AVTA – PHEV Demonstrations and Testing (DOE FY10 Merit Review)

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Idaho National Laboratory – Advanced Vehicle Testing Activity (AVTA)
June 9, 2010

Project ID # VSS015
INL/CON-10-18396

Overview

Timeline

- **The AVTA is an ongoing, annually funded DOE activity, designed to test and validate emerging technologies in whole-vehicle systems**

Barriers

- **Barriers addressed**
  - Overcome lack of timely real-world PHEV performance data
  - Document how consumers operate PHEVs
  - Document environmental and charging impacts on PHEV fuel use

Budget

- **FY09 project funding**
  - $900k DOE share
  - $4,750k+ partners' share (does not include partners' fuel, personnel, and maintenance costs)
- **Funding for FY10**
  - $1,300k DOE share

Partners

- **Idaho National Laboratory, Electric Transportation Engineering Corporation & National Energy Technology Laboratory**
- **ANL, ORNL, NREL**
- **OEMs via USABC Tech Teams**
- **93 government (local, state and national) agencies, universities, electric utilities, private companies and more**

AVTA Description

- Idaho National Laboratory (INL) and Electric Transportation Engineering Corporation (eTec) conduct the AVTA for DOE's Vehicle Technologies Program
- NETL manages eTec's DOE contract
- DOE's sole independent tester in field applications of light-duty whole-vehicle systems with advanced technologies; including:
  - 100% electric and dual-fuel electric drive systems
  - Advanced energy storage systems
  - Some hydrogen and other advanced control systems (i.e., start/stop hybrids)
- Provide benchmarked vehicle data to R&D programs, modelers, manufacturers, and target/goal setters (DOE)
- Assist early adaptor fleet managers and the general public in making informed vehicle purchase, deployment and operating decisions

AVTA Testing by Technology

- Plug-in hybrid electric vehicles (PHEVs)
  - 12 models, 259 vehicles, 1.5 million test miles
- Hybrid electric vehicles (HEVs)
  - 18 models, 47 vehicles, 5 million test miles
- Neighborhood electric vehicles (NEVs)
  - 23 models, 200,000 test miles

- Hydrogen internal combustion engine (ICE) vehicles
  - 7 models, 500,000 test miles
- Full-size battery electric vehicles (BEVs)
  - 41 EV models, 5+ million test miles
- Urban electric vehicles (UEVs)
  - 3 models, 1 million test miles

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

AVTA PHEV Testing

- 12 PHEV models tested to date
  - Hymotion Prius (A123 Systems)
  - Hymotion Escape (A123 Systems)
  - Ford E85 Escape (Johnson Controls/Saft)
  - EnergyCS Prius, 2 models (Valance and Altair Nano)
  - Electrovaya Escape (Electrovaya) - done
  - Hybrids Plus Escape, 2 models (Hybrids Plus and K2 Energy Solutions)
  - Hybrids Plus Prius (Hybrids Plus)
  - Manzanita Prius (lead acid and Thunder Sky)
  - Renault Kangoo (Saft NiCad) - done

  (Lithium unless noted)
- PHEV 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

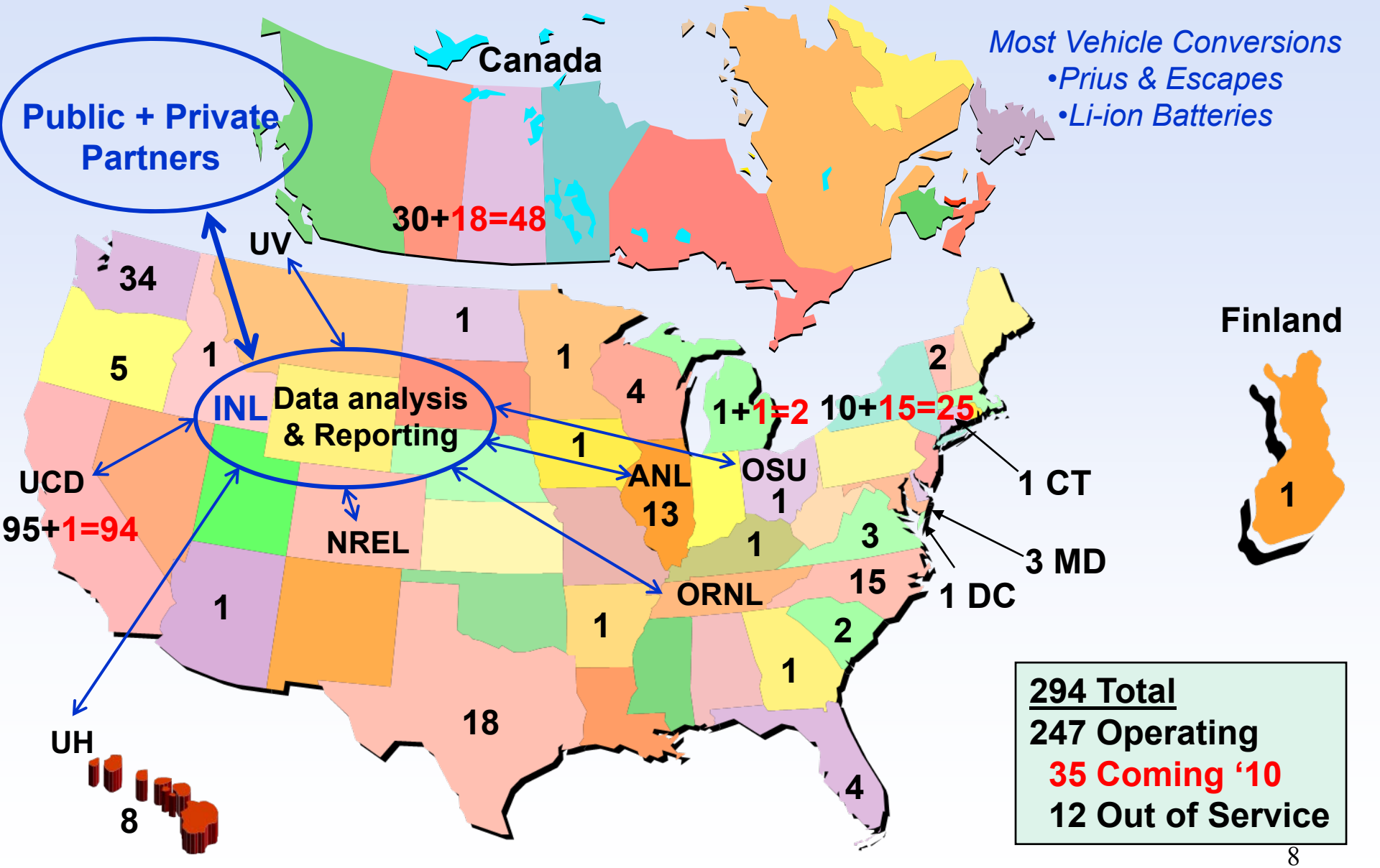
AVTA Vehicle Testing Approach

- Depending on vehicle technology and capabilities, vehicles are tested via:
  - Closed test tracks: highly repeatable
  - Dynamometer testing: highly repeatable
  - Laboratory testing (batteries): highly repeatable
  - Accelerated testing, using dedicated drivers and other methods to accumulate miles and cycles
  - Fleet testing, uses unstructured vehicle utilization
  - Different testing methods are used to balance testing control/repeatability, sample size, costs, and cost-share opportunities
- Publish testing results in relevant ways to accurately
  - Document real-world petroleum reduction potentials
  - Document fuel and infrastructure use
  - Document life-cycle risks and costs

