NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Thermal Performance Benchmarking




Gilbert Moreno
Organization: NREL
Email: Gilbert.Moreno@nrel.gov
Phone: 303-275-4450

Team members/collaborators: Kevin Bennion (NREL), Tim Burress (ORNL)

USDRIVE
DRIVING RESEARCH AND INNOVATION FOR VEHICLE EFFICIENCY AND ENERGY SUSTAINABILITY

U.S. DEPARTMENT OF ENERGY
Energy Efficiency & Renewable Energy

DOE Vehicle Technologies Office
Electric Drive Technologies
FY15 Kickoff Meeting

Oak Ridge National Laboratory
Oak Ridge, Tennessee
November 18 – 20, 2014

This presentation does not contain any proprietary or confidential information.

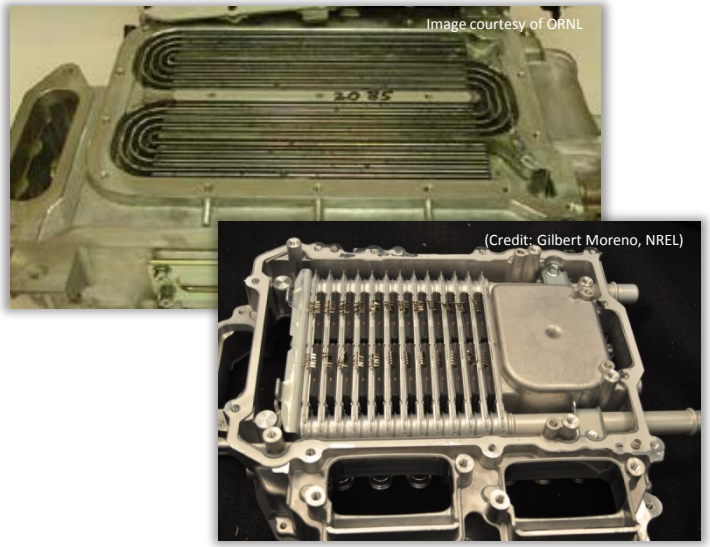
NREL/PR-5400-63001

State-of-the-Art Thermal Management Systems

Power electronics thermal management

- Cast aluminum, serpentine channel heat exchangers
- Double-side cooling of power modules

2012 Nissan Leaf



2013 Toyota Camry

2012 Nissan Leaf

Electric motor thermal management

- Liquid (water-ethylene glycol)-cooled stator jacket
- Automatic transmission fluid-cooled end-windings

Proposed Technology
Strategy to Address Limitations of SOA

- Provide insight into various thermal management technologies
- Identify areas of improvement to advance thermal management SOA
- Complement Oak Ridge National Laboratory's (ORNL's) benchmarking of power electronics and electric motors project, but only focus on the thermal management technologies

Challenges/Barriers to Meet Project Goals

- Obtaining the vehicle components may be an issue

- Experiments may not exactly replicate the actual automotive environments or operating conditions

Project Approach: Objectives and Motivation

Overall objective: To benchmark the thermal characteristics of the power electronics and electric motor thermal management systems

- Establish baseline metrics for the thermal management systems
- Evaluate advantages and disadvantages of different thermal management systems
- Identify areas of improvement to advance the SOA

FY15 objective: Benchmark the 2012 Nissan Leaf power electronics and motor thermal management systems

- ORNL benchmarked the electrical aspects of the 2012 Nissan Leaf in 2013

Motivation: Help industry to reduce the weight, volume, and cost of vehicle traction-drive systems by providing information that may influence future product designs; also help guide future APEEM R&D efforts

Project Approach: Overview

Collaborate with industry and ORNL to identify the vehicle system to benchmark

Acquire the vehicle components

Measure the characteristics of the thermal management systems

- Experimentally measure thermal performance metrics
- Utilize modeling, particle image velocimetry, high speed video, and infrared imaging to understand heat transfer mechanisms

