HEV, PHEV, EV Test Standard Development and Validation

2013 DOE Hydrogen Program and Vehicle Technologies Annual Merit Review

May 13-17, 2013

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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 # VSS094

Test Procedure Development Overview

Timeline

- Continuing effort since 2006
  - HEV/PHEV test procedure 2010 (J1711)
  - Completed BEV test procedure in 2012 (J1634)
- Dyno Drive Parameters
  - Phase 1 completed in 2012
  - Phase 2 on-going (est.. 2013)
- SAE 2711 MD/HD Test Procedure
  - Draft procedure under internal review
  - Part 1: est. 2013

Budget

- $150k in FY13
- Highly leveraged with APRF staff, tests, and test vehicles

Barriers

- Barriers addressed
  - Address codes and standards needed to enable wide-spread adoption of electric-drive transportation technologies

Partners

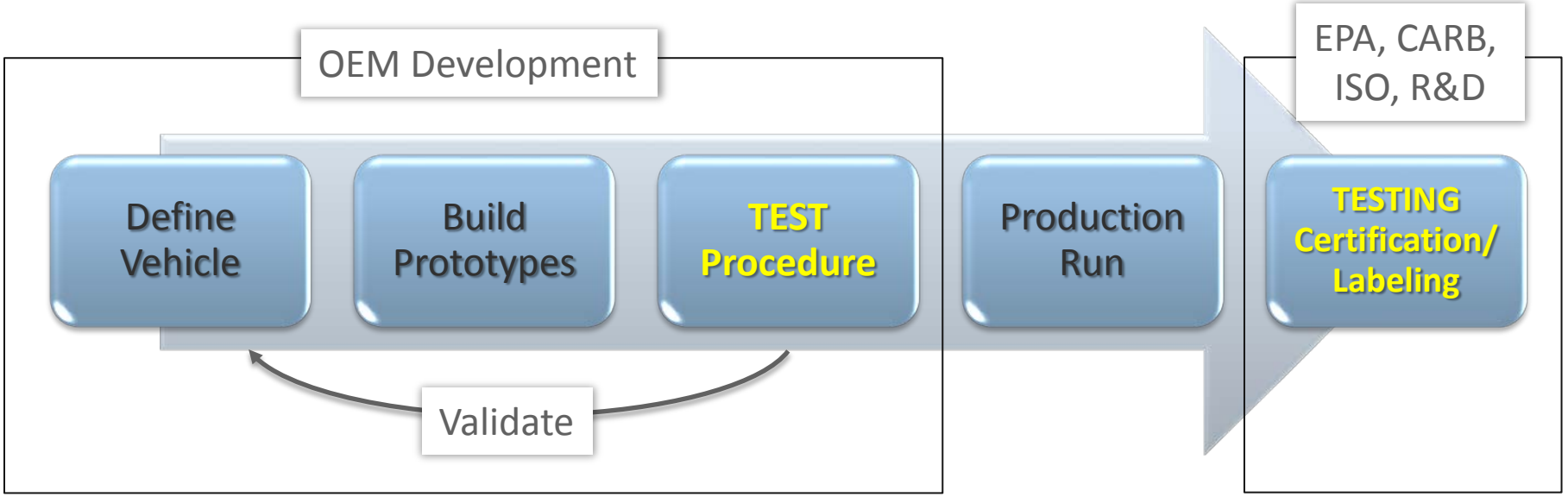
- Committee members include experts from EPA, Toyota, Honda, Ford, Chrysler, GM, Nissan, JARI, Mitsubishi, and CARB
- AVTA, OEMs and Suppliers, Customers, X-Prize, Tesla, BMW

Standards Activities Background

- **J1711: HEV/PHEV** dynamometer test procedures
  - Rewrite focused on PHEV procedure (published in 2010)
- **J1634**: **BEV** dynamometer test standards (consumption and range)
  - Rewrite for modern BEVs (published in 2012)
- **ISO 23274-2**: **PHEV** dyno testing in depleting mode
  - 23274-1 is testing in the sustaining mode (completed in 2012)
- **J2951**: **Drive Quality** Evaluation for Chassis Dynamometer Testing
  - Fuel economy variations based upon driver performance (New, published in 2011)
- **J1715**: **HEV Terminology** ("to EREV or not to EREV")
  - Updated from version several years ago
- **J2711**: Dyno testing of **MD/HD** vehicles including HEV
  - Phase 1 = dyno procedures (Phase 2 & 3 are HIL and "powerpack" testing)
- **J????**: **Powertrain power** standards
  - Committee not yet formed. M. Duoba chairing.

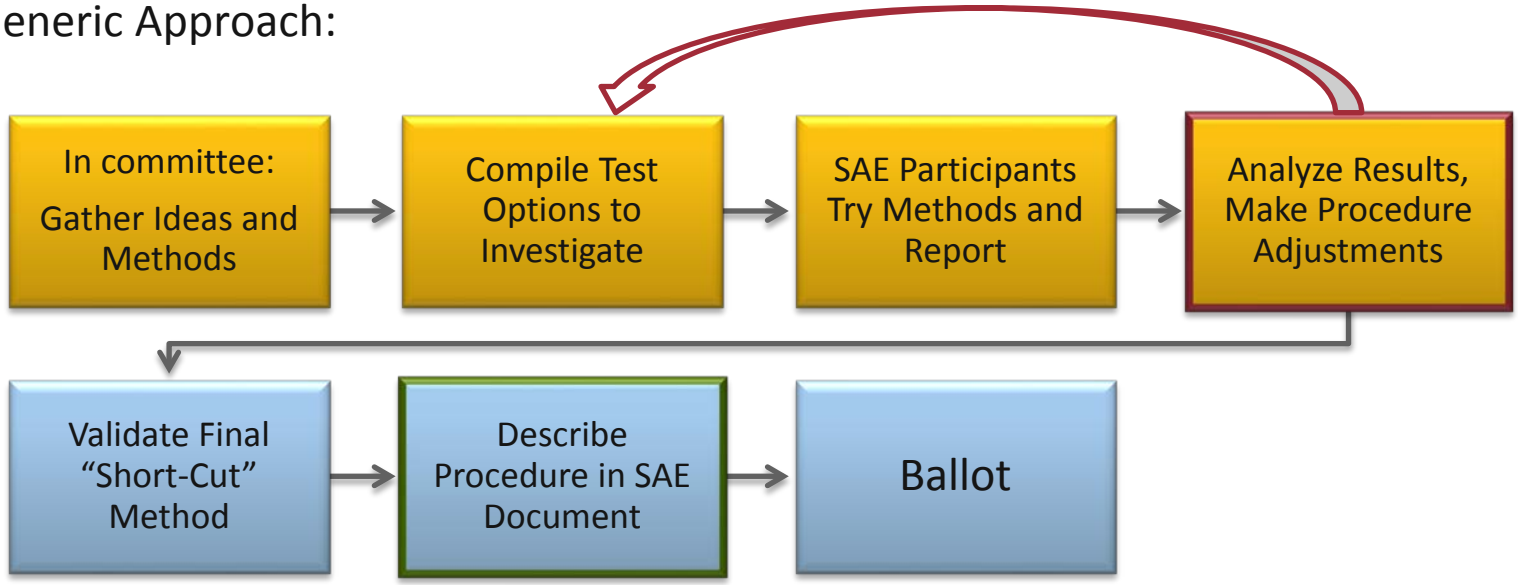
Relevance: Test Procedures Directly Support Industry and Regulatory Agencies

