



U.S. Department of Energy's Vehicle Technologies Program

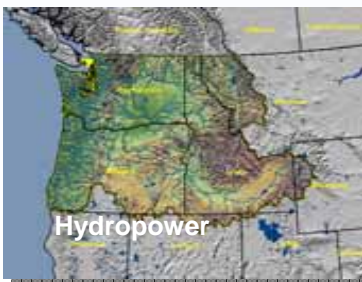
Oregon E.V. Road Map - Electric Drive Vehicle (PHEVs) Testing Activities and Results

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*E.V. Road Map – Preparing Oregon for the
Introduction of Electric Vehicles*
November 2009

Idaho National Laboratory (INL)

- Eastern Idaho based U.S. Department of Energy (DOE) Federal research laboratory
- 890 square mile site with 3,600 staff
- Support DOE's strategic goal:
 - Increase U.S. energy security and reduce the nation's dependence on foreign oil
- Multi-program DOE laboratory
 - Nuclear Energy
 - Fossil, Biomass, Wind, Geothermal and Hydropower Energy
 - Advanced Vehicles and Battery Development
 - Energy Critical Infrastructure Protection



AVTA Background

- INL's PHEV and other vehicle testing is conducted for DOE's Advanced Vehicle Testing Activity (AVTA). The AVTA is part of DOE's Vehicle Technologies Program
- INL and the Electric Transportation Engineering Corporation (eTec) jointly conduct the AVTA

AVTA Goal

- Provide benchmark data for DOE technology modeling, simulations, research and development activities, and to fleet managers and the general public to support their vehicle purchase, operations, and infrastructure deployment decisions
 - Accomplished via the development of cost-shared partnerships with public, private, and regional groups to test, deploy and demonstrate advanced vehicle and infrastructure technologies

AVTA Testing by Technology

- **Plug-in hybrid electric vehicles (PHEVs)**
 - 12 models, 216 vehicles, 1.1 million test miles
- **Hybrid electric vehicles (HEVs)**
 - 18 models, 47 vehicles, 4.7 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)**
 - 40 EV models, 5+ million test miles
- **Urban electric vehicles (UEVs)**
 - 3 models, 1 million test miles
- **Total of 12 million test miles accumulated on 1,600 electric drive vehicles representing 96 different electric drive models**



12 PHEVs Models in Testing/Demonstrations

- Hymotion Prius (A123Systems)
- Hymotion Escape (A123Systems)
- Ford E85 Escape (Johnson Controls/Saft)
- EnergyCS Prius, 2 models (Valance and Altair Nano)
- Electrovaya Escape (Electrovaya)
- Hybrids Plus Escape, 2 models (Hybrids Plus and K2 Energy Solutions)
- Hybrids Plus Prius (Hybrids Plus)
- Manzanita Prius (lead acid)
- Manzanita Prius (Thunder Sky)
- Renault Kangoo (Saft NiCad)
- (All batteries are Lithium unless noted)



PHEV Testing Methods and Objectives

- Perform independent testing of PHEVs, using:
 - Baseline performance testing: closed test tracks and dynamometers
 - Accelerated testing: dedicated drivers operating vehicles on defined onroad loops
 - Fleet testing: everyday unstructured \ non-directed fleet and public use, with onboard data loggers
 - Laboratory testing of batteries
- Testing used to document:
 - Battery life, charging patterns and profiles and infrastructure requirements
 - Vehicle operations, fuel use (electricity and gasoline)
 - Driver and environmental influences on fuel use
 - Document the PHEV technology concept as well as PHEV batteries and models

PHEV Operating Modes

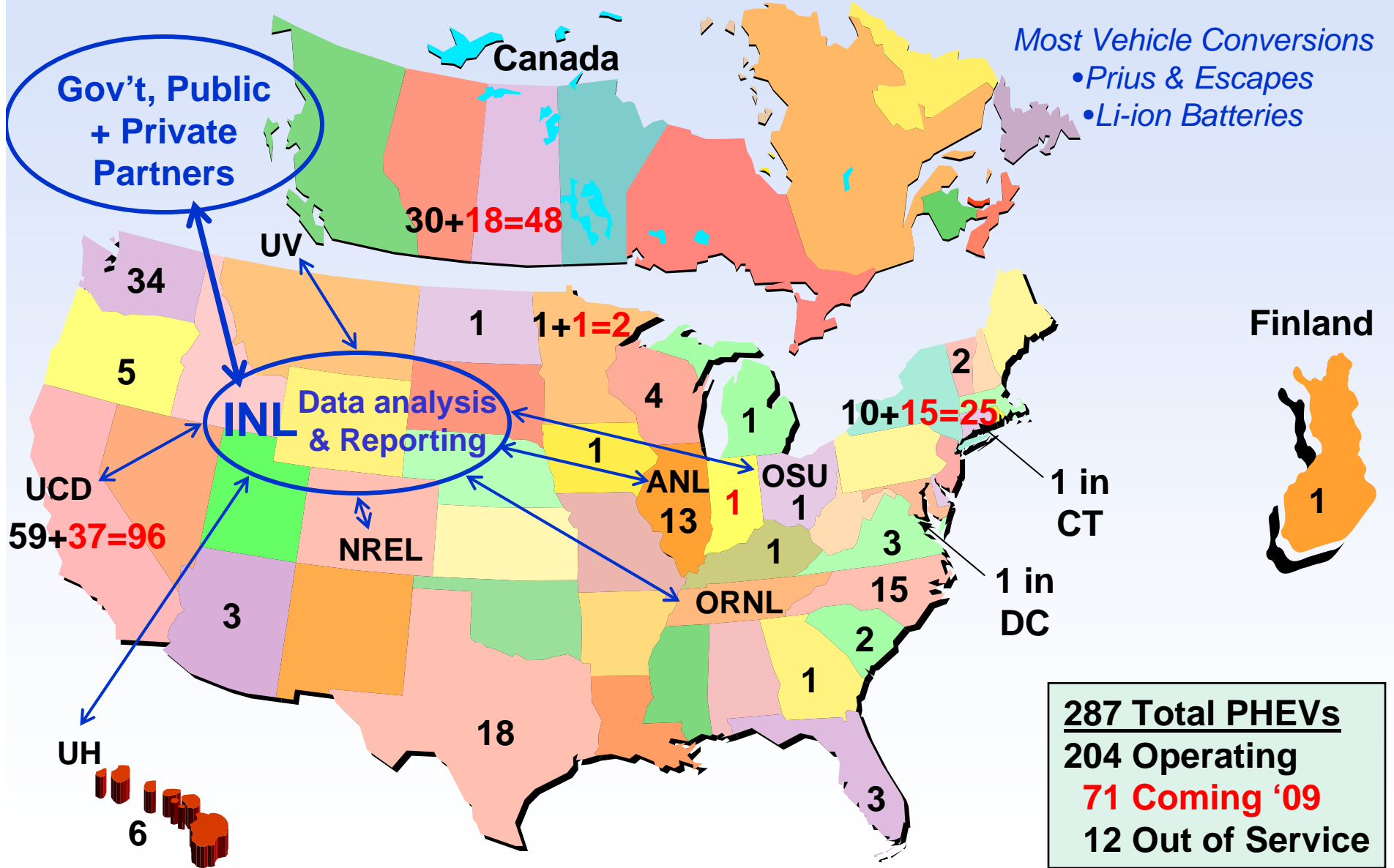
- **Charge sustaining (CS) mode**: from start to finish of a single trip, there is no energy available for electric drive propulsion in the PHEV battery. Therefore, the battery state-of-charge (SOC) at 0% is sustained
- **Charge depleting (CD) mode** – from start to finish of a single trip, there is energy available for partial or full electric drive propulsion in the PHEV battery. Therefore, the battery SOC is being depleted during the entire trip
- **Mixed CD/CS mode** – there is energy in the battery pack at the start of a single trip, but the PHEV battery is fully depleted before the trip ends



