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Argonne Facilitation of PHEV Standard Testing Procedure (SAE J1711)

SAE International

SAE International | SURFACE VEHICLE RECOMMENDED PRACTICE | J1711 | REV. PropDft JUN2006

Issued 1999-03
Revised Proposed Draft 2006-06
Superseding J1711 MAR1999

Recommended Practice for Measuring the Exhaust Emissions and Fuel Economy of Hybrid-Electric Vehicles

SAE International | SURFACE VEHICLE RECOMMENDED PRACTICE | SAE J2841

Issued 04-24-2008
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Superseding Jxxxx Date (SupersededBy)

Definition of the Utility Factor for Plug-In Hybrid Electric Vehicles Using US DOT National Household Travel Survey Data

Michael Duoba
Danny Bocci
Ted Bohn
Richard Carlson
Forrest Jehlik
Henning Lohse-Busch
Argonne National Laboratory

Project ID: vss_05_duoba

U.S. Department of Energy

UChicago Argonne LLC

Office of Science U.S. DEPARTMENT OF ENERGY

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J1711 Project Overview

Timeline

- Started in mid 2006
- FY2009, work will continue with J1634
- 80% complete

Budget

- $300k
- Many other ANL tasks support this effort

Barriers

- PHEVs unique operation
- Compatibility with legacy testing requirements
- Test equipment not always capable for long PHEV tests
- Different types of PHEVs all must be on equal playing field
- Definitions must be sound

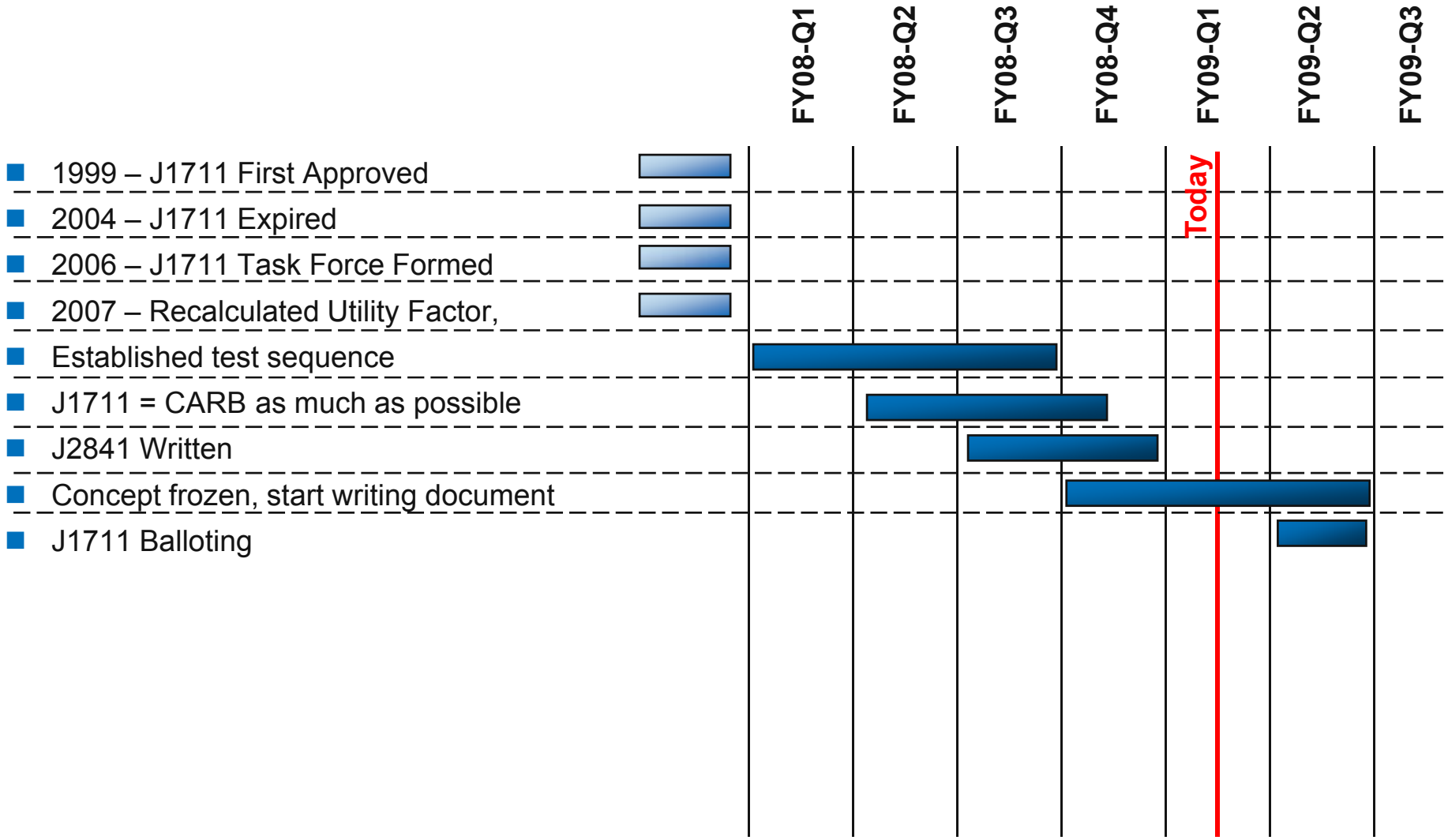
Partners

- ANL chair of J1711
- Members include: Chrysler, GM, Ford, CARB, EPA, Toyota, Honda, Environment Canada, INL, NREL and others
- Collaborate with JARI-organized ISO work group

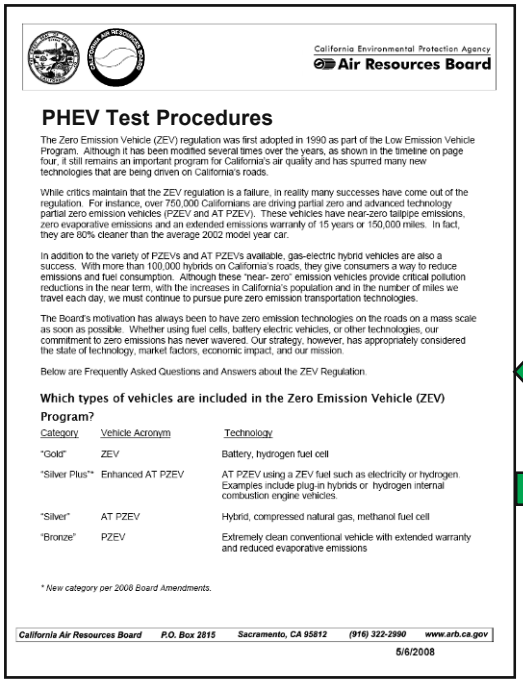
J1711 Objectives

- Chair / Organize J1711 Task Force
- Develop procedures
  - Addressing all the significant challenges
- Validate using APRF dyno lab
- Ensure that all stakeholders have consensus
  - JARI-ISO, CARB, EPA
- In FY09, write document for ballot
- In FY09, support EPA MPG Labeling developement
  - ANL and INL working together on Test vs On-Road PHEV results

Milestones for FY08 an FY09



EPA, DOT Will Reference SAE Standard CARB and J1711 Procedures Made Similar ISO and J1711 Collaborate



California Environmental Protection Agency
Air Resources Board

PHEV Test Procedures

The Zero Emission Vehicle (ZEV) regulation was first adopted in 1990 as part of the Low Emission Vehicle Program. Although it has been modified several times over the years, as shown in the timeline on page four, it still remains an important program for California's air quality and has spurred many new technologies that are being driven on California's roads.

While critics maintain that the ZEV regulation is a failure, in reality many successes have come out of the regulation. For instance, over 750,000 Californians are driving partial zero and advanced technology partial zero emission vehicles (PZEV and AT PZEV). These vehicles have near-zero tailpipe emissions, zero evaporative emissions and an extended emissions warranty of 15 years or 150,000 miles. In fact, they are 80% cleaner than the average 2002 model year car.

