Advanced Technology Vehicle Lab Benchmarking – Level 1 & 2

2015 U.S. DOE Vehicle Technologies Program
Annual Merit Review and Peer Evaluation Meeting

Kevin Stutenberg - *Principal Investigator- L1*
Eric Rask – Principle Investigator – L2

Argonne National Laboratory

June 9, 2015

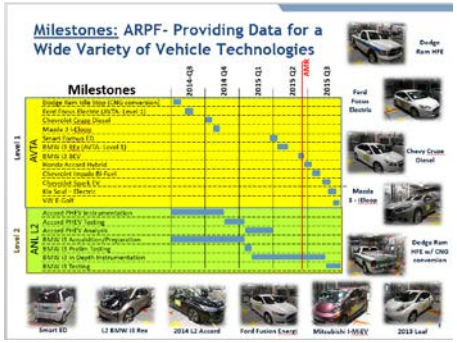
Project ID # VSS030

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

U.S. Department of Energy
Energy Efficiency and Renewable Energy
Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable

Overview

- **Timeline**
  - Benchmarking at ANL started in 1998
  - FY14 & FY15 Completed Testing:
    - 10 vehicles thoroughly evaluated in FY14, 5 in FY15 (L1/L2)
  - FY14 and FY15 Test Vehicles
    - See Milestone on slide 6



- **Budget**
  - L1/L2 FY2014 $2.265k
  - L1/L2 FY2015 $1.925k
  - Other Leveraged DOE Projects (separate funding)

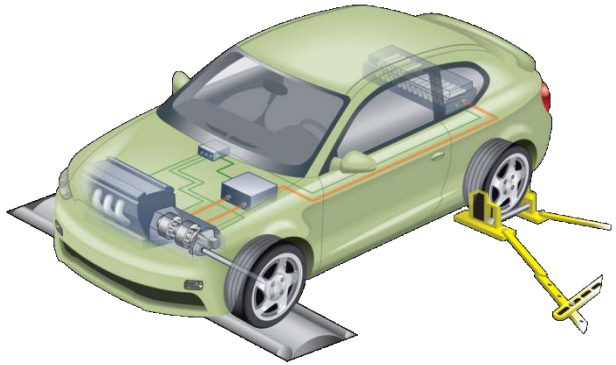
- **DOE VSST barriers addressed:**
  - Computational Models, Design and Simulation Methodologies (C)
    - Model development and validation
  - Lack of Standardized Testing Protocols (D)
    - Validating BEV and PHEV test procedures
    - Support of SAE committee (J2951 Drive Metrics, J2907/2908 Powertrain rating, J2263 Coast Down, etc…)
  - Constant Advances in Technology (F)
    - Public data generation from benchmarking recent mass-produced BEVs and PHEVs.
    - Advances in HEVs and Alt Fueled Vehicles compared to previous models

- **Partners:**
  - AVTA (Advanced Vehicle Testing Activity): DOE, INL, ANL, Intertek
  - DOE, National Laboratories, USDrive, OEMs, Component Suppliers, Vehicle Competitions
  - EPA, CARB

Relevance: Objectives of the Advanced Powertrain Research Facility (APRF)

Technology Assessment Objective

"Provide to DOE and Partners the Best Advanced Vehicle Test Data and Analysis"



Codes and Standards Objective

"Assist in codes and standards development with public and independent research and data"

Laboratory Testing Mission

Enable petroleum displacement through technology assessment & data dissemination

- Establish the state-of-the-art automotive technology baseline for powertrain systems and components through test data generation and analysis
- Provide independent and public data for evaluation of emerging technology
- Generate data to support model creation and validation, standards development, and DOE target setting

Focus for FY15

- Establish technology benchmarks for advanced technology powertrains, including: HEV, PHEV, BEV, Conventional and Alternative Fuel Vehicles.
- Enhance instrumentation and signal capture through advanced analog instrumentation and capture of vehicle communications messaging.
- Continued evaluation of thermal effects on energy consumption and powertrain behavior.

Relevance: Advanced Technology Benchmark- Matching Technology to Targets

- Vehicle Research: Dynamometer Testing
  - Vehicle system testing
    - Energy consumption (fuel + electricity)
    - Emissions
    - Performance
    - Vehicle operation and powertrain strategy
  - 'In-situ' component and system testing
    - Component performance, efficiency and operation over drive cycles
    - Component mapping
  - Technology assessment and goal setting

Vehicle Technologies Office Plan

- Hybrid and Vehicle Systems
- Energy Storage
- Advanced Power Electronics
- Materials Technology
- Advanced Combustion Engines
- Fuels and Lubricants

VSST Challenges and barriers

A. Risk Aversion
B. Cost.
C. Infrastructure.
D. Lack of standardized test protocols.
E. Computational models, design and simulation methodologies.
F. Constant advances in technology.

Relevance: Purpose and Destination of Vehicle Testing and Analysis

"Knowing how good you are requires an accurate picture of how good everybody else is"

Data and Analysis

D^3 Dynamometer Downloadable Database
www.transportation.anl.gov/D3/
Limited public data sets

US Drive Tech Team Support
Full data sets

Supporting DOE

Independent technology evaluation
Baseline for technical targets and goal setting