- Advanced vehicle achievements in efficiency or petroleum displacement are only defined by results taken with a standard test
- Steps taken in procedure development for fast and efficient methods can save industry millions in development and certification costs
- Accomplishments in LD methods are being adopted in MD/HD procedures



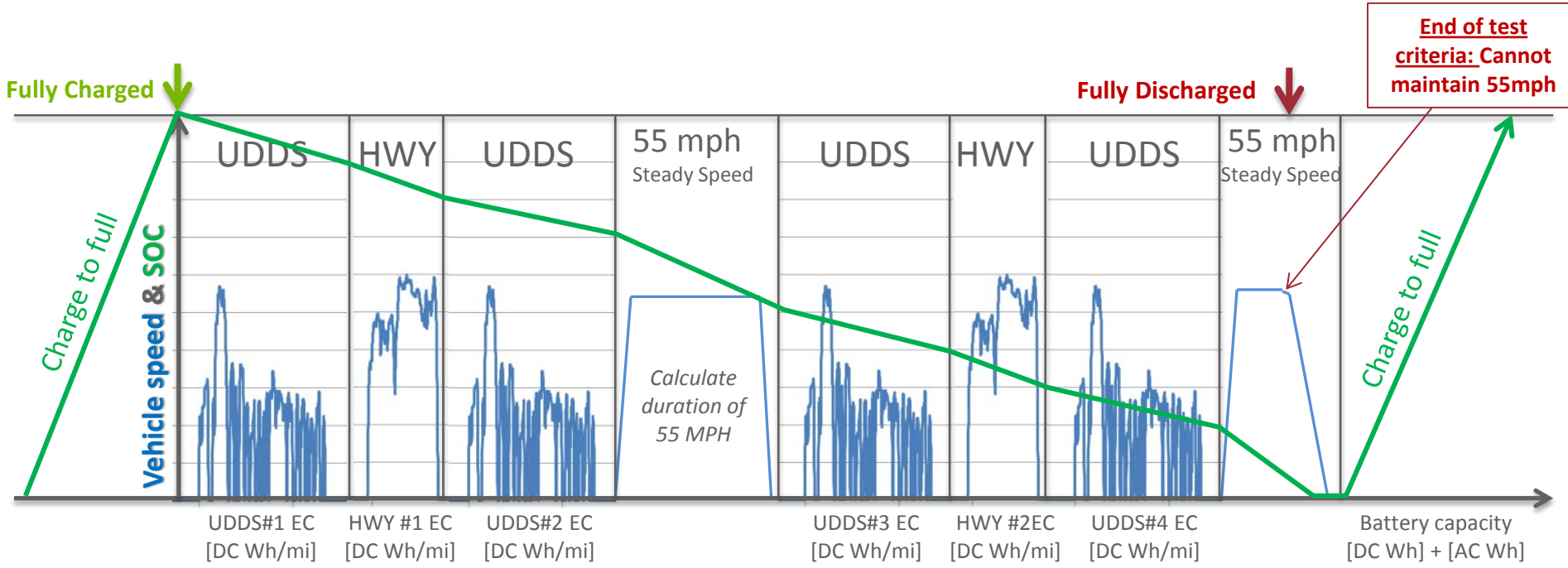
Approach: Provide Data, Direction, Validation, Document Development

- Argonne staff chair, co-chair, or serve as key member of SAE Committees
  - Chair J1711, co-chair J1634, chair J2711-1, key expert in ISO ISO/TC 22/SC 21/WG 2
- Argonne provides unrestricted data for entire committee to analyze
  - Argonne provided hot / cold data for applying "5-Cycle" to BEV and PHEVs
  - Argonne providing driver performance metrics and fuel economy (CV, BEV,HEV, PHEV)
- Argonne leads investigations in applying procedures for advanced technology vehicles
- Generic Approach:



Accomplishment: Final Revision of J1634 Balloted

→ "Multi-Cycle Test" – provides both UDDS and HWY data throughout SOC range. Expanded version includes US06 cycle data.



- Cycles are tested at beginning and end of SOC
- Depletion cycles are steady-state speeds (55 MPH)
- Test ends during steady-state speed
- Provides Wh/mi and range for bother UDDS and HWY

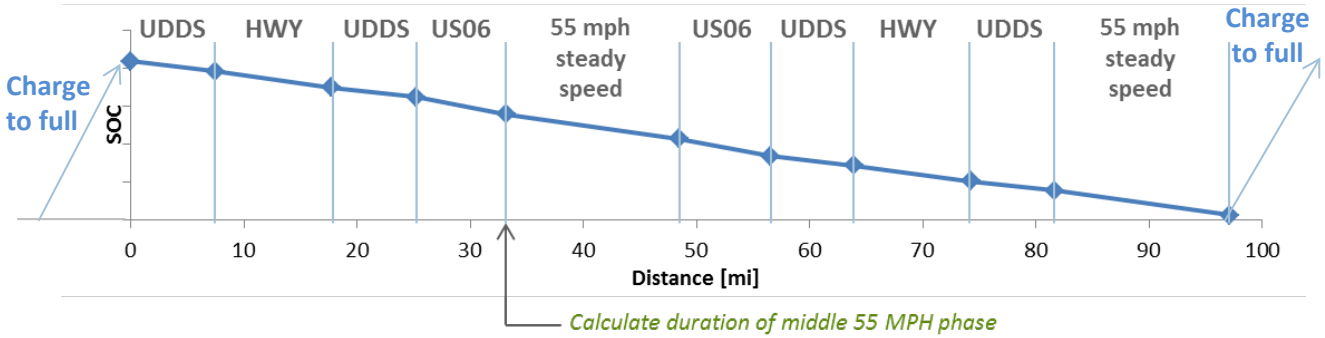
Accomplishment: On Going Validation of Existing Procedures With Newly Available OEM Vehicles

- **SAE J1634** is new, remains to be seen which new **BEVs** are certified with new procedure, or with longer, old procedure
  - Nissan Leaf and Tesla Roadster were testing using SAE J1634 procedure concepts
  - Upcoming work will investigate results from Focus Electric (with active thermal management)
  - Future work on Hot/Cold corrections for BEVs

- **SAE J1711** was used for **PHEV** certification
  - Old J1711 procedure not adequate for today's PHEVs
  - Testing Volt validated J1711's sophisticated approach to range calculations
  - Testing Prius PHV validated J1711 generic approach that works for EREVs and Blended PHEVs
  - Current work focused on hot and cold testing in charge-depleting mode

Accomplishment: Expanded Multi-Cycle Test J1634 Used for Preliminary OEM BEV Testing

→ Expanded MCT provides UDDS, HWY and US06



	Whr	Whr/mi
UDDS	1346.8	180.5
HWY	2092.7	203.5
UDDS	1275.2	171.0
US06	2302.1	286.8
SS55	3241.5	
US06	2268.5	282.8
UDDS	1251.0	167.7
HWY	2044.4	199.0
UDDS	1246.9	167.1
SS55	3245.7	
Test Discharge	**20315**	
AC Recharge	**24048**	

Weighting UDDS for "First Cycle Effect"
K1 = 1346.8 / 20315 = 0.06629
K2 = K3 = K4 = (1 – 0.06629)/3 = 0.31123
DC Wh/mi = K1*UDDS1 Wh/mi + K2…
DC Wh/mi = 169.4