In addition to the variety of PZEVs and AT PZEVs available, gas-electric hybrid vehicles are also a success. With more than 100,000 hybrids on California's roads, they give consumers a way to reduce emissions and fuel consumption. Although these "near- zero" emission vehicles provide critical pollution reductions in the near term, with the increases in California's population and in the number of miles we travel each day, we must continue to pursue pure zero emission transportation technologies.

The Board's motivation has always been to have zero emission technologies on the roads on a mass scale as soon as possible. Whether using fuel cells, battery electric vehicles, or other technologies, our commitment to zero emissions has never wavered. Our strategy, however, has appropriately considered the state of technology, market factors, economic impact, and our mission.

Below are Frequently Asked Questions and Answers about the ZEV Regulation.

Which types of vehicles are included in the Zero Emission Vehicle (ZEV) Program?

Category	Vehicle Acronym	Technology
"Gold"	ZEV	Battery, hydrogen fuel cell
"Silver Plus"*	Enhanced AT PZEV	AT PZEV using a ZEV fuel such as electricity or hydrogen. Examples include plug-in hybrids or hydrogen internal combustion engine vehicles.
"Silver"	AT PZEV	Hybrid, compressed natural gas, methanol fuel cell
"Bronze"	PZEV	Extremely clean conventional vehicle with extended warranty and reduced evaporative emissions

** New category per 2006 Board Amendments.*

California Air Resources Board P.O. Box 2815 Sacramento, CA 95812 (916) 322-2990 www.arb.ca.gov

5/6/2008

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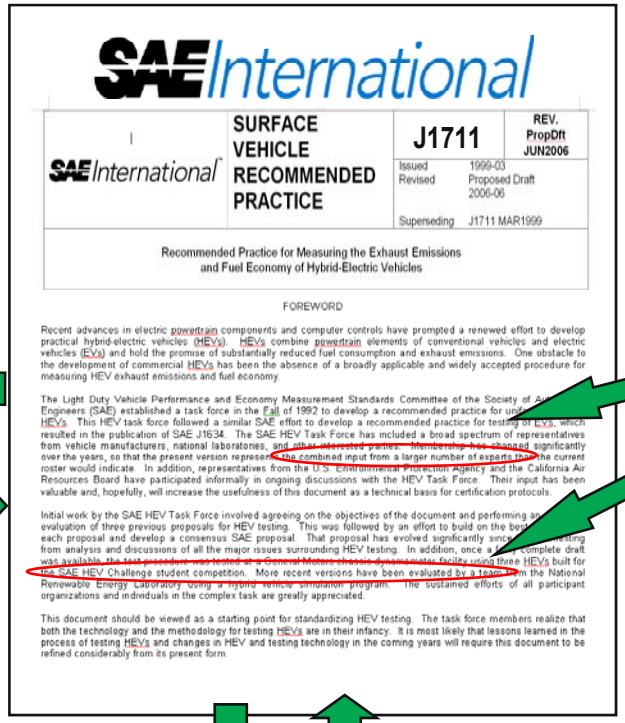

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Recommended Practice for Measuring the Exhaust Emissions and Fuel Economy of Hybrid-Electric Vehicles

FOREWORD

Recent advances in electric powertrain components and computer controls have prompted a renewed effort to develop practical hybrid-electric vehicles (HEVs). HEVs combine powertrain elements of conventional vehicles and electric vehicles (EVs) and hold the promise of substantially reduced fuel consumption and exhaust emissions. One obstacle to the development of commercial HEVs has been the absence of a broadly applicable and widely accepted procedure for measuring HEV exhaust emissions and fuel economy.

The Light Duty Vehicle Performance and Economy Measurement Standards Committee of the Society of Automotive Engineers (SAE) established a task force in the Fall of 1992 to develop a recommended practice for unified testing of HEVs. This HEV task force followed a similar SAE effort to develop a recommended practice for testing of EVs, which resulted in the publication of SAE J1634. The SAE HEV Task Force has included a broad spectrum of representatives from vehicle manufacturers, national laboratories, and other interested parties. Membership has changed significantly over the years, so that the present version represents the combined input from a larger number of experts than the current roster would indicate. In addition, representatives from the U.S. Environmental Protection Agency and the California Air Resources Board have participated informally in ongoing discussions with the HEV Task Force. Their input has been valuable and, hopefully, will increase the usefulness of this document as a technical basis for certification protocols.

Initial work by the SAE HEV Task Force involved agreeing on the objectives of the document and performing an evaluation of three previous proposals for HEV testing. This was followed by an effort to build on the best features of each proposal and develop a consensus SAE proposal. That proposal has evolved significantly since initial testing from analysis and discussions of all the major issues surrounding HEV testing. In addition, once a fully complete draft was available, the test procedure was tested at a General Motors chassis dynamometer facility using three HEVs built for the SAE HEV Challenge student competition. More recent versions have been evaluated by a team from the National Renewable Energy Laboratory using a hybrid vehicle simulation program. The sustained efforts of all participant organizations and individuals in the complex task are greatly appreciated.

This document should be viewed as a starting point for standardizing HEV testing. The task force members realize that both the technology and the methodology for testing HEVs are in their infancy. It is most likely that lessons learned in the process of testing HEVs and changes in HEV and testing technology in the coming years will require this document to be refined considerably from its present form.

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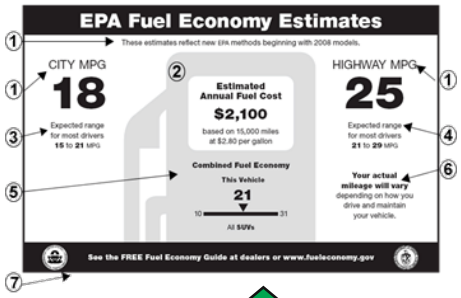
ISO International Organization Standardization



EPA Fuel Economy Estimates

These estimates reflect new EPA methods beginning with 2008 models.

CITY MPG **18**
Expected range for most drivers **15** to **21** MPG

Estimated Annual Fuel Cost **$2,100**
based on 15,000 miles at $2.80 per gallon

Combined Fuel Economy
This Vehicle **21**
10 — 31
All SUVs

HIGHWAY MPG **25**
Expected range for most drivers **21** to **29** MPG

Your actual mileage will vary depending on how you drive and maintain your vehicle.

See the FREE Fuel Economy Guide at dealers or www.fueleconomy.gov

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

NHTSA

(DOT) CAFE calculation

Much effort has gone into keeping CARB and ISO compatible with J1711

Summary of Approach / Progress

Summary of "Electrified Vehicles"

	Vehicle Type	Electric Power	Electric Storage	Grid Connected	Electric Driving
Civic HEV VUE HEV	**Mild HEV**	Low	Low	No	No
Escape HEV Prius HEV	**Full HEV**	Med	Low	No	Very limited
Hymotion Prius	**Conversion PHEV**	Med	Med	Yes	Limited
Toyota Demo PHEV	**AER- Capable PHEV**	Med+	Med	Yes	UDDS cycle
Chevy Volt	**"E-REV" PHEV**	High	High	Yes	Full Performance
RAV-4 EV EV1	**BEV**	High	High	Yes	Full Performance