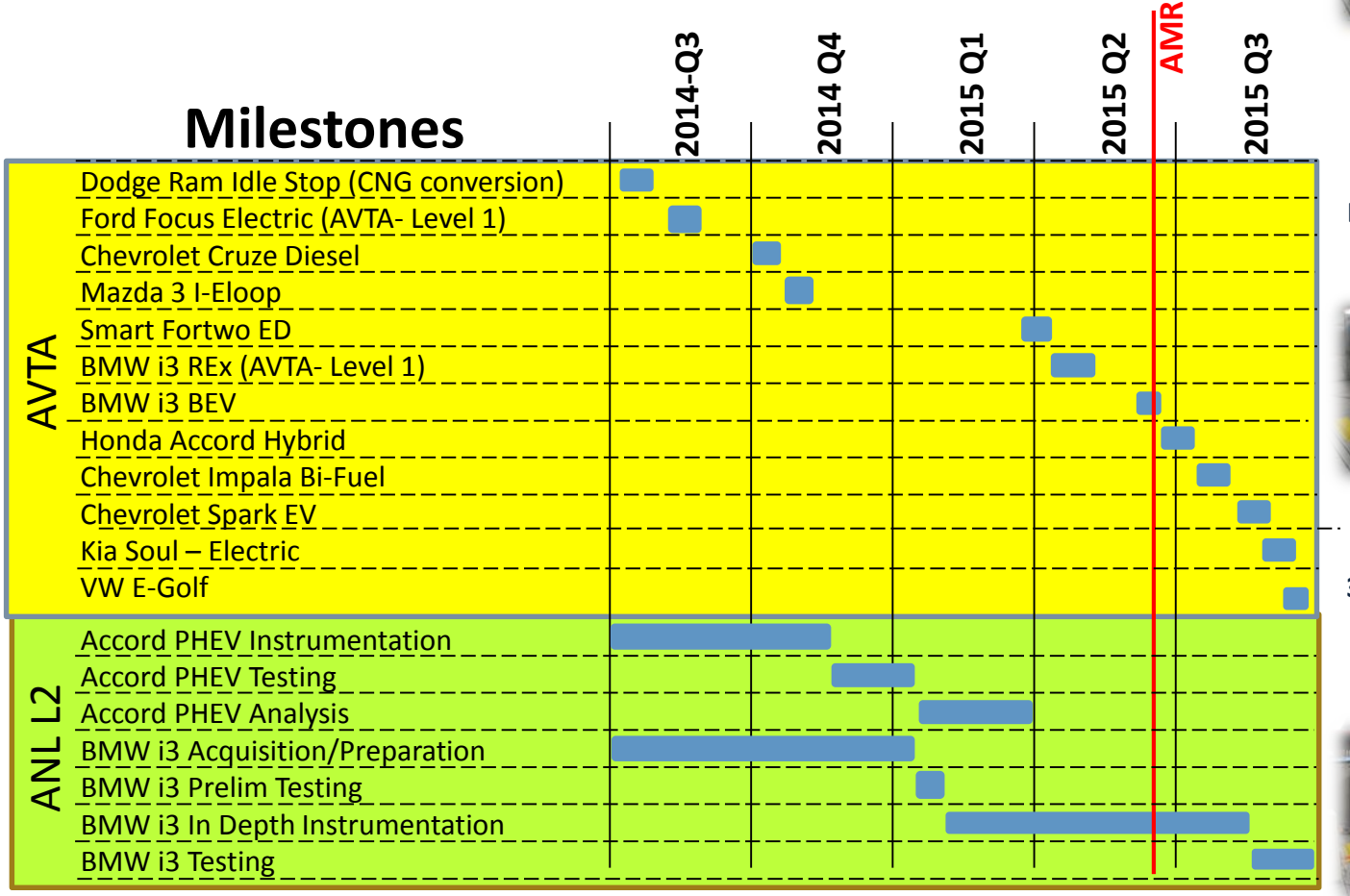
- *Vehicle efficiencies and energy use: average over drive cycles at different temperatures*
- *Component behaviors from a vehicle system perspective*
- *Charging profiles, battery capacities, battery characterizations*

Technology challenge
→ Innovation opportunity
Heating , Thermal management, Accessory loads,….

Codes and Standards
Data for procedures development and validation

Modeling Support
Component mapping
Thermal analysis
Climate control system
Data for validation

Milestones: ARPF- Providing Data for a Wide Variety of Vehicle Technologies



Dodge Ram HFE

Ford Focus Electric

Chevy Cruze Diesel

Mazda 3 - iEloop

Dodge Ram HFE w/ CNG conversion

Smart ED

L2 BMW i3 Rex

2014 L2 Accord

Ford Fusion Energi

Mitsubishi I-MiEV

2013 Leaf

Approach: L1- Well-Established and Proficient Testing Methods Adjusted to Individual Technologies

The vehicle benchmark activity has been refined during the past decade, which has resulted in:

- Advanced and unique facilities and instrumentation
- Continuous improvement of testing procedures
- Standardization of test plans including instrumentation and drive cycles which are adjusted for individual vehicles
- Significant knowledge of advanced vehicles and testing methods

APRF expertise in testing

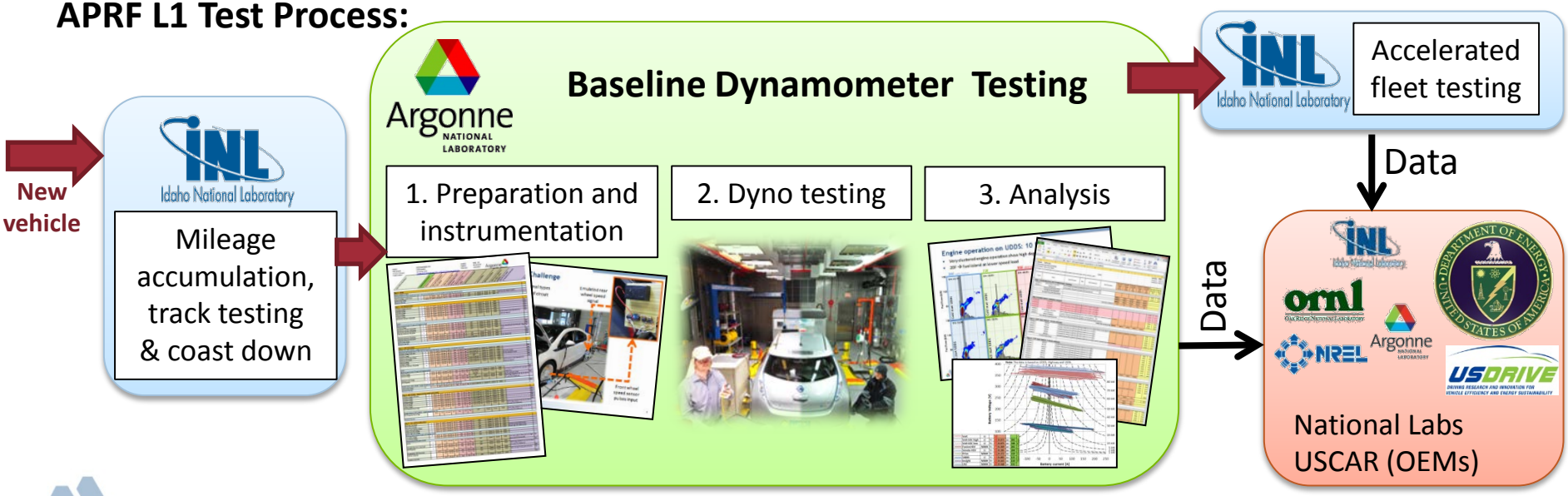
Powertrains

- Conventional
- Hybrid Electric (HEV)
- Plug-in HEV (PHEV)
- Battery Electric (BEV or EV)
- Fuel Cell Vehicle

Alternative fuels

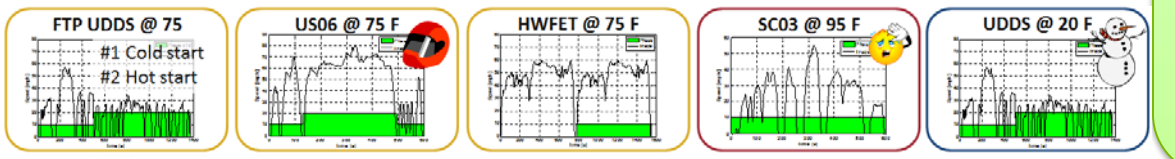
- Hydrogen, Natural Gas
- Ethanol, Butanol
- Diesel (Bio, Fisher-Tropsch)

