PLUG-IN 2010

U.S. Department of Energy's Advanced Vehicle Testing Activity Vehicle Testing and Demonstrations

John Smart

Idaho National Laboratory

Presentation Outline

- Advanced Vehicle Testing Activity (AVTA) background, vehicle technologies, and testing methods
- PHEV demonstrations and testing
  - Background and methodology
  - Vehicle energy consumption and sensitivities
  - Vehicle charging demand and location
  - Controlled charging study findings
- Future outlook

AVTA Description

Advanced Vehicle Testing Activity (AVTA) is part of DOE's Vehicle Technologies Program. Conducted by:

- **Idaho National Laboratory (INL)**
  - Program execution in support of DOE goals
  - Conducts engineering, data analysis, and reporting
- **Ecotality North America (formerly eTec)**
  - Private company based in Phoenix, AZ with access to numerous testing facilities / tracks
  - Conducts vehicle test operations and engineering
- ANL and ORNL provide AVTA dynamometer testing support and vehicle data acquisition support (ANL)

AVTA Description – cont'd

- AVTA tests light-duty whole vehicle systems and fueling infrastructures that employ:
  - Electric drive systems
  - Advanced energy storage systems
  - Advanced control systems (i.e., start/stop HEVs)
  - Some ICE 100% Hydrogen and HCNG blended fuels
- Provide benchmark vehicle data to R&D programs, modelers, OEMs, battery manufacturers, and target/goal setters (DOE)
- Assist early adopter fleet managers and the general public in making informed vehicle purchase, deployment and operating decisions. Presentations to industry groups, including via DOE's Clean Cities Coalitions
- DOE's only light-duty vehicle testing activity of new technologies deployed in whole-vehicle systems operated in real-world fleet environments

AVTA Testing by Technology

- **Plug-in hybrid electric vehicles (PHEV)**
  - **12 models, 259 vehicles, 1.5 million test miles**
- **Hybrid electric vehicles (HEV)**
  - **18 models, 47 vehicles, 5 million test miles**
- **Full-size battery electric vehicles (BEVs)**
  - **40 EV models, 5+ million test miles**
- **Neighborhood & Urban electric vehicles**
  - **26 models, 1.2 million test miles**
- **Hydrogen internal combustion engine vehicles**
  - **7 models, 500,000 test miles**

14 million test miles have been accumulated on 1,600 electric drive vehicles representing 97 different electric drive models

AVTA Vehicle Testing Approach

- Depending on vehicle technology and capabilities, vehicles are tested via:
  - Closed test tracks
  - Dynamometer testing
  - Laboratory testing (batteries)
  - Accelerated on-road testing
  - Fleet deployment and evaluation
- Graded approach (from the lab to the field) used to balance testing control, realism, sample size, and costs
- Publish testing results to simply and accurately
  - Document real-world petroleum reduction potentials
  - Document fuel and infrastructure use
  - Document life-cycle risks and costs

PHEV Testing

12 PHEV models tested to date

- Hymotion Prius (A123 Systems)
- Hymotion Escape (A123 Systems)
- EnergyCS Prius, 2 models (Valence and Altairnano)
- Electrovaya Escape (Electrovaya)
- Hybrids Plus Escape, 2 models (Hybrids Plus and K2 Energy Solutions)
- Hybrids Plus Prius (Hybrids Plus)
- Manzanita Prius, 2 models (lead acid and Thunder Sky)
- Renault Kangoo (Saft NiCad)
- Ford E85 Escape (Johnson Controls/Saft)

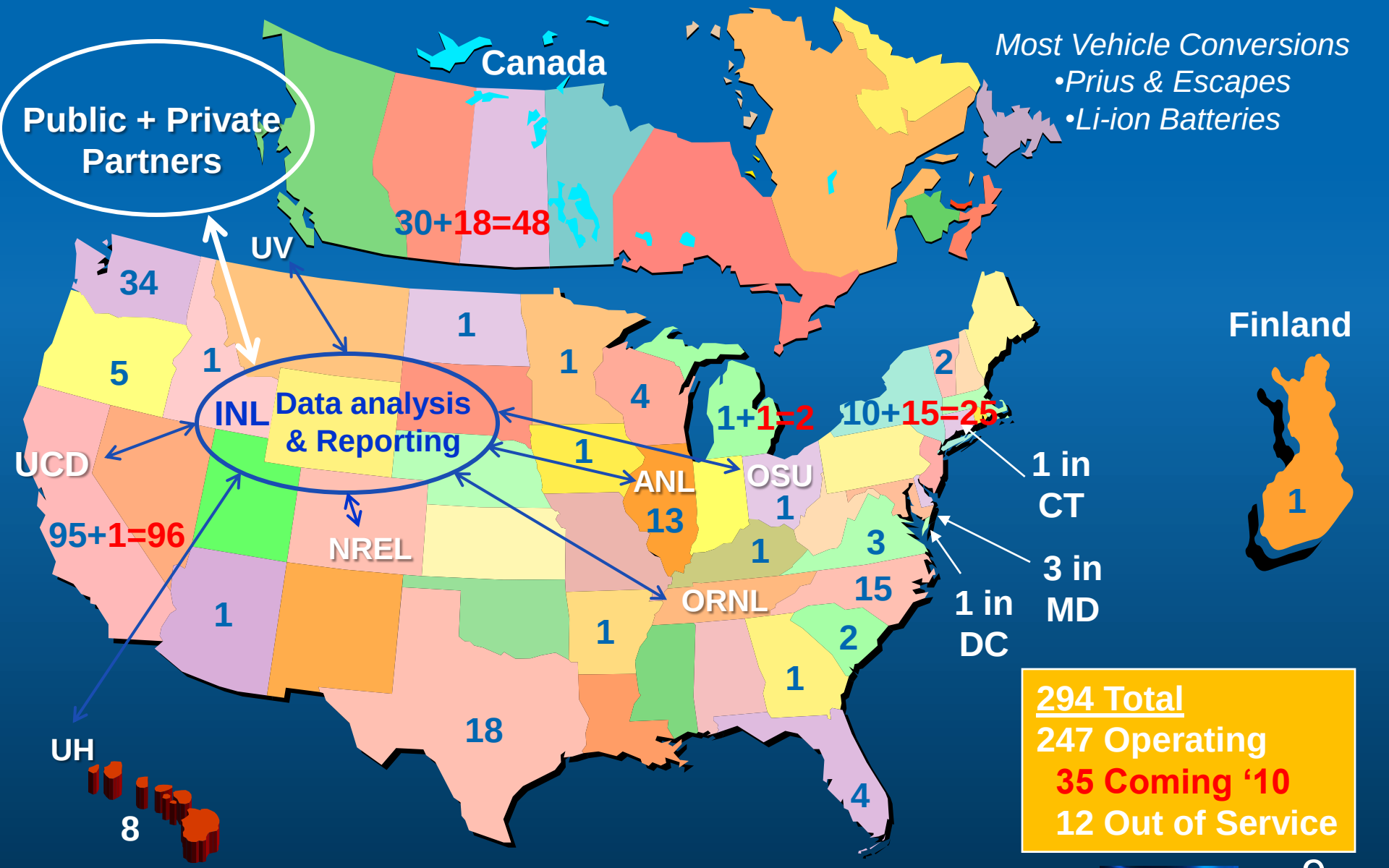
(Lithium-ion unless noted)

Testing focus is on the PHEV technology concept and batteries, and driver and environmental impacts on fuel efficiencies and charging rates, not on individual PHEV conversions

PHEV Testing Partners

- 259 PHEVs in 26 states, Canada, and Finland
- 1.5 million miles
- 93 PHEV testing partners include:
  - 38 Electric utilities
  - 10 County governments
  - 4 State governments
  - 10 Canadian government groups
  - 3 Sea ports and military bases
  - 2 PHEV conversion companies
  - 5 Private companies and advocacy organizations
  - 9 City governments
  - 10 Universities
  - 2 Clean Air Agencies
- 2,500+ automated monthly PHEV 3-page summary reports have been generated and disseminated to testing partners, 1,176 reports disseminated just in FY09

PHEV Testing / Demonstration Locations



Fleet Data Collection & Reporting Process

INL is maintaining and enhancing automated data warehousing, analysis, and reporting process for fleet data

- Accommodates 6 different data transfer methods from a multitude of vehicle/data logger combinations:
  - 9 PHEV, 1 BEV, 1 EREV, 8 HEV, and 1 HICE models
  - 5 data logger makes/models in use, with development efforts started for 3 more
- PHEV reporting formats include 71 metrics describing energy use, driving patterns, and charging patterns
- Developed quality assurance/exploratory analysis tools
- Created flexible automated report generation processes for individual and multiple vehicle reports
- The PHEV onboard data collection system is growing at approximately 60 million records per month

Vehicle Data Management Process

Process Affected by Disclosure Agreements

HICEVs

HEVs

PHEVs

BEVs

EVSE & Chargers

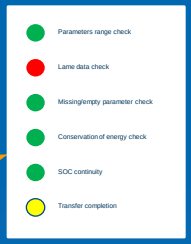
File server

SQL Server data warehouse

Report generator

INL Vehicle Data Management System

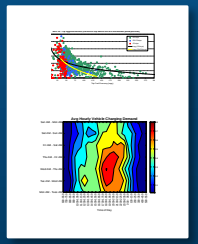
Data quality reports



Individual vehicle reports

Fleet summary reports to public

Focused technical analyses and custom reports



Inputs to modeling and simulation

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

North American PHEV Demonstration

Vehicle Technologies Program

Fleet Summary Report: Hymotion Prius (V2Green data logger)

Number of vehicles: 182

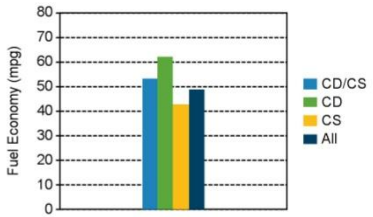
Reporting Period: Apr 08 - Feb 10

Date range of data received: 4/18/2008 to 2/28/2010

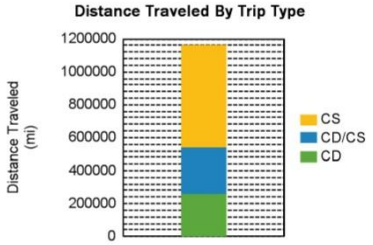
Number of days the vehicles were driven: 675

All Trips Combined	
Overall gasoline fuel economy (mpg)	49
Overall AC electrical energy consumption (AC Wh/mi) [1]	59
Overall DC electrical energy consumption (DC Wh/mi) [2]	43
Total number of trips	125,328
Total distance traveled (mi)	1,161,489
Trips in Charge Depleting (CD) mode [3]	
Gasoline fuel economy (mpg)	62
DC electrical energy consumption (DC Wh/mi) [4]	140
Number of trips	57,053
Percent of trips city / highway	86% / 14%
Distance traveled (mi)	261,411
Percent of total distance traveled	23%
Trips in both Charge Depleting and Charge Sustaining (CD/CS) modes [5]	
Gasoline fuel economy (mpg)	53
DC electrical energy consumption (DC Wh/mi) [6]	49
Number of trips	10,749
Percent of trips city / highway	47% / 53%
Distance traveled (mi)	278,541
Percent of total distance traveled	24%
Trips in Charge Sustaining (CS) mode [7]	
Gasoline fuel economy (mpg)	43
Number of trips	57,526
Percent of trips city / highway	74% / 26%
Distance traveled (mi)	625,034
Percent of total distance traveled	54%
Number of trips when the plug-in battery pack was turned off by the vehicle operator [8]	3194
Distance traveled with plug-in battery pack turned off by the vehicle operator (mi) [9]	103,635

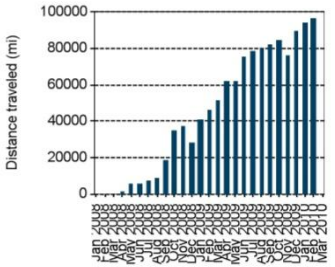
Gasoline Fuel Economy By Trip Type



Distance Traveled By Trip Type



Miles Logged by Month This Year

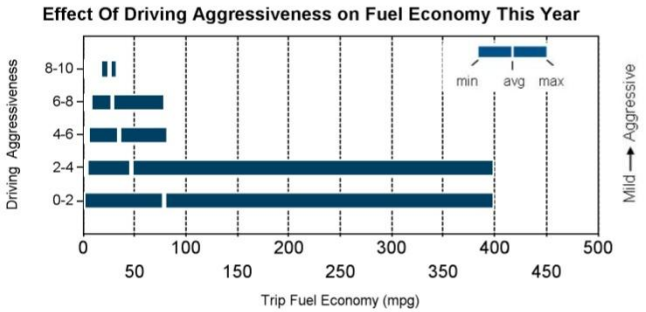


Notes: 1 - 9. Please see http://avt.inel.gov/phev/reportnotes for an explanation of all PHEV Fleet Testing Report notes.