J1711

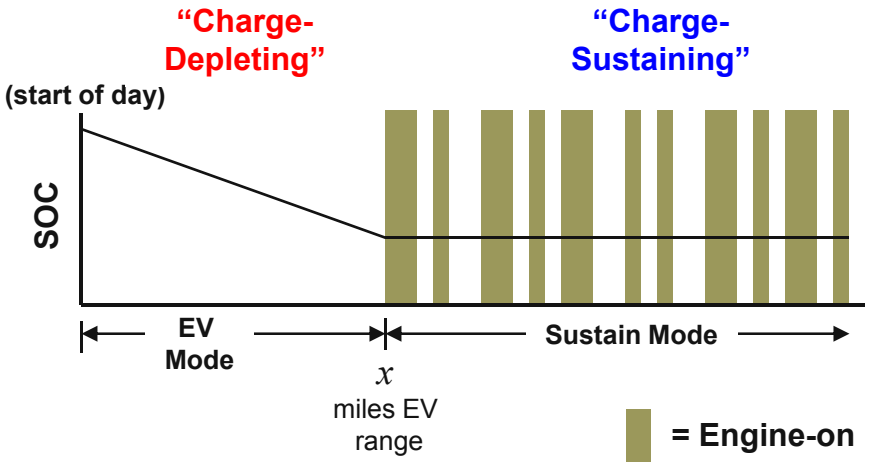
J1634

AER = All Electric Range

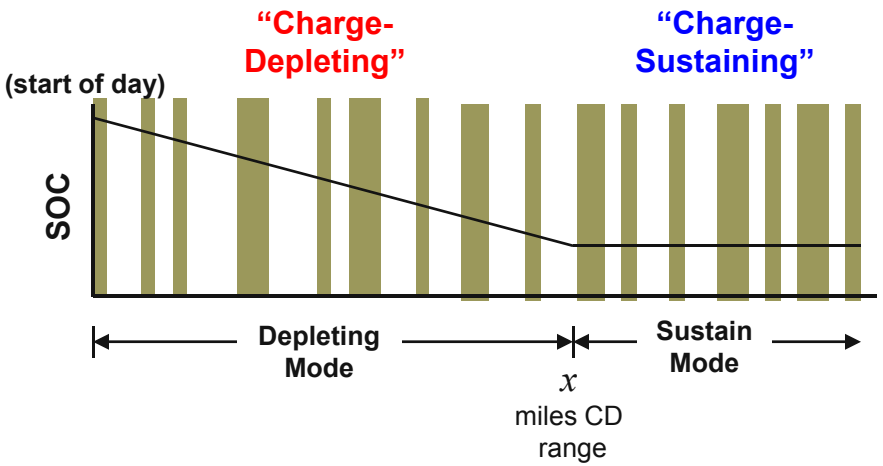
Plug-In HEV Definitions

Initially, all PHEVs were EV capable. EV, then hybrid operation.

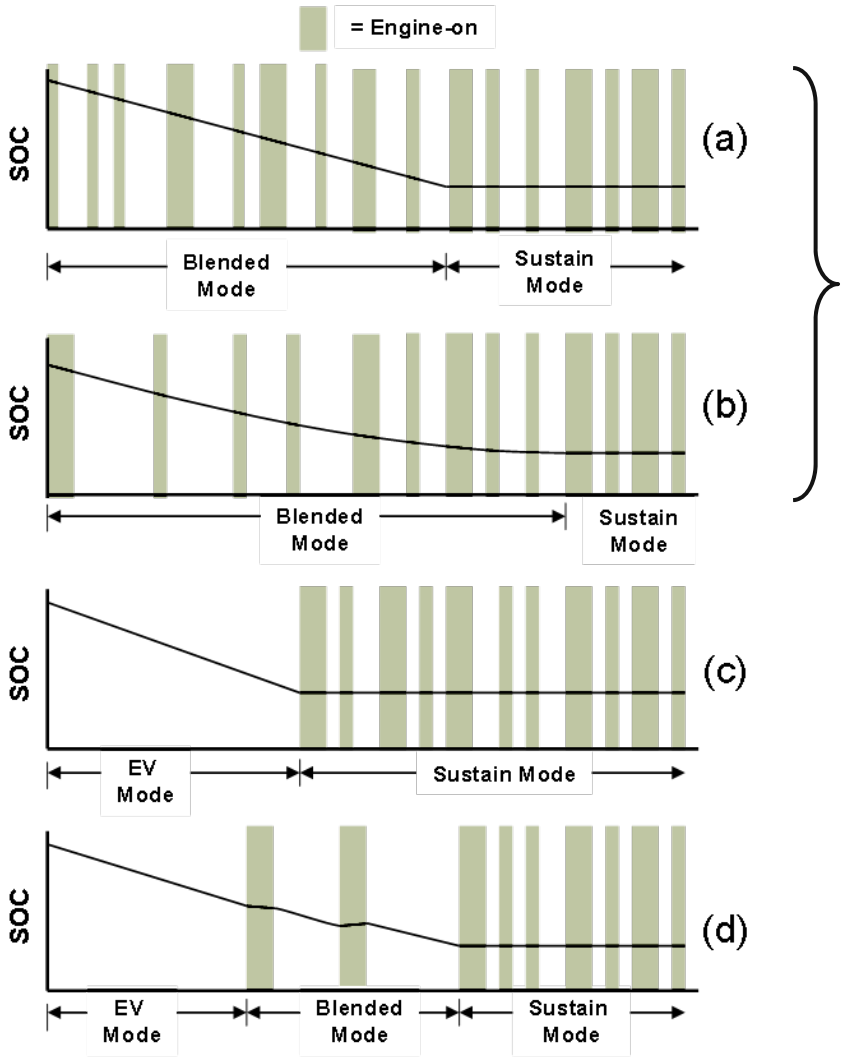
Note: E-REV is a PHEV, despite what GM says



Blended PHEVs – not "full performance" electric. Engine operation needed during test cycles. However, significant fuel use displaced.



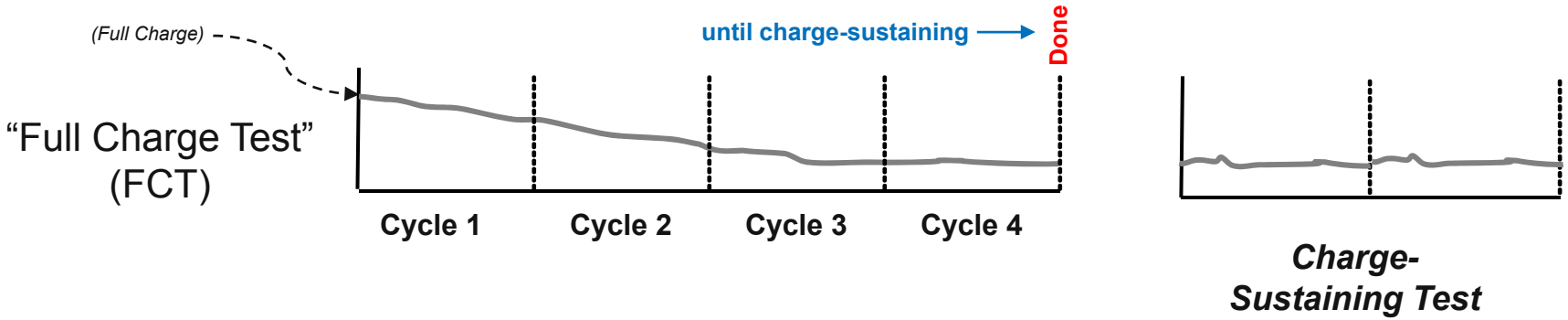
PHEV Operation Diversity Poses Challenges For Testing



- Blended depletion may vary
- If EV → Sustain Mode abrupt,
- Or, EV / Blended / Sustaining

Testing Depleting Operation With "FCT"

