US-China Advanced Vehicle Testing Collaboration

*A **CAERI** and **Argonne** Collaboration*

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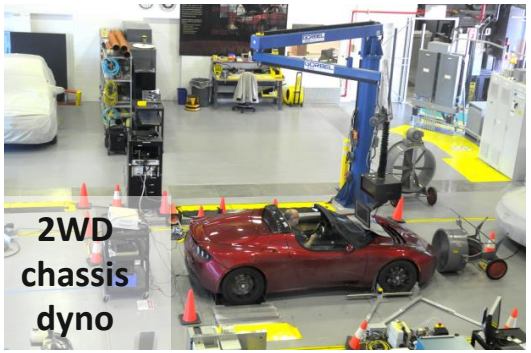
Advanced Powertrain Research Facility - Dedicated Lab for Advanced Vehicle Testing

Benchmarking

Provide to DOE and partners the best advanced vehicle **test data and analysis**

Codes and Standards

Develop **codes and standards** for advanced vehicles with open and independent testing



Test Facilities:

- 2-wheel drive and 4-wheel drive vehicle dynamometers
- State-of-the-art environmental chamber for vehicle tests ranging from 90° F (32° C) to 20° F (-7° C)

Testing Experience:

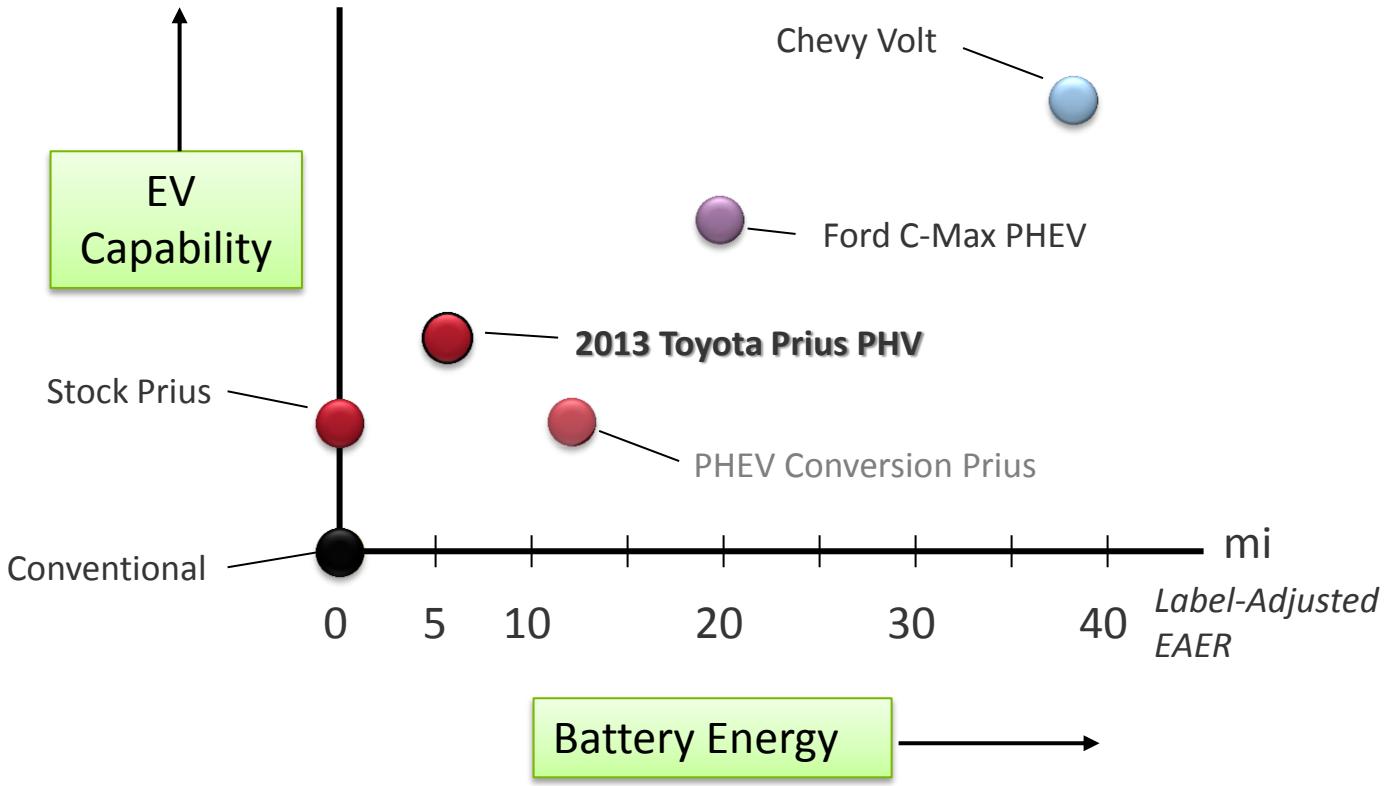
- Research conventional technology to alternative fuels and electric drive
  - Alcohols, biodiesel, hydrogen, CNG, LPG
  - EVs/PHEVs/FCEVs/ HEVs
- Developed HEV and EV test procedures and instrumentation used as the industry-standard

