INL ADVANCED VEHICLE TESTING RESULTS FROM A RANGE OF USAGE SCENARIOS

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Outline

Introduction

- Advanced Vehicle Testing Activity

PHEV On-Road Operation

- Chevrolet Volt, Ford C-Max Energi, and Toyota Prius Plug-in
- Gasoline and Electricity usage by trip type
- Range of battery energy throughput, cycling by mode
- Battery capacity and power capability testing

BEV Fast Charging

- Effects at low, moderate, and hot temperatures

Advanced Vehicle Testing Activity Introduction

Advanced Vehicle Testing Activity (AVTA) – Managed by Idaho National Laboratory for DOE Vehicle Technologies Office

http://avt.inl.gov

- Intertek Testing Services North America
- Accelerated testing on-road
- System and component Testing
- Dynamometer testing – Argonne National Laboratory
- Vehicle technologies with petroleum reduction potential
- Focus on Plug-In Electric Technologies
  - PHEV, EREV
  - BEV
  - Charging Infrastructure

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Intertek

Argonne NATIONAL LABORATORY

Three AVTA PHEV Models

Three plug-in models using gasoline and electricity

- **Distinct designs – examine and objectively compare operation**
- **Varying degrees of 'electrification'**

	2013 Toyota Prius Plug-in	2013 Ford C-Max Energi	2013 Chevrolet Volt
Rated Battery Capacity (kWh)[1]	4.4	7.6	16.5
EV Capable Cycles at 72°F[1]	UDDS, HWFET	UDDS, HWFET	UDDS,HWFET,US06
FC 0-60MPH Peak Battery Power (kW)[1]	29	50	112
AC L2 Full Charge Avg. AC Power (kW) [1]	2.0	3.1	3.1
ACL2 Full Charge Duration (HH:MM) [1]	1:28	2:17	4:00

On-road, in-fleet testing with data collection

- **User behavior varies, not controlled**

Examine fuel and energy usage, battery cycling



- **Range of results, bounded by design attributes *and* operation**
- **Variation within range due to operation (charging frequency, route type, ambient conditions…)**

1. Source AVTA baseline testing fact sheets:
   http://avt.inl.gov/pdf/phev/fact2013toyotapriusphev.pdf, http://avt.inl.gov/pdf/phev/fact2013fordc-maxenergi.pdf , http://avt.inl.gov/pdf/EREV/fact2013chevroletvolt.pdf

One Year of Data – Results for 2014

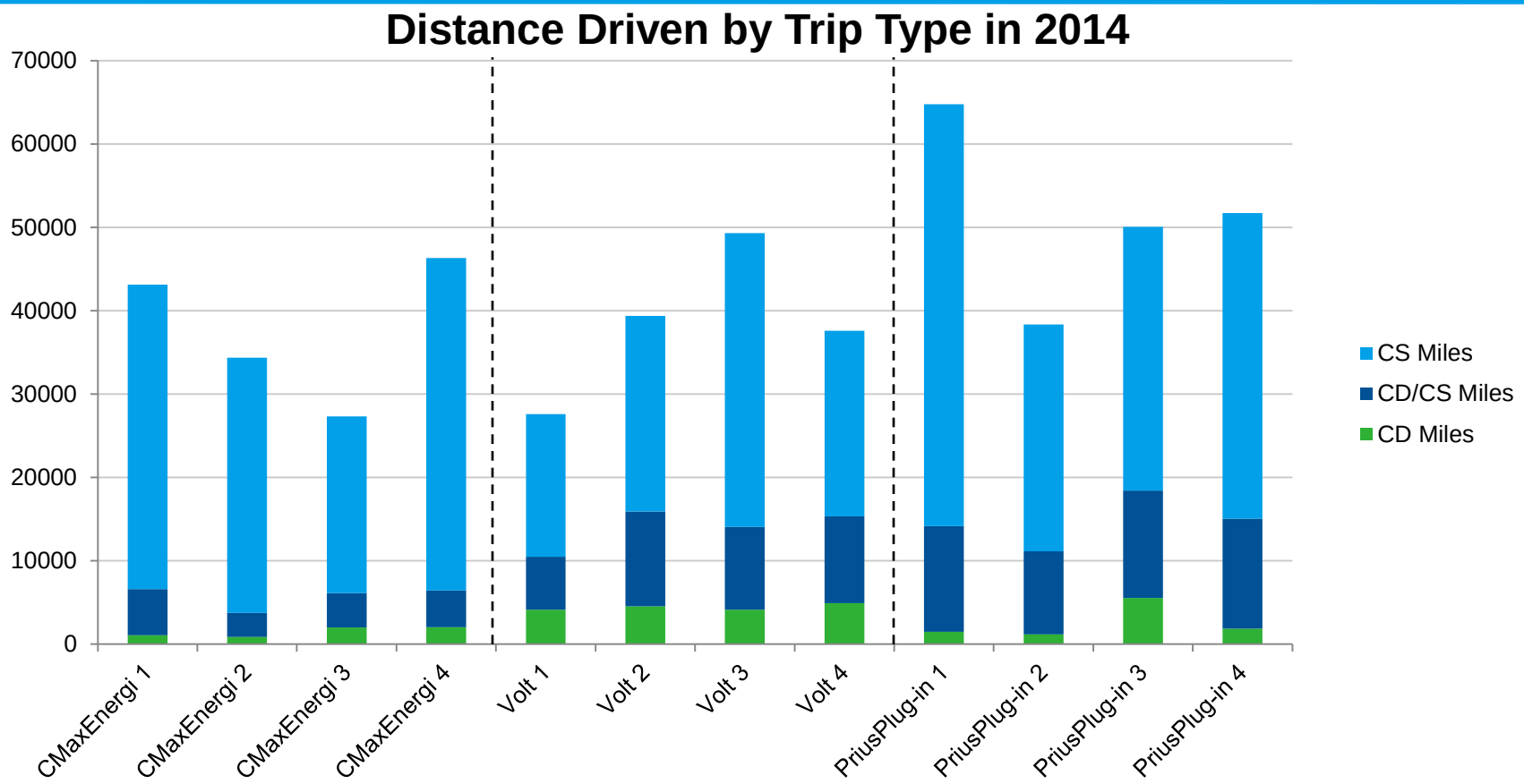
Vehicles used as legal document courier fleet in Phoenix, Arizona area