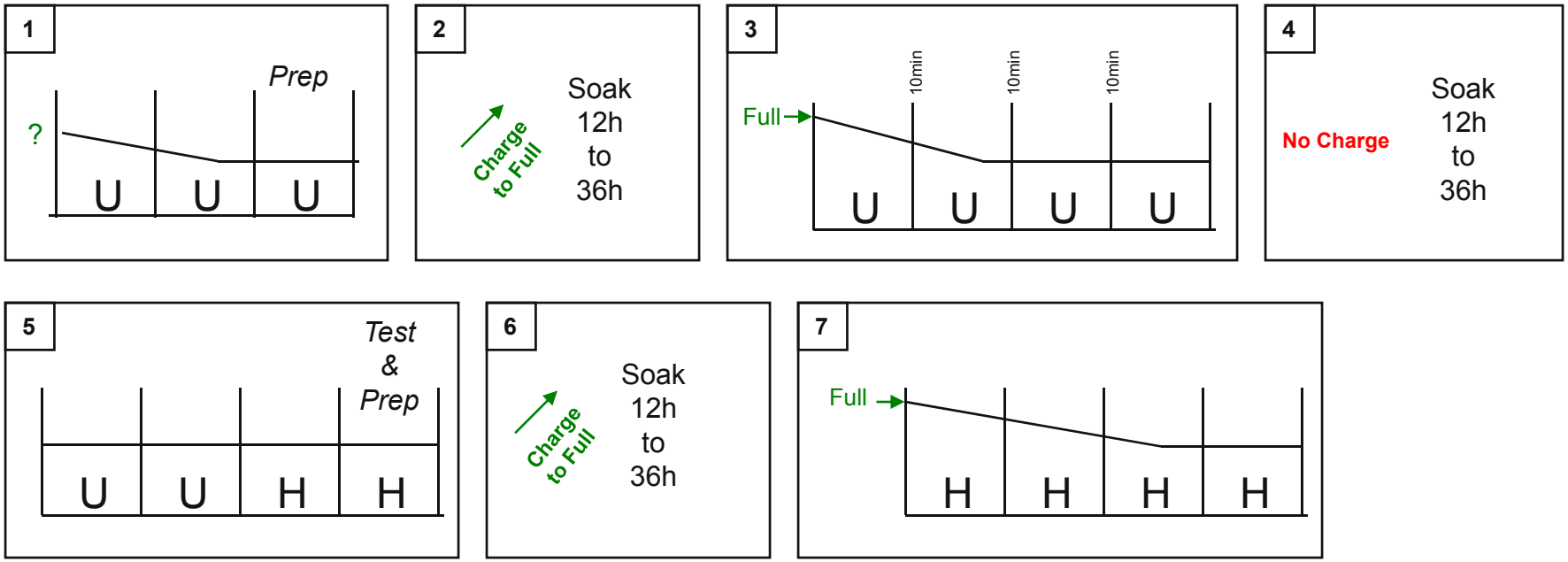
Full Charge Test (FCT) - Start fully charged, repeat cycle until car behaves like a charge-sustaining hybrid



Easy? What's the problem?

1. Limitations of **test cell** hardware / software:
2. Vehicle **initial conditions** conflict with conventional vehicle procedures
3. Compatibility with **existing test procedures**, conditions, and calculations

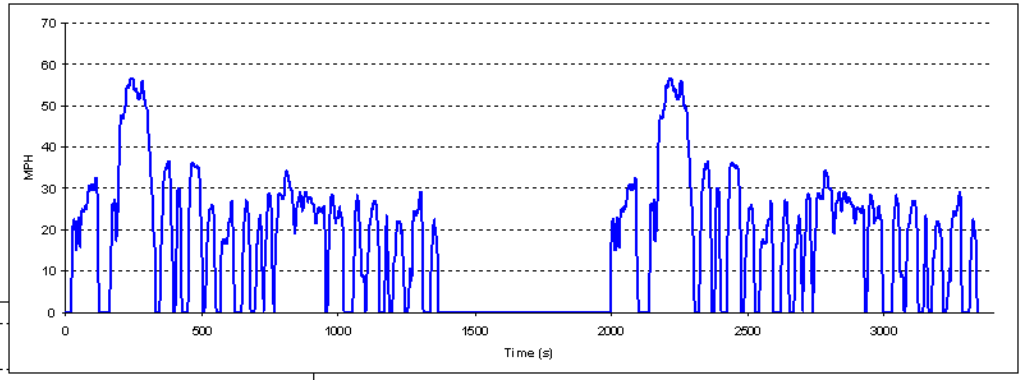
Test Sequence For Urban and Highway Cycle Tests

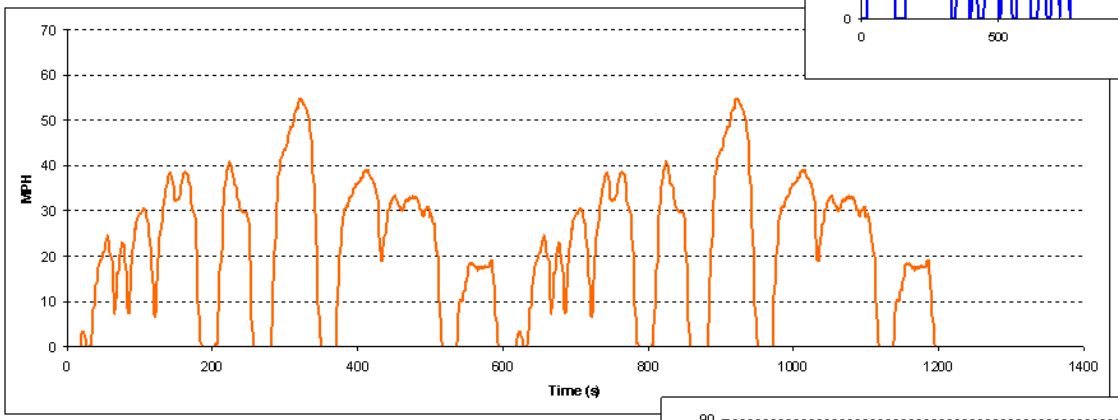


- Four (4) days of testing for PHEV UDDS and Highway
- Non plug-in hybrids, day and a half

EPA Label Includes Three More Cycles to Test!!!

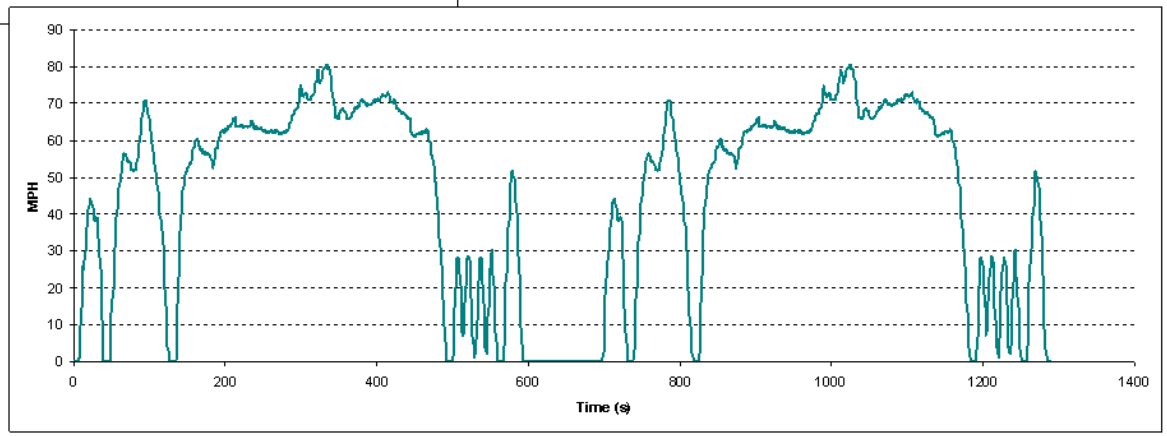
Cold CO Test
-7˚C Urban





35˚C SC03 Air Conditioner Test
with solar simulation lights

US06
Run like HWY, only second cycle counts



Major Consensus Items of J1711

- Do not combine fuel and electricity into a composite MPG Result
  - Report both MPG and AC Wh/mi (from plug) separately
- Baseline charging assumption: 1 charge per day
  - Missed charge = Opportunity charging
- Retain *"Utility Factor"* method of combining depleting with sustaining
- Emissions certification may not be the same procedure as fuel economy determination
- Typical Cold / Hot Weighting for UDDS not possible in Charge-Depleting test