Argonne-CAERI Collaboration Activity 2013-2014

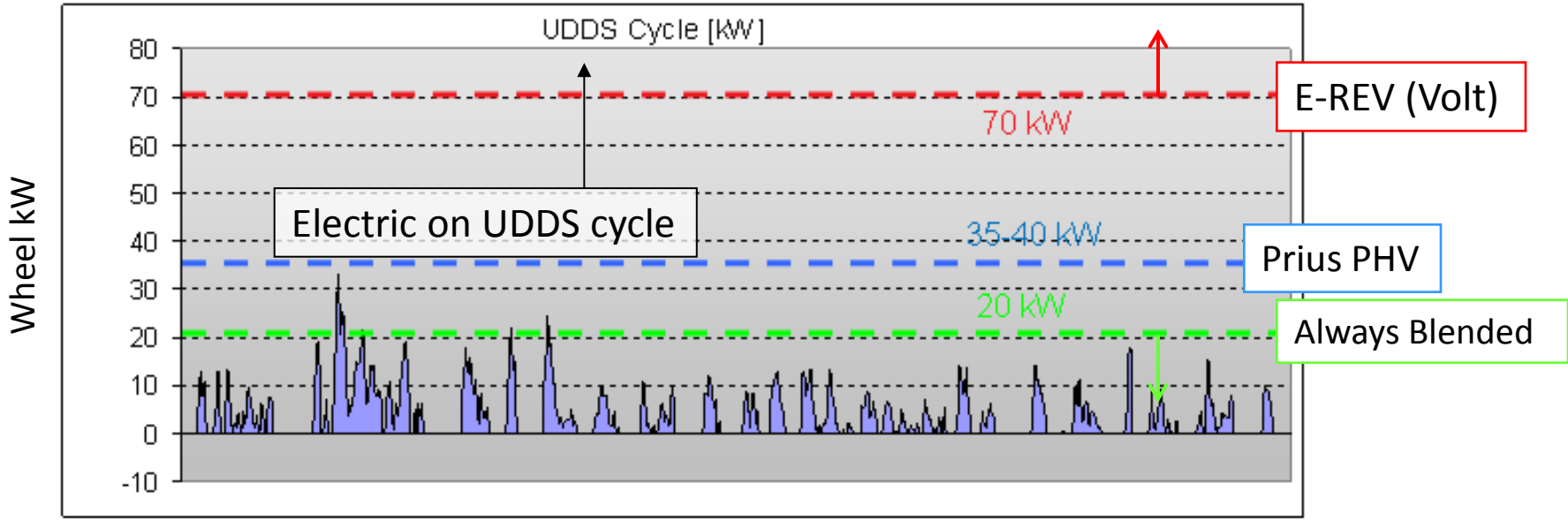
- CAERI vehicle sent to Argonne
  - Test according to typical Argonne **procedures and methods**
  - Co-located **researchers** CAERI-Argonne
  - **Data analysis** by both CAERI and Argonne
- Vehicle sent to CAERI
  - Using similar **tools and sensors**, vehicle tested on dyno in China
  - **On-road testing**

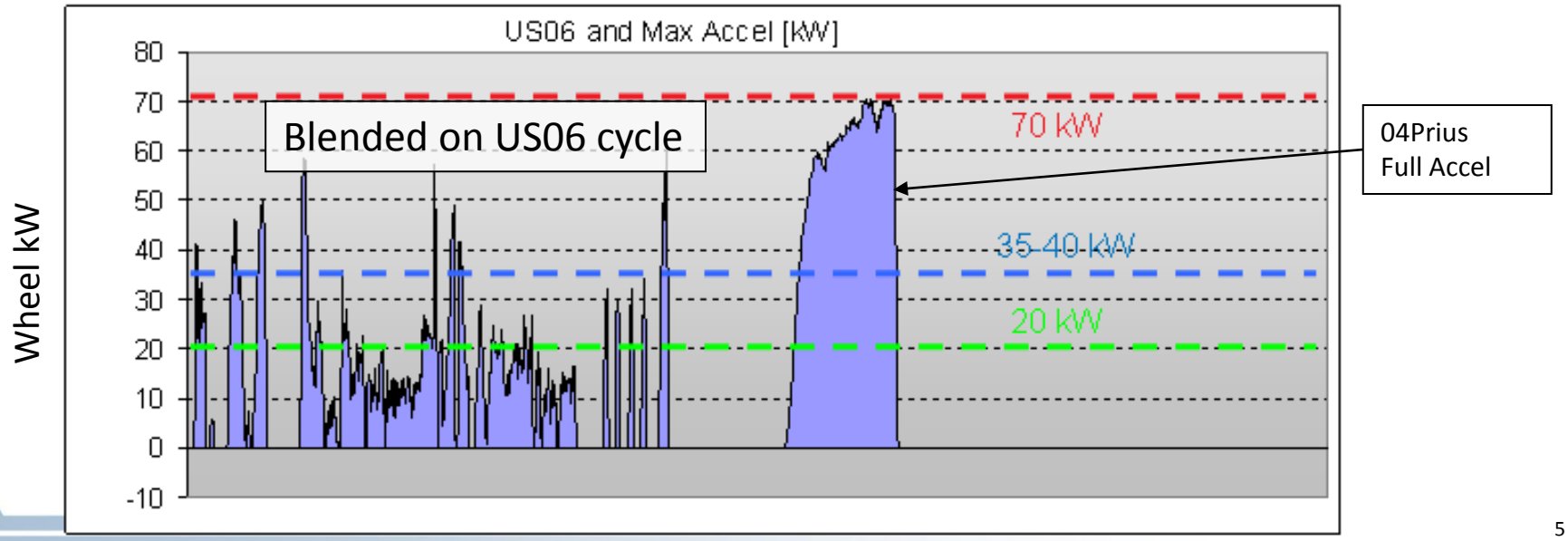
中国汽车工程研究院股份有限公司
China Automotive Engineering Research Institute Co., Ltd

