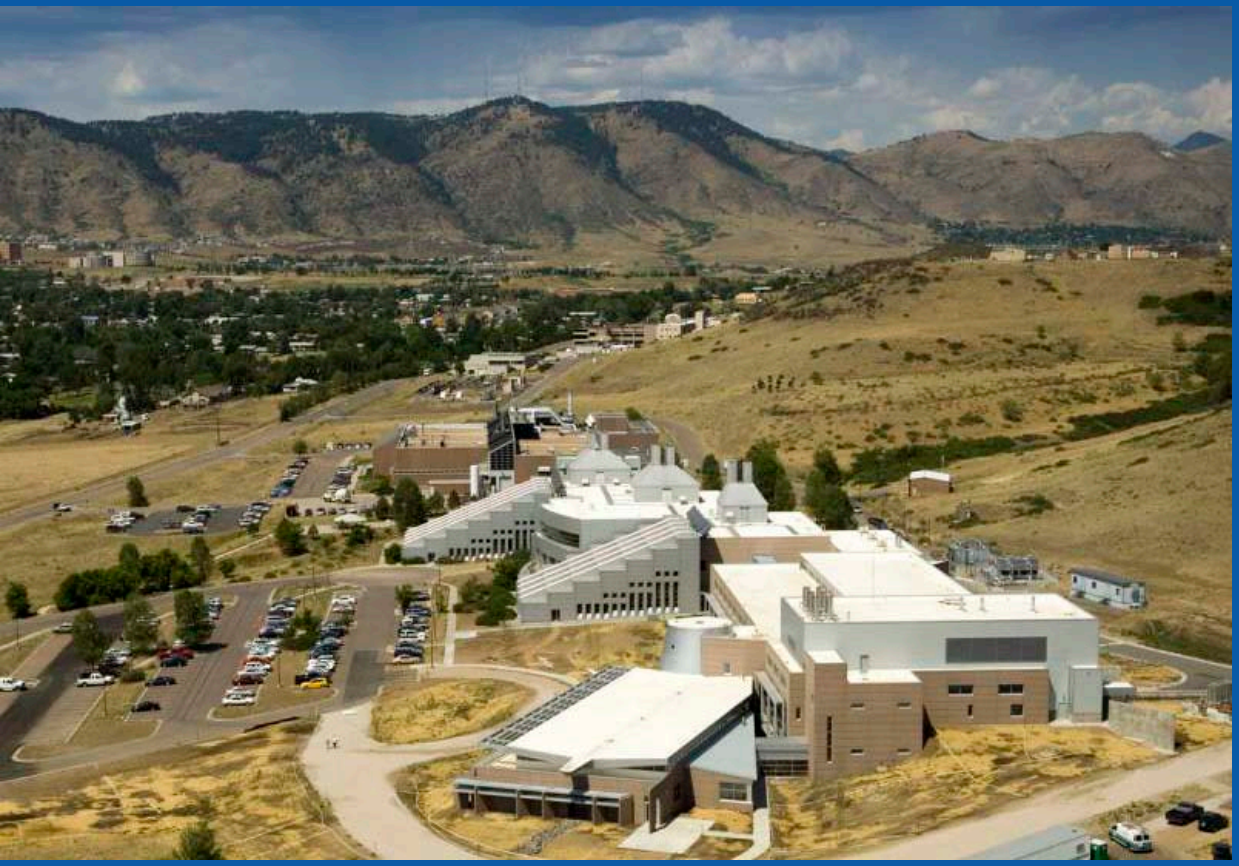
National Renewable Energy Laboratory
Innovation for Our Energy Future

Integrated Vehicle Thermal Management



U.S. Department of Energy
Annual Merit Review

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National Renewable Energy Laboratory

presented by
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VSS028

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NREL is a national laboratory of the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy operated by the Alliance for Sustainable Energy, LLC

Overview

Timeline

- Project Start: FY 2007
- Project End: FY 2009
- Percent Complete: 100%

Budget

- Total Funding (FY07-FY09)
  - DOE: $550K
  - Contract: $0K
- Annual Funding
  - FY09: $100K
  - FY10: $0K

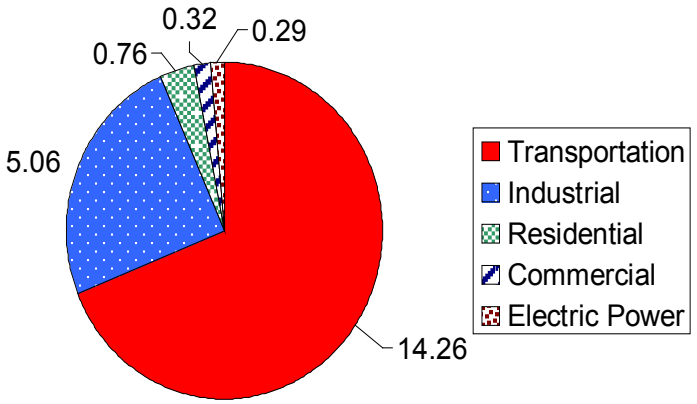
Partners/Collaboration

- Collaboration with Electrical and Electronics Technical Team (EETT) which includes NREL and ORNL.

Barriers

- Commercially viable integrated vehicle thermal management enabling advanced propulsion technologies to reduce oil consumption.

2007 Oil Consumption by Sector – Million Barrels per Day



Data Source: EIA Annual Energy Review 2007

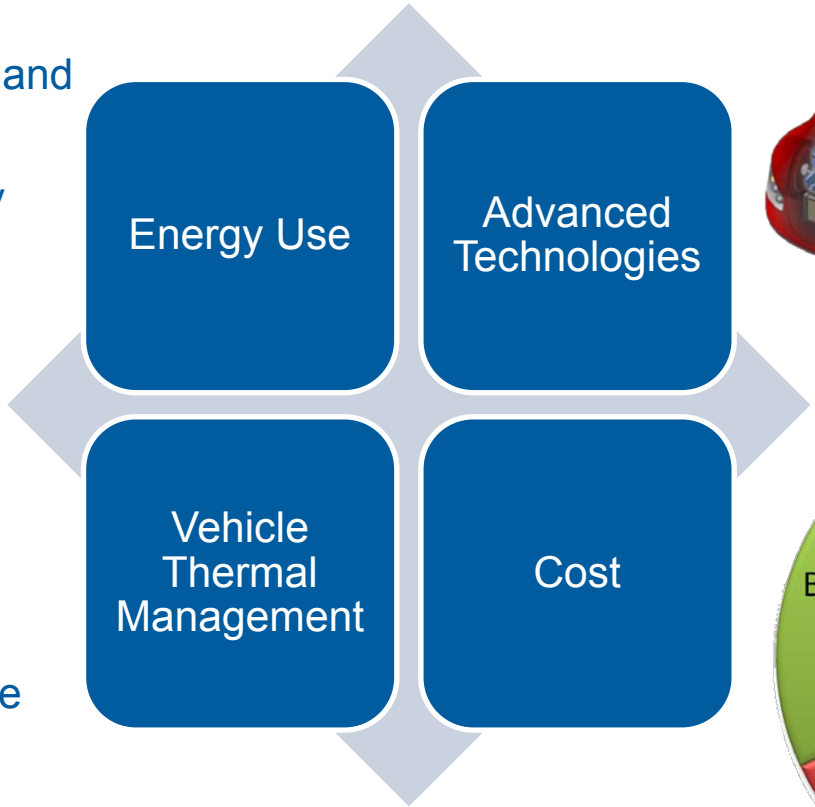
Vehicle Systems Analysis Technical Tasks

- Modeling and Simulation
- Integration and Validation
- Benchmarking

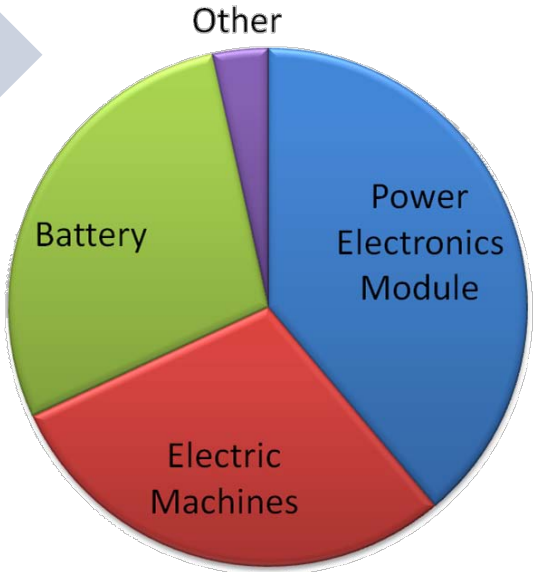
Objectives: Relevance (1/3)

Why is vehicle thermal management important?

