National Renewable Energy Laboratory
Innovation for Our Energy Future

Integrated Vehicle Thermal Management Systems (VTMS) Analysis/Modeling

2009 DOE Vehicle Technologies Annual Merit Review

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May 19, 2009

Project ID: vssp_02_thornton

This presentation does not contain any proprietary, confidential, or otherwise restricted information.

Overview

Timeline

- Project Start: FY 2007
- Project End: FY 2010
- Percent Complete: 55%

Budget

- Total Funding (FY07-FY10)
  - DOE: $450K
  - Contract: $0K
- Annual Funding
  - FY08: $150K
  - FY09: $100K

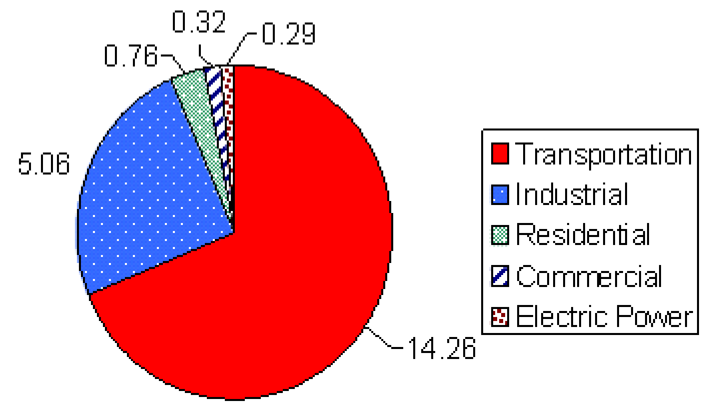
Partners/Collaboration

- 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

VTMS Objectives

- Safety
- Reliability
- Performance
- Comfort

Energy Use Pressures

- Consumer demand
- Regulations
- Energy security
- Environment

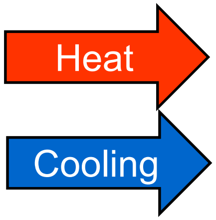
FY 08 Objectives

1) Investigate current technologies for improved vehicle thermal management, waste heat utilization, and integrated cooling.
2) Propose areas of focus for research into waste heat utilization and integrated cooling that apply to advanced vehicle propulsion systems.
3) Develop initial concepts of new waste heat utilization techniques and integrated cooling.

Objectives: Definition

What is integrated vehicle thermal management?

HVAC



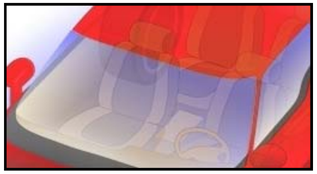
Look at Total Thermal Management Package Based on Vehicle Type

<u>Not</u>

Add-on Compartmentalized Component Focused Thermal Management

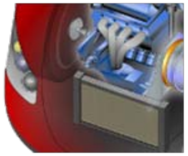
Electronics, Communication, & Entertainment

