Argonne NATIONAL LABORATORY

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

2013 DOE Hydrogen Program and Vehicle Technologies Annual Merit Review

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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

U.S. DEPARTMENT OF ENERGY

Overview

- **Timeline**

  2013 Peugeot 3008 Hybrid 4
  - Testing complete
  - Final reporting and data out-reach ongoing

  2014 Ford Focus BEV
  - Final instrumentation in development
  - Initial as-received testing complete
  - Vehicle break-in study ongoing
    - On-dyno break-in helpful for more miles-per-day (especially in winter)
  - In-depth testing spring/summer

- **Budget**
  - FY 2013 $250k
    - Peugeot 3008 HYbrid4
      - Collaboration with IFP in France
  - FY 2014 $300k
    - Ford Focus BEV

- **DOE strategic goals/barriers addressed**
  - **F:** Constant advances in technology
  - **D:** Lack of standardized test protocols
  - **E:** Computational models, design and simulation methodologies (Data availability)

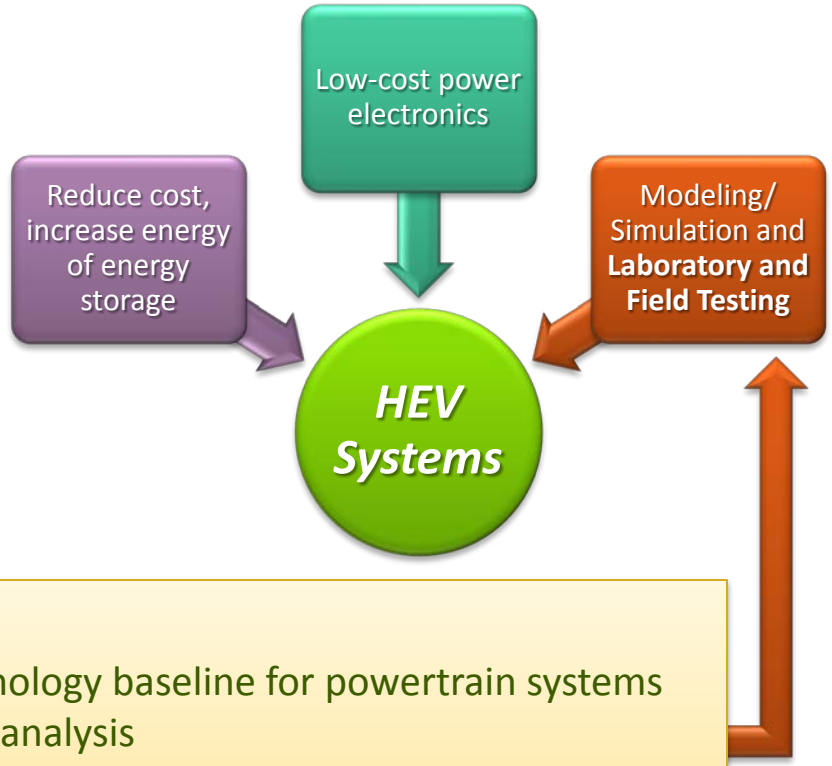
- **Partners**
  - DOE and other National Laboratories
  - USCAR, OEMs, and Suppliers
  - IFP for Peugeot vehicle testing

Relevance: Three Components of HEV Systems

"VTP is advancing the large-scale, cost-competitive production of the next generation of electric-drive vehicles through **three complementary component-and system-level technology pathways**:"

In-depth vehicles selected with DOE, Lab, and OEM input to assess emerging vehicle and component technologies:

- **Peugeot 3008 Hybrid4**:
  - DOE emphasis on HEV content reduction while retaining efficiency
    - Rear-drive traction motor (eRDM)
    - Front-drive diesel engine with ~8kW BAS system
    - 6-speed SMG transmission
  - Evaluation of diesel hybridization benefits and challenges



Laboratory and Field Testing Objectives

- Establish the state-of-the-art automotive technology baseline for powertrain systems and components through data generation and analysis
- Provide independent evaluation of technology
- Generate data to support DOE target creation and hardware/model validation

Approach/Strategy: Vehicle Selection

- Unique hybrid architecture
  - Rear-drive traction motor (eRDM)
  - Front-drive diesel engine with ~8kW BAS system
  - 6-speed SMG transmission
- Diesel + hybrid is interesting and infrequently used…
- Provides 4 different user-selectable operating modes

