Advanced Technology Vehicle Lab Benchmarking – Level 1

2013 U.S. DOE Hydrogen and Fuel Cell Program and Vehicle Technologies Program Annual Merit Review and Peer Evaluation Meeting

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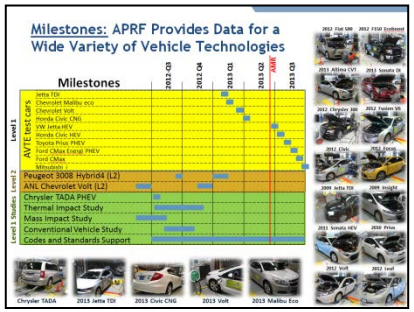
Overview

- **Timeline**
  - Benchmarking at ANL started in 1998
  - FY13 Completed Testing:
    - Leaf BEV, Volt, Jetta TDI, Malibu
    - Thermal Impact study
    - Conventional Vehicle Study
  - FY13 and FY14 Test Vehicles
    - See Milestone on slide 6



- **Budget**
  - FY2012 $600k
  - FY2013 $1,300k
  - Other Leveraged DOE Projects (separate funding): Codes and Standards test support, TADA (OEM PHEV), Mass Impact Study, Thermal Evaluations, Conventional Vehicle Study

- **DOE VSSST barriers addressed:**
  - Cost (B)
    - New, lower-cost Sonata HEV design
  - Lack of Standardized Testing Protocols (D)
    - Validating BEV and PHEV test procedures
    - Support of SAE committee (J2951 Drive metrics, JXXX Powertrain rating, … etc…)
  - Constant advances in technology (F)
    - Public data generation from benchmarking recent mass-produced BEV and PHEV.
    - New HEVs compared to previous models

- **Partners:**
  - AVTE (Advanced Vehicle Technology Evaluation): DOE, INL, ANL, ECOtality
  - DOE, National Laboratories, USDrive, OEMs, Suppliers, Vehicle Competitions

Relevance: Objectives of the Advanced Powertrain Research Facility

Benchmark 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"

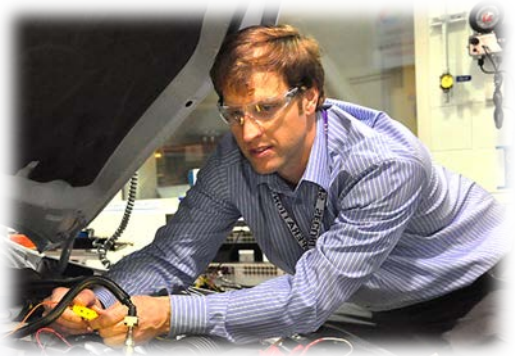
Laboratory Testing Mission

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 evaluation of emerging technology
- Generate data to support model creation and validation, as well as DOE target setting

Focus for FY13

- Technology benchmarks for diesel, CNG, conventional, HEV, PHEV, BEV.
- Thermal effects on energy consumption and powertrain behavior
- Status of conventional vehicle evolution-relentless raising of the baseline



Relevance: Advanced Technology Benchmark

- 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

APRF direct impact on DOE VTP

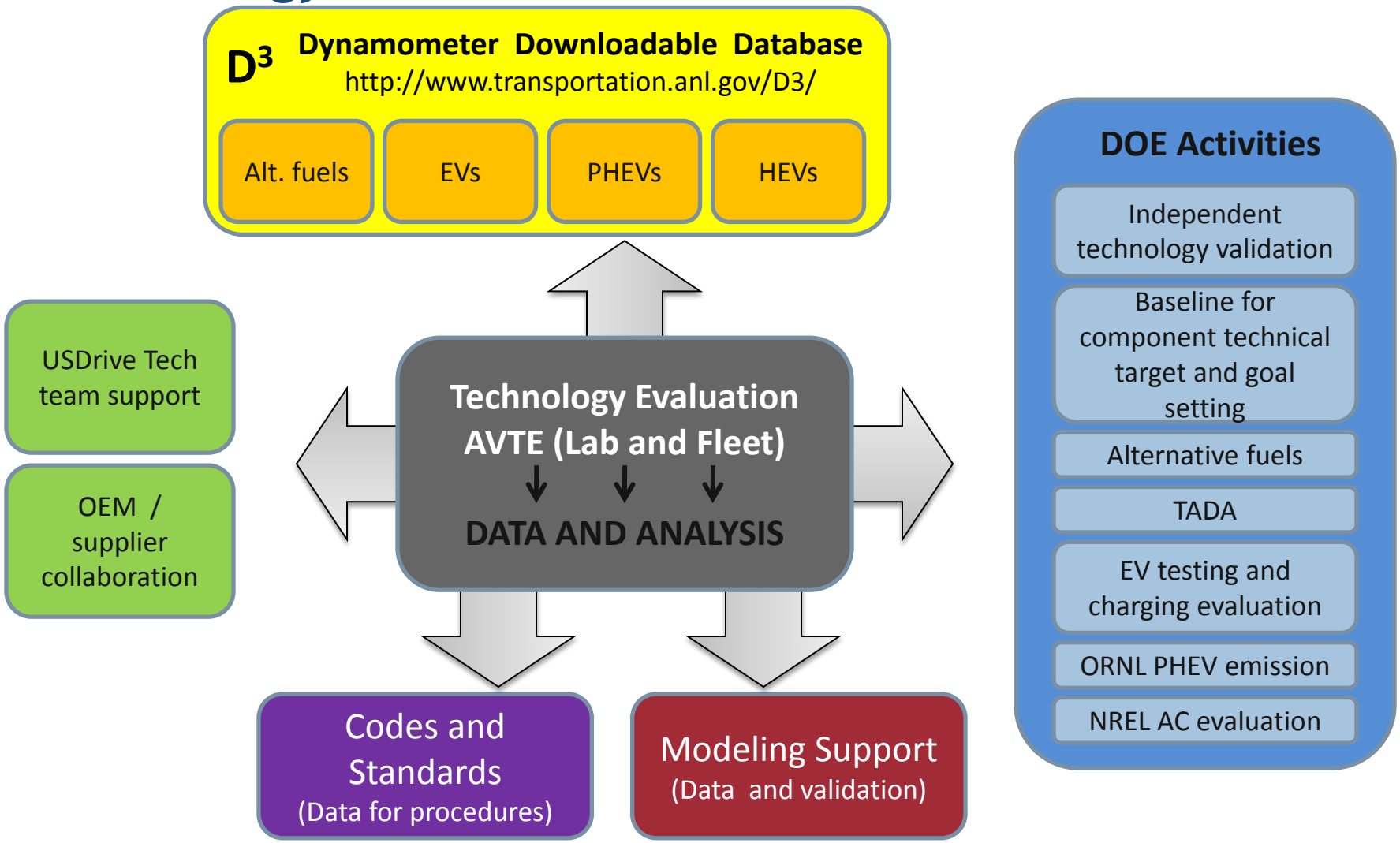
Vehicle Technologies Program Plan

- Batteries and Electric Drive Technology
- Advanced Combustion Engine R&D
- Fuels Technology
- Materials Technology
- Outreach, Deployment and Analysis
- Vehicle and Systems Simulations and Testing