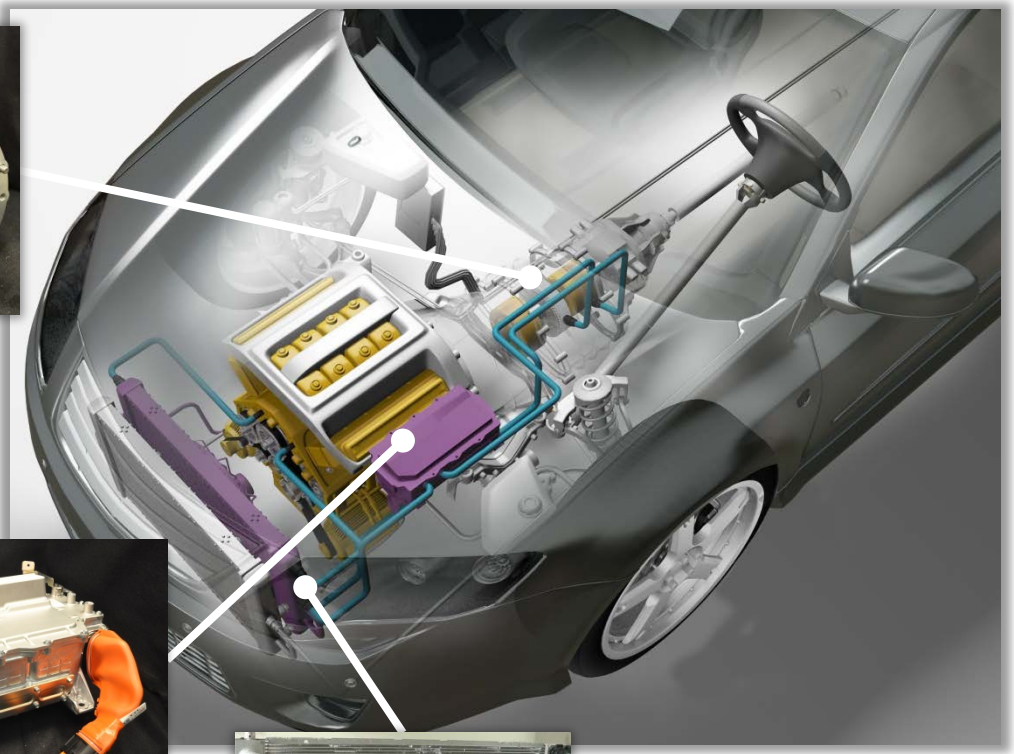
Analyze the data and calculate thermal performance metrics

Share results with industry and research institutions

Project Approach: Thermal Measurements

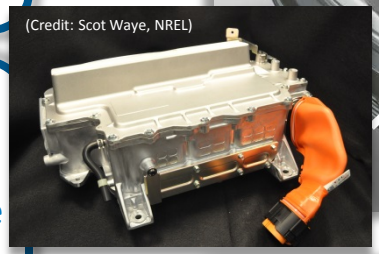
Electric motor thermal management

- Winding-to-liquid thermal resistance
- Motor lamination and winding thermal properties
- Pressure drop through the heat exchanger
- Volume and weight of the heat exchanger



Power electronics thermal management

- Junction-to-liquid thermal resistance
- Interface material thermal resistance
- Capacitor thermal properties
- Thermal resistance and pressure drop through the heat exchanger
- Volume and weight of the heat exchanger



Thermal management components

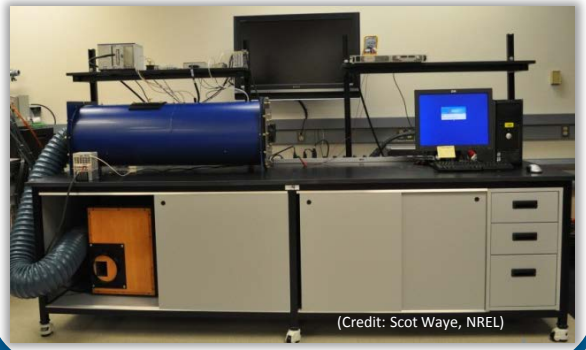
- Pump pressure versus flow rate characteristics and efficiency
- Radiator thermal resistance and liquid- and air-side pressure drop

Project Approach: NREL Lab Facilities Utilized

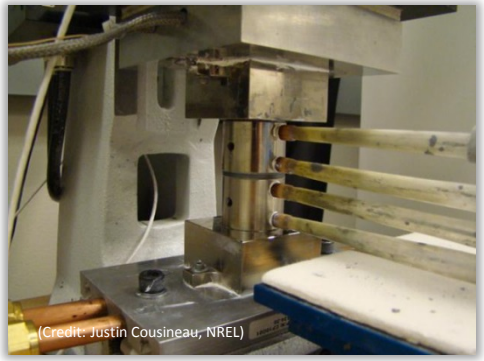
Water–ethylene glycol (WEG) test bench

Transient thermal tester (T3ster)

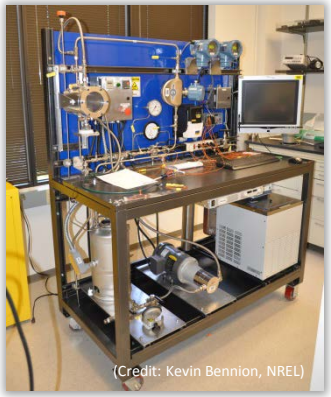
Air-cooling test bench



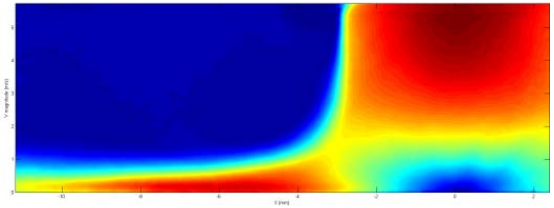
ASTM thermal interface material (TIM) test bench