PHEV Designs Vary in Their Capabilities
The Design Space Is Filled with Recent PHEVs



PHEV Designs – Differentiated by Electric Power





Argonne Leveraged 2010 Prius Testing Effort in 2013 PHV Testing Project

- CAN Codes
- Axles Torq
- Scan Tool

- Argonne has been testing the Gen 3 Prius since 2010.
- Several key testing components and knowledge from that effort has leveraged work on the 2013 PHV Prius
  - Axles are identical, 2010 Prius **axle torque sensors** were installed in PHV
  - Nearly all **CAN codes** were identical
  - Expensive scan tool and software with logging capability reused

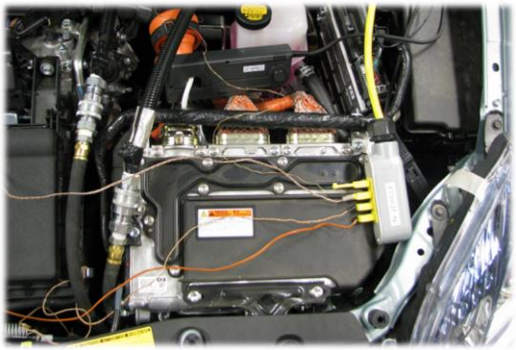
Instrumentation

Analog Sensors

- Direct fuel scale
- Cabin temperature (passenger head rest)
- Vent temperature Center Vent
- Engine oil temperature
- Radiator Air flow temp (behind the fans)
- Engine bay temp (above valve cover)
- Heater core hose out surface
- **Axle torque sensors** from CAERI PHEV Prius

CAN Data

- Pedal_Brake_CAN[%]
- Brake_Regen_Act_CAN[Nm]
- Drive_Torq_CAN[Nm]
- Eng_Torq_CAN[Nm]
- ACComp_Spd_Act_CAN[rpm]
- A/C_On
- Eng_MAP_CAN[kPa]
- Pedal_Accel_CAN[%]
- MG2_Spd_CAN[rpm]
- EcoIndicatorBar
- EcoMode
- PwrMode
- EV_Mode
- Gear
- Batt_Curr_CAN[A]
- Batt_SOC_CAN[%]
- Eng_Spd_CAN[rpm]
- Eng_Temp_Intake_CAN[C]
- Brake_Mech_CAN[Nm]
- Brake_Sw_CAN
- Eng_Temp_Clnt_CAN[C]



CAERI Prius PHV Tested in Multiple Phases

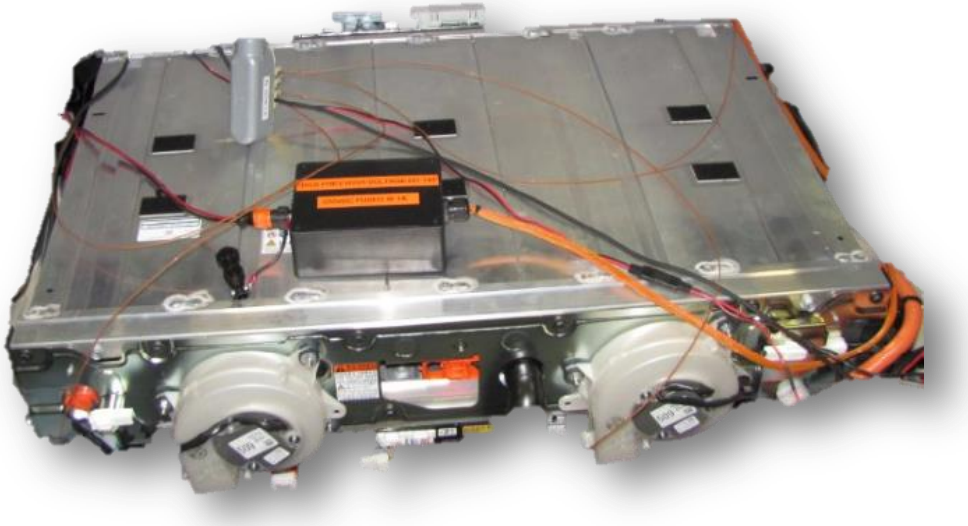
- **Phase 1: Exploratory Testing (only 25 C) – Nov 2012**
  - 2 weeks
  - Check charge-depleting operation, depletion rates, estimating time for testing
- **Phase 2: Focus on Emissions and Hot and Cold Temperatures – Feb/Mar 2013**
  - 3 weeks
  - Fast-response THC and NOX analyzers pre and post catalyst
  - Run CD and CS cycles at -7C, 25C, 35C
- **Phase 3: Focus on Fuel Economy, Depleting Operation, and Controls (only 25C) – March 2013**
  - 1 week
  - Test many non-standard cycles, explore engine on/off and assist