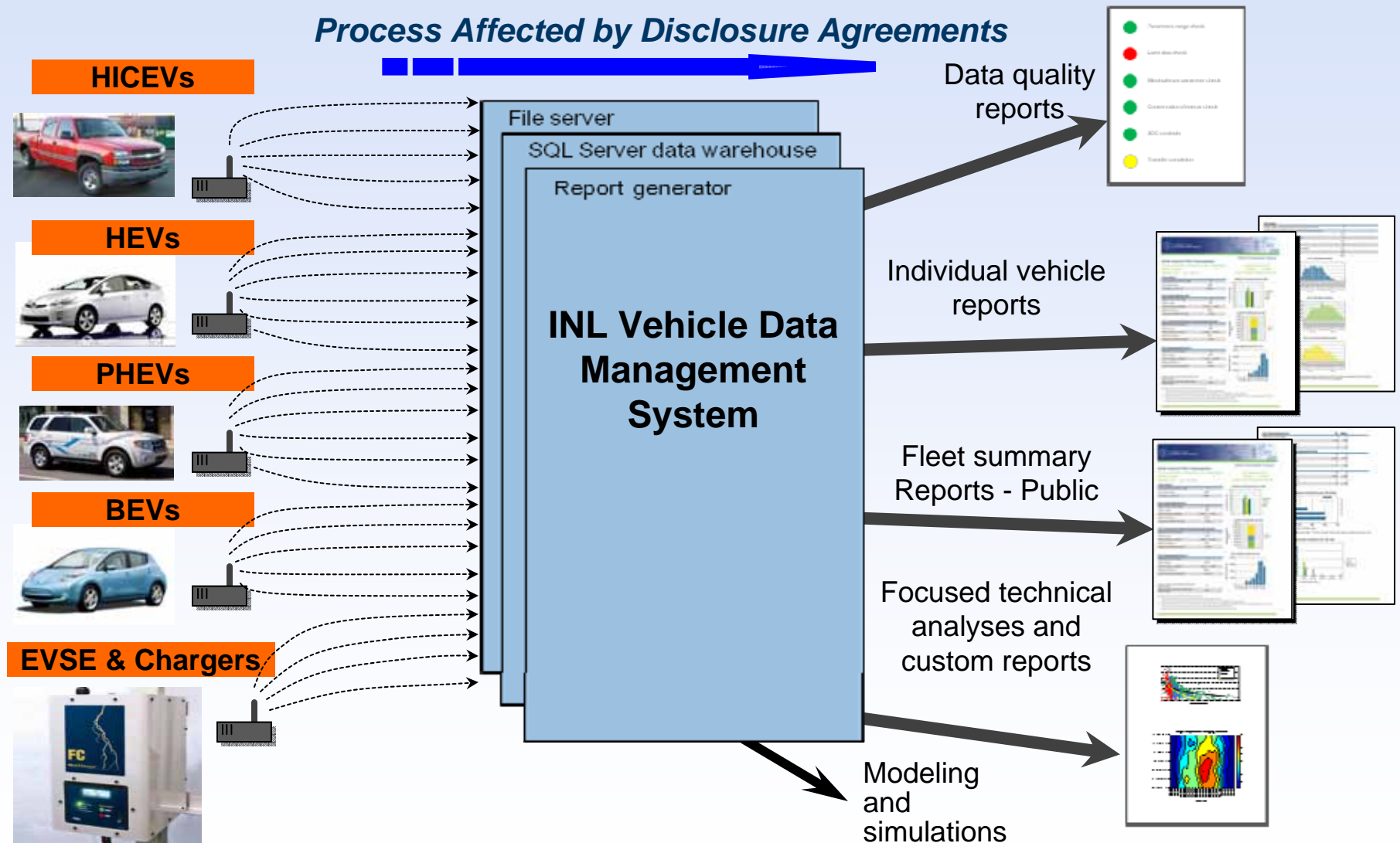
PHEV Fleet Testing Partners

- **75+ U.S., Canadian and Finnish testing partners**
 - **38 Electric utilities and 2 clean-air agencies**
 - **13 City, county, state and national governments**
 - **7 Private companies and advocacy organizations**
 - **8 Universities and colleges, and 4 Canadian provinces**
 - **2 PHEV companies 1 sea port and 1 DOD facility**
- **Testing partners include: A123Systems, EnergyCS, NYSERDA, NRECA, UC Davis, Google, Austin Energy, Central Vt PSC, Duke Energy, Advanced Energy, Salem Electric, Progress Energy, Portland and Pacific G&E, SDGE, Basin Electric, Buckeye Power, WI Public Power, Madison GE, Reliant Energy, SCANA, HCATT, BC Hydro, BC Government, Seattle, Tacoma Power, Ports of Chelan and Seattle, Puget Sound CAA, Wenatchee; King, Fairfax, Benton, Chelan and Douglas Counties; and several other Washington State fleets**