- Consumer demand
- Regulations
- Energy security
- Environment



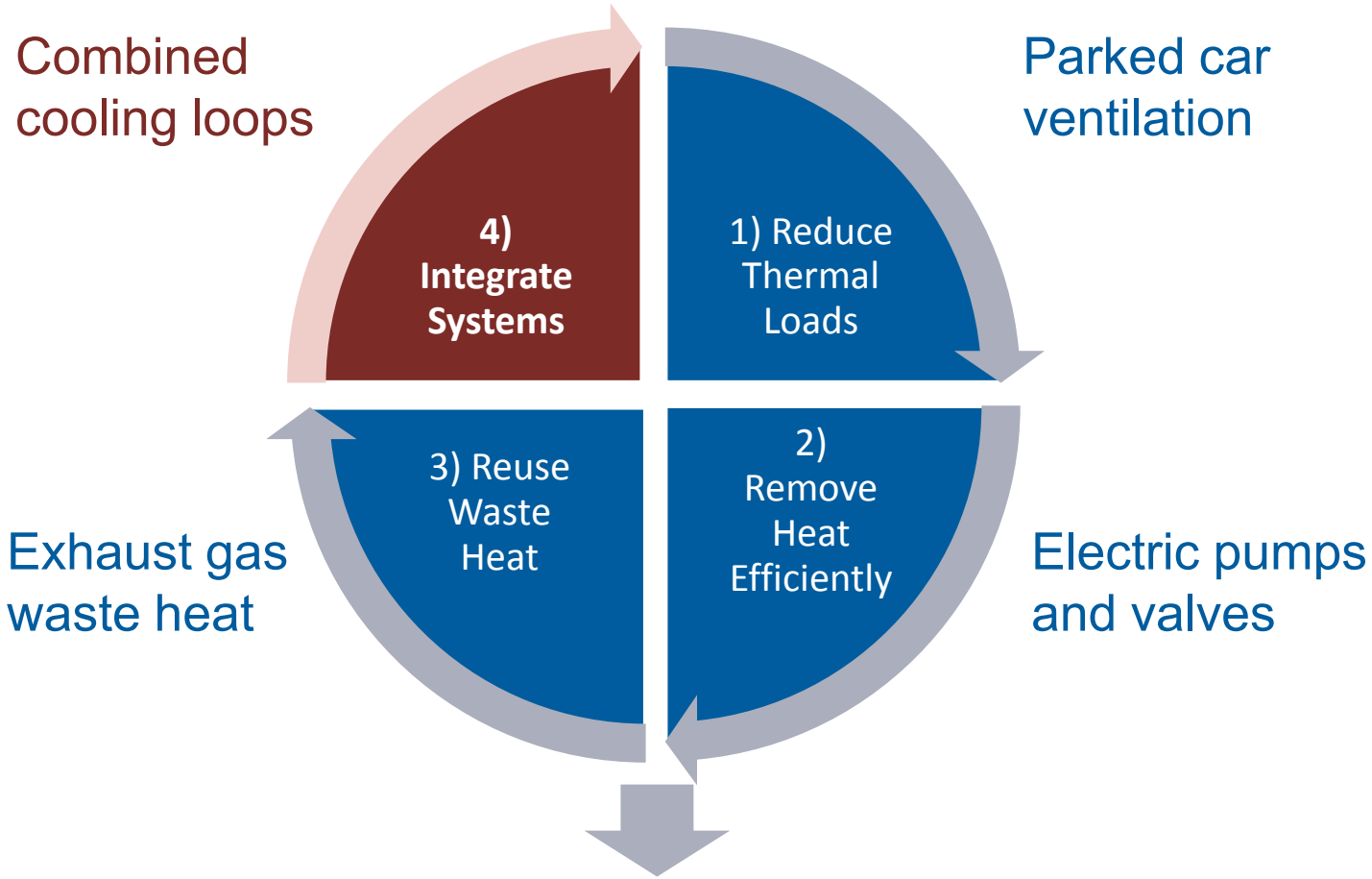
- Safety
- Reliability
- Performance
- Comfort



Source: Technology and Cost Report of the MY2007 Toyota Camry - ORNL

Objectives: Relevance (2/3)

Why is vehicle thermal management important?

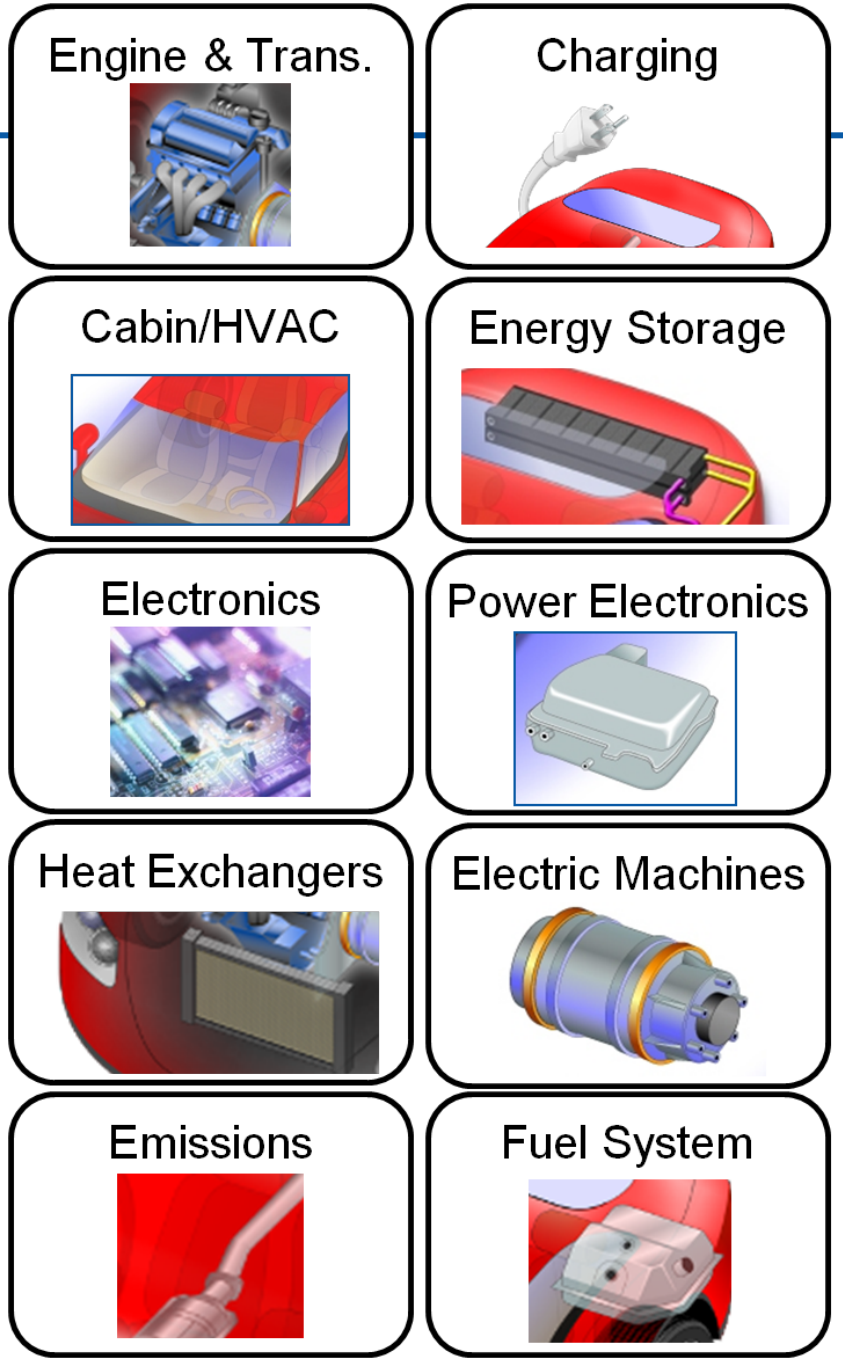


Improved operating robustness and reduced energy use.