- **Data collected from four of each model**
- **Charged overnight, start each day with a full charge (minimal daytime charging)**
- **Driven higher miles per year than private owner average**

- **Results in high miles between charges**
  - Break out mileage from trips categorized in different modes:
    - CD
    - CD/CS Mixed
    - CS

- **Large amount of data for both CS and CD trips**
- **Look at operation in both modes**
  - CAN signals collected – Battery V&I, MAF, Eq. Ratio, Ground Speed
  - Electricity and Fuel Consumption
  - Battery energy throughput and cycling

Miles by Trip Mode



Variation in CD miles driven among cars of same model

- Charging frequency
- Route Type – longer routes push more miles into CD/CS
- Blended models more variation in electrical energy intensity, addition of gasoline energy variable
- Examine CD trip metrics among vehicles

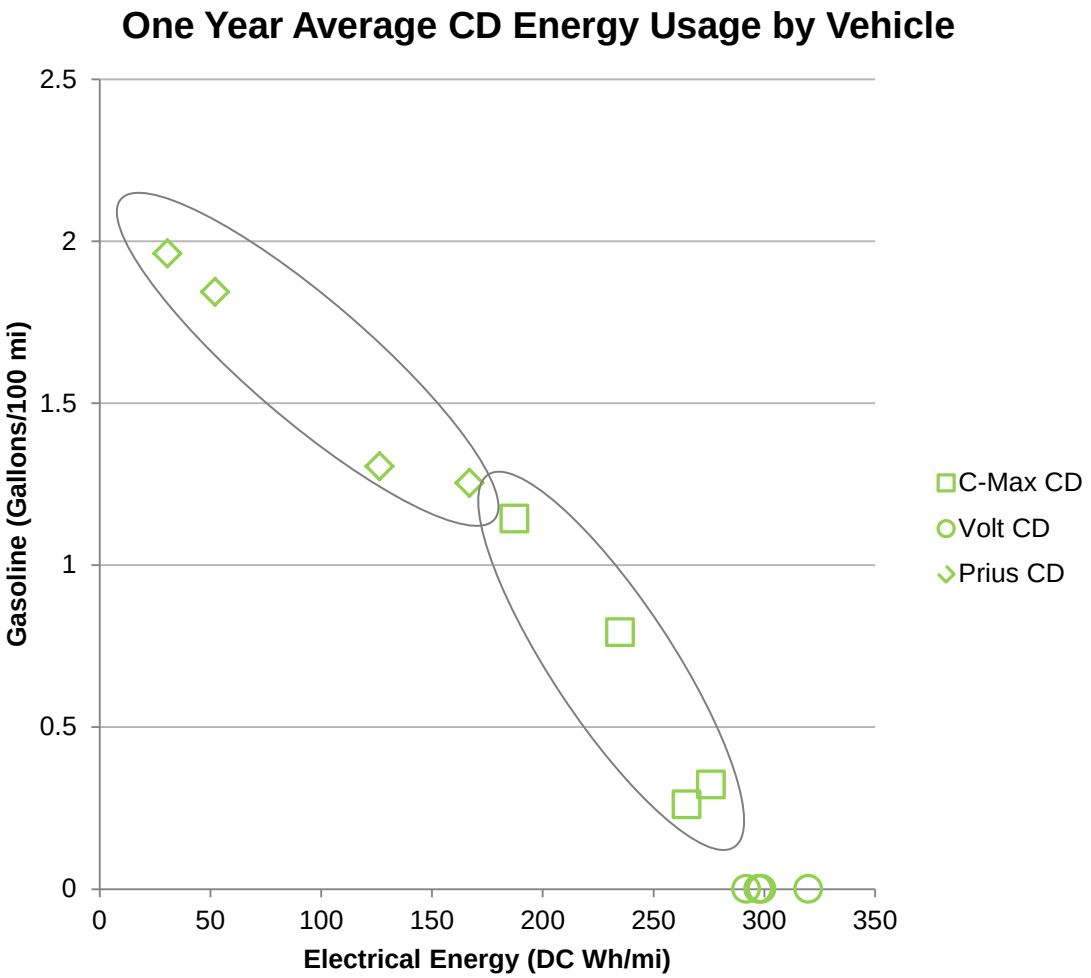
CD Trips

Increased variation in gasoline, electricity blending proportion observed

- **Blended architecture**
- **Smaller ESS, electric powertrain**
- **Drivetrain kinematics**

Differences in ESS and electric powertrain demand

- **Route type – speed, acceleration**
- **Driver habits – climate control, aggressiveness**

