Advanced Technology Vehicle Lab Benchmarking - Level 2 (in-depth)

2011 DOE Hydrogen Program and Vehicle Technologies Annual Merit Review

May 10, 2011

Eric Rask

Argonne National Laboratory

Sponsored by Lee Slezak

U.S. Department of Energy

Energy Efficiency and Renewable Energy

Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable

Project ID # VSS031

Overview

- **Timeline**

  2010 Vehicle: Gen 3 Prius
  - CAN Decoding – Q2 2010
  - Vehicle Instrumentation – Q2/3 2010
  - Vehicle Testing (Phase 1) – Q3/4 2010
  - Torque sensor design/install - Q4 2010
  - Vehicle testing (Phase 2) Q4 2010

  2011 Vehicles
  - Developing test/instrumentation plans
  - Purchasing vehicles (OEM delays)

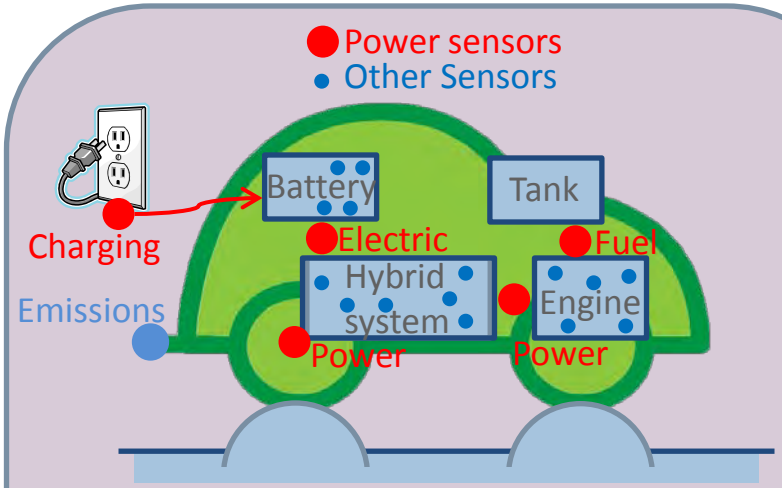
- **Budget**
  - FY 2010 $350k
    - Gen3 Toyota Prius
  - FY 2011 $850k
    - Hyundai Sonata Hybrid
    - VW TSI with 7-speed DCT
    - Chevrolet Volt EREV

- **DOE strategic goals/barriers addressed**
  - Availability of detailed vehicle and component data/operation
  - Codes and standards development
  - Continued support for model development and validation (AUTONOMIE) with test data
  - Assist in technical goal setting

- **Partners**
  - DOE and other National Laboratories
  - USCAR, OEMs, and Suppliers

Approach/Strategy: Focus on In-depth Testing and Analysis

Level 2: In-depth Testing



Invasive instrumentation:

- Incremental to level 1 ANL Benchmark Approach
- Engine, shaft torque & speed sensors
- All major power flows (mechanical, electric,…)
- Component specific instrumentation

Purpose:

- Energy analysis, efficiency analysis on vehicle and components
- Component characterization in vehicle system

In-depth Testing Provides:

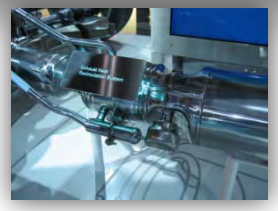
- Power-flow assessment
- Component performance
- Component duty cycles
- Operating temperatures
  - Nominal and de-rating
- In-situ component assessment

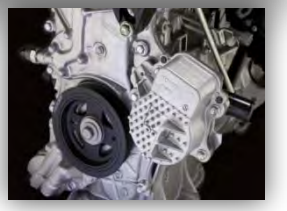
Extensive, publicly available data for advanced vehicles

Approach/Strategy: 3rd Generation Toyota Prius

Gen 3 Toyota Prius Specifications

- Gasoline Engine
  - 1.8 liters Atkinson cycle engine, 98 hp@5200
- Electric Motors
  - Permanent magnet AC synchronous motors
  - Traction motor: 60 kW, 207 Nm
  - Generator: 41 kW, 40 Nm (observed)
- Traction Battery + Boost Converter
  - 201.6V, NiMH pack
  - HV Boost converter to 650V





- **Notable Features**
  - 51/48/50 City/Hwy/Combined MPG
  - Advanced engine with EGR system
  - Exhaust heat recovery system
  - Significant accessory electrification
  - Revised transmission with motor speed reduction

Approach/Strategy: Extensive Vehicle Instrumentation

Significant instrumentation contributes to detailed vehicle/component understanding (100+ signals available for most tests)