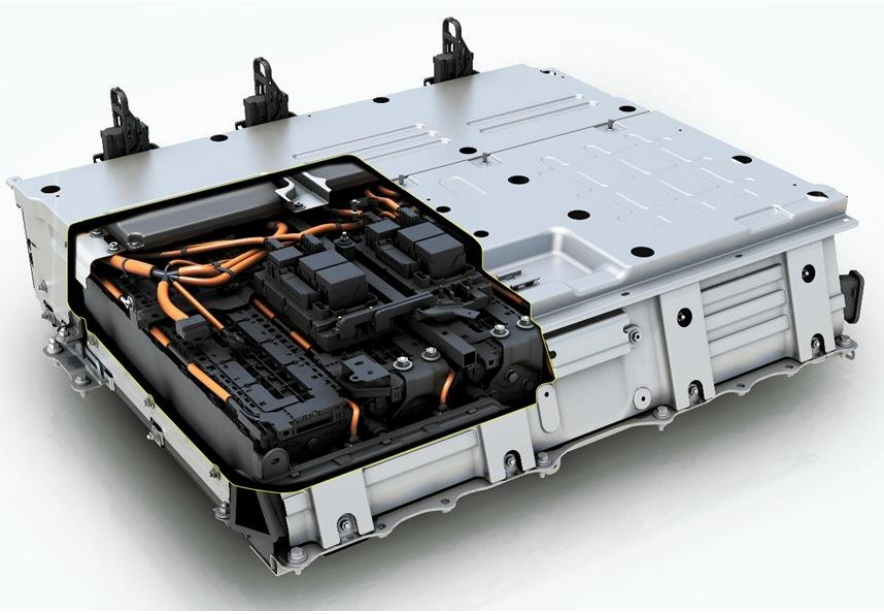
Test Plan: Many Cycles, Varying Conditions

Cycle	72F	20F	95F
UDDS FCT	X	X	X
HWY FCT	X	X	X
US06 FCT	X	X	X
SC03 FCT	X		X
NEDC FCT	X	X	X
NREL RWDC FCT	X		
UDDS CS	X	X	X
HWY CS	X	X	X
US06 CS	X	X	X
NEDC C	X	X	X
Performance (0-80, passing)	X		
Steady-State Speeds	X		
UDDSx1.2 FCT	X		
*many special test for emissions and control strategies	X		

New Technology: Battery

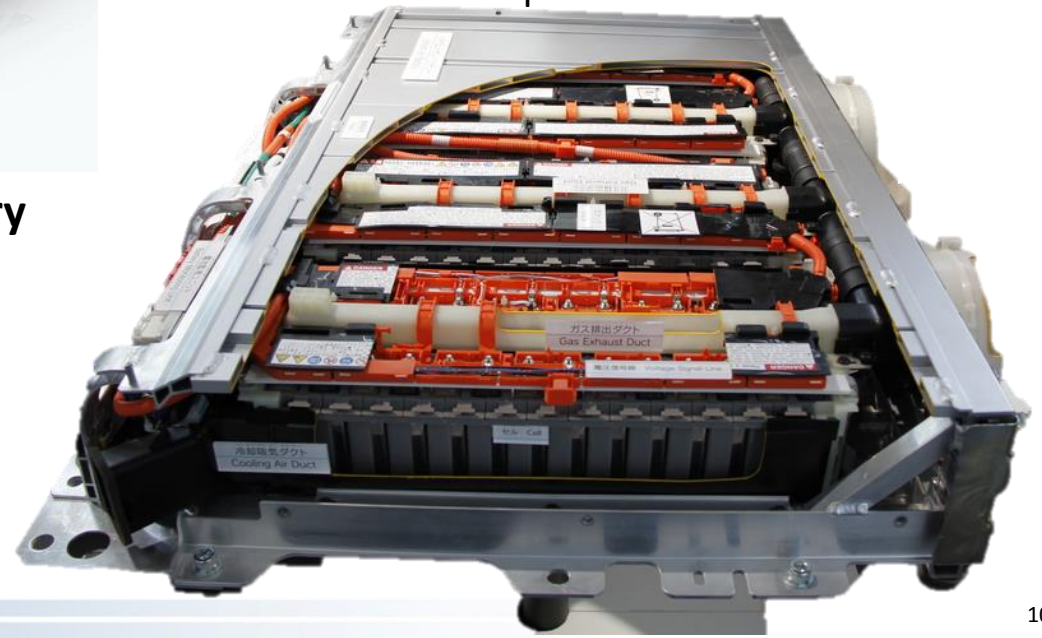
Actual Battery
Note different aluminum cover – hand-welded?



