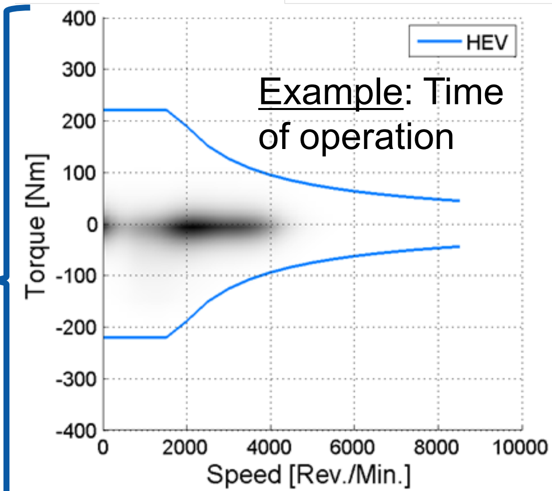
Component Use
Heat Loads / Efficiency
(Peak, Continuous, Dynamic, …)

Cooling System
Coolant Temperature
(Vehicle Integration)
Heat Exchanger



EM Package
Configuration
Materials

Understand critical operating points.



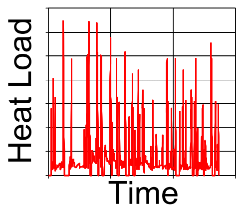
Losses/Efficiency
What are critical points in terms of heating?

Energy
What are critical points in terms of energy use?

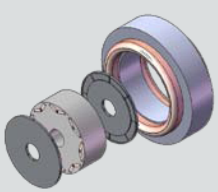
- Quantify energy impact.
- Focus efficiency improvements.
- Improve thermal management.

Approach/Strategy (2/3)

Vehicle Type
HEV, PHEV, EV, FCV, …



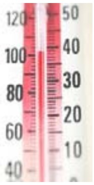
Component Use
Heat Loads / Efficiency
(Peak, Continuous, Dynamic, …)



Cooling System
Coolant Temperature
(Vehicle Integration)
Heat Exchanger

EM Package
Configuration
Materials

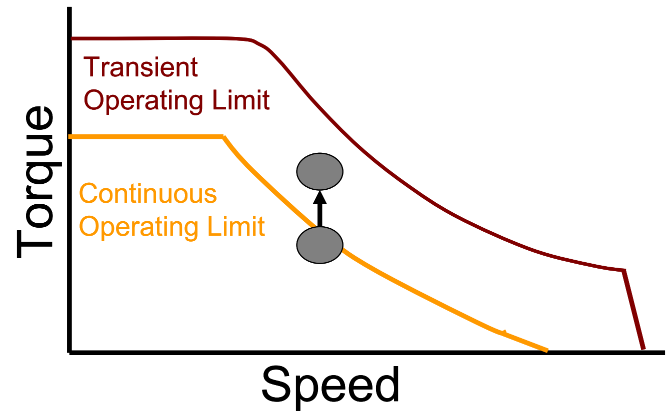
Thermal Limits (T_{max})