Cabin



Windows

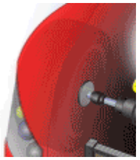
Heat Exchangers



Emissions Controls

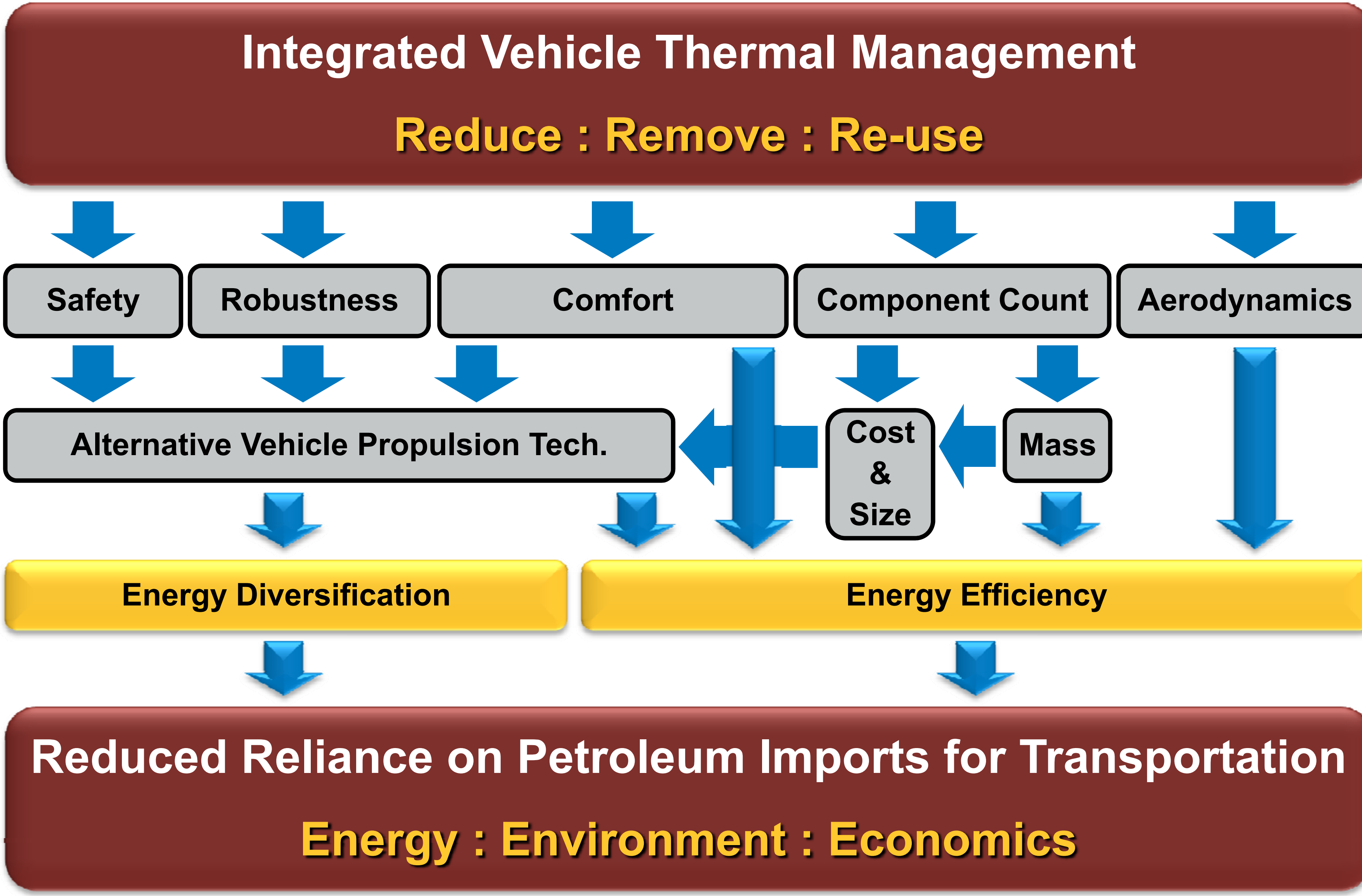
ICE & Trans.

Brakes



Fuel System

Objectives: Benefits



Milestones (FY08 & FY09)

FY08

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

- Investigated challenges related to vehicle thermal management.
- Reviewed current and proposed technologies related to improving vehicle thermal management.
- Identified potential areas for future research focus.

NREL National Renewable Energy Laboratory

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Office of Energy Efficiency & Renewable Energy

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Milestone 6.1: Integrated Vehicle Thermal Management Systems Analysis/Modeling

Milestone Report
May 2008

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FY09

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

Approach (FY08 & FY09)

- Conduct review of thermal management challenges and technologies across multiple vehicle propulsion technologies.

- Identify potential areas for research and development (R&D) specifically related to:
  - Waste heat utilization.
  - Integrated systems.

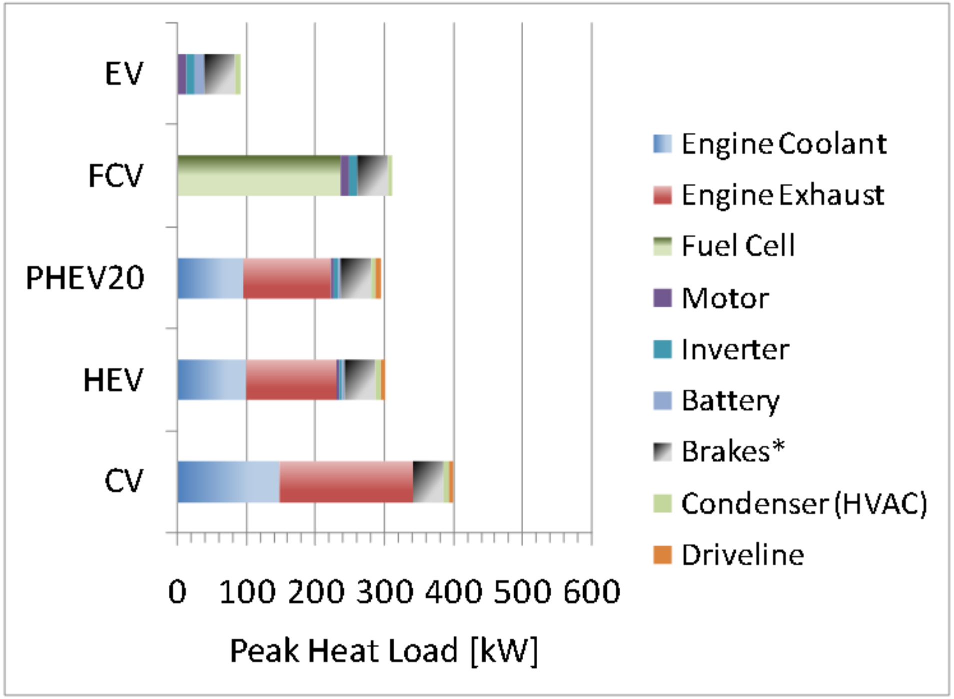
- Propose R&D concepts that:
  - Maximize benefit with least change.
  - Have wide application to multiple advanced vehicle propulsion technologies.