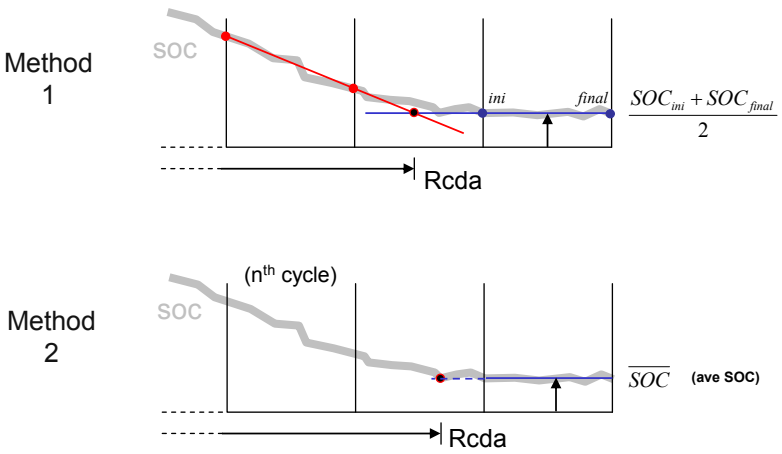
What is NOT in Scope of J1711

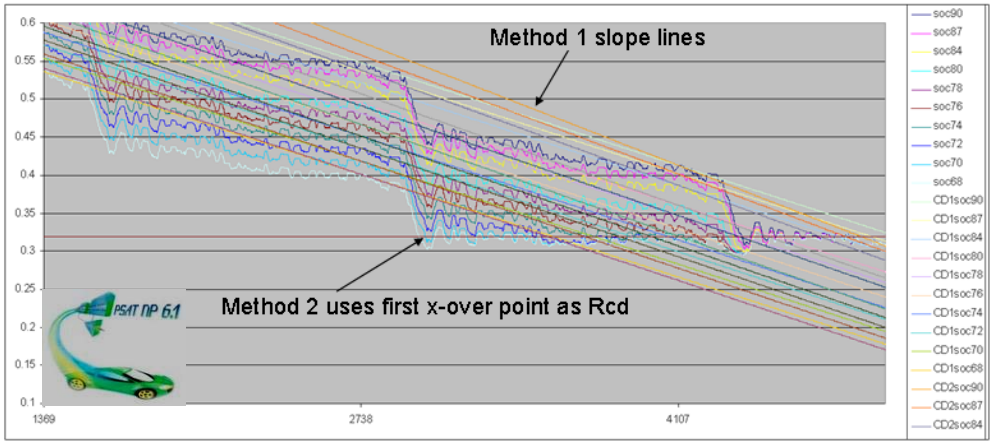
- **Emissions certification** → worst case emissions
  - Depleting or the Sustaining test results
  - OEMs demonstrate worst case
  - J1711 include emissions calculation similar to fuel (like CO2)
- **Label Fuel Economy** → EPA
  - However, the committee is now spending time on this subject
  - Contract with Emmeskay Inc. to help provide “Individual” Utility Factors for MPG label calculations

Examples of ANL Tools Used Develop J1711 Concepts

OEMs do not share data, ANL had to address the problems using its wide array of systems tools

Using Simulation to Define End of Charge-Depleting Range

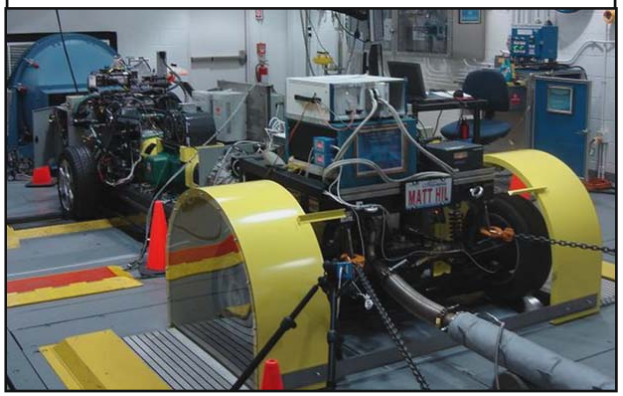


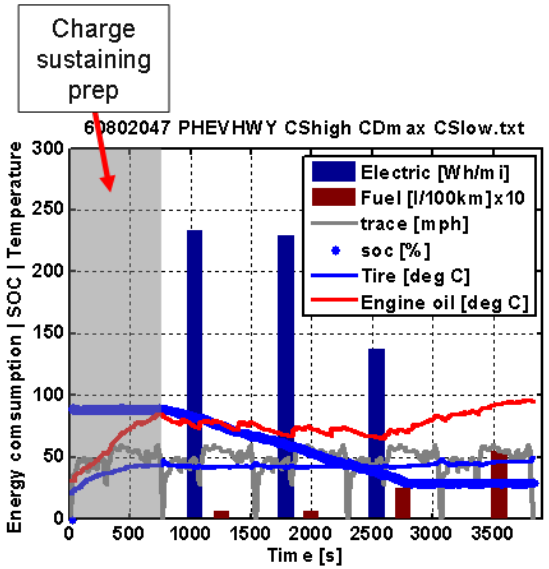


- Major issue with SAE and JARI ISO workgroup – how to define end of charge-depleting?
- Found that both definitions are useful, depending upon use and level of data