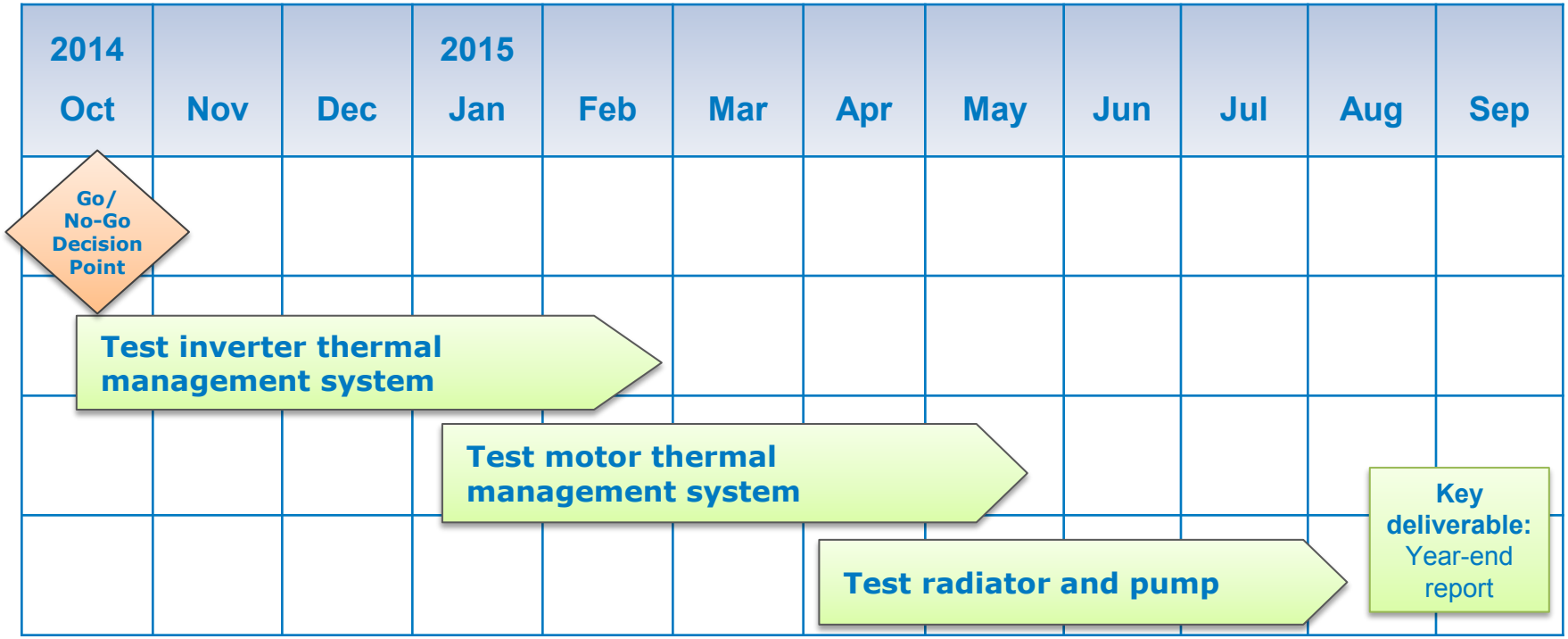
Automatic transmission fluid test bench



Particle image velocimetry, high-speed video, and infrared imaging cameras



FY15 Tasks to Achieve Key Deliverable



Go / No-Go Decision Point: Determine if a vehicle system is available and relevant for benchmarking

Key Deliverable: A year-end report describing the thermal characteristics of the 2012 Nissan Leaf power electronics and motor thermal management systems