MY 2012 Peugeot 3008 Hybrid4	
Vehicle architecture	Electric rear motor + Diesel with BAS system in front
Test weight	1700 kg (3,750 lbs)
Power plant	Engine 2.0L HDi with particulate filter (120 kW @ 3750 rpm, 300 Nm @ 1580 rpm) Rear traction motor Permanent magnet 27 kW max power 200 Nm max torque Dog-clutch to disconnect @ 120 kph Engine Alternator System (BAS) 8 kW, 52 Nm for start/stop and engine charging
Battery	Sanyo - NiMH ~230 V nominal 1.3 kWhr Total capacity ~30 kW Peak power capability
Fuel Economy	3.8L/100km claimed… 99-108 gCO_2/km
Performance	Reported 0-60 Time: 8.0 s

Approach/Strategy: Wide Range of Evaluation Cycles

Vehicle was tested across a wide range of US and EU regulatory cycles as well as supplemental real-world and specialized evaluation cycles

Normal Ambient Temperature

Cold Start | Hot Start

UDDS - CS	UDDS - HS	Hwy 2x	US06 2x	SC03 2x	Passing 2x	WOT	Steady State	Long SS	Access walk
Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
ZEV	ZEV								
Sport	Sport	Sport		Sport		Sport	Sport		
4x4	4x4	4x4		4x4		4x4	4x4		

NEDC - CS	UL 2x	Artemis 2x	Hyzem rural 2x	A1 2x
Normal	Normal	Normal	Normal	Normal
ZEV	ZEV	ZEV		
Sport			Sport	Sport
4x4			4x4	4x4

NEDC - CS	UDDS
Hi SOC (Normal)	Hi SOC (Normal)
Lo SOC (Normal)	Lo SOC (Normal)

WLTC	WLTC
Normal	Normal

Cold Ambient Temperature (Normal Mode)

UDDS - cs	UDDS - hs	Hwy2x
NEDC - cs	NEDC - hs	
WLTC - cs	WLTC - hs	

Hot Ambient Temperature (Normal Mode)

UDDS - cs	UDDS
	Hwy 2x
	SC03 2x

Approach/Strategy: Extensive Vehicle Instrumentation

A wide mix of direct instrumentation, off-line sensors, and CAN bus information was used during testing

Vehicle CAN Bus

Accel. Pedal Position
Vehicle Speed
Brake [on/off]
Fuel Counter
Gear
HV Battery Current
HV Battery Voltage
HV Battery SOC
HV Battery Temperature
Engine Speed
Engine Torque
Alternator Trq. Target
Eng. Coolant Temp
Rear Motor Speed

Power Analyzer

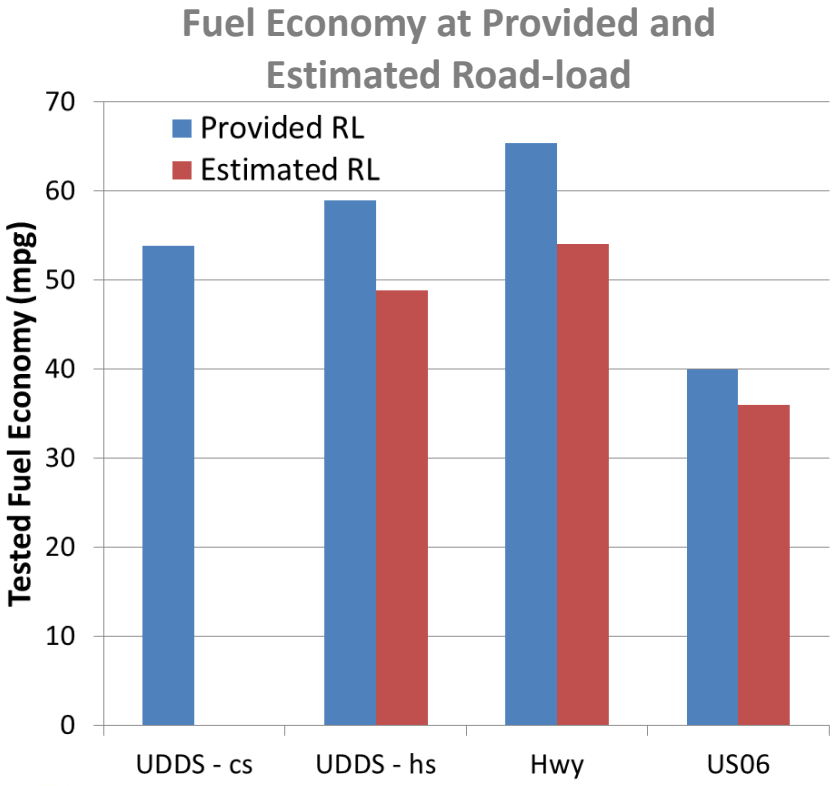
HV Battery Voltage
HV Battery Current
HV Battery Power
LV Battery Voltage
LV Battery Current
LV Battery Power
DC-DC Output Voltage
DC-DC Output Current
DC-DC Output Power
Battery Fan Current
Battery Fan Power