- Develop analytical analysis capabilities and methodologies to evaluate system feasibility of R&D concepts.

Technical Accomplishments

- As one transitions away from internal combustion engines the quantity (kW) and quality (°C) of the waste heat decreases.
- The impact is significant for PHEVs during engine off operation.

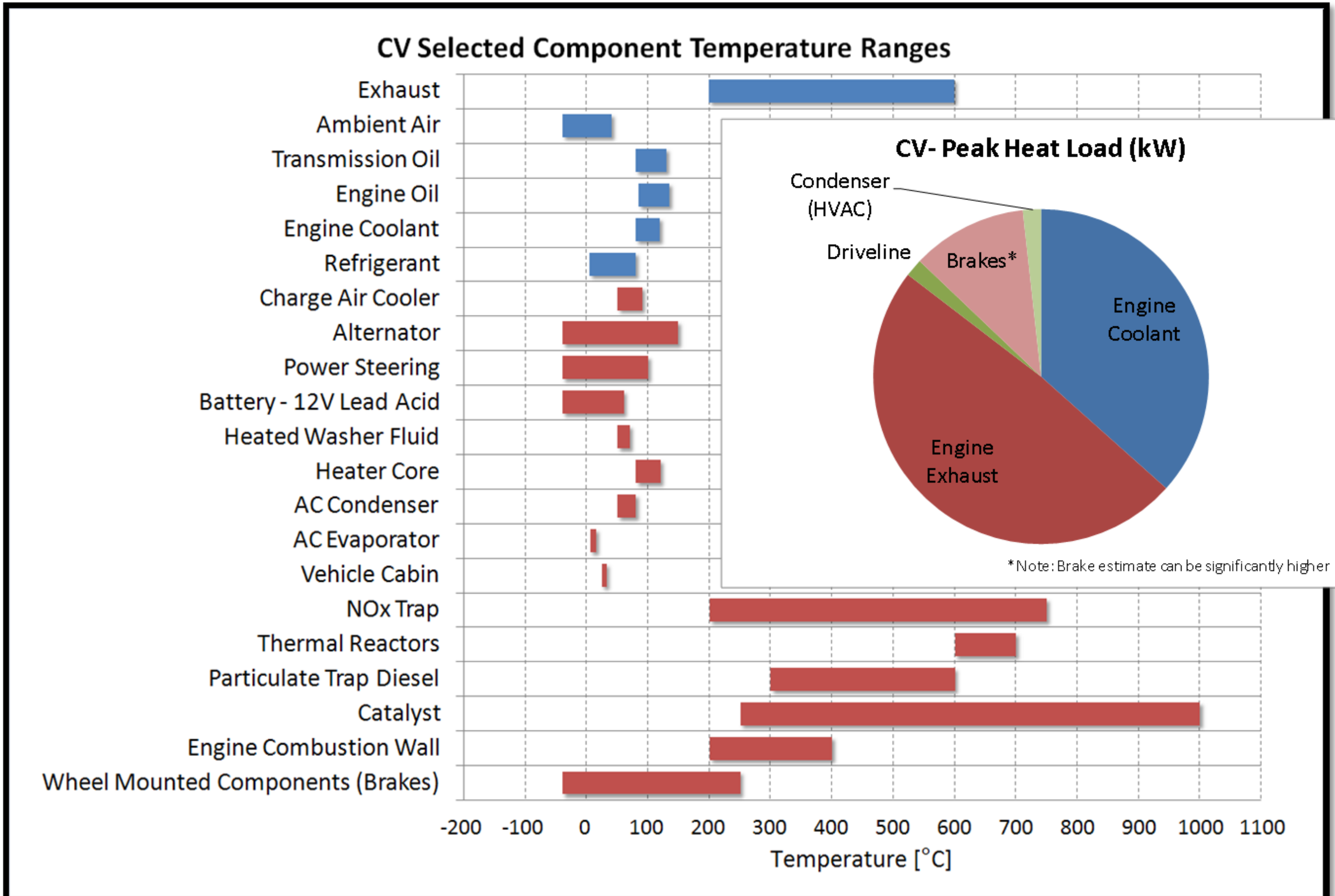
Configuration	Component	Peak Output Power (kW)
Conventional Vehicle (CV)+	Engine (ICE)	122
HEV+	Engine (ICE) Electric Machine Inverter Battery	82 39 39 50
PHEV+	Engine (ICE) Electric Machine Inverter Battery	79 44 44 47
Fuel Cell Vehicle (FCV) (Battery and DC/DC converter not included)	Fuel Cell Electric Machine Inverter	150 120 120
Electric Vehicle (EV)	Electric Machine Inverter Battery	120 120 150