Objectives: Relevance (3/3)

1. Demonstrate that integration of thermal management systems is needed for alternative propulsion technologies with electric drives.
   - Cost
   - Weight
   - Size

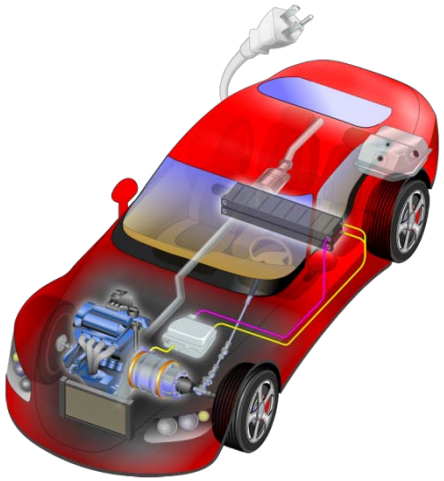
2. Provide an approach to evaluate combined heat loads under a wide range of operating conditions.



Approach/Strategy (1/4)

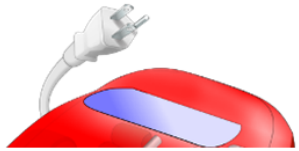
What is integrated thermal management?

- Thermal management viewed at larger vehicle system.
- Not add-on compartmentalized approach to thermal management.
- Requires analysis of both temperature and thermal loading compatibility between systems.



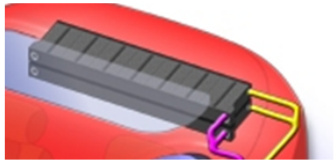
Engine & Trans.

Charging



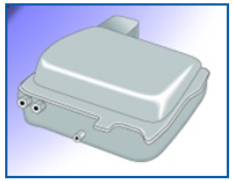
Cabin/HVAC

Energy Storage



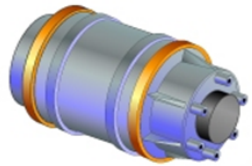
Electronics

Power Electronics



Heat Exchangers

Electric Machines



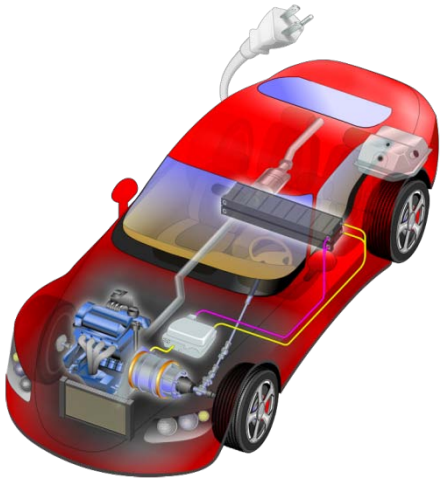
Emissions

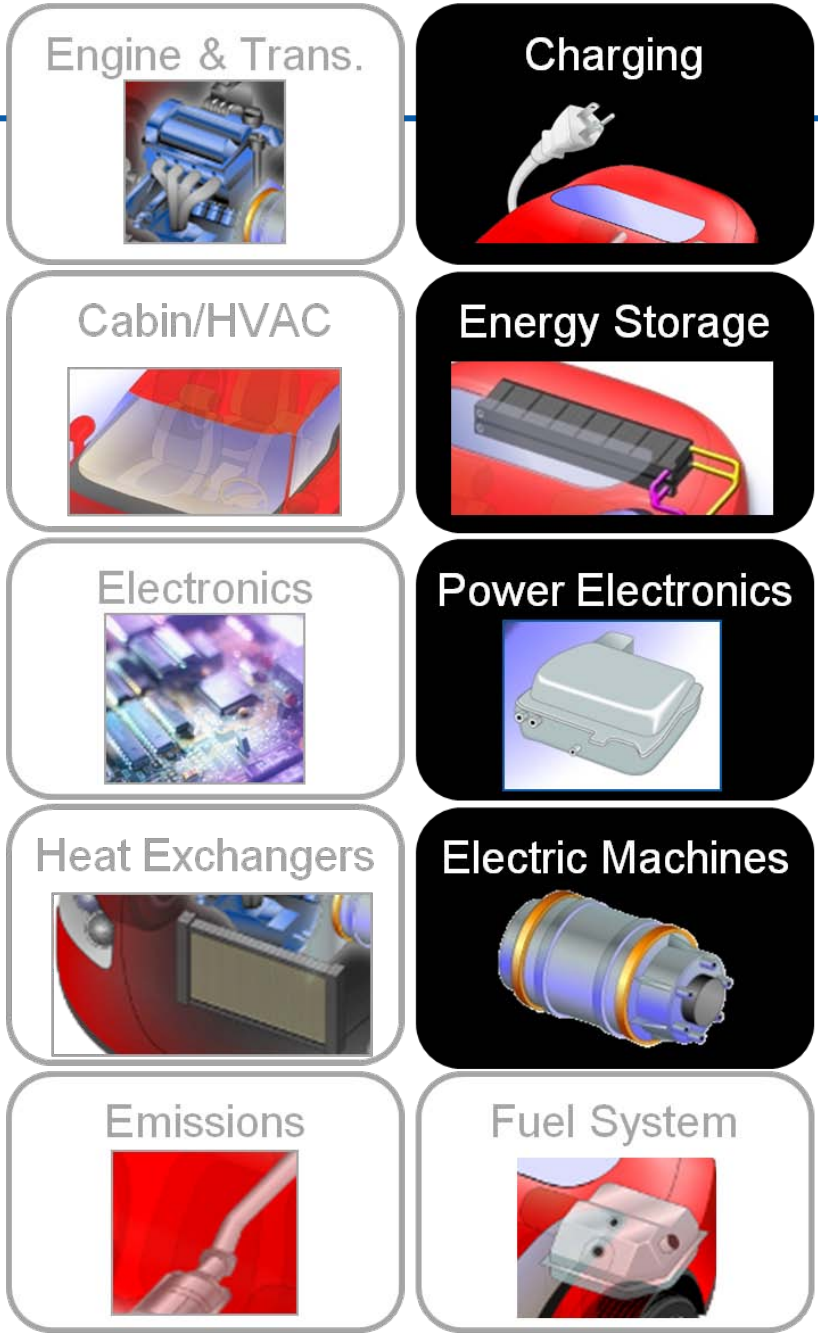
Fuel System

Approach/Strategy (2/4)

Problem

- How are thermal management systems integrated into alternative electric drive propulsion systems?