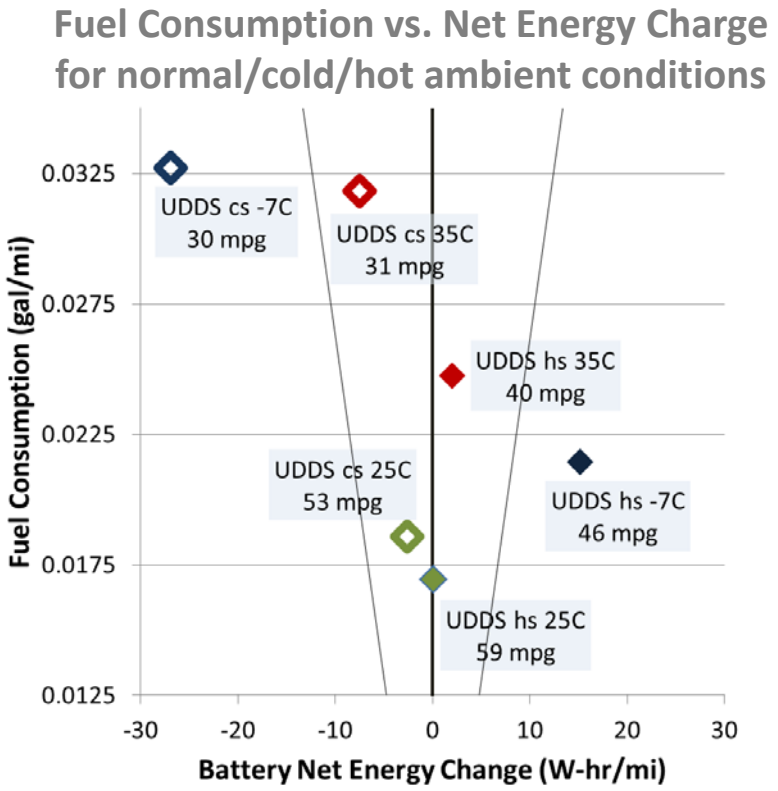
Other Signals

Front axle torque
Eng. Oil Temperature
PreDPF Exhaust Temperature
Cabin Temperature
Cabin Vent Temperature
THC [mg/s]
CH4 [mg/s]
NOx [mg/s]
COlow [mg/s]
COmid [mg/s]
CO2 [mg/s]
HFID [mg/s]
NMHC [mg/s]
Fuel [g/s]