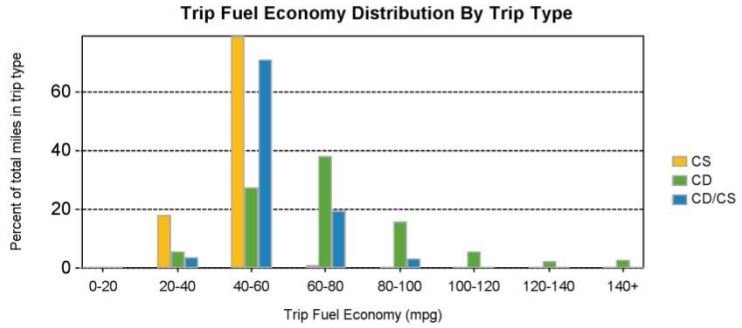
PHEV 3-Page Report

- Report by charge mode:
  - Charge depleting (CD)
  - Charge sustaining (CS)
  - Mixed (CD/CS)
- All trips, 49 mpg, 59 AC Wh/mi & 43 DC Wh/mi
- CD, 62 mpg & 140 DC Wh/mi
- CD/CS, 53 mpg & 49 DC Wh/mi
- CS, 43 mpg
- Report represents 1.2 million Hymotion Prius test miles and 125,000 trips

Trips in Charge Depleting (CD) mode	City	Highway
Gasoline fuel economy (mpg)	60	66
DC electrical energy consumption (DC Wh/mi)	165	109
Percent of miles with internal combustion engine off	29%	10%
Average trip aggressiveness (on scale 0 - 10)	1.7	1.7
Average trip distance (mi)	3.0	14.4
Trips in both Charge Depleting and Charge Sustaining (CD/CS) modes		
Gasoline fuel economy (mpg)	55	53
DC electrical energy consumption (DC Wh/mi)	80	44
Percent of miles with internal combustion engine off	24%	6%
Average trip aggressiveness (on scale 0 - 10)	1.8	1.6
Average trip distance (mi)	8.6	40.9
Trips in Charge Sustaining (CS) mode		
Gasoline fuel economy (mpg)	37	45
Percent of miles with internal combustion engine off	22%	5%
Average trip aggressiveness (on scale 0 - 10)	1.8	1.7
Average trip distance (mi)	3.6	31.8



Aggressiveness factor is based on accelerator pedal position. The more time spent during a trip at higher accelerator pedal position, the higher the trip aggressiveness.



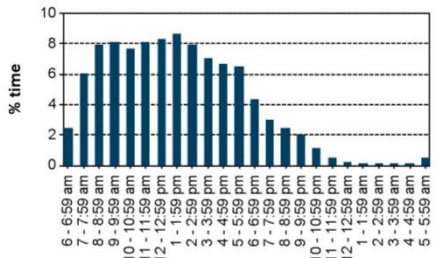
PHEV 3-Page Report

- **Report fuel use by highway/city cycles and driver style**
- CD city, 60 mpg (62%+), 165 DC Wh/mi
- CD highway, 66 mpg (47%+), 109 DC Wh/mi
- CS city, 37 mpg
- CS highway, 45 mpg
- Less aggressive driving (0 to 20%) averages ~80 mpg
  - (Aggressiveness = accelerator pedal position)

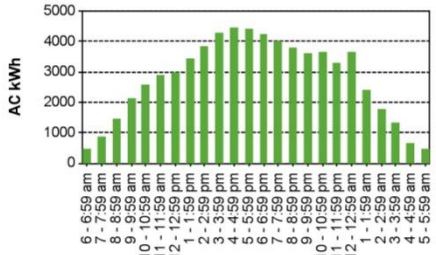
Plug-in charging

Average number of charging events per vehicle per month when driven	14
Average number of charging events per vehicle per day when vehicle driven	1.0
Average distance driven between charging events (mi)	44.8
Average number of trips between charging events	4.8
Average time plugged in per charging event (hr)	20.9
Average time charging per charging event (hr)	2.8
Average energy per charging event (AC kWh)	2.6
Average charging energy per vehicle per month (AC kWh)	37.1
Total number of charging events	25,928
Total charging energy (AC kWh)	67,996

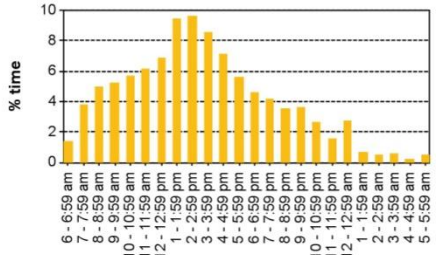
Time of Day When Driving



Time of Day When Charging



Time of Day When Plugging In

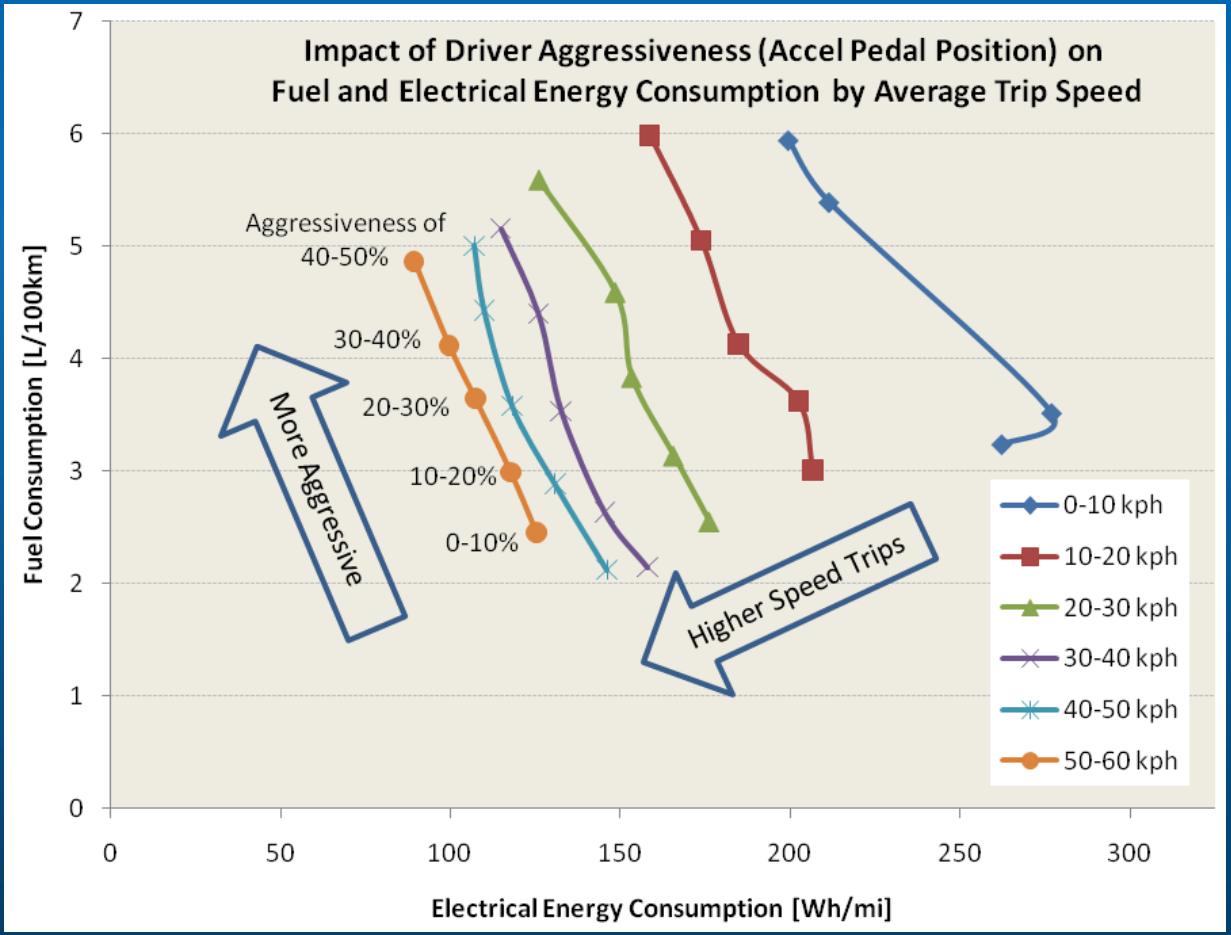


PHEV 3-Page Report

- **Report charging stats, time of day driving, and charging profiles**
- Average 1 charging event per day when PHEV driven
- 44.8 miles between charge events
- 4.8 trips between charge events
- 2.8 hours per charge
- 20.9 hours time plugged in per charge
- 2.6 AC kWh per charge event