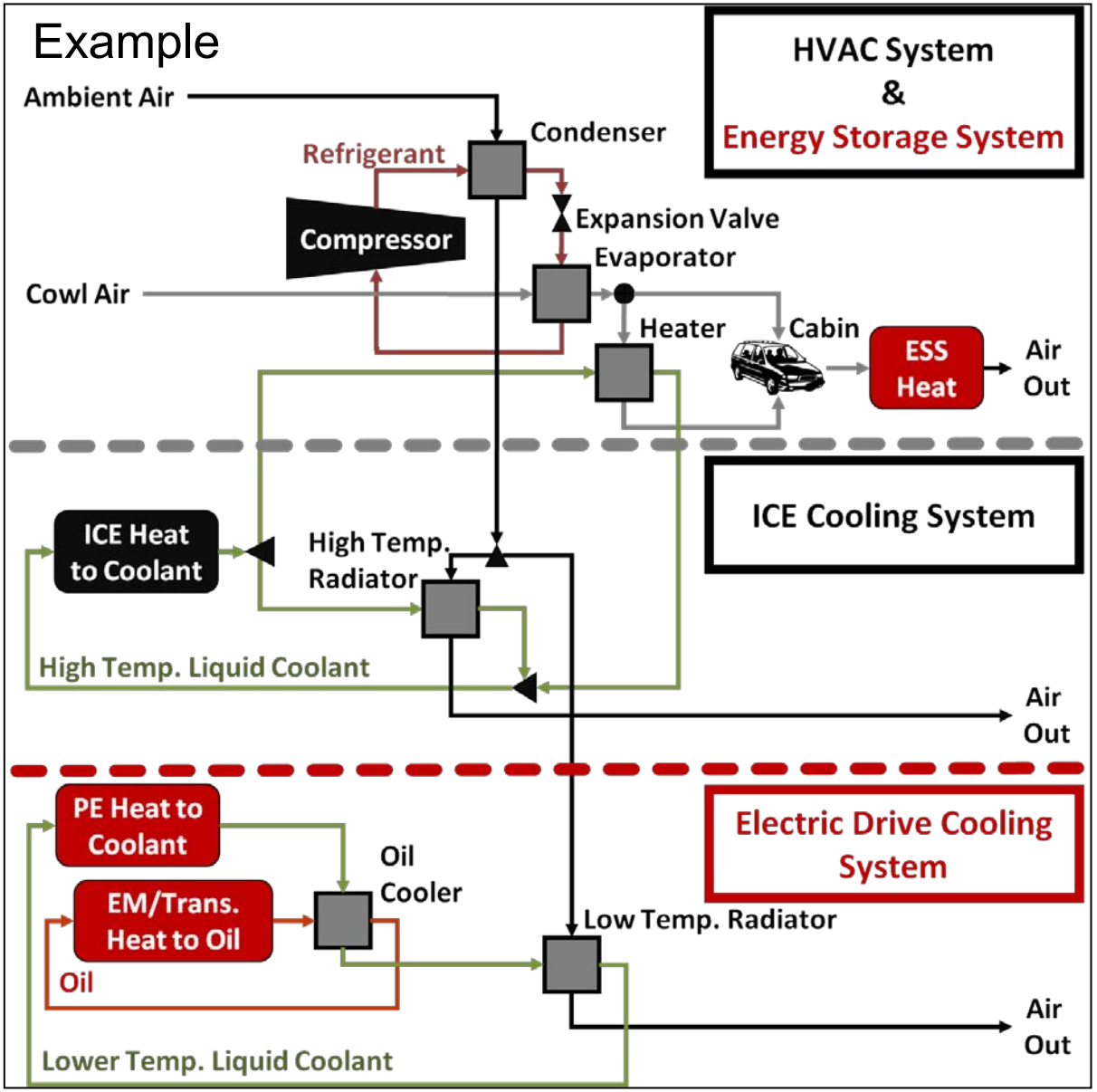


Approach/Strategy (3/4)

Problem

Additional cooling loop added to vehicle thermal management system.

- Cost
- Weight
- Package Space



Approach/Strategy (3/4)

Problem

Additional cooling loop adde
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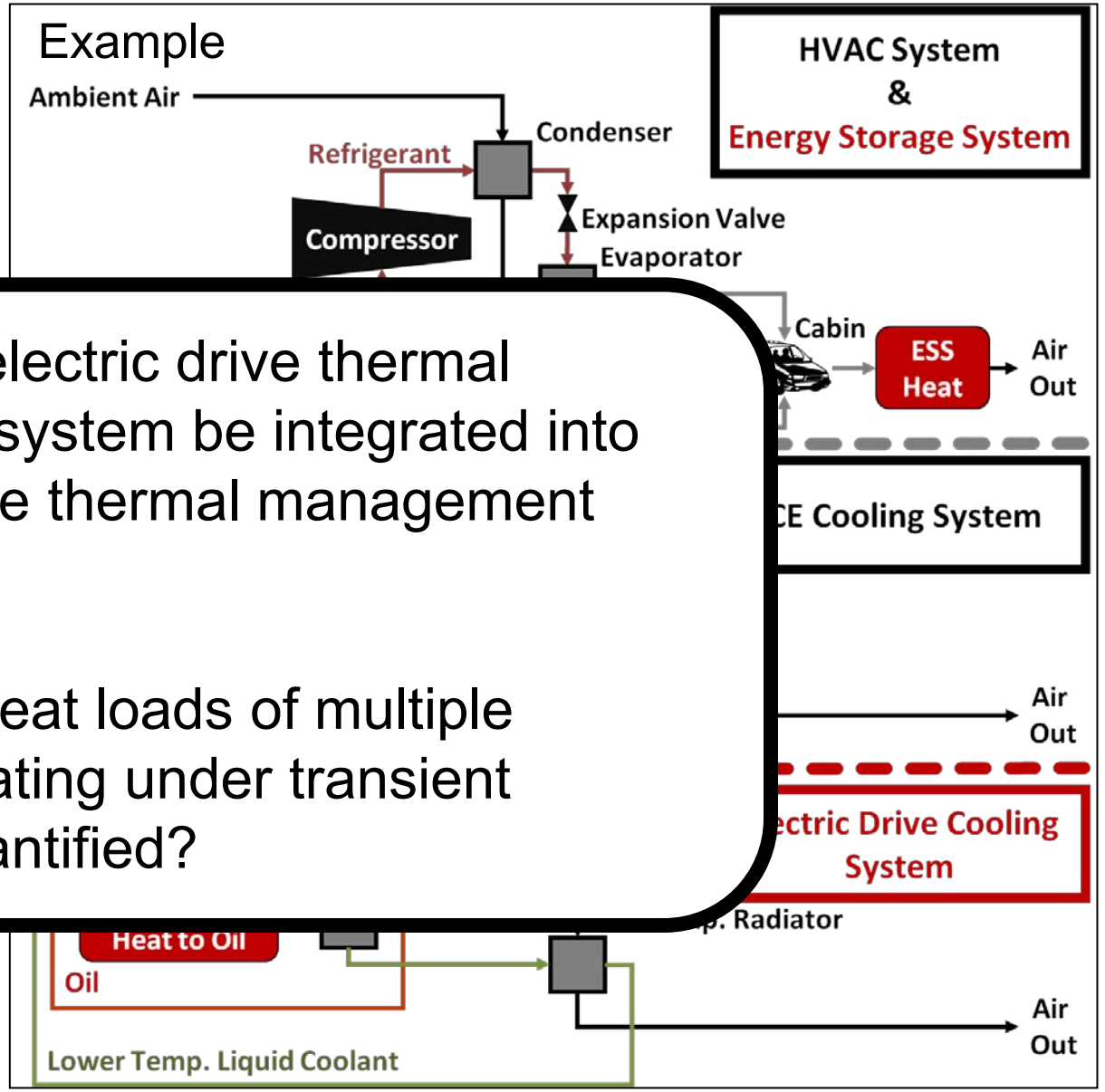
- C
- W
- P

1. How can the electric drive thermal management system be integrated into existing vehicle thermal management systems?

2. How are the heat loads of multiple systems operating under transient conditions quantified?



Approach/Strategy (4/4) - Milestones

FY08

Integrated Vehicle Thermal Management Systems Analysis/Modeling (May 2008).

FY09

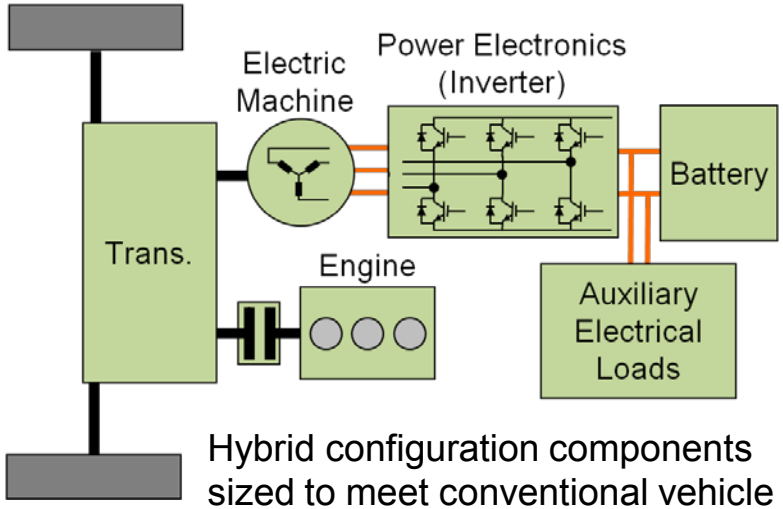
Vehicle Thermal Management System Integration and Waste heat Utilization (August 2009).