Accomplishments: Normal Mode US Cycle Testing

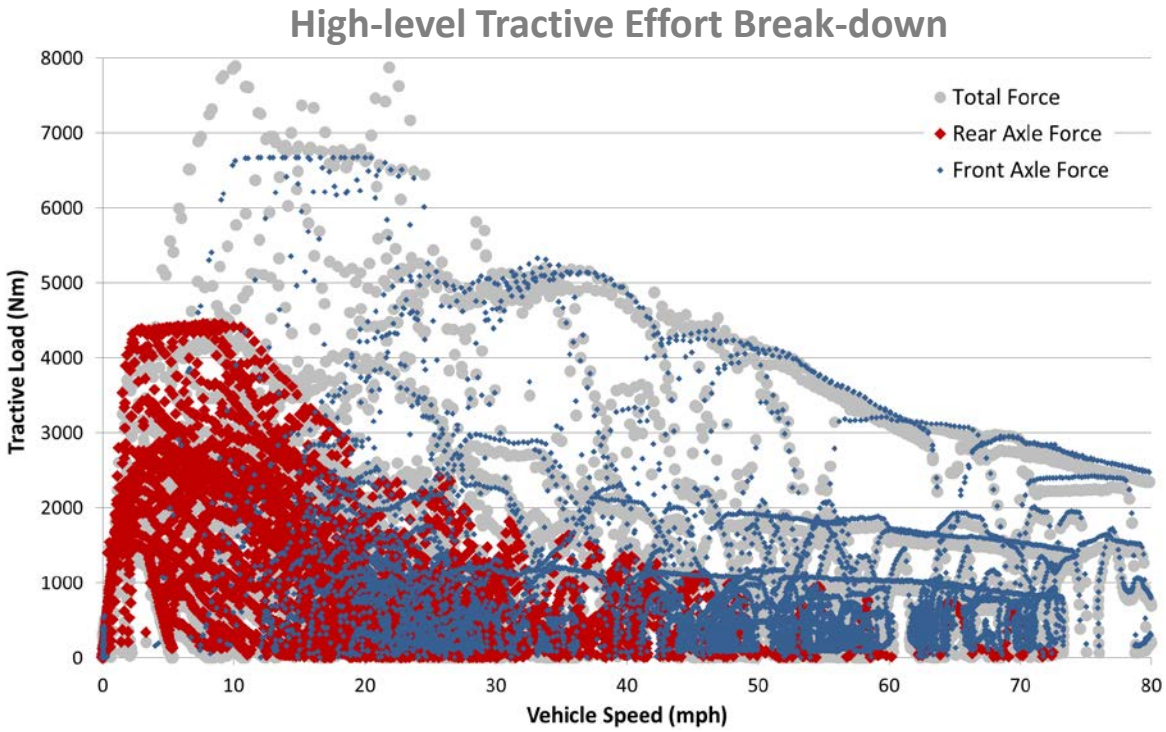
- Vehicle shows relatively high fuel economy with higher Highway versus UDDS results
- Majority of vehicle testing was done using provided road-loads that appear somewhat optimistic
  - Some additional testing was done using Argonne estimated rolling and aerodynamic loss calculations
- Testing leverages Argonne's upgraded hot/cold capability to assess the impacts of temperature
  - Hot and cold operation dramatically impacts both fuel consumption and Net Battery Energy Change
  - Extended engine operation during cold conditions leads to large SOC swings

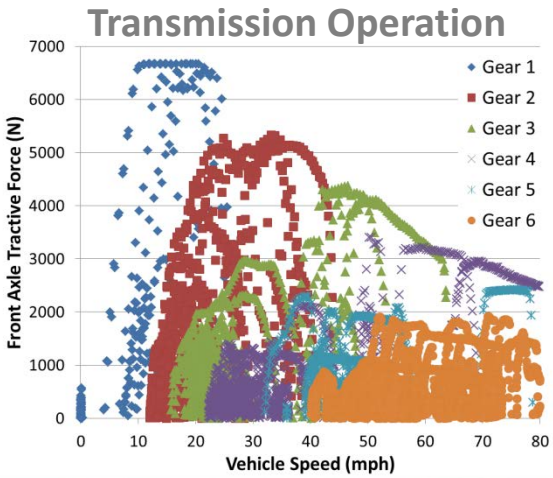


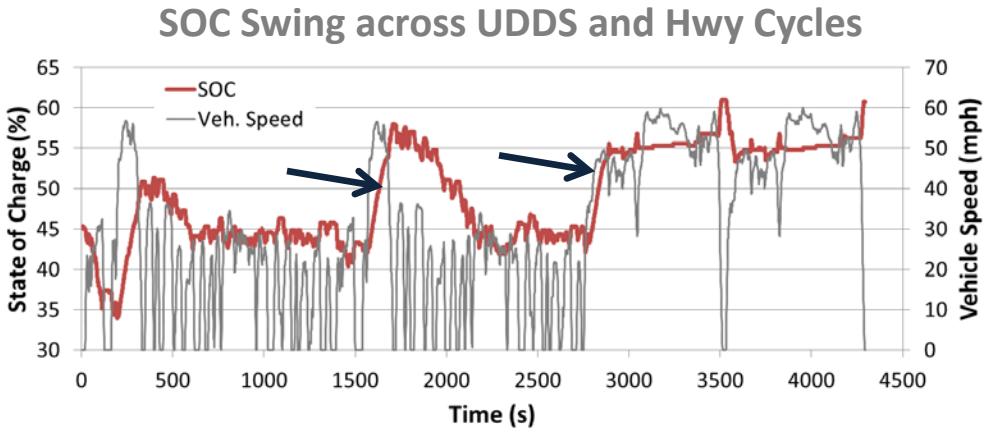


Accomplishments: Basic Vehicle Operation

- **Despite unique configuration, operation is fairly traditional:**
  - Frequent electric launch and e-assist from eRDM
  - Rear motor is used for EV driving at moderate speeds/loads
  - 6-speed transmission works to optimize engine operation
  - BAS system is used often for battery charging
    - Actually results in large SOC increases for certain cycles…



