Advanced Technology Vehicle Lab Benchmarking

2016 U.S. DOE Vehicle Technologies Program
Annual Merit Review and Peer Evaluation Meeting

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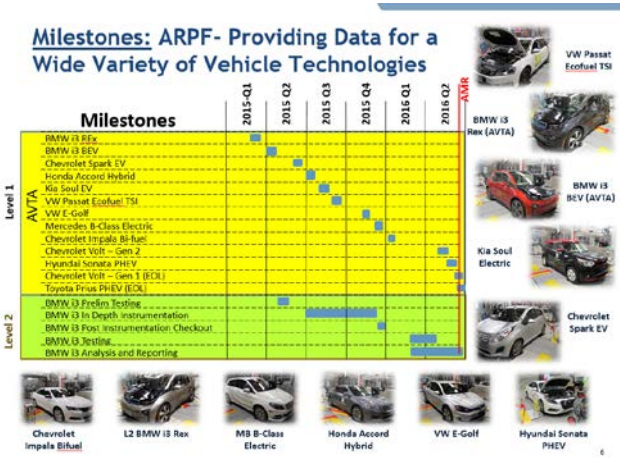
Overview

- **Timeline**
  - Benchmarking at ANL started in 1998
  - FY15 & FY16 Completed Testing:
    - 10 vehicles extensively evaluated in FY15, 4 in FY16 (L1/L2)
  - FY15 and FY16 Test Vehicles
    - See Milestone on slide 6



- **Budget**
  - L1/L2 FY2015- $1,925k
  - L1/L2 FY2016- $1,600k

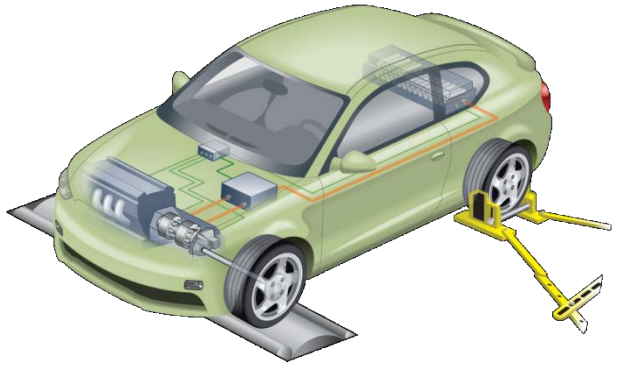
- **DOE VSST barriers addressed:**
  - Computational Models, Design and Simulation Methodologies (C)
    - Model development and validation
  - Lack of Standardized Testing Protocols (D)
    - Validating HEV, BEV & PHEV procedures
    - Support of SAE committee (J2951 Drive Metrics, J2907/2908 Powertrain 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, Intertek CECET, ANL
  - 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

- Complete technology evaluations of current generation of battery electric vehicles
- Advance methods of data collection, reporting and analysis
- Continue to enhance instrumentation and signal capture through advanced analog instrumentation and capture of vehicle communications messaging.
- Evaluate the effect of advanced thermal management systems on BEV's
- Determine impact of new vehicle architectures (REx) on codes and standards

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.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