- Evaluate practicality of power electronics and electric machine waste heat utilization.
- Quantify the integration potential in terms of temperature compatibility and misalignment of transient heat loads of proposed integrated vehicle thermal management systems.

Technical Accomplishments & Progress (1/6)

Thermal Loading Conditions

- Parallel hybrid configuration.
- Vehicle drive cycles represent real-world vehicle operation instead of standard test cycles.
- GPS data used to construct second-by-second drive profiles over a 24 hour period.
- Paper focuses on drive profiles that represent 227 vehicles from the St. Louis area to demonstrate application to a large data set.
- Approach can be expanded to include wide range of drive conditions including standard thermal tests.

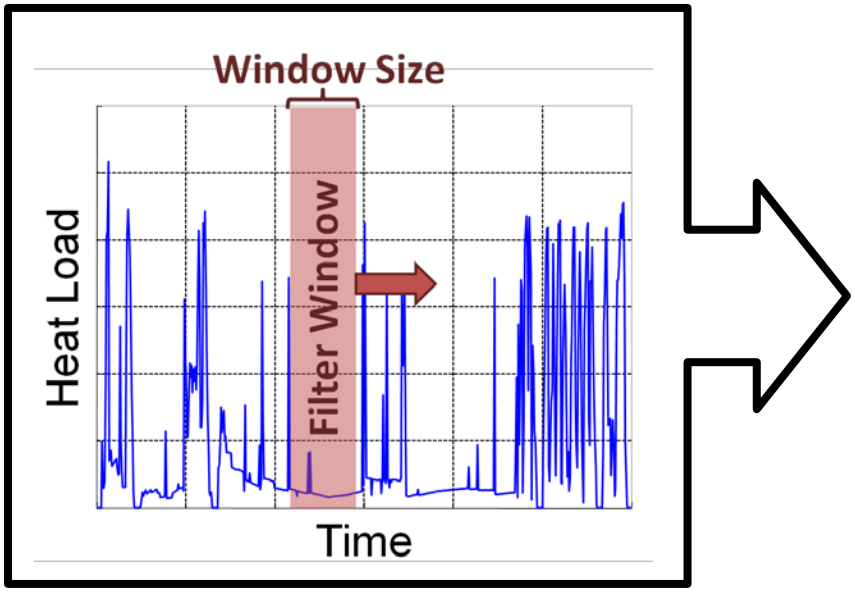


Hybrid configuration components sized to meet conventional vehicle performance specifications.

Reference:
J. Gonder, et al., "Using GPS Travel Data to Assess the Real World Driving Energy Use of Plug-In Hybrid Electric Vehicles (PHEVs)."
A. Simpson, "Cost-Benefit Analysis of Plug-In Hybrid Electric Vehicle Technology."

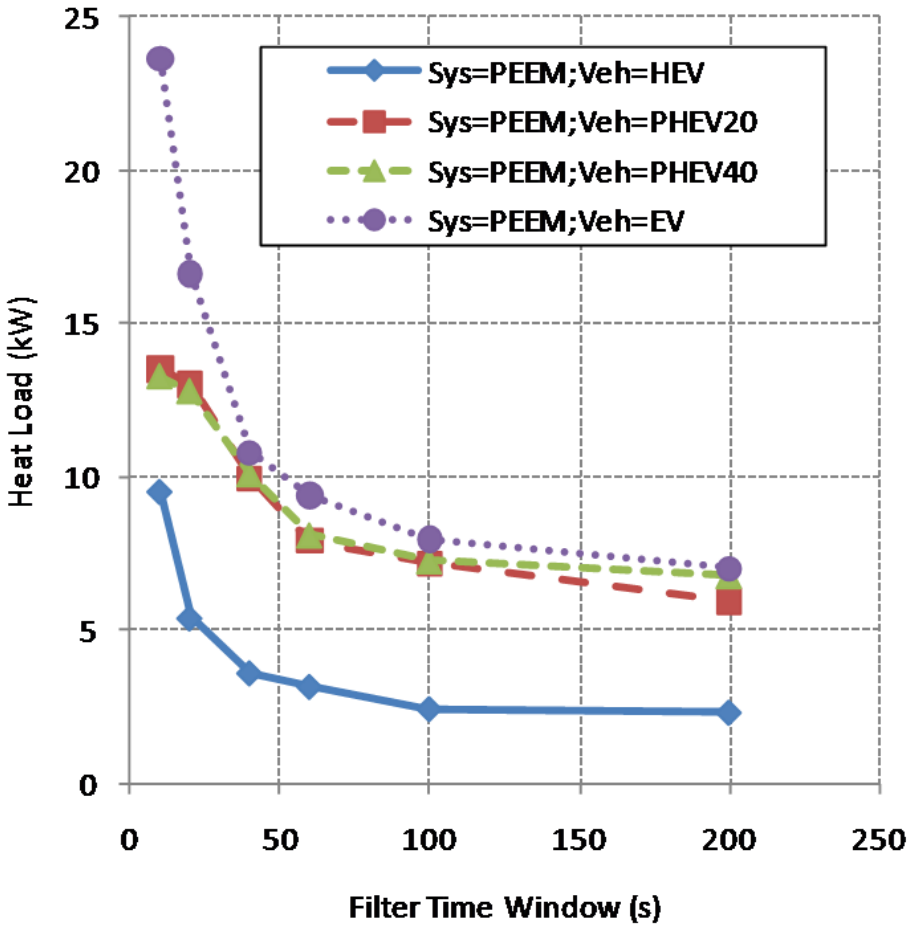
Technical Accomplishments & Progress (2/6)

Heat Load Curve



- A moving average filter records the peak heat load averaged over a variable time window over all drive cycles.
- Provides both transient and continuous heat load requirements for cooling system.
- Can be applied to components or combined systems.

Electric Drive System or Power Electronics and Electric Machine (PEEM) Heat Loading

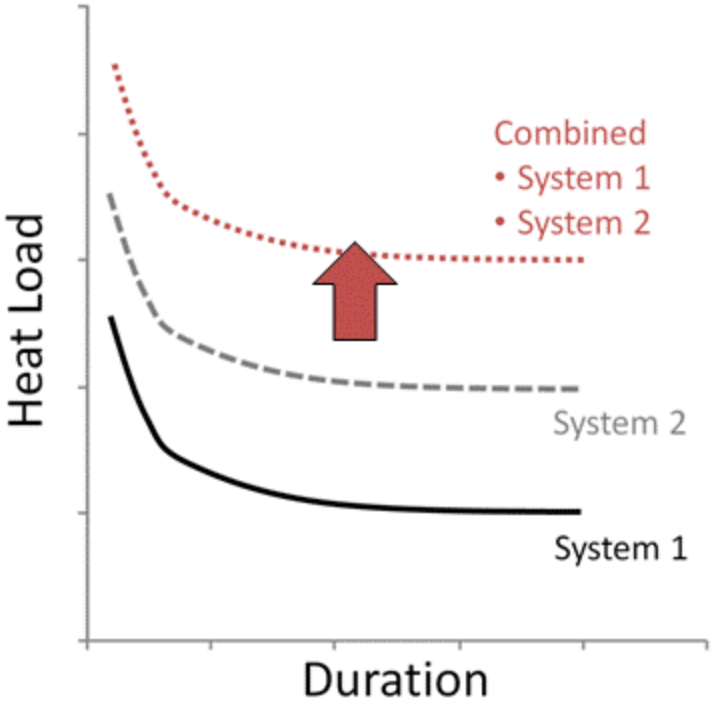


Technical Accomplishments & Progress (3/6)