VSST Challenges and barriers

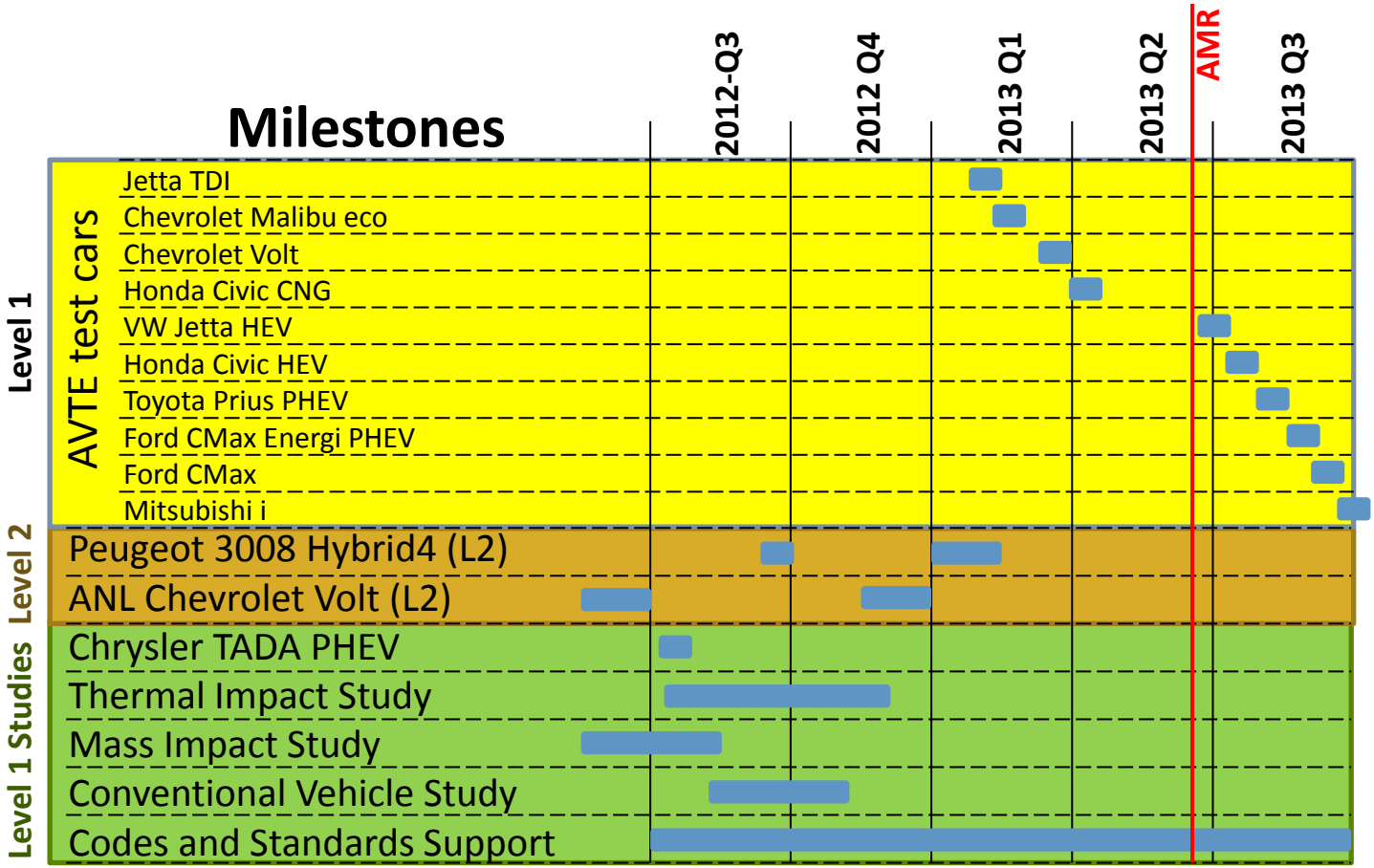
A. Risk Aversion
B. Cost.
C. Infrastructure.
D. Lack of standardized test protocols.
E. Computational models, design and simulation methodologies.
F. Constant advances in technology.

Relevance: Enable Petroleum Displacement through Technology Assessment and Data Dissemination



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

Milestones: APRF Provides Data for a Wide Variety of Vehicle Technologies




Chrysler TADA


2013 Jetta TDI


2013 Civic CNG


2013 Volt


2013 Malibu Eco


2012 Fiat 500


2012 F150 Ecoboost


2013 Altima CVT


2013 Sonata DI


2012 Chrysler 300


2012 Fusion V6


2012 Civic


2012 Focus


2009 Jetta TDI


2009 Insight


2011 Sonata HEV


2010 Prius


2012 Volt


2012 Leaf

Approach: 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:

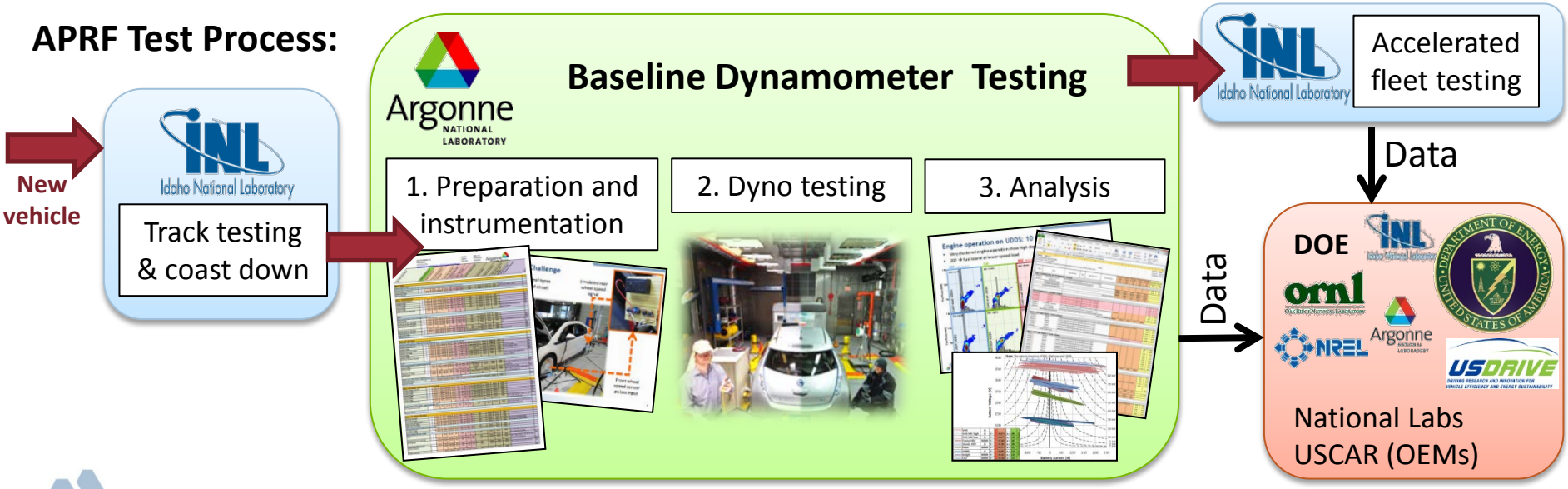
- Advanced and unique facilities and instrumentation
- Continuous improvement of testing procedures
- Standardization of test plans including instrumentation and drive cycles which are adjusted for individual vehicles
- Significant knowledge of advanced vehicles and testing methods