PHEVs and Demonstration Locations

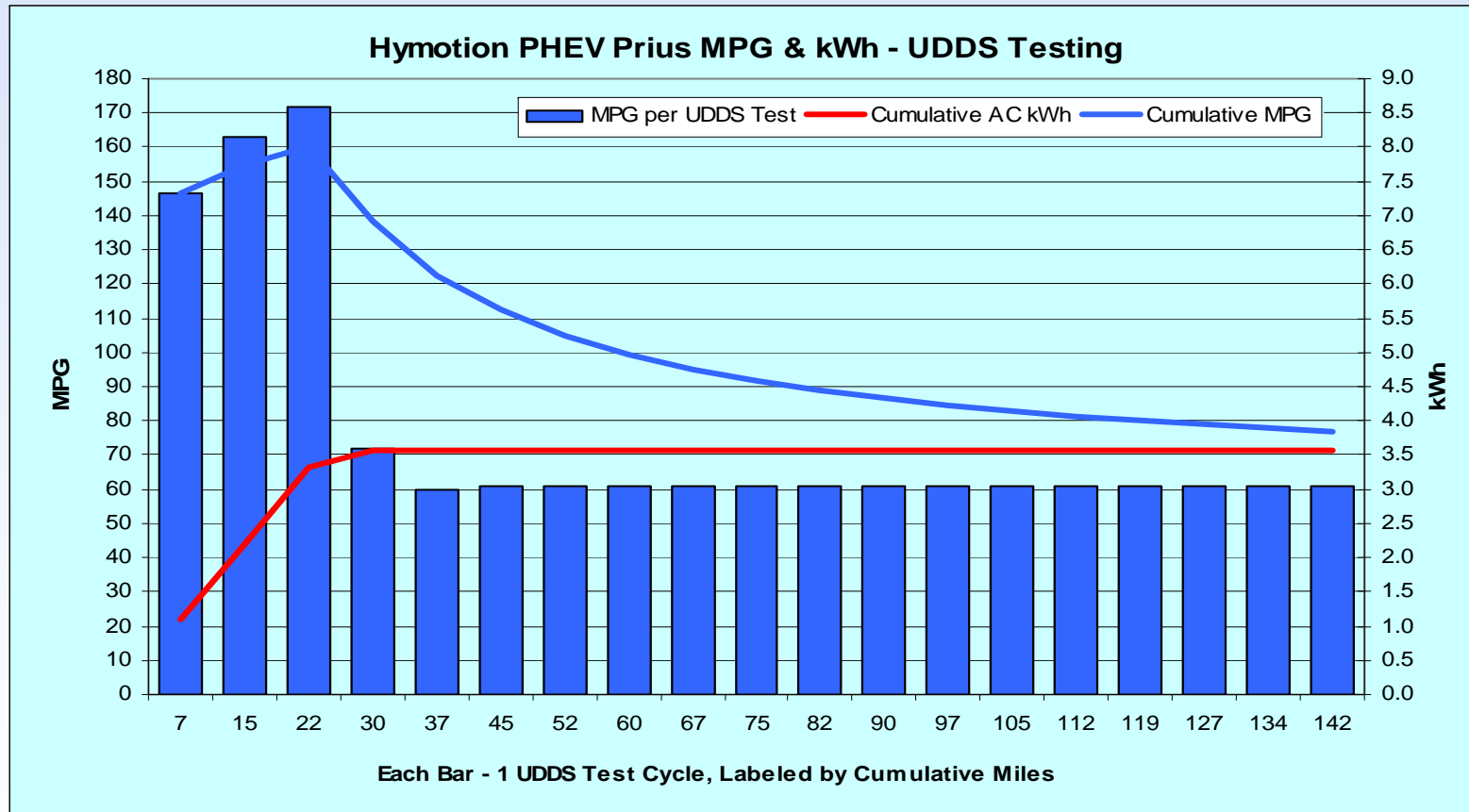


Vehicle Data Management Process



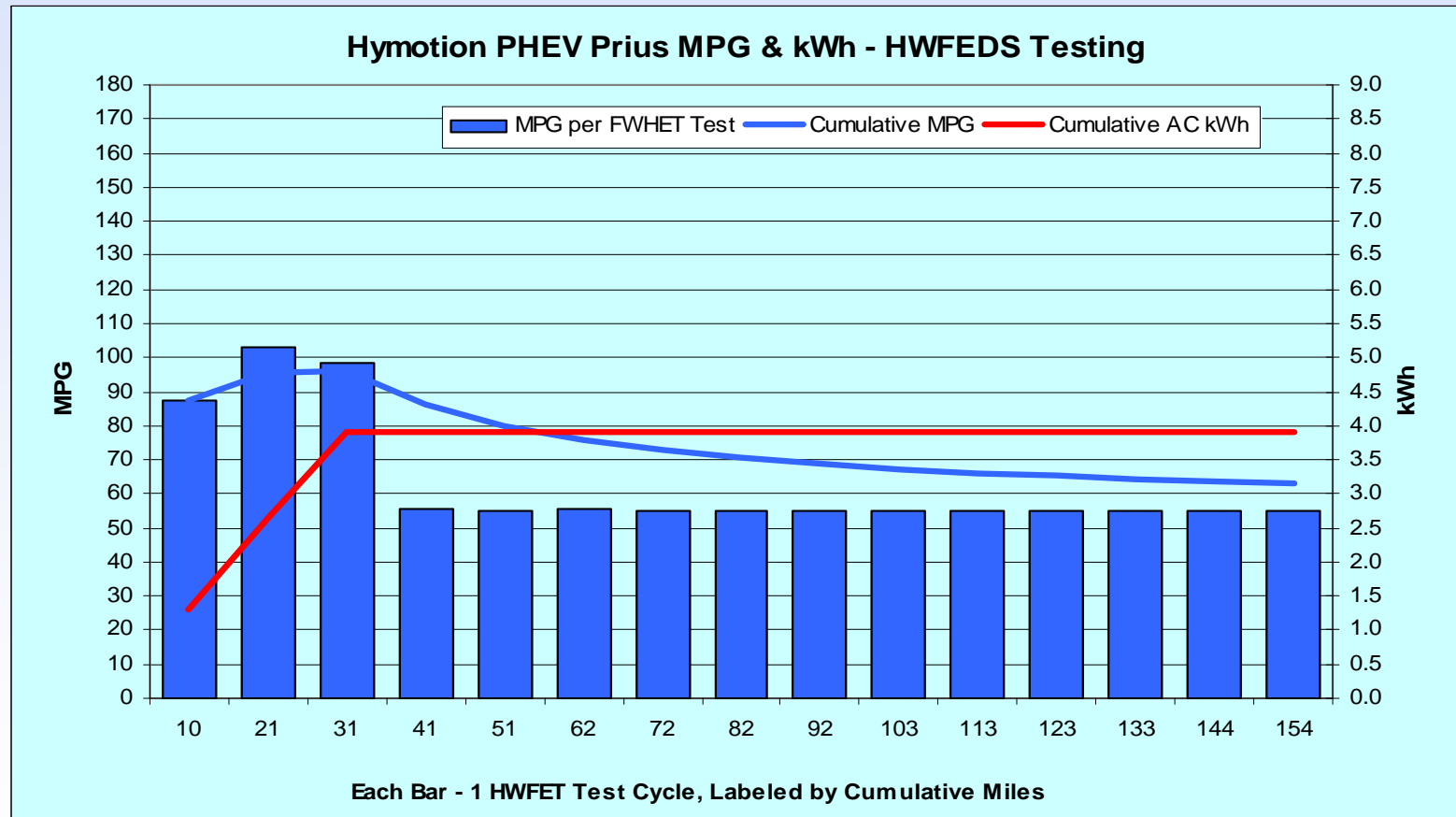
Hymotion Prius Gen I – UDDS Fuel Use

- 5 kWh A123Systems (Li) and Prius packs (AC kWh)



Hymotion Prius Gen I – HWFEDS Fuel Use

- 5 kWh A123Systems (Li) and Prius packs (AC kWh)



PHEV Accelerated Testing

- Accelerated testing in Phoenix over 5,440 onroad miles
- GPS units track distance, average and maximum speeds

Cycle (mi)	Urban (10 mi)	Highway (10 mi)	Charge (hr)	Reps (N)	Total (mi)	Reps (%)	Miles (%)
10	1	0	4	60	600	37%	11%
20	1	1	8	30	600	19%	11%
40	4	0	12	15	600	9%	11%
40	2	2	12	15	600	9%	11%
40	0	4	12	15	600	9%	11%
60	2	4	12	10	600	6%	11%
80	2	6	12	8	640	5%	12%
100	2	8	12	6	600	4%	11%