Heat Load Curve

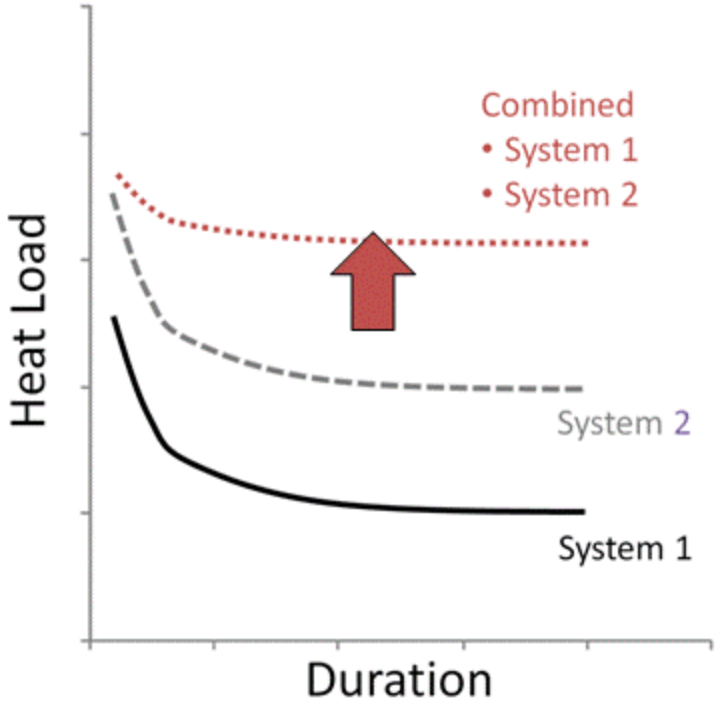
Time aligned heat loads

- Transient peaks aligned.
- Transient and continuous loads add.



Unaligned heat loads

- Combined cooling curve flattens.
- Peak transient load shows less impact.

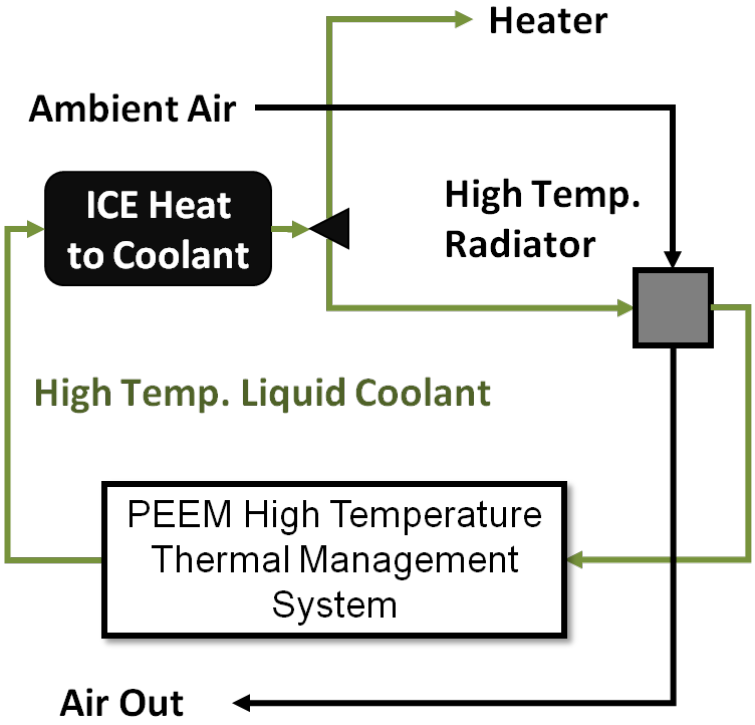


Technical Accomplishments & Progress (4/6)

Integration Examples

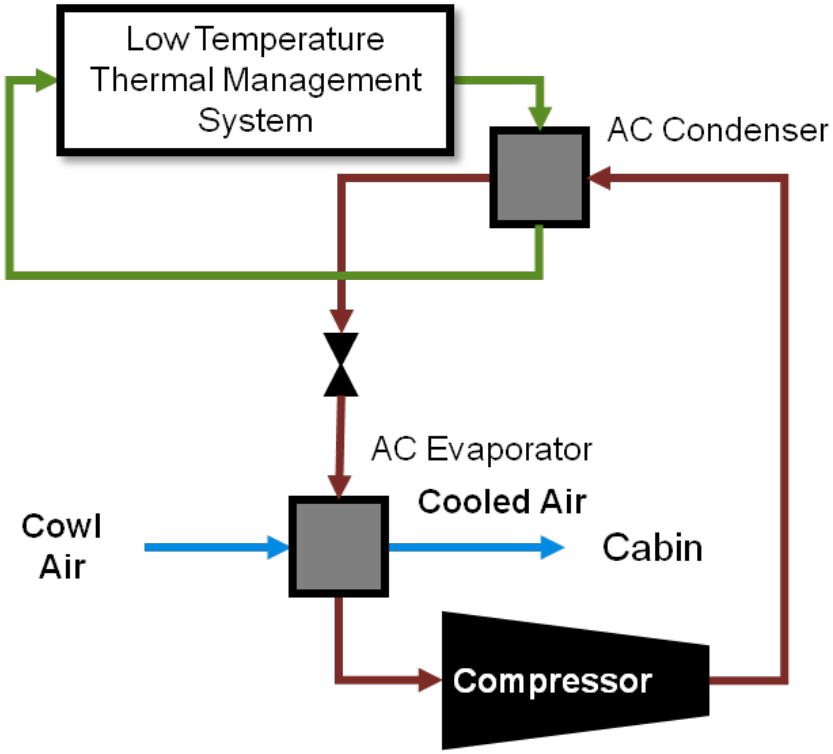
1. Engine Cooling Integration

High temperature coolant loop serving engine and electric drive (PEEM) systems.



2. Air Conditioner Integration

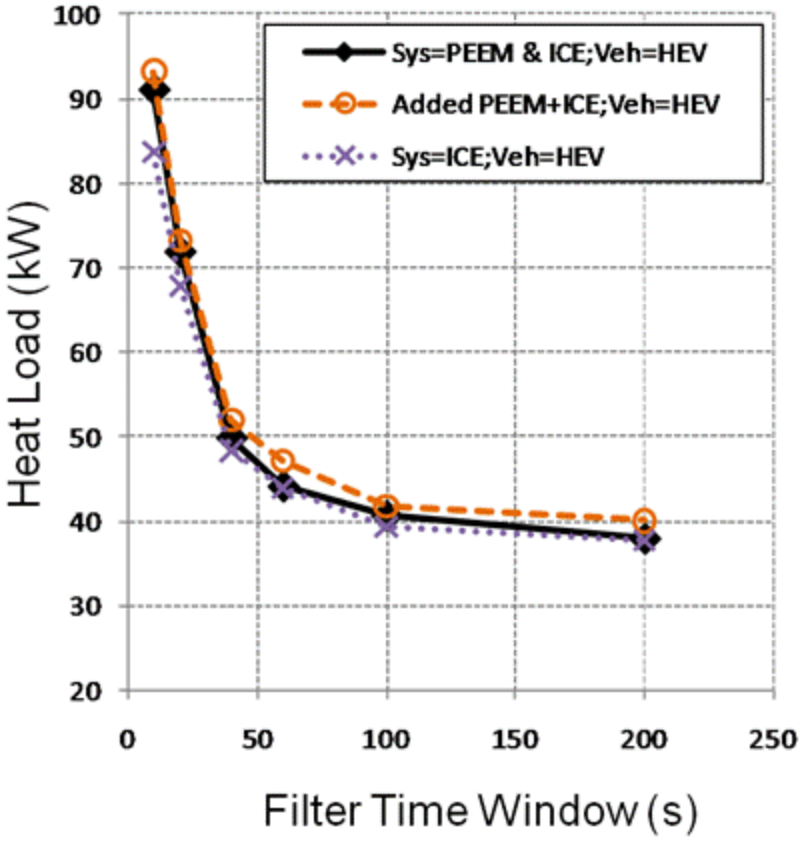
Low temperature coolant loop serving HVAC and electric drive (PEEM) systems.



