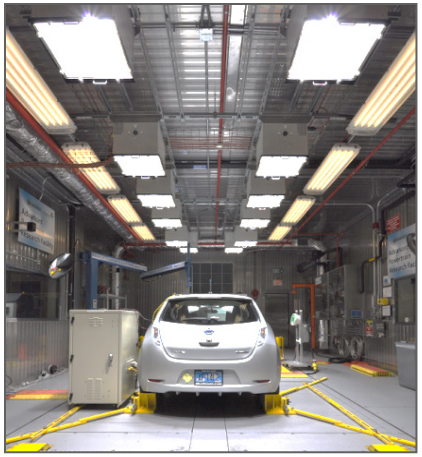
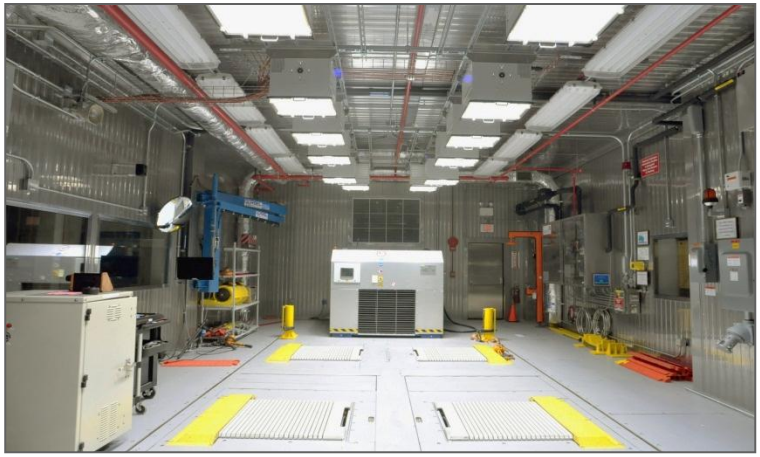
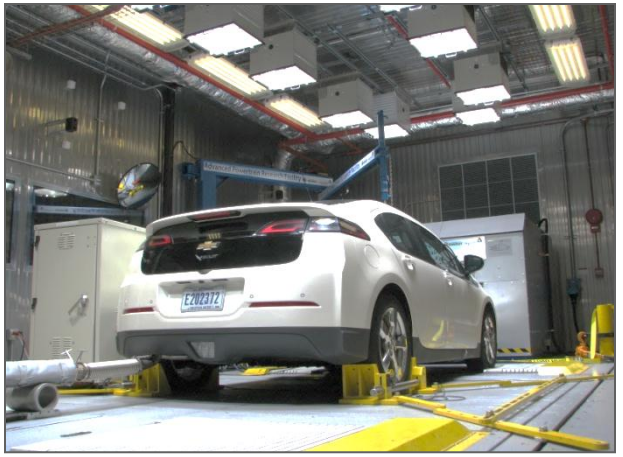
Evaluating Plug-In Vehicles (PHEV & BEV) Using Standard Dynamometer Protocols

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6th US – CHINA Electric Vehicles and Battery Technology WORKSHOP

August 22 – 24, 2012, Boston, MA

Importance of well-developed test procedures cannot be overstated

"You get what you pay for"… **"You get what you test for"**

Challenges:

- Legacy test methods
  "square peg / round hole"
- New instrumentation / vehicle access
- Longer test days
- New post-processing concepts
- New "fuel" → electricity
- Valid for all vehicle types/designs
  (even ones that don't make sense)
- Recharge procedures/equipment