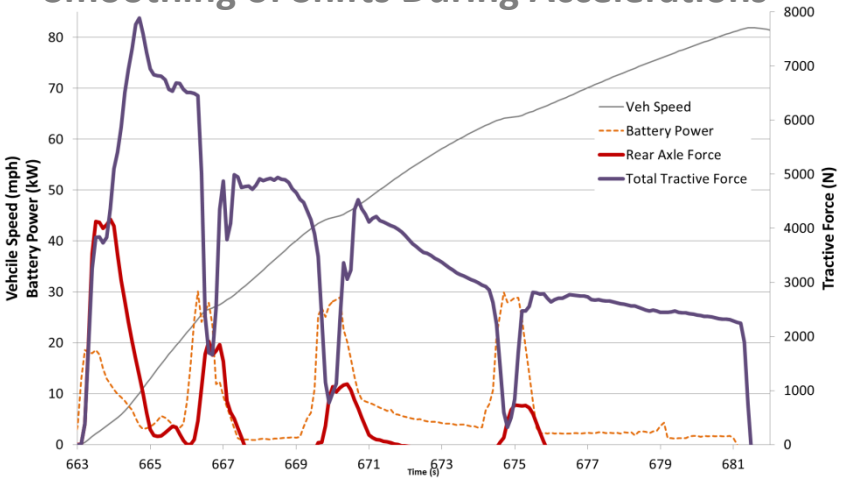




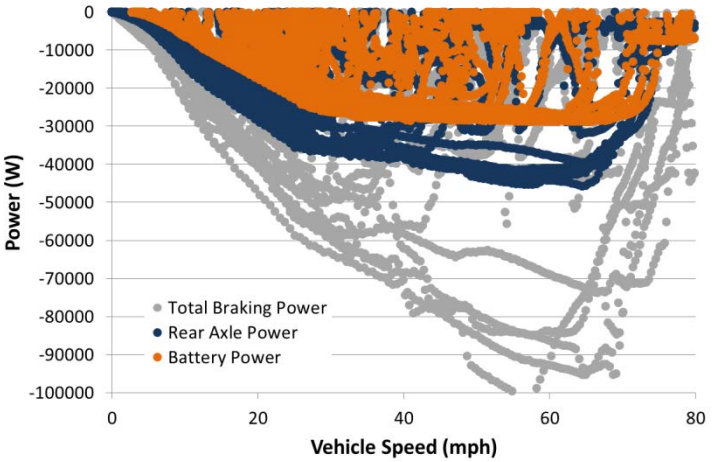
Accomplishments: Selected Component/Operation Details

Testing highlights include unique aspects of through-the-road hybrids and component usage and capability information

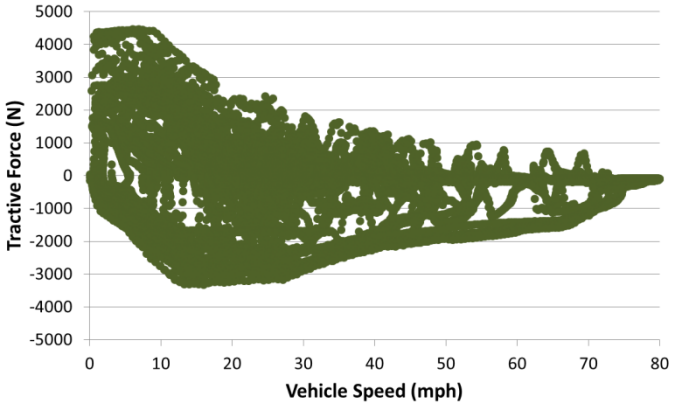
Smoothing of Shifts During Accelerations