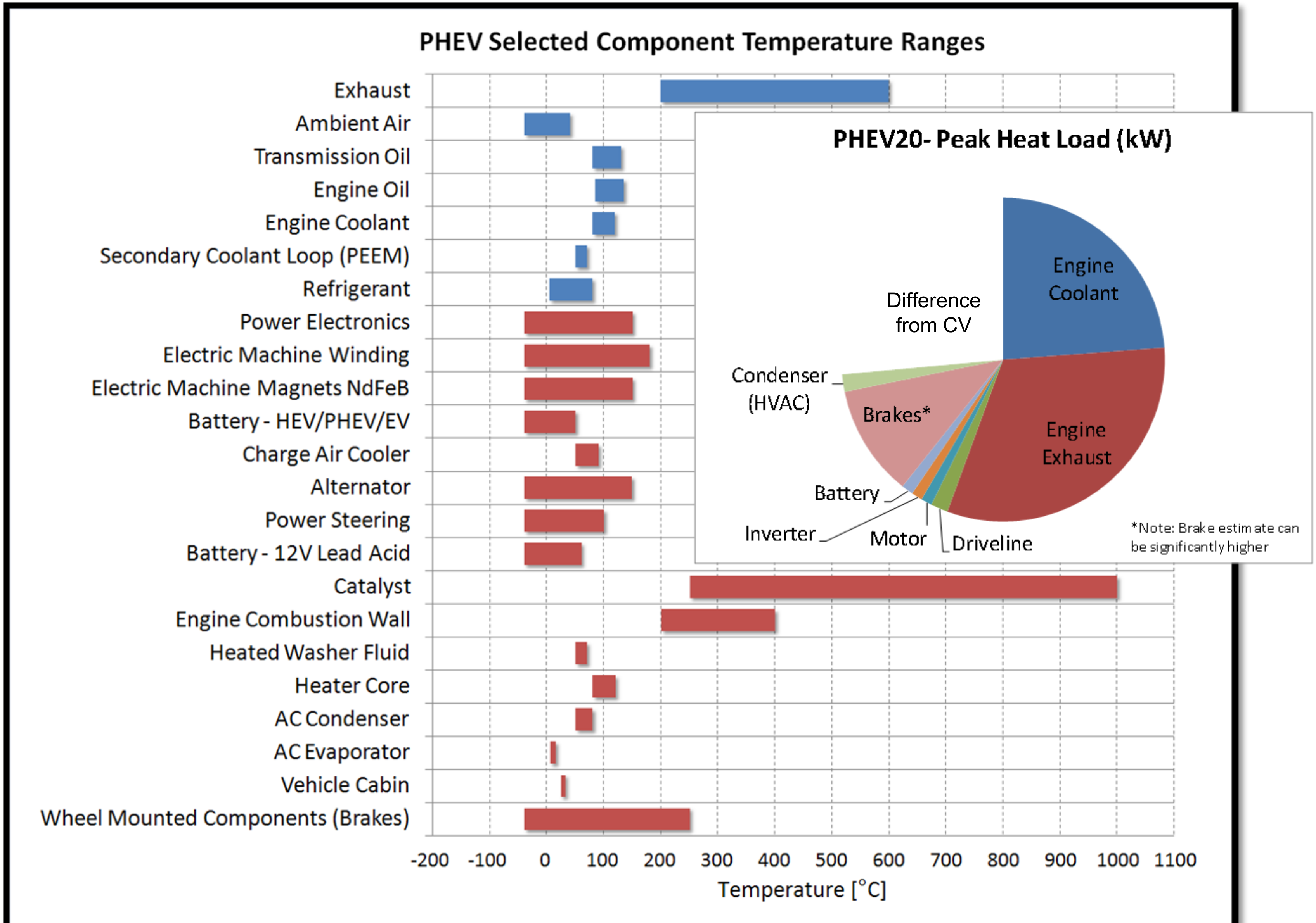
*Note: Brake values can be significantly higher. Comparison value based on the kinetic energy of a midsize vehicle at 40 MPH stopping within 7 seconds.