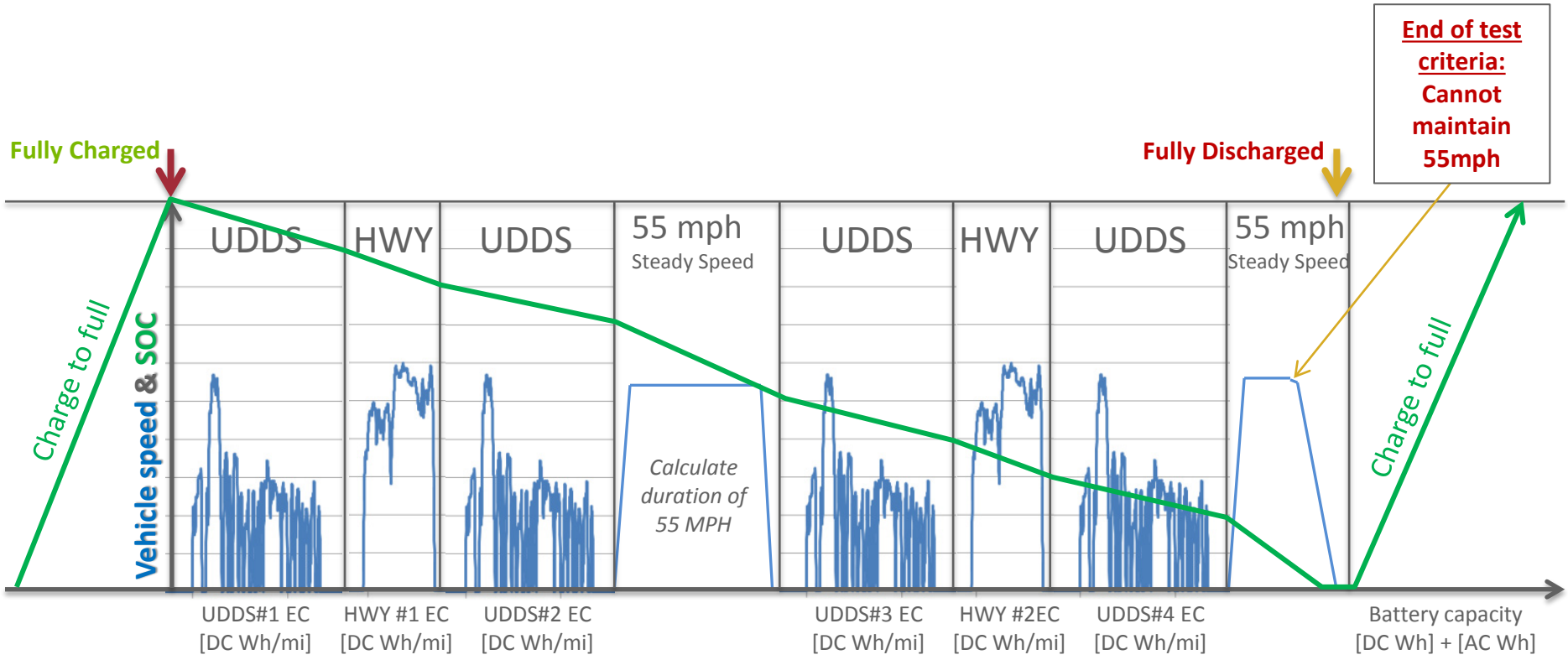
Battery Electric Vehicle Testing

Problem: Original J1634

250mi = 17+ hours of testing, no interruptions allowed

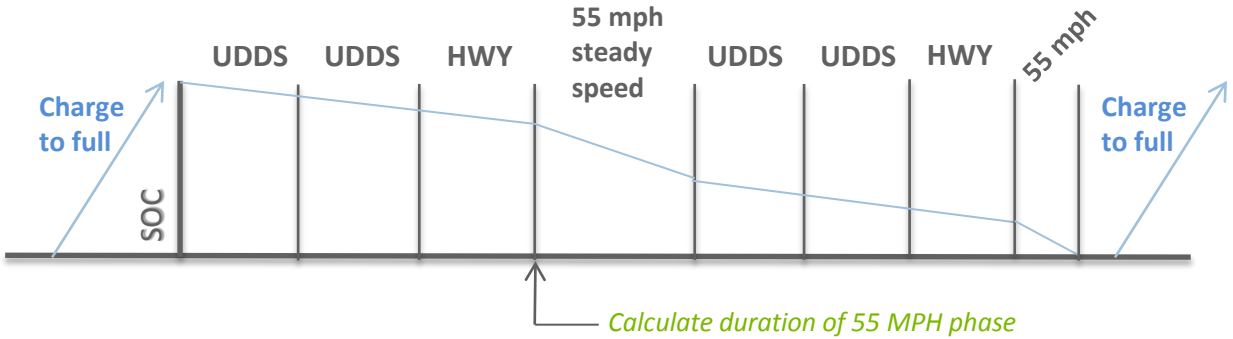
"Death by Urban Cycle"

Final Revision Includes Arranging Cycles Across Entire Range, With 55 MPH in Middle and End



- Cycles are tested at beginning and end of SOC
- Depletion cycles are steady-state speeds (55 MPH)
- Test ends during steady-state speed

Leaf Test Results



Battery Current Loop Modification

Charge Recovery

CR = C_c / C_d
CR = 57.43 Ah / 58.55 Ah
CR = 98.08%
(must be greater than 97%)

Test #	Cycle	Wh	Cycle Dist [mi]	DC [Wh/mi]
71109006	UDDS	1583.6	7.47	211.9
71109007	UDDS	1494.0	7.47	199.9
71109007	HWY	2422.8	10.26	236.1
71109008	SS @ 55	7844.5	30.94	253.5
71109009	HWY	2409.4	10.25	235.2
71109010	UDDS	1494.2	7.48	199.7
71109011	UDDS	1468.5	7.47	196.7
71109012	SS @ 55	2429.2	9.39	258.6
	Total	21146.2	90.7	

AC Recharge energy into charger = 25.08 AC kWh
DC Recharge energy into battery = 21.64 DC kWh

Weighting UDDS for "First Cycle Effect"