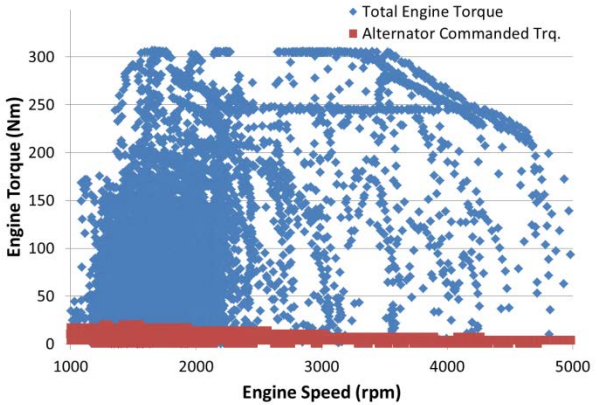
Limited Peak Regen. Braking for RWD



Rear Electric Traction System Usage



Engine Usage and Capability

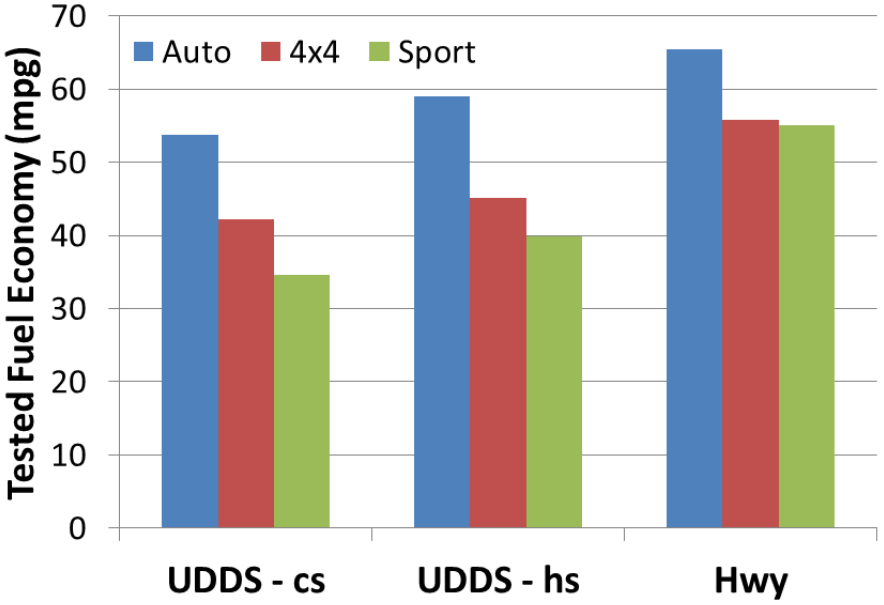


Accomplishments: Evaluation of User Selectable Modes

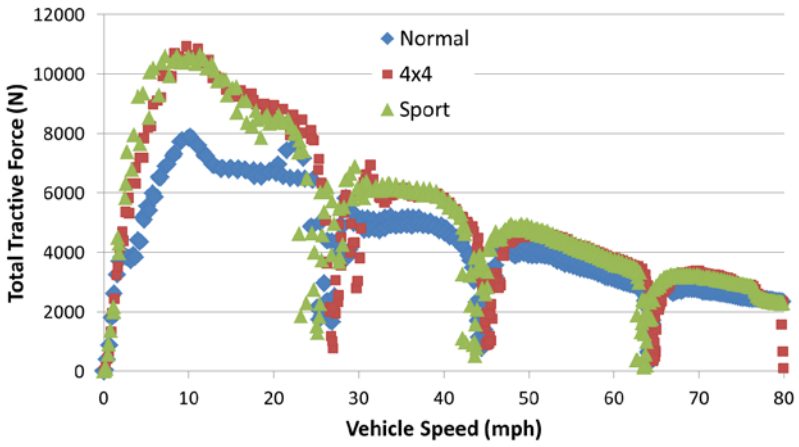
Vehicle has 3 additional operating modes:

- ZEV - Mode fairly limited (on US cycles)
- Sport – More aggressive shift scheduling, continued engine stop @ idle, minimal EV driving
- 4x4 – Engine is always on and e4WD is provided