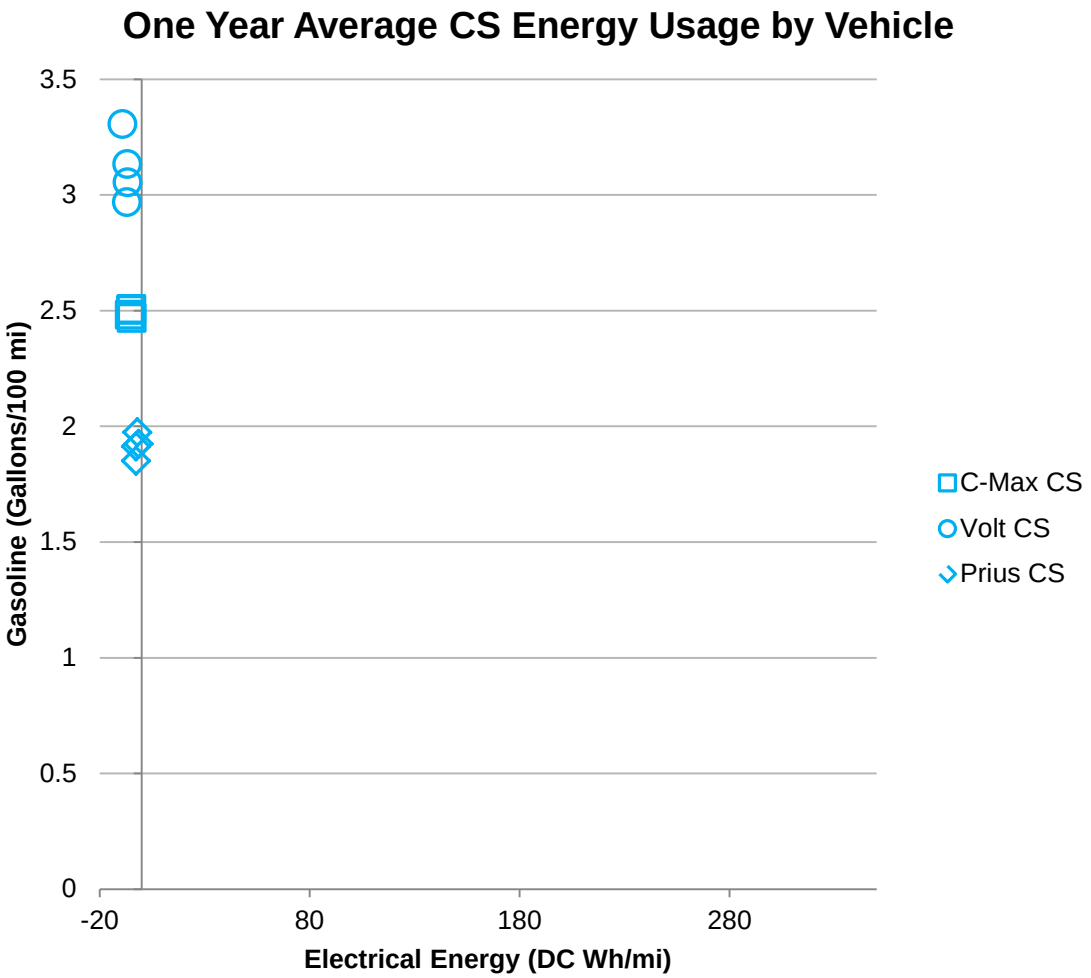


CS Trips

Observed reverse in CD Trend

•FC increases with increased ESS, electric powertrain size

Where do CD/CS mixed trip results fit?



All Trip Types

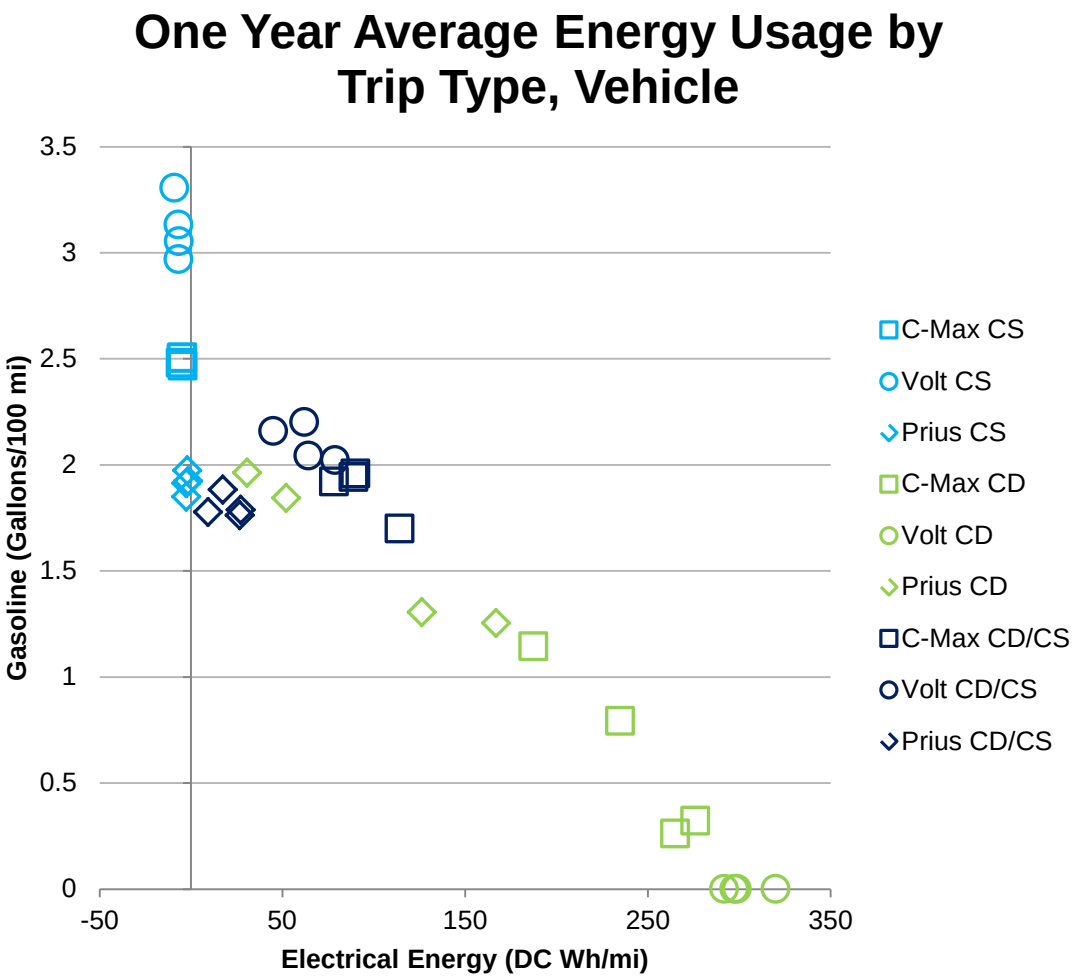
Overall electricity and gasoline consumption depend greatly on the mode