K1 = 1583.6 / 21146.2 = 0.0749
K2 = K3 = K4 = (1 – 0.0749)/3
DC Wh/mi = K1*UDDS1 Wh/mi + K2…
DC Wh/mi = 199.75

Recharge Allocation Factor

RAF = DC $kWh_{total\ test}$ / AC $kWh_{recharge}$
RAF = 21.146 / 25.084 = 0.8430

AC Energy Consumption

UDDS:
AC Wh/mi = DC Wh/mi / RAF
AC Wh/mi = 199.75 / 0.843 = 236.95
HWY:
aveDC Wh/mi = 235.62
AC Wh/mi = 279.49

Range Extrapolations

Usable Battery Energy (UBE)
UBE = 21146.2 Wh

UDDS

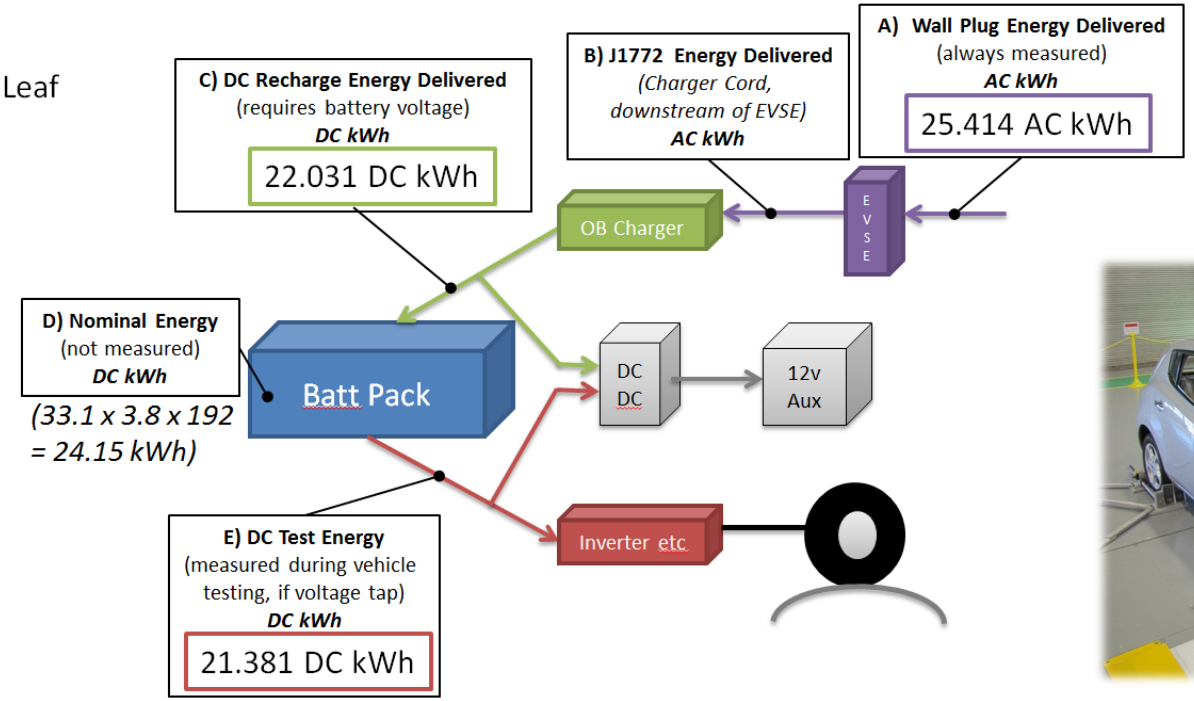
R = 21146.2 / 199.75 = 105.8 miles

HWY

R = 21146.2 / 235.62 = 89.75 miles

“Charger Efficiency”?
“Recharge Efficiency”?
“Round-Trip Efficiency”?

Nissan Leaf



Leaf Recharge Results

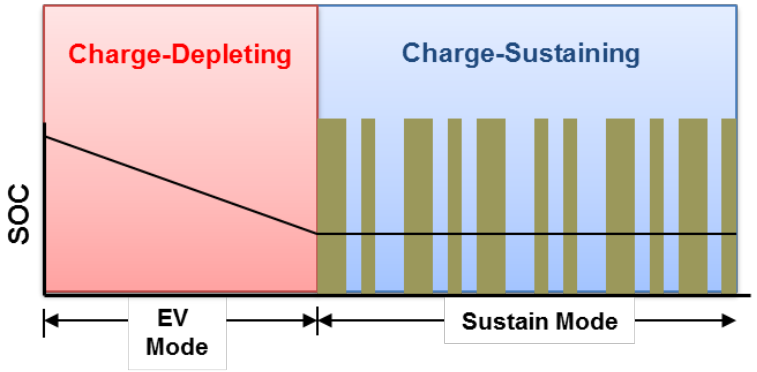
Draft Terms:

Charger Efficiency = C / B = *unknown, modifications to EVSE required*
Charger & EVSE Efficiency = C / A = 86.69%
Overall Trip Efficiency = E / A = 84.13%
Battery Efficiency = E / C = 97.05%
Pack Utilization = E / D = 88.5%
Energy counted in J1711 and J1634 → A

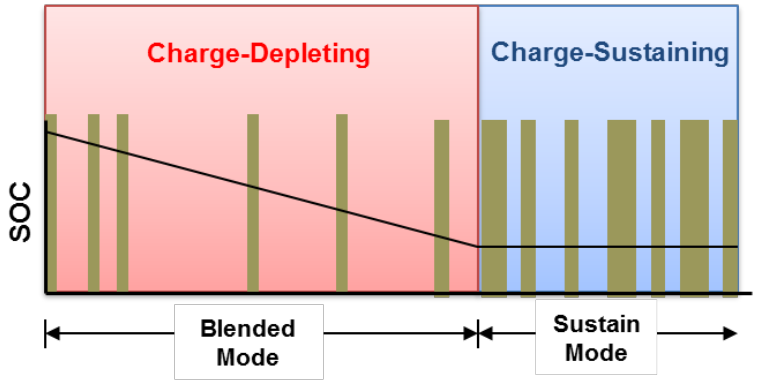
Plug-in Hybrid Electric Vehicle Testing

Different Types of Charge-Depleting Behavior During Testing

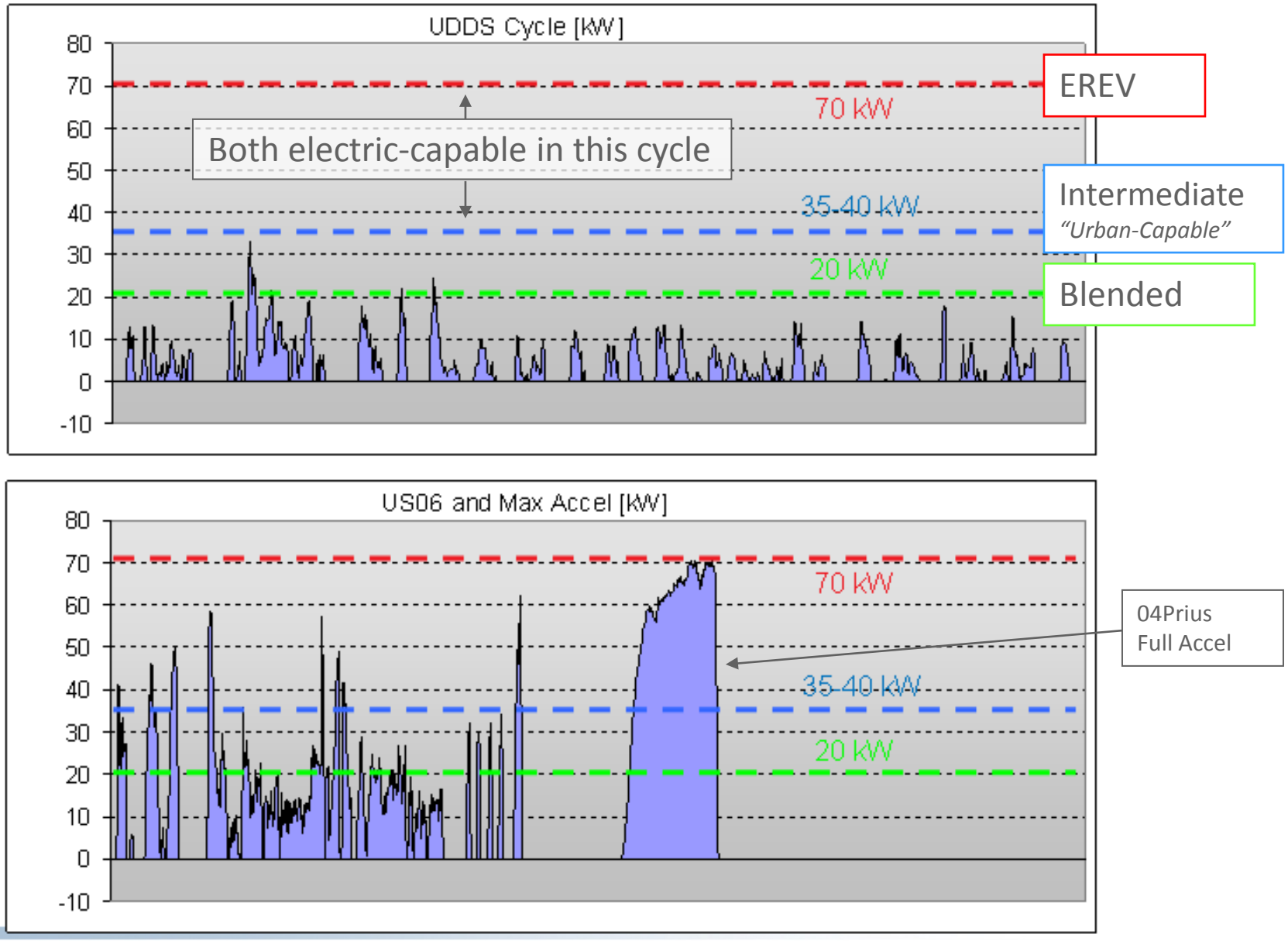
New to SAE J1711-2010 Established Procedures