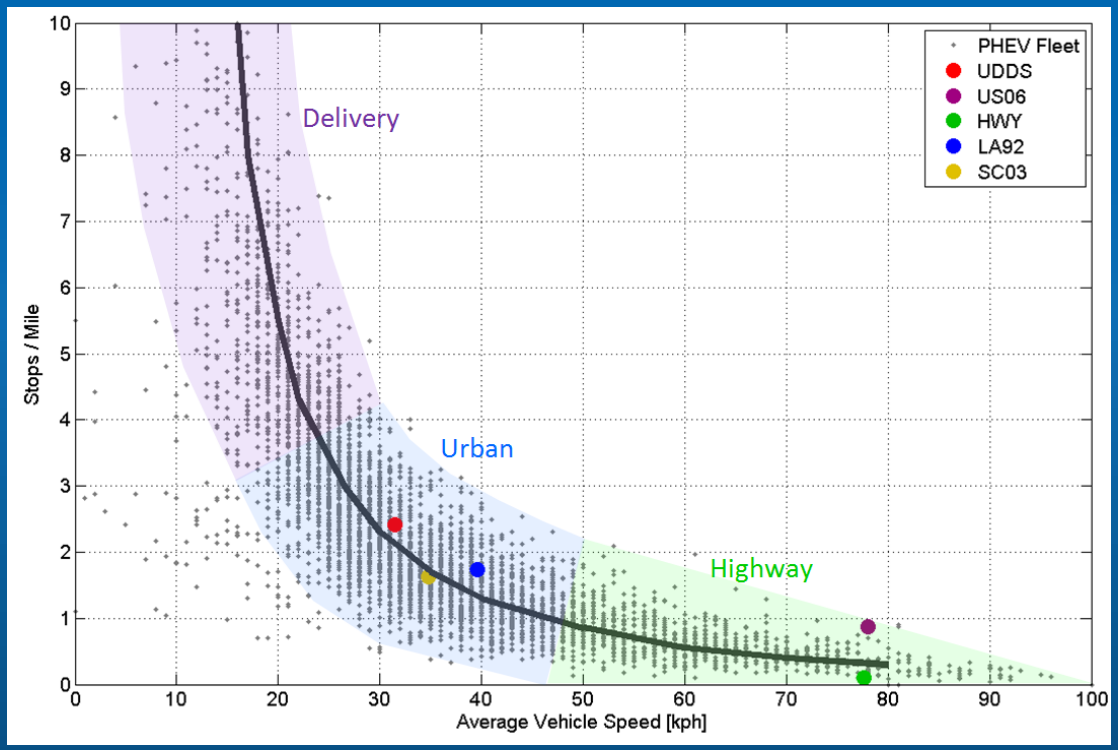
Driver Aggressiveness

- With increase in driver aggressiveness
  - Fuel consumption increases
  - Wh/mi slightly decreases



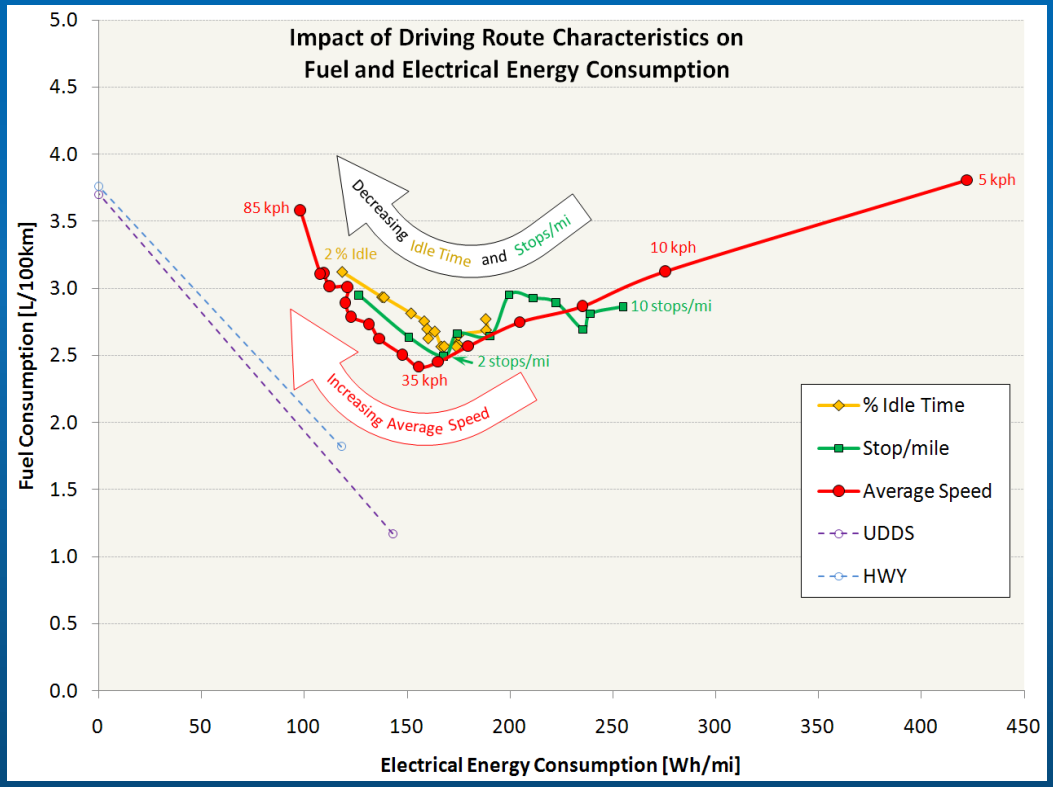
Route Type

- Discernable by
  - Average Vehicle Speed
  - Stops per mile
  - % time stopped
- For typical driving
  - Strong correlation between average speed and stops per mile



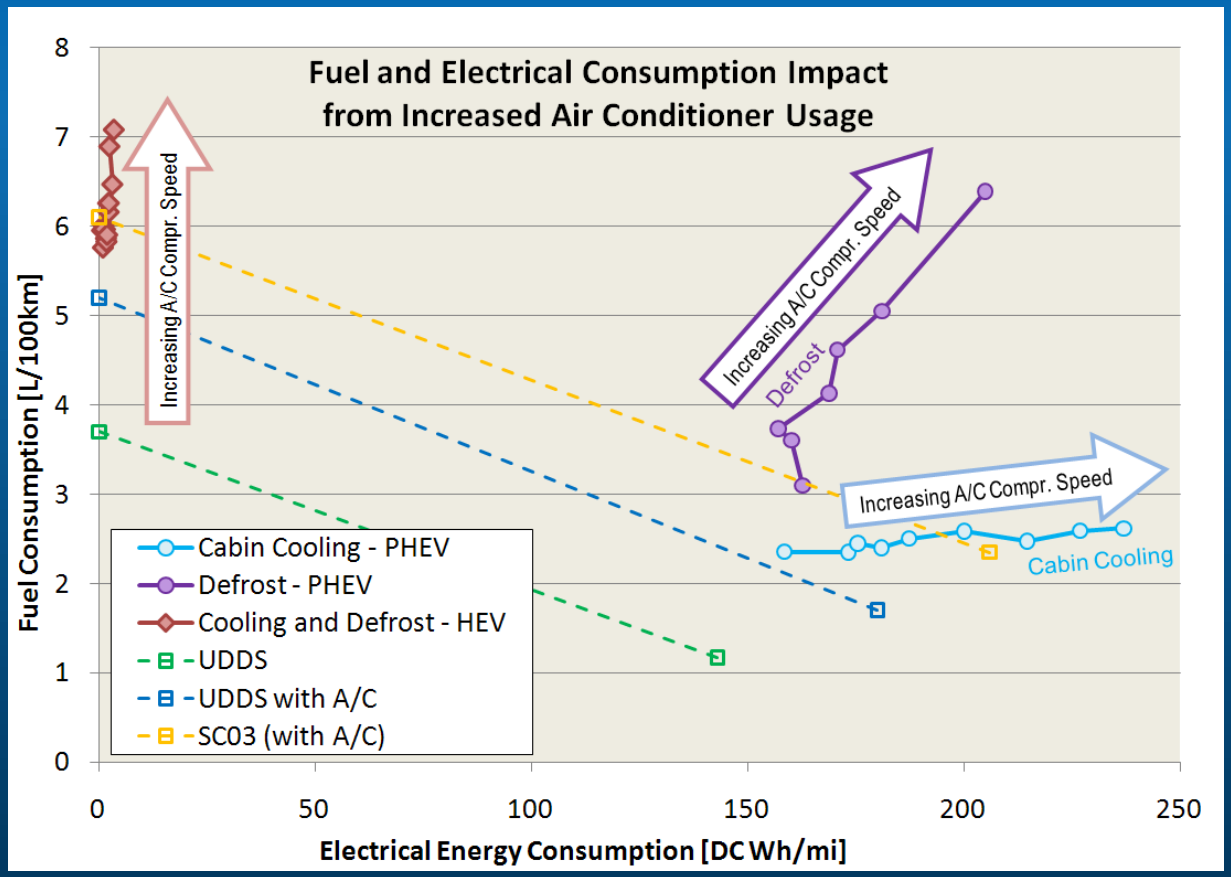
Route Type

- Inflection point around 35 kph and 2 stops/mile
- Lower average speed results in higher fuel consumption and higher electrical consumption
- Higher average speed also results in higher fuel consumption BUT lower electrical consumption



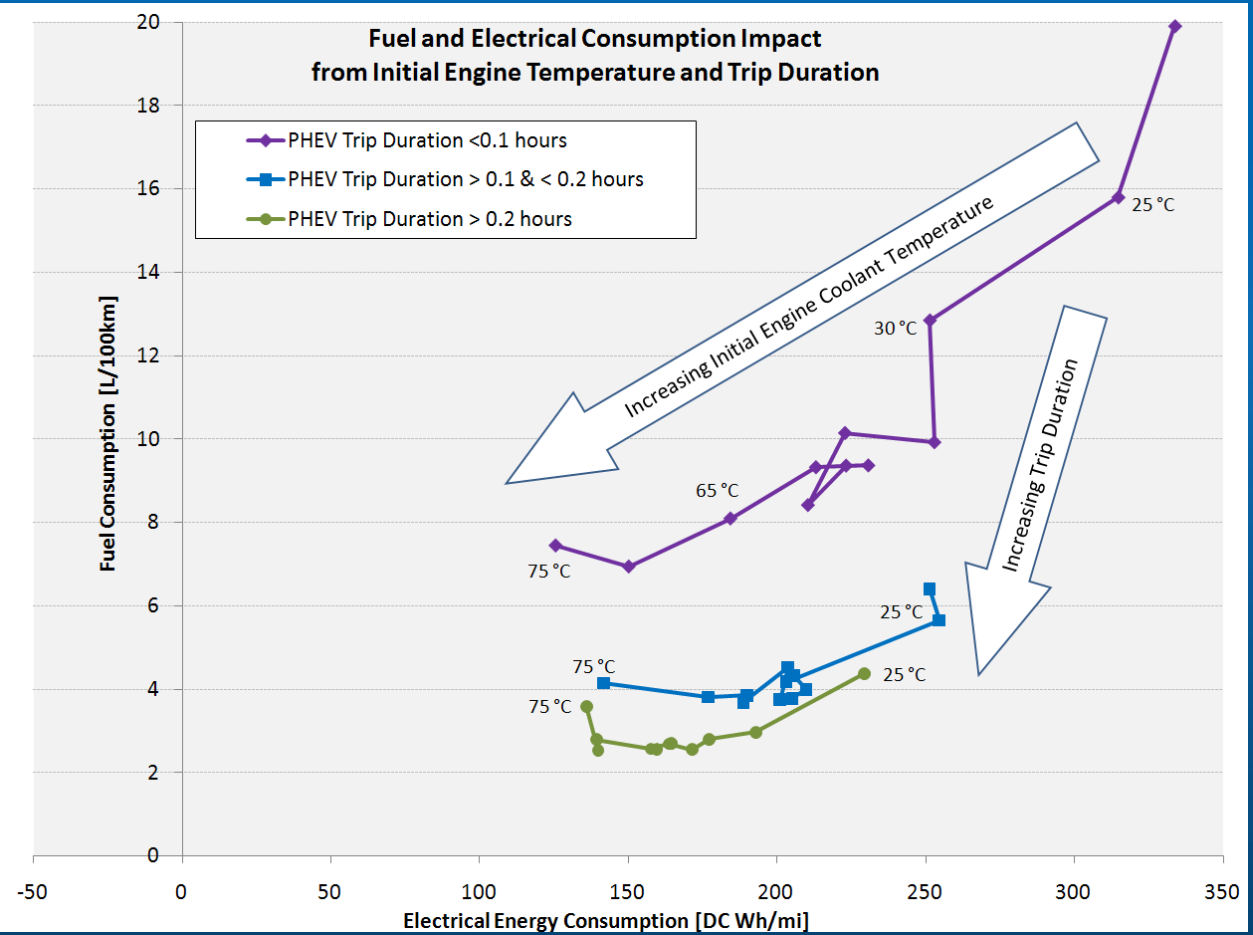
Accessory Utilization – Air Conditioner

- As A/C compressor speed (and load) increases
  - CD: Wh/mi increases, minimal change to fuel consump.
  - CS: Fuel consumption increases