2012 Nissan Leaf Traction-Drive Thermal Management System

Inverter thermal management system

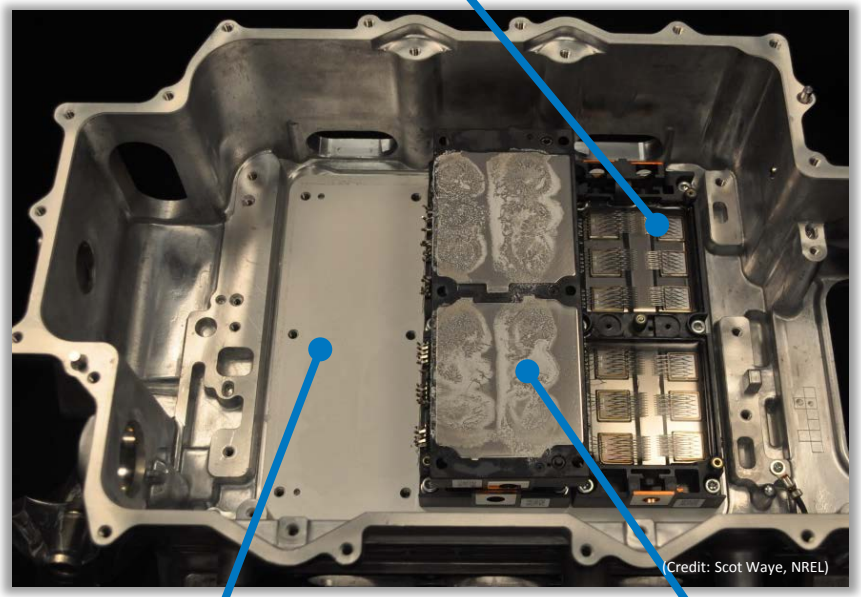
Electric motor thermal management system

Cooling system components (radiator and pump)

Inverter Thermal Management System Tests

- Power modules are attached to an aluminum cold plate
- Devices are bonded to a copper-molybdenum plate that helps to spread heat but leaves the backside of the modules electrically active
- Dielectric insulator is provided to electrically isolate the modules

Measure the thermal resistance
- *total resistance (junction-to-liquid),*
- *passive stack resistance (junction-to-case).*