200	2	18	12	3	600	2%	11%
Total	2,340	3,100	1,344	162	5,440		
Average	43%	57%	8.3	18			

Hymotion Prius Gen I – Accelerated Testing

Cycle	Urban	Highway	Charge	Reps	Total	Electricity	Gasoline	
(mi)	(10 mi)	(10 mi)	(hr)	(N)	(mi)	AC kWh	Gals	MPG
10	1	0	4	60	600	136.33	4.81	127.2
20	1	1	8	30	600	122.02	5.37	115.9
40	4	0	12	15	600	84.10	6.05	101.1
40	2	2	12	15	600	87.22	5.78	106.9
40	0	4	12	15	600	79.82	8.54	73.1
60	2	4	12	10	600	55.33	8.98	68.9
80	2	6	12	8	640	43.99	11.36	58.3
100	2	8	12	6	600	35.98	8.43	73.2
200	2	18	12	3	600	15.0	11.02	54.8
Total	2340	3100	1404	167	5,440	Weighted Average		79.5

Each total distance slightly greater than 600 and 640 miles. HEV version = 44 mpg

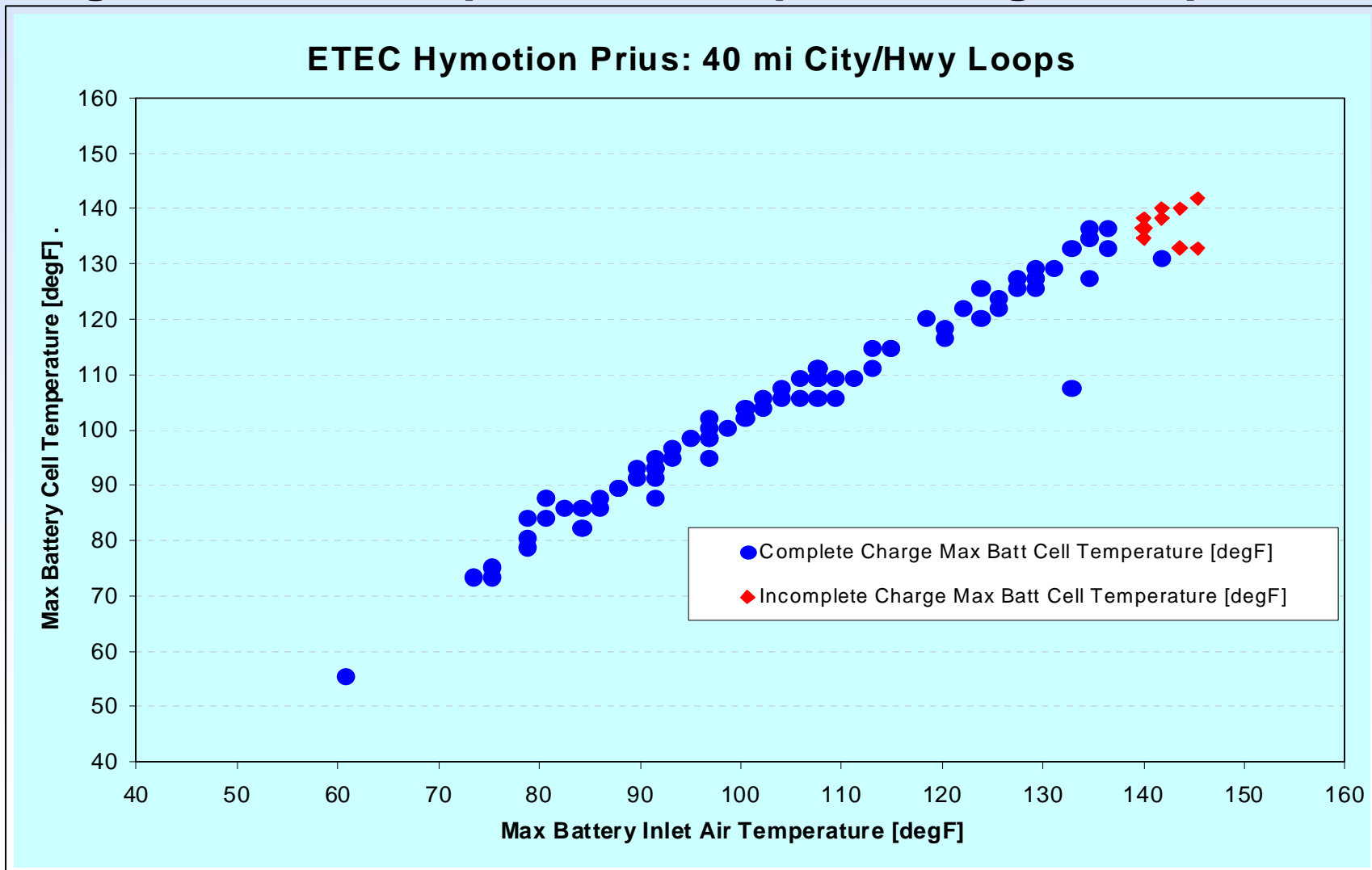
Hymotion Prius Gen II – Accelerated Testing