Increasingly true with amount of electrification

Miles driven between charges will impact fuel usage of all electric capable PHEV the most

Route type shows the most variation for blended, mildly electrified PHEV

How is the battery used in the different modes?



Battery Energy Discharged

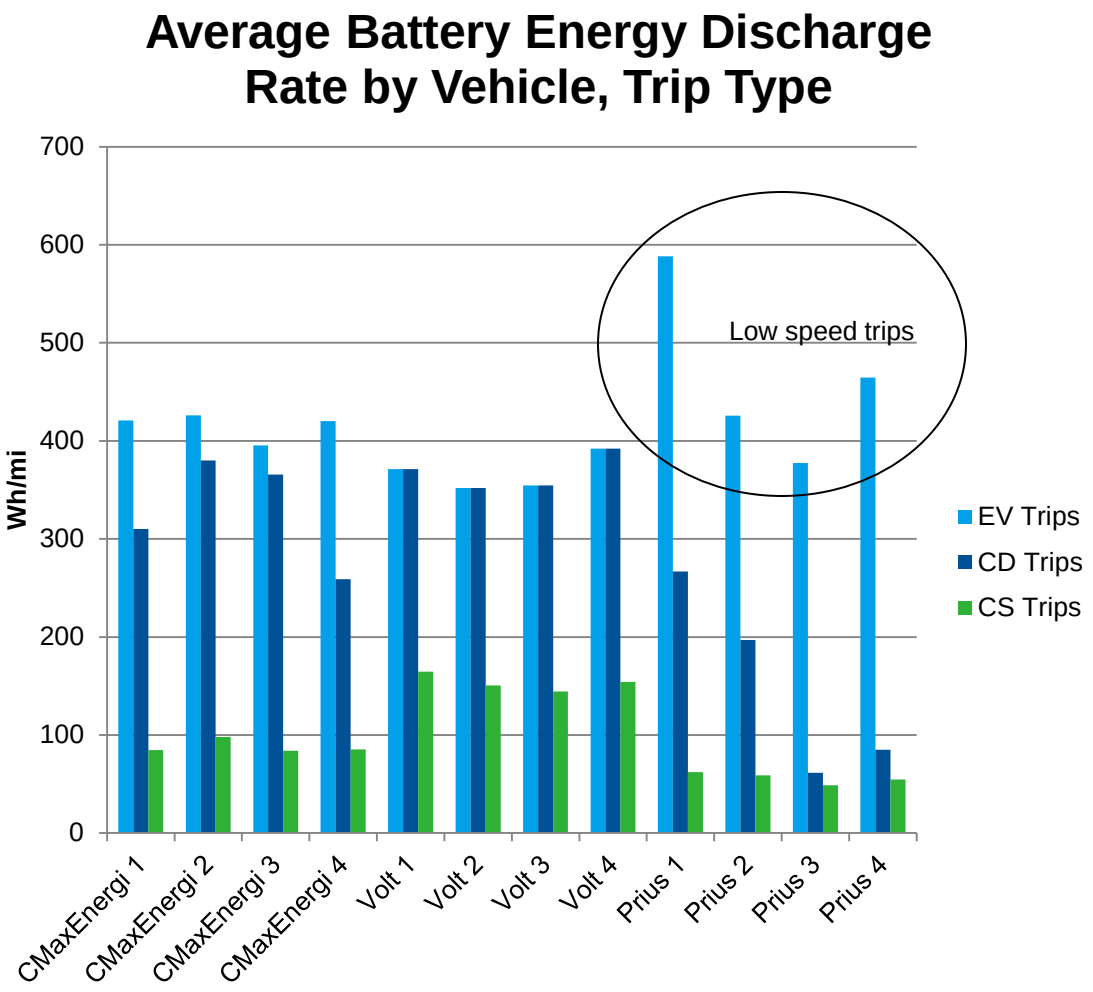
All energy discharged (not net)

Prius EV trips show large discharged energy

- **Very low speed – accessory loads highly influence**

Amount of energy discharged from the battery in CS mode varies by model

- **Related to pack size**



Battery Cycling – CD and CS Modes

Charge Depleting Mode

•Deeper cycling

•All electric mode, higher rate discharge may be needed more often to meet road load