Recharge Allocation Factor
RAF = DC $kWh_{total\ test}$ / AC $kWh_{recharge}$
RAF = 20315 / 24048 = 0.8447

* Note that these results are unadjusted and do not reflect expected in-use performance

Charge Recovery
CR = C_c / C_d
CR = 63.69 Ah / 63.49 Ah
CR = 100.3%
(must be greater than 97%)

AC Energy Consumption*
UDDS:
AC Wh/mi = DC Wh/mi / RAF
AC Wh/mi = 169.4 / 0.8447 = 200.5

HWY:
Ave DC Wh/mi = 201.3
AC Wh/mi = 238.2

US06:
Ave DC Wh/mi = 284.8
AC Wh/mi = 337.1

Range Extrapolations*
Usable Battery Energy (UBE)
UBE = 20315 Wh

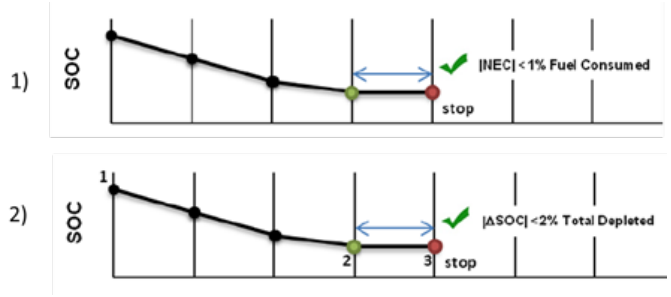
UDDS
R = 20315 / 169.4 = 119.9 miles
HWY
R = 20315 / 201.3 = 100.9 miles
US06
R = 20315 / 284.8 = 71.3 miles

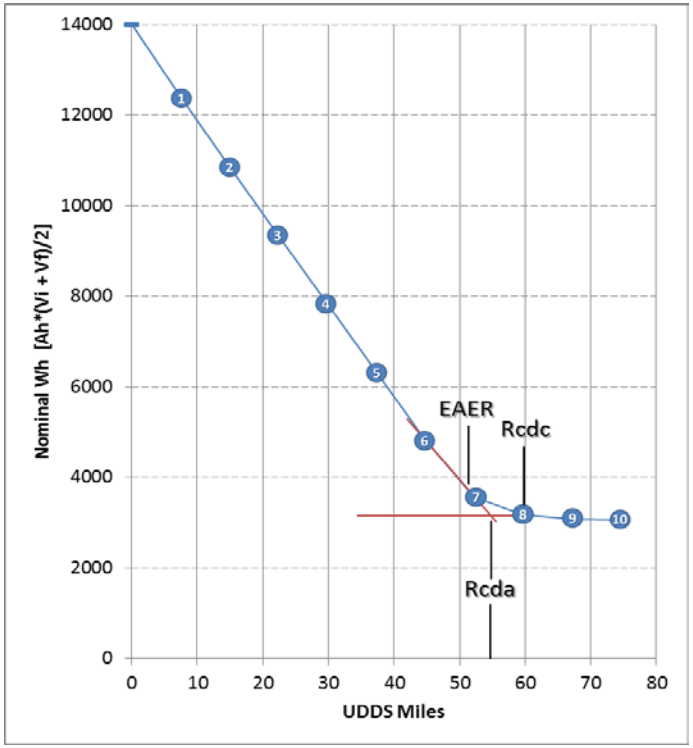
Accomplishment: J1711 Concepts Validated on Volt

Volt UDDS Full Charge Test Data

				EOT Criteria		AC Wh Calcs	
Cycle	Miles	MPG actual	Ah x (Vi+Vf) /2	(1) Δ% of Fuel	(2) Δ% of Disch	Total % of Disch	AC Wh/mi[1]
1	7.43	inf	1582.9	25.72%	--	14.47%	255.3
2	14.86	inf	1535.7	25.22%	49.24%	14.04%	247.4
3	22.29	inf	1521.0	25.33%	32.78%	13.91%	245.1
4	29.73	inf	1515.2	25.61%	24.62%	13.85%	244.2
5	37.16	inf	1505.6	25.75%	19.65%	13.76%	242.7
6	44.59	inf	1506.1	26.12%	16.43%	13.77%	242.6
7	52.03	232.4	1267.6	22.44%	12.15%	11.59%	204.2
8	59.47	60.6	386.5	6.95%	3.57%	3.53%	62.2
9	66.90	51.0	86.2	1.56%	**0.79%**	0.79%	13.9
10	74.33	49.0	31.3	**0.57%**	**0.29%**	0.29%	5.0

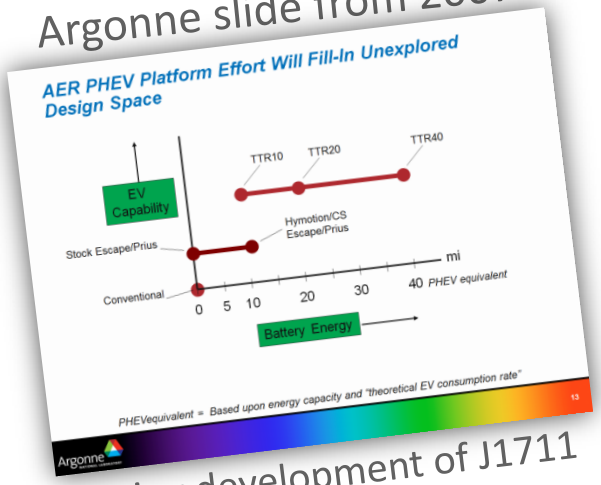
[1] Based upon 13.102 AC kWh recharge to full