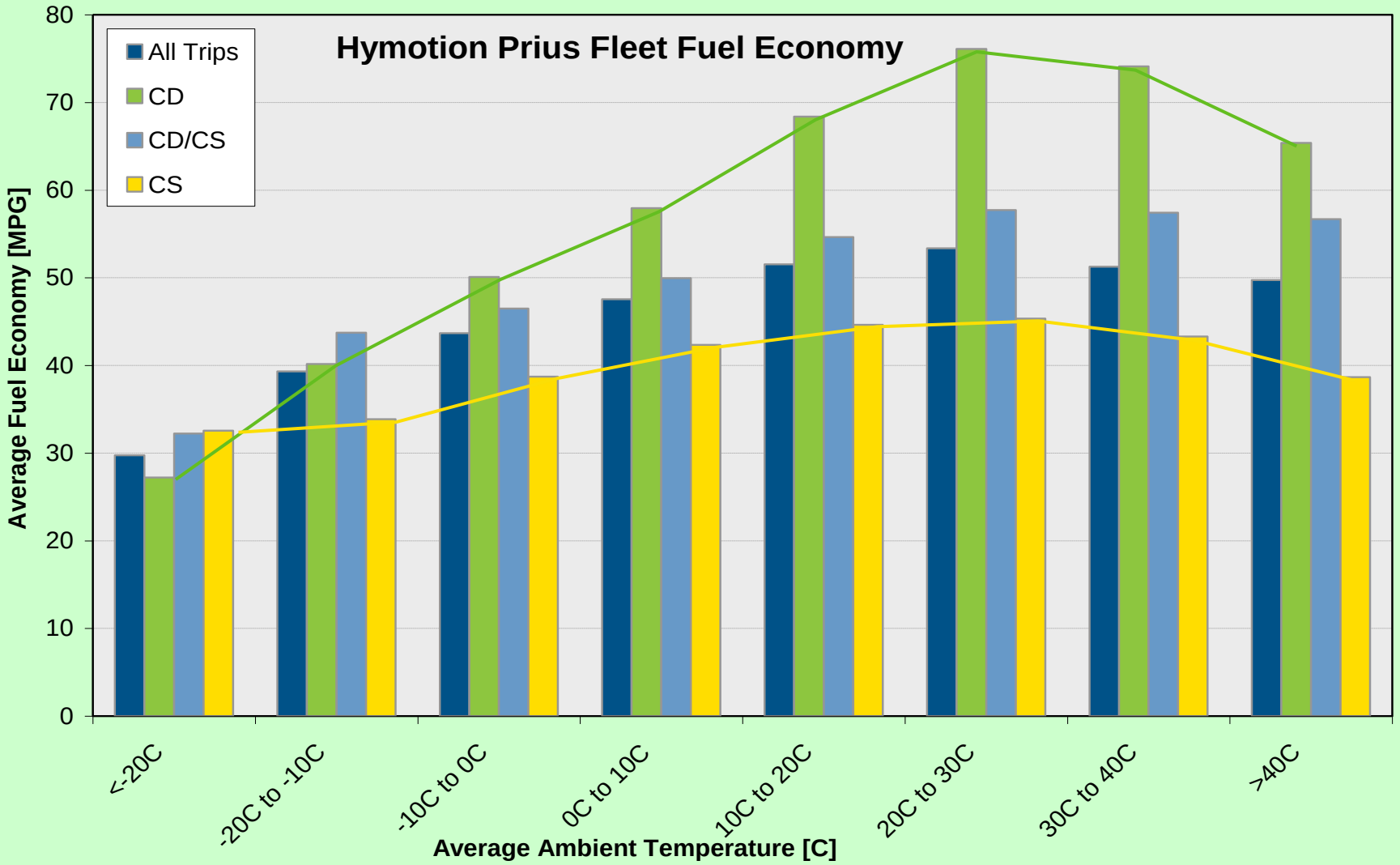


Engine Warm-up / Start-up

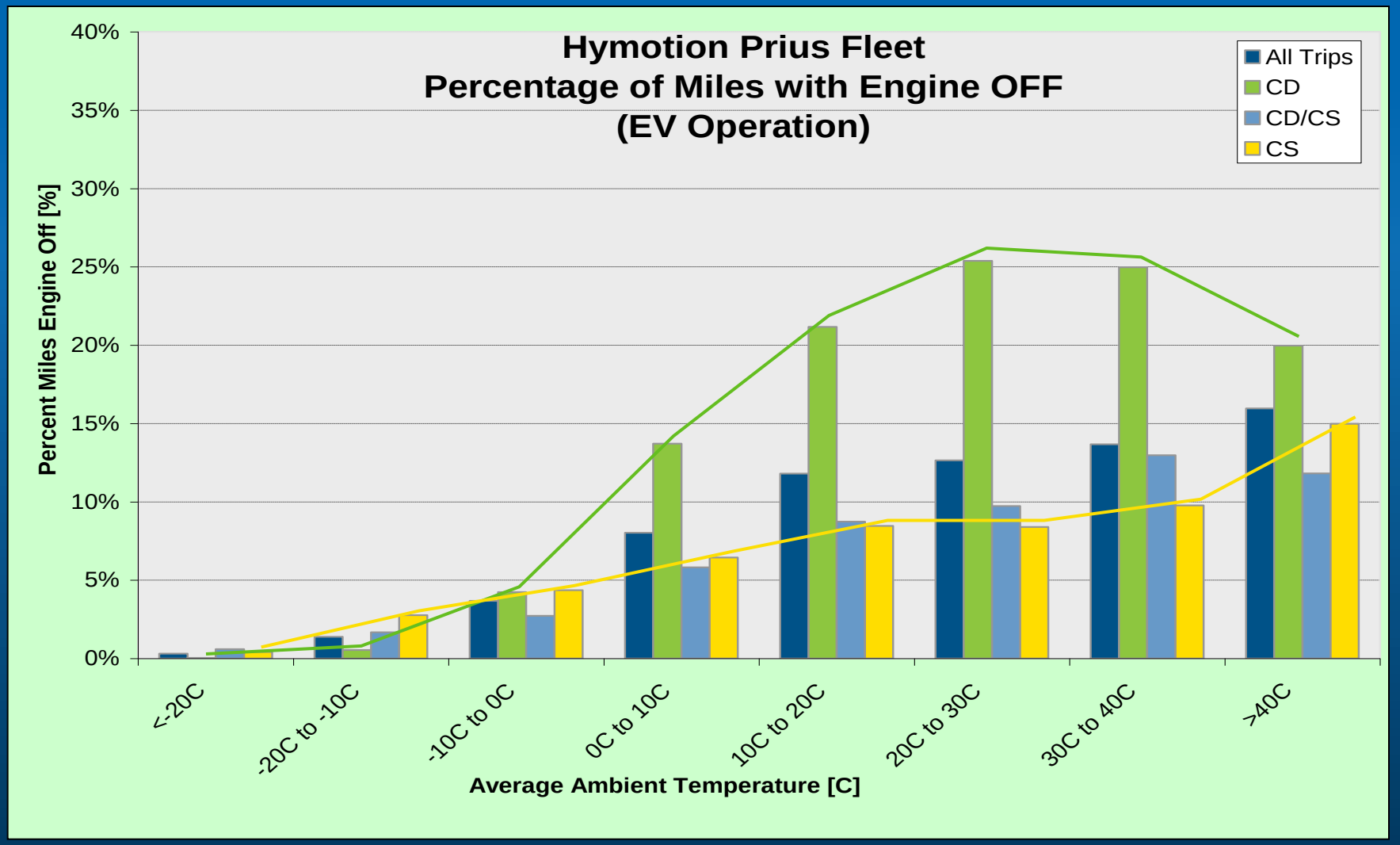
- Total energy consumption dramatically decreases as initial engine temperature increases
- Longer trip duration reduces fuel consumption due to greater time driving with warm engine (less start-up effect)