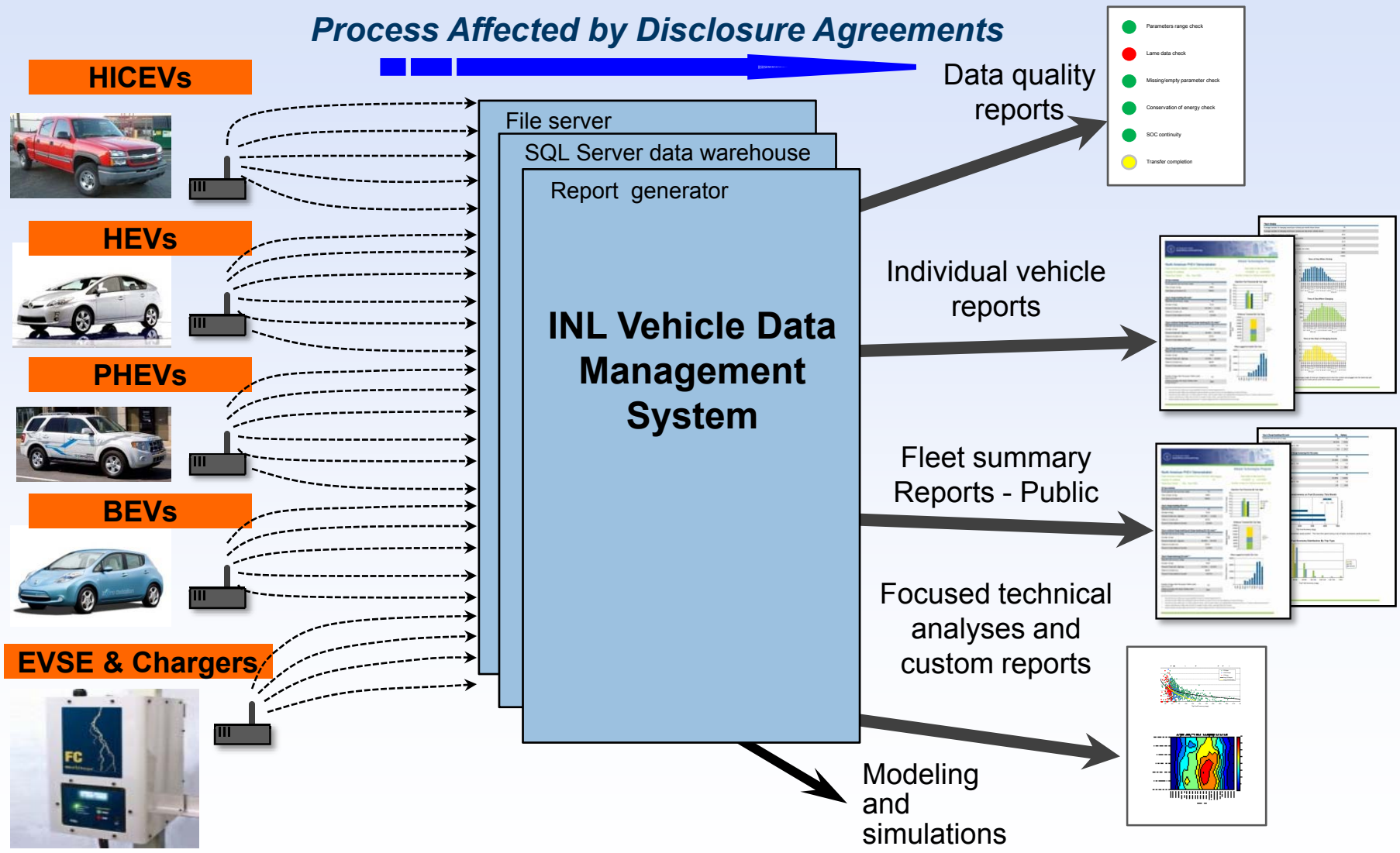
PHEV Testing Partners

- 259 PHEVs in 26 states, Canada and Finland, 1.5 million miles - AVTA only purchased 2 PHEVs and conducted 12 conversions. Highly leveraged testing activity
- 93 PHEV testing partners include:
  - 38 Electric utilities
  - 10 County governments
  - 4 State governments
  - 9 City governments
  - 10 Universities
  - 2 Clean Air Agencies
  - 10 Canadian government groups
  - 3 Sea ports and military bases
  - 2 PHEV conversion companies
  - 5 Private companies and advocacy organizations
- 2,500+ monthly PHEV 3-page summary reports have been generated and disseminated to testing partners, 1,176 reports disseminated just in FY09
- 120 PHEVs added in FY09

AVTA PHEVs and Demonstration Locations



Vehicle Data Management Process



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

North American PHEV Demonstration

Vehicle Technologies Program

Fleet Summary Report: Hymotion Prius (V2Green data logger)

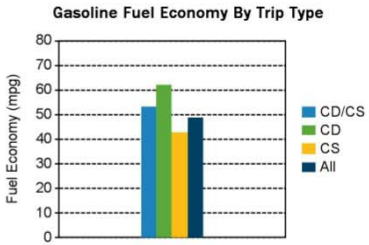
Number of vehicles: 182

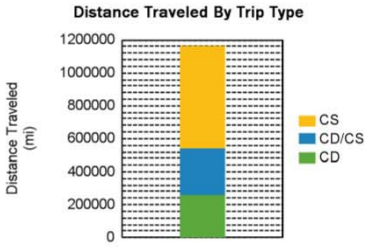
Reporting Period: Apr 08 - Feb 10

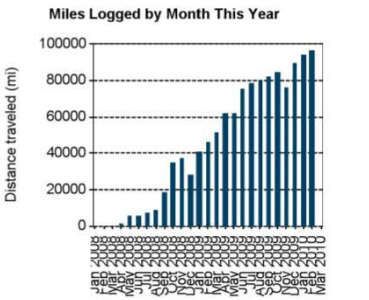
Date range of data received: 4/18/2008 to 2/28/2010

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



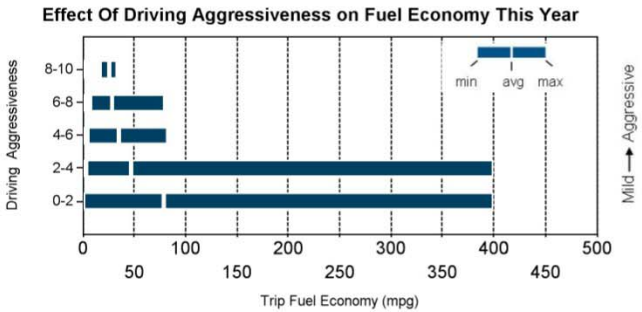




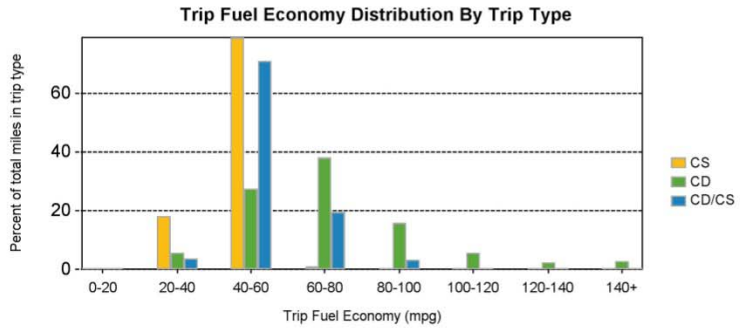
Notes: 1 - 9. Please see http://avt.inel.gov/phev/reportnotes for an explanation of all PHEV Fleet Testing Report notes.

- **3-page PHEV fact sheets provide fuel use 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**
- **682,000 Hymotion Prius test miles and 74,000 trips in 2009**
- **Total 1.2 million 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.

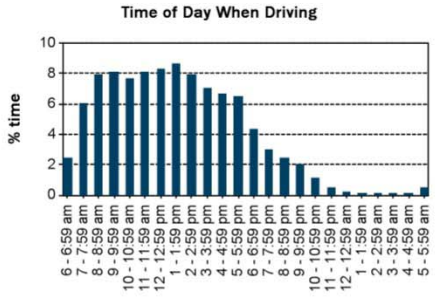


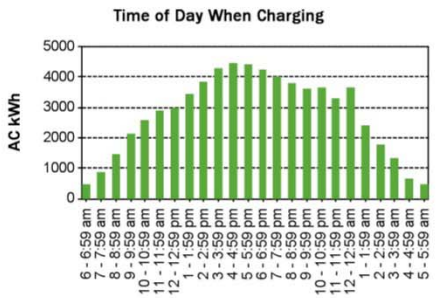
- **3-page PHEV fact sheets provide fuel use by highway/city cycles and driver style**
  - **CD city, 60 mpg (-38%), 165 DC Wh/mi**
  - **CD highway, 66 mpg (-32%), 109 DC Wh/mi**
  - **CS city, 37 mpg**
  - **CS highway, 45 mpg**
  - **Less aggressive driving (0 to 20%) averages ~80 mpg**

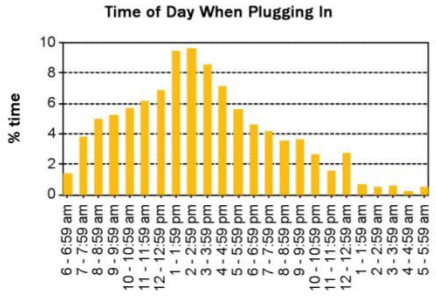
    (Aggressiveness = accelerator pedal position)