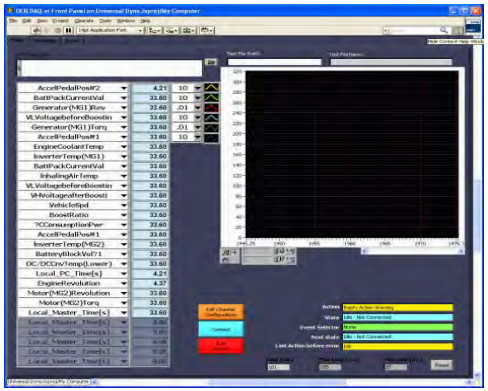
Engine Oil Temperature

Battery Voltage/Current

Direct Fuel Measurement

Engine Torque Sensor

Scan-tool OCR Module

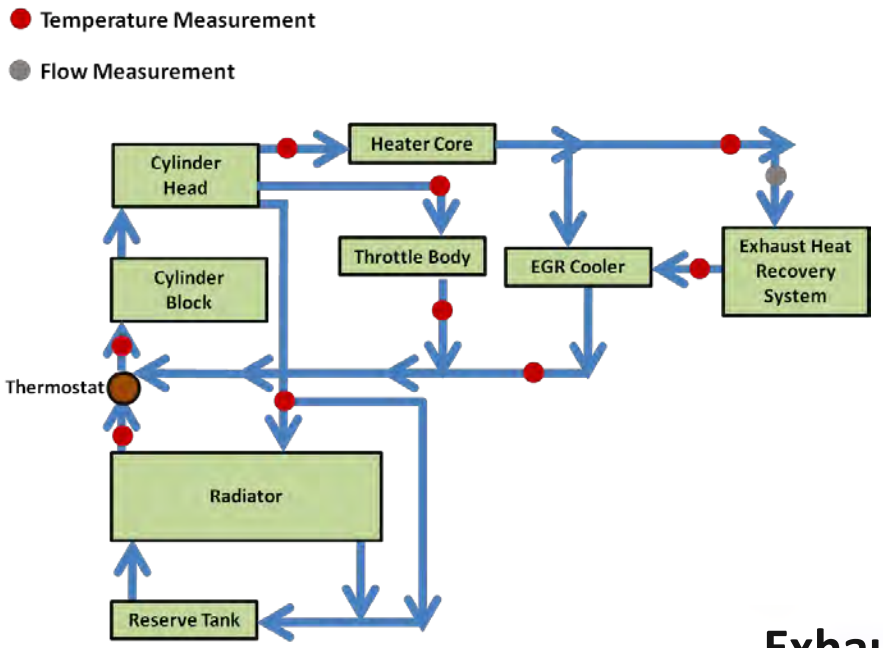


Trans. Oil Temperature

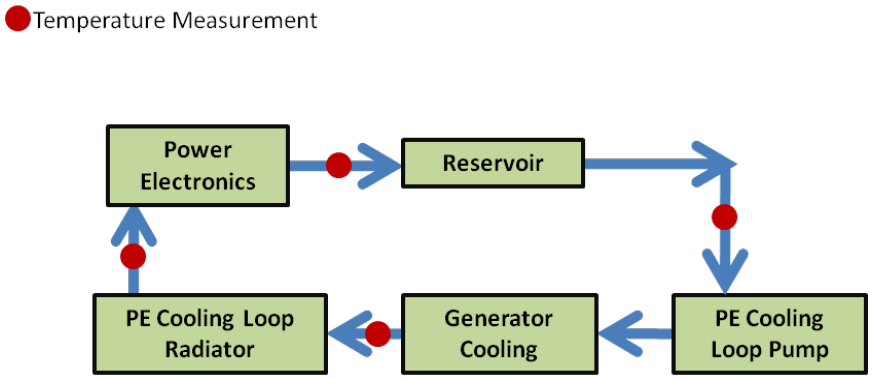
Approach/Strategy: Detailed Thermal Data Collection