Cycle (mi)	Urban (10 mi)	Highway (10 mi)	Charge (hr)	Reps (N)	Total (mi)	Electricity AC kWh	Gasoline		Recalculated without incomplete charges
							Gals	MPG	
10	1	0	4	60	600	111.43	5.205	117.6 E	
20	1	1	8	30	600	124.50	8.105	80.1 I	
40	4	0	12	15	600	71.28	9.8	62.1 I	64.2
40	4	0	12	15	600	44.97	7.2	84.2 E	135.6
40	2	2	12	15	600	64.36	9.70	64.3 I	65.5
40	2	2	12	15	600	75.14	6.20	99.8 E	101.7
40	2	2	12	15	600	70.98	6.83	90.6 I	98.9
40	0	4	12	15	600	75.18	6.10	103.3 E	100.0
40	0	4	12	15	600	63.46	8.88	70.8 I	92.4
60	2	4	12	10	600	33.38	10.54	58.8 I	
80	2	6	12	8	640	41.38	10.71	61.8 I	
100	2	8	12	6	600	26.48	10.91	56.5 I	
200	2	18	12	3	600	16.01	10.41	57.7 I	
Total	2340	3100	1404	167	7,840	Weighted Average			

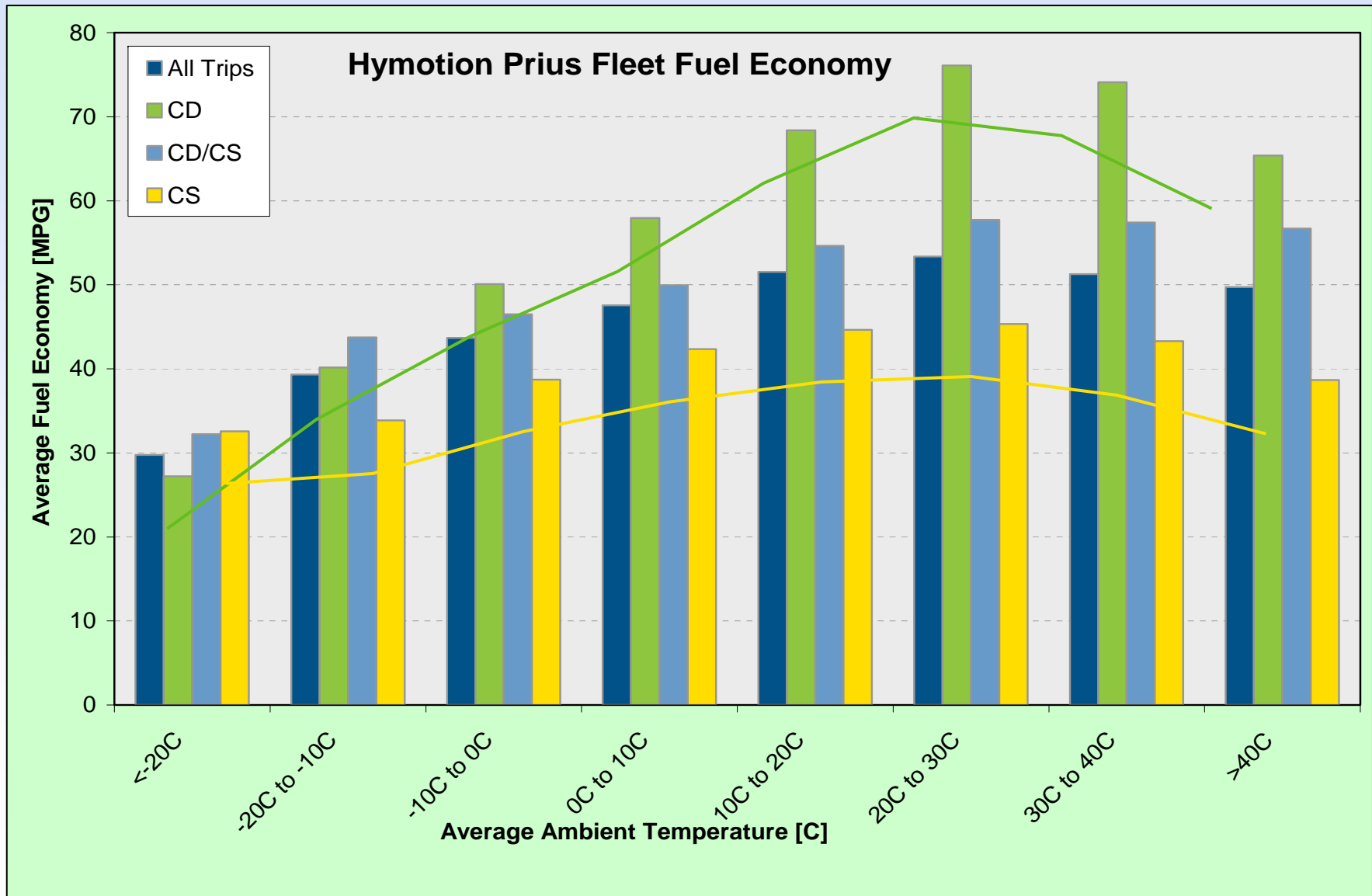
Each total distance slightly greater than 600 and 640 miles. HEV version = 44 mpg.
 E = experienced HEV driver, I = inexperienced driver