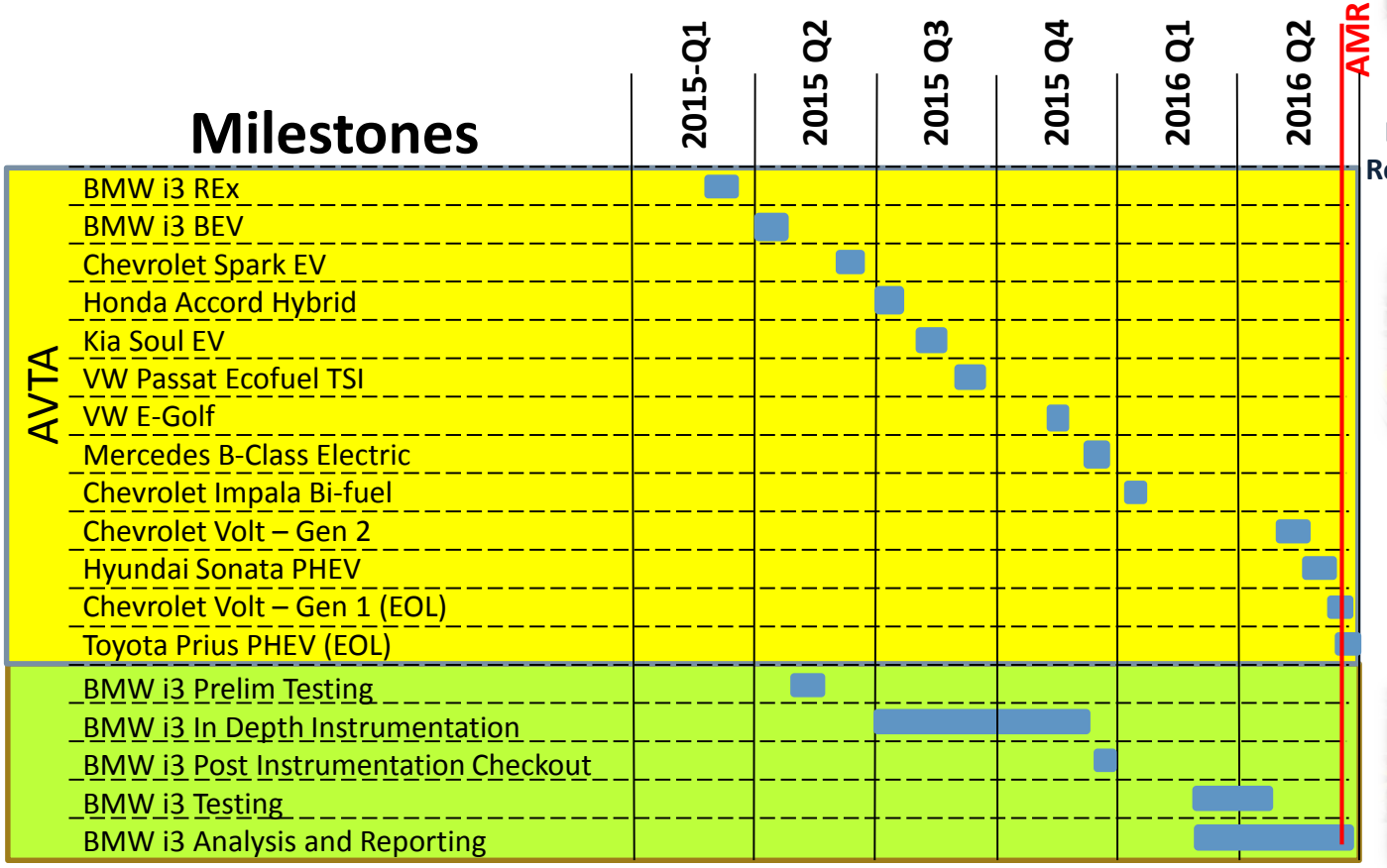
- *Vehicle efficiencies and energy use: average over drive cycles at different temperatures*
- *Component behaviors from a vehicle system perspective*
- *Charging profiles, battery capacities, battery characterizations*

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



VW Passat Ecofuel TSI

BMW i3 Rex (AVTA)

BMW i3 BEV (AVTA)