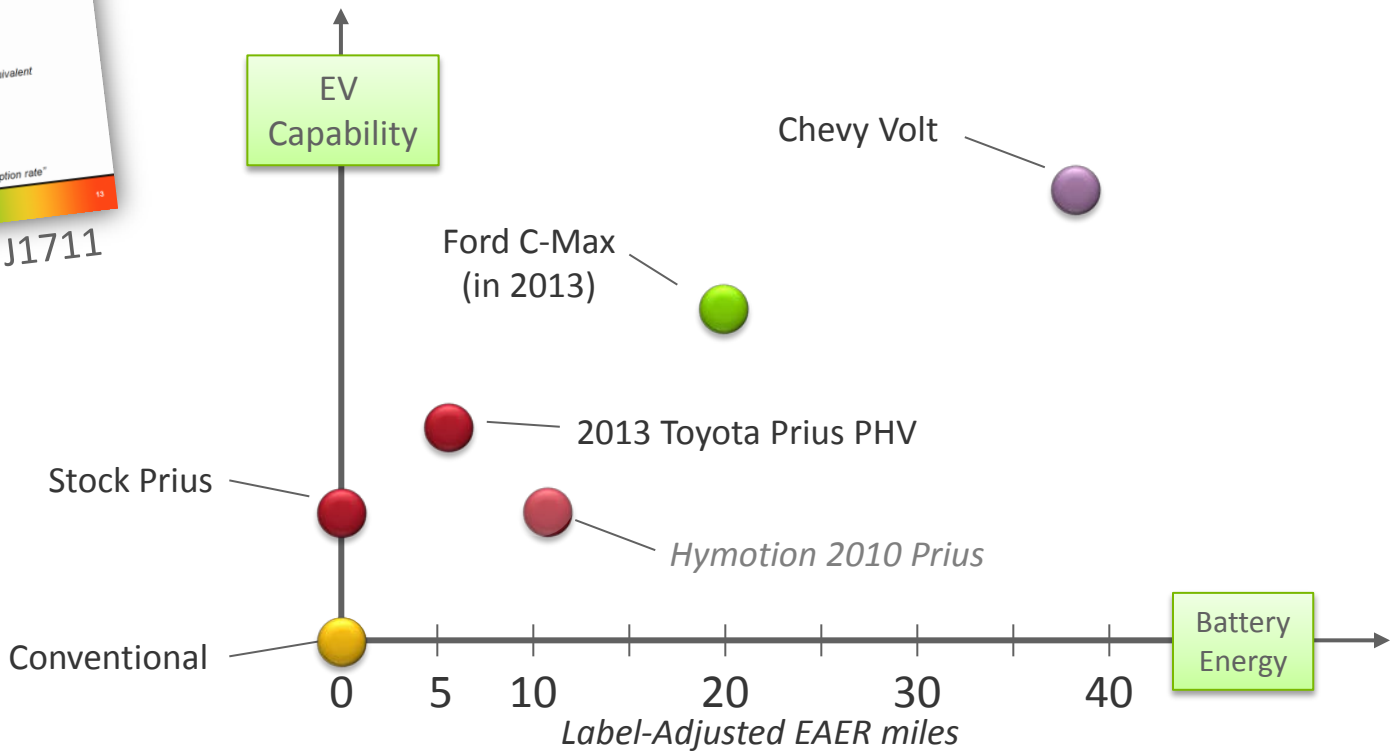
- End of Test Criteria checked for robustness. Argonne-prescribed option works best.
- Numerous SAE J1711 range definitions important for calculations of results.
- Same calculations for all PHEVs. PHEV type drives decision of which results are presented.

Argonne slide from 2007:



During development of J1711

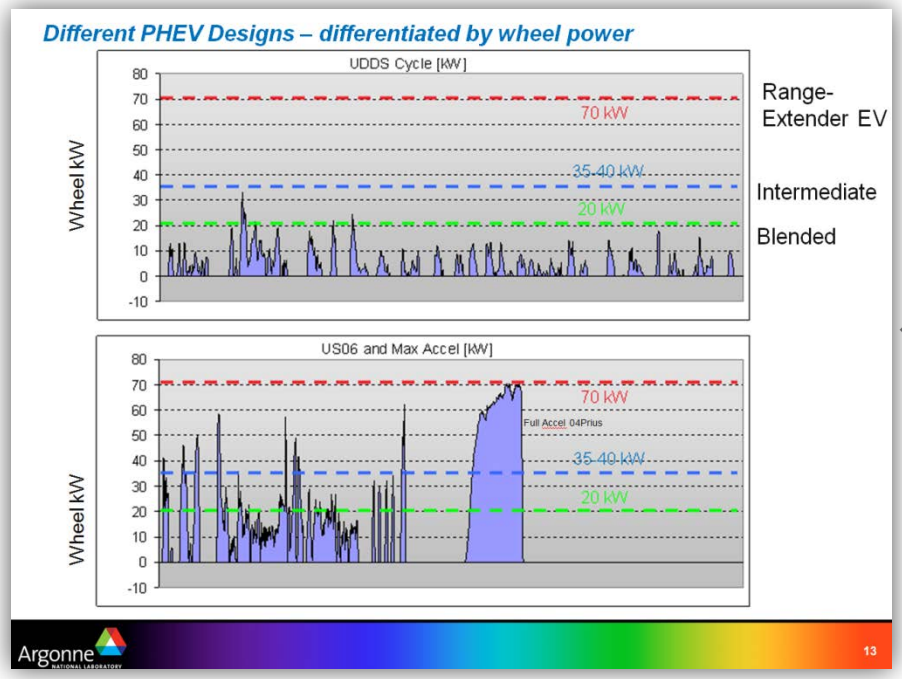
Accomplishment: SAE J1711 Validation - Now with OEM Vehicles

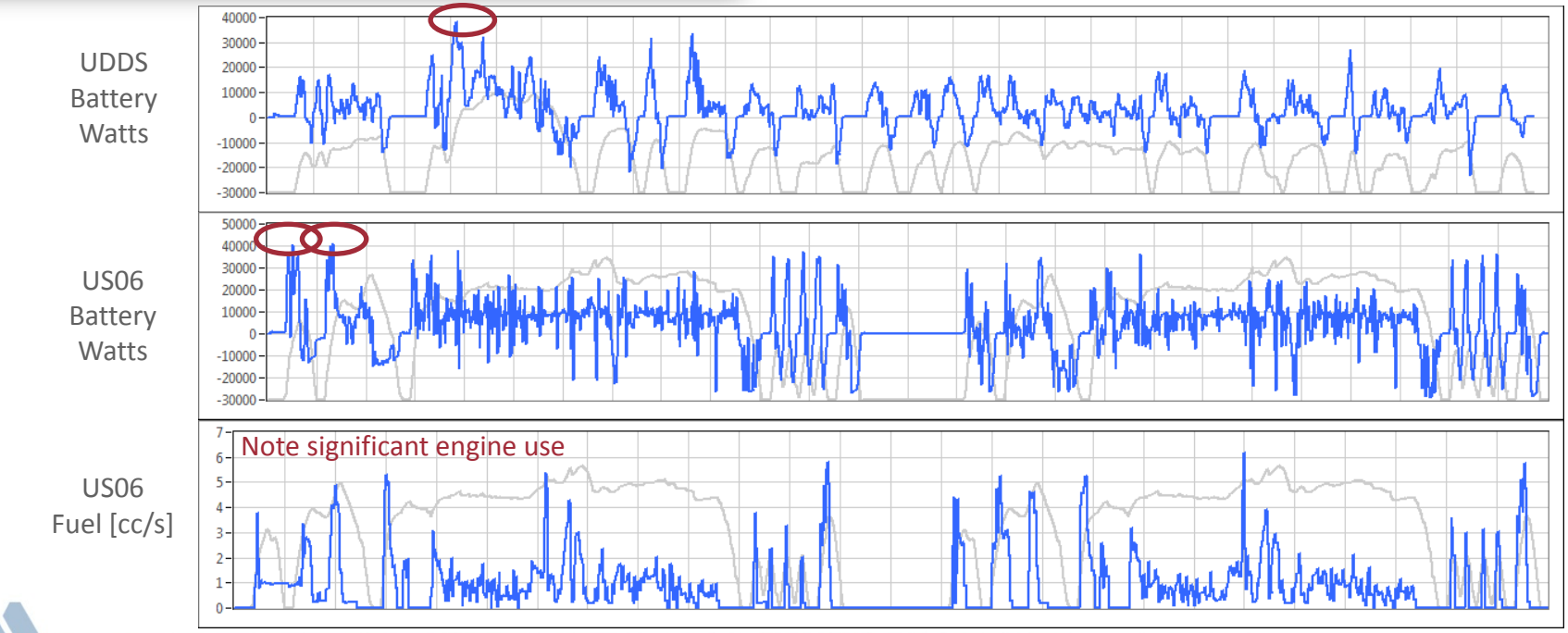


- J1711 carefully developed using prototypes
- However, no validation performed with OEM vehicles
- By end of 2013, most of PHEV design space can be tested with OEM PHEVs