APRF L1 Test Process:



Approach: Purpose Built Research Laboratory for Automotive Benchmark Activities

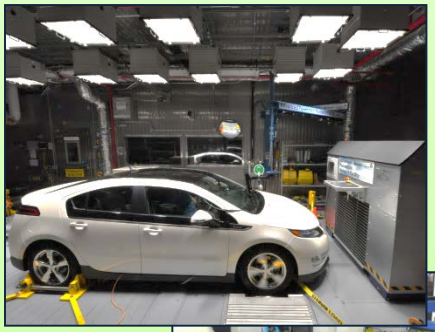
- Level 1 and Level 2: Comprehensive instrumentation and evaluation
  - Level 2: invasive / Level 1: non-invasive
  - Vehicle characterization (fuel and energy consumption, emissions, performance)
  - Vehicle operation and strategy
  - Component specific instrumentation for analysis and modeling (speed, temp, and other technology specific removable instrumentation)
- Drive cycles and test conditions
  - Standard drive cycles, technology specific cycles, performance tests, vehicle and component mapping cycles
  - Thermal test conditions: 20°F, 72°F and 95°F with 850 W/m^2 radiant solar energy "5-Cycle"
  - Additional testing at 0°F and 40 °F as desired



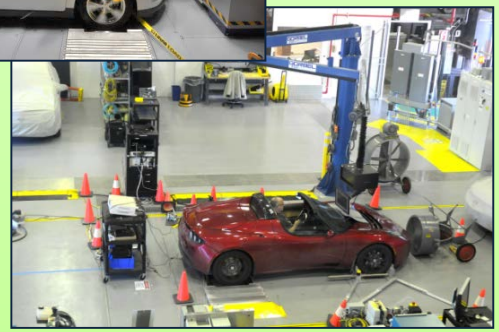
Advanced Powertrain Research Facility

The right tools for the task:

- *Two chassis dynamometer cells*
- *Custom DAQ, flexible, module-driven, used in both cells*
- *Thermal chamber which is 5-Cycle compliant (+)*



4WD chassis dyno with thermal chamber

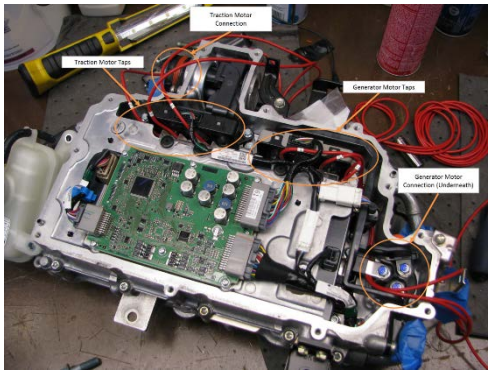


2WD chassis dyno

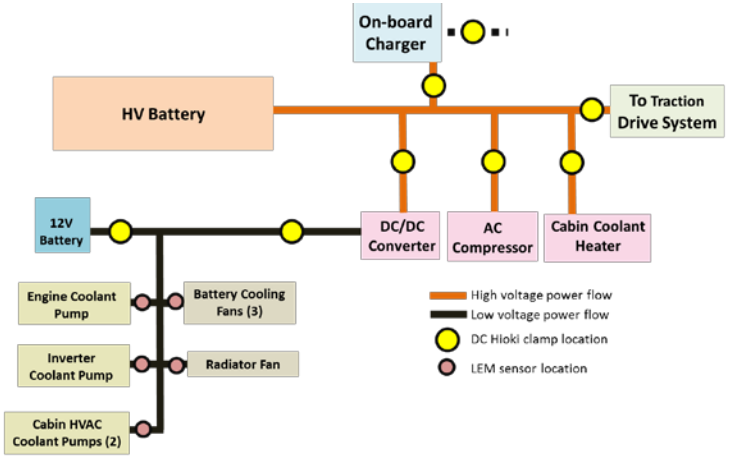
Approach: L2- Extensive Vehicle Instrumentation

A wide mix of direct instrumentation (temperature, electrical, flow, pressure, etc.) as well as CAN and Diagnostic bus information was used during testing