Kia Soul Electric

Chevrolet Spark EV

Chevrolet Impala Bifuel

L2 BMW i3 Rex

MB B-Class Electric

Honda Accord Hybrid

VW E-Golf

Hyundai Sonata PHEV

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

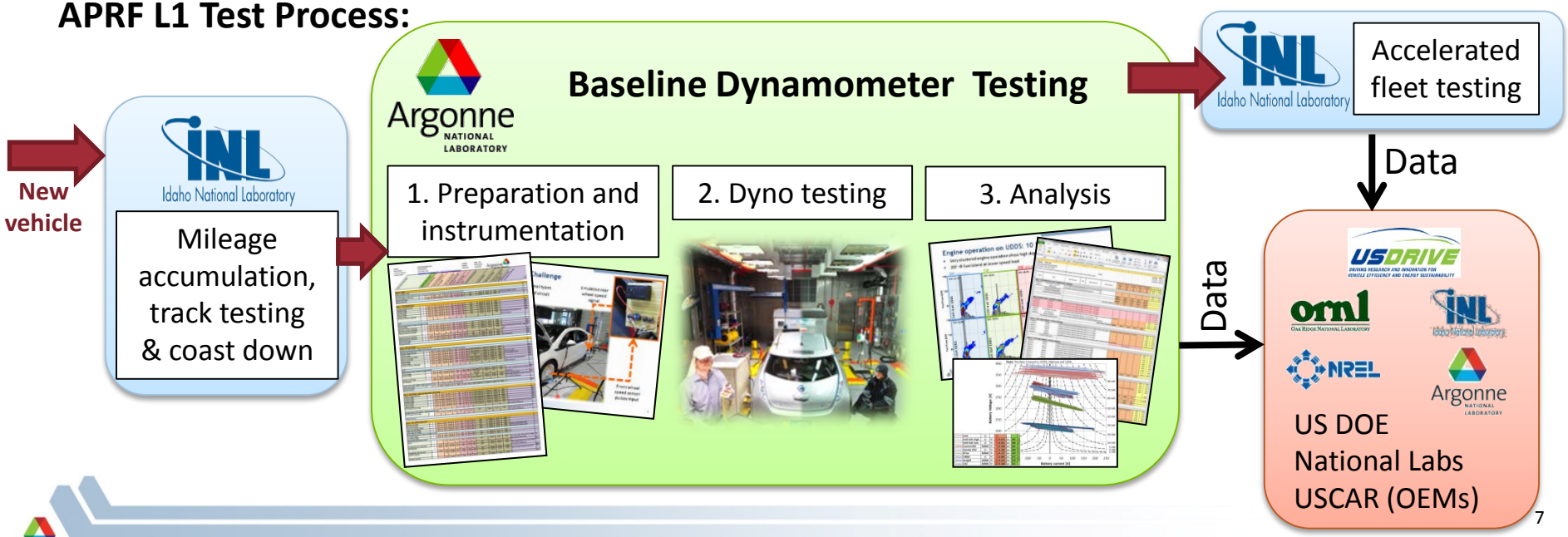
Powertrains

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

Alternative fuels

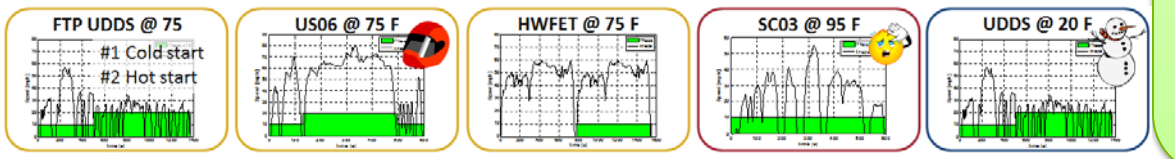
- Hydrogen, Natural Gas
- Ethanol, Butanol
- Diesel (Bio, Fisher-Tropsch)

APRF L1 Test Process:



Approach: Purpose Built Research Laboratory for Automotive Technology Evaluations

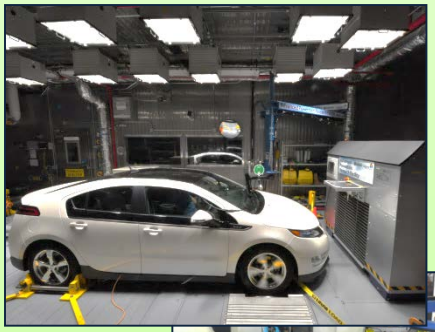
- Level 1 and Level 2: Comprehensive instrumentation and evaluation
  - Level 2: Focused, component and systems level
  - Level 1: Systems level, **reversible!**
  - Vehicle characterization (fuel and energy consumption, emissions, performance)
  - Vehicle operation and strategy
  - Component specific 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: 0°F to 95°F with 850 W/m^2 radiant solar energy (full "5-Cycle")



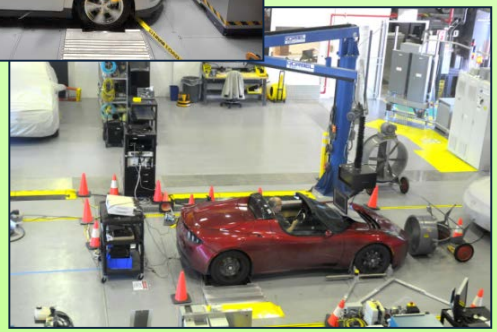
Advanced Powertrain Research Facility

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 (2014 BMW i3 REx)