+References: 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



Technical Accomplishments



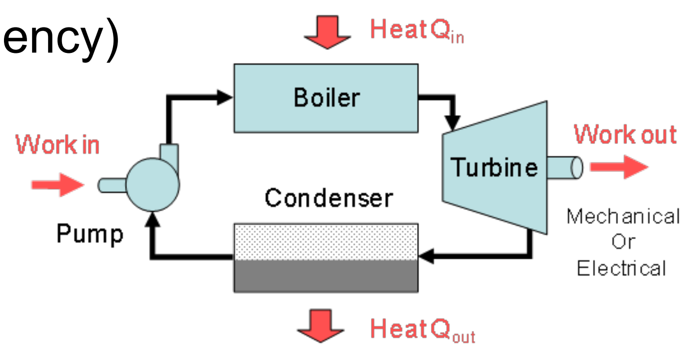
Technical Accomplishments

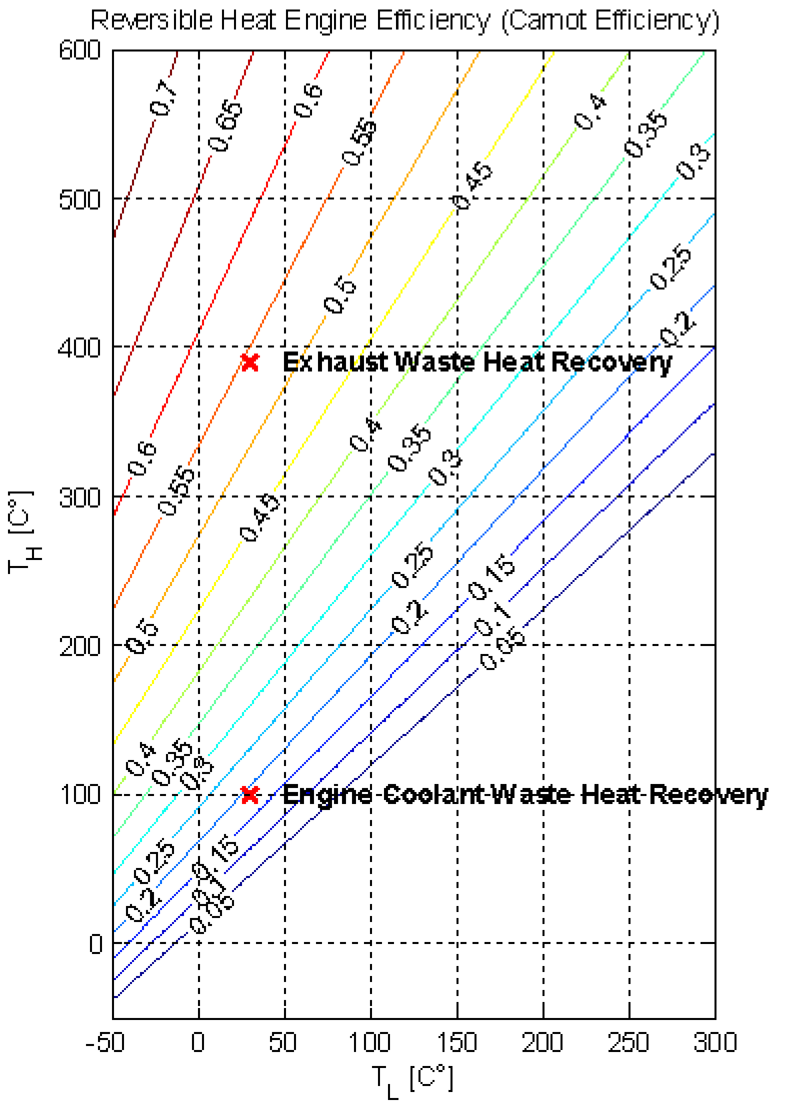
Waste Heat Recovery

- Large heavy-duty diesel applications would see the most benefit.
- Lower heat source temperatures and intermittent heat source operation decrease performance.
- Includes:
    - Turbo-Compounding.
    - Thermoelectrics.
    - Rankine Cycle (shown below).
    - etc.