ANL PHEV Platforms Critical in Procedure Development & Validation

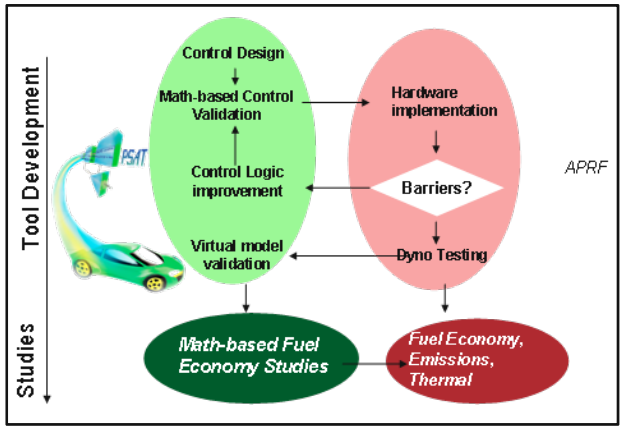
"MATT" Platform as PHEV





-- "Charge-sustaining switch"
-- Solve "Cold HWY" Problem

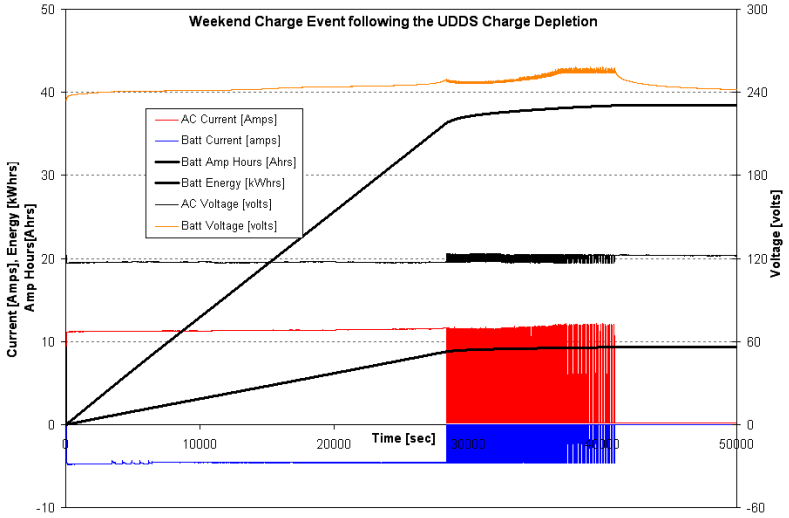
"TTR" PHEV

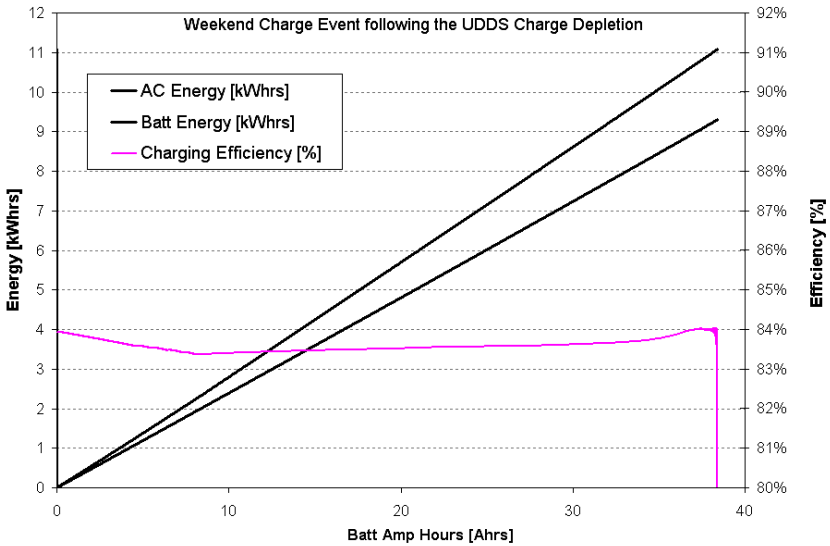


Full control allows testing various PHEV operation
-- Blended
-- E-REV

New Ideas for Treating Charging Data

- Needed a way to relate DC energy measured on vehicle to AC kWh from charger
- ANL's analysis of actual PHEV charge data of Li-Ion batteries led to an ANL proposal to deal with difficult problem





Many PHEVs Tested to Aid in J1711 Development

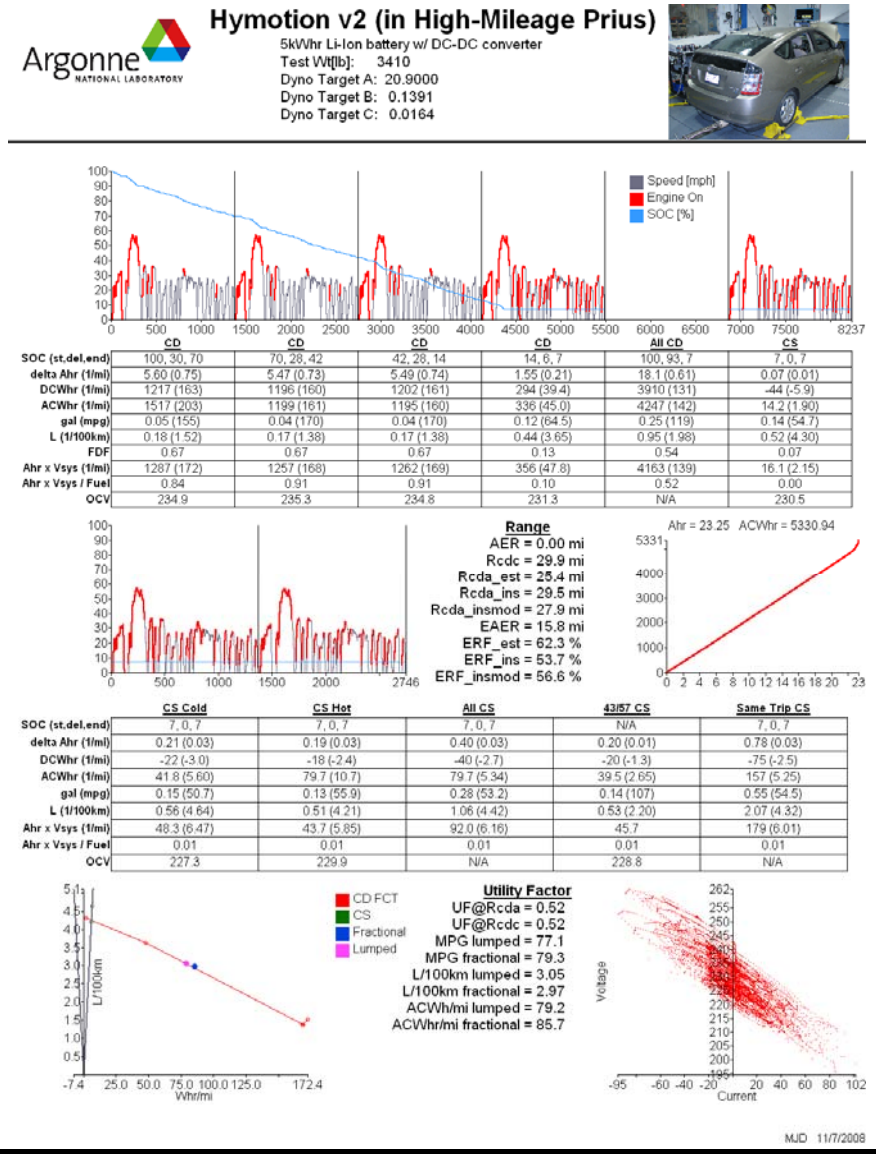
- Prius Conversions
  1. Hymotion (1st gen) Prius (highly instrumented)
  2. HybridsPlus Prius (highly instrumented)
  3. Hymotion (2nd gen) Prius (AVTA)
  4. EnergyCS Prius ver.1 and ver.2 (AVTA)
  5. Hymotion (3nd gen) Prius (owned by A123)
- Escape Conversions
  6. Electrovya Escape (AVTA / NYSERDA)
  7. Hymotion Escape (AVTA / NYSERDA)
- OEM
  8. Renault Kangoo
  9. OEM PHEV Mule (NDA-protected)
  10. BEV Tested for range/eff, short-cut

OEM, NDA PRotected 9

OEM, NDA PRotected 10

Analytical Tools Developed to Evaluate Equations and Results

- PHEV “One-Pager”
- Calculates all relevant test outputs from APRF test data
- Real data shows limitations in equations, methods
- Several problems found, ANL recommended changes



	CD	CD	CD	CD	All CD	CS
SOC (st,del,end)	100, 30, 70	70, 28, 42	42, 28, 14	14, 6, 7	100, 93, 7	7, 0, 7
delta Ahr (1/mi)	5.60 (0.75)	5.47 (0.73)	5.49 (0.74)	1.55 (0.21)	18.1 (0.61)	0.07 (0.01)
DCWhr (1/mi)	1217 (163)	1196 (160)	1202 (161)	294 (39.4)	3910 (131)	-44 (-5.9)
ACWhr (1/mi)	1517 (203)	1199 (161)	1195 (160)	336 (45.0)	4247 (142)	14.2 (1.90)
gal (mpg)	0.05 (155)	0.04 (170)	0.04 (170)	0.12 (64.5)	0.25 (119)	0.14 (54.7)
L (1/100km)	0.18 (1.52)	0.17 (1.38)	0.17 (1.38)	0.44 (3.65)	0.95 (1.98)	0.52 (4.30)
FDF	0.67	0.67	0.67	0.13	0.54	0.07
Ahr x Vsys (1/mi)	1287 (172)	1257 (168)	1262 (169)	356 (47.8)	4163 (139)	16.1 (2.15)
Ahr x Vsys / Fuel	0.84	0.91	0.91	0.10	0.52	0.00
OCV	234.9	235.3	234.8	231.3	N/A	230.5

	CS Cold	CS Hot	All CS	43/57 CS	Same Trip CS
SOC (st,del,end)	7, 0, 7	7, 0, 7	7, 0, 7	N/A	7, 0, 7
delta Ahr (1/mi)	0.21 (0.03)	0.19 (0.03)	0.40 (0.03)	0.20 (0.01)	0.78 (0.03)
DCWhr (1/mi)	-22 (-3.0)	-18 (-2.4)	-40 (-2.7)	-20 (-1.3)	-75 (-2.5)
ACWhr (1/mi)	41.8 (5.60)	79.7 (10.7)	79.7 (5.34)	39.5 (2.65)	157 (5.25)
gal (mpg)	0.15 (50.7)	0.13 (55.9)	0.28 (53.2)	0.14 (107)	0.55 (54.5)
L (1/100km)	0.56 (4.64)	0.51 (4.21)	1.06 (4.42)	0.53 (2.20)	2.07 (4.32)
Ahr x Vsys (1/mi)	48.3 (6.47)	43.7 (5.85)	92.0 (6.16)	45.7	179 (6.01)
Ahr x Vsys / Fuel	0.01	0.01	0.01	0.01	0.01
OCV	227.3	229.9	N/A	228.8	N/A

Defining Fuel Economy of a PHEV ….?