Broadcast and Diagnostic CAN

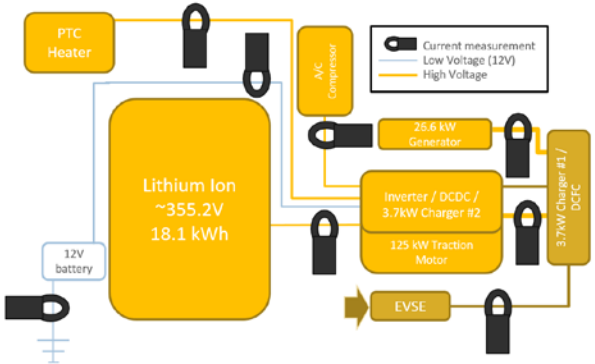
HV Battery Cell & Module Temp/Voltage

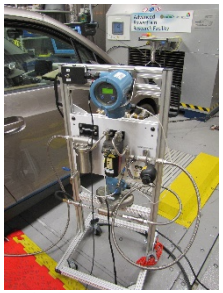
Interior Temperatures

3 Phase Motor Voltage

Direct Axle Torque

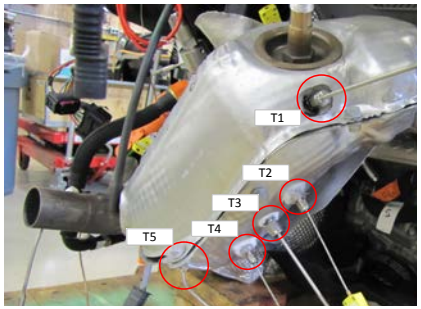
HV/ LV Current and Voltage



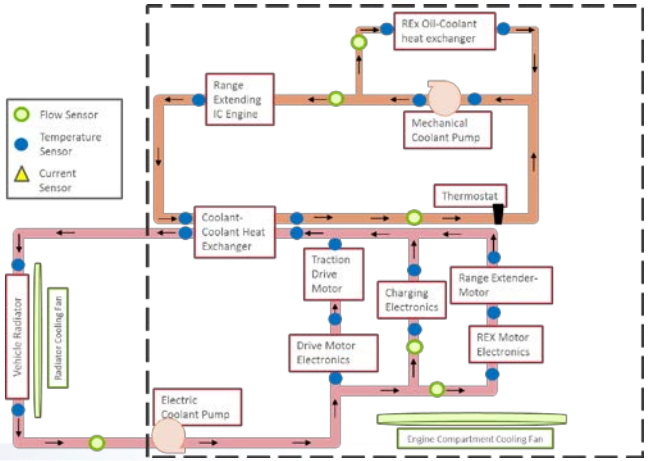


Direct Fuel Flow

Exhaust Temperatures

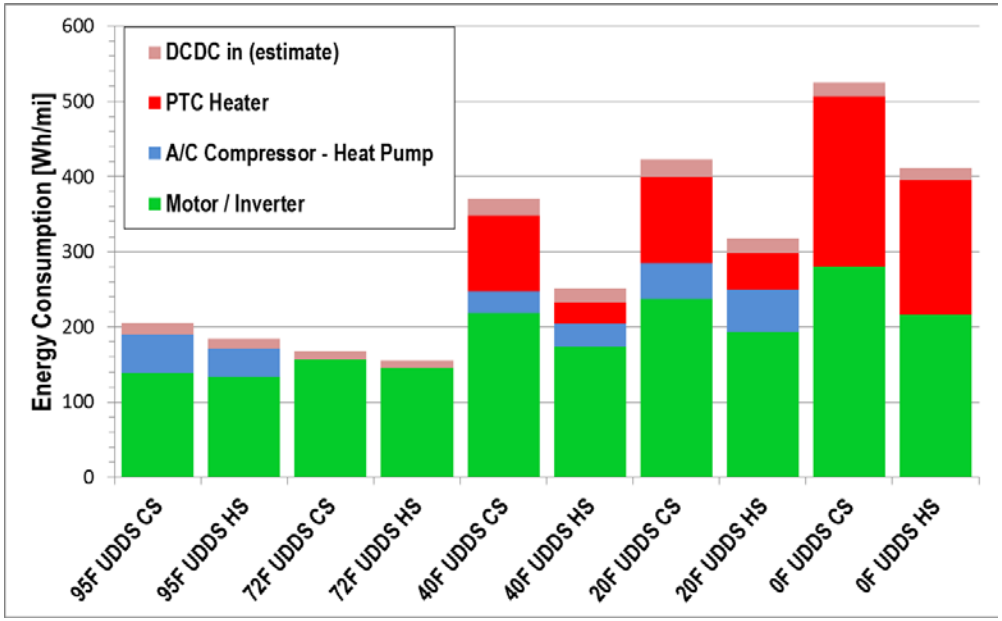


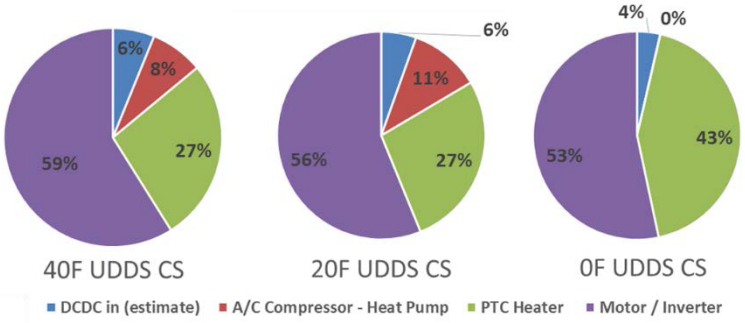
Cooling System Temperatures

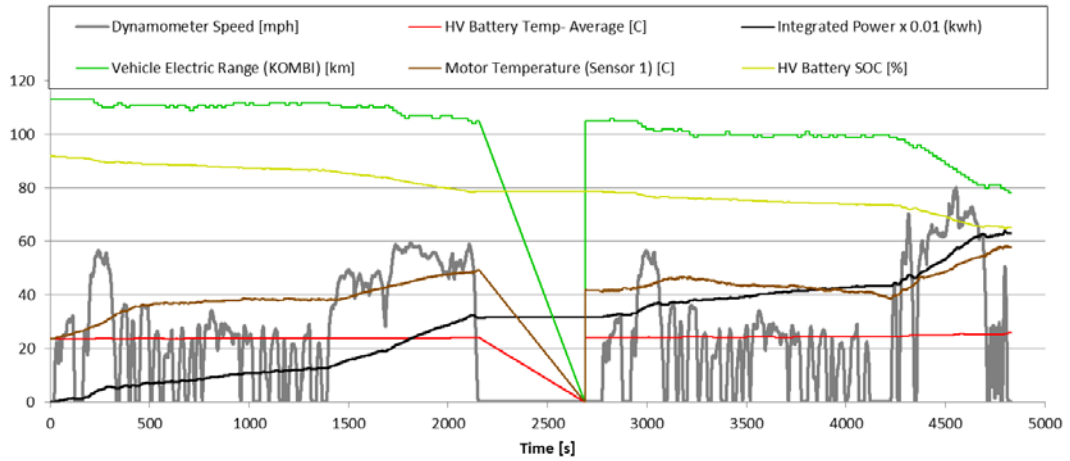


Accomplishments: Quantification of BEV Heat Pump Use – AVTA BMW i3 BEV

- J1634 MCT (w/standardized soak times)
- Test temps [F] of 0, 20, 40, 72, 95 +SE
- Instrumentation:
  - HVAC system component energy flow
  - Vehicle data for system operational points and control requests.