Charge Sustaining Mode

•Shallow cycling around 20% SOC

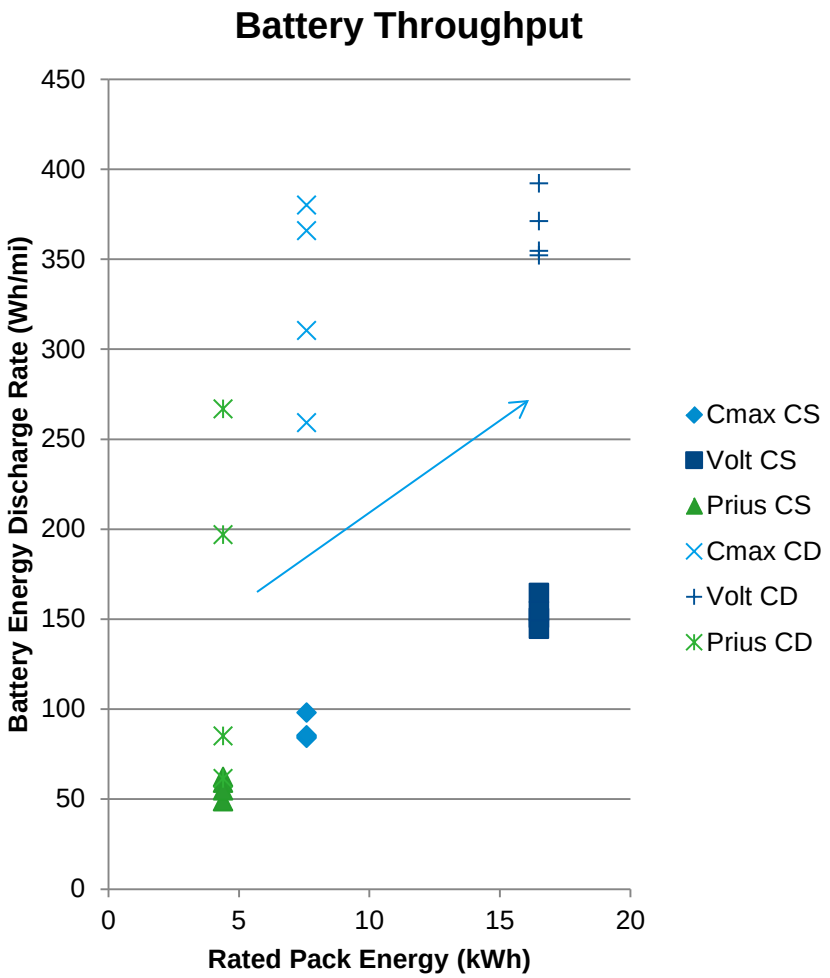
•Variations in ICE response to load

- •Battery may be needed to maintain full performance transient operation

Largest variation in CD throughput is observed for blended powertrain

Battery cycling, aging depends on more than miles driven

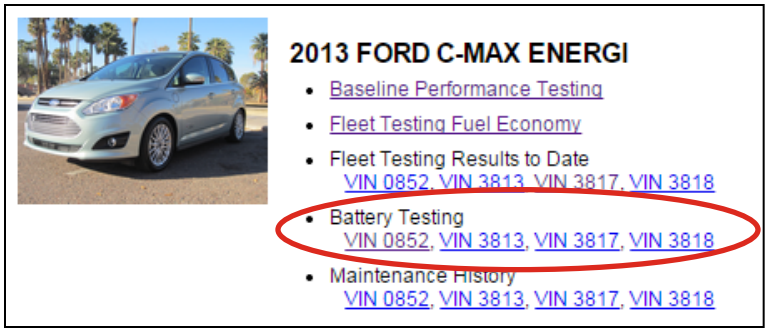
	Observed range of distance to throughput 1C rated battery energy by model (miles)		
	C-Max Energi	Volt	Prius Plug-in
CD	20-29	42-47	16-72
CS	78-91	100-114	70-90

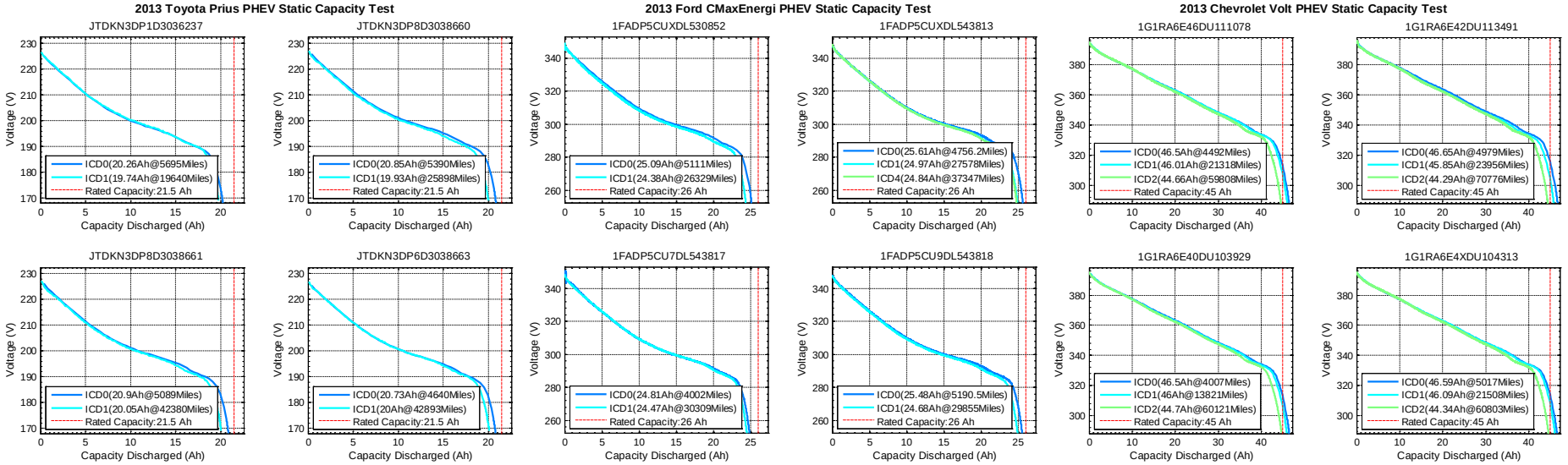


PHEV Battery Testing

Constant Current Capacity Test for PHEV

- **Discharge test current held constant from Vmax to Vmin to approximate 10 kW**
  - Prius Plug-In: 46.95 A
  - Chevrolet Volt: 29.14 A
  - Ford C-Max Energi: 33.07 A
- **Non eye-chart version available in reports posted on http://avt.inl.gov for each vehicle tested**