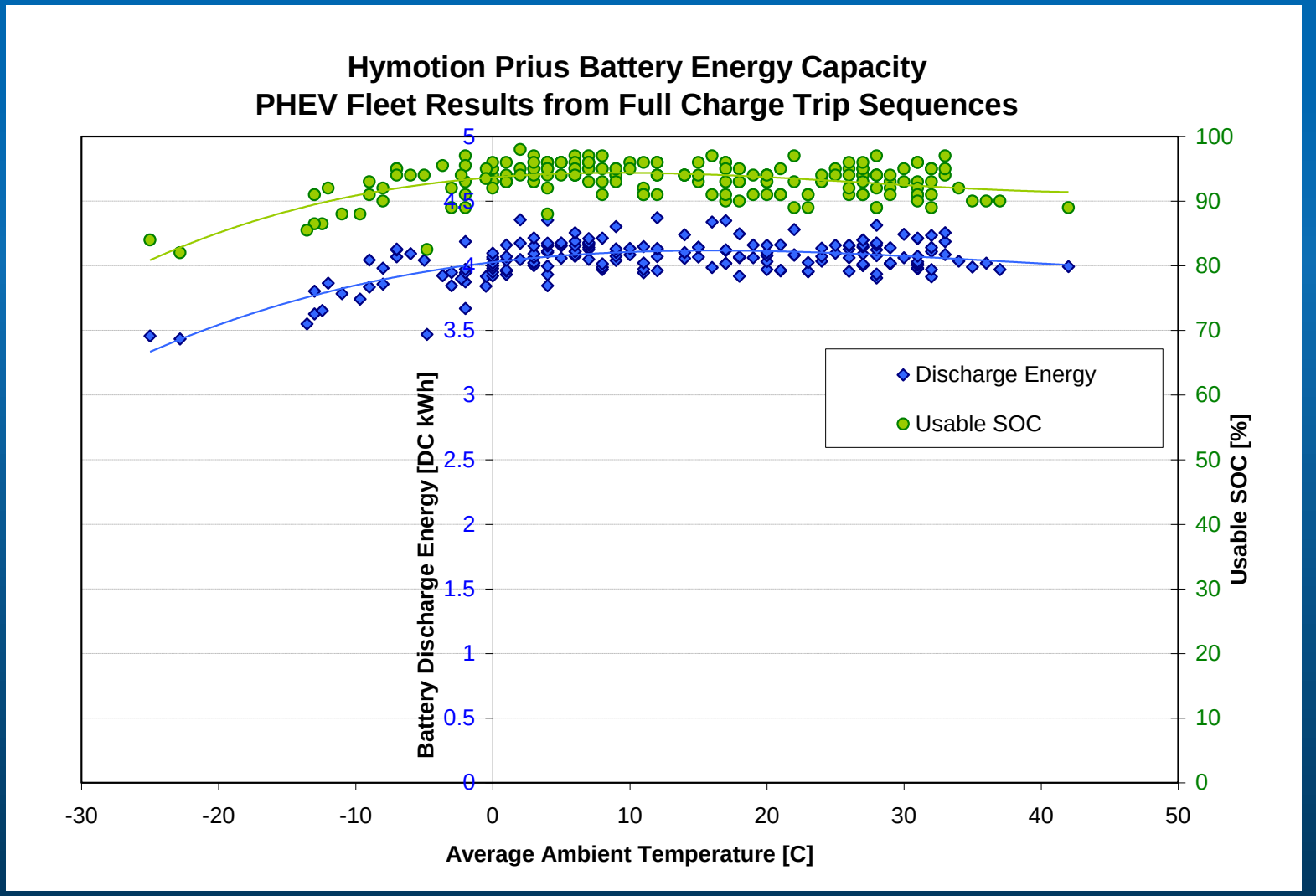
PHEV Ambient Temperature MPG Impacts



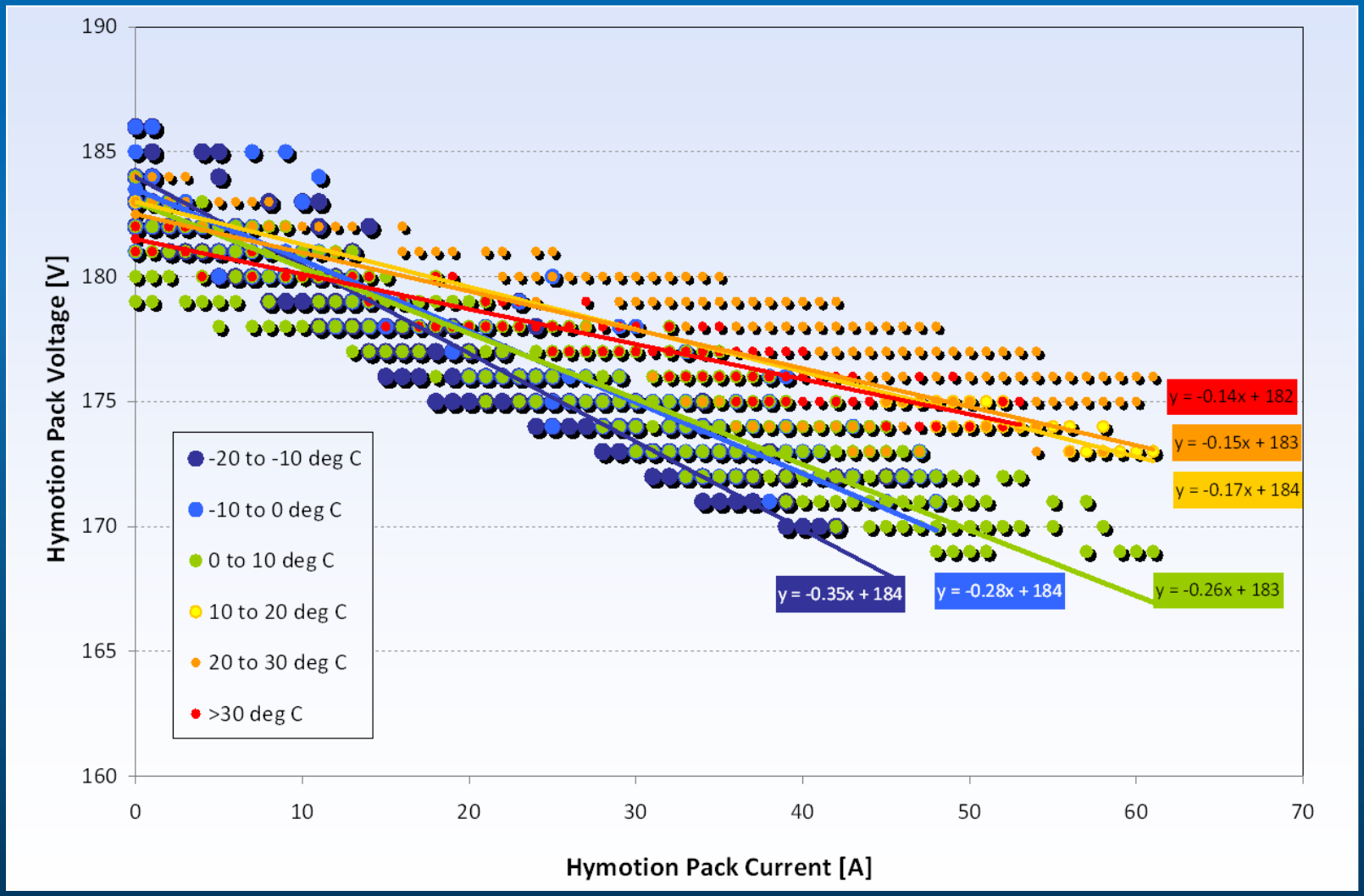
Engine Operation is a Main Factor for PHEV Fuel Economy Changes



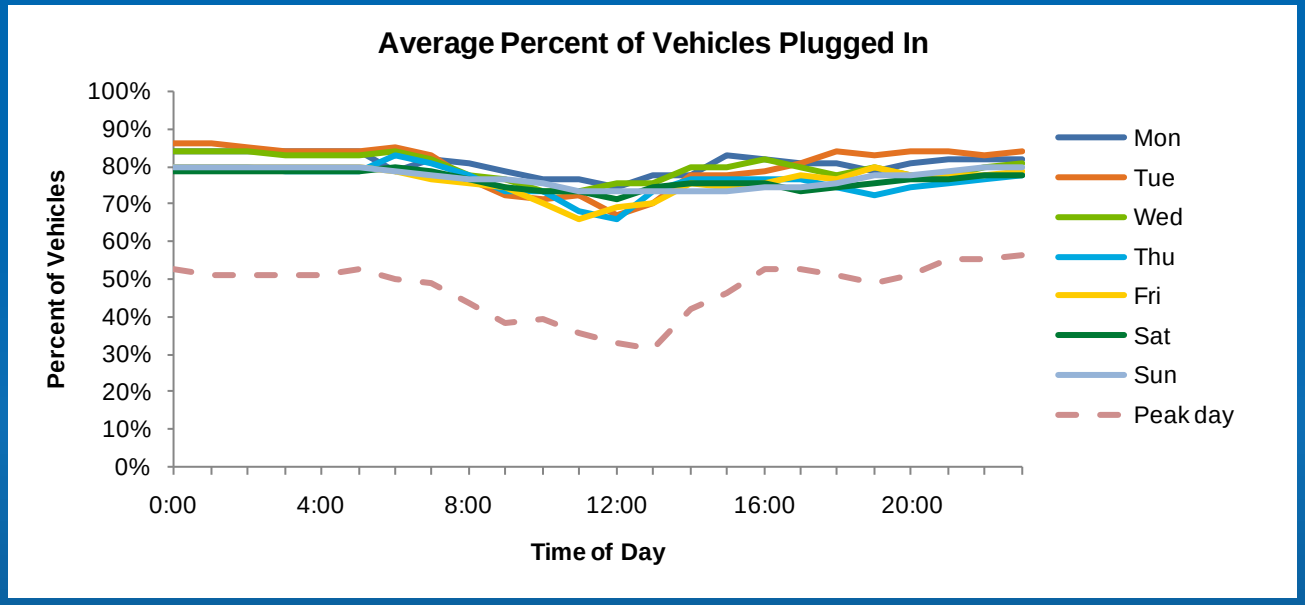
Usable Battery Capacity is Slightly Effected by Temperature



Hymotion Li-Ion Battery Internal Resistance Change with Temperature

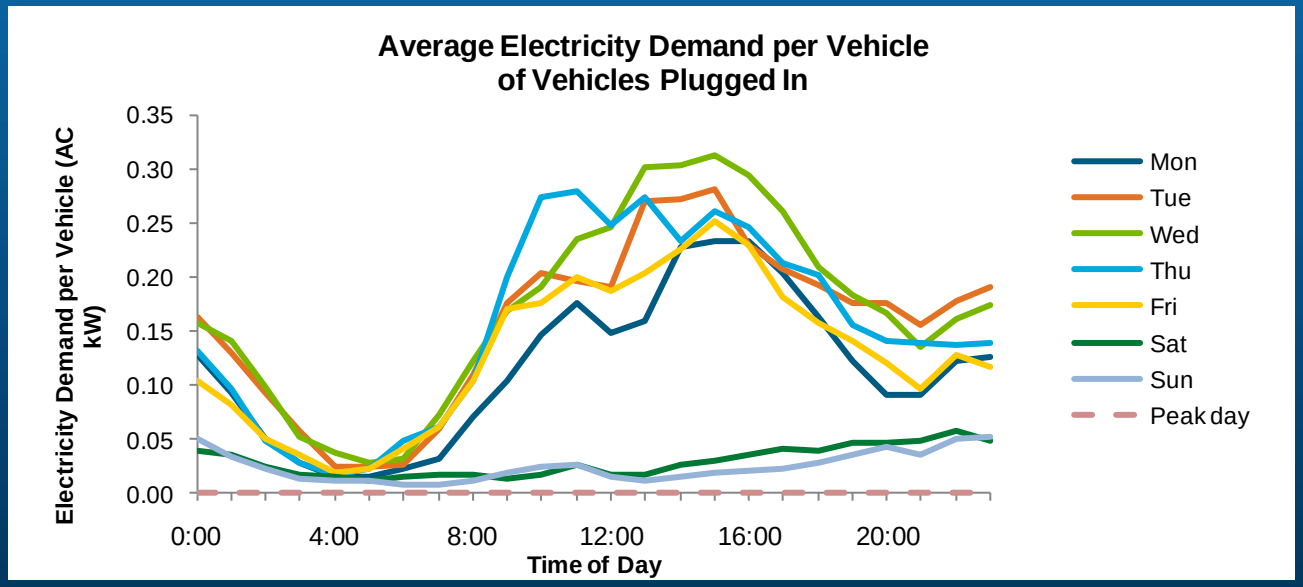


PHEV Time of Day Charging Demand



Personal-use Vehicles in Private Households (UC Davis Study)

- **Data from last week of charging at 67 households**
- **Uncontrolled charging**