Most Converter Companies Claim "100+ MPG" Pointless Number Unless Conditions are Described

→ *Importance of standard*

(Only Rob Lowe gets 150+ MPG?)

On-Road Results Illustrate Importance of Daily Driving Distance

***INL and ANL studying Test vs On-Road** (addresses last year's reviewer's remark)*

Increasing Distance

Hymotion Prius – Accelerated Testing

Cycle	Urban	Highway	Charge	Reps	Total	Electricity	Gasoline	
(mi)	(10 mi)	(10 mi)	(hr)	(N)	(mi)	kWh	Gals	MPG
10	1	0	4	60	600	136.33	4.81	127.2
20	1	1	8	30	600	122.02	5.37	115.9
40	4	0	12	15	600	84.10	6.05	101.1
40	2	2	12	15	600	87.22	5.78	106.9
40	0	4	12	15	600	79.82	8.54	73.1
60	2	4	12	10	600	55.33	8.98	68.9
80	2	6	12	8	640	43.99	11.36	58.3
100	2	8	12	6	600	35.98	8.43	73.2
200	2	18	12	3	600	15.0	11.02	54.8
Total	2540	3100	1404	167	5,440	Weighted Average		79.5

Decreasing MPG

From: http://avt.inl.gov/pdf/phev/HymotionPriusAccelTestingResultsReport.pdf

Utility Factor (UF) Defined to Weight Depleting with Sustaining

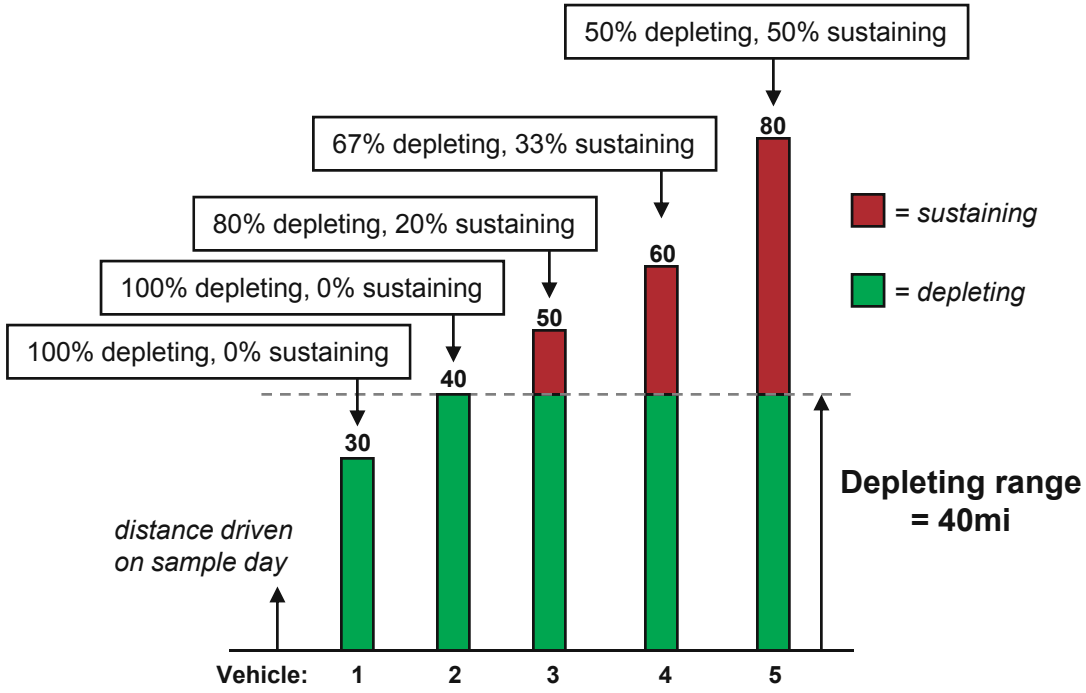
- UF: Weighting of Depleting operaiton
- US DOT National Highway Transportation Survey, 2001
- 84,000 vehicles

Depleting miles

$$UF(40) = \frac{30+40+40+40+40}{30+40+50+60+80}$$

Total miles

$$UF_{proposed}(D) = \frac{\sum_{d_k \in R} \min(d_k, D)}{\sum_{d_k \in R} d_k}$$



SAE J2841 Standard Finished, Balloted

- SAE J2841 was written to reference the Utility Factor calculations for 2001 National Household Travel Survey Data
- CARB now references document
- Balloted and now available from SAE

SAE International

SURFACE VEHICLE RECOMMENDED PRACTICE

J2841 PropDft 2008

Issued	*04-24-2006*
Revised	Proposed Draft (LastDate)
Cancelled	Date (CancelledDate)
Superseding	Jxxxx Date (SupersededBy)

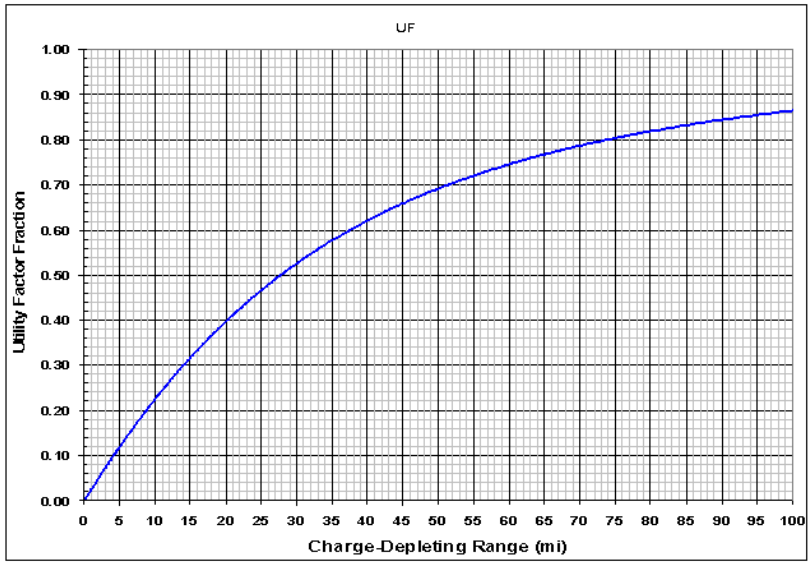
Definition of the Utility Factor for Plug-In Hybrid Electric Vehicles Using US DOT National Household Travel Survey Data

1. SCOPE

This SAE Information Report establishes a "Utility Factor" (UF) curve and its method of generating this curve. The UF is used when combining test results from battery charge-depleting and charge-sustaining modes of a Plug-in Hybrid Electric Vehicle (PHEV). This document will define the UF curve(s) using 2001 United State Department of Transportation "National Household Travel Survey" data. The input is daily vehicle miles traveled and the UF curve output is a percentage fraction that is applied to the charge-depleting mode results.