(Thermal Efficiency)

$$\eta_{th} = \frac{W_{net}}{Q_{in}}$$





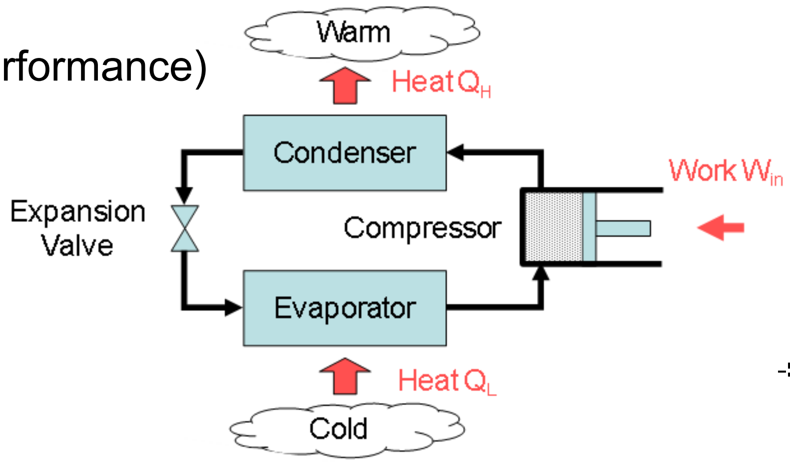
Technical Accomplishments

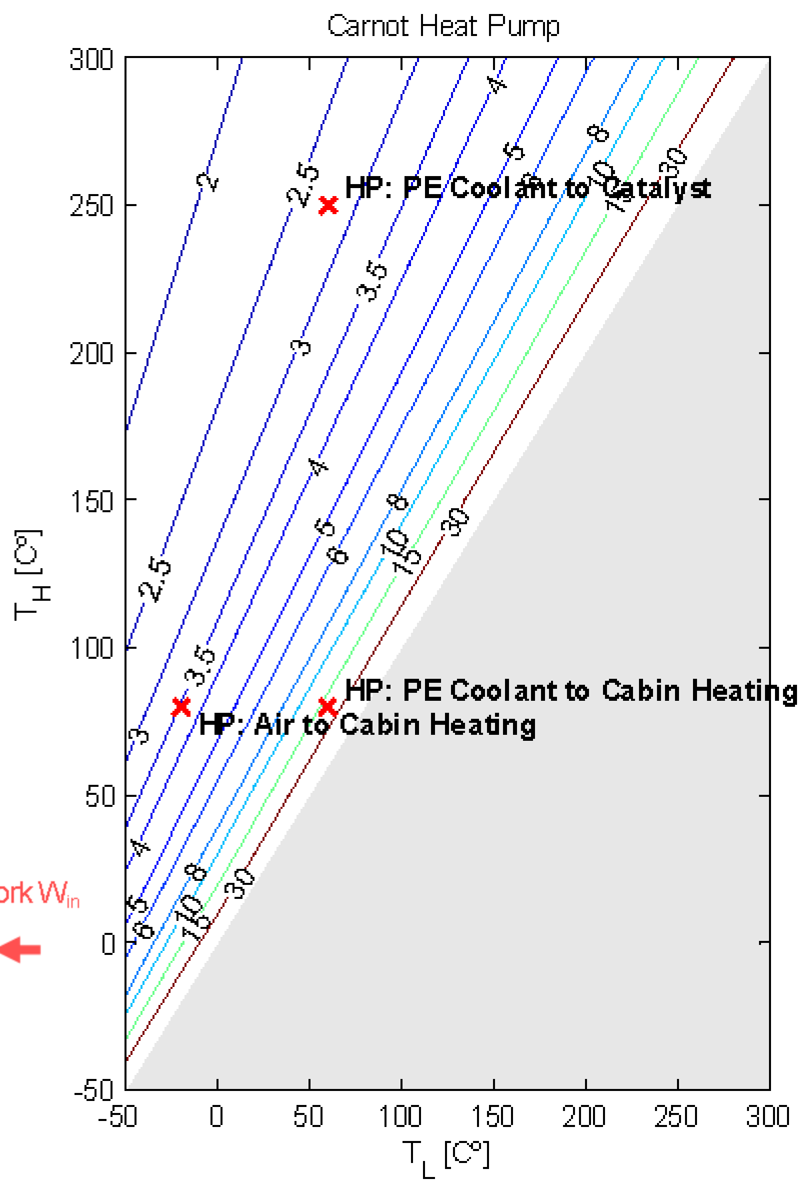
Heat Pump

- Transfers heat from low temperature environment to a higher temperature environment.
- Performance degrades as temperature delta increases.
- Cabin heating uses: Reverse AC system to aid cabin heating.
  - Air source heat pumps can freeze.
  - Coolant source heat pumps increase coolant warm-up time.
  - Window fogging safety concern.