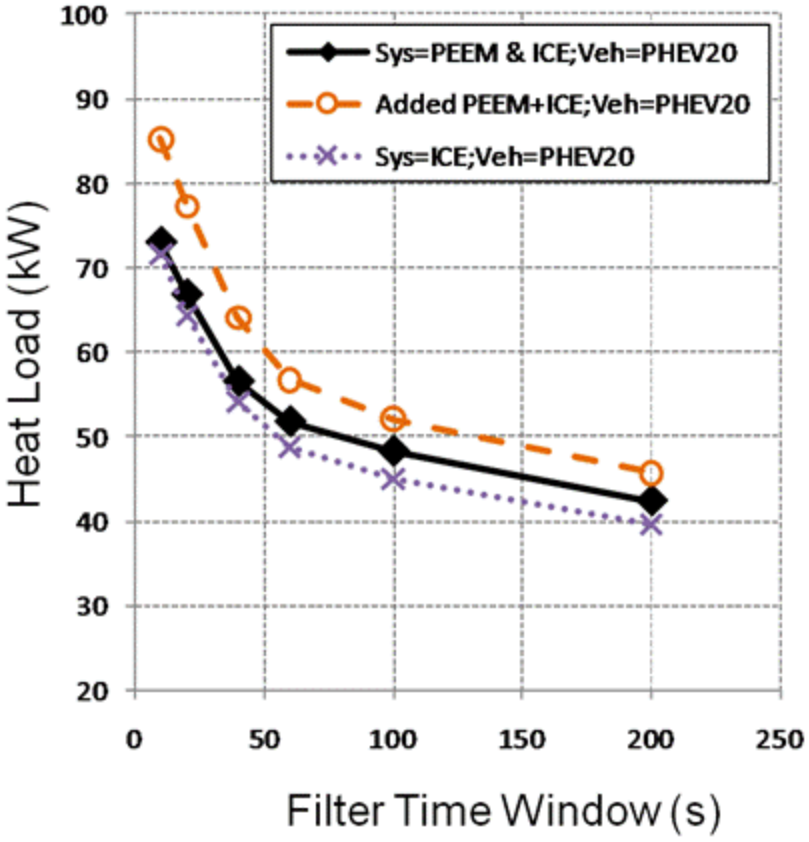
Technical Accomplishments & Progress (5/6)

High Temperature Integration (HEV vs. PHEV)

- Alignment in transient heating.
- Continuous heat load shows little change over ICE.



- Less alignment in transient heating.
- Continuous heat load increases slightly.
- Potential application for combined cooling loop.



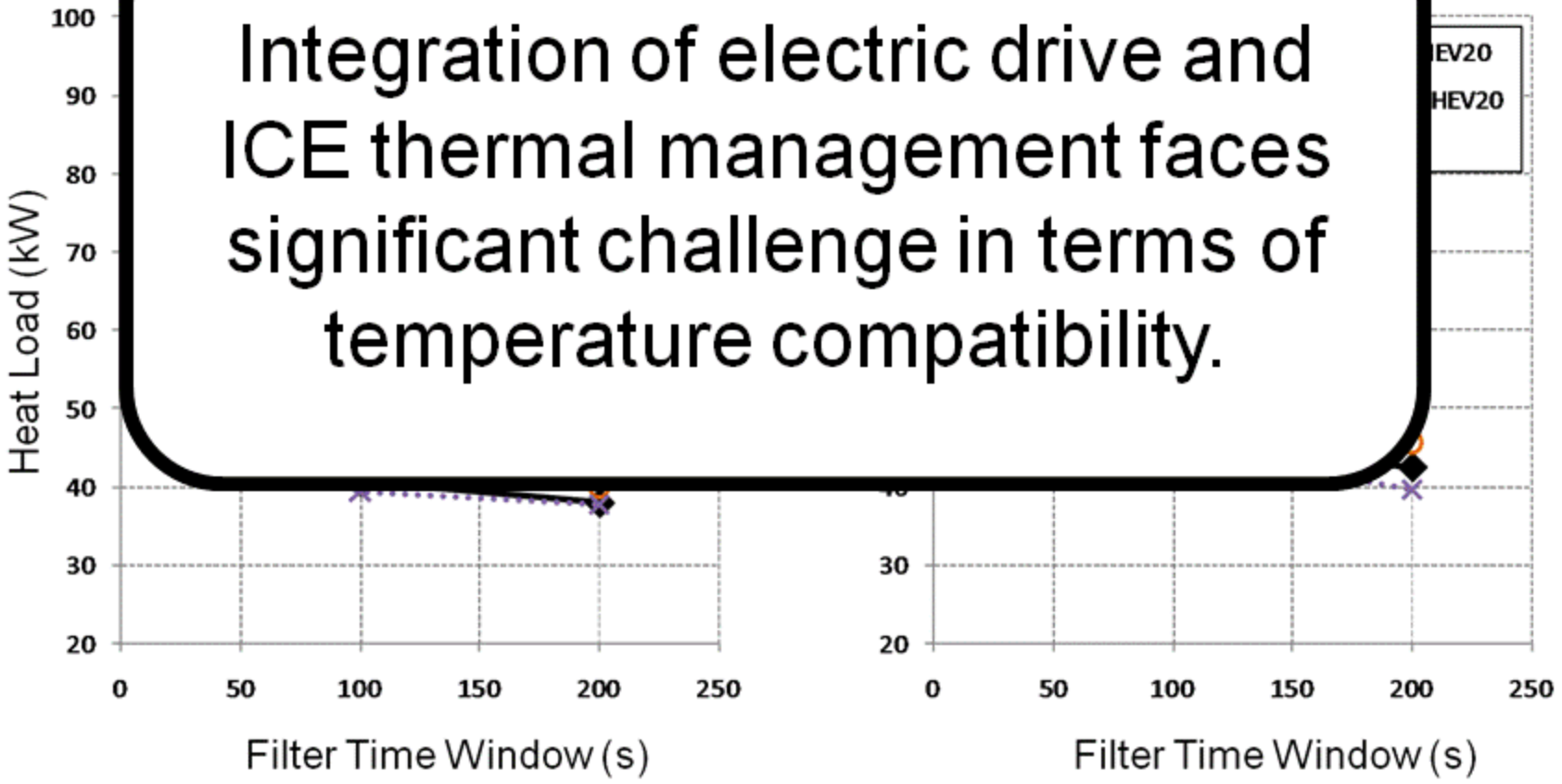
Technical Accomplishments & Progress (5/6)

High Temperature Integration (HEV vs. PHEV)

- Alignment in transient heating.
- Continuous heat load shows little change over ICE

- Less alignment in transient heating.
- Continuous heat load increases slightly.
- Potential application for combined cooling

Integration of electric drive and ICE thermal management faces significant challenge in terms of temperature compatibility.



Technical Accomplishments & Progress (6/6)