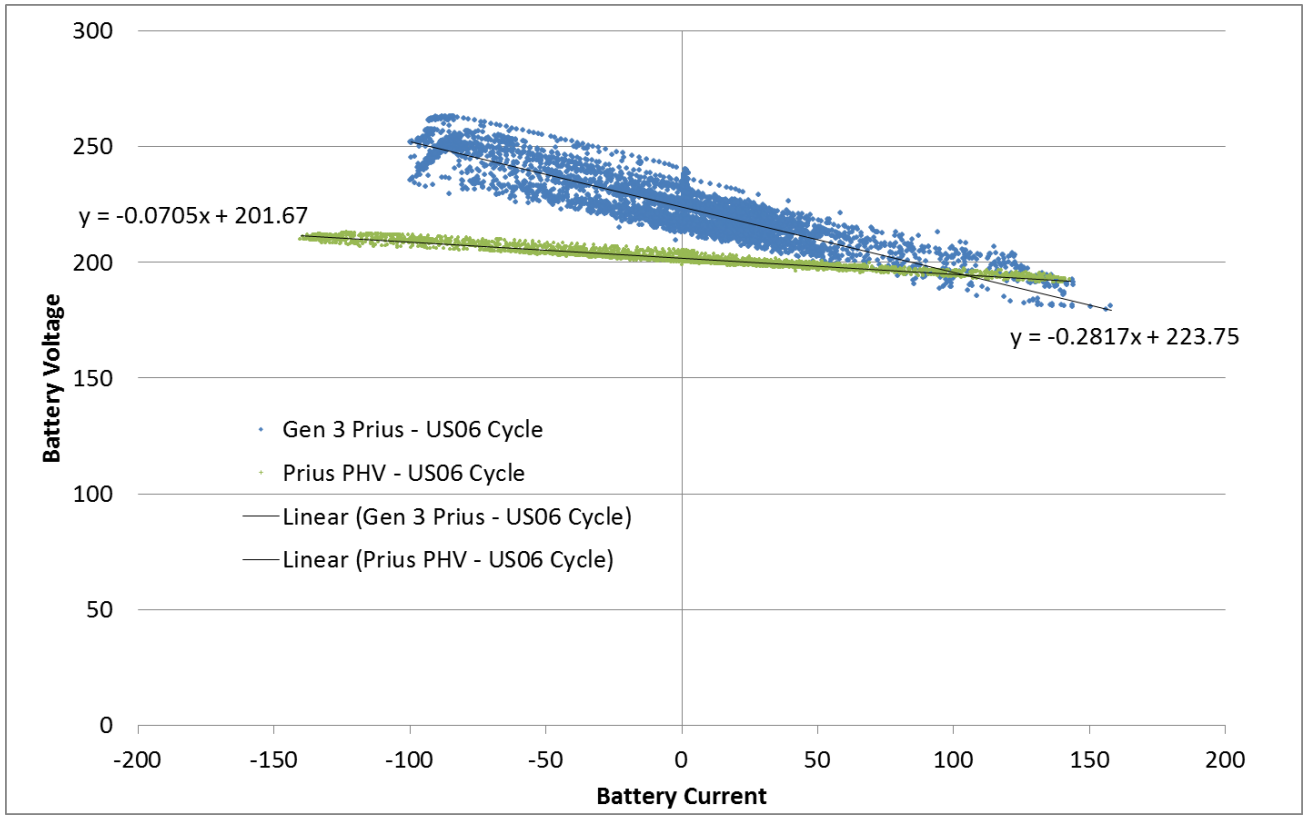


2012 Limited Run Prius Li-Ion Battery

Photo of Mockup from expo
Note thick open channels on cover

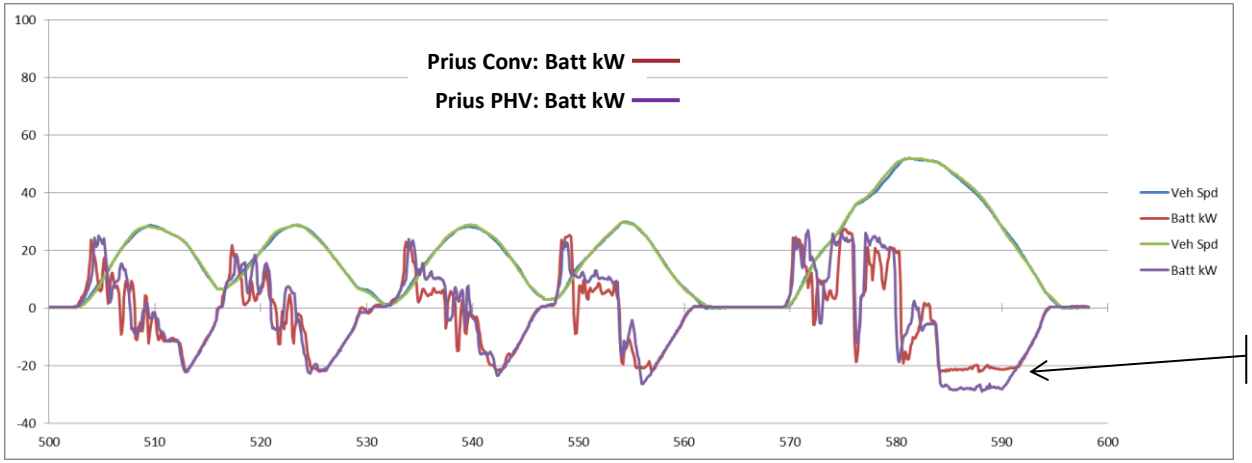


Large Li-Ion Battery Performance



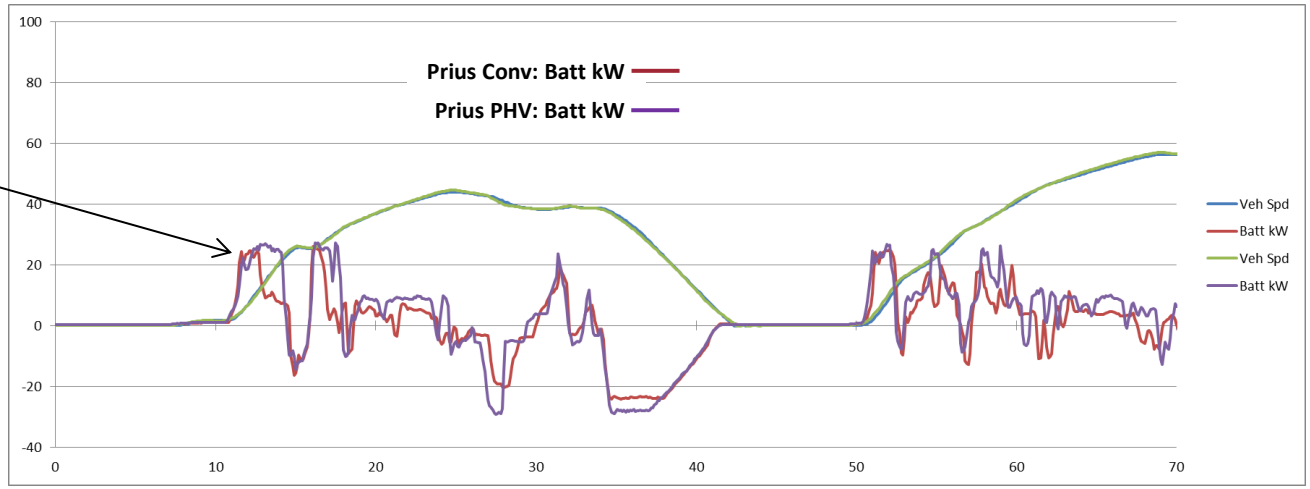
- **Resistance**: Gen3 Prius = **0.282** Ohms, PHV = **0.071** Ohms
- **Losses significant?**