- Highlighted results
  - Heat pump use not seen at 0F test temp
  - Cabin heating loads continues to be more impactful than required cooling loads.
  - Thorough instrumentation provides opportunity for detailed analysis



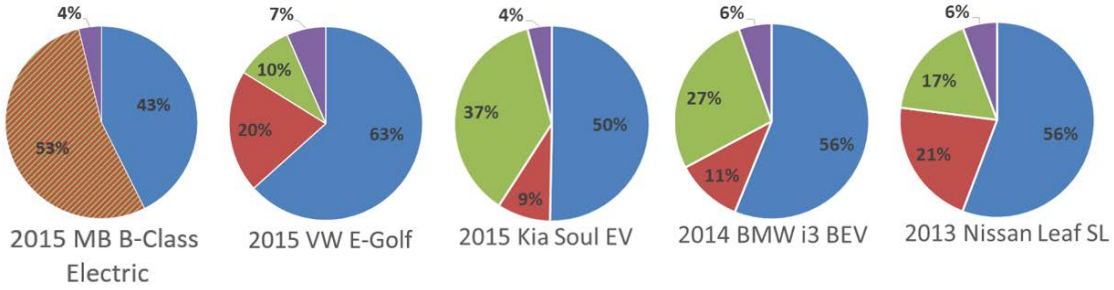


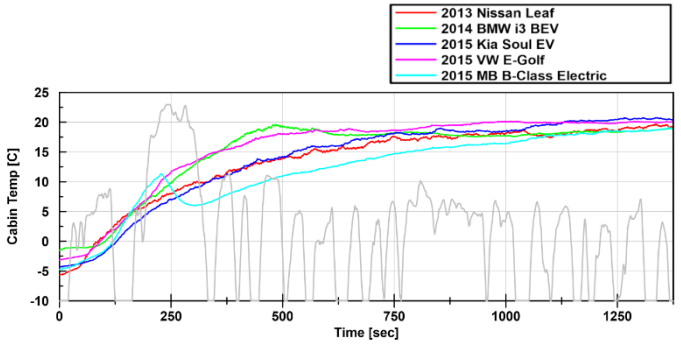


Accomplishments: Quantification of BEV Heat Pump Use

- Comparative data available for five vehicles with heat pumps
- Four vehicles offer additional testing at 0F, two at both 40F & 0F
- Heat pump operation varied among manufacturers
  - 0F- only E-Golf found to operate heat pump (25% of HVAC load)
- Vehicle with greatest utilization of heat pump operation, demonstrates greatest reduction in EC
- Heating loads for UDDS CS require, at minimum, 30% of total battery energy