Heat Removal Capability

Q

Power Improvement



Impacts on Metrics

Approach/Strategy (3/3) - Milestones

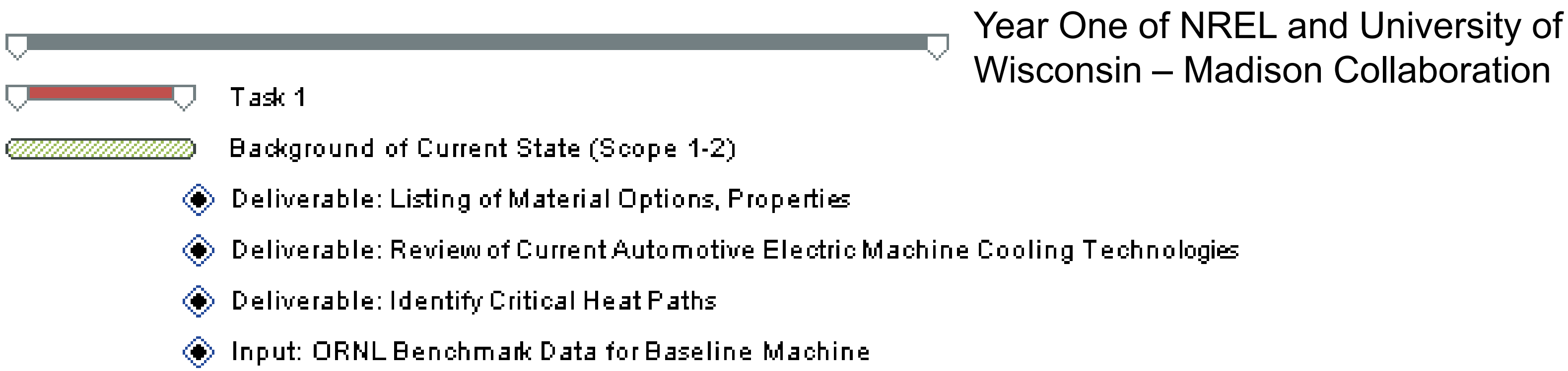
FY10 (Scheduled)

- Annual milestone report - status update (October)

Technical Accomplishments & Progress (1/4)

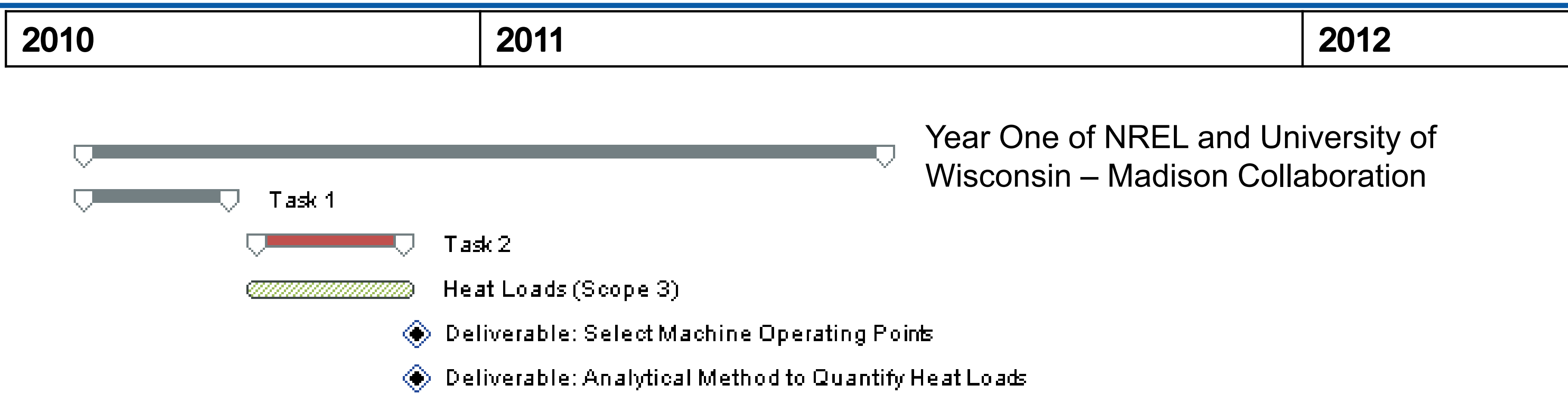
Completed formal agreements between NREL and the University of Wisconsin – Madison for collaboration efforts on electric machine thermal management.

2010	2011	2012



- Identify material options for automotive electric drives.
- Review current cooling technologies for automotive traction drives.
  - Identify known synergies between cooling technologies and machine types (such as air, water ethylene glycol, oil…).
- Identify critical heat paths based on machine type and cooling method.