Temperature and other measurements taken at numerous thermal nodes

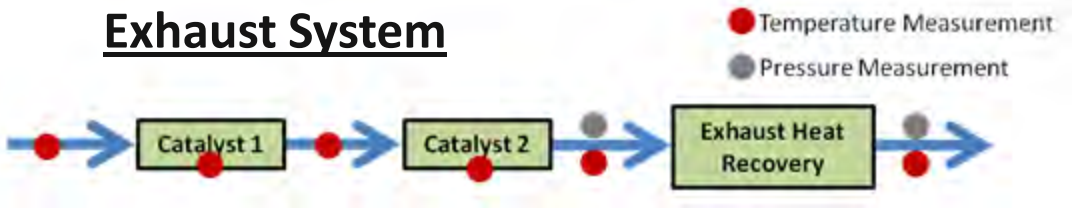
Main cooling system



Power Electronics Cooling



Exhaust System



Thermal instrumentation to leverage 5-cycle laboratory upgrade

Accomplishments: Fuel Economy and Vehicle Operation

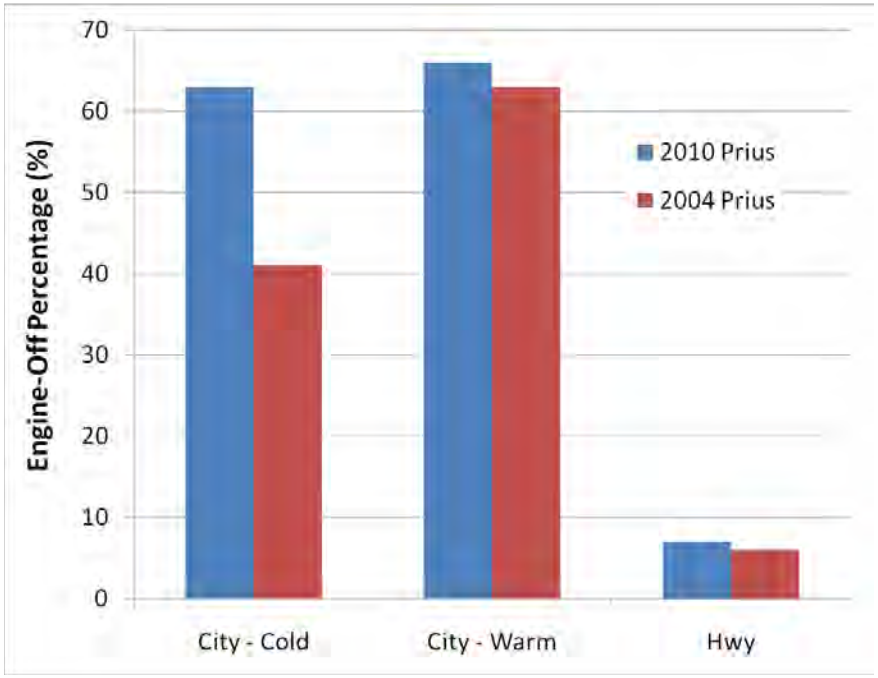
MY 2010 Vehicle Displays Improved Fuel Economy and More Electric-Only Capability

Fuel Economy

Despite larger vehicle size, Prius achieves improved City and Highway fuel economy

EV Operation

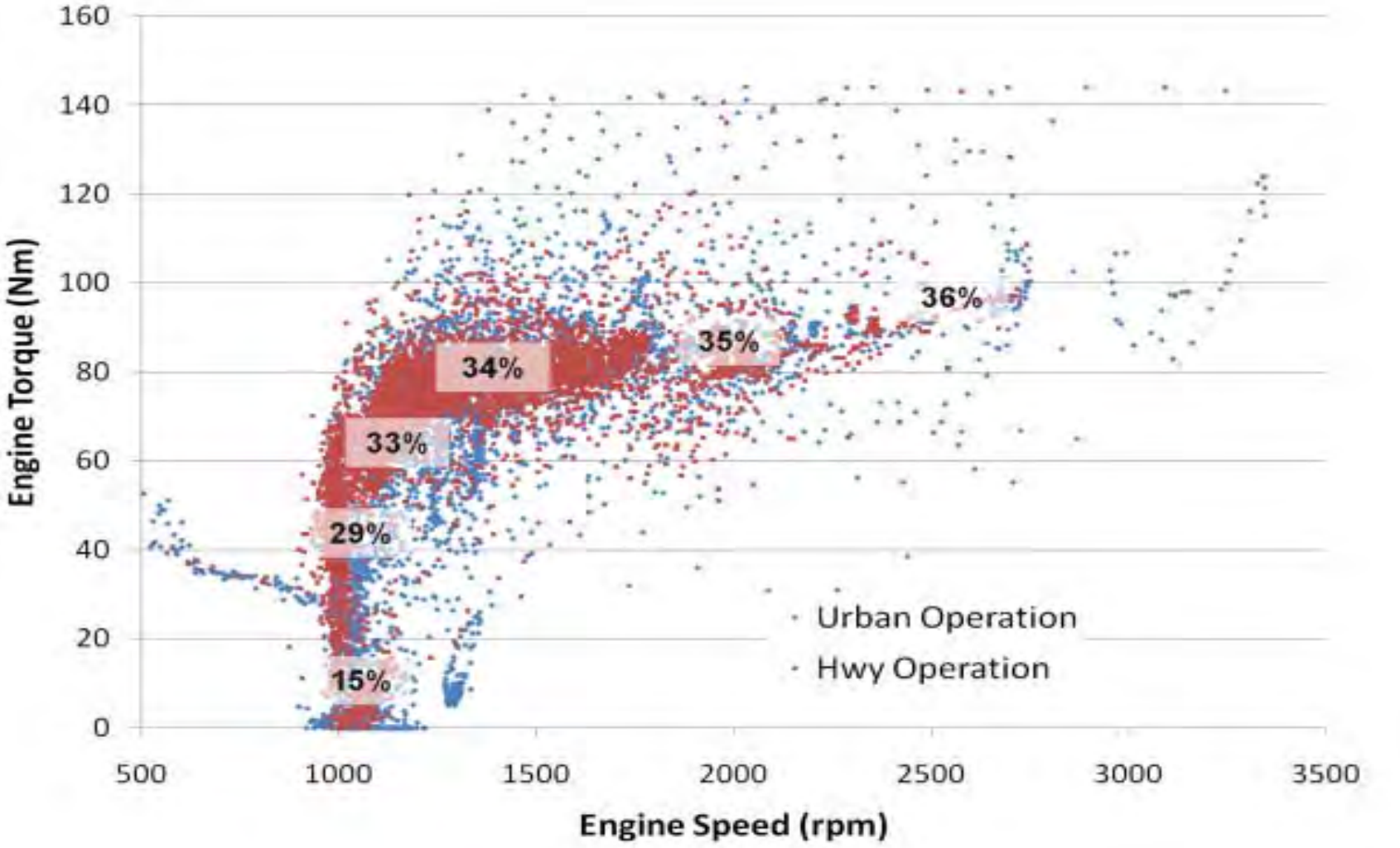
Prius shows more EV operation, especially during cold-city cycle operation