Accomplishment:
Blended Prius PHV Testing Using J1711

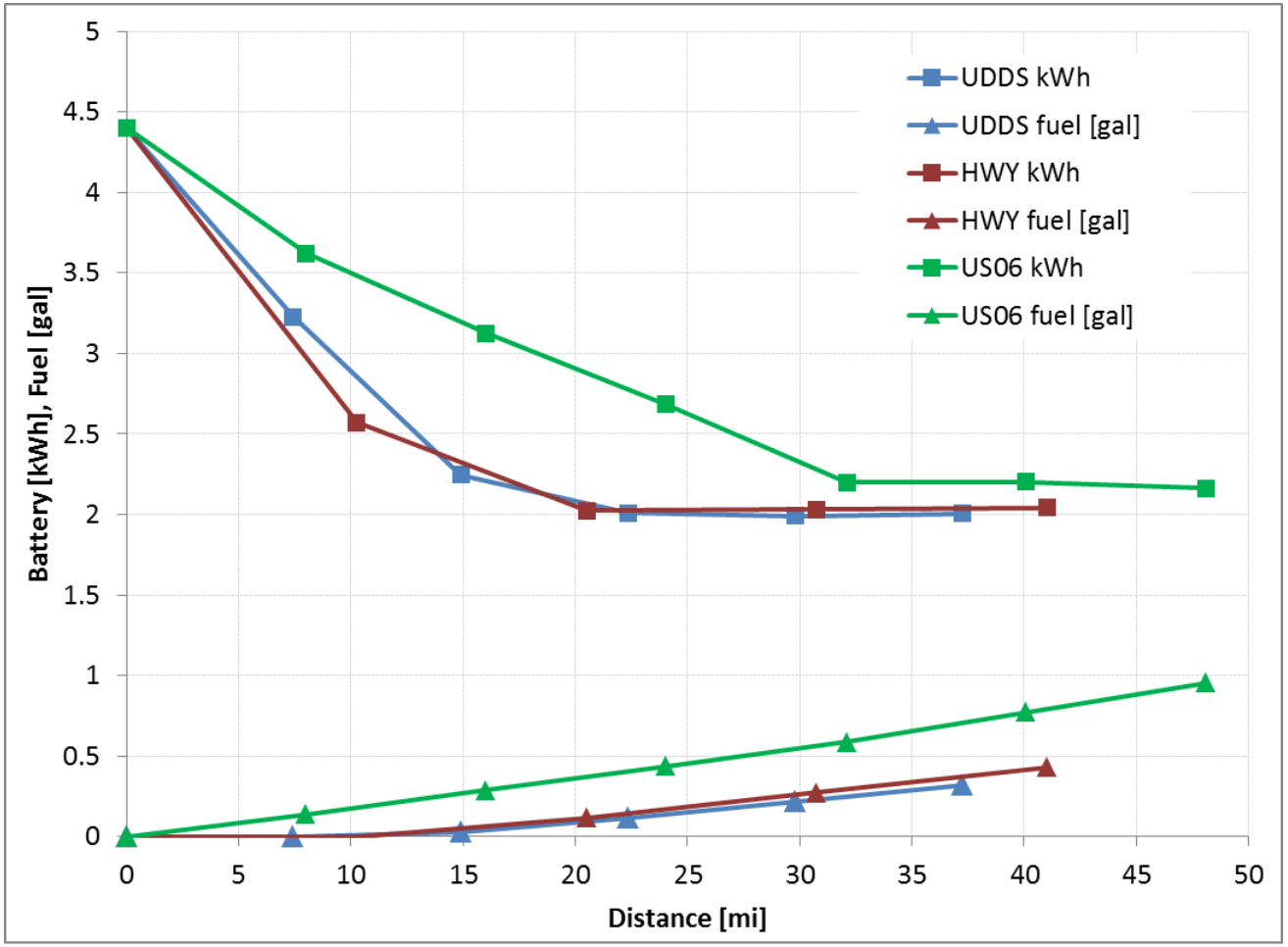
← Slide from 2007



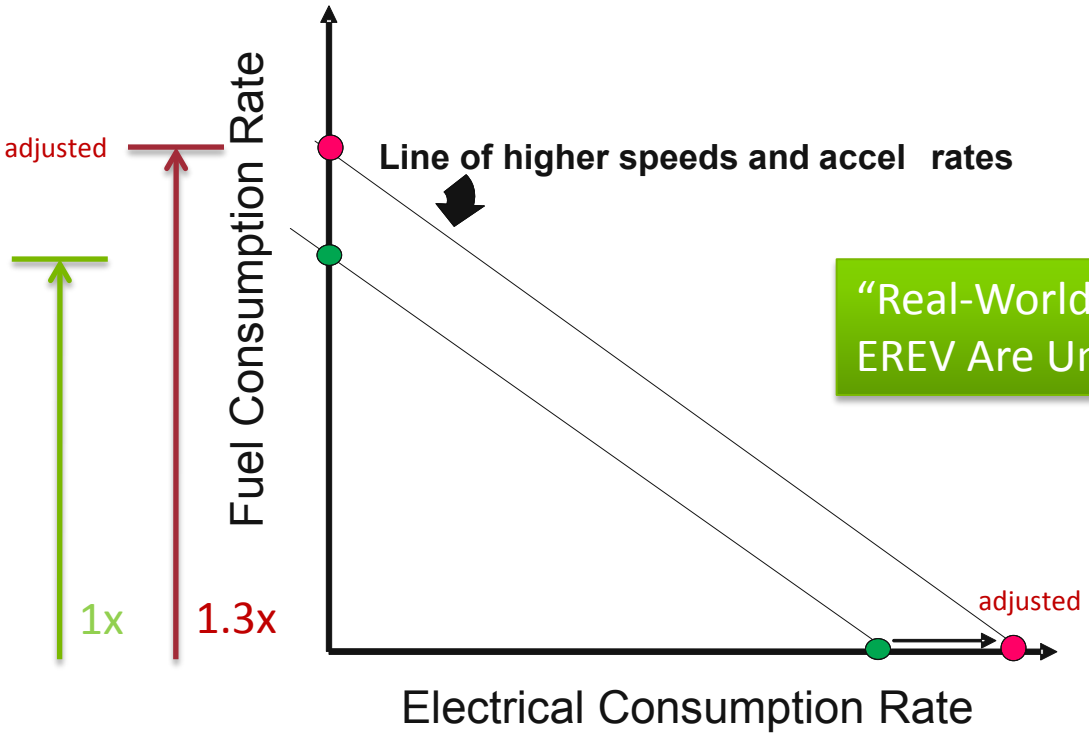


Accomplishment: Blended Prius PHV Testing Using J1711 (US06 Cycle)

→ US06 slow depletion not favorable for petroleum displacement (Utility Factor)
→ US06 not currently tested in charge-depleting mode under EPA rules