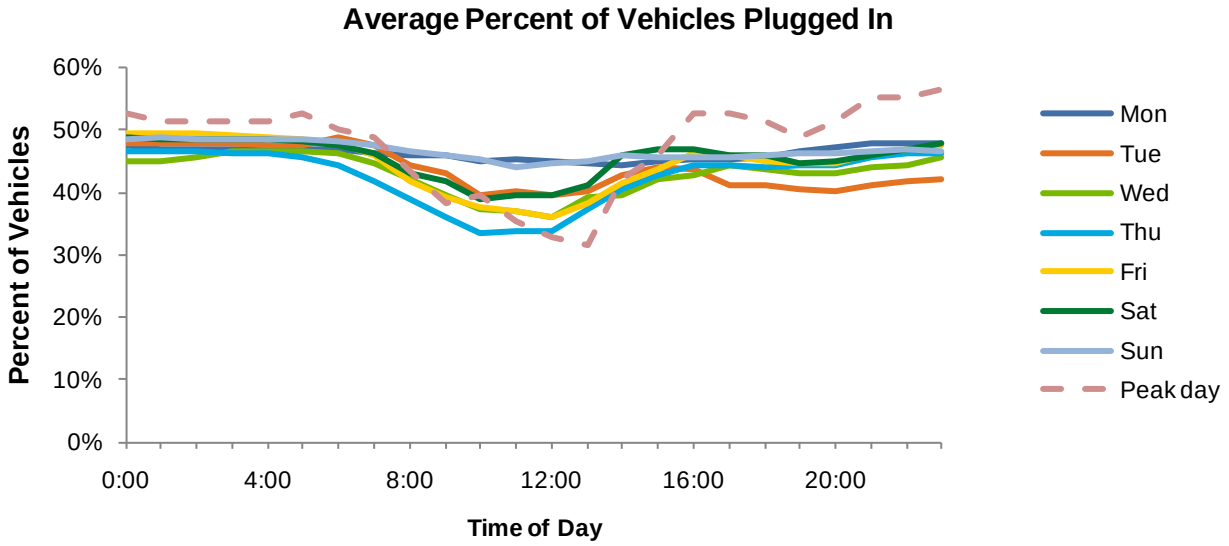


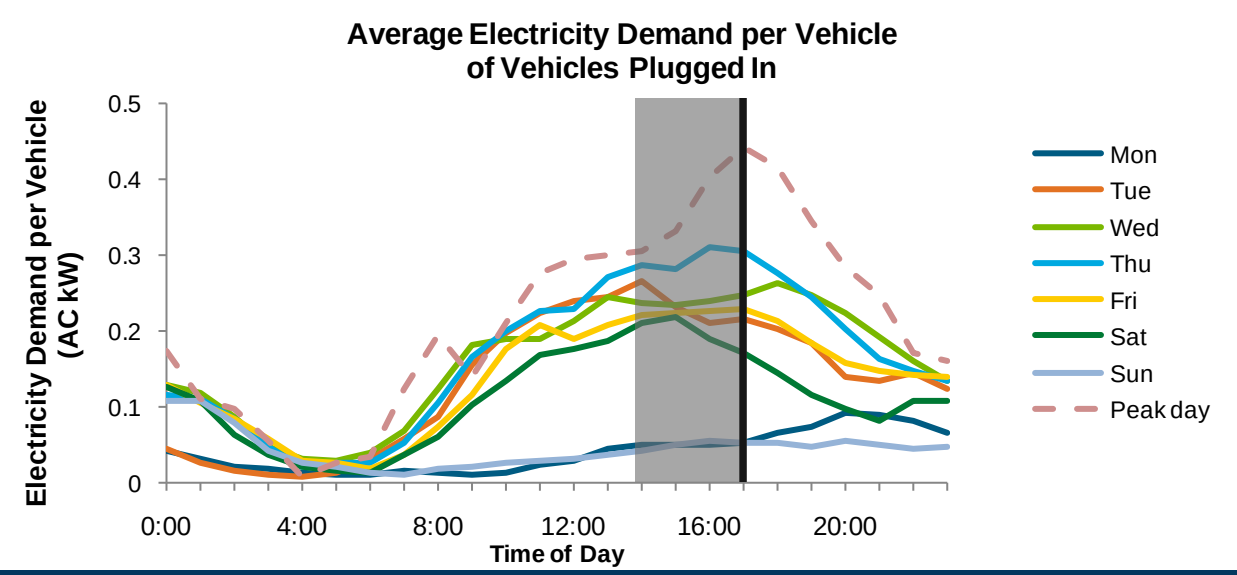
Weekday peak occurs between X:00 and X:00

Weekend peak occurs around midnight

Peak day has peak in X:00 hour

PHEV Time of Day Charging Demand





Commercial-use Fleet Vehicles

- **Data from 6 randomly sampled weeks during 2009**
- **138 distinct vehicles**

Weekday peak occurs between 2:00 and 5:00

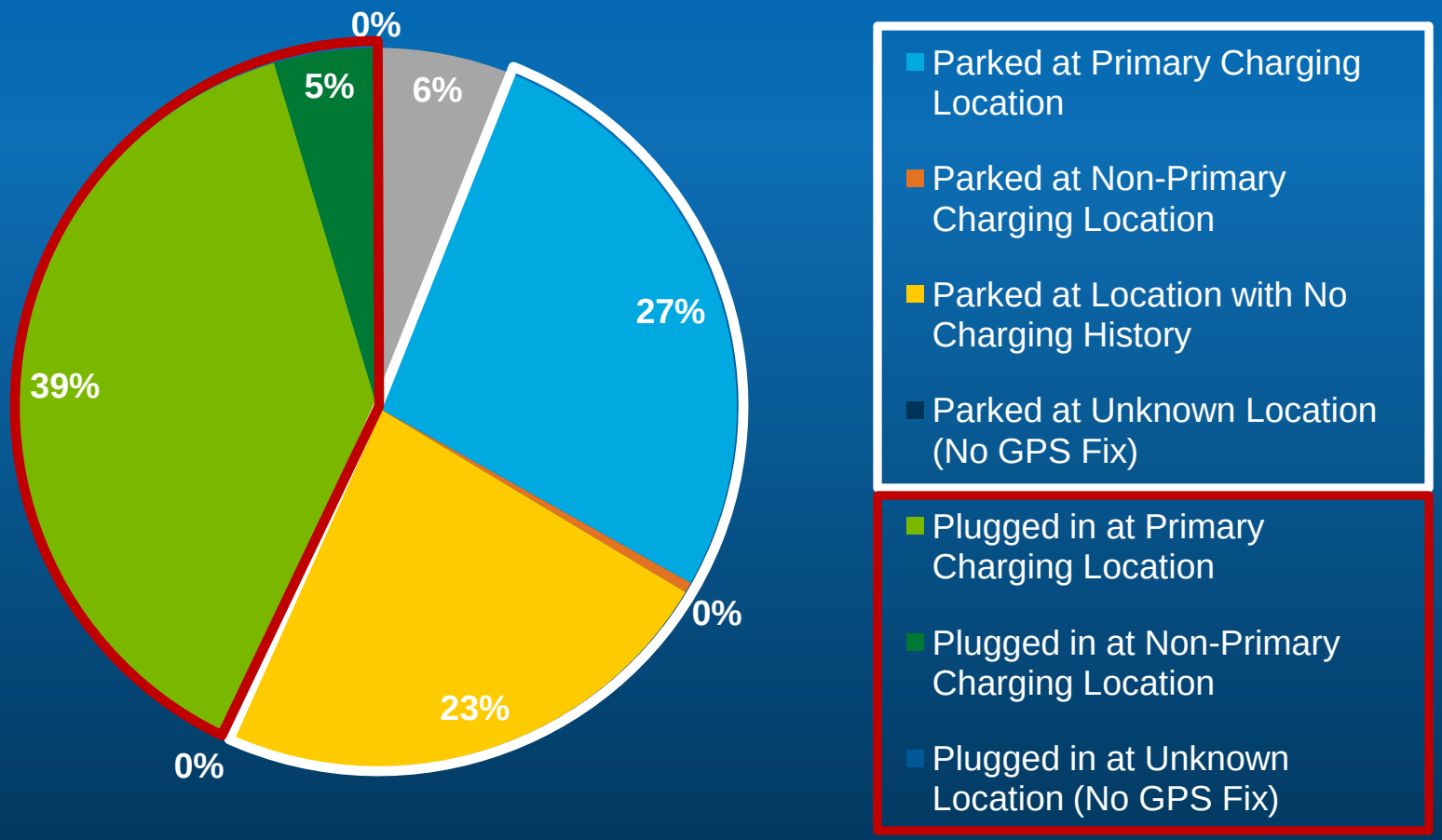
Weekend peak occurs around midnight

Peak day has peak in 5:00 hour

PHEV Charging Location

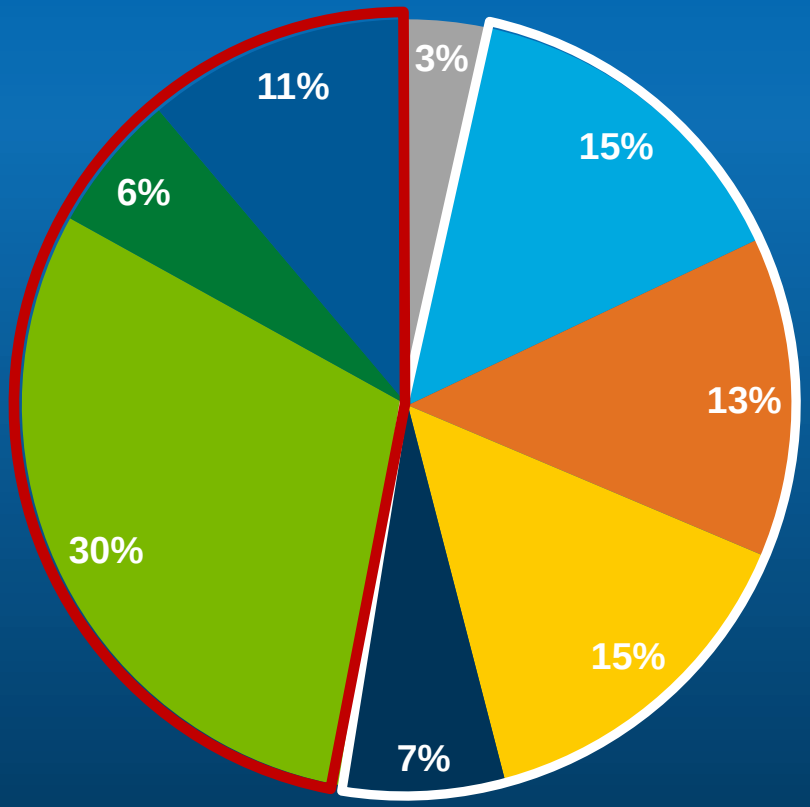
Personal-use Vehicles in Private Households (UC Davis Study)