  - HEV Ni pack losses in US06 = 52 W average
  - PHV Li battery losses in US06 = 20 W average

Added Capabilities of Prius PHV
Prius PHV vs HEV Prius



Added regen braking power

- Peak accel power same
- Evidence of added time at high power
- Time>100A,
  - Gen3 = 2.7%
  - PHV = 4.1%



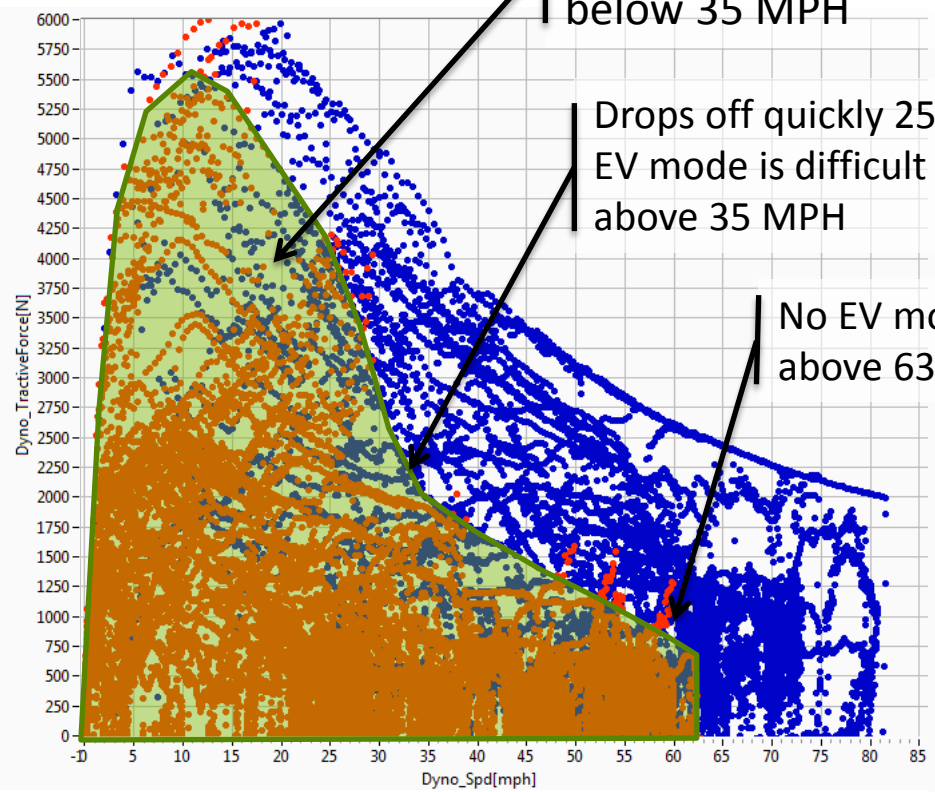
Extra Capability in Charge-Depleting Mode