3-Phase AC Voltage and Current

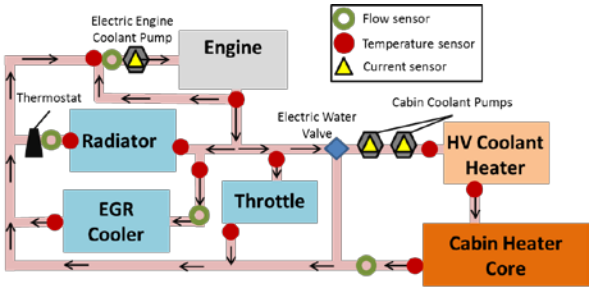


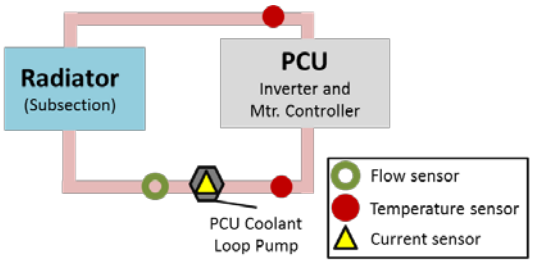
HV and LV Electrical Nodes



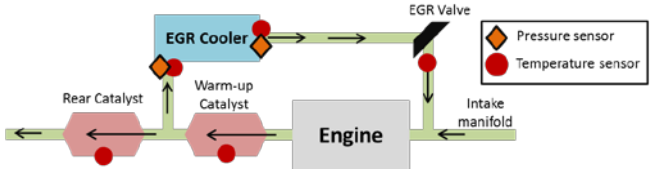
Thermal System Instrumentation

Cabin, low temp., and high temp. loops



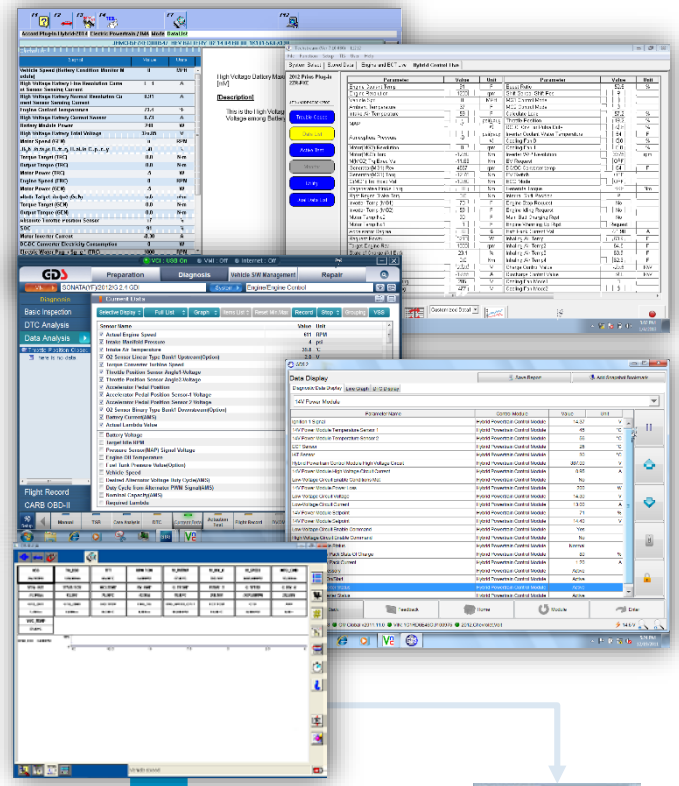


EGR and Exhaust System

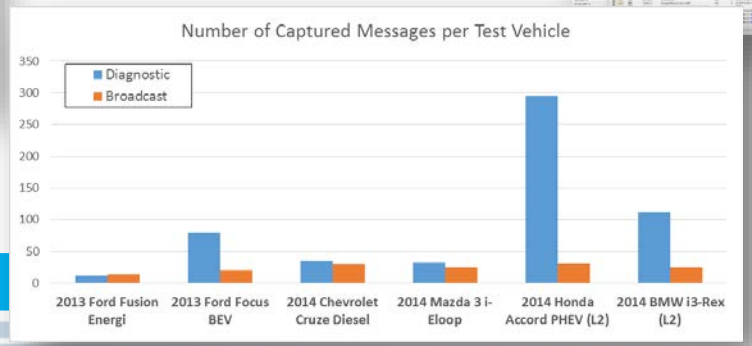


Accomplishments: Revised Instrumentation Methods

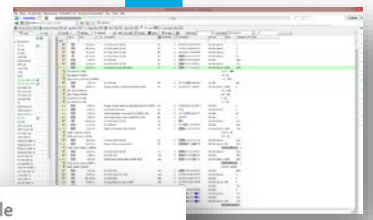
- Development of Diagnostic Database
- Determination of message Id's and scaling
  - Historically- OCR used to capture / combine
  - Now- database captured for streamlined logging
- Diagnostic messages are then:
  - Utilized for broadcast CAN decoding
  - Desired signal logging during testing
    - Multiple Module / Multiple Modes
  - Distributed to AVTA partnership for fleet testing



Data Collection / Merge



Old- OCR Module

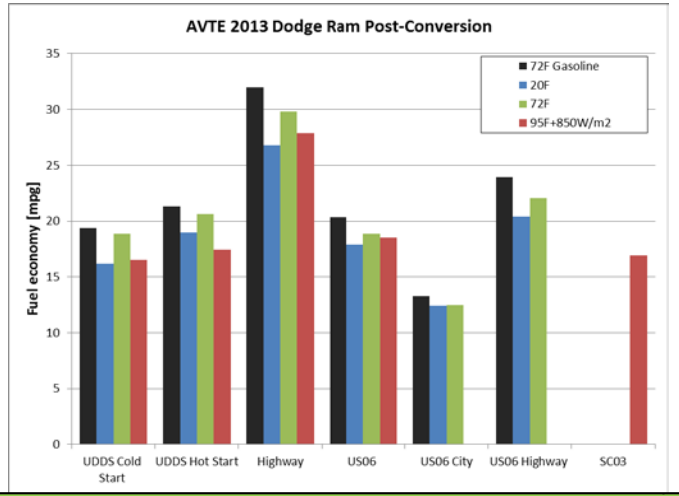


New- Database Development

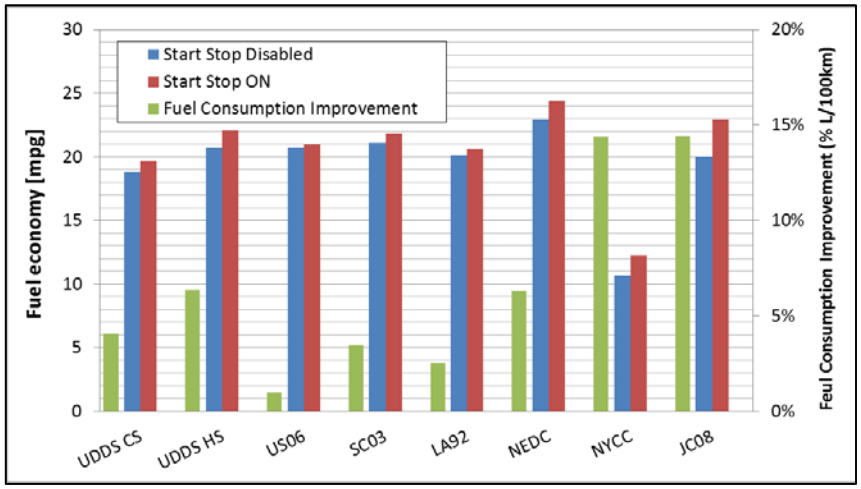
Accomplishments: Idle Stop / NGV Vehicle Evaluations

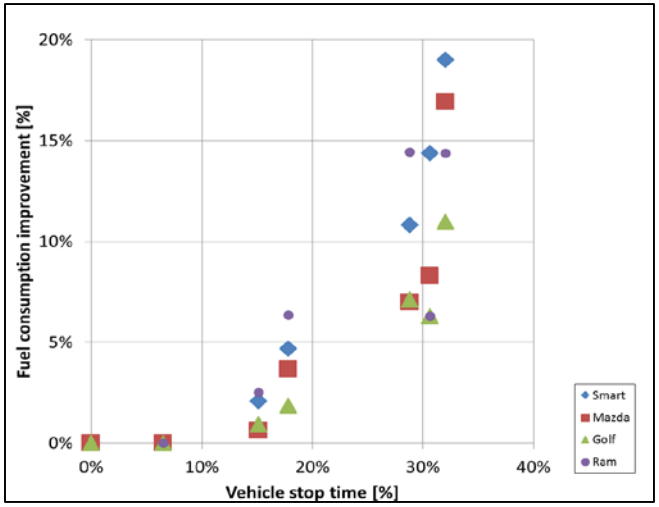
Idle Stop & CNG Operation

- HFE Idle Stop Impact
  - Up to 14% improvement on NEDC/NYCC, 9% on UDDS
- Aftermarket CNG conversion
  - CNG MPGe reduction of 2.5% to 8%
  - Fuel economy consistently lower- as expected (lower energy density)
- Further NGV testing occurred on ANL Bifuel 2012 VW Passat TSI Ecofuel