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



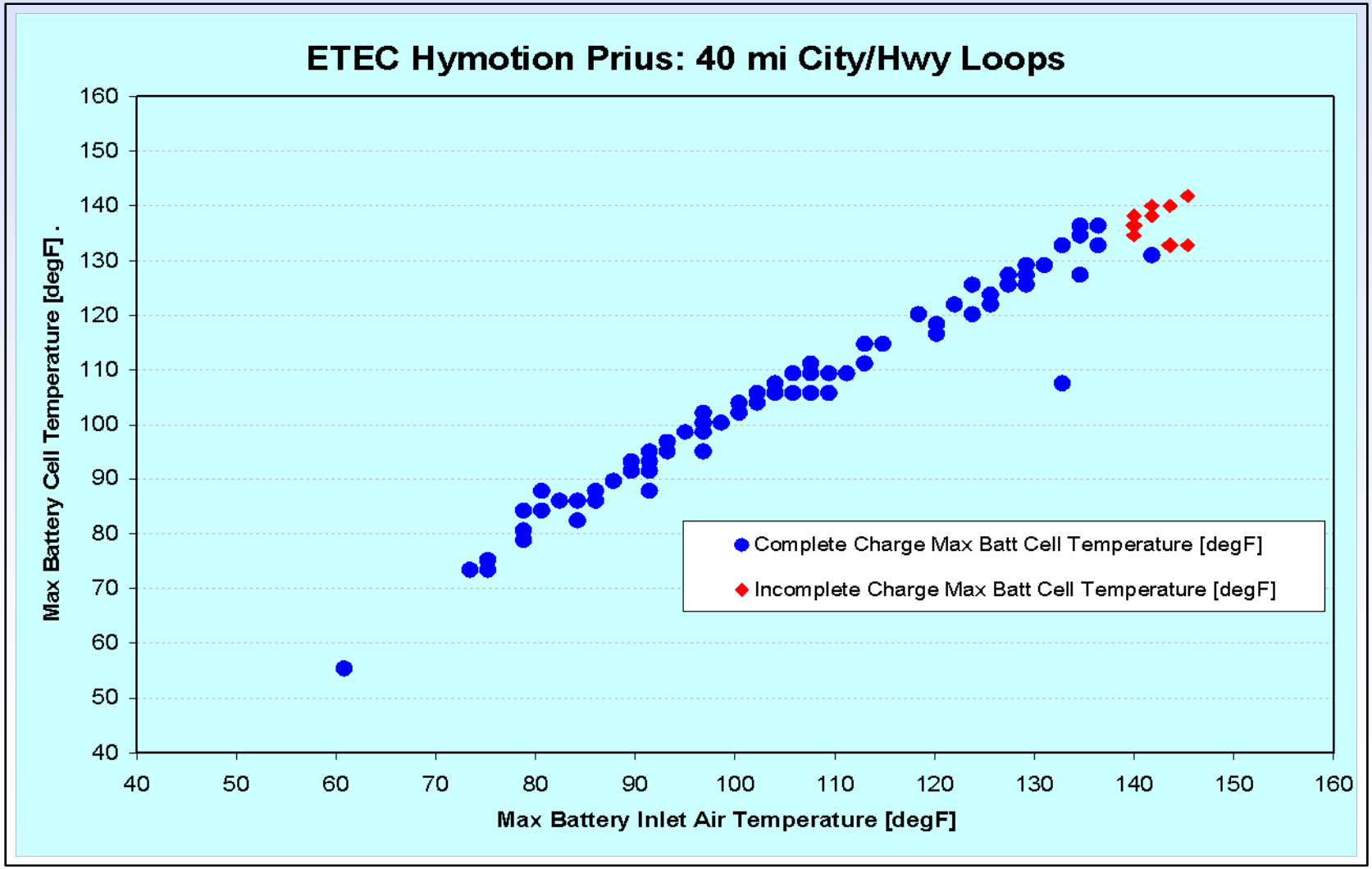




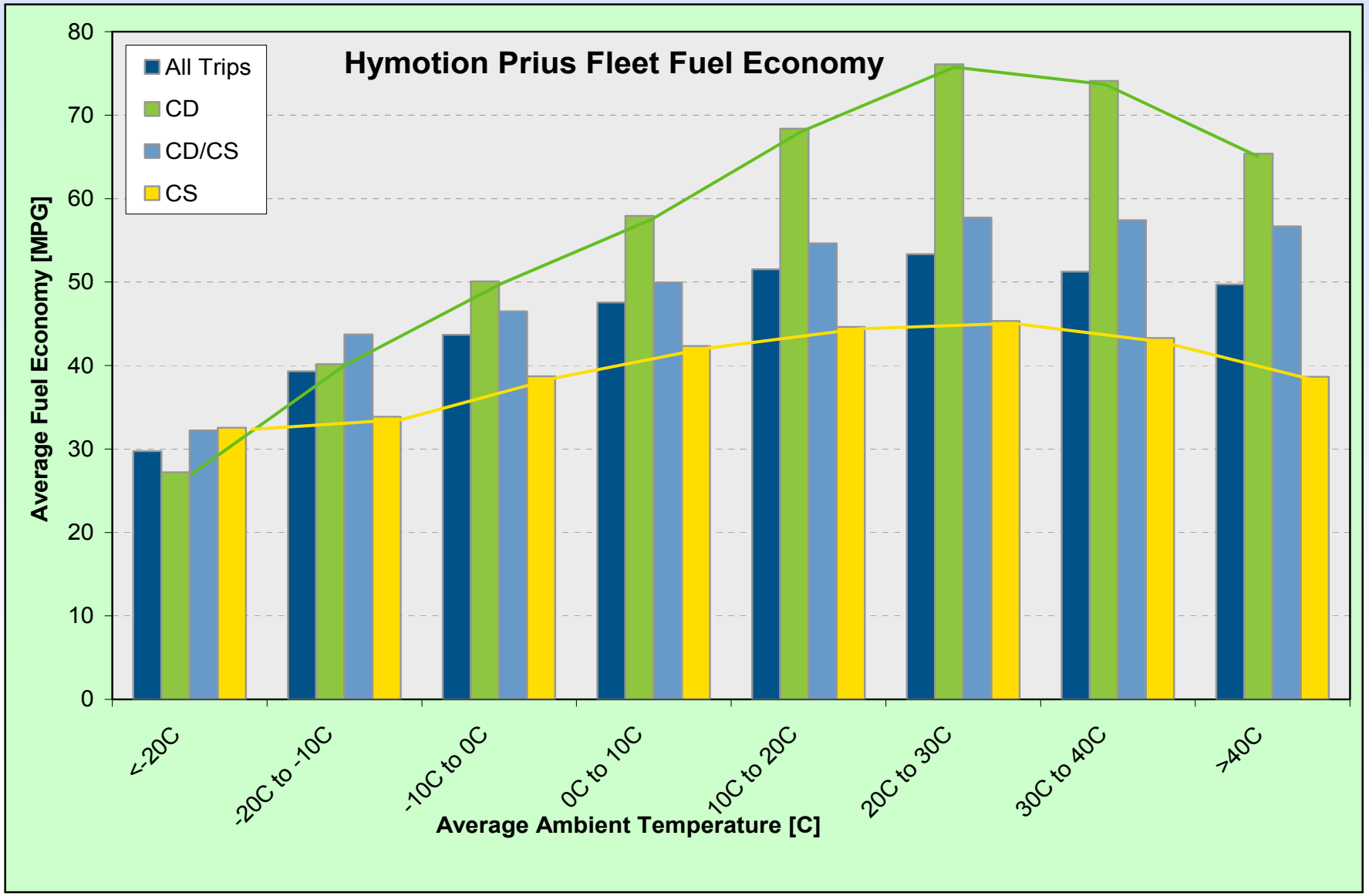
- **3-page PHEV fact sheets provide charging stats, time of day driving, and charging profiles**
  - **Average 1 charging event per day when PHEV driven**
  - **44.8 miles between charge events**
  - **4.8 trips between charge events**
  - **2.8 hours per charge**
  - **20.9 hours time plugged in per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

Hymotion Prius PHEV – Accelerated Testing

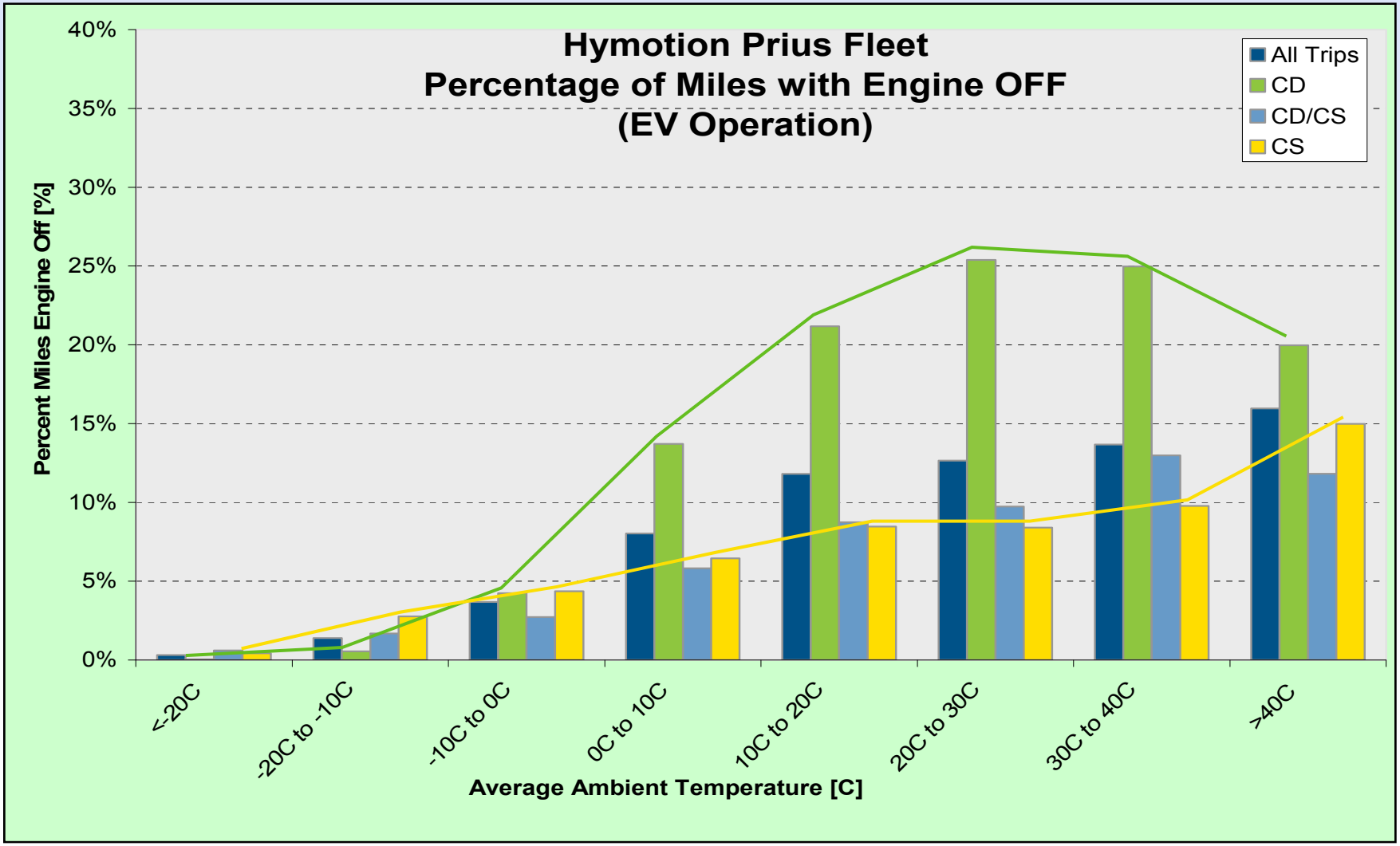
- **High ambient temperatures impact charge completion**