= Engine-on



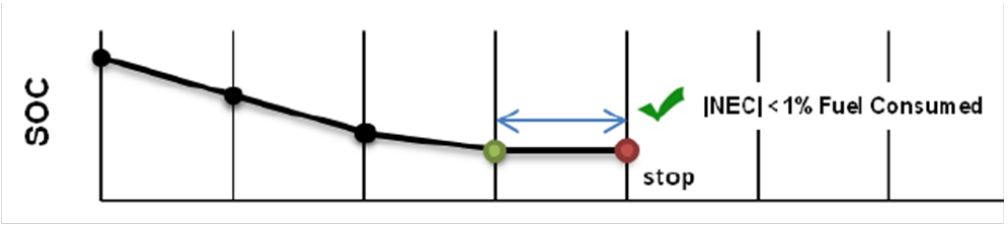
Wheel Power Requirements Show When Electric Dive Can Displace Engine Operation



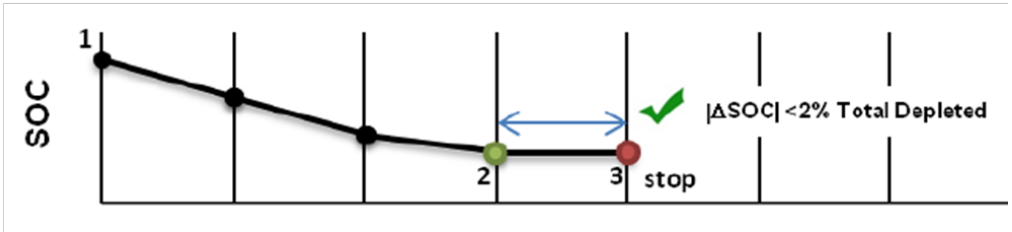
Procedure = Repeat Cycles Until Test Complete
End of Test (EOT) Criterion was Developed

- Charge Depleting Test is complete when all depleting behavior is captured
- Two criteria are provided in J1711
  1) Use charge-sustaining Net Energy Change tolerance as a criteria for EOT
  2) Define new criterion, “End of (significant) Depleting”
- PHEVs in sustaining mode push more battery energy in/out, EOT criterion 1 may be difficult to achieve

1)



2)