(Coefficient of performance)

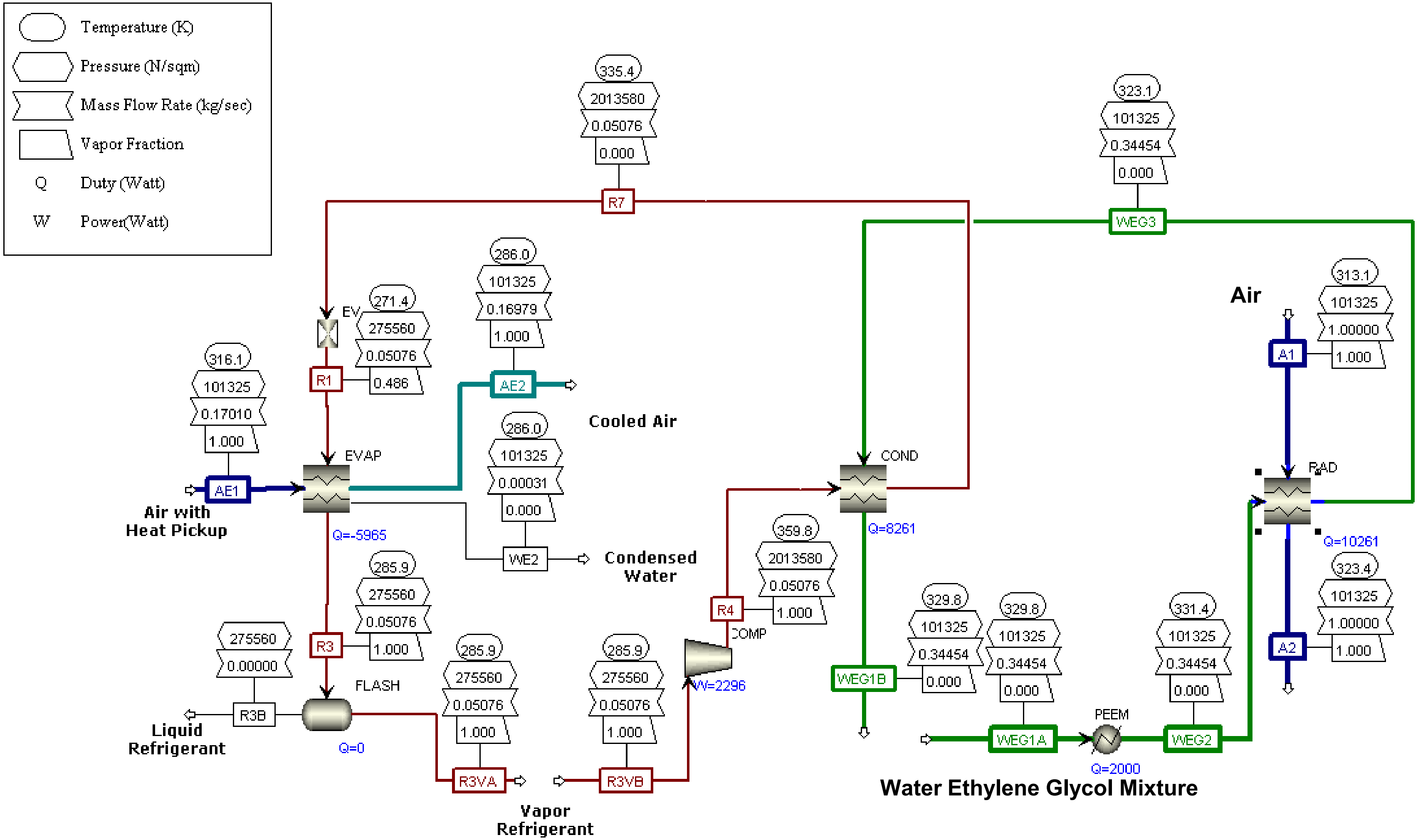
$$COP_{HP} = \frac{Q_H}{W_{in}}$$



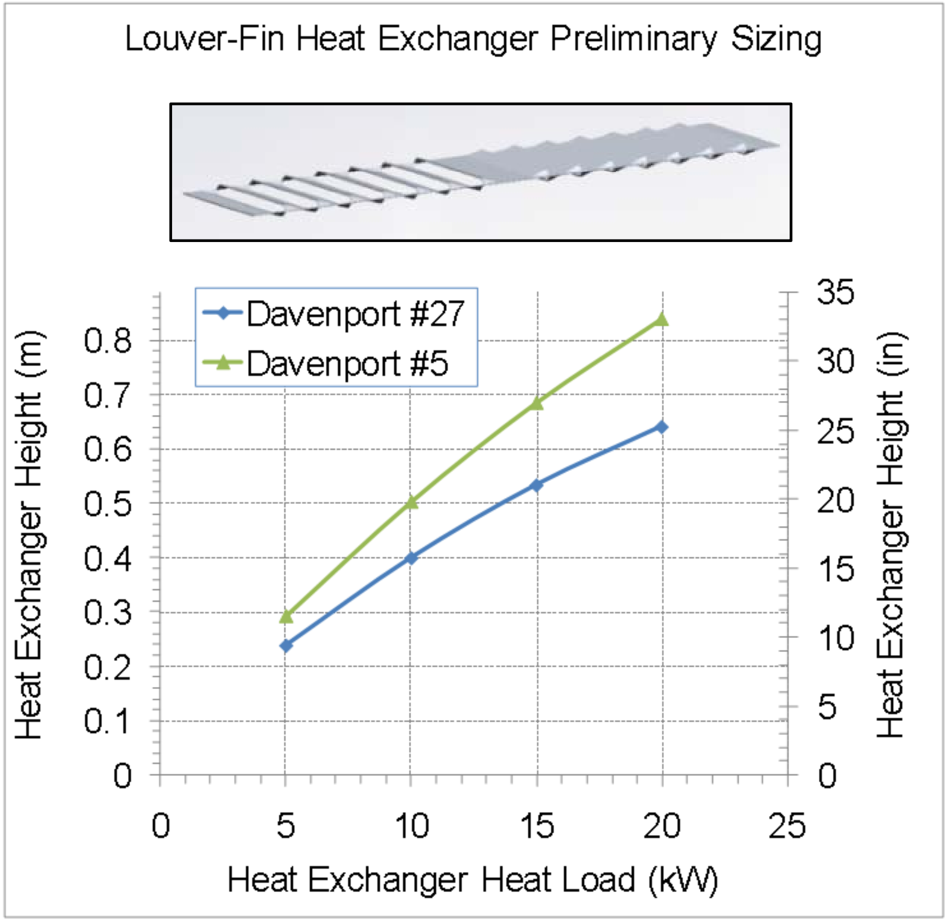


Technical Accomplishments

- Developing methodology and analysis capabilities to evaluate options for integrated thermal management.
- Example shows integration of AC condenser and PE coolant loops.



Technical Accomplishments



- Preliminary heat exchanger sizing shows potential to integrate PE and AC condenser cooling into an integrated system within a vehicle package.

Assumptions:

- Fixed width 711 mm or 28 in.
- Air mass flux 5.42 kg/s-m^2 based on minimum free-flow cross-sectional area.
- Water ethylene glycol mass flow 0.35 kg/s (~20L/min).
- Aluminum construction (k=170W/m-K).
- Air inlet temperature 40°C.
- Water ethylene glycol outlet temperature 50°C.

*References: C. Davenport., "Correlations for Heat Transfer and Flow Friction Characteristics of Louvred Fin." Proceedings of the 21st National Heat Transfer Conference, AlChE Symposium Series N0. 225 1983.
Y. Park and A. Jacobi, "Air-Side heat Transfer and Friction Correlations for Flat-Tube Louver-Fin Heat Exchangers." Journal of Heat Transfer, Vol. 13, 2009.

Future Work

- Refine heat exchanger and integrated cooling analytical analysis methods (FY09).
  - Integrate pressure drop analysis.
  - Explore alternative heat exchanger designs.
  - Develop analytical models for alternative integrated packages.
- Peak vs. continuous component heat loads and variation over drive cycles across multiple vehicle propulsion configurations (FY09-FY10).
- Investigation of thermal energy storage technologies and other waste heat utilization technologies (FY09-FY10).
- Hardware validation with industry partner (FY10).

Summary

- Advanced energy efficient vehicles face multiple challenges related to thermal management, such as PHEVs.
  - Low waste heat availability with engine off.
  - Cabin heating.
  - Thermal management of additional subsystems.

- Power electronics waste heat recovery is limited due to the lower quantity(kW) and quality(°C) energy in the liquid coolant loop.

- Integrated or combined cooling loops could potentially include opportunities for power electronics.

- Initial analytical capabilities and methodologies to evaluate integrated thermal management options and heat exchanger impacts have been developed.