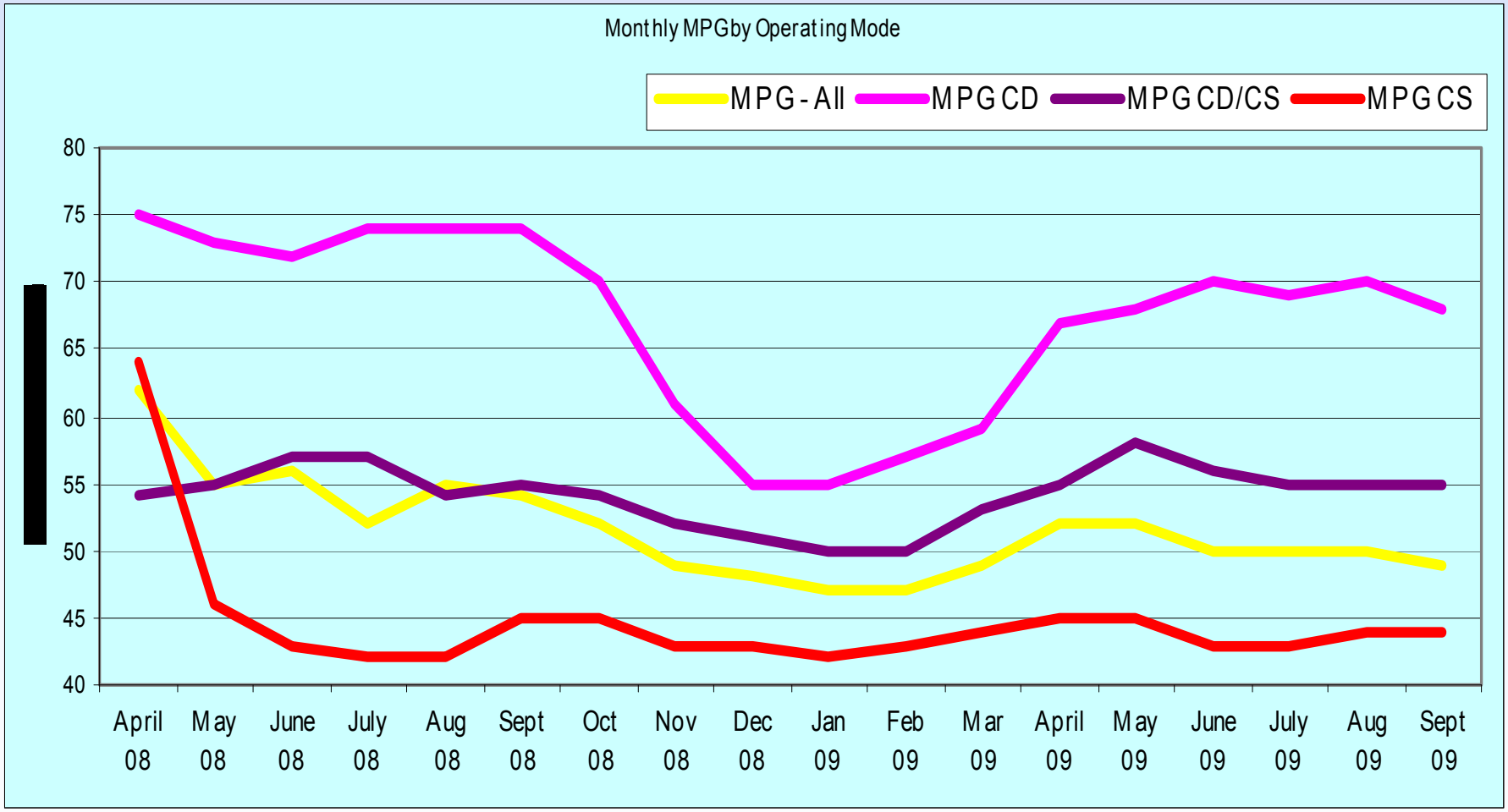
PHEV Ambient Temperature MPG Impacts



Engine Operation is a Main Factor for PHEV Fuel Economy Changes

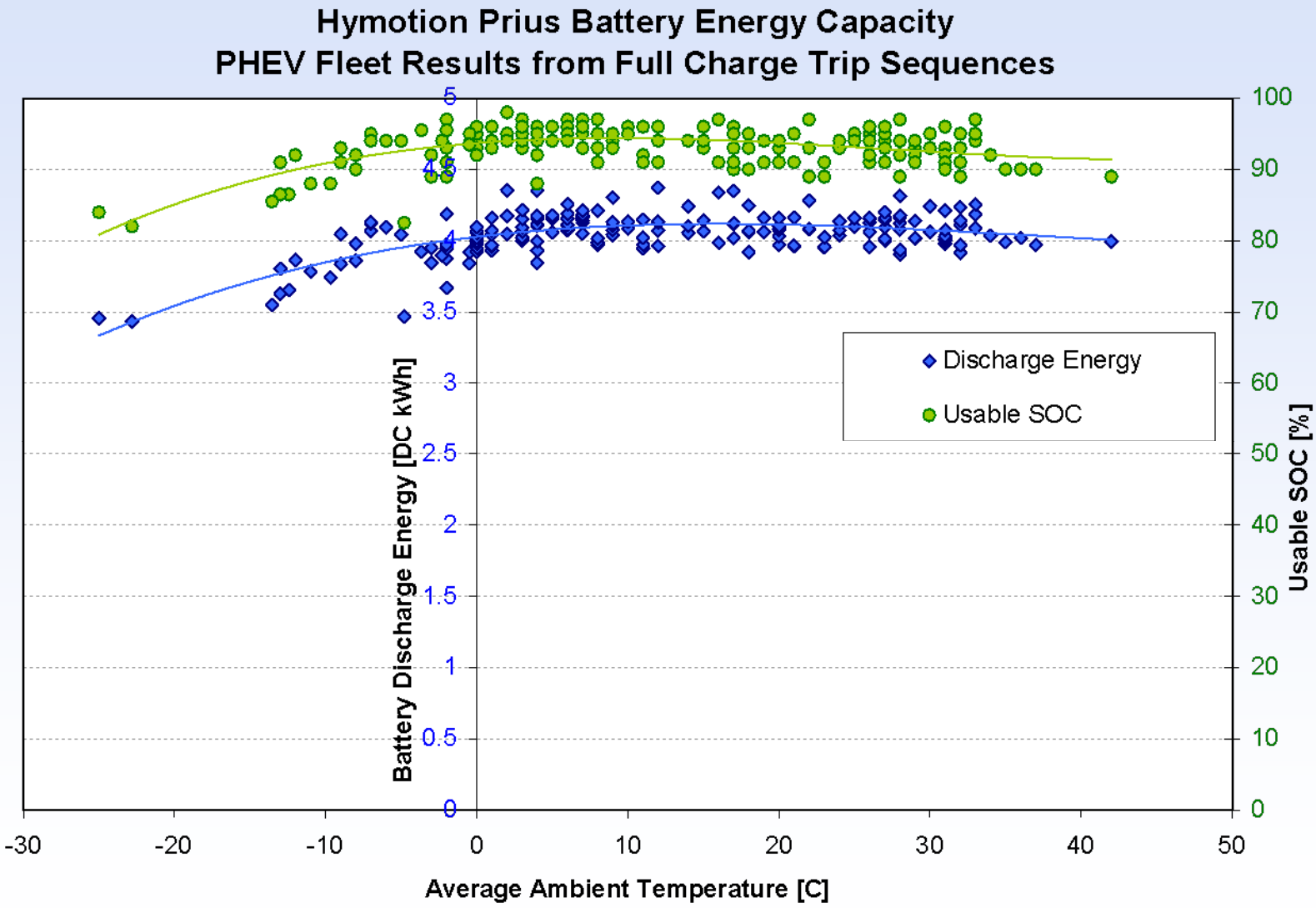


Monthly Fleet Testing MPG Results

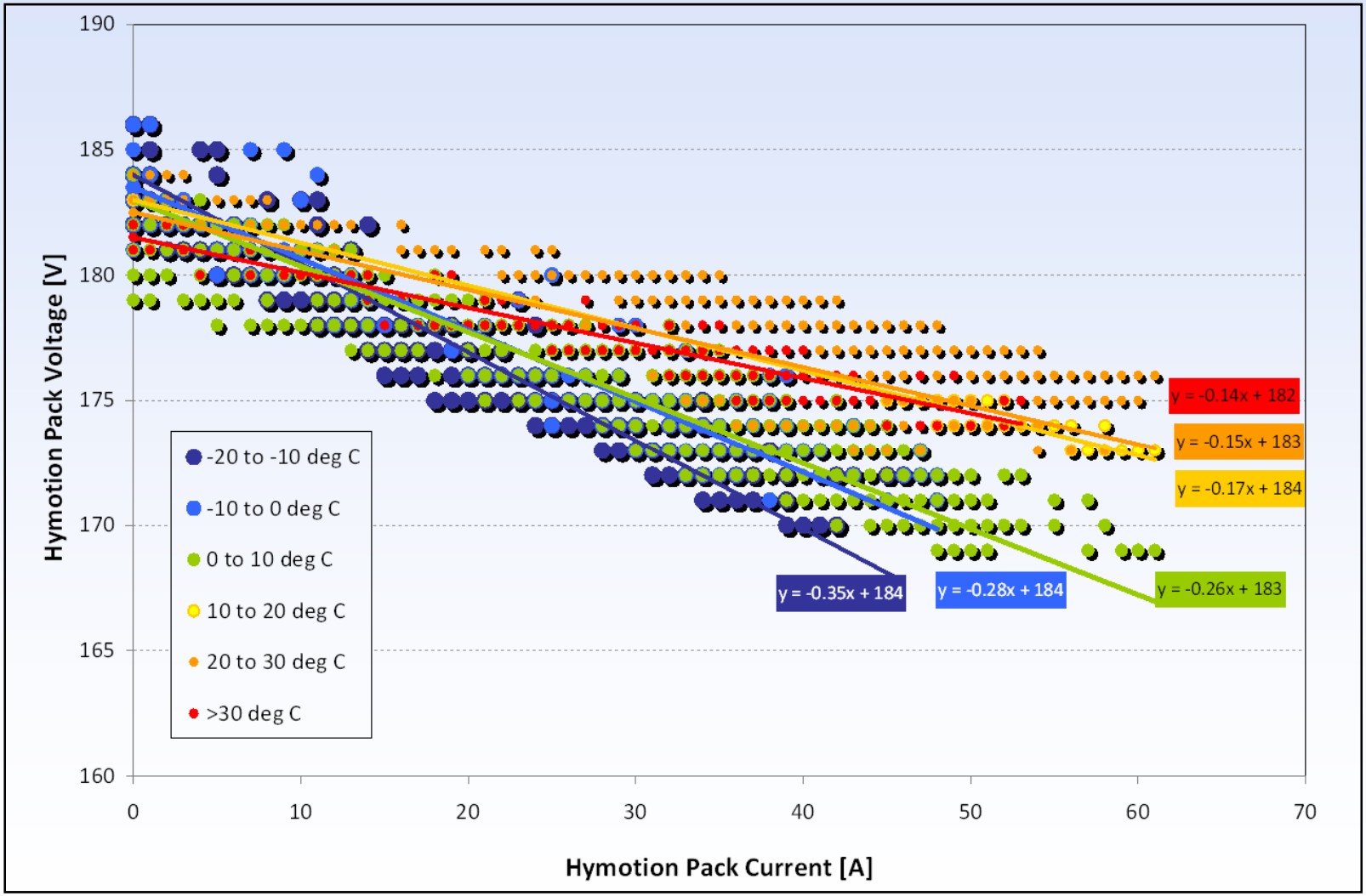


Hymotion Prius PHEVs with GridPoint (V2Green) data loggers – 731,000 miles of data from 108 vehicles (as of September 2009)