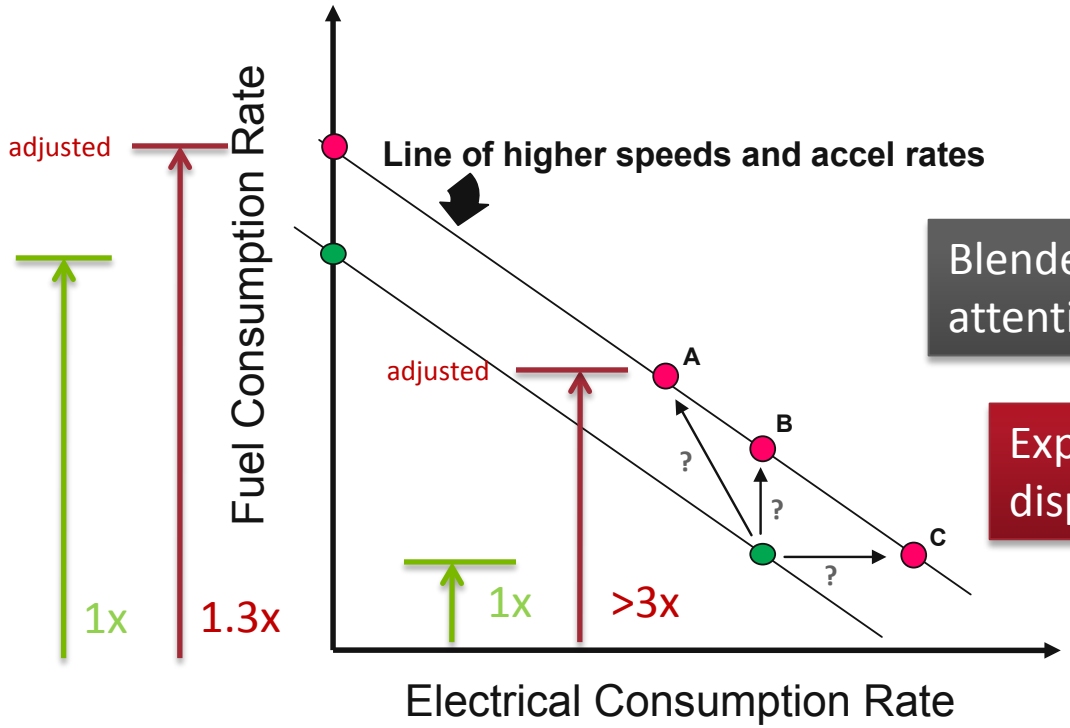
Accomplishment: Exploring Adjustments Using J1711 Data
→ EREV PHEV



"Real-World" Adjustments for EREV Are Understood

- Current adjustments for electric-only operation is modeled after gasoline fuel adjustments

Accomplishment: Exploring Adjustments Using J1711 Data
→ Blended PHEV



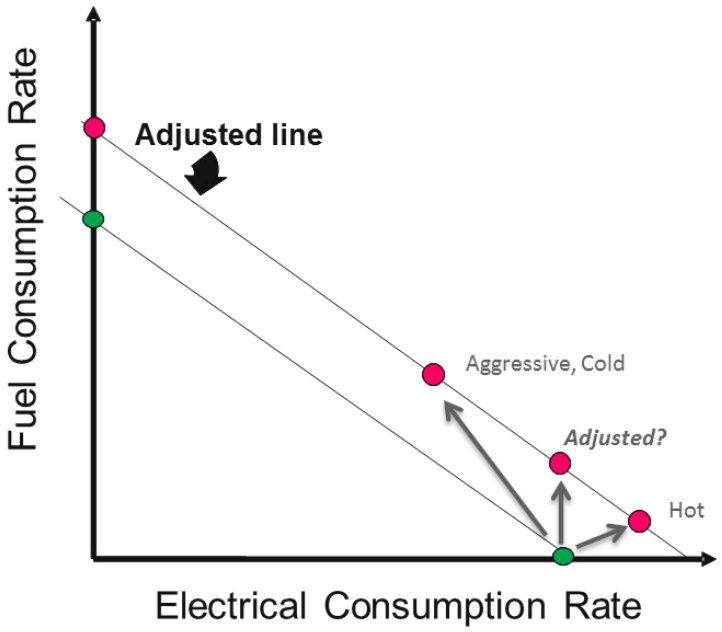
Blended PHEVs require more attention and research

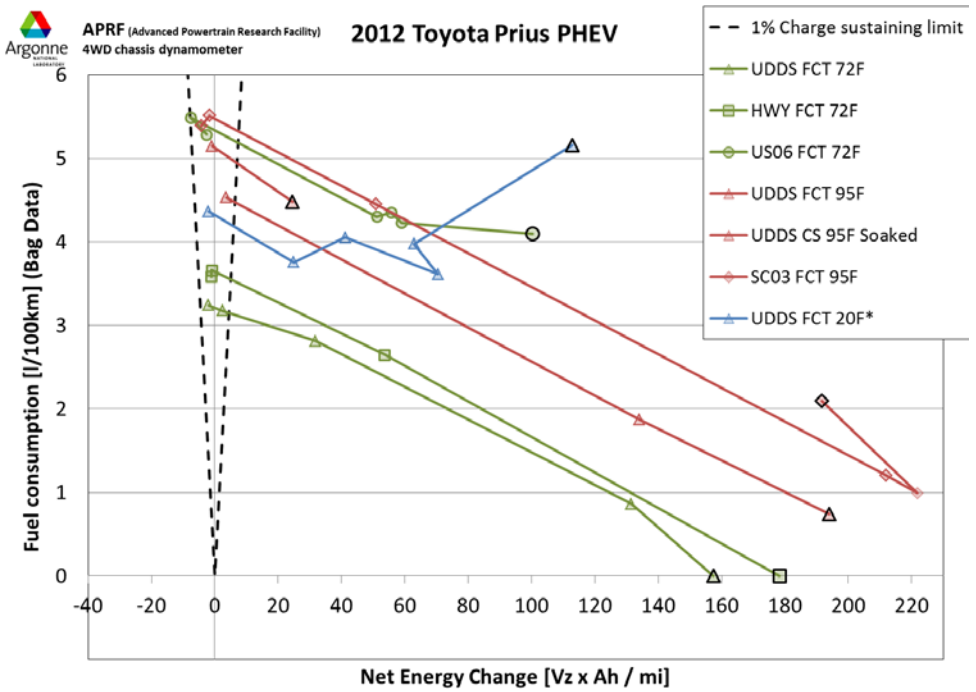
Expected levels of fuel displacement more uncertain

- Compared to UDDS and HWY cycles, if real world requires more energy, where will the added energy come from?
- Conventional vehicle fuel consumption adjustments are single scalar numbers
- Blended adjustments need to be 2-D vectors

Accomplishment: Exploring Adjustments Using J1711 Data

→ Prius PHV Blended Operation in Hot/Cold?