Expertise in testing

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

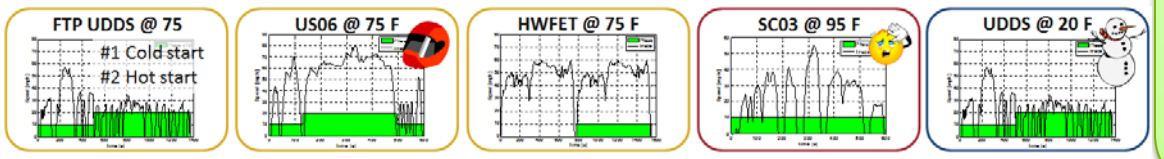
Alternative fuels
- Hydrogen, Natural Gas
- Ethanol, Butanol
- Diesel (Bio, Fisher-Tropsch)

APRF Test Process:



Approach: Purpose Built Research Laboratory for Automotive Benchmark Activities

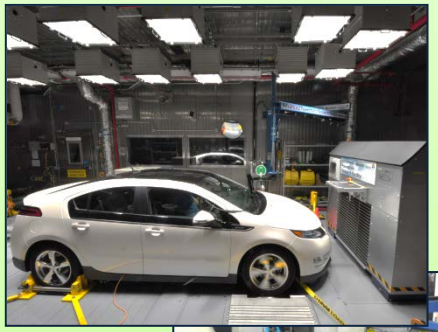
- Level 1 testing: Basic and comprehensive instrumentation
  - Level 1 = non-intrusive instrumentation
  - Vehicle characterization (fuel and energy consumption, emissions, performance)
  - CAN-decoded data, speeds, thermocouples, battery power, other technology specific removeable instrumentation
  - Vehicle operation and strategy
- Drive cycles and test conditions
  - Standard drive cycles, technology specific cycles, performance tests, vehicle and component mapping cycles
  - Thermal "5-Cycle" test conditions: 20°F, 72°F and 95°F with 850 W/m^2 radiant solar energy



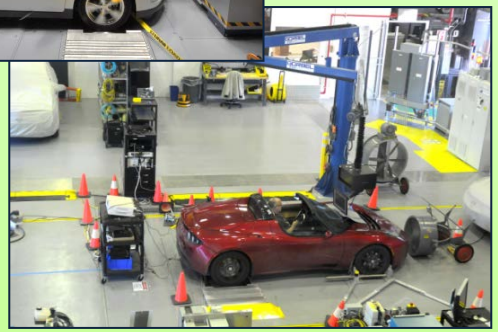
Advanced Powertrain Research Facility

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 (+)*

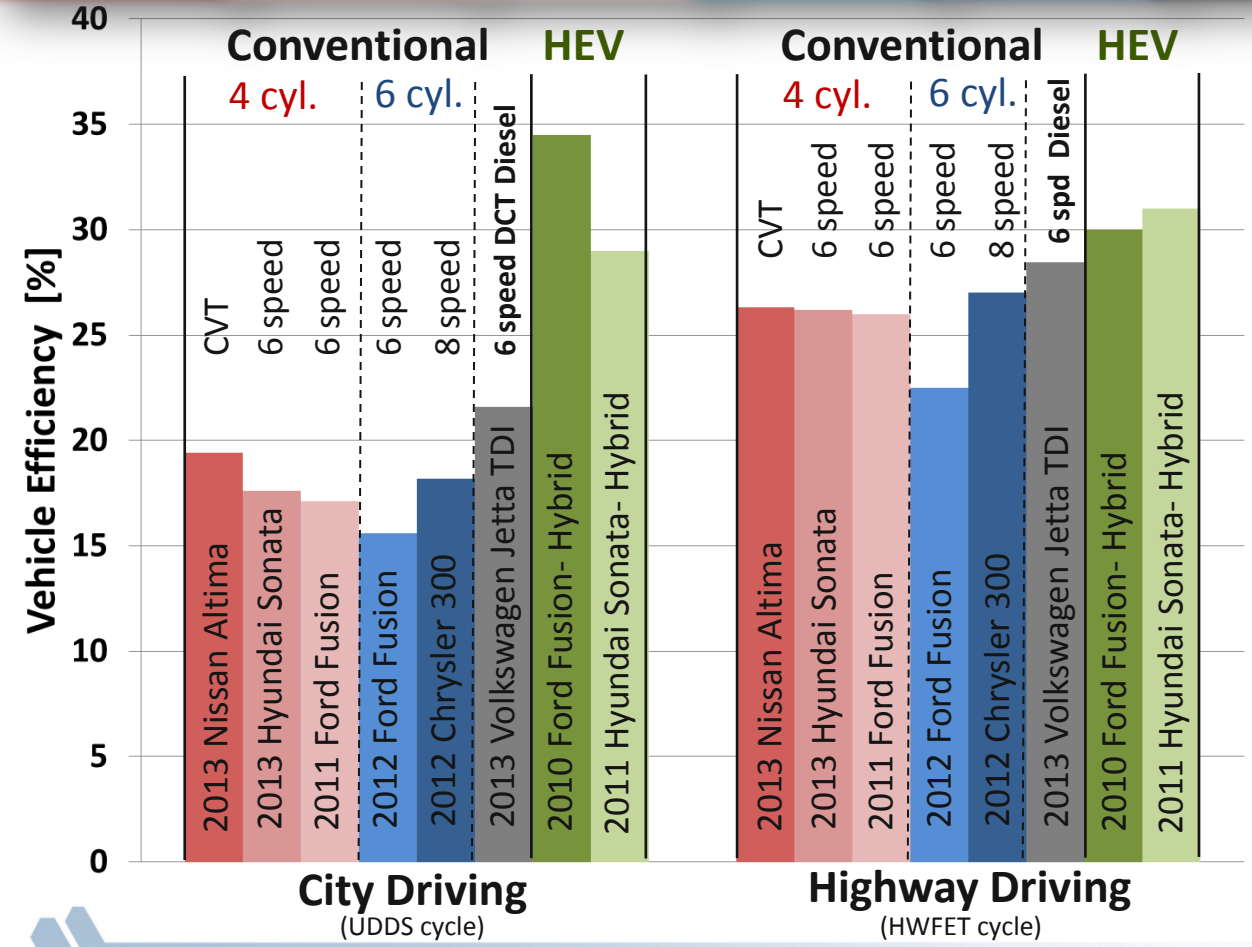


4WD chassis dyno with thermal chamber



2WD chassis dyno

Accomplishments: Measured Today's Conventional Vehicle Efficiencies by Technology