Percent of Time Driving, Plugged in, and Parked while Unplugged by Location



PHEV Charging Location
Commercial-use Fleet Vehicles

Percent of Time Driving, Plugged in, and Parked while Unplugged by Location

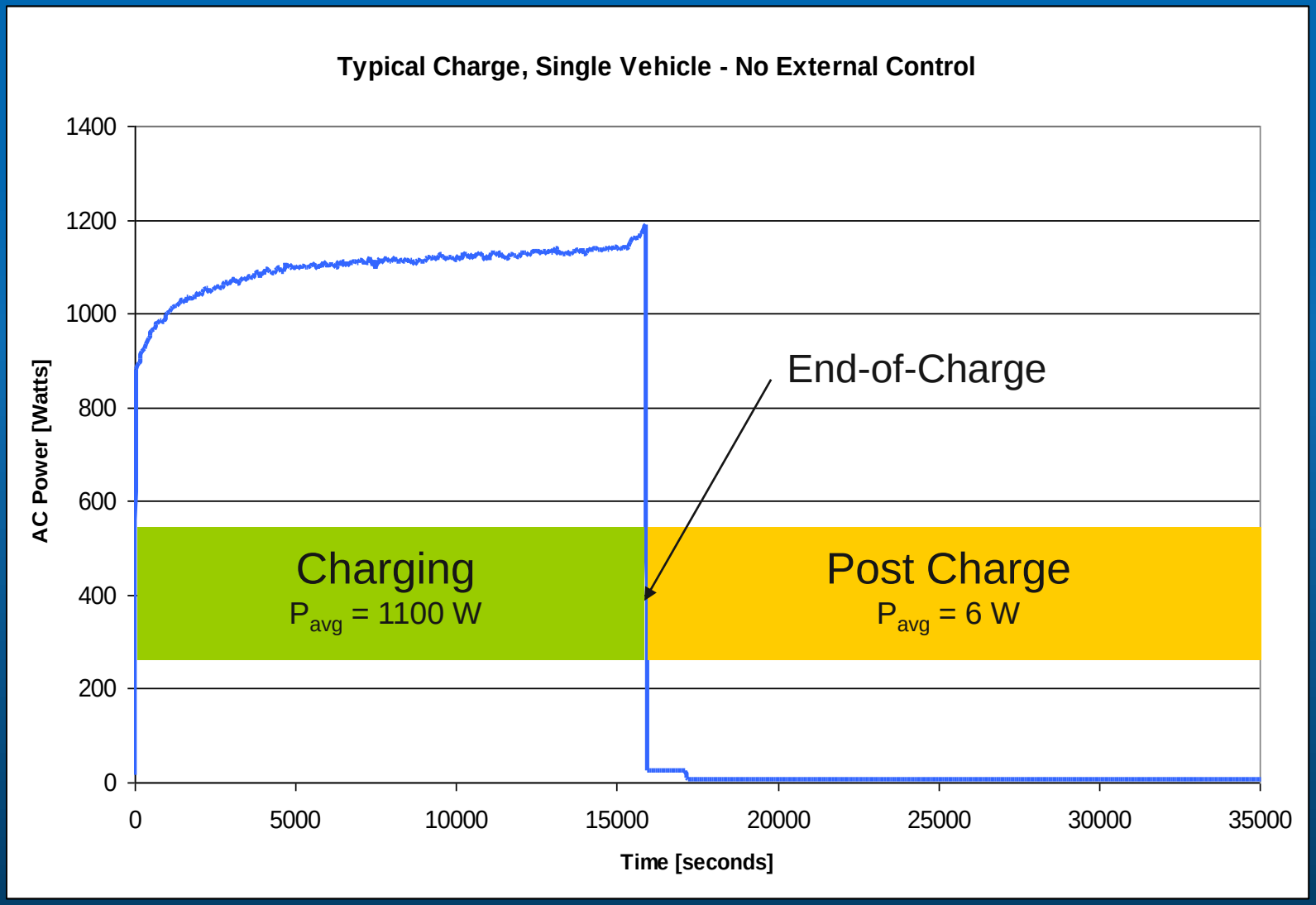


- Driving
- Parked at Primary Charging Location
- Parked at Non-Primary Charging Location
- Parked at Location with No Charging History
- Parked at Unknown Location (No GPS Fix)
- Plugged in at Primary Charging Location
- Plugged in at Non-Primary Charging Location
- Plugged in at Unknown Location (No GPS Fix)

Seattle Area PHEV Smart Charging Trials

- 13 Hymotion PHEVs using GridPoint's *Electric Vehicle Management Solution*
- Types of trials conducted with GridPoint and Seattle City Light (project lead):
  - Time of Day Charging – Vehicle charging only allowed during certain hours of the day
  - Goal Based Charging – Normalize power demand for vehicle charging around a kW goal load
  - Economic Charging – Allow vehicle charging only when the price of electricity is below a threshold
- GridPoint Vehicle Connectivity Modules (VCM) used to control charging as directed by GridPoint's server and to log vehicle charging and driving data
- VCM requests the pack to wait to charge or to charge at a specified power level - no physical circuit interruption
- INL analyzed the data collected from the vehicles

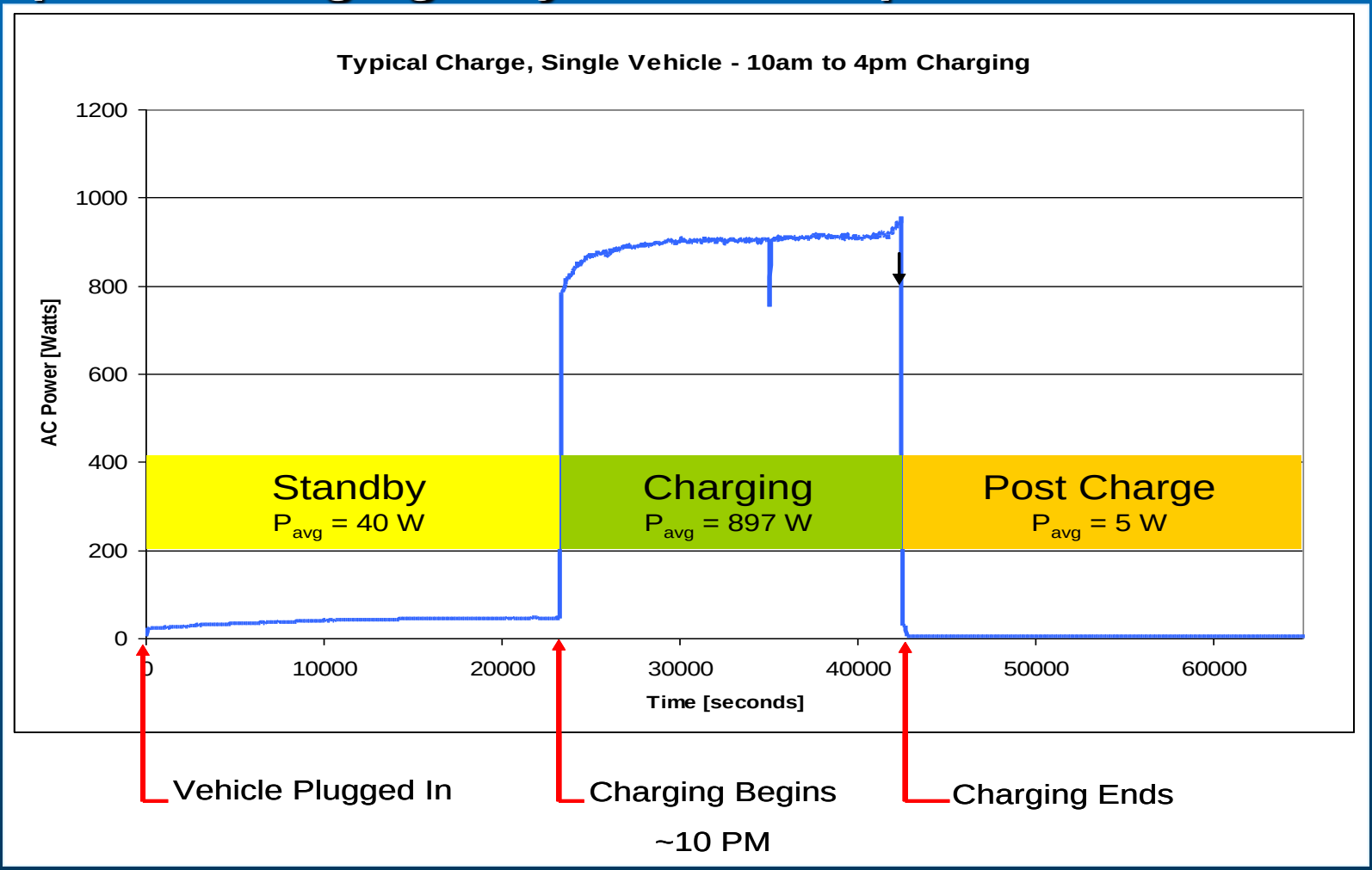
Charging – No Control



Hymotion Prius PHEV battery from A123 Systems

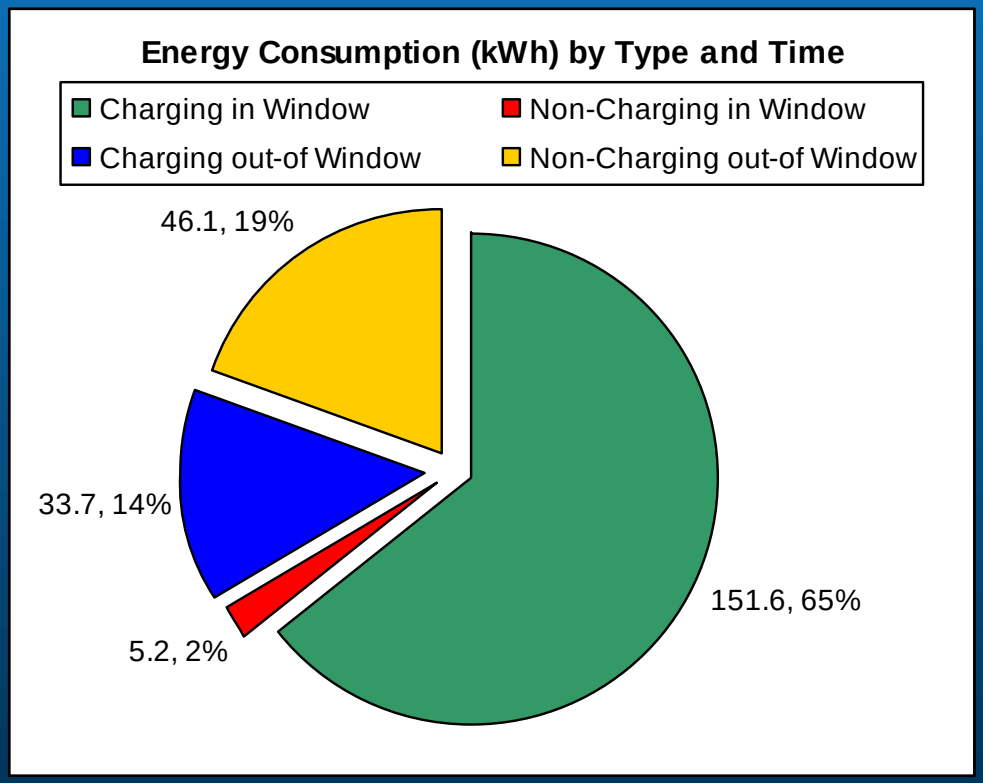
Results of Time of Day Charging Trials

- VCM establishes communication with control server, requests charging only between 10pm & 4am



Results of Time of Day Charging Trials

- **35% Rogue AC kWh – energy drawn outside of allowable charging window:**
  - **Communication not established or lost - charging occurs**
  - **Cumulative standby energy draw when not charging**



Timeline of Electric Drive Vehicle Availability



Production OEM HEVs

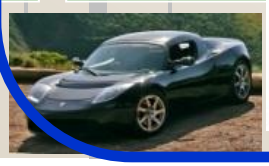
Conversion PHEVs


AVTA has done extensive testing of vehicles available to date

Prototype / Production OEM PHEVs*


AVTA is collaborating with auto makers to begin testing OEM PHEVs and BEVs. HEV and conversion PHEV testing continues.