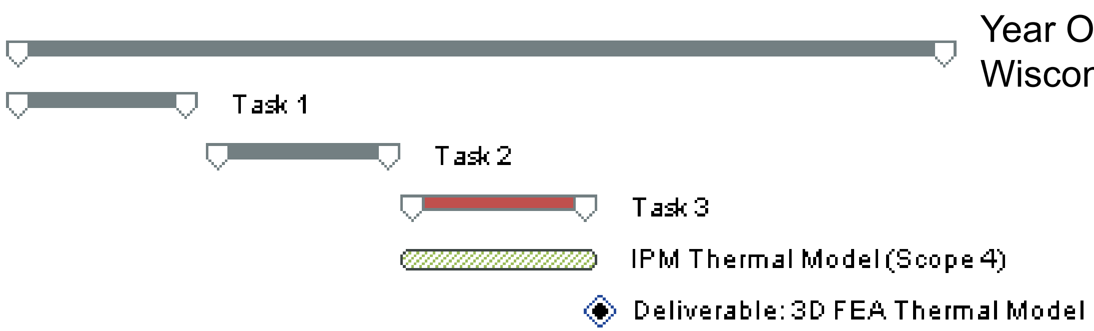
Technical Accomplishments & Progress (2/4)



- Identify baseline machine and limited set of operating points for analysis.
- Propose analytical method to determine the electric machine heat load distribution of an IPM machine.
  - Compare heat load estimates against available experimental data of baseline machine.
  - Ensure compatibility with MATLAB/Simulink.

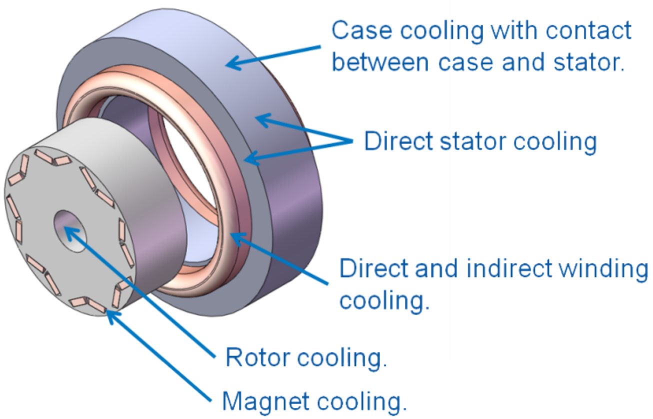
Technical Accomplishments & Progress (3/4)