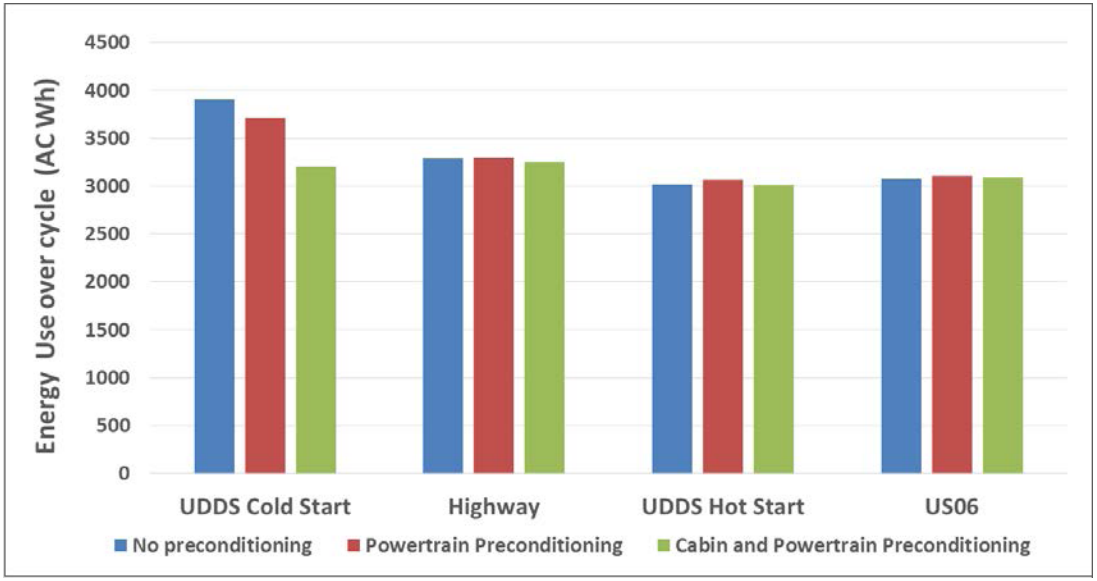
Energy Consumption (Wh/mi)	Motor / Inverter	A/C – Heat Pump	PTC Heater	DCDC in (estimate)	Total
2015 MB B-Class	320.0	**402.3 (Joint measurement)**		28.6	**750.9**
2015 VW E-Golf	221.3	71.6	33.6	22.8	**351.8**
2015 Kia Soul EV	221.1	38.8	161.7	17.7	**439.3**
2014 BMW I3 BEV	237.5	46.7	115.6	23.0	**420.5**
2013 Nissan Leaf	217.9	82.9	67.6	22.2	**390.5**

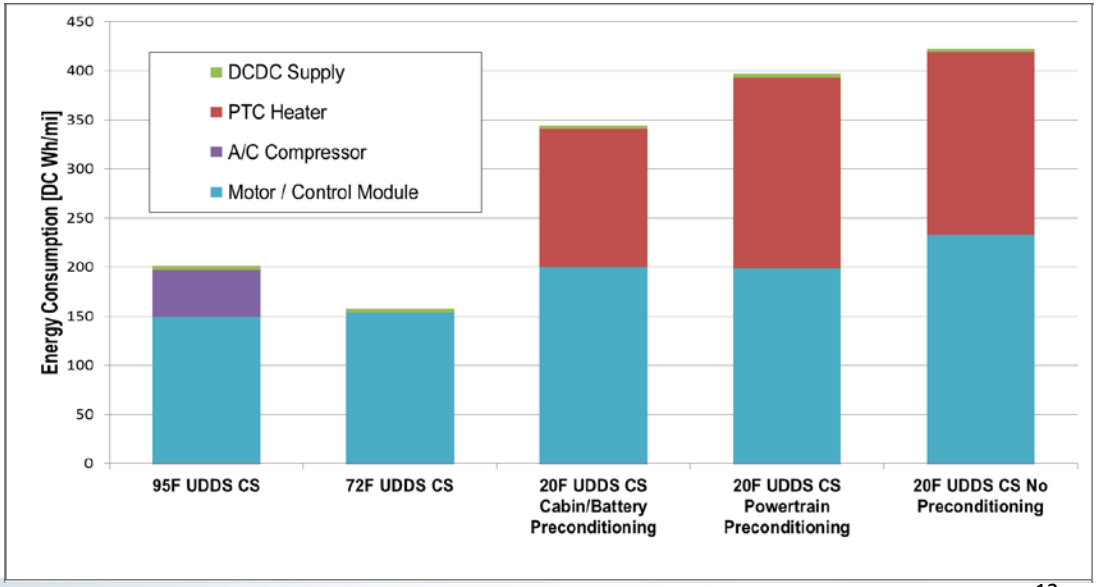




Accomplishments: BEV Preconditioning

- Test vehicle- AVTA 2015 Chevrolet Spark BEV
- J1634 MCT varied evaluations
  - No preconditioning
    - Unplugged overnight
  - Powertrain preconditioning
    - Plugged until testing
  - Cabin preconditioning
    - Plugged until testing
    - 2x20 minute cabin preconditioning cycles
- 2.8 AC kWh used during preconditioning cycles