Measure the dielectric insulator thermal resistance

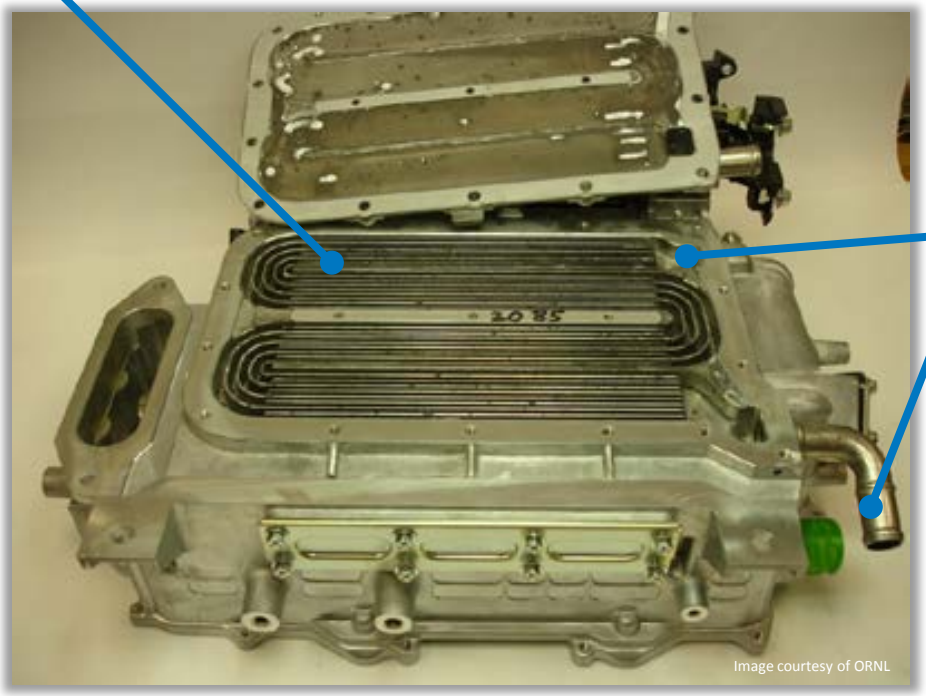
Measure the TIM thermal resistance

Measure the capacitor thermal conductivity

Inverter Thermal Management System Tests

- Serpentine channel-type heat exchanger that uses WEG

Measure the cold plate thermal resistance



Measure the coolant pressure drop

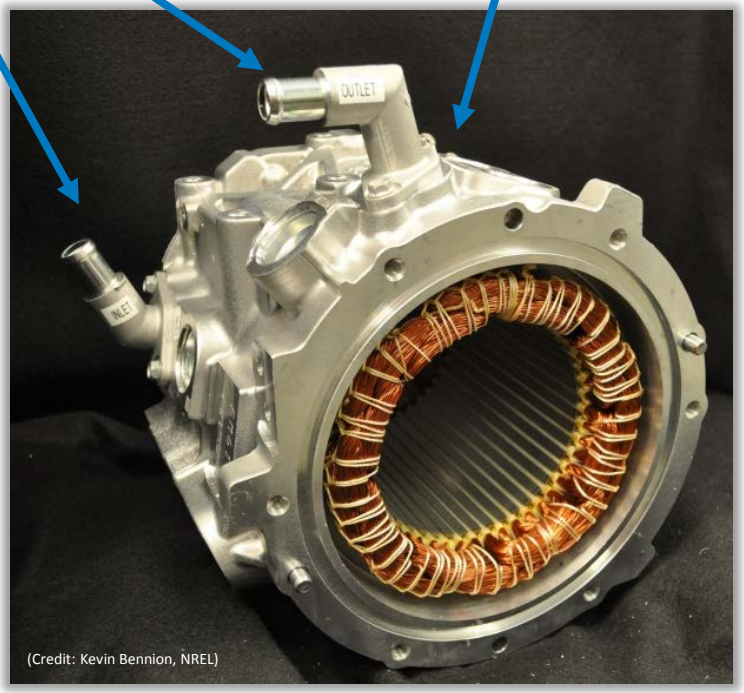
Motor Thermal Management System

- Motor is cooled with an aluminum cooling jacket that surrounds the stator
- WEG is circulated through the cooling jacket channels

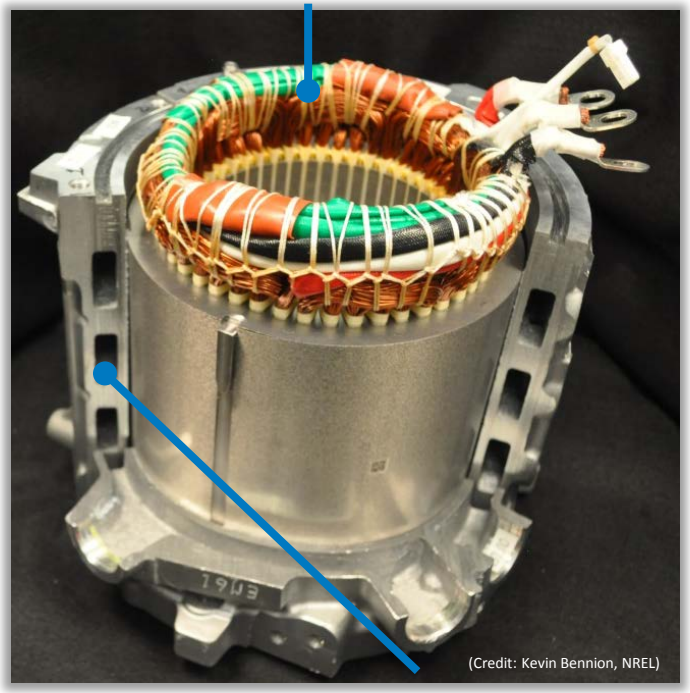
WEG outlet

WEG inlet

Liquid cooling jacket



Measure the total thermal resistance (winding-to-liquid)

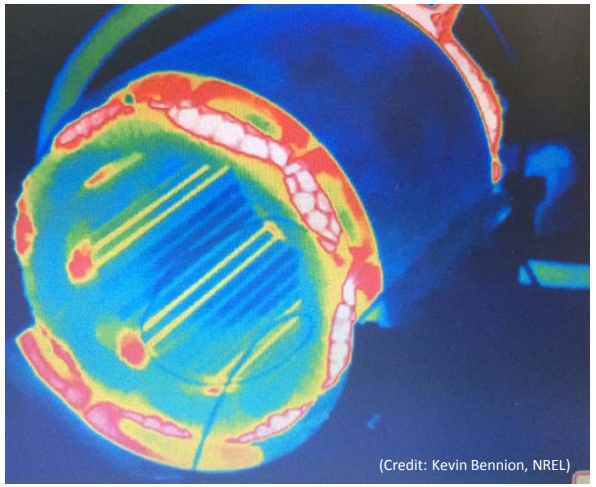


Measure the coolant pressure drop

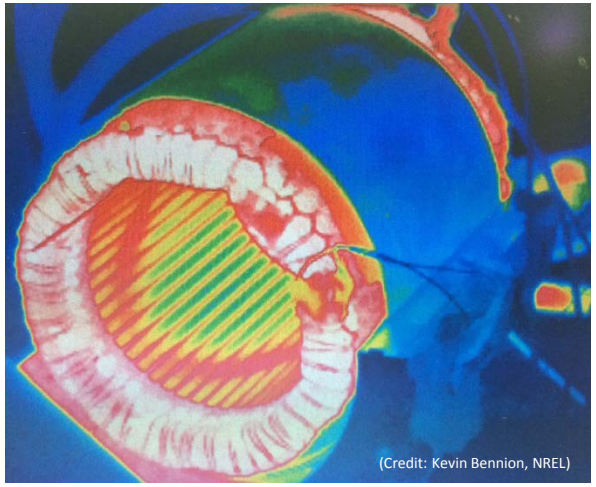
Motor Thermal Management System Tests

- Circulate WEG through the cooling jacket
- Heat the windings by running a high current (low voltage) through each of the phases
- Measure the end-winding temperature using thermocouples, copper electrical resistance measurements, and/or infrared imaging