2010	2011	2012

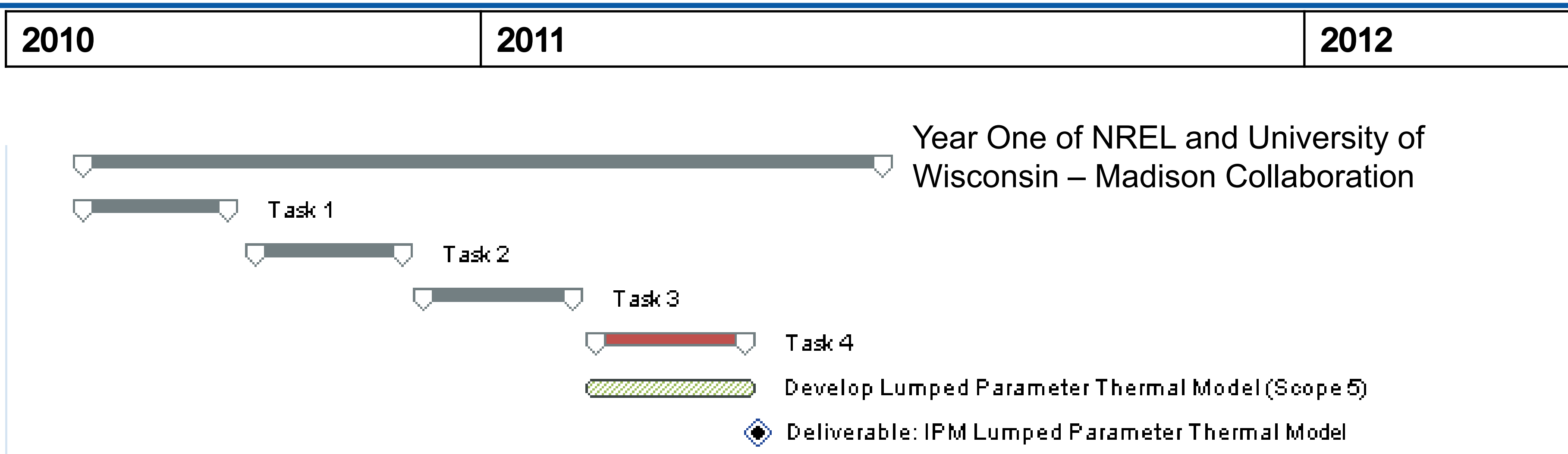


- Develop thermal FEA model of baseline IPM machine.
  - Identify appropriate levels of detail.
  - Develop foundation on which to characterize impact of alternative cooling strategies.

Multiple Cooling Options



Technical Accomplishments & Progress (4/4)



➢ Develop approach for the creation of a lumped parameter thermal model of IPM machines.
  - Identify appropriate levels of detail.
  - Maintain compatibility with MATLAB/Simulink.

Collaboration and Coordination

University

- University of Wisconsin – Madison (Thomas M. Jahns): Partner
  - Support with electric machine expertise.

Industry

- Electrical & Electronics Tech Team: Partner
  - Input on plans and accomplishments.

Other Government Laboratories

- Oak Ridge National Laboratory: Partner
  - Support from benchmarking activities.
  - Ensure thermal design space is appropriate and modeling assumptions are consistent with other aspects of APEEM motor research.

Proposed Future Work

- Expand to other machine types.
    - Ensure thermal design space is appropriate and modeling assumptions are consistent with other aspects of APEEM motor research.

- Perform cooling technology characterization and development in an electric machine context.
    - Develop avenues for improved cooling of motors (such as water jacket, stator cooling, winding cooling, magnet cooling, and rotor cooling).

- Transient analysis modeling capabilities.
    - Develop transient thermal modeling capabilities necessary to evaluate performance in real-world usage conditions.

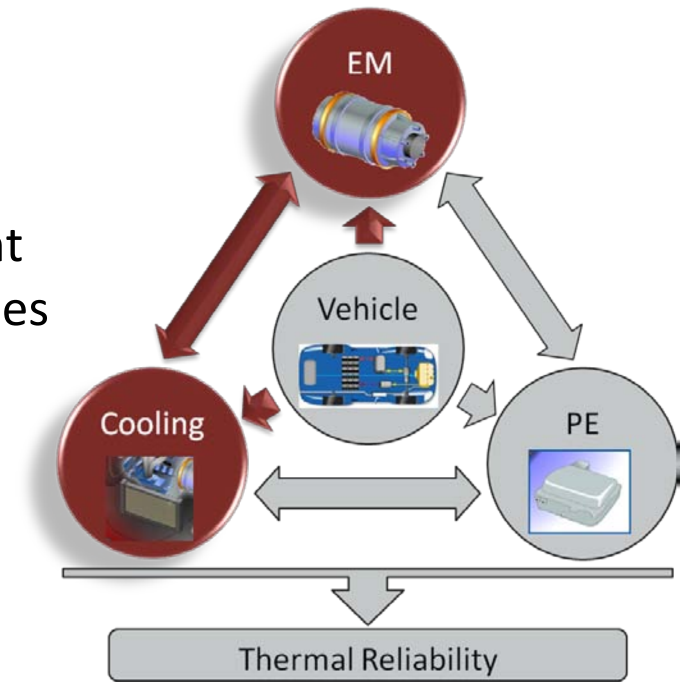
Summary

Relevance

- Facilitate the integration of APEEM thermal management technologies into commercially viable advanced automotive systems.

Approach/Strategy

- Understand critical operating regions for thermal management and energy use.
- Develop process to evaluate thermal management trade-offs between alternative cooling technologies for electric machines.



Summary

Technical Accomplishments

- Previously illustrated impact on motor thermal management with transition to more electrically dominate vehicle propulsion systems.
- Formal agreements between NREL and the University of Wisconsin – Madison are complete.
- Baseline IPM thermal test data provided by ORNL.

Collaborations

- Collaborations established with R&D partners.
  - University of Wisconsin – Madison
  - Oak Ridge National Laboratory