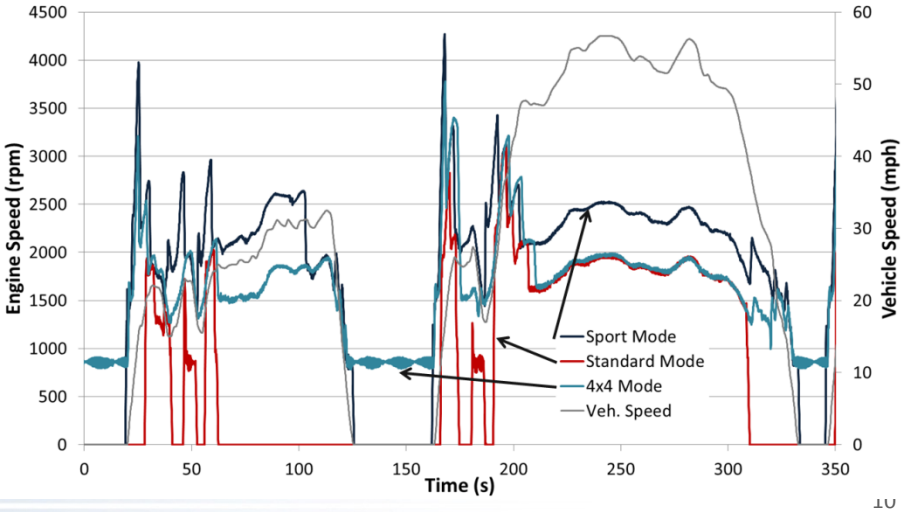
- Both 4x4 and sport show higher performance during aggressive accelerations
  - More electric assist for rear drive system
  - Sport shifting does not have a huge impact
- 4x4 and sport modes also show a dramatic reduction in fuel economy
  - Sport is actually worse due to engine operation



Aggressive Acceleration Tractive Effort



Highlighted UDDS Engine Operation

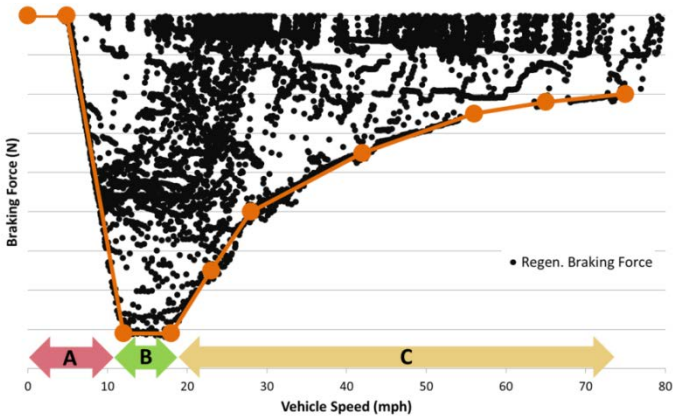


Accomplishments: Regenerative Braking Study for FWD Vehicles

Previous in-depth vehicle testing data used for a report discussing regenerative braking and vehicle operation during braking across several vehicles

	Estimated Regen Ramp-In Speed (mph)	Estimated Speed @ Max Regen Force (mph)	Max. Estimated Regen Axle Force (g)	Max Observed Regen Battery Power (kW)
MY 2010 Prius	4	8.5	-0.19	-24
MY 2011 Hyundai Sonata	5	12	-0.25	-27
MY 2012 Chevrolet Volt	2	6.5	-0.20	-63

- Study leverages previous vehicle testing and instrumentation (axle torque sensors)
- SAE paper: “Analysis of Input Power, Energy Availability, and Efficiency during Deceleration for X-EV Vehicles”
- Actual regenerative braking is frequently misunderstood and minimal data is available



Collaborations and Coordination with Other Institutions

In-depth Benchmarking Informs Many Stakeholders

J1711 HEV & PHEV test procedures
J1634 EV 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

Other Research Partners
- IFP Energies nouvelles

Autonomie
- Support of modeling and simulation with data

AUTONOMIE

USDRIVE, tech teams and OEMs
- Shared test plans, data and analysis

USDRIVE Driving Research and Innovation for Vehicle Efficiency and Energy Sustainability

Summary

In-depth testing of the selected 2012MY vehicles aids the DOE goal of petroleum displacement/reduction through data dissemination and technology assessment

- Peugeot 3008 Hybrid4 offers several unique features:
  - Rear-drive traction motor (eRDM)
  - Front-drive diesel engine with ~8kW BAS system
  - 6-speed SMG transmission
  - Configuration shows some benefits and challenges versus single axle drive systems
- Diesel + hybrid is interesting, but overall operation is fairly traditional
  - Interesting to contrast diesel versus gasoline hybrid operation
  - 3008 does exhibit large SOC swings due to engine-based battery charging
  - Although not shown, emissions for a diesel start-stop system are very challenging