72F- CNG						
Test	Test #	Gasoline Used (gal)	CNG Use (GGE)	Combined Fuel Use (GGE)	Comined MPGe	MPGe Impact
UDDS cold start	61409037	0.118	0.277	0.395	18.9	-2.7%
UDDS	61409038	0.042	0.319	0.361	20.6	-3.4%
Highway	61409041	0.003	0.341	0.345	29.8	-6.7%
US06	61409042	0.088	0.336	0.424	18.9	-7.2%
US06 City	61409042	0.067	0.075	0.142	12.5	-5.8%
US06 Highway	61409042	0.022	0.261	0.282	22.1	-7.9%

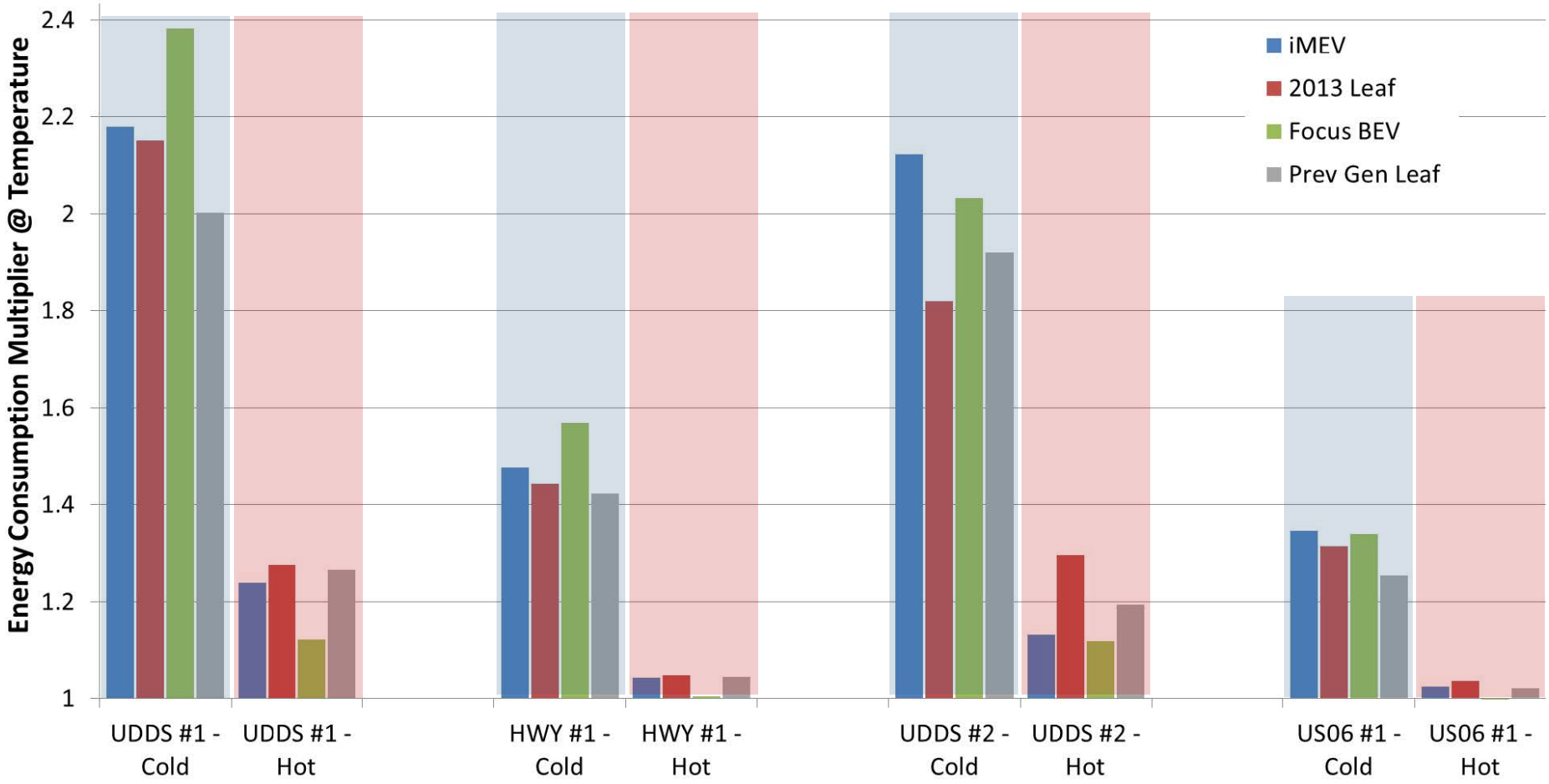




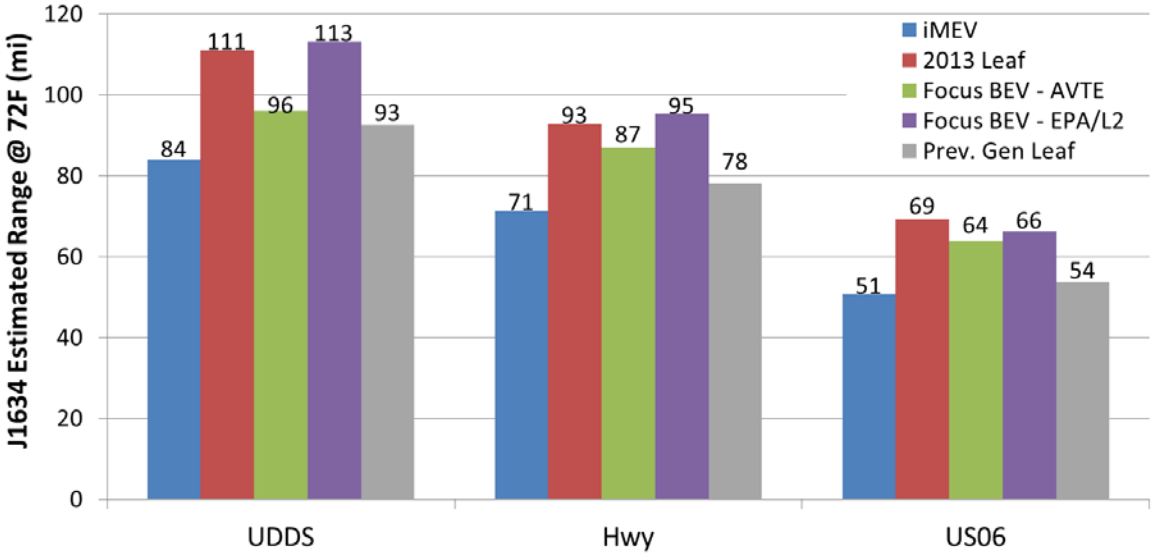
Accomplishments: EV Energy Consumption vs. Ambient Temp.