In-depth benchmarking seeks to better understand enablers for improvement

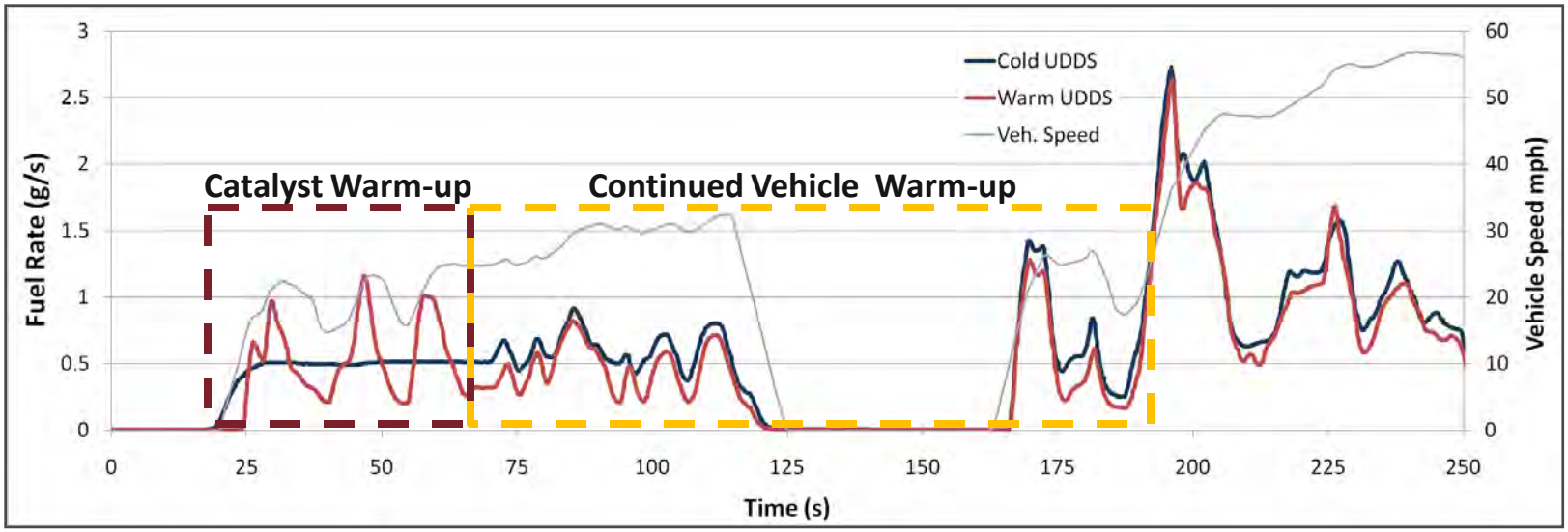
Accomplishments: In-depth Engine Operation and Efficiency

Prius shows high engine efficiency for a wide range of power levels (especially at higher engine speeds)

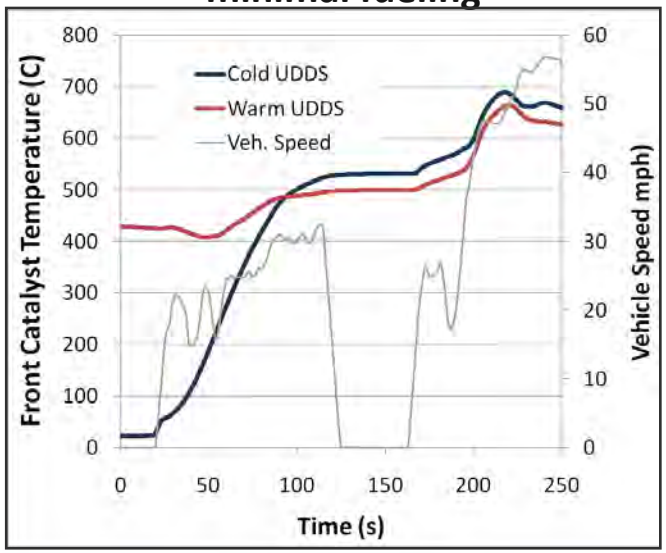


Accomplishments: Cold Engine Start Strategy Assessment

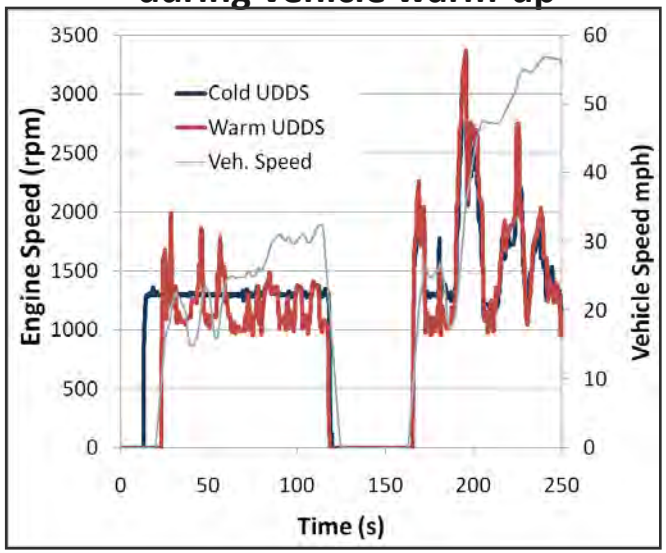
MY 2010 Prius uses a specialized cold-start/catalyst warm-up strategy