Usable Battery Capacity is Slightly Effected by Temperature

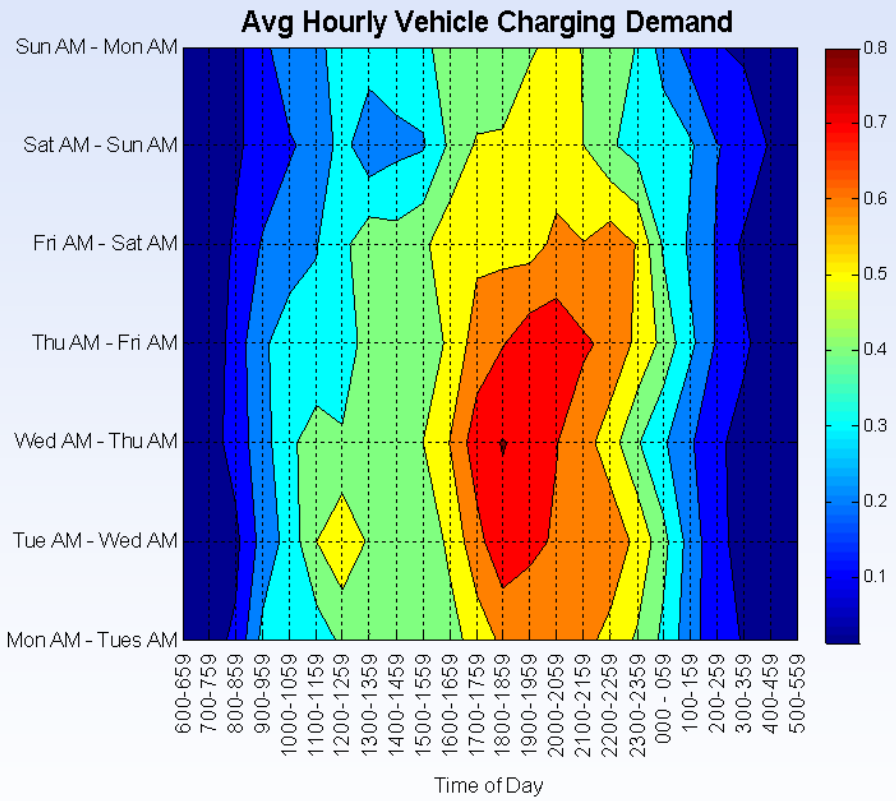


Hymotion Li-Ion Battery Internal Resistance Change with Temperature

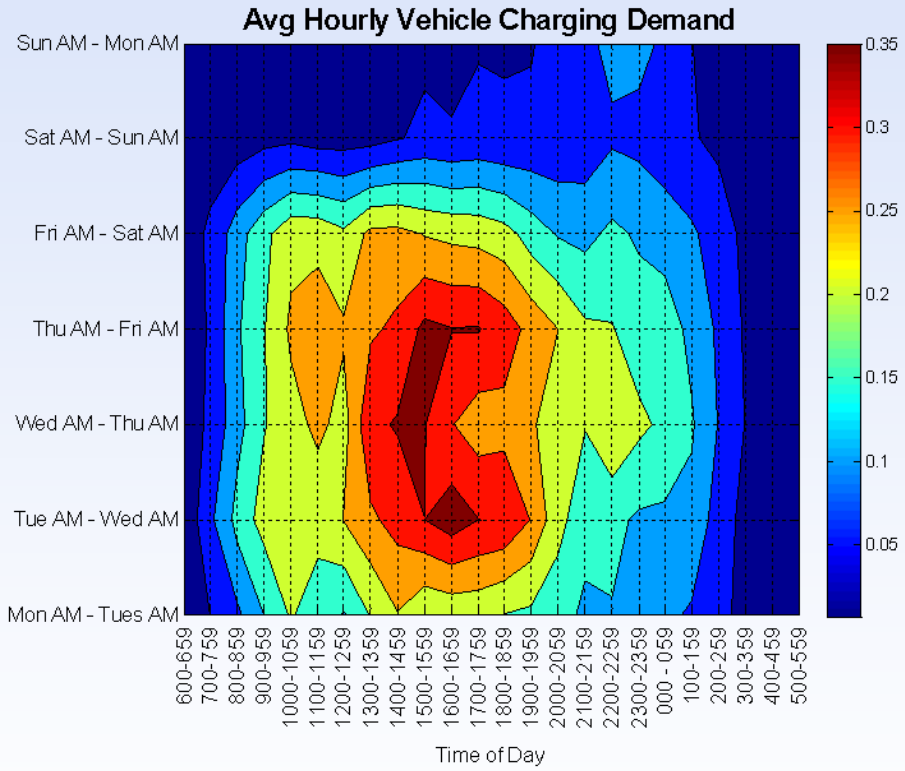


Commercial / Private Fleet Charge Demand

Private Fleet



Commercial Fleet



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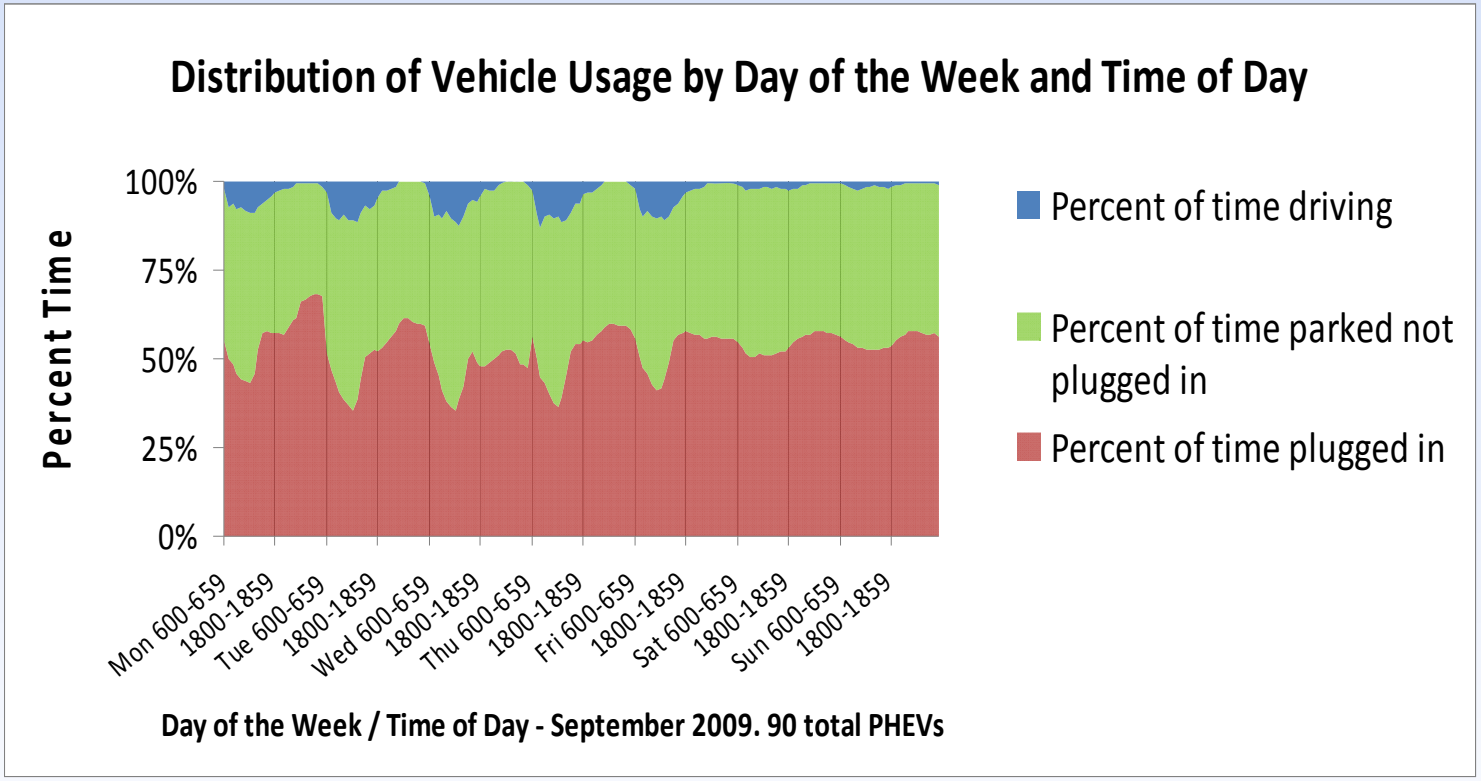