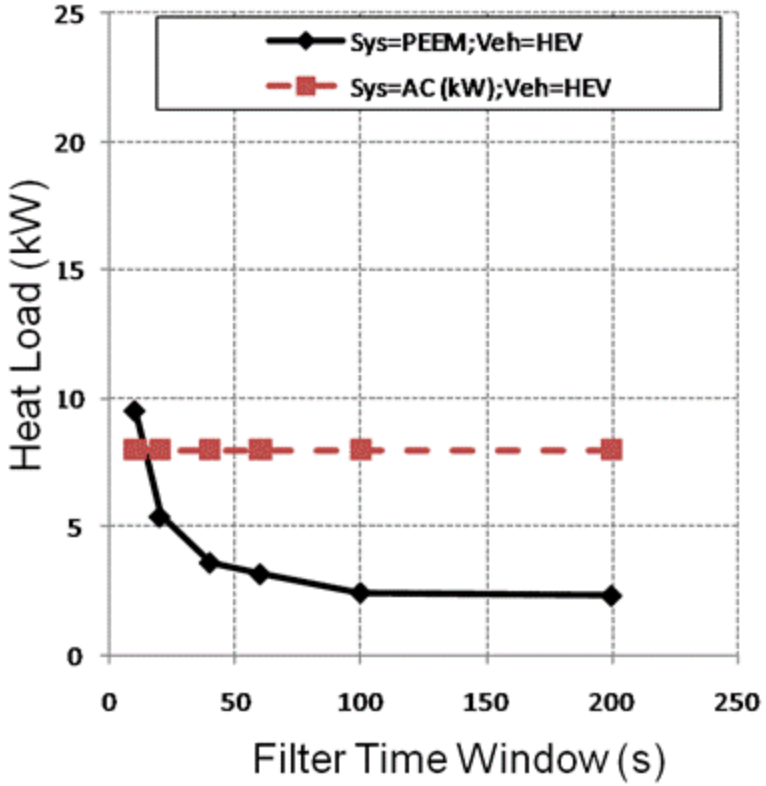
Low Temperature Integration

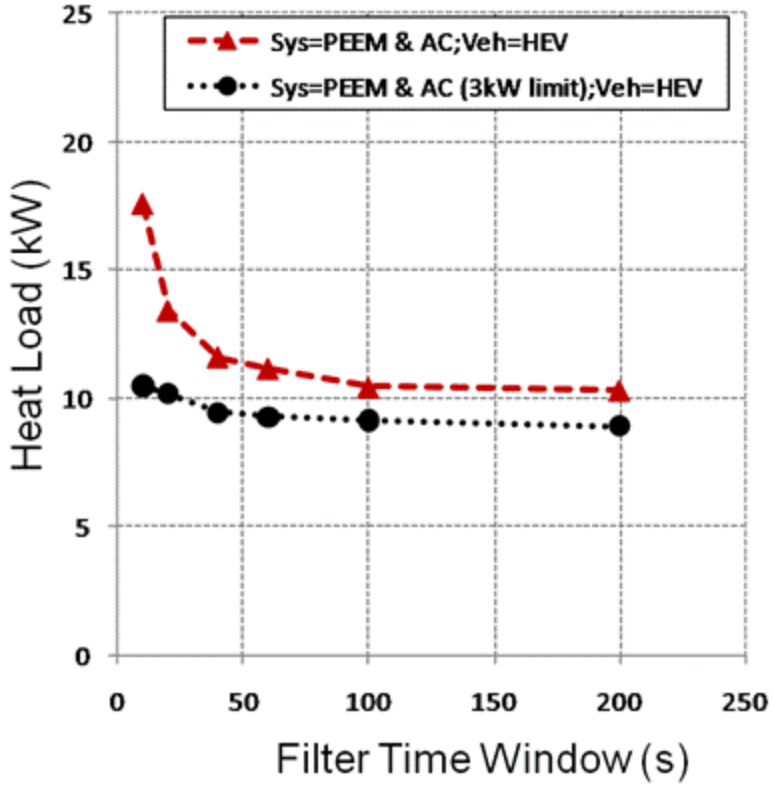
Component

- Fixed air conditioning (AC) condenser heat load.
- Variable PEEM heat load based on HEV.

Combined Systems

- Without control the transient heat load is increased significantly.
- Controlling the AC system during peak power events provides a significant heat load reduction.

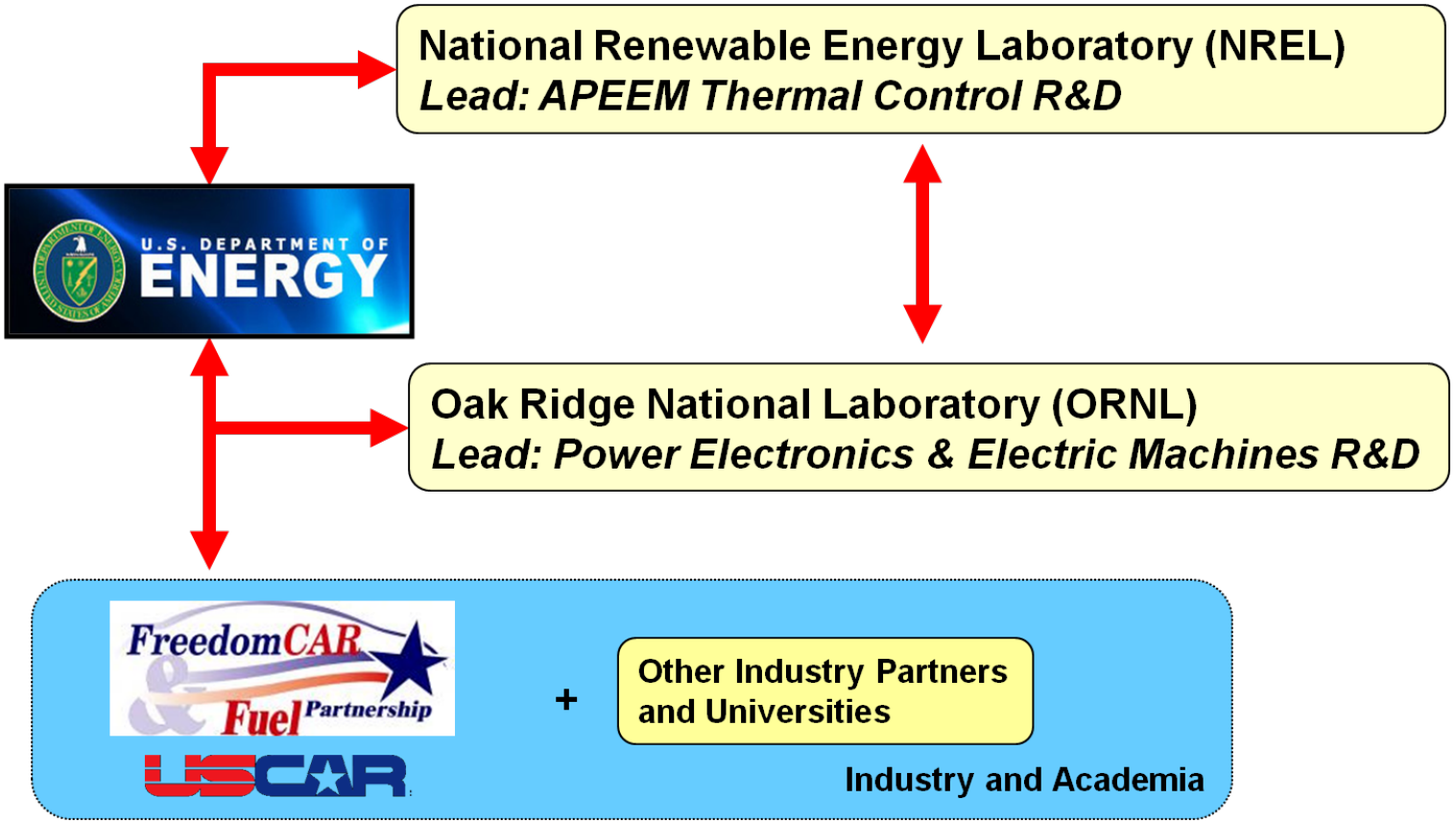




Collaboration and Coordination

Collaboration with the Advanced Power Electronics and Electric Machines (APEEM) thermal management activity.

– Guidance on thermal targets and current challenges.



Proposed Future Work

- Project is not funded in future years.
- The analysis of a “complete vehicle” solution requires interaction between multiple activities within the Department of Energy’s Vehicle Technologies Program. Examples include Advanced Power Electronics and Electric Machines (APEEM), Energy Storage Systems (ESS), and Vehicle Systems Analysis (VSA).
- Future work could include a jointly funded project between the APEEM, ESS, and VSA activities to investigate integrated vehicle thermal management.

Summary

Relevance

- Vehicle thermal management is a critical component for reducing fuel use and supporting the commercialization of viable alternative vehicle technologies.
- Integration of thermal management systems is needed to reduce cost and weight while maintaining robustness.

Approach/Strategy

- Provide an approach to evaluate combined heat loads under a wide range of operating conditions.
- Illustrate application to potential thermal management concepts that integrate the electric drive cooling system with other vehicle thermal management systems.

Summary

Technical Accomplishments

- Developed analysis techniques to quantify the transient and continuous heat loads of individual components and integrated systems over in-use operating conditions.
- Applied the developed analysis approach to the electric drive thermal management system to investigate potential integration opportunities with the internal combustion engine (ICE) and heating ventilation and air conditioning (HVAC) thermal management systems.
- Documented the analysis in a Department of Energy (DOE) milestone and an SAE publication (2010-01-0836).

Collaborations

- The Advanced Power Electronics and Electric Machines activity under the Vehicle Technologies Program.