Thermal image of motor with single phase heated



Thermal image of motor with all phases heated

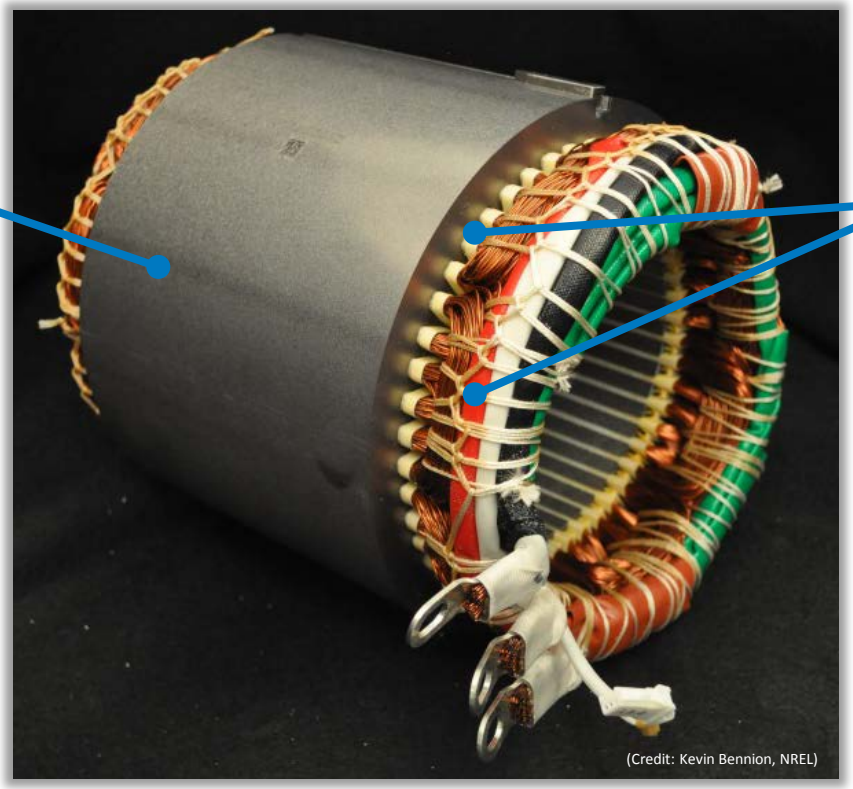


Motor Thermal Management System Tests

Motor passive-stack thermal properties

- Measure the effective thermal conductivity and heat capacity

Measure the stator lamination effective thermal conductivity and specific heat



Measure the end- and slot-winding effective thermal conductivity and specific heat

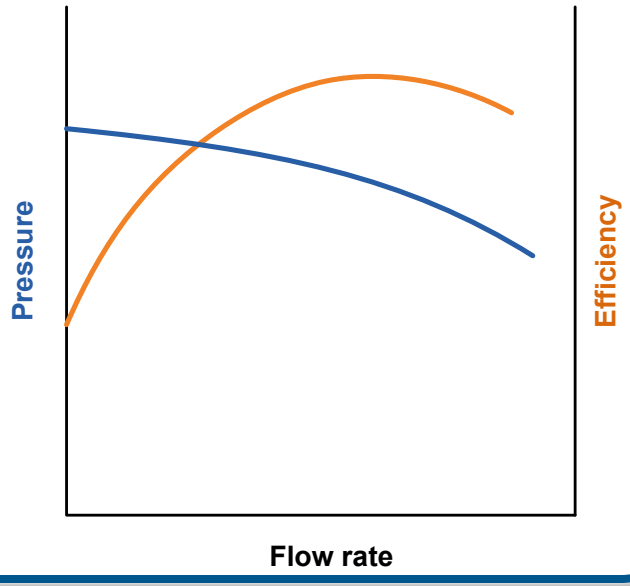
System Component Tests

Radiator

- Air-to-liquid thermal resistance (at various air-flow rates)
- Air- and liquid-side pressure drops
- Volume and weight

Coolant pump

- Pressure versus flow rate
- Efficiency versus flow rate
- Volume and weight



Calculate System Thermal Metrics

Measure:

- Component (inverter, motor, radiator) and total (junction-to-air, winding-to-air) thermal resistances
- Total parasitic power
- Total volume and weight

Compute:

- System coefficient-of-performance
- Thermal power density
- Thermal specific weight

Identify thermal bottlenecks and propose strategies to improve thermal management

FY16 Task Description

- Benchmark the thermal characteristics of the 2014 Honda Accord (hybrid) inverter and electric motor thermal management systems