All vehicles show dramatically higher impact due to heating versus A/C

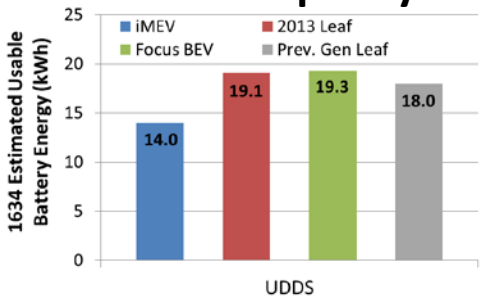
- For aggressive cycles, A/C is a wash with other factors (improved losses)
- Cabin temp. trajectory from cycle-to-cycle makes direct impact assessment difficult
- HVAC is not the only contributor towards elevated “cold” energy consumption



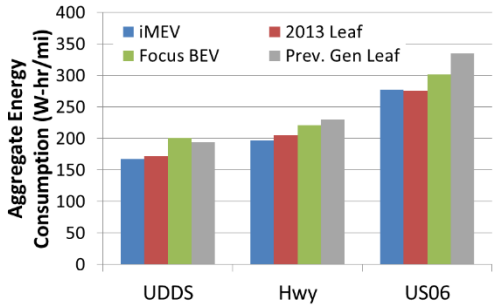
Accomplishments: Understanding BEV Range Variations



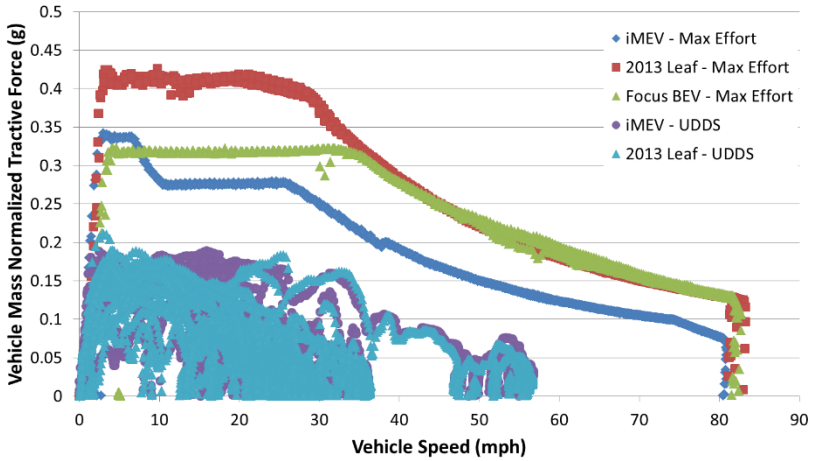
Usable Capacity



Energy Consumption



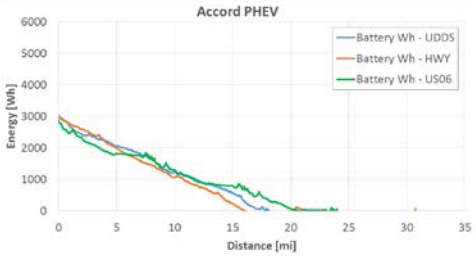
- **Although some clear trends exist, recent vehicles show variations in range due to:**
  - **Useable battery capacity**
  - **Energy consumption**
  - **Drive cycle usage relative to maximum capability**

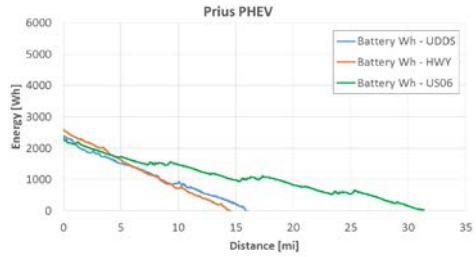


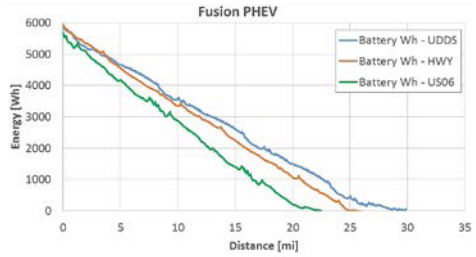
Accomplishments: In-depth Blended PHEV Evaluation

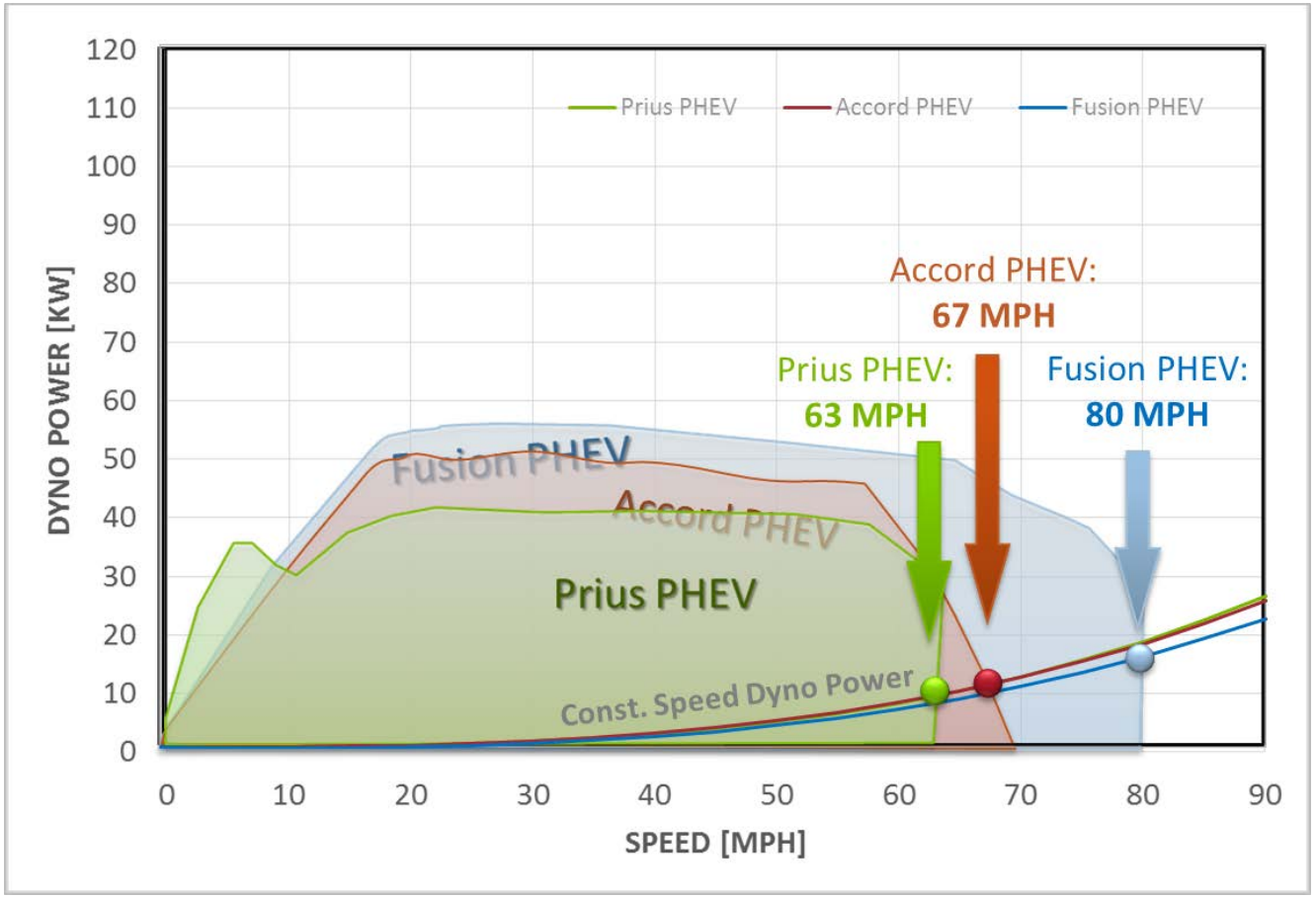
- **Honda Accord PHEV provides an additional data point for blended PHEV vehicle usage and capabilities**