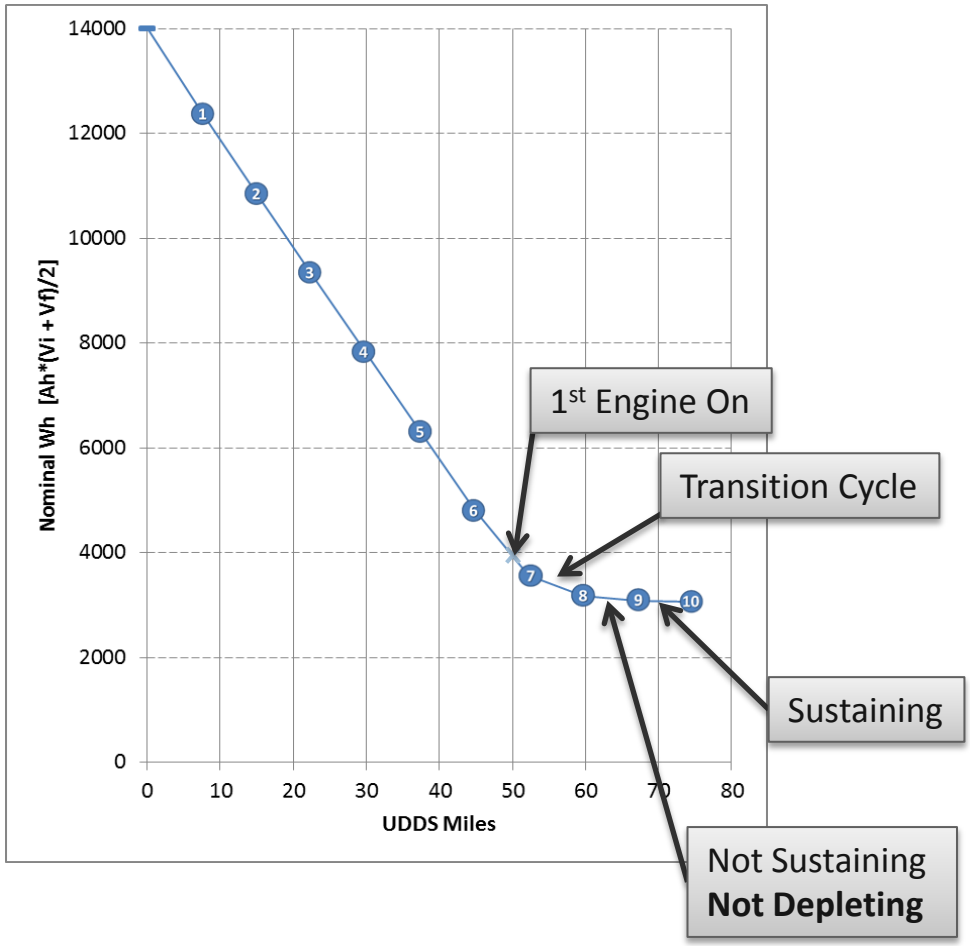


UDDS Cycles Run Until Both EOT Criteria Satisfied

				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

14 kWh nominally chosen for graph



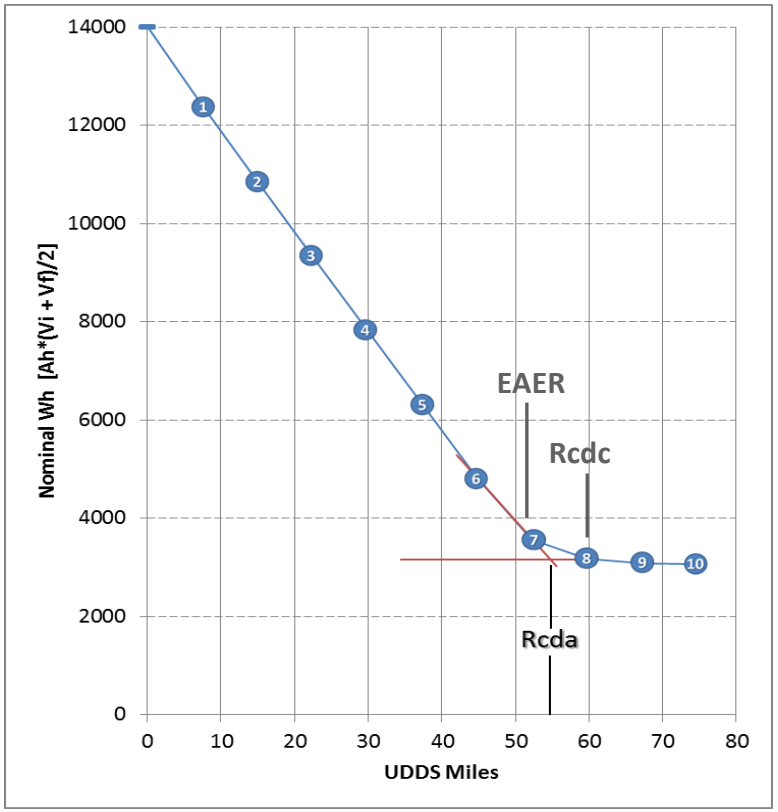
Range Definitions - Illustrated with Volt UDDS Results

All-Electric Range (AER)
Engine first starts at 50.5 miles

Equivalent All-Electric Range (EAER)
EAER = **Rcdc** x (FCcs – FCcd)/FCcs
EAER = 59.47 x (0.872006)
EAER = 51.86 mi

Actual Charge-Depleting Range (Rcda)
n = transition cycle (cycle 8)
Z_n = NEC8 / NEC7 = 386.5 / 1267.6 = 0.3049

$\mathbf{R_{cda}} = R_{n-1} + (Z_n \times D_n)$
$R_{cda} = 52.03 + (0.3049 \times 7.440) = 54.30$ mi



“Alternative” Method in J1711 is Used to Describe Charge-Depleting Results

Charge-Sustaining Mode Results
Weighted: 46.1 MPG (2.17 gal/100mi)

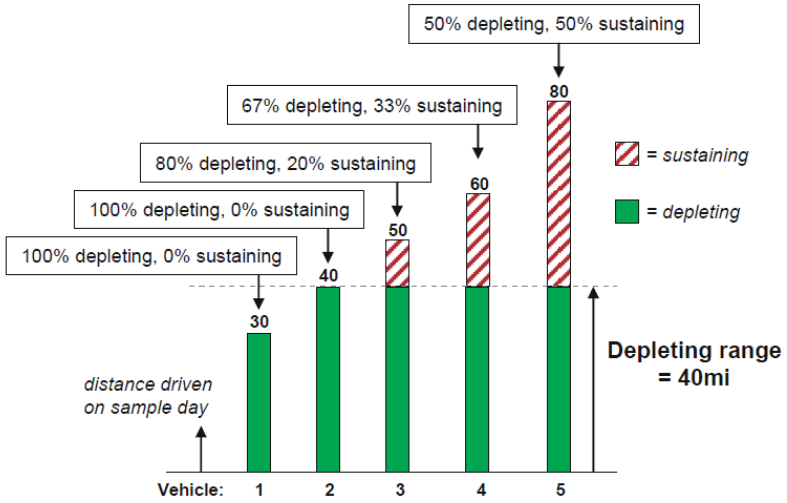
Charge-Depleting Mode Results
For Volt, two options:

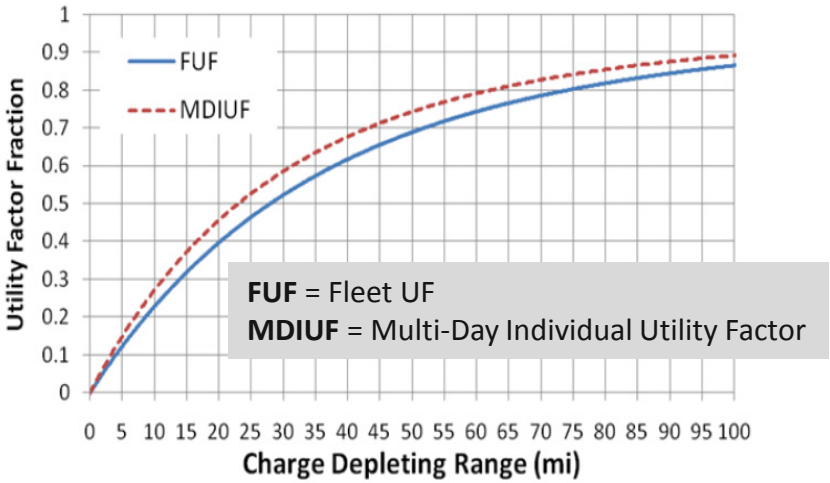
1) All electricity consumed divided by EAER
   13102 / 51.86 mi = **252.6 Wh/mi** ***for 51.9 mi (EAER)***

2) Report both fuel and electricity consumed
   13102 / 59.47 mi = **220.3 Wh/mi and 0.26 gal / 100 mi** (383 MPG) ***for 54.3 mi*** *(Rcda)*

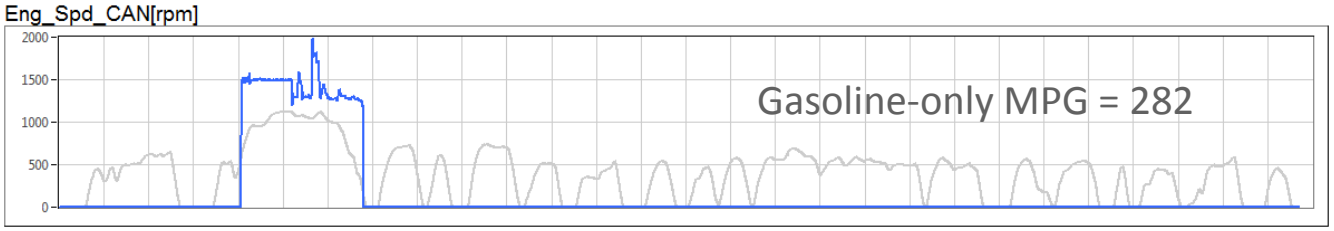
Combine Depleting and Sustaining Using Utility Factor (UF) Analysis

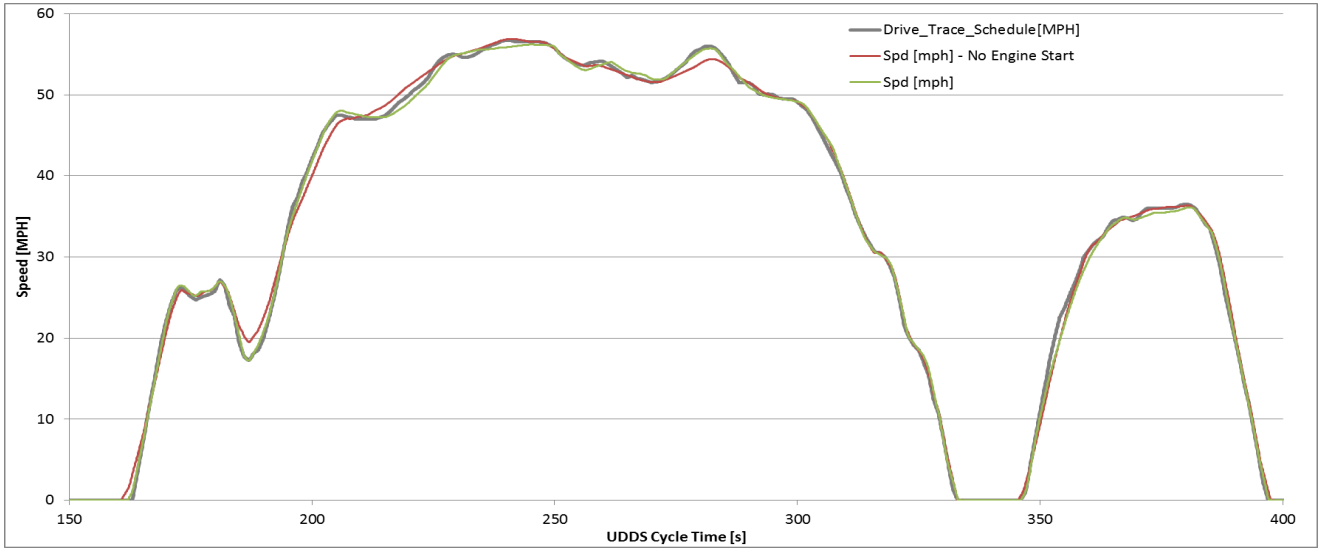
- UF(x): UF is function of CD range
- Two curves exist
  - Miles weighted: predicting total miles in depleting of a large fleet (FUF)
  - Driver weighted: predicting average driver experience (MDIUF)
- Label MPG results use MDIUF
- The suggestion is for CAFE to use FUF
  - EPA/DOT NPRM states that UF also to be used for bi-fuel CNG vehicles