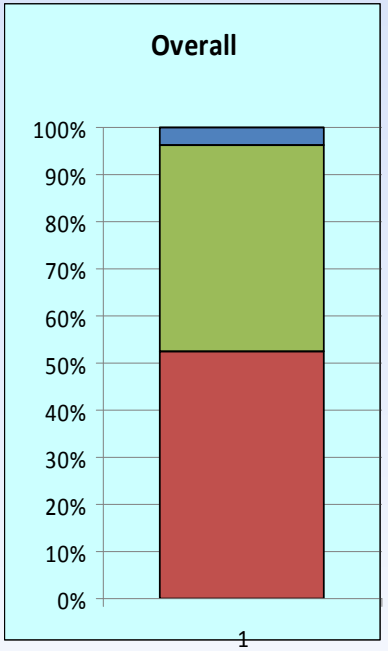
PHEV Charging Profiles



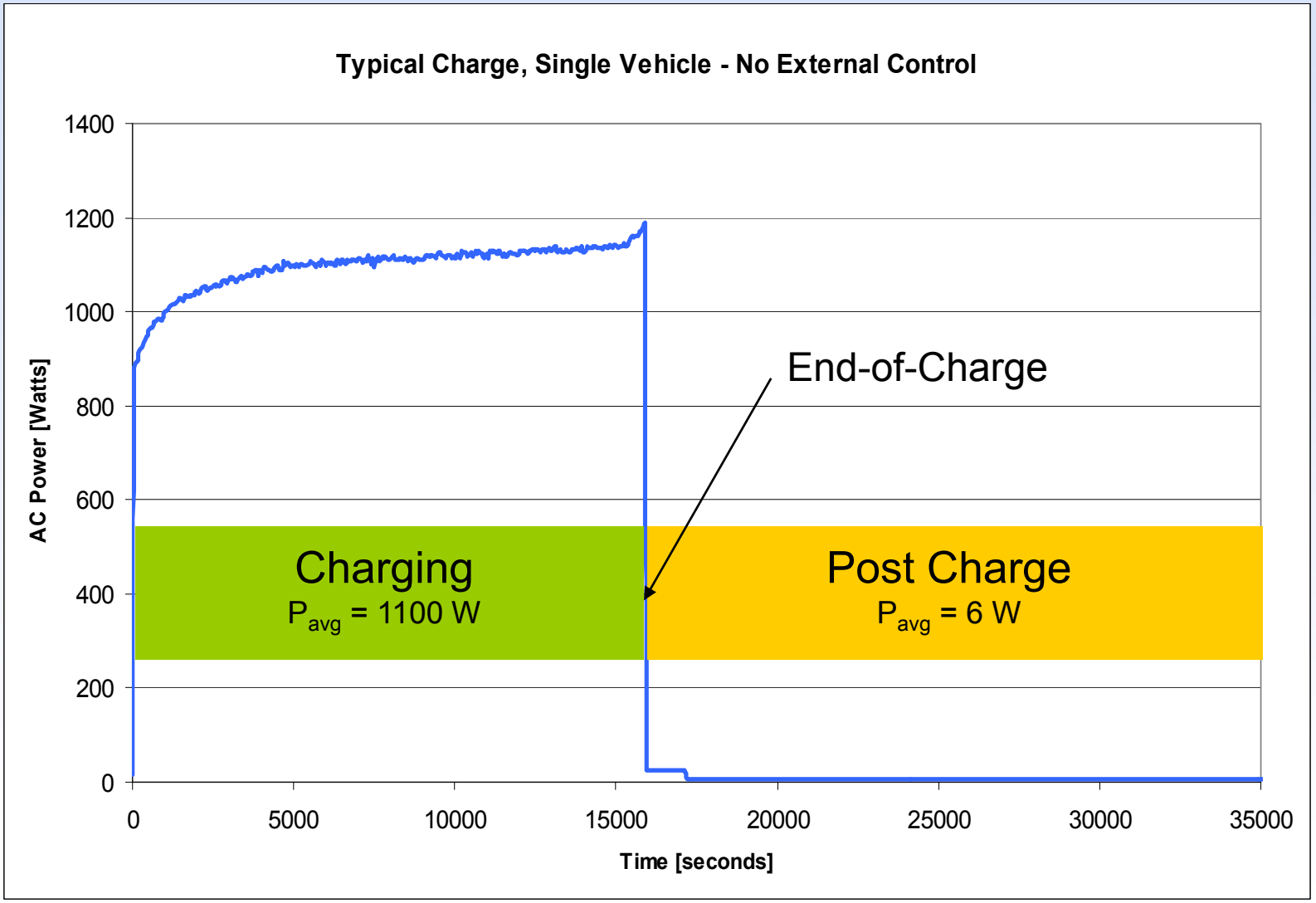


- **Next steps include:**
  - **Breaking down time parked by previous charge locations**
  - **SOC trends when parked at previous charge location**
  - **Duration and frequencies of individual parking events**
  - **GPS data substitutes for charge infrastructure data**

