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

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

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

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 both 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

### Charge Recovery

CR = \( \frac{C_c}{C_d} \)

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

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* Note that these results are unadjusted and do not reflect expected in-use performance.
Accomplishment: J1711 Concepts Validated on Volt

Volt UDDS Full Charge Test Data

<table>
<thead>
<tr>
<th>Cycle</th>
<th>Miles</th>
<th>MPG actual</th>
<th>Ah x (Vi+Vf)/2</th>
<th>EOT Criteria</th>
<th>AC Wh Calcs</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(1) Δ% of Fuel</td>
<td>(2) Δ% of Disch</td>
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<tr>
<td>1</td>
<td>7.43</td>
<td>inf</td>
<td>1582.9</td>
<td>25.72%</td>
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<tr>
<td>2</td>
<td>14.86</td>
<td>inf</td>
<td>1535.7</td>
<td>25.22%</td>
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<tr>
<td>3</td>
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<td>4</td>
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<td>6</td>
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<td>7</td>
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<td>10</td>
<td>74.33</td>
<td>49.0</td>
<td>31.3</td>
<td>0.57%</td>
<td>0.29%</td>
</tr>
</tbody>
</table>

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.
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

Different PHEV Designs – differentiated by wheel power

Range-Extender EV
Intermediate
Blended

UDDS Cycle [kW]

US06 and Max Accel [kW]

UDDS Battery Watts

US06 Battery Watts

US06 Fuel [cc/s]

Note significant engine use
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

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

"Real-World" Adjustments for EREV Are Understood
Accomplishment: Exploring Adjustments Using J1711 Data → Blended PHEV

- 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

Blended PHEVs require more attention and research

Expected levels of fuel displacement more uncertain
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](image1)

![Driven Energy vs. Cycle Energy](image2)
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
**Summary: SAE Standards Timeline**

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

**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

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

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

Argonne

Working-level individual collaborations
- Chrysler – CTC
- GM – Powertrain, Milford
- Ford – Powertrain, APTL

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

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

Idaho National Laboratory
Argonne

Cooperative Research and Development Agreement
Future Work: New Standards and Continued Validation / Improvement of Existing Procedures

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