Hymotion Prius Gen II – Accelerated Testing

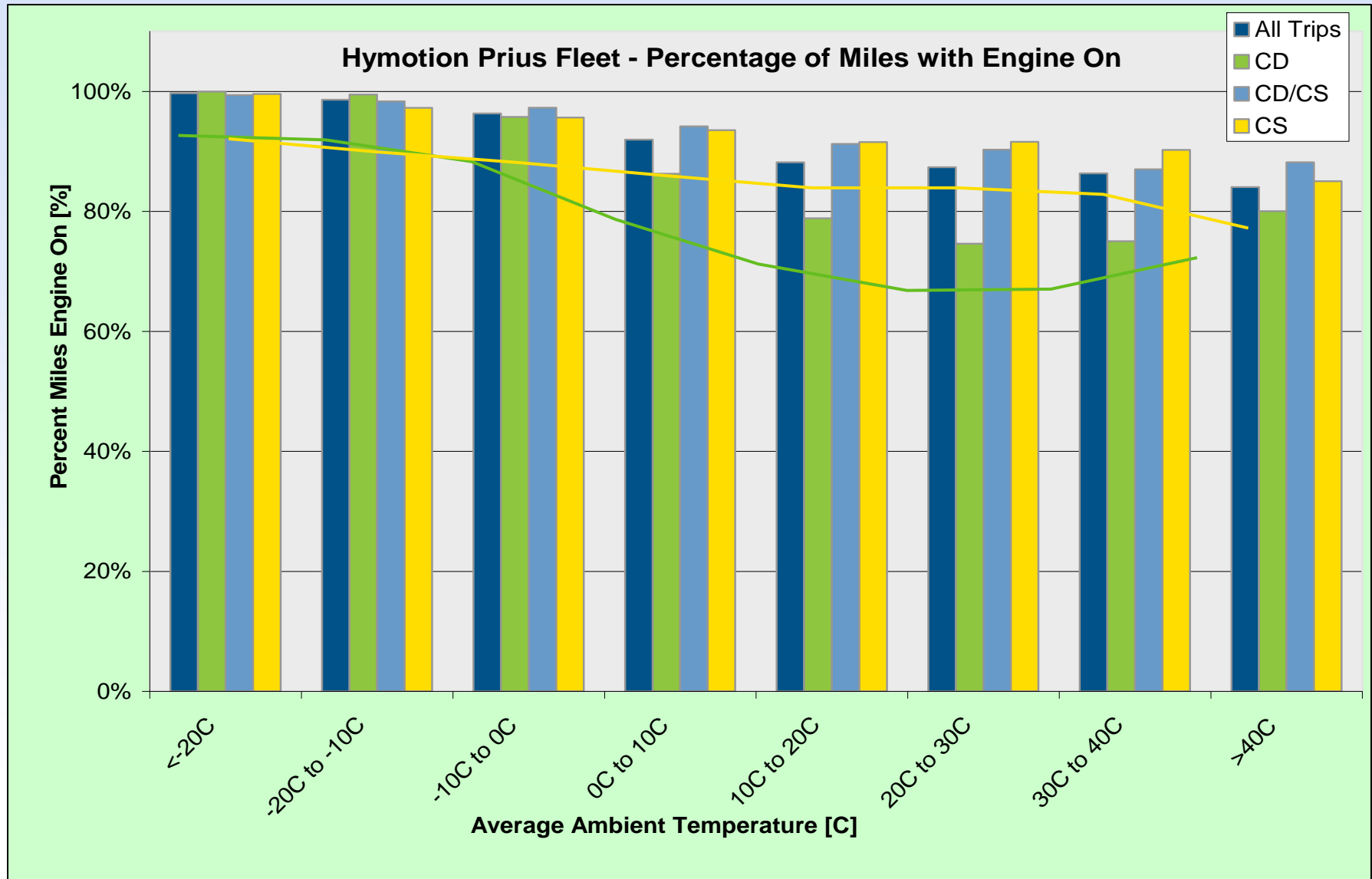
- High ambient temperatures impact charge completion