- Testing generates data for model development and validation to facilitate increased speed-to-market of advanced technology (1+ GB of test data)

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

Background Slides

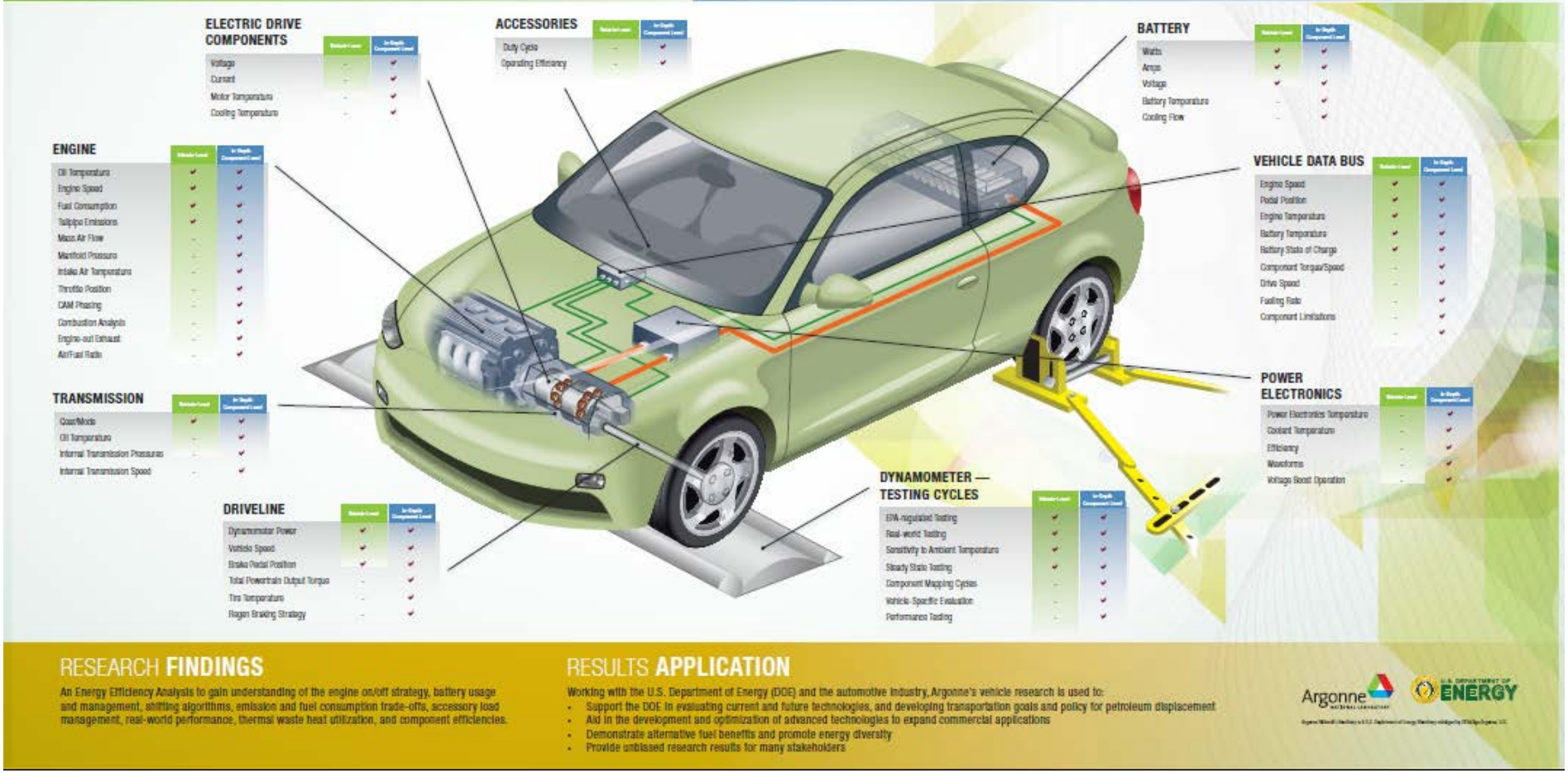
Advanced Vehicle and Component Research at Argonne's APRF

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 attain 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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