Fast catalyst warm-up with minimal fueling

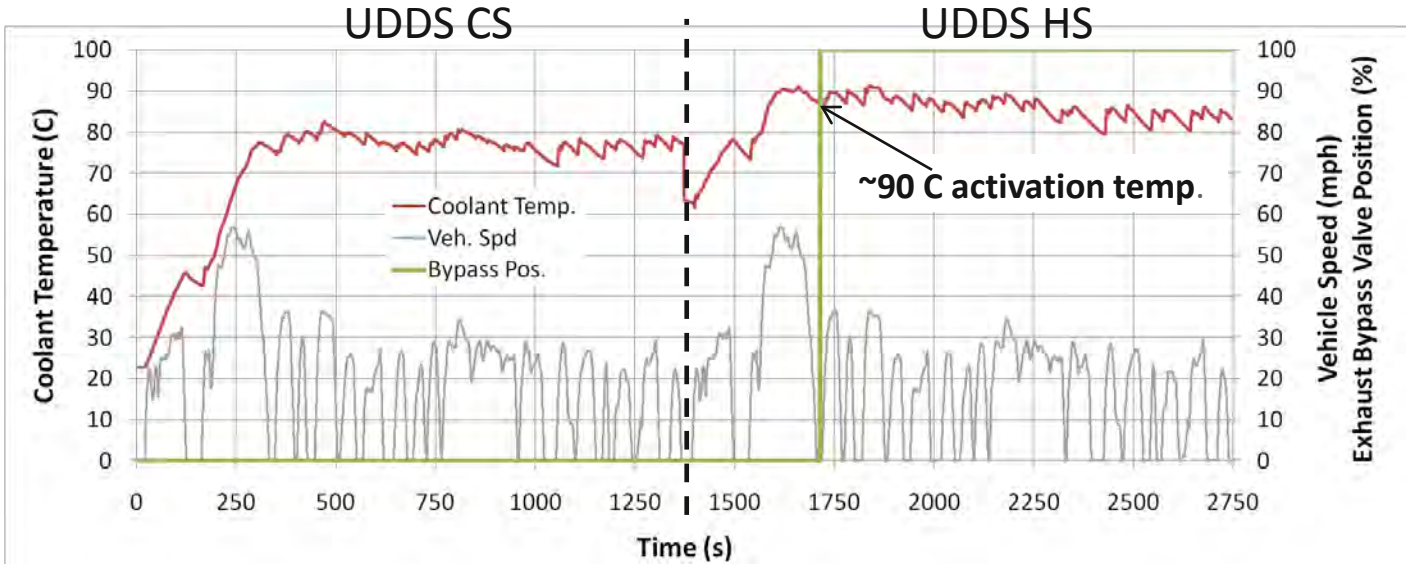


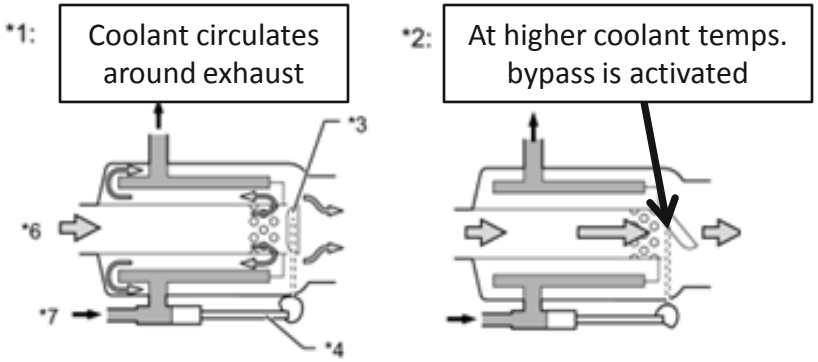
Reduced engine speed variability during vehicle warm-up



Accomplishments: Exhaust Heat Recovery System Evaluation

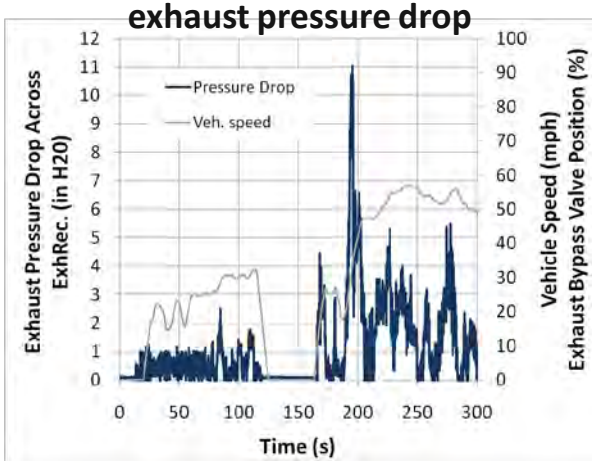
MY 2010 Prius utilizes an exhaust-to-coolant heat exchanger for improved warm-up. Larger impact expected during very cold ambient operation (FY11 testing)