Collaborate with industry and ORNL to identify the vehicle system to benchmark

Acquire the vehicle components

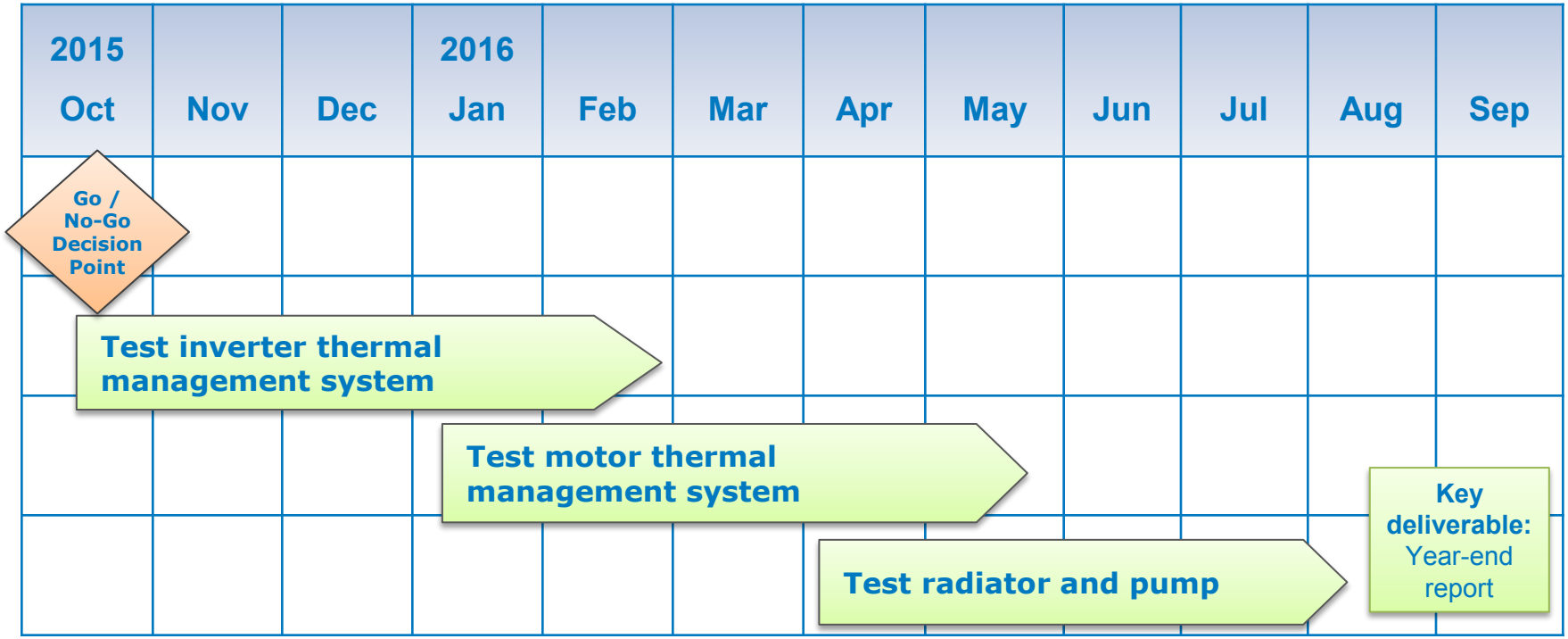
Measure the characteristics of the thermal management systems

- Experimentally measure thermal performance metrics
- Utilize modeling, particle image velocimetry, high-speed video, and infrared imaging to understand heat transfer mechanisms

Analyze the data and calculate thermal performance metrics

Share results with industry and research institutions

FY16 Tasks to Achieve Key Deliverable



Go / No-Go Decision Point: Determine if a vehicle system is available and relevant for benchmarking

Key Deliverable: A year-end report describing the thermal characteristics of the 2014 Honda Accord Hybrid power electronics and motor thermal management systems