PHEV Battery Testing

HPPC Test for PHEV

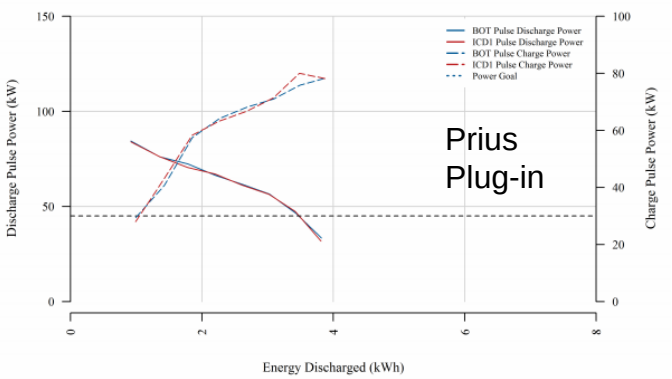
•Discharge and Charge pulses performed at 10% DOD intervals from 10% to 90%

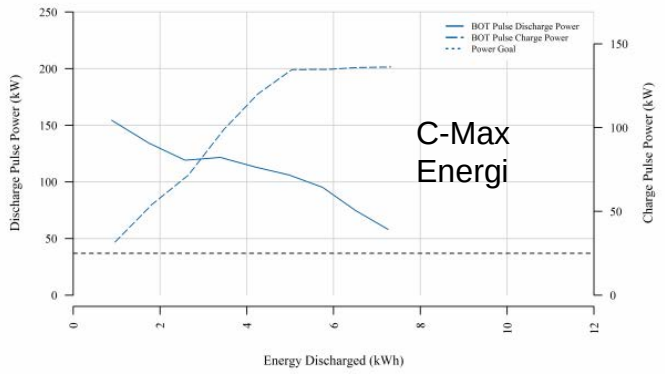
•Calculate charge & discharge IR, power capability over discharge range

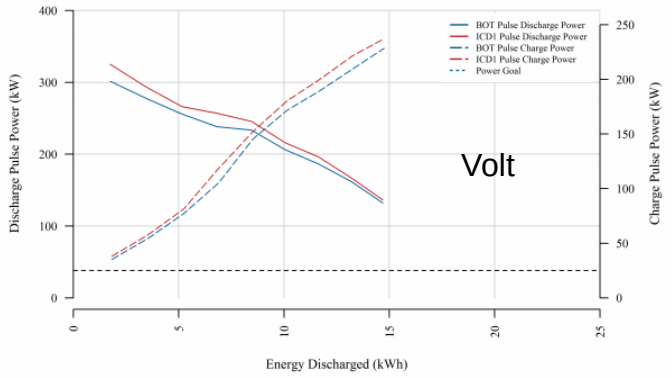
•Battery testing reports posted on http://avt.inl.gov for each vehicle tested

•Track and on-road testing peak discharge

- •C-max – 50 kW
- •Prius – 29 kW WOT Acceleration to 100 MPH
- •Volt – 112 kW
- •All values below discharge capability calculated from test data – interesting as packs age







DC Fast Charging of BEVs under 3 Climate Conditions

BEVs

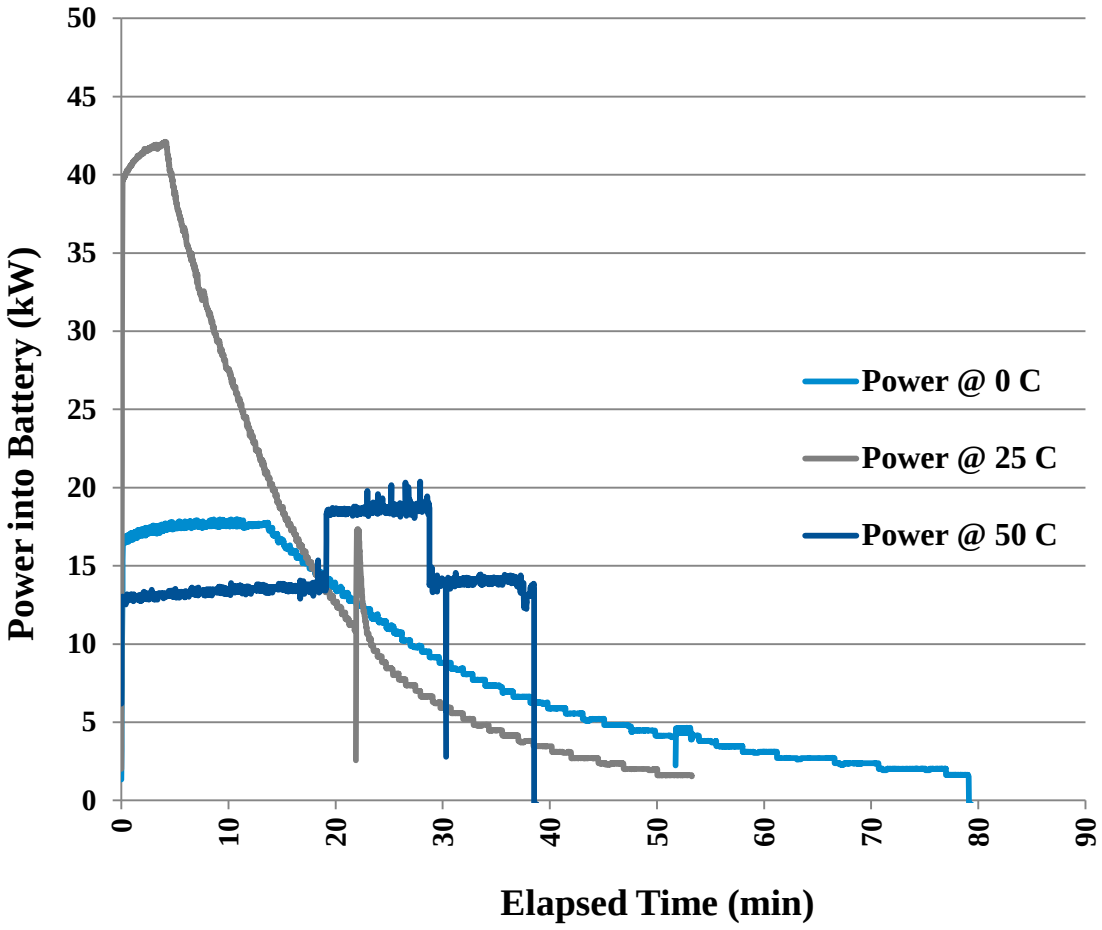
- **50 kW Fast Charger limited to 500V, 120 A DC Output**
- **Vehicle batteries depleted, then soaked at test temp 20+ hours**
- **Two models with DCFC capability tested**
  - 2012 Mitsubishi iMiev, 16 kWh battery pack, rated, conditioned air cooled
  - 2013 Nissan Leaf, 24 kWh battery pack, passive cooling
- **Three test conditions**
  - 0ºC
  - 25ºC
  - 50ºC,
- **For a charge event**
  - DCFC re-started after end of first charge segment
  - Measure power, energy into battery
  - Battery temperature
  - Ancillary loads