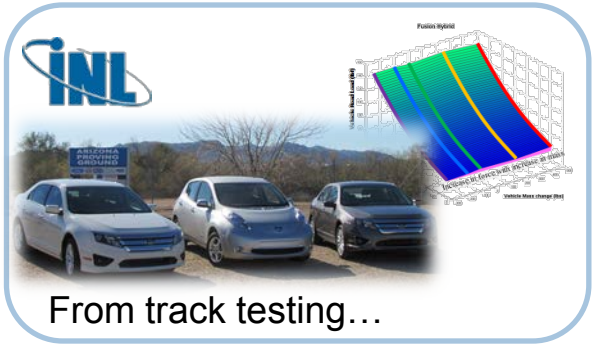


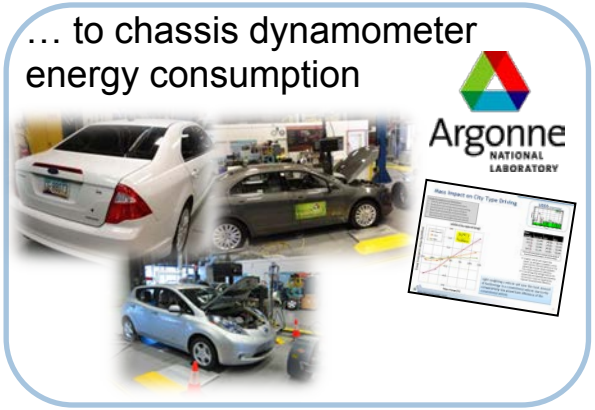
Vehicle efficiency = (Positive cycle energy at wheel) / (Cycle fuel energy)

- Vehicle efficiency is dependent on driving style
  - City driving: transient with lower loads and idle time impacts efficiency
  - Highway driving: higher steady engine loads result in greater average efficiency
- Technology observation
  - Engine size: smaller engine→ higher average efficiency
  - CVT & 8 speed: enables optimized engine loading in city driving
  - Diesel: highest vehicle efficiency of conventional technology
  - HEV: increased freedom to leverage engine operation

Accomplishments: Energy Consumption Benefits of Reducing Vehicle Mass

- The mass of a conventional vehicle, a hybrid electric vehicle and a battery electric vehicle were varied between +500 lbs. to -500 lbs. to determine impact on energy consumption
- The light weighting benefits on fuel/energy consumption depends on the driving type.
  - In city-type driving and aggressive type driving with many and/or larger accelerations, light weighting for any vehicle type will reduce the energy/fuel consumption
  - In highway-type driving where a vehicle will cruise at relative steady speed, light weighting vehicles does not significantly reduce the energy/fuel consumption
- Light weighting a conventional vehicle will provided the largest improvement in fuel consumption due to the relative lower powertrain efficiency compared to a battery electric vehicle.





For a 10 % mass reduction						
	[%] consumption reduction			[Liter gas equivalent/100km] consumption reduction		
Driving type	City	Highway	Aggressive	City	Highway	Aggressive
Conv V6	~3.5	~3.0	~4.5	~0.35	~0.19	~0.40
HEV	~2.5	~1.5	~4.0	~0.12	~0.06	~0.19
BEV	~5.0	~0.1	~2.5	~0.08	~0.01	~0.10