1.1 Purpose

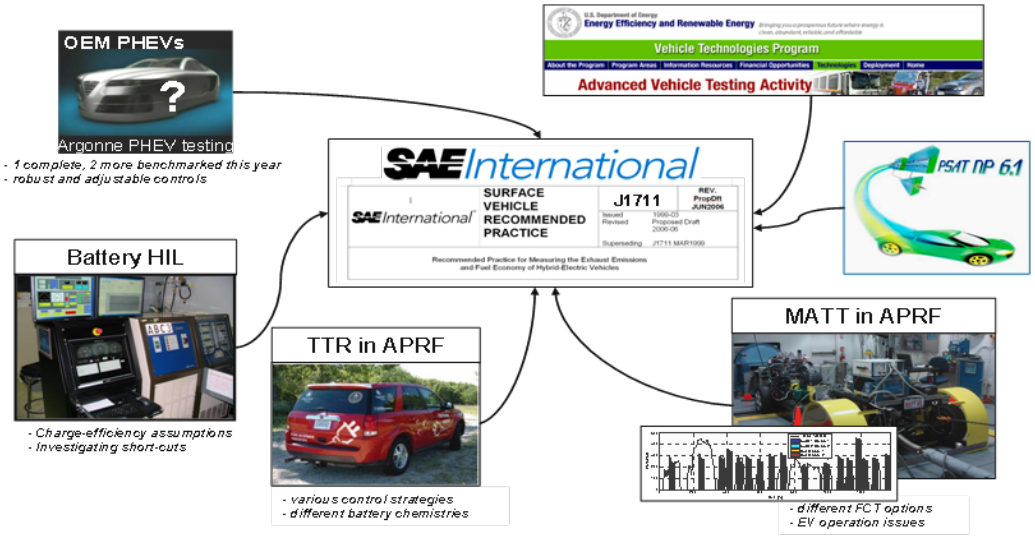
In use, the total fuel and energy consumption rates of a Plug-In Hybrid Electric Vehicle (PHEV) vary depending upon daily driving distances. For PHEVs, the underlying assumption using the UF is that operation starts fully charged, and begins in battery charge-depleting mode. Eventually the vehicle must change to a charge-sustaining mode. The vehicles miles



ANL: mined the NHTS database, wrote the code to generate factors, wrote doc
GM: generated curve fits based upon ANL UF outputs

Summary: Argonne / DOE PHEV Tools Make Possible Procedure Development

- Vehicle Systems tools support procedure development and validation
- ANL Expertise in HEV/PHEV testing unparalleled
- Significant challenges in development have been met
  - collaboration (international, CARB, EPA, OEMs)
  - DOE access to real vehicles for testing
- Effort cross-cuts all aspects of DOE vehicle systems activities
- Success would not have been possible without DOE maintaining leadership in vehicle systems



Future: Use of ANL's Experience in Testing
SAE LDV Standards Committee Requested ANL to help chair J1634 – Electric Vehicle Test Procedure

- Currently evaluating "short-cut" procedures for 100+mi range
- OEMs not providing data, but are supplying cars
  - ANL to keep DOE informed, but release sanitized data
- Procedures validated by June/July 2009
- Keep J1711 and J1634 harmonized

Many Unnamed OEMs and start-ups

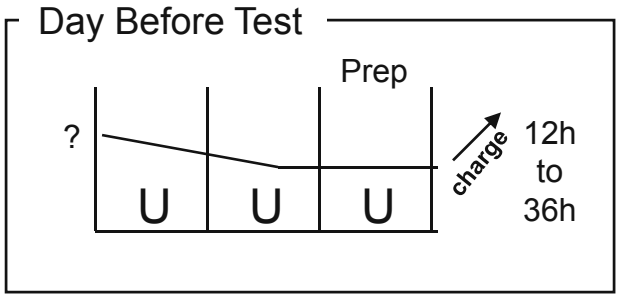
Thank You

We would like to gratefully acknowledge the sponsorship of Pat Davis, Program Manager and Lee Slezak, Manager, Advanced Vehicle Systems Simulation & Evaluation Team, Office of Vehicle Technologies Program, U.S, Department of Energy.

Vehicle Technologies Program

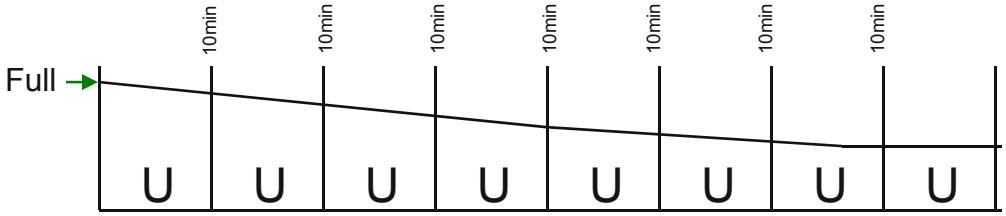
PHEV FCT Procedure for FTP

Concept also valid for Cold FTP test

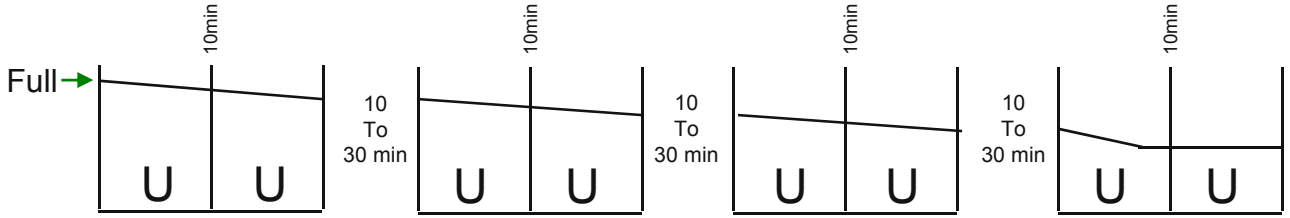


Test facility limitations requires backup options.

Best interpretation of FCT, but may not be possible for many test facilities



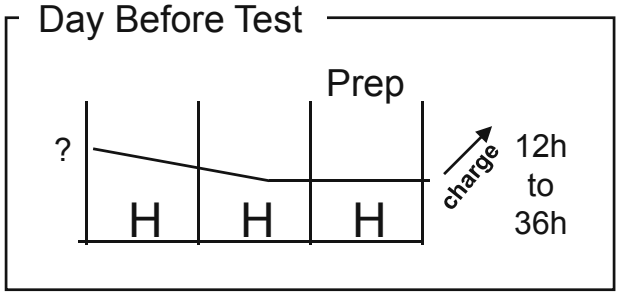
If above option is not possible, run this test

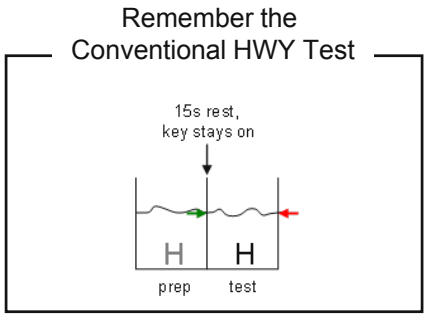


U – Urban Dynamometer Drive Cycle (UDDS)

PHEV Highway FCT Procedure

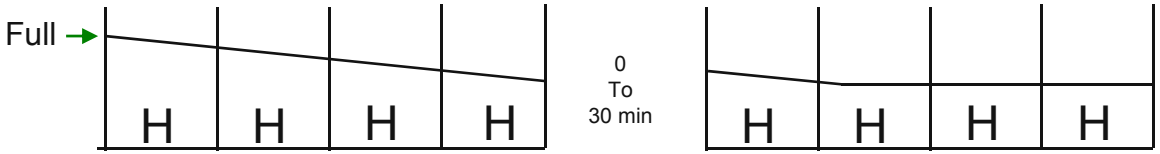
Concept also valid for US06 and SC03

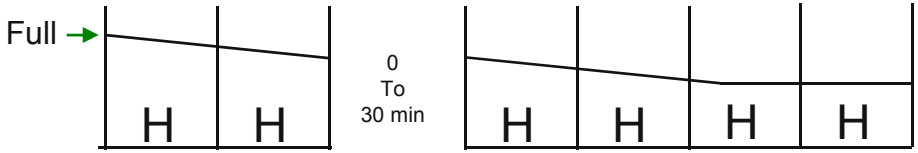




Objective: run as many tests in a row as possible

Sequence in least disruptive manner





H – Highway Cycle

UF-Weighted MPG Calculations for E-REV PHEV