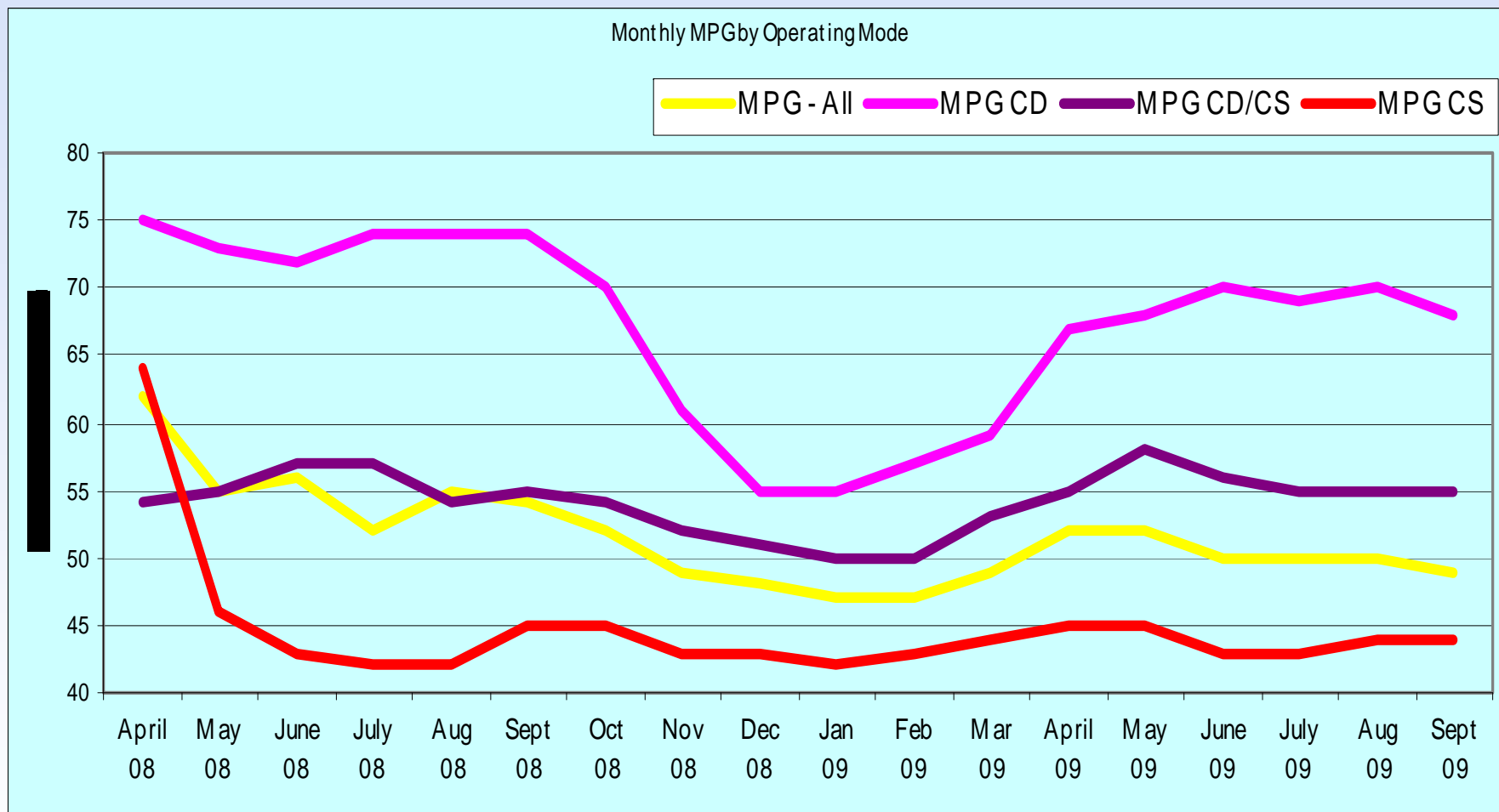
Ambient Temperature MPG Impacts



Engine Operations by Ambient Temperatures

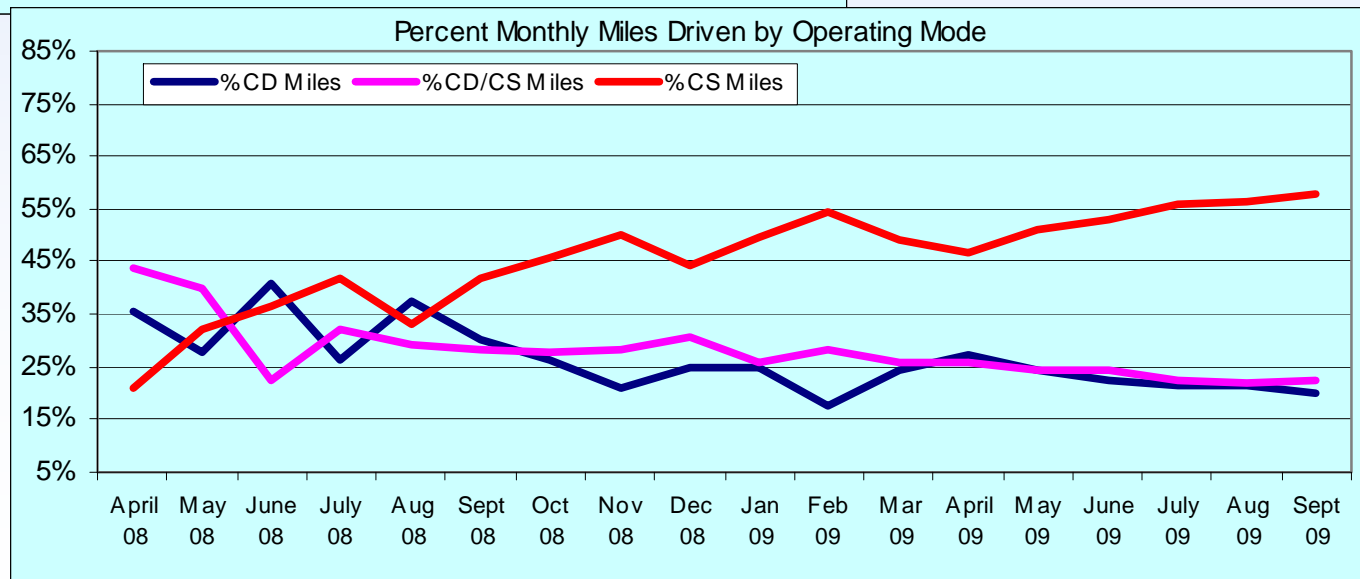
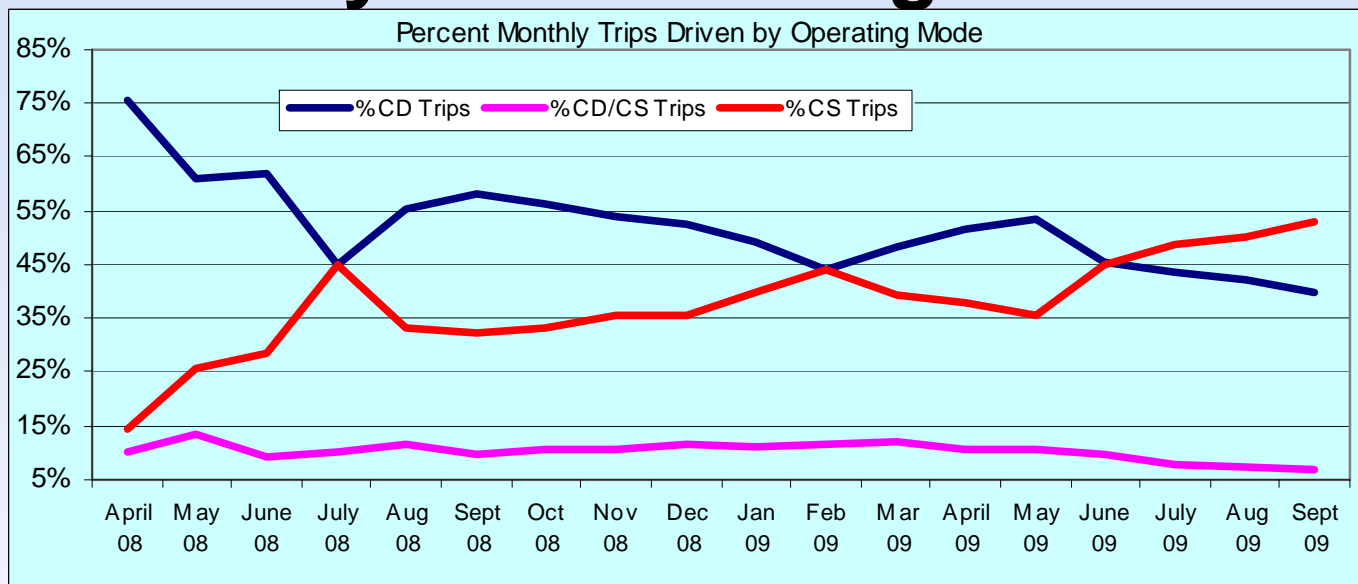