FY17 Task Description

- Vehicle system to be benchmarked remains to be identified

Collaborate with industry and ORNL to identify the vehicle system to benchmark

Acquire the vehicle components

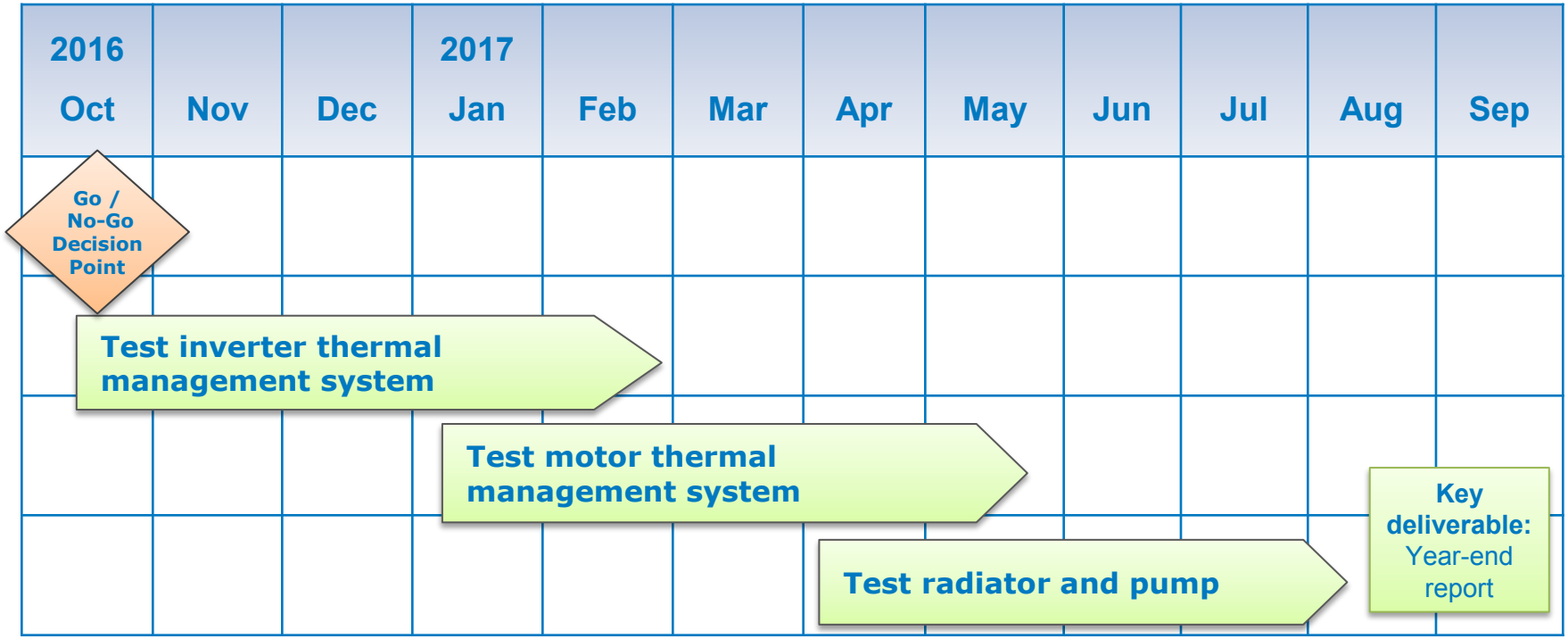
Measure the characteristics of the thermal management systems

- Experimentally measure thermal performance metrics
- Utilize modeling, particle image velocimetry, high-speed video, and infrared imaging to understand heat transfer mechanisms

Analyze the data and calculate thermal performance metrics

Share results with industry and research institutions

FY17 Tasks to Achieve Key Deliverable



Go / No-Go Decision Point: Determine if a vehicle system is available and relevant for benchmarking

Key Deliverable: A year-end report

Project Summary

Project Duration: FY15 – FY17 **Overall Objective (all years): Benchmark the thermal characteristics of the power electronics and motor thermal management systems**
FY15 Focus: Benchmark the 2012 Nissan Leaf thermal management systems
Deliverable: Year-end report detailing the performance of the 2012 Nissan Leaf power electronics and motor thermal management systems
Go/No-Go Decision Point: Determine if a vehicle system is available and relevant for benchmarking
FY16 Focus: Benchmark the 2014 Honda Accord Hybrid thermal management systems
Deliverable: Year-end report detailing the performance of the 2014 Honda Accord Hybrid power electronics and motor thermal management systems
Go/No-Go Decision Point: Determine if a vehicle system is available and relevant for benchmarking
FY17 Focus: Benchmark the performance of a vehicle's thermal management systems
Deliverable: Year-end report
Go/No-Go Decision Point: Determine if a vehicle system is available and relevant for benchmarking

Technology-to-Market Plan

- Results from these benchmarking studies will be a resource to industry and may influence future industry product designs

- Help guide future APEEM R&D efforts

Partners/Collaborators

Organization	Role
Oak Ridge National Laboratory	• Benchmark the packaging, materials, and electrical performance aspects of the power electronics and electric motor(s) • Consulted on thermal benchmarking activities

Acknowledgments:

Susan Rogers and Steven Boyd
U.S. Department of Energy

For more information, contact:

Principal Investigator
Gilbert Moreno
Gilbert.Moreno@nrel.gov
Phone: (303) 275-4450

Team Members:

Kevin Bennion (NREL)
Tim Burress (ORNL)

APEEM Task Leader:

Sreekant Narumanchi
Sreekant.Narumanchi@nrel.gov
Phone: (303) 275-4062