* Figures from TMC Prius Manual

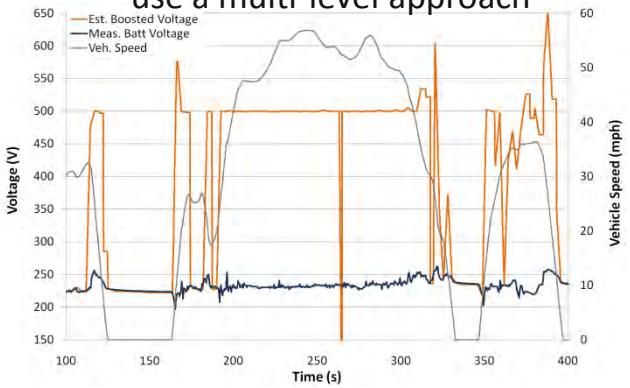
System does show an appreciable exhaust pressure drop



Accomplishments: Additional Component Usage and Analysis

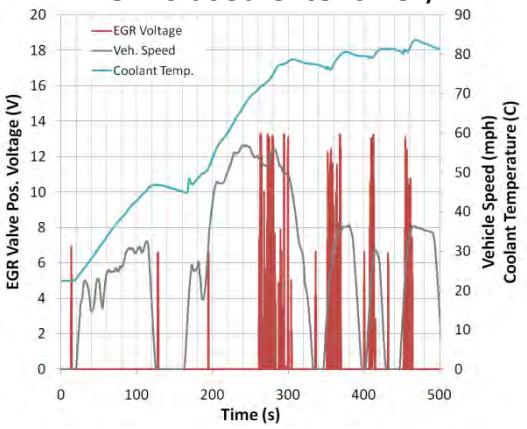
Boost Converter

Boost sees significant use, appears to use a multi-level approach



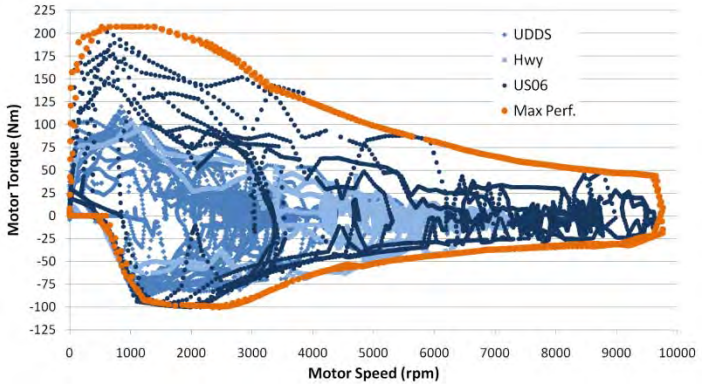
EGR Valve

Following coolant warm-up (~70C) EGR is used extensively



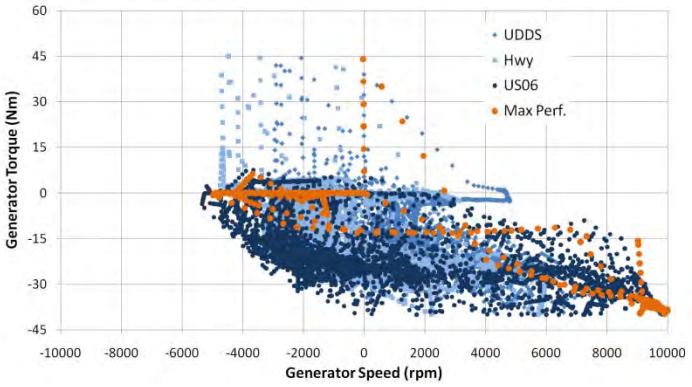
Traction Motor

207 Nm, 54 kW observed capability, regen. capability reduced due to system limits



Generator Motor

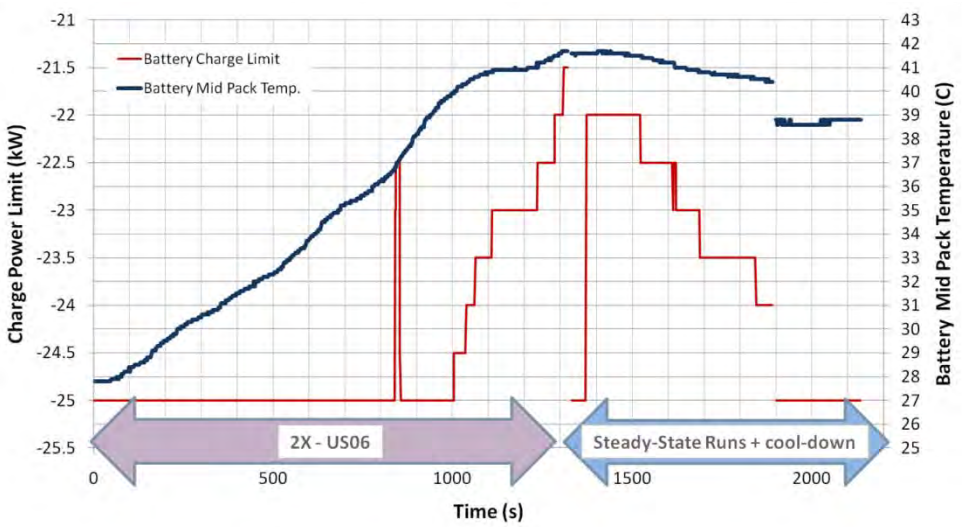
40 Nm, 41 kW observed capability



Accomplishments: Assessment of Battery Derating Strategy

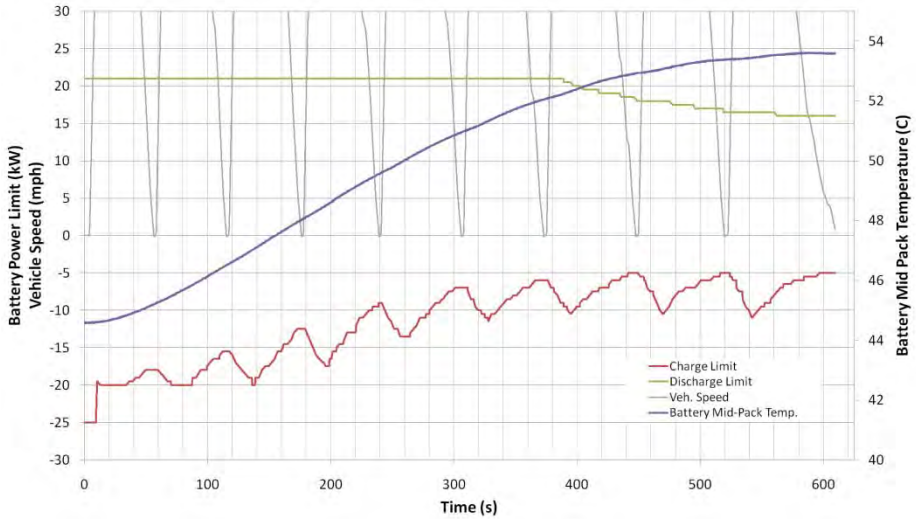
US06 and Steady-state Operation

- Battery first begins to derate charge power near 40C (Discharge begins later)
- Recharge power continues to reduce as battery continues to heat



Repeat Accelerations (higher temps)

- Charge power continues to derate and appears to adjust with vehicle speed
- Discharge power begins to derate near 52 C



Collaborations and Coordination with Other Institutions

In-depth Benchmarking Informs Many Stakeholders

J1711 HEV & PHEV test procedures

SAE International®

AVTA (Advanced Vehicle Testing activities)

- In-depth vehicle and component evaluation

INL Idaho National Laboratory · Argonne National Laboratory

In-depth Benchmarking

DOE technology evaluation

- DOE requests
- National Lab requests

NREL · ornl Oak Ridge National Laboratory · INL Idaho National Laboratory · Argonne National Laboratory

Automonie

- Support of modeling and simulation with data

AUTONOMIE