2012 Mitsubishi iMiev Fast Charging Tests

Battery power acceptance limited relative to 25ºC for cold and hot test conditions

Curtailed currents early in charge do not approach V_{max}

Sizable differences in charging power affect time to charge



2012 Mitsubishi iMiev Fast Charging Tests

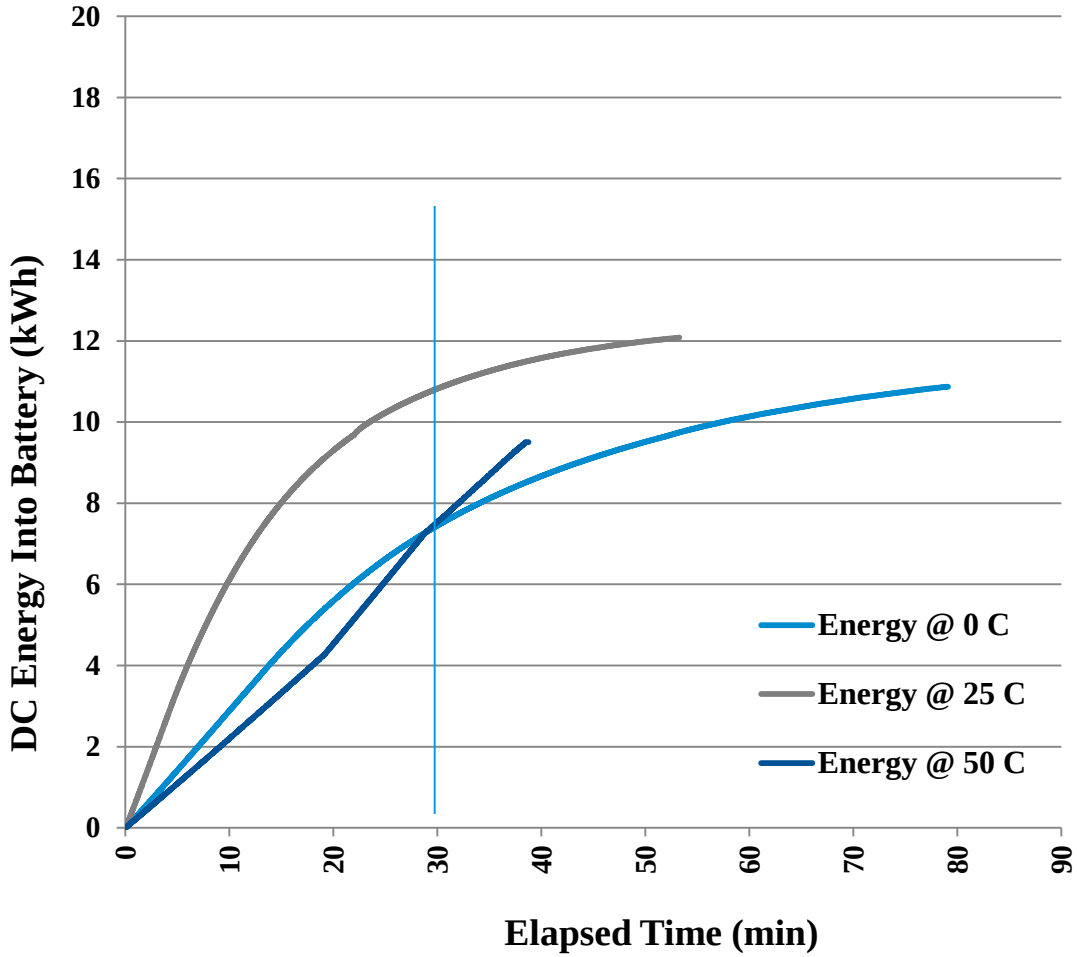
Cold test transferred less energy than mild test case, took longer