Production OEM EVs*



2004 2006 2008 2010 2012 2014

* Refers to PHEVs and BEVs produced for the mass market. OEMs have produced PHEVs and BEVs in low volume intermittently since the 1990's.

elec electric transportation engineering corporation

INL Idaho National Laboratory

U.S. DEPARTMENT OF ENERGY

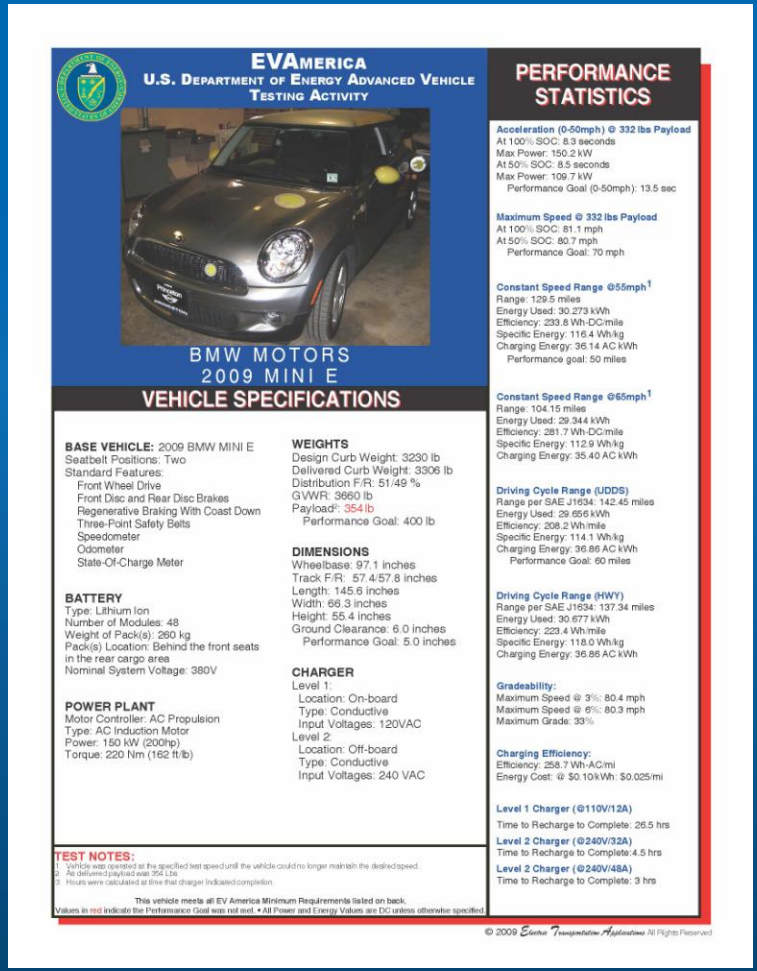
AVTA Grid-connected Vehicle Testing

FY10

- Tested first BEV from OEM in 10+ years
- Ford Escape PHEV Prototype
- USPS LLV BEV conversions

FY11 outlook includes:

- Nissan Leaf BEV
- Chevrolet Volt EREV
- Mitsubishi iMiEV BEV
- THINK City BEV
- Ford Transit Connect, Focus BEVs
- Toyota Prius PHEV
- Others as they become available



EVAMERICA
U.S. DEPARTMENT OF ENERGY ADVANCED VEHICLE TESTING ACTIVITY

BMW MOTORS
2009 MINI E

VEHICLE SPECIFICATIONS

BASE VEHICLE: 2009 BMW MINI E
Seatbelt Positions: Two
Standard Features:
Front Wheel Drive
Front Disc and Rear Disc Brakes
Regenerative Braking With Coast Down
Three-Point Safety Belts
Speedometer
Odometer
State-Of-Charge Meter

BATTERY
Type: Lithium Ion
Number of Modules: 48
Weight of Pack(s): 260 kg
Pack(s) Location: Behind the front seats in the rear cargo area
Nominal System Voltage: 380V

POWER PLANT
Motor Controller: AC Propulsion
Type: AC Induction Motor
Power: 150 kW (200hp)
Torque: 220 Nm (162 ft/lb)

WEIGHTS
Design Curb Weight: 3230 lb
Delivered Curb Weight: 3306 lb
Distribution F/R: 51/49 %
GVWR: 3660 lb
Payload[2]: 354 lb
Performance Goal: 400 lb

DIMENSIONS
Wheelbase: 97.1 inches
Track F/R: 57.4/57.8 inches
Length: 145.6 inches
Width: 66.3 inches
Height: 55.4 inches
Ground Clearance: 6.0 inches
Performance Goal: 5.0 inches

CHARGER
Level 1:
Location: On-board
Type: Conductive
Input Voltages: 120VAC
Level 2:
Location: Off-board
Type: Conductive
Input Voltages: 240 VAC

PERFORMANCE STATISTICS

Acceleration (0-50mph) @ 332 lbs Payload
At 100% SOC: 8.3 seconds
Max Power: 150.2 kW
At 50% SOC: 8.5 seconds
Max Power: 109.7 kW
Performance Goal (0-50mph): 13.5 sec

Maximum Speed @ 332 lbs Payload
At 100% SOC: 81.1 mph
At 50% SOC: 80.7 mph
Performance Goal: 70 mph

Constant Speed Range @55mph[1]
Range: 129.5 miles
Energy Used: 30.273 kWh
Efficiency: 233.8 Wh-DC/mile
Specific Energy: 116.4 Wh/kg
Charging Energy: 36.14 AC kWh
Performance goal: 50 miles

Constant Speed Range @65mph[1]
Range: 104.15 miles
Energy Used: 29.344 kWh
Efficiency: 281.7 Wh-DC/mile
Specific Energy: 112.9 Wh/kg
Charging Energy: 35.40 AC kWh

Driving Cycle Range (UDDS)
Range per SAE J1634: 142.45 miles
Energy Used: 29.656 kWh
Efficiency: 208.2 Wh/mile
Specific Energy: 114.1 Wh/kg
Charging Energy: 36.86 AC kWh
Performance Goal: 60 miles

Driving Cycle Range (HWY)
Range per SAE J1634: 137.34 miles
Energy Used: 30.677 kWh
Efficiency: 223.4 Wh/mile
Specific Energy: 118.0 Wh/kg
Charging Energy: 36.86 AC kWh

Gradeability:
Maximum Speed @ 3%: 80.4 mph
Maximum Speed @ 6%: 80.3 mph
Maximum Grade: 33%

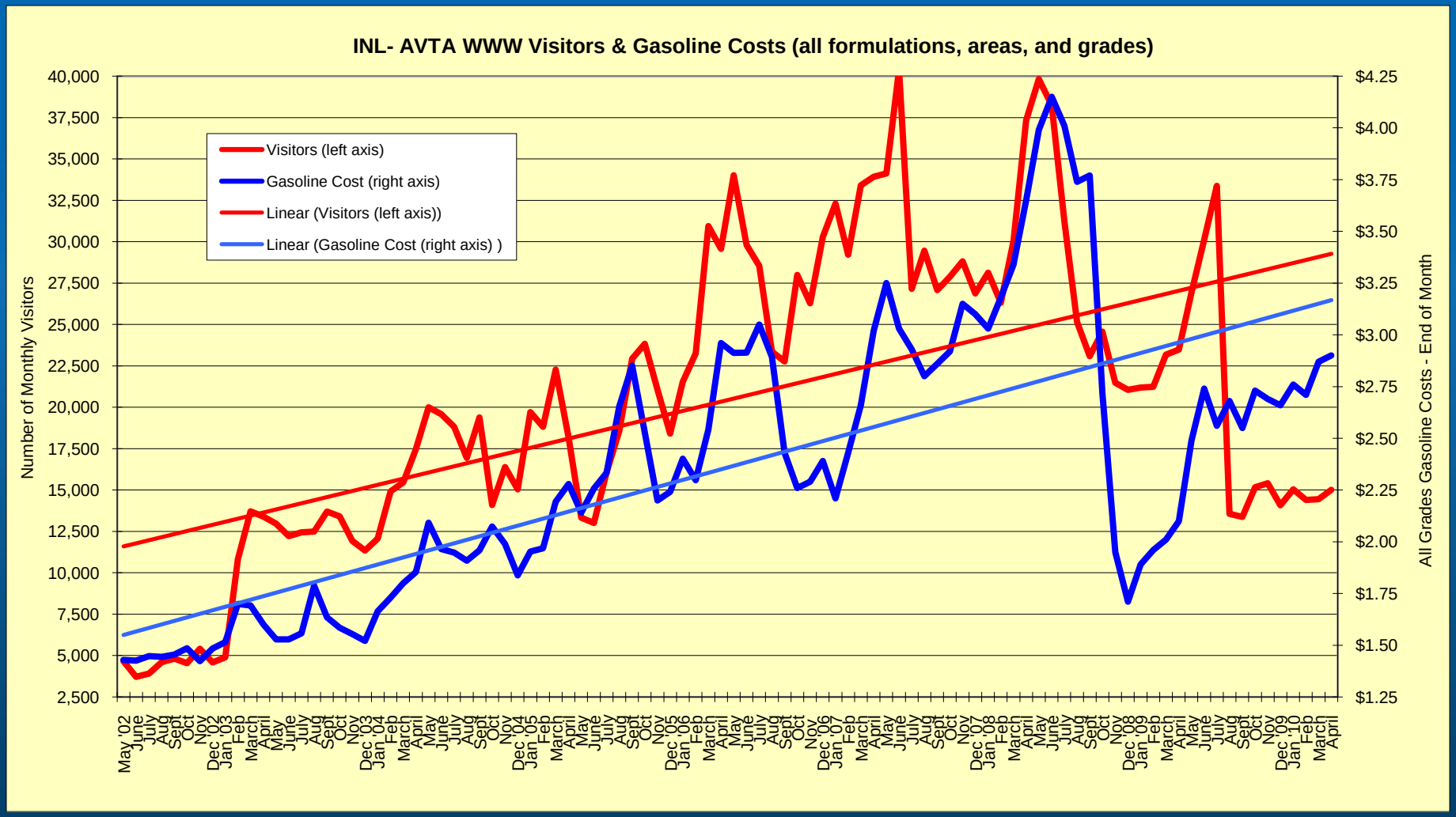
Charging Efficiency:
Efficiency: 258.7 Wh-AC/mi
Energy Cost: @ $0.10/kWh: $0.025/mi

Level 1 Charger (@110V/12A)
Time to Recharge to Complete: 26.5 hrs
Level 2 Charger (@240V/32A)
Time to Recharge to Complete: 4.5 hrs
Level 2 Charger (@240V/48A)
Time to Recharge to Complete: 3 hrs

TEST NOTES:
1. Vehicle was operated at the specified test speed until the vehicle could no longer maintain the desired speed.
2. As delivered payload was 354 Lbs.
3. Hours were calculated at time that charger indicated completion.

This vehicle meets all EV America Minimum Requirements listed on back.
Values in red indicate the Performance Goal was not met. • All Power and Energy Values are DC unless otherwise specified.

AVTA Summary – WWW Visitors



Acknowledgement

This work is supported by the U.S. Department of Energy's Vehicle Technologies Program

Additional Information

http://avt.inl.gov
or
http://www1.eere.energy.gov/vehiclesandfuels/avta/

INL/MIS-10-19317