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

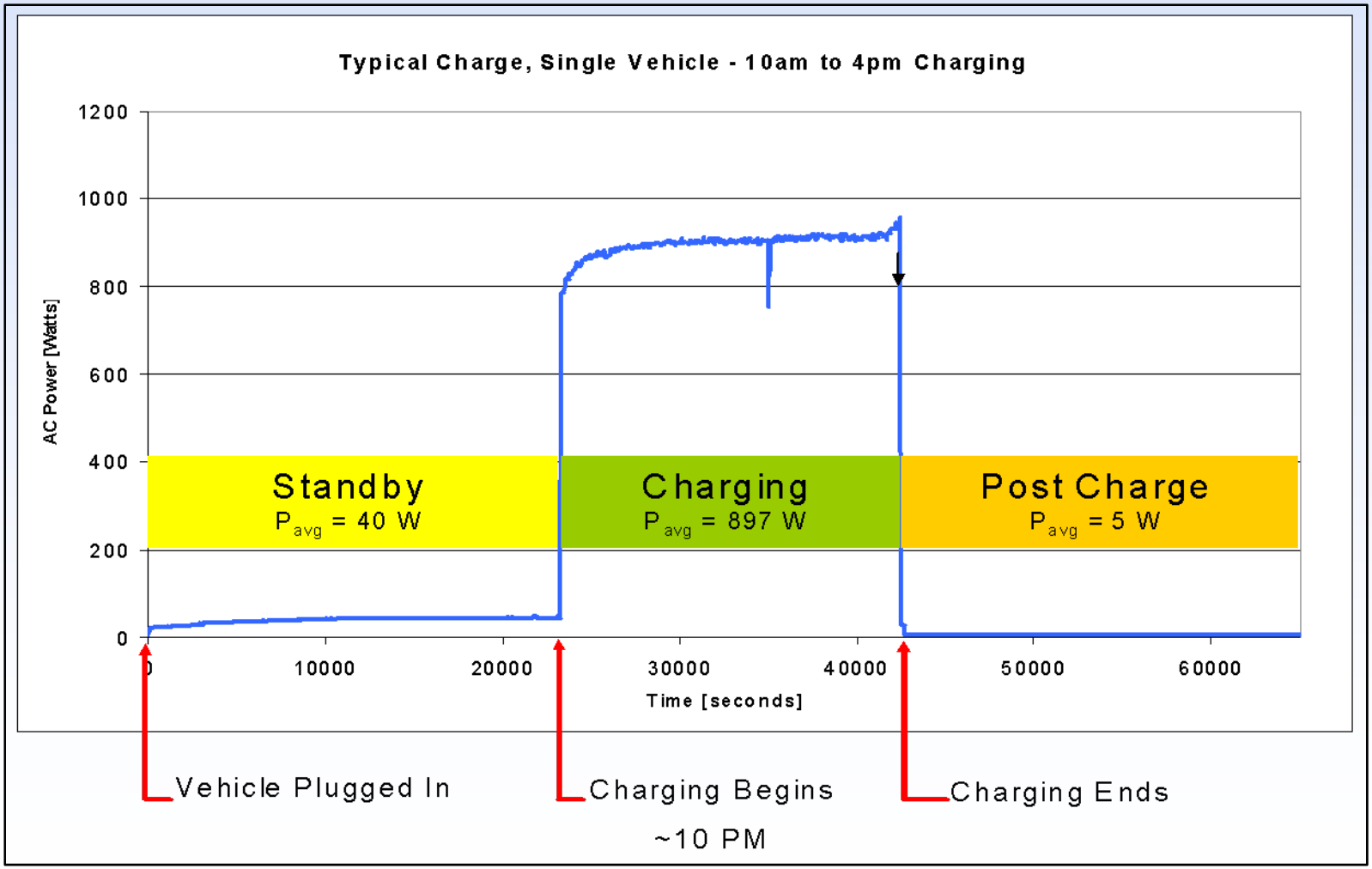
Charging – No Control



Hymotion Prius PHEV battery from A123 Systems

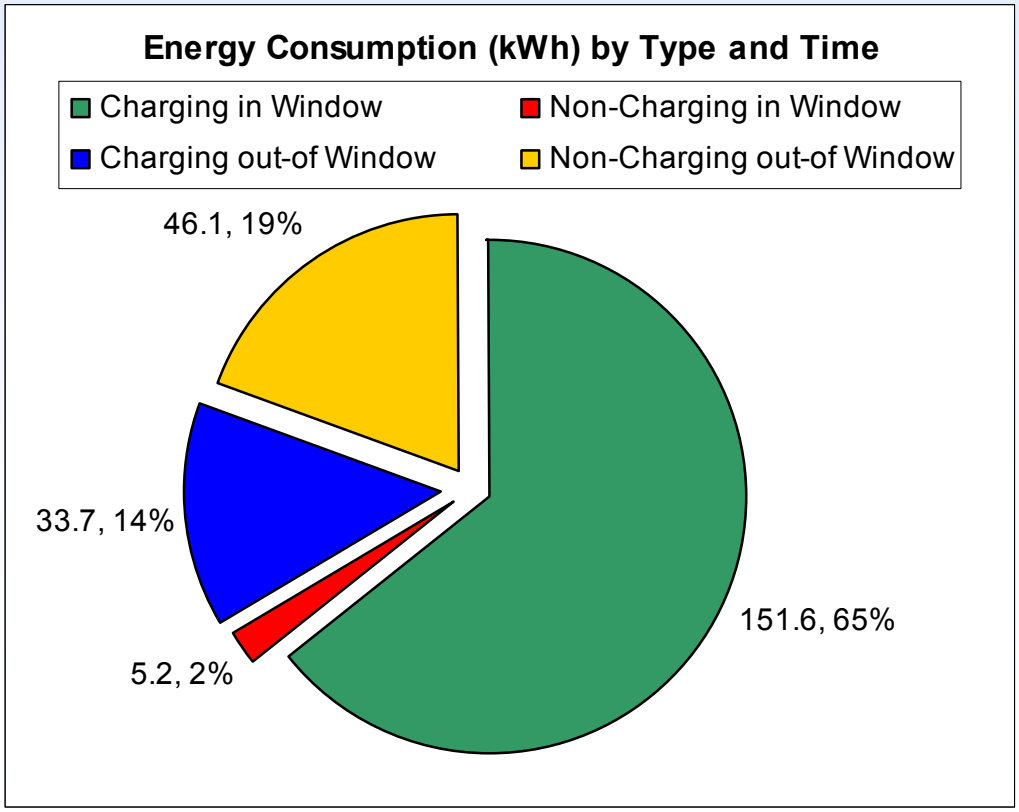
Results of Time of Day Charging Trials

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



Results of Time of Day Charging Trials

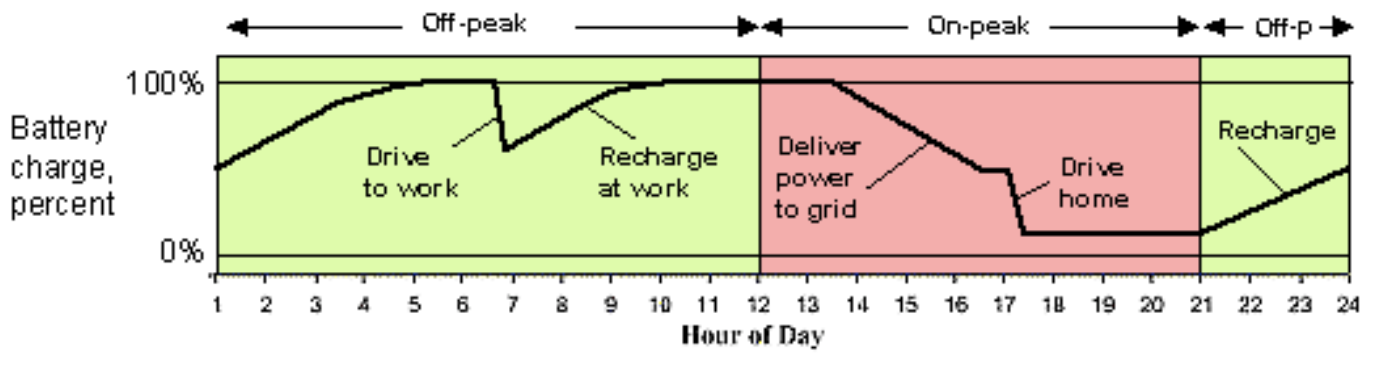
- Rogue AC kWh – energy drawn outside of allowable charging window
- Communication not established or lost - charging occurs
- Cumulative standby energy draw when not charging
- Only 65% of energy used as desired for charging



Vehicle To Grid/Building (V2B) Study

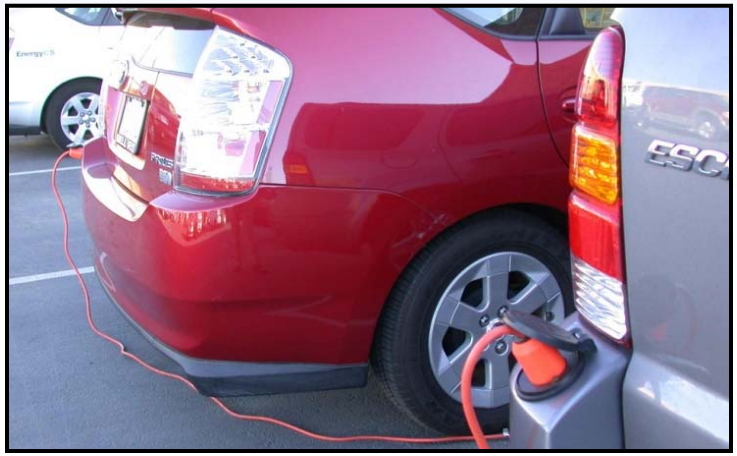
- Peak power
- Spinning reserve
- Regulation services

} V2G applications



- Distribution load reduction
- Facility demand reduction

} V2B applications



V2B Unknowns and Issues

- V2B Unknowns
  - How can potential demand reduction benefits be identified and realized?
  - What is the impact of V2B operations on battery life?
  - How should benefits and costs be allocated: vehicle owner ? facility owner ? electric utility ?
- Issues to Resolve
  - Discover practical difficulties with smart grid interface
  - Develop predictive discharge/charge algorithm to realize benefits
  - Quantify costs & benefits
    - Facility owner
    - Vehicle owner
    - Deal structure

V2B Project Scope

- Establish V2B interface
  - Hymotion Prius (A123)
  - eTec submeter
  - GridPoint communications
- Develop V2B algorithm to minimize facility demand
- Operate vehicles in V2B field demonstration
- Conducting laboratory battery cycling to establish cost parameters