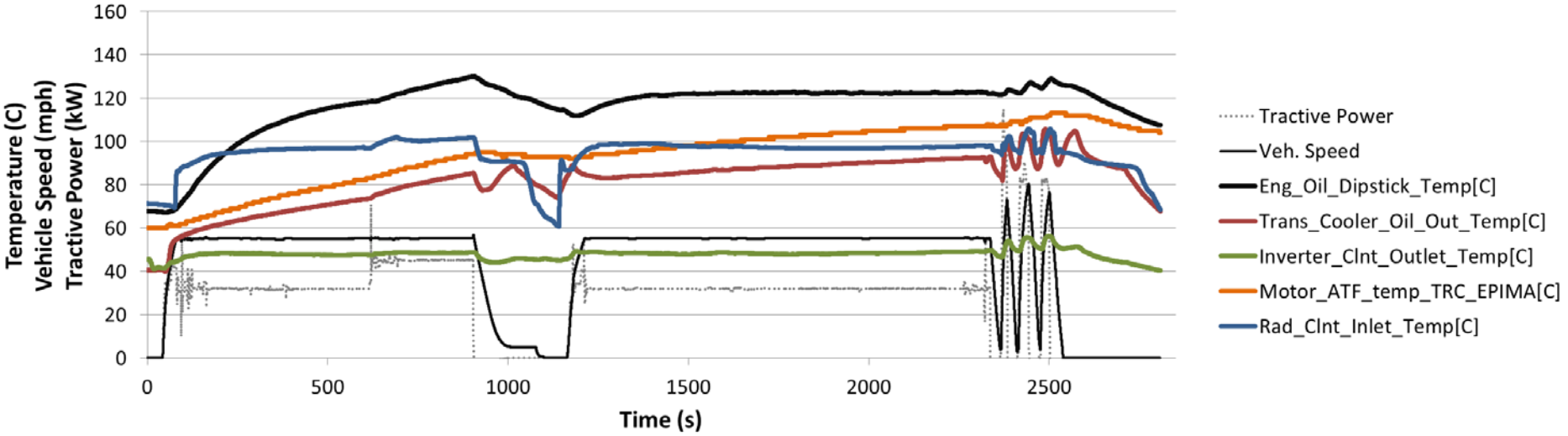




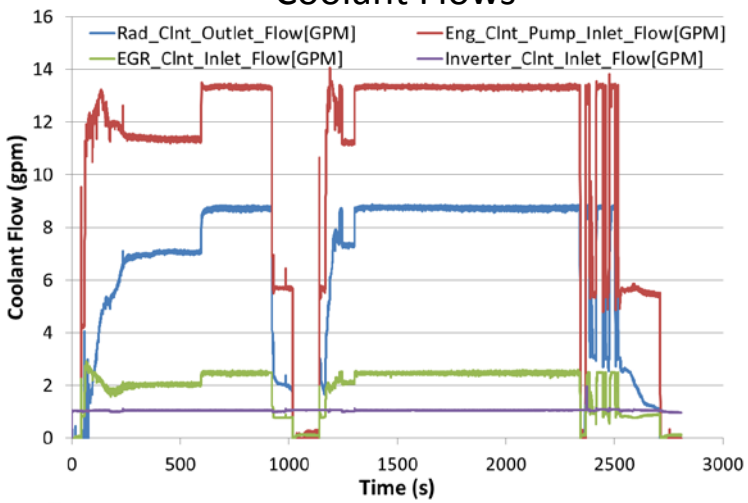
Accomplishments: Aggressive Thermal Usage Assessment

55 mph steady-state operation @ 6-9% grade, 95F ambient + solar loading

Working Fluid Temperatures: Eng. Oil, Trans. Oil, Eng. Coolant, PE Coolant

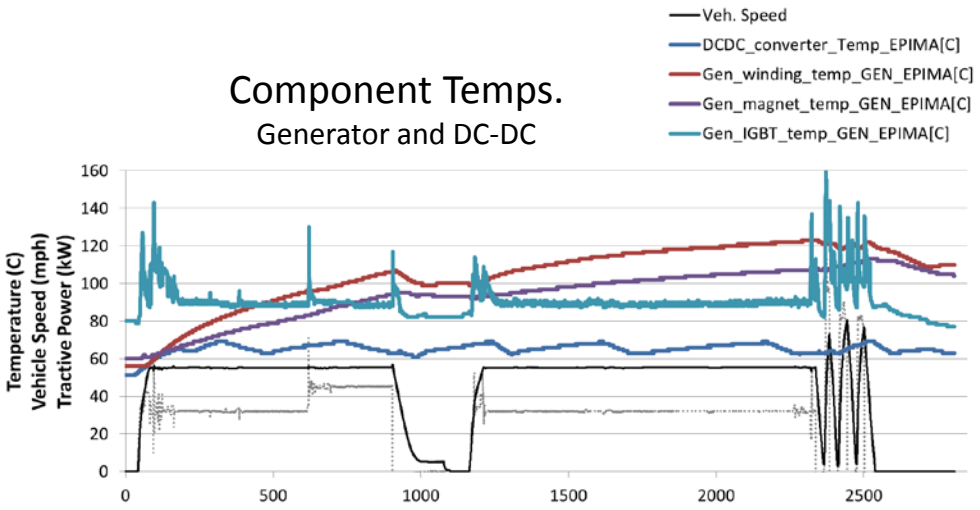


Coolant Flows



Component Temps.