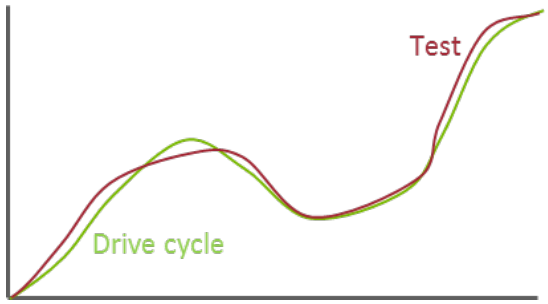


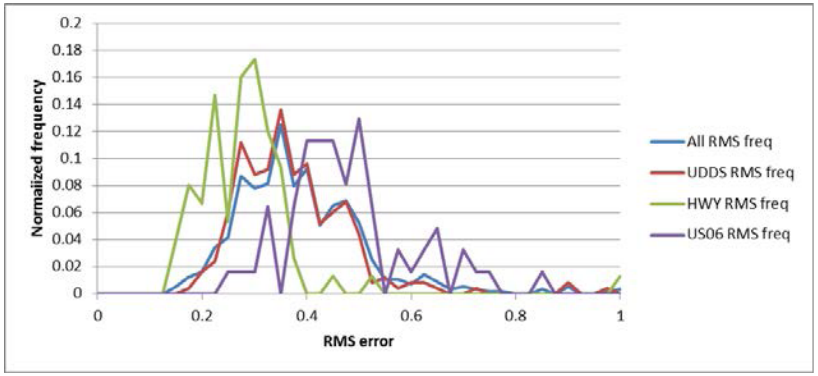


- Note location on 2-D plot are in terms of *consumption / distance*
- High-speed, aggressive operation → higher fuel, lower electricity consumption rate
- Hot operation with A/C → higher fuel and higher electric consumption rates
- Cold operation → higher fuel, lower electricity consumption rate
- Needed → Real world cycles, not a real world adjustment

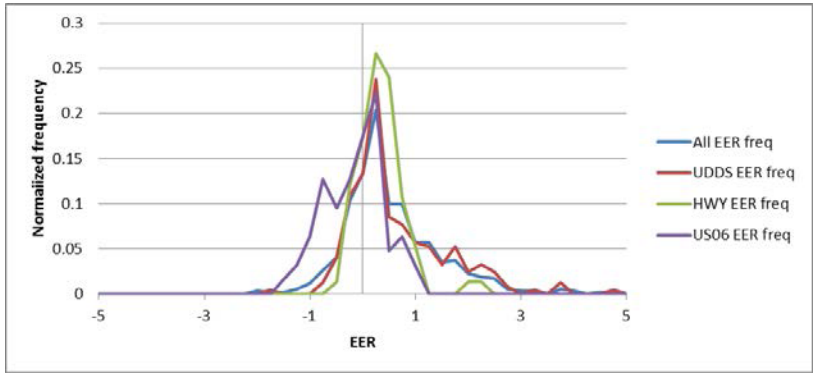
Accomplishment: Start Phase 2 of SAE J2951
Find variability and practical guidelines for drive statistics

- **Started**: Aug 2010. **Finished**: 2012
- Prescribed certification tolerances leave room for significant fuel economy variation
- Existing speed tolerance is not enough information to explain varied results
- Data has shown that higher fuel consumption results correlate with higher driven dyno energy





RMS Speed Error



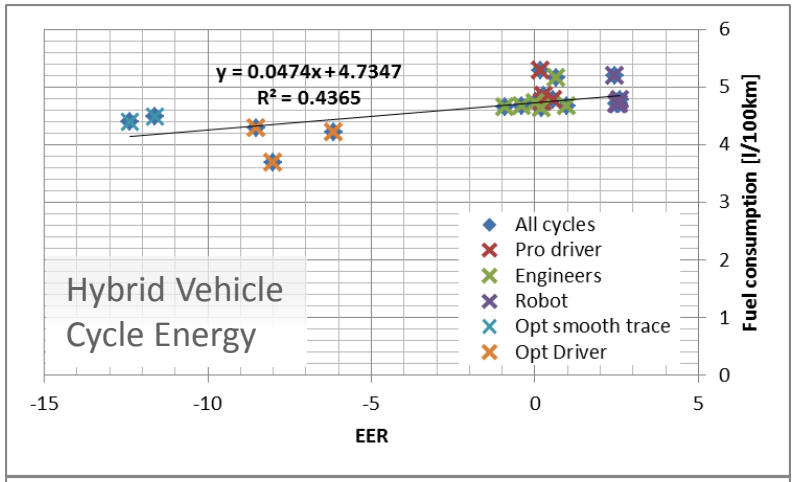
Driven Energy vs. Cycle Energy

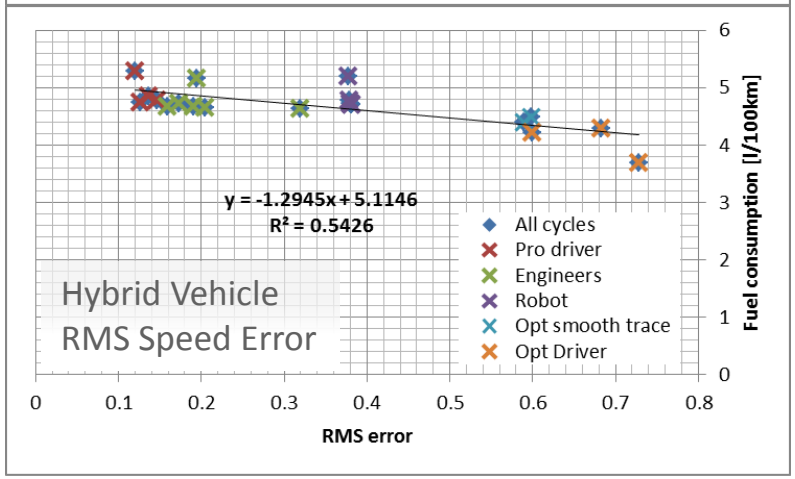
Accomplishment: Start Phase 2 of SAE J2951

Argonne Able to Openly Share Dyno Driving Statistics to Entire Research Community

- All other participants showing only variation of drive statistics, not actual results
- Specific correlations between MPG and driving statistics are unique in HEVs
- Current HEV MPG controversy may be solved by looking at SAE J2951 statistics

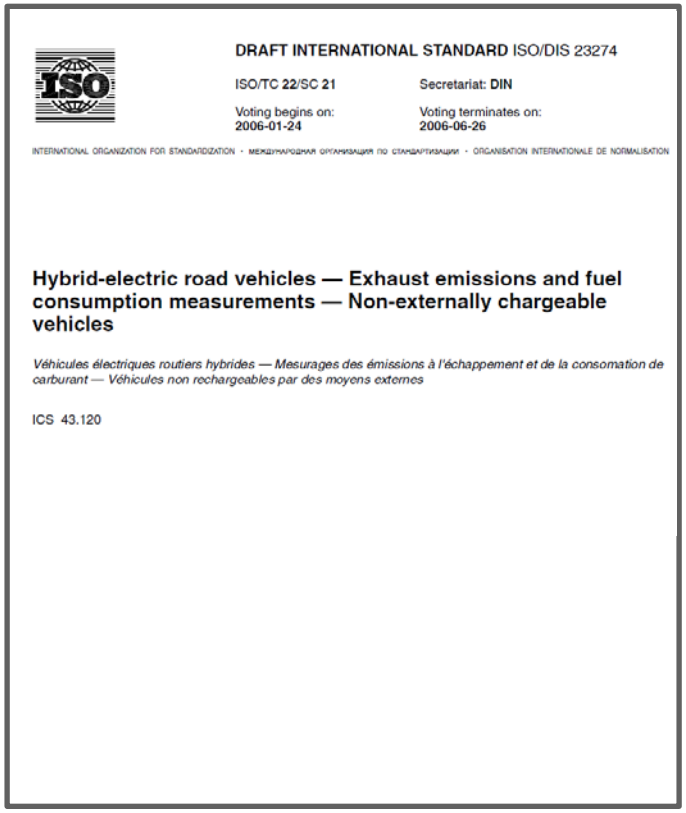
- MPG results from hybrids are notoriously "noisy"
- ANL has been using driver performance metrics for 10 years
- Data from HEV tested at Argonne (at right)
  - Different drivers achieved different consumption results
  - Higher fuel consumption results correlate with both higher driven dyno energy and speed error
  - When drivers intentionally deviate speeds to achieve better fuel economy, speed error increases
  - Speed error has highest correlation with consumption
  - Could imply that limits in speed error could force more consistent results representative of real world driving.