USCAR, tech teams and OEMs

- Shared test plans, data and analysis

FreedomCAR & Fuel Partnership

Future/On-going Work

- On-going 2011 In-depth Vehicle Benchmarking:

VW Jetta TSI
1.4L boosted Engine with 7-speed DCT offers increased performance and improved fuel economy

Hyundai Sonata Hybrid
Single-motor hybrid systems seeing renewed development as an alternative to power-split

Chevrolet Volt
Benchmarking geared toward standards validation and exploration of EREV real-world fuel economy

* Vehicle Images from Wikipedia, all images released into the Public Domain

- Gen 3 Prius evaluation across a range of hot and cold ambient temperatures underway for FY2011

- Continued in-depth benchmarking of state-of-the-art vehicles for integration into DOE planning, target setting, modeling/simulation, and standards development activities

Summary

In-depth testing of the MY2010 Toyota Prius aids in DOE goals of petroleum displacement/reduction through data dissemination and technology assessment:

- MY 2010 Prius establishes state-of-the-technology hybrid vehicle baseline
  - Larger, more efficient engine with EGR
  - Alternative engine cold-start operating strategy
  - Greater engine-off operation
  - Exhaust heat recovery system for improved warm-up
  - Significant electrification of accessories
- Generates data for model development and validation to facilitate increased speed-to-market of advanced technology (1+ GB of test data)
- Supports codes and standards development for unbiased technology assessment

In-depth benchmarking data and analysis are highly leveraged within and outside the DOE (other national labs, OEMs, technical teams, enthusiasts)