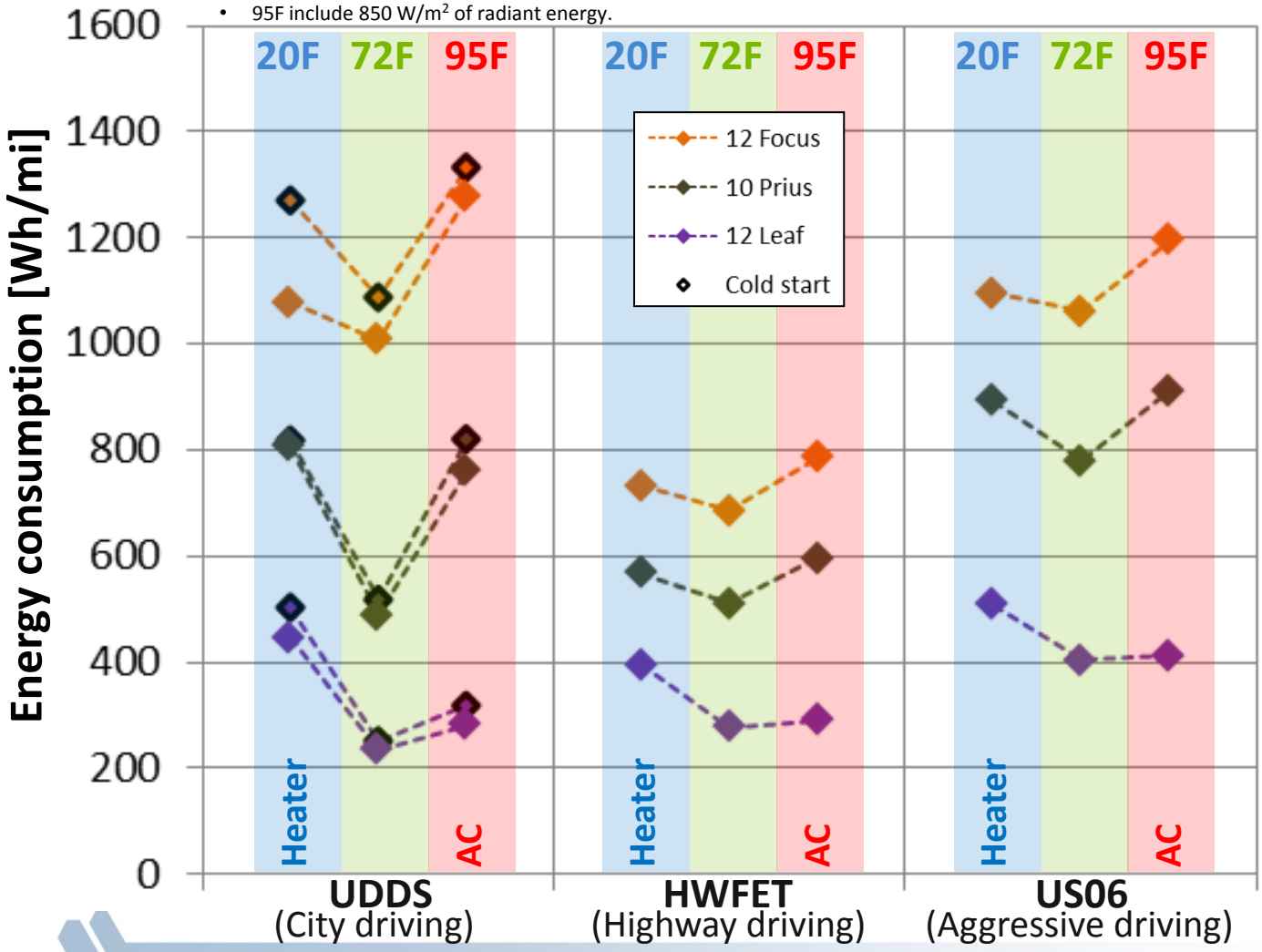
Study Assumptions and limitations

- Vehicle powertrain remained constant
- Study does not include mass compounding
- Results based on single car per category
- Road load input based on track test data
- Manufacturer recommended tire pressure maintained for all weight cases per vehicle

Accomplishments: Ambient Temperatures and Driving Style Impact Energy Consumption

Test Notes:

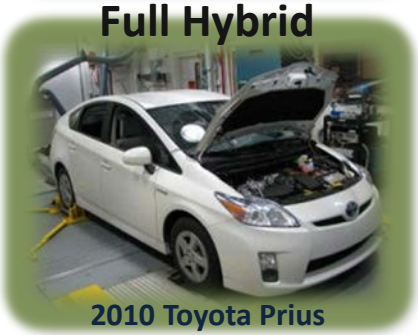
- Cold start → vehicle soaked at target temperature for at least 12hr. Powertrain is hot in the other tests.
- In 20F and 95F, climate control setting targeted 72F in automatic mode.
- 95F include 850 W/m^2 of radiant energy.



Conventional

2012 Ford Focus

Full Hybrid



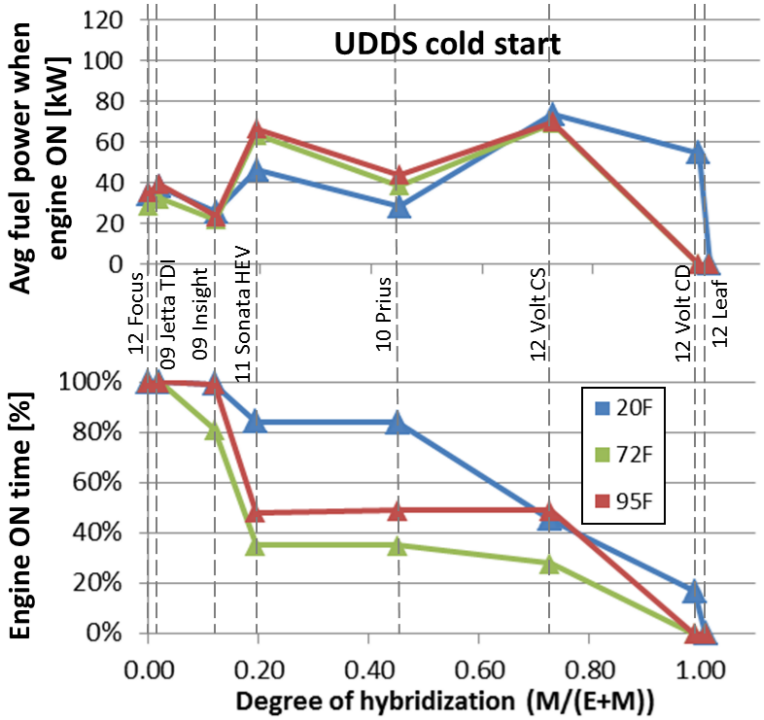
2010 Toyota Prius

Electric Vehicle

2012 Nissan Leaf

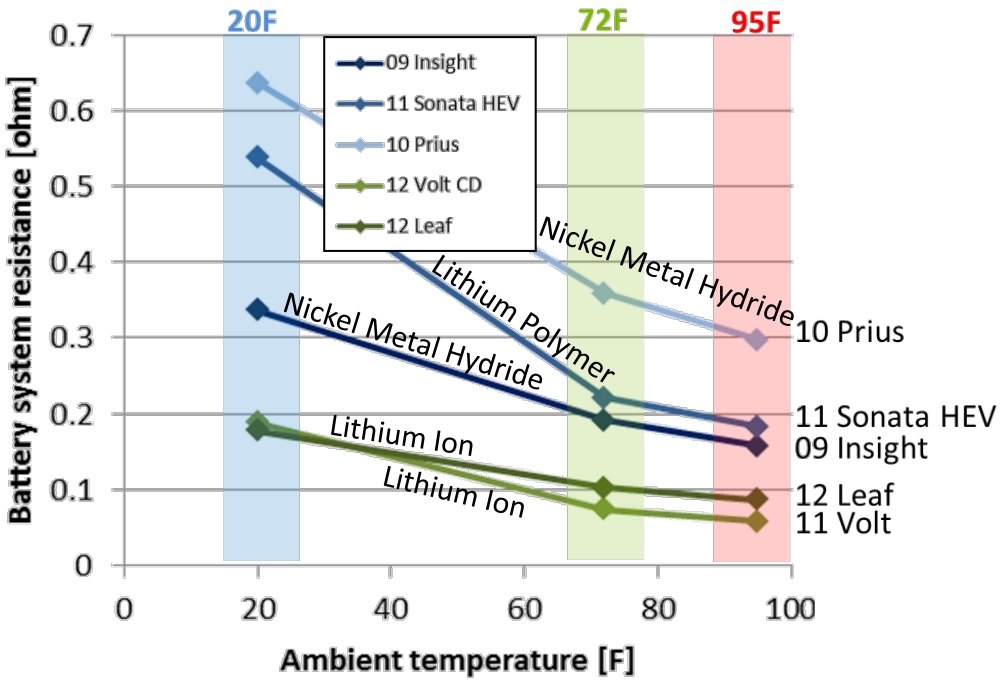
Accomplishments: Studies Impact of Ambient Temperature on Advanced Technology Vehicles

- **Comprehensive thermal study**: 7 vehicles tested on cold start UDDS, hot start UDDS, HWFET and US06 at ambient temperature of 20°F, 72°F and 95°F with 850 W/m^2 of sun emulation
- The more efficient the vehicle the higher the impact of climate control on energy consumption and range
- **20°F cold start** has the largest cold start penalty due to high powertrain losses and frictions. Once the powertrain reached operating temperatures the energy consumption is close to the 72°F results again
- **95°F environment** requires a constant A/C compressor load that impacts the energy usage across all vehicle types on hot and cold starts