Monthly Fleet Testing MPG Results



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

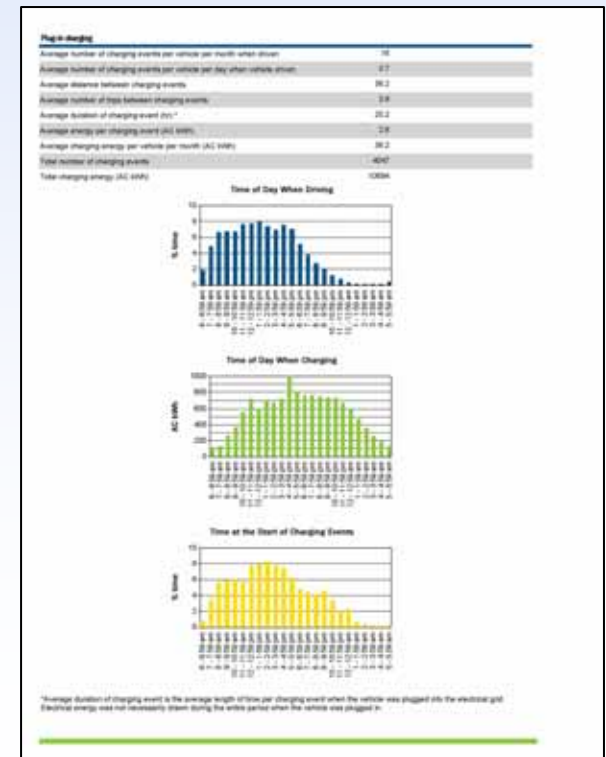
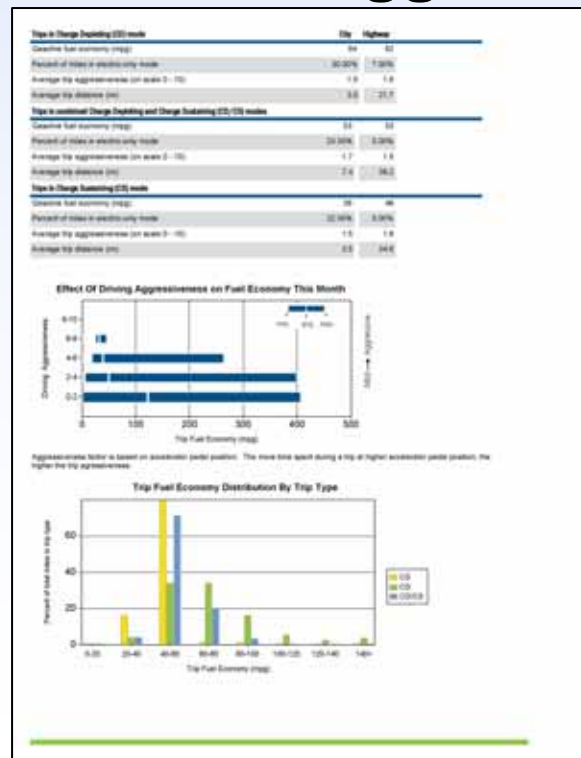
Monthly Fleet Testing Drive Modes



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

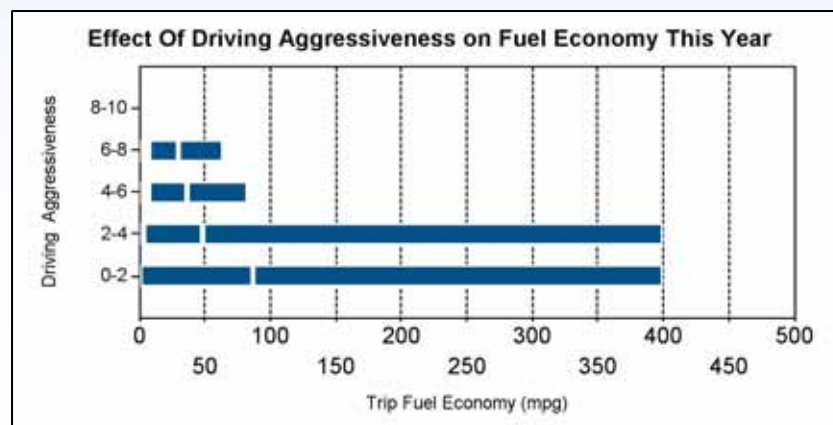