Preliminary Testing of Prius "PHV" is Inconclusive of Intermediate/Blended



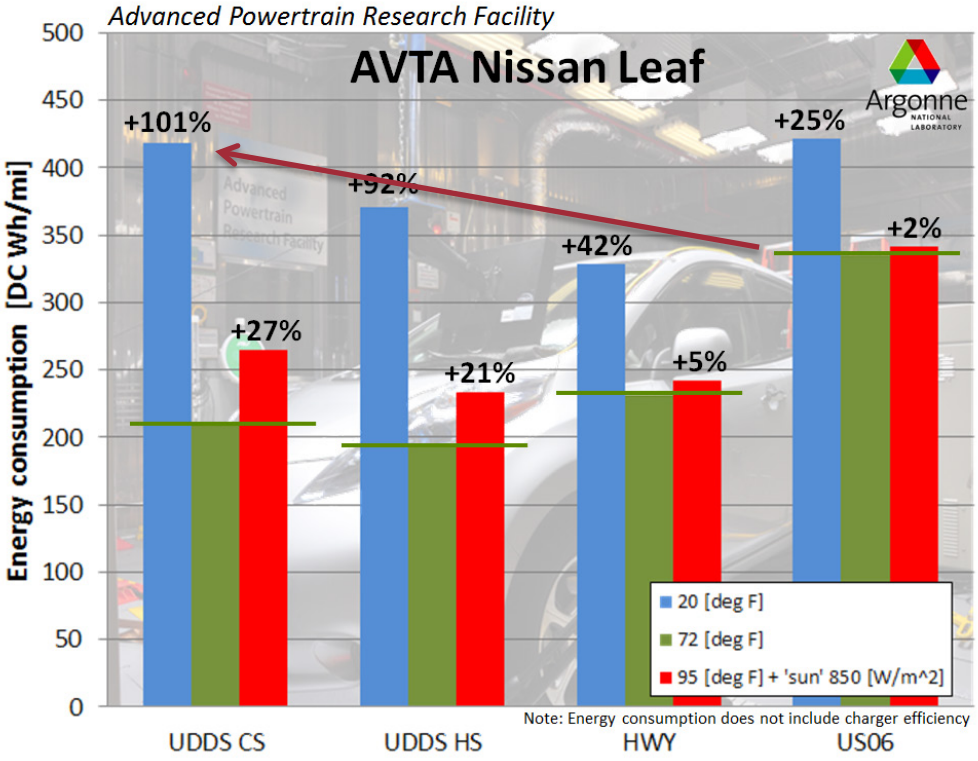


- **Label**: 0.2 gal/100mi, Electricity+Gasoline range = 11 mi, All electric range = 6 mi
- Driving normally on UDDS yielded a single engine start
- Driving very carefully, no engine start → not sure within tolerance
  - Regulatory categories may have influenced design

Standard Test Cycle → Report to Consumers / Regulators

Enormous Challenge!

- Many cycles are “best case”
  - Driving aggressively
  - Hot weather with A/C
  - Cold weather with heater
- Urban and Highway energy consumption differ by 15-20%.
- Aggressive Driving – 40%
- **Cold weather – 92-100%…!!**
- PHEVs: Does extra energy come from battery or fuel…??
  - EREV
  - Blended



In Summary

- Similar instrumentation and testing concepts are effectively used to test BEVs and PHEVs
- A “shortcut” J1634 procedure was developed using a number of BEVs, and validated with Nissan Leaf
- Rigorous development of PHEV procedures proven to be robust so far
- No guarantee that future BEV and PHEV designs may find procedural weaknesses
- Test procedures useful as inputs for certification testing and R&D testing
  - Challenges remain in properly conveying label information