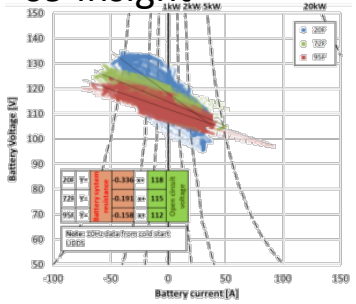


12 Focus	09 Jetta TDI	09 Insight	11 Sonata HEV	10 Prius	12 Volt	12 Leaf
Conventional 2.0L DI 6 spd DCT Gasoline	*Conventional* 2.0L TDI 6 spd DCT Diesel	*Mild HEV* 1.3L CVT 10kW motor	*Pre-trans HEV* 2.4L DI 6 spd auto 30kW motor	*Full HEV* 1.8L DI Power split 60kW prim motor	*PHEV EREV* 1.4L DI 111kW prim motor	*BEV* Single gear 80kW motor
						

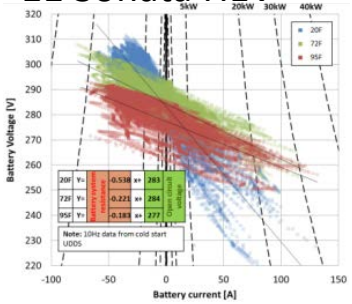
Accomplishments: Quantified Battery System Resistance Change with Temperature



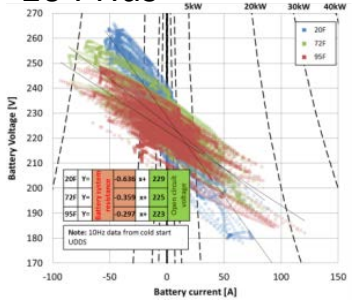
09 Insight



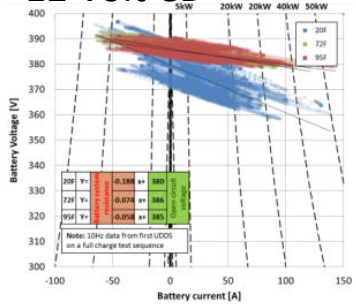
11 Sonata HEV



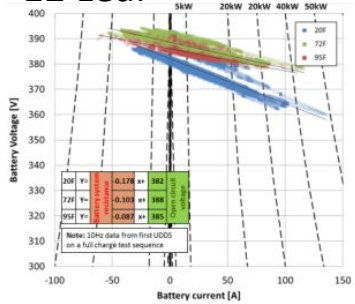
10 Prius



12 Volt CD



12 Leaf



Note: the voltage scale of the graphs varies but the window is always 100V.

Accomplishments: Collaborations Contributing to Technology Development

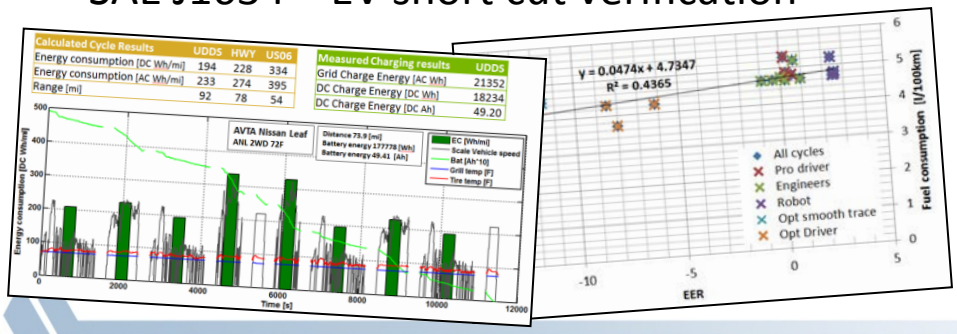
CNG conversion testing

- Standard conversion benchmark to capture current state of the art

E-250 CNG conversion

Codes and Standards Support

- SAE J2951™ Drive Metric implementation
- SAE J1634™ EV short cut verification



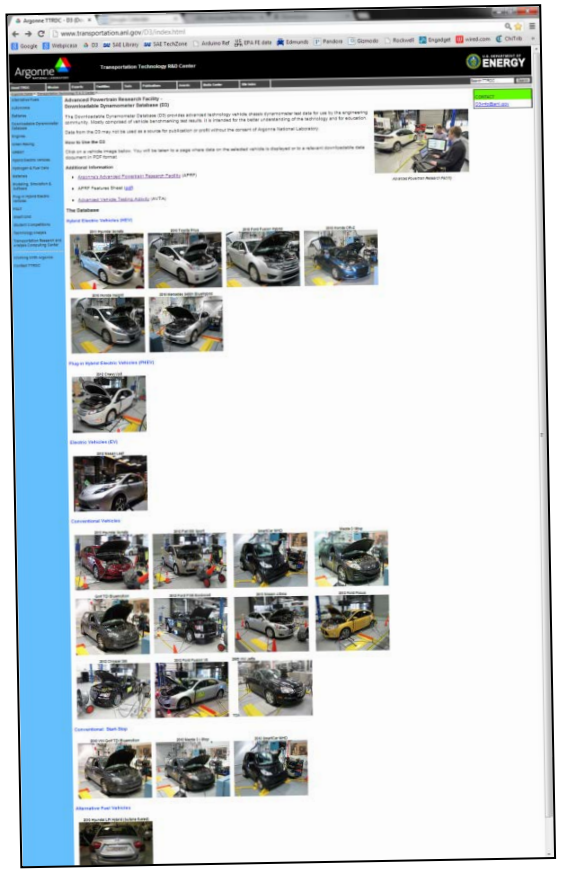
TADA (Technology Assessment and Deployment Activity)

- Data used for SAE J1711™ validation
- OEM vehicles → wider EV range and better controlled to a more refined PHEV compared to conversions
- 5-cycle testing with testing at OEM for cold and hot testing

Chrysler TADA vehicle

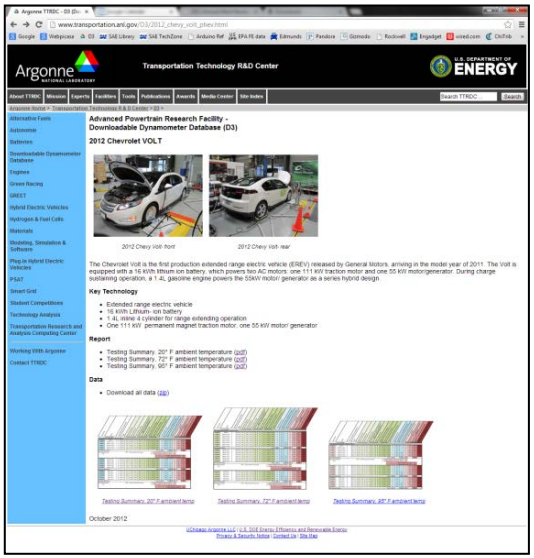
Accomplishments: Downloadable Dynamometer Database (D3) www.transportation.anl.gov/D3/