- = Engine-OFF (electric mode)
- = Engine-ON

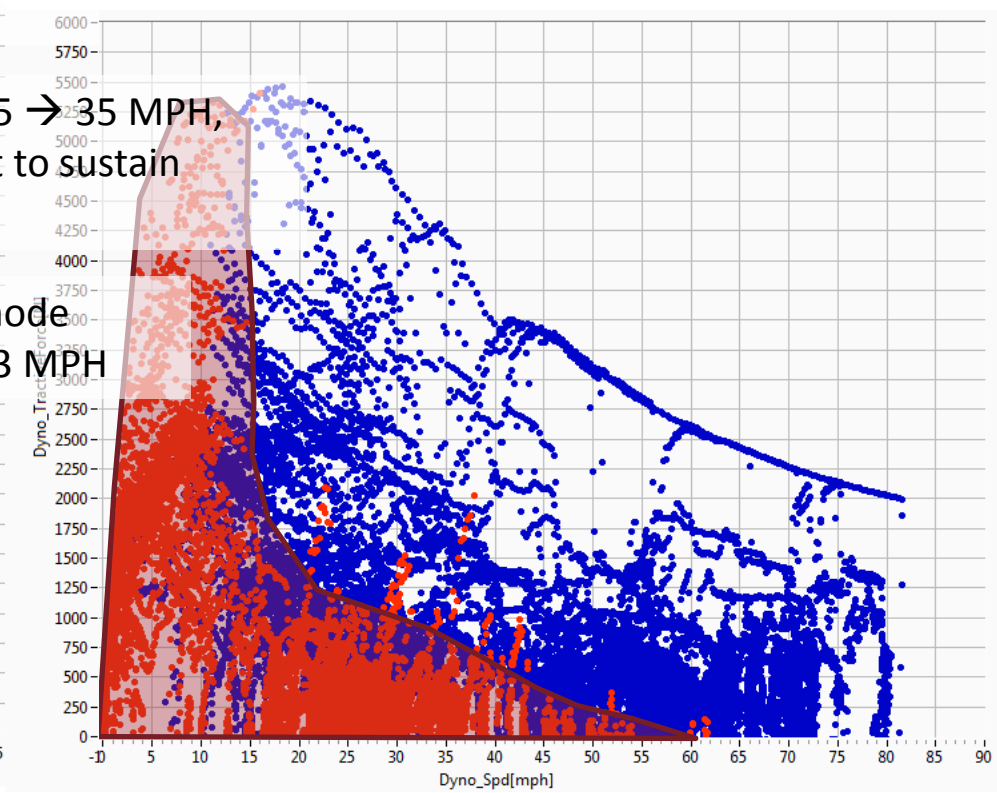
Good EV capability below 35 MPH

Drops off quickly 25 → 35 MPH, EV mode is difficult to sustain above 35 MPH

No EV mode above 63 MPH

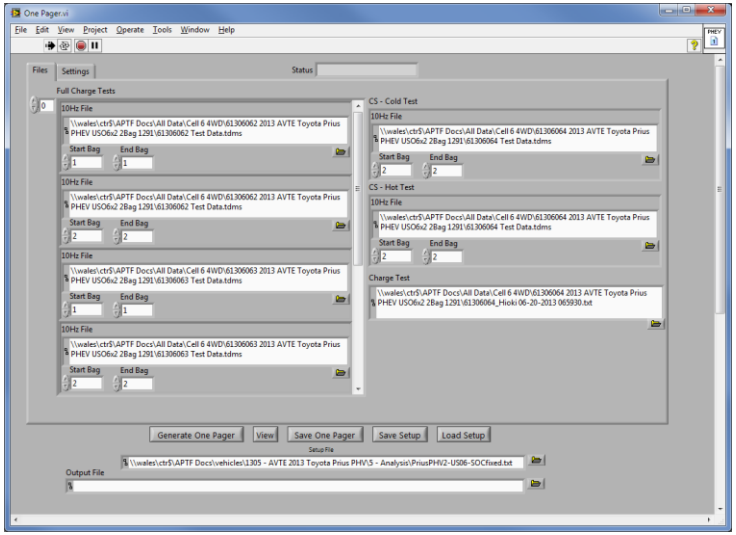


Charge-Depleting



Charge-Sustaining

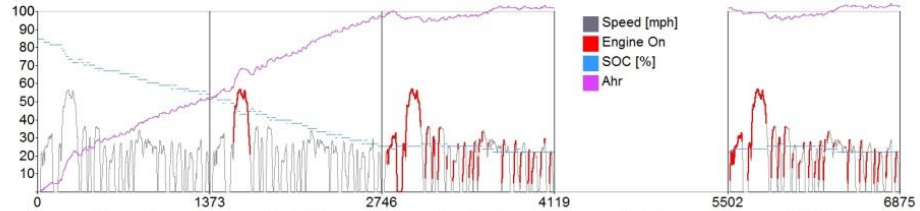
Custom Data Analysis Tool for Complex PHEV Analysis



Labview code accepts native Argonne data files

Argonne NATIONAL LABORATORY

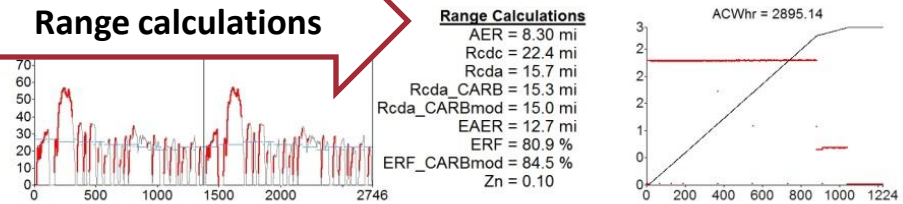
Prius PHV AVTE



	61306055	61306056	61306057	All CD	61306058
SOC (st,del,end)	85, 30, 54	53, 27, 25	25, 3, 22	85, 61, 22	22, 0, 22
delta Ahr (1/mi)	5.93 (0.80)	5.23 (0.70)	0.54 (0.07)	11.7 (0.52)	0.12 (0.02)
DCWhr (1/mi)	1209 (162)	1013 (136)	84.2 (11.3)	2306 (103)	1.27 (0.17)
ACWhr (1/mi)	1490 (200)	1250 (168)	128 (17.2)	2868 (128)	27.4 (3.67)
gal (mpg)	-0.0 (-29426)	0.03 (288)	0.11 (69.4)	0.13 (168)	0.10 (73.1)
L (1/100km)	-0.0 (-0.0)	0.10 (0.82)	0.41 (3.39)	0.50 (1.40)	0.39 (3.22)
FDF	1.00	0.75	-0.0	0.56	-0.0
Ahr x Vnom (%tot)	1270 (51.5%)	1066 (43.2%)	109 (4.42%)	2445	23.4 (0.95%)
NEC (1/mi)	1185 (159)	1045 (140)	109 (14.6)	2338 (104)	23.3 (3.13)
NEC / Fuel	-14677 %	126.5 %	3.174 %	55.11 %	0.717 %
			200.6	N/A	200.1