Accomplishment: North American Annex of ISO 23274-2 Test Standard (PHEV in Depleting Mode)

- M. Duoba serving as “expert member” of ISO/TC 22/SC 21/WG 2 technical committee
- Attended meetings since 2007
  - Tokyo, Paris, Berlin, Chicago, Paris
- 23274-2 was published in 2012
- Each member country has to write an Annex specific to local regulations
- M. Duoba wrote the Annex covering North America that followed the ISO guidelines
  - Crafted so as not to conflict with J1711



DRAFT INTERNATIONAL STANDARD ISO/DIS 23274

ISO/TC 22/SC 21 Secretariat: DIN

Voting begins on: 2006-01-24 Voting terminates on: 2006-06-26

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION · МЕЖДУНАРОДНАЯ ОРГАНИЗАЦИЯ ПО СТАНДАРТИЗАЦИИ · ORGANISATION INTERNATIONALE DE NORMALISATION

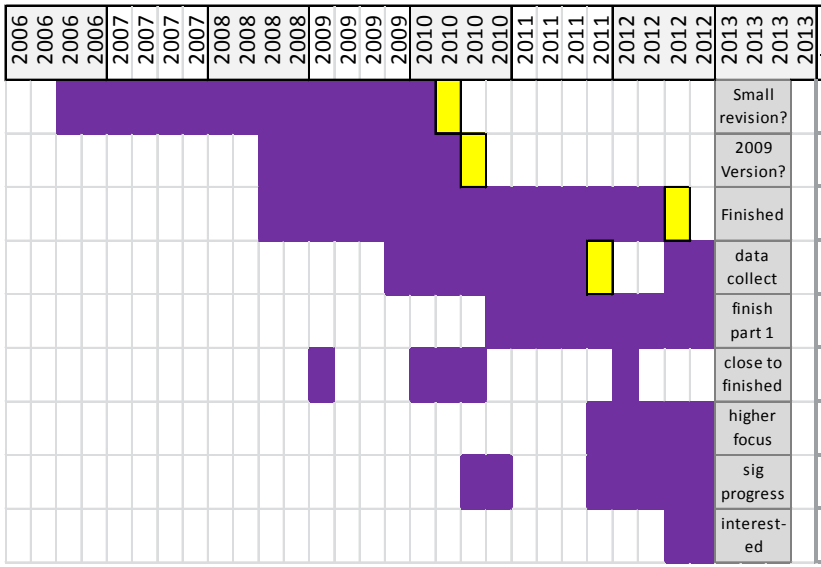
Hybrid-electric road vehicles — Exhaust emissions and fuel consumption measurements — Non-externally chargeable vehicles

Véhicules électriques routiers hybrides — Mesurages des émissions à l'échappement et de la consomation de carburant — Véhicules non rechargeables par des moyens externes

ICS 43.120

Summary: SAE Standards Timeline

= Balloted



Project	Title	Sponsor
J1711	Recommended Practice for Measuring the Exhaust Emissions and Fuel Economy of Hybrid-Electric Vehicles, Incl PHEVs	Mike Duoba (ANL)
J2841	Utility Factor Definitions for Plug-In Hybrid Electric Vehicles Using 2001 U.S. DOT National Household Travel Survey Data	Mike Duoba (ANL)
J1634	Electric Vehicle Energy Consumption and Range Test Procedure (Cancelled Oct 2002)	Jeff Glodich / Mike Duoba
J2951	Drive Quality Evaluation for Chassis Dynamometer Testing	Jeff Glodich
J2711	Recommended Practice for Measuring Fuel Economy and Emissions of Hybrid-Electric and Conventional HD Vehicles	Eric Rask (ANL)
J1715	Hybrid Electric Vehicle (HEV) & Electric Vehicle (EV) Terminology	Mark A. Theobald
J2263	Road Load Measurement Using Onboard Anemometry and Coastdown Techniques	Jeff Glodich
J2264	Chassis Dynamometer Simulation of Road Load Using Coastdown Techniques	Jeff Glodich
J2908	Power rating method for hybrid-electric and battery electric vehicle propulsion	Mark A. Theobald

Highlights

- J1711 being validated, application for 5-cycle investigated
- J1634 finished, application for 5-cycle investigated
- Analyzing data for J2951 Drive Quality (related to HEV MPG shortfall?)
- J2711 (Part 1 – chassis dyno) draft under internal review

Collaborations and Coordination with Other Institutions

Advanced Vehicle Testing and Evaluation (AVTE)
Dyno, track, road/fleet testing

ecotality
INL Idaho National Laboratory
Argonne NATIONAL LABORATORY

SAE Task Force Membership
- OEMs
- Suppliers
- Regulators
- National Labs

SAE International

Argonne

AIGER - Auto Industry / Gov. Emissions Research
- EPA
- CARB
- Industry

AUTOMOBILE INDUSTRY/GOVERNMENT EMISSIONS RESEARCH
AIGER
Cooperative Research and Development Agreement

Working-level individual collaborations

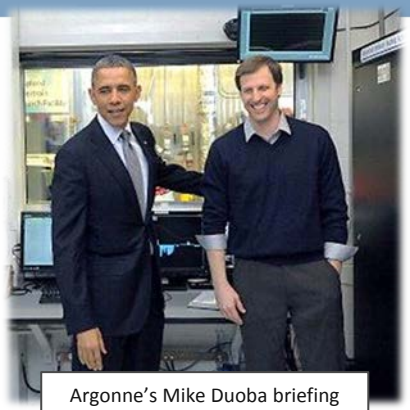
Chrysler – CTC — CHRYSLER

GM – Powertrain, Milford — GM

Ford – Powertrain, APTL — Ford

International Collaborations
- KATECH (Korea)
- CAERI (China
- ISO (TC 22/SC 21/WG 2)
- JARI (Japan)
- IEA
- Joint Research Centre (EU)

Future Work: New Standards and Continued Validation / Improvement of Existing Procedures



Argonne's Mike Duoba briefing President Obama on Testing Standards March 15, 2013

Refinement:

- HEV and PHEV procedures (J1711) will be exercised and evaluated with diverse set of OEM PHEVs (Prius and C-Max PHEVs)
- More BEV and 5-Cycle evaluations
  - Current "70% Rule" should eventually be replaced with procedures that reflect and reward advances in BEV thermal management, efficient auxiliaries and improved thermal insulation

New or Revised Standards:

- Newly formed SAE task addressing Powertrain Power in HEVs
  - Specifications in engine net power and torque currently follow SAE J1349
  - However, "specmanship" in hybrid vehicle power and electric motor power do not currently conform to a uniform standard
  - The new task force will address standard methods to define, measure, and report Vehicle Power, Motor Power, and Battery Power (among other parameters)
- Finish SAE J2711-1 (Chassis dynamometer test procedures)
  - Draft generated using past J2711 and current J1711 has been distributed among members
  - Take current draft to ballot