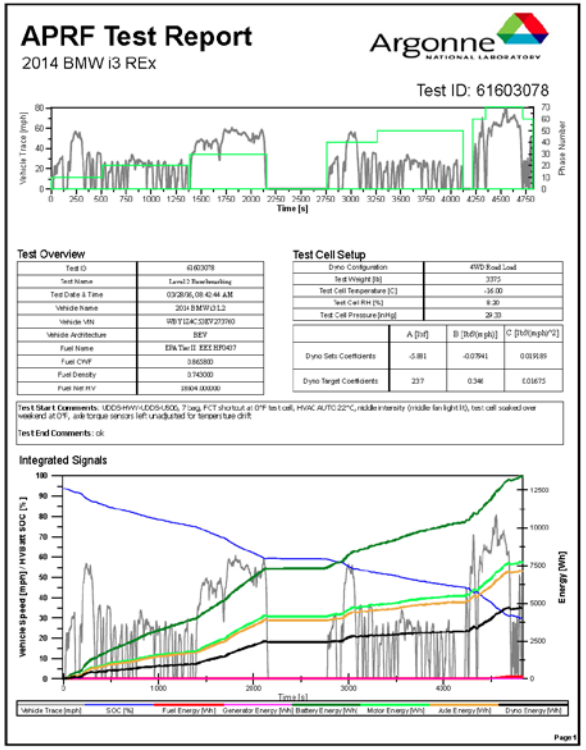


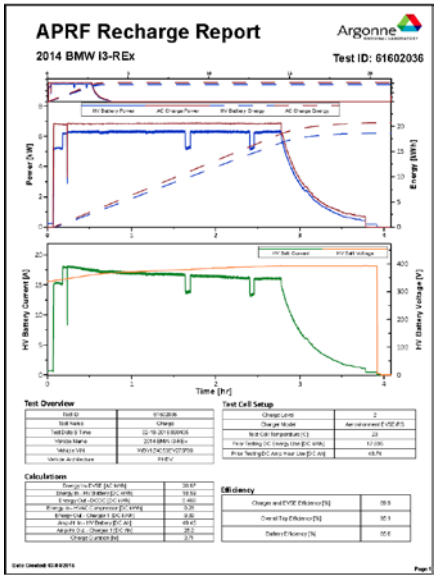


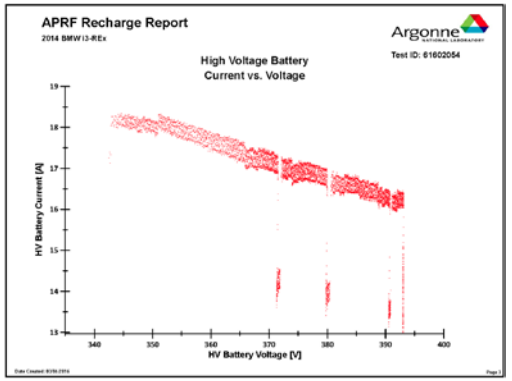
Accomplishments: Continued Revision of Analysis Methods

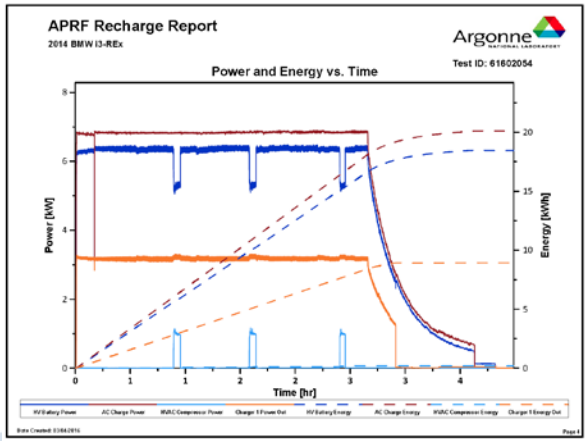
- Continued refinement of reporting methods
- Cycle based test reports
  - Cycle overview
  - Phase based calculations
  - Simplistic plots/ tables for reference
  - Energy / emissions focus
- EV Charge Reports
  - Multiple charge rates (L1-DCFC)
  - Component analysis
  - Energy & Efficiency Reporting
- Summary reports, with corresponding data sets, posted to public database:

ANL.gov/D3



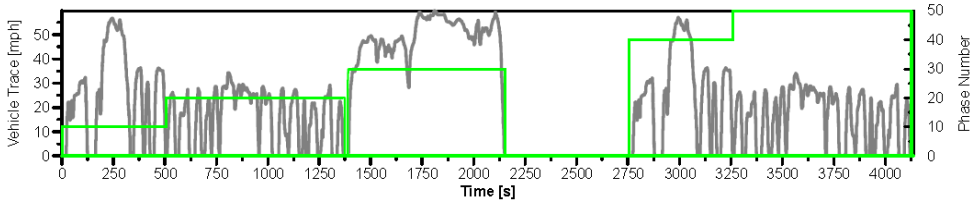


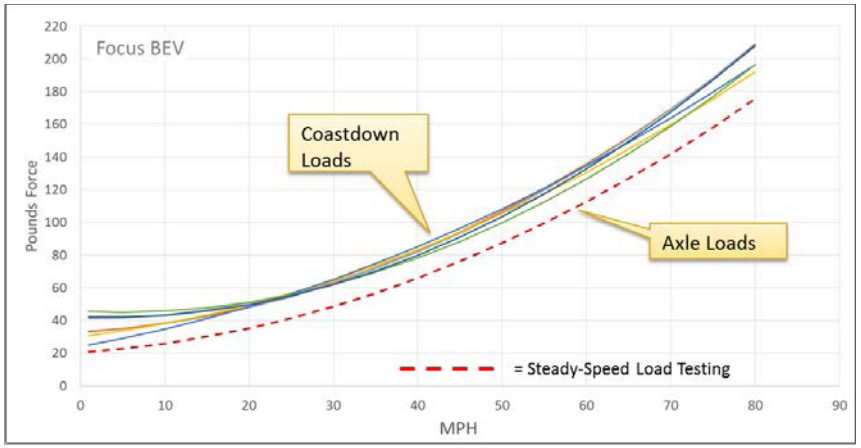




Accomplishments: Codes and Standards

- **Continued efforts to advance automotive codes and standards**
- **SAE J2908- HEV Net power rating**
  - Development and evaluation of test methods
- **SAE J2951 – BEV Coast downs**
  - Effect of BEV powertrain controls on coast down performance
- **SAE J1634- BEV Energy Consumption and Range Test Procedure**
  - Test methods independently evaluated on most recent BEV's





Hub Dynamometer

Chassis Dynamometer

Vehicles Tested:

Coordination: Existing Collaborations with Other Institutions

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

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

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

APRF

DOE technology evaluation
- DOE requests
- National Lab requests

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

AVTC (Advanced Vehicle Technology Competition)
Universities
AVTC, GM, EcoCAR3 Advanced Vehicle Technology Competition

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

Autonomie
Support of modeling and simulation with data
AUTONOMIE

Chrysler – CTC
CHRYSLER

GM – Powertrain, Milford
GM

Ford – Powertrain, APTL
Ford

Proposed Future Work: Benchmark focus will begin to include AVTA End of Life vehicles

Upcoming AVTA Vehicles (as of Apr 2016):

- 2016 Chevrolet Volt
- 2016 Hyundai Sonata PHEV
- 2016 Audi A3 E-tron
- AVTA End of Life (EOL) vehicles
  - 2013 Chevrolet Volt (AVTA EOL)
  - 2011 Chevrolet Volt (AVTA EOL)
  - 2013 Toyota Prius PHEV (AVTA EOL)
- Further potential AVTA and L2 vehicles:
  - 2016 Toyota Prius PHEV
  - 2016 Toyota Mirai
  - 2017 Chevrolet Bolt
- Increased focus on analysis and reporting

FY2015 APRF L2 Research Vehicle: 2014 BMW i3 REx

Level 2 Vehicles + ANL Vehicles

- 2014 BMW i3 Rex (FY2015 L2 vehicle continued)

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 for support of 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**
  - Evaluation of recent advanced BEV cabin thermal management strategies
  - Development of advanced reporting methods with distribution to DOE partners and D^3
  - Continued AVTA vehicle evaluation collaboration with INL and Intertek CECET
  - Test results and raw data available publicly at the Downloadable Dynamometer Database website (http://www.transportation.anl.gov/D3/)
  - Enhanced 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, and assist in aiming testing direction

Technical Back-Up Slides

Advanced Powertrain Research Facility
4WD Chassis Dynamometer Thermal Test Cell

"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

"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