Generator and DC-DC



Coordination: Existing Collaborations with Other Institutions

J1711 HEV & PHEV test procedures
J1634 EV test procedures
SAE International

International
- KATECH (Korea)
- ISO
- JARI (Japan)
- IEA
- Joint Research Centre (EU)

AVTA (Advanced Vehicle Testing Activity)
Baseline dynamometer testing of vehicles
INL Idaho National Laboratory, Argonne National Laboratory

APRF


DOE technology evaluation
- DOE requests
- National Lab requests

NREL, ORNL, INL Idaho National Laboratory, Argonne National Laboratory

AVTC (Advanced Vehicle Technology Competition)
Universities
AVTC, GM, EcoCAR2 Plugging in to the Future

Autonomie
Support of modeling and simulation with data
AUTONOMIE

USCAR, tech teams and OEMs
Shared test plans, data and analysis
USDRIVE Driving Research and Innovation for Vehicle Efficiency and Energy Sustainability

Chrysler – CTC
GM – Powertrain, Milford
Ford – Powertrain, APTL

Proposed Future Work: Level 1 & 2 Benchmark Will Continue with Emphasis on BEVs

Upcoming AVTA Vehicles (as of Apr 2015):

- 2014 BMW i3 BEV
- 2015 Chevy Spark Electric
- 2015 Kia Soul EV
- 2015 Honda Accord Hybrid
- 2015 Chevrolet Impala Bi-Fuel CNG
- 2015 Mercedes Benz B-Class Electric
- 2015 Infiniti Q50 Hybrid
- Further potential AVTA vehicles:
  - 2015 VW e-Golf
  - 2016 Toyota Mirai
  - 2016 Hyundai Sonata PHEV
  - 2016 Mitsubishi Outlander PHEV
  - 2016 Nissan E-NV200
  - 2016 Via Vtrux
  - 2016 Chevrolet Volt

FY2015 APRF L2 Research Vehicle: 2014 BMW i3 REx

Level 2 Vehicles + ANL Vehicles

- 2014 Honda Accord PHEV (further testing)
- 2014 BMW i3 Rex (FY2015 L2 vehicle)
- 2012 VW Passat TSI EcoFuel (CNG bi-fuel)

Summary

- **APRF Vehicle Technology Evaluation Activity** continues to provide precise laboratory test data for a wide range of vehicle technologies that address DOE goals
  - Establish the state-of-the-art automotive technology baseline for powertrain systems and components through data collection and analysis
  - Providing independent evaluation of technology and support for DOE target setting
  - Generating test data for model development and validation to encourage speed-to-market of advanced technologies
  - Supporting codes and standards development for unbiased technology weighting
- **Highlighted Accomplishments from Level 1 and Level 2 Testing**
  - Greatly enhanced data collection through non-invasive methods (CAN and Diagnostics)
  - Continued evaluation of thermal impact on energy consumption and powertrain operation of conventional, alt fuel, and electrified vehicle technologies
  - AVTA vehicle testing in-progress in collaboration with INL and Interek
  - Test results and raw data available publicly at the Downloadable Dynamometer Database website (http://www.transportation.anl.gov/D3/)
  - Continued collaboration with OEM & DOE Partners with resource of extended data sets of level 1 and level 2 test vehicle.
- **Continued Link to Industry** is an important component of vehicle testing
  - Sharing best test practices, facility hardware recommendations, data analysis methods
  - Industry technology experts provide insight into what data is of interest, assisting in testing direction

Technical Back-Up Slides

Advanced Powertrain Research Facility
4WD Chassis Dynamometer Thermal Test Cell

Argonne NATIONAL LABORATORY

U.S. DEPARTMENT OF ENERGY

"Research and Data Driven Lab"
"Independent Public Data"

• Test cell features

- ✓ 4WD chassis dynamometer
  - Variable wheel base (180inches max)
  - 250 hp/axle
  - 300 to 12,000 lbs.. inertia emulation
- ✓ Radiant sun energy emulation 850W/m^2 (adjustable)
- ✓ Variable speed cooling fan (0–62mph)
- ✓ Gaseous fuel and hydrogen capable
- ✓ Diesel: Dilution tunnel, PM, HFID

• Thermal chamber

- ✓ EPA 5 cycle capable (20°F, 72°F and 95°F + 850W/m^2 solar load)
- ✓ Demonstrated as low as 0°F
- ✓ Intermediate temperatures possible

• Research aspects

- ✓ Modular and custom DAQ with real time data display
- ✓ Process water available for cooling of experiment components
- ✓ Available power in test cell
  - 480VAC @ 200A
  - 208VAC @ 100A
- ✓ ABC 170 Power supply capable to emulate electric vehicle battery
- ✓ Custom Robot Driver with adaptive learning
- ✓ Several vehicle tie downs
  - chains, low profile, rigid,…
  - 2, 3 and 4 wheel vehicle capable
- ✓ Expertise in testing hybrid and plug-in hybrid electric vehicles, battery electric vehicles and alternative fuel vehicles

• Special instrumentation

- ✓ High precision power analyzers (testing and charging)
- ✓ CAN decoding and recording
- ✓ OCR scan tool recording
- ✓ Direct Fuel Flow metering
- ✓ Infra Red Temperature camera
- ✓ In cylinder pressure indicating systems
- ✓ In-situ torque sensor measurement
- ✓ 5 gas emissions dilute bench with CVS (modal and bag emissions analysis)
- ✓ FTIR, Mobile Emissions unit
- ✓ Raw and Fast HC and NOx bench
- ✓ Aldehyde bench for alcohol fuels

***APRF** (Advanced Powertrain Research Facility)*

ver. Jan2012

Advanced Powertrain Research Facility
2WD Chassis Dynamometer

Argonne NATIONAL LABORATORY

U.S. DEPARTMENT OF ENERGY

"Research and Data Driven Lab"
"Independent Public Data"

- **Test cell features**
  - ✓ 2WD Light Duty / Medium Duty chassis dynamometer
    - 300 hp
    - 300 to 14,000 lbs.. inertia emulation
    - 10,000 lbs.. max weight driven axle
  - ✓ Multiple cooling fans available
  - ✓ Vehicle lift (max 10,000 lbs..)
  - ✓ Remotely located control room with conference area

- **Research aspects**
  - ✓ Modular and custom DAQ with real time data display
  - ✓ Flexible to adopt any drive cycle
  - ✓ Available power in test cell
    - 480VAC @ 200A & 100A
    - 208VAC @ 50A, 30A & 20A x3
  - ✓ ABC 170 power supply capable to emulate electric vehicle battery
  - ✓ Custom Robot Driver with adaptive learning
  - ✓ Expertise in testing hybrid and plug-in hybrid electric vehicles, battery electric vehicles and alternative fuel vehicles

- **Special instrumentation**
  - ✓ High precision power analyzers (testing and charging)
  - ✓ CAN decoding and recording
  - ✓ OCR scan tool recording
  - ✓ Direct Fuel Flow metering
  - ✓ Infra Red Temperature camera
  - ✓ In cylinder pressure indicating systems
  - ✓ In-situ torque sensor measurement
  - ✓ SEMTECH-DS (Mobile Emissions unit) with AVL DVE mass flow sensor

APRF (Advanced Powertrain Research Facility)

ver. Jan2012