Range calculations

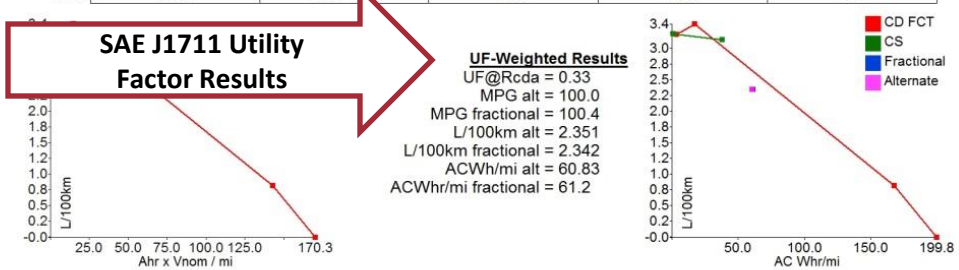
Range Calculations
AER = 8.30 mi
Rcdc = 22.4 mi
Rcda = 15.7 mi
Rcda_CARB = 15.3 mi
Rcda_CARBmod = 15.0 mi
EAER = 12.7 mi
ERF = 80.9 %
ERF_CARBmod = 84.5 %
Zn = 0.10



	61306038 - CS Cold	61306039 - CS Hot	All CS	43/57 CS	Same Trip CS
SOC (st,del,end)	27, 5, 22	22, 0, 22	27, 5, 22	N/A	N/A
delta Ahr (1/mi)	1.20 (0.16)	0.03 (0.00)	1.22 (0.08)	0.53 (0.07)	1.25 (0.06)
DCWhr (1/mi)	214 (28.7)	-19 (-2.6)	194 (13.0)	80.9 (10.9)	175 (7.83)
ACWhr (1/mi)	283 (38.0)	6.25 (0.84)	289 (19.4)	125 (16.8)	295 (13.2)
gal (mpg)	0.10 (75.0)	0.10 (72.7)	0.20 (73.8)	0.10 (73.7)	0.30 (73.5)
L (1/100km)	0.38 (3.13)	0.39 (3.24)	0.76 (3.19)	0.38 (3.19)	1.15 (3.20)
Ahr x Vnom (%tot)	241 (9.8%)	5.32 (0.22%)	246	107	252
NEC (1/mi)	239 (32.1)	5.32 (0.71)	245 (16.4)	106 (14.2)	250 (11.2)
NEC / Fuel	7.567 %	0.163 %	3.802 %	0.033	2.575 %
Vnom	201.1	199.7 V	N/A	N/A	N/A

SAE J1711 Utility Factor Results

UF-Weighted Results
UF@Rcda = 0.33
MPG alt = 100.0
MPG fractional = 100.4
L/100km alt = 2.351
L/100km fractional = 2.342
ACWh/mi alt = 60.83
ACWhr/mi fractional = 61.2



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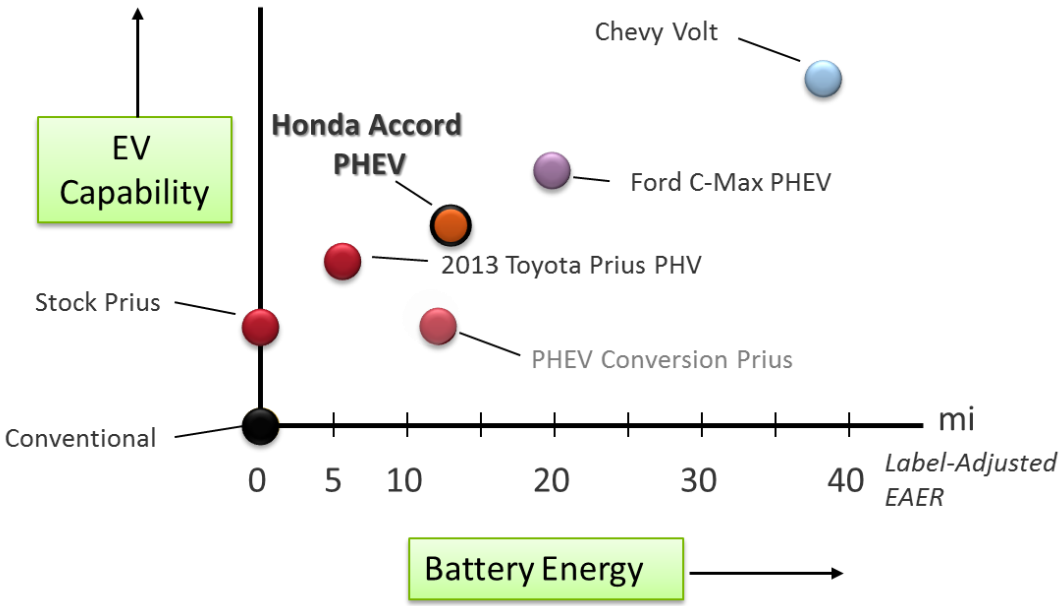
Next Project: Honda Accord PHEV



- **Benchmarking**
  - Efficiency and Emissions
  - Raw emissions measurements
- **Test Procedure Methods**
  - Many ways to test blended PHEVs
  - Efficiency and Emissions results depend upon methods