V2B Assumed Vehicle Operation

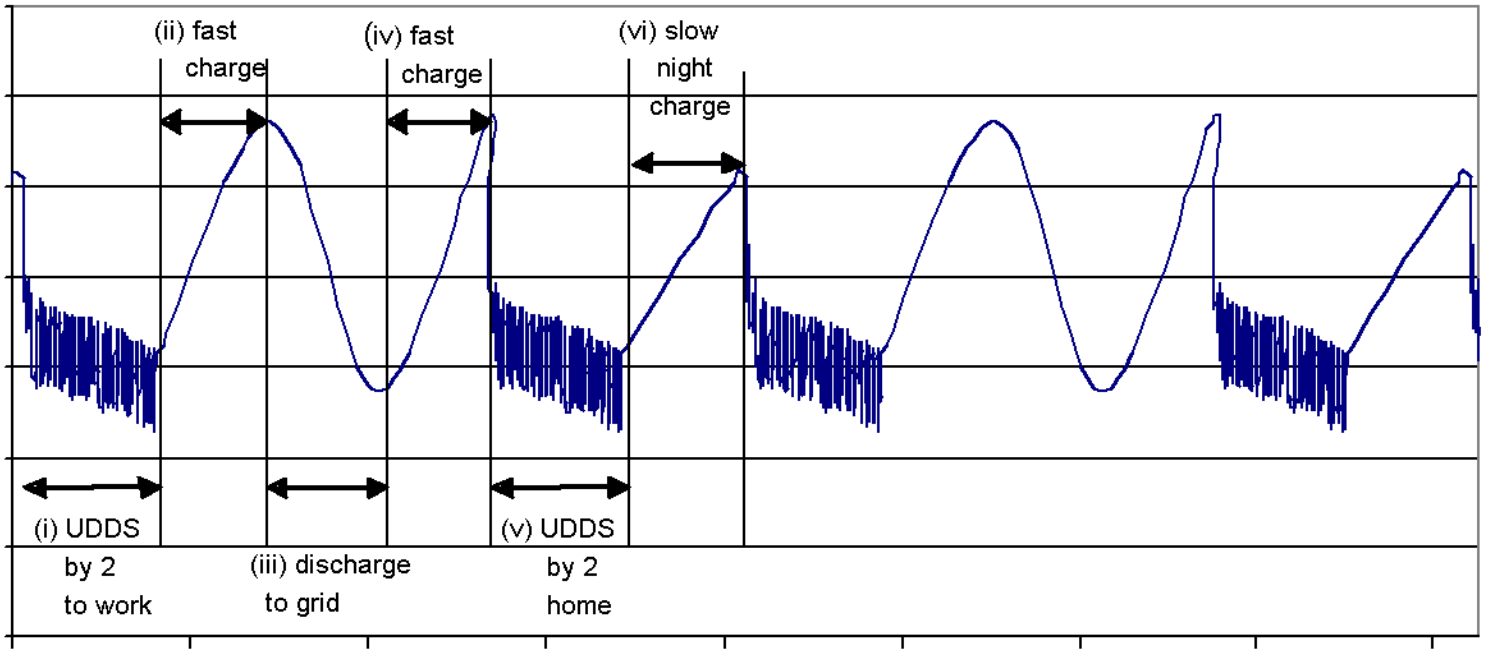
1. Drive on fixed route (drive to work)
2. Connect to grid (at work) and battery fast-charged (below facility peak)
3. Battery discharged during facility peak
4. Battery fast-charged after facility peak
5. Drive on fixed route (drive home)
6. Battery charged with onboard charger overnight

V2B Battery Testing

- Cycle PHEV Battery Pack In Laboratory
  - UDDS on road simulation
  - Accelerated test cycle (6 months/40,000 miles)
  - Evaluate cycle life - cost of building support
- Cycle two, 3-Cell Strings
  - Ambient temperature
  - Elevated temperature
- Test Protocol for 3-Cell Strings and Pack
  - UDDSx2 cycle (15 miles) - 100% to 40% SoC
  - Fast charge off peak – 40% to 90% SoC @ 2C
  - Discharge on peak – 90 to 30% SoC @ 2C
  - Fast charge post peak – 30 to 90% SoC @ 1C
  - UDDSx2 cycle (15 miles) - 90 to 30% SoC
  - “Overnight” charge – 30 to 100% SoC @ 1C

V2B Battery Testing

- **Pack and 3-Cell strings cycling is ongoing**



- **Voltage of Gen II A123 battery pack and cells during simulated PHEV service 2 days of simulated service shown; charge and discharge rates at 2C**

FY09 PHEV Milestones

- Introduced 4 new PHEV models into testing and demonstration activities
- Initiated demonstrations of another 105 PHEVs in FY09 at zero cost to DOE
- Produced and disseminated 1,176 monthly PHEV 3-page summary reports to testing partners during FY09
- 27 PHEV papers and presentations given in FY09
- 850,000 PHEV test miles and 95,000 trips in 2009, all with onboard data loggers
- Responded to numerous interview requests that ranged from DOE Clean Cities groups, to print, radio and video media
- Initiated V2B Project
- The PHEV onboard data collection system is growing at approximately 60 million records per month

Future PHEV Testing Activities

- **Continue to focus on testing PHEV technologies and sub-systems that:**
  - **Incorporate advanced electric drive systems and electric storage (battery) technologies**
  - **Support DOE's goal of ensuring the continued supply of secure energy sources**
  - **Can be tested in a lower-cost manner that accurately portrays real world performance**
  - **Can be tested in a manner that leverages non-DOE cost share**
  - **Document PHEV potential**
- **Continue to supply testing results to modelers at other DOE laboratories and OEMs**
- **Transition to OEM PHEV data collection. In CRADA and NDA data collection negotiations with several OEMs**
- **Continue role as DOE's sole independent tester of light-duty whole-vehicle technologies in field applications**

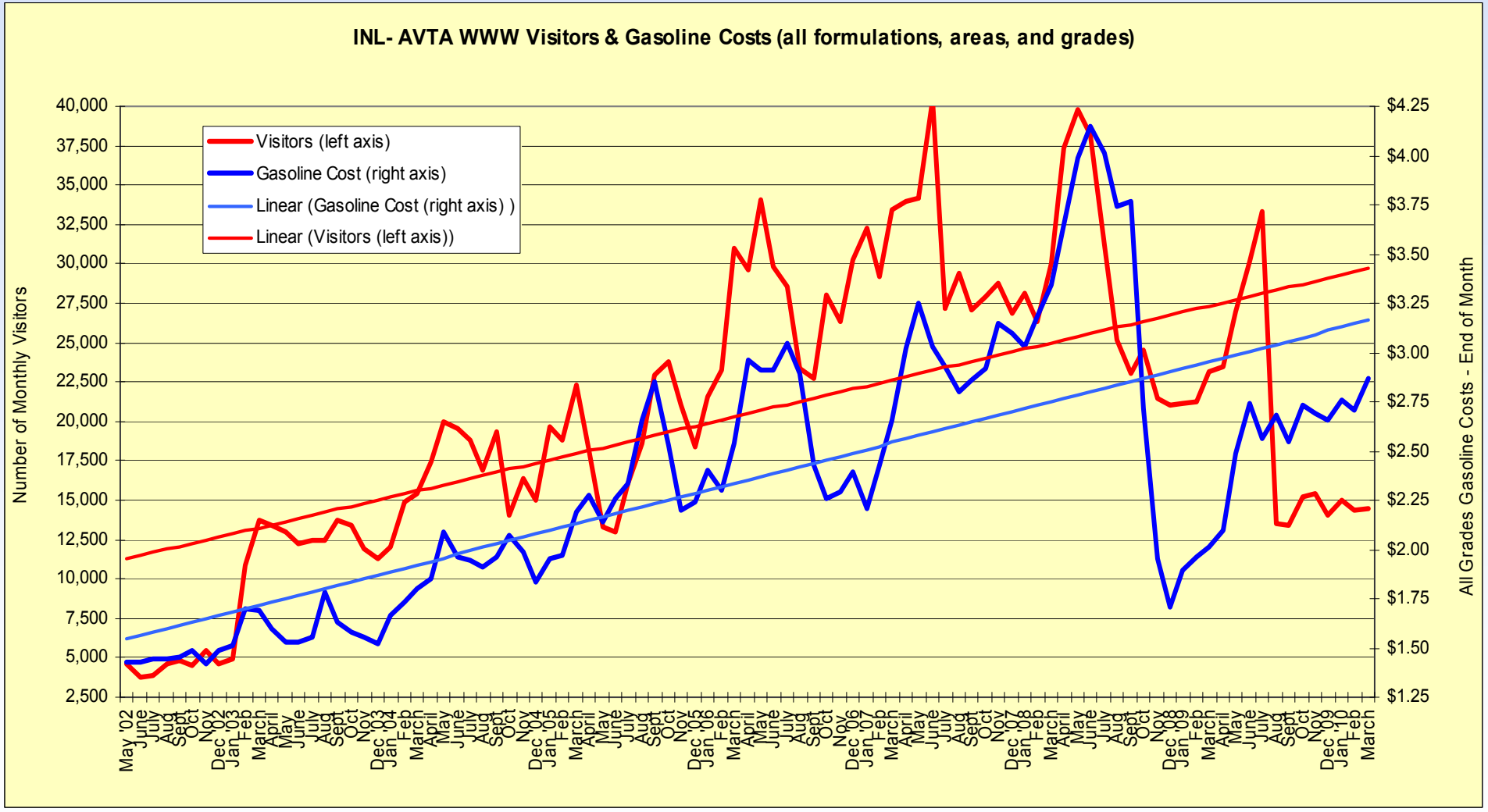
Summary

- Before a vehicle testing regime or demonstration is initiated, the AVTA identifies and determines the technical and economic values of testing partnerships to ensure that the maximum value to DOE and taxpayers are achieved
- AVTA is a very low-cost project for the number of test miles and data accumulated, and the number of reports published, as all funding is highly leveraged via testing partnerships to provide maximum benefits to DOE and taxpayers
- Every testing regime has at least 20% cost share, and most PHEV testing is cost-shared at greater than 50% with non-DOE sectors
- Taxpayers receive independent information on emerging technologies and the associated amounts of petroleum used or avoided

Summary – cont'd

- In addition to continuing to cooperate with the 93 non-DOE partners, the AVTA will continue to coordinate vehicle selection, testing and publishing activities with other DOE labs and OEMs, including:
  - ANL
  - ORNL
  - NREL
  - Several OEMs and battery manufacturers via VSATT and other DOE/USCAR technical teams such as the EESTT
- Continue to explore additional electric drive vehicle data collection and demonstration projects that:
  - Provide access to new vehicles and technologies
  - Provide operating environment diversity
  - Provide high value to DOE

AVTA Summary – WWW Visitors



Acknowledgement

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Pat Davis, Lee Slezak, Dave Howell

And my personal thanks to the great AVTA Staff at INL, eTec, and NETL

Additional Information

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

INL/CON-10-18396