Hot test – less energy, stopped sooner

30 Minutes:

<75% of energy into pack for hot and cold tests

Pack temperature regulation for each case…

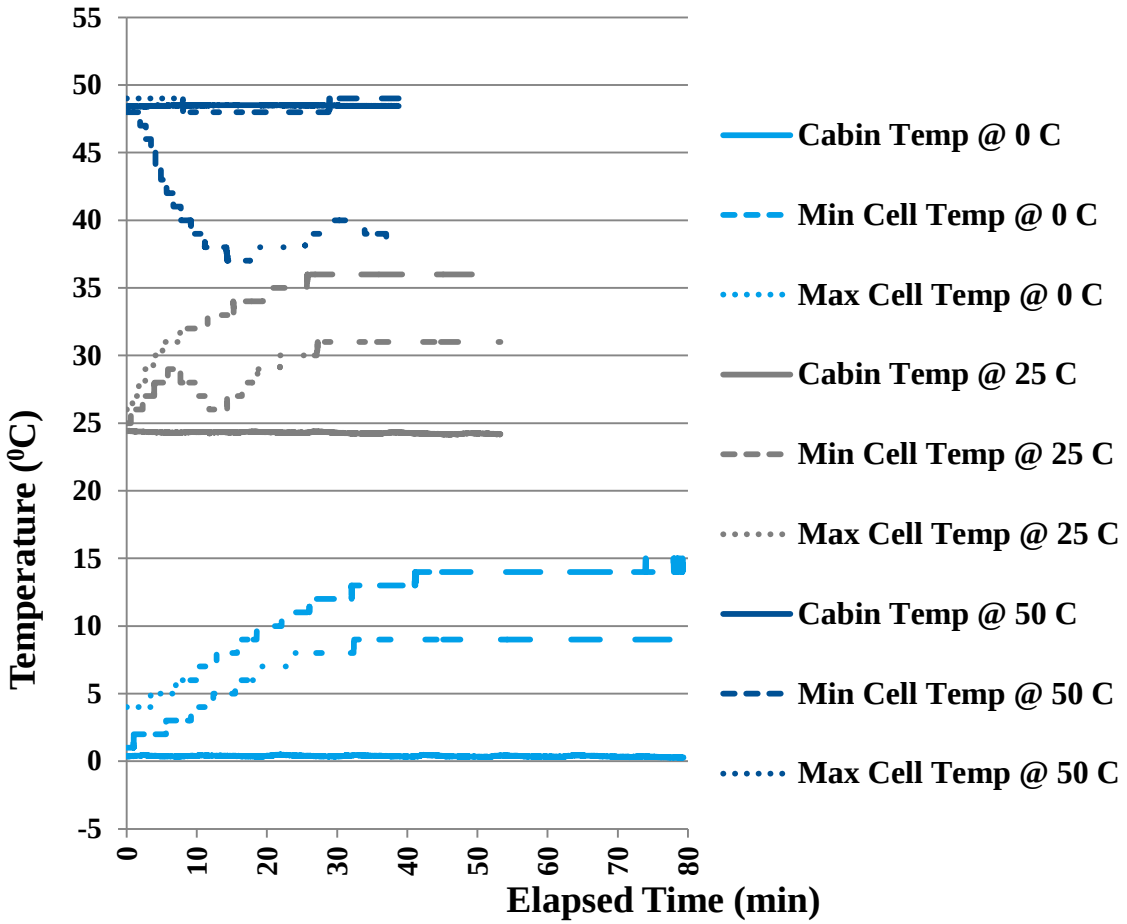


2012 Mitsubishi iMiev Fast Charging Tests

Cooling observed for 25ºC and 50ºC tests, difference between highest and lowest temp cells

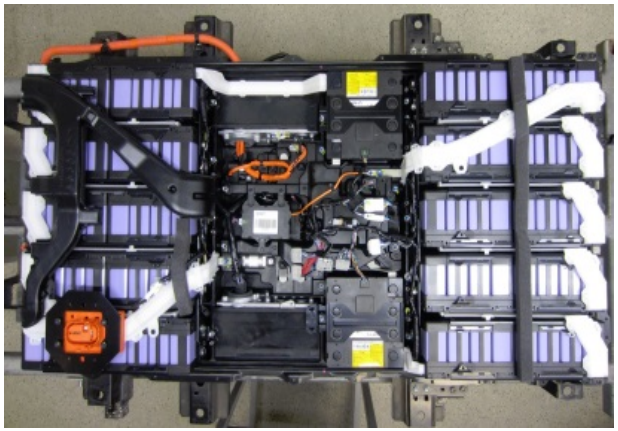
Pack temperature rise for 0ºC test considerable

Energy used to cool pack when needed



2012 Mitsubishi iMiev Fast Charging Tests

TEST RESULTS SUMMARY								
Test Temp. (°C)	Total Charge Duration (hh:mm:ss)	Mileage Range (mi)	Total DC Charge Energy (kWh)	Initial Charge Start/End SOC[3] (%)	Top-Off Charge Start/End SOC[3] (%)	Initial/Top-Off Charge Avg. Power (kW)	ESS ΔT (Min/Max Cell)[4] (°C)	ESS Thermal Regulation Energy[5] (kWh)
VIN 3178 - Beginning-of-Test (at 7,865 miles)								
0 °C	01:19:06	60	10.9	15.0 / 80.0	80.0 / 88.5	11.2 / 2.2	8 / 11	Not Activated
25 °C	00:53:16	66	12.1	15.5 / 79.5	79.5 / 96.5	26.5 / 2.6	6 / 10	0.73
50 °C	00:38:31	73	9.5	15.0 / 67.5	67.5 / 80.5	15.1 / 13.9	-10 / 0	1.95



Summary

PHEV customer usage variation – charging, driving – for a given architecture

- As much or more impact on petroleum reduction than the differences between models
- System usage varies as well – engine, battery

Different designs have trade offs

- No technology can be ideal for every usage scenario
- User must choose technology/design based on their needs
  - Important to understand how it will work in their application

BEV Fast Charging

- Time to fill battery will vary with temperature – can be considerable
  - Limitations on pack current acceptance
  - Power split between charging, conditioning system draw

Acknowledgement

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EERE Vehicle Technologies Office**

More Information

http://avt.inl.gov