Background Slides

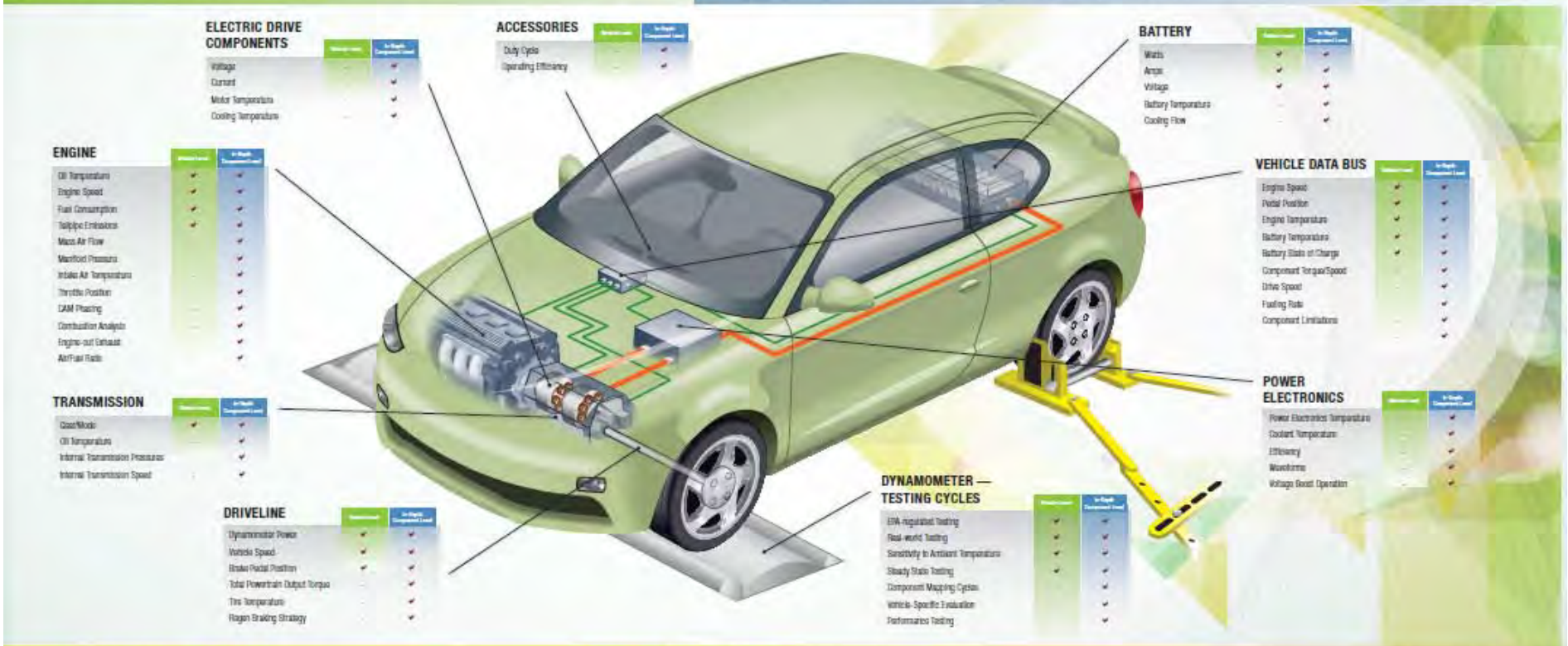
Advanced Vehicle and Component Research at Argonne's APRF

VEHICLE-LEVEL BENCHMARK RESEARCH

Vehicle-Level Benchmark Research is the initial testing performed on a wide variety of vehicles at Argonne's Advanced Powertrain Research Facility (APRF). Engineers use the facility's two wheel drive and four wheel drive dynamometers and state-of-the-art instrumentation to reveal important information on performance, fuel economy, energy consumption and emissions output. This data, which seeks to broadly understand a specific vehicle, is critical to evaluating the progress and viability of current and future transportation technologies.

IN-DEPTH VEHICLE AND COMPONENT-LEVEL RESEARCH

In-Depth Vehicle and Component-Level Research takes vehicle evaluation a step further with invasive instrumentation and extensive testing to reveal even more significant data and insight. By outfitting vehicles with equipment such as torque sensors, power analyzers and thermocouples, researchers obtain a more complete vehicle assessment, including detailed component mapping and operating strategy evaluation. As compared to the standard Vehicle-Level Benchmark Research, this in-depth approach provides more comprehensive data, component characterization and understanding of the powertrain system operation. The schematic below illustrates the varying levels of data provided by the two types of vehicle evaluation.



RESEARCH FINDINGS

An Energy Efficiency Analysis to gain understanding of the engine on/off strategy, battery usage and management, shifting algorithms, emission and fuel consumption trade-offs, accessory load management, real-world performance, thermal waste heat utilization, and component efficiencies.

RESULTS APPLICATION

Working with the U.S. Department of Energy (DOE) and the automotive industry, Argonne's vehicle research is used to:

- Support the DOE in evaluating current and future technologies, and developing transportation goals and policy for petroleum displacement
- Aid in the development and optimization of advanced technologies to expand commercial applications
- Demonstrate alternative fuel benefits and promote energy diversity
- Provide unbiased research results for many stakeholders

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