Vehicle Database
organized by vehicle type



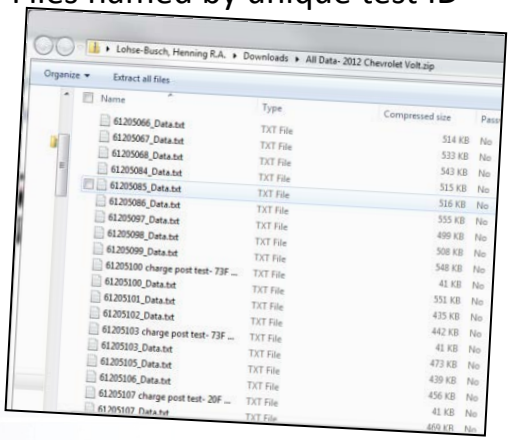
A Page for each vehicle

- Brief description with key technologies and pictures
- Analysis presentation / report (when available)
- Test summary results
- 10Hz data download



Test Summary Results
Each test has a unique test ID

10Hz raw data files
Files named by unique test ID



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)

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

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, 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

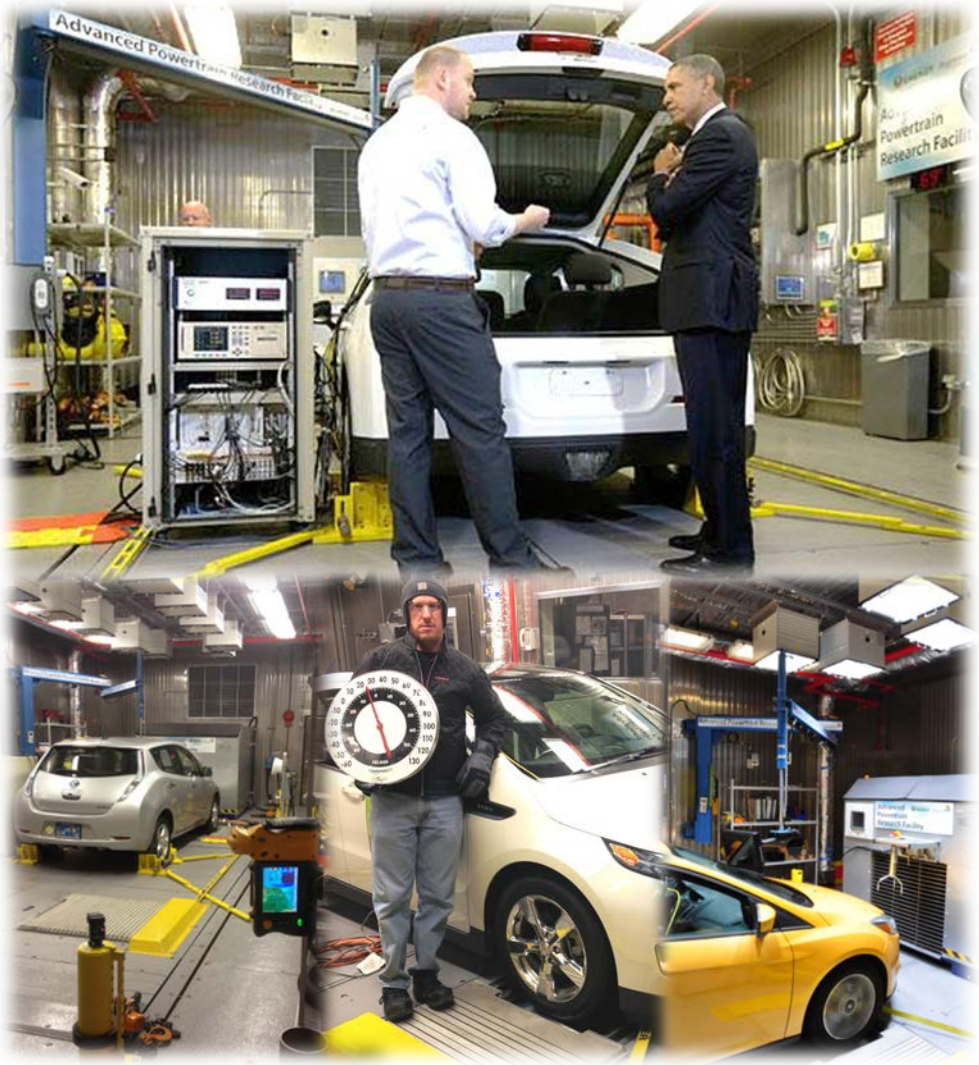
Proposed Future Work: Level 1 Benchmark Will Continue with Emphasis on Thermal Testing

Future AVTE Level 1 Vehicle Testing Plans (FY13 and FY14)

- Ford Focus EV
- VW Jetta HEV
- Coda Sedan EV
- Ford CMax Energi PHEV
- Ford CMax HEV
- Toyota Prius PHEV
- Toyota Rav4 EV
- Honda Civic HEV
- Honda Accord PHEV
- Mitsubishi I EV

New Vehicle Technology Evaluations

- New PHEVs/BEVs from other OEMs
- Many OEMs adding novel powertrain warm-up hardware and controls
- Climate control load investigations
- Lab can achieve 0° F for investigations in very cold operation
- Lab continues to be Fuel Cell Vehicle capable
- Benchmark new Natural Gas Vehicles (NGV)



Summary

- **Level 1 Benchmark Activity** provides precise laboratory test data for a wide range of vehicle technologies that address DOE goals
  - Establish 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
- **Accomplishments from Level 1 testing**
  - Conventional vehicle baseline study
  - Mass impact study
  - Thermal impact on energy consumption and powertrain operation
  - AVTE vehicle testing in-progress
  - Test results and raw data available at Downloadable Dynamometer Database on public website (http://www.transportation.anl.gov/D3/i)
- **Maintaining a Link to Industry** is an important component of vehicle testing
  - Sharing best test practices, facility hardware recommendations, data analysis methods
  - Industry technology developers provide insight into what data is of interest

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

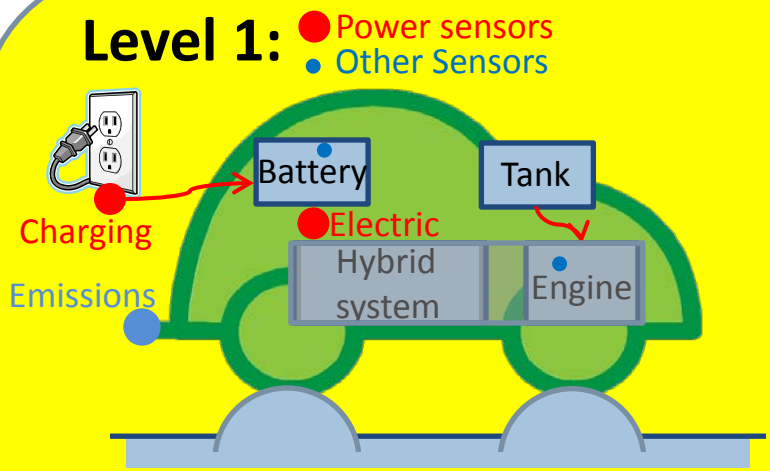
- **Special instrumentation**
  - ✓ High precision power analyzers (testing and charging)
  - ✓ CAN decoding and recording
  - ✓ OCR scan tool recording
  - ✓ Direct Fuel Flow metering
  - ✓ Infra Red Temperature camera
  - ✓ In cylinder pressure indicating systems
  - ✓ In-situ torque sensor measurement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

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

ver. Jan2012

Approach: Dynamometer Vehicle Benchmark Testing Approach - Level 1 and Level 2 Testing

Level 1:



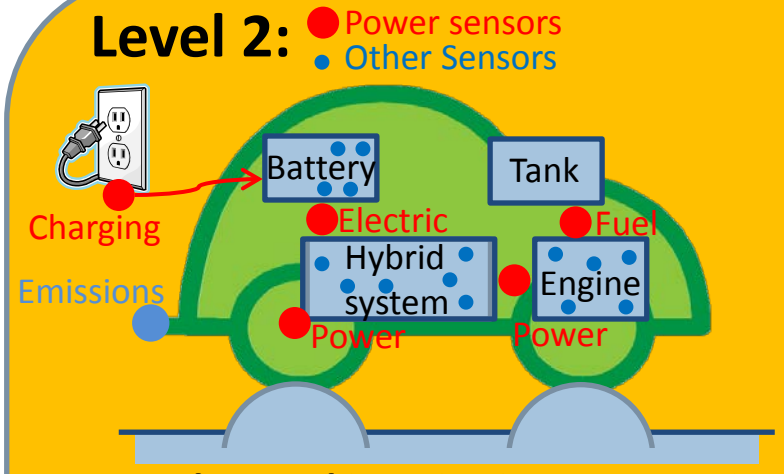
Basics instrumentation:

- Engine speed, fuel flow (bench), oil temp
- Battery, Charger V I (Hioki)
- CAN (if possible)
- Further … if required (but still non invasive)

Purpose:

- Vehicle operating parameter study
- Vehicle characterization (energy consumption, emissions level, performance)

Level 2:



Complete and invasive instrumentation:

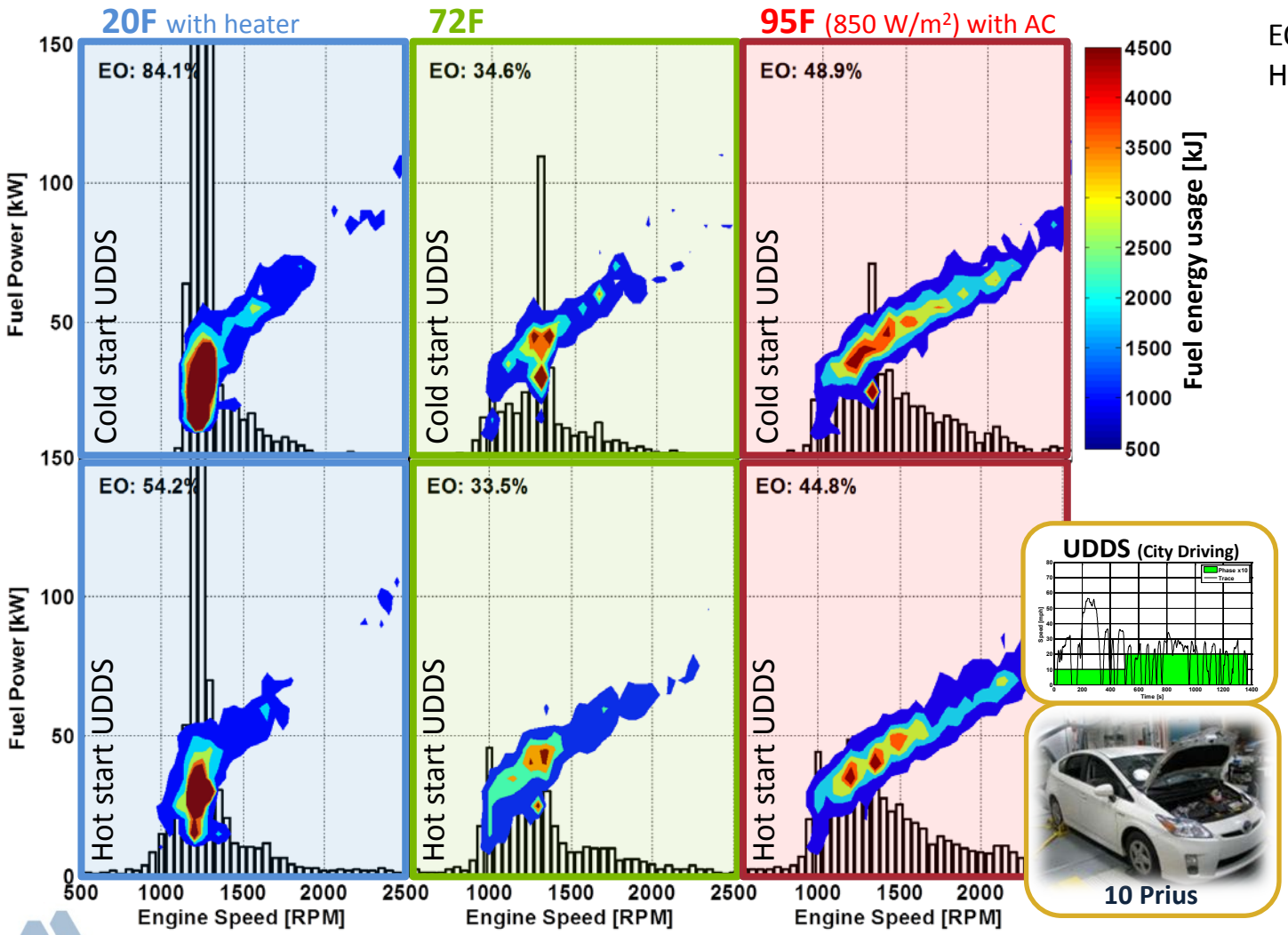
- Incremental to level 1
- Engine, shaft torque & speed sensors
- All major power flows (mechanical, electric,…)
- Component specific instrumentation

Purpose:

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

Accomplishment: Engine operation on UDDS 10 Prius

- Very clustered engine operation show high degree of freedom in engine operation
- 20F → fuel island at lower speed load 95F → higher power level for AC



EO = Engine On time in [%]
Histogram is frequency

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Accomplishment: Energy Consumption at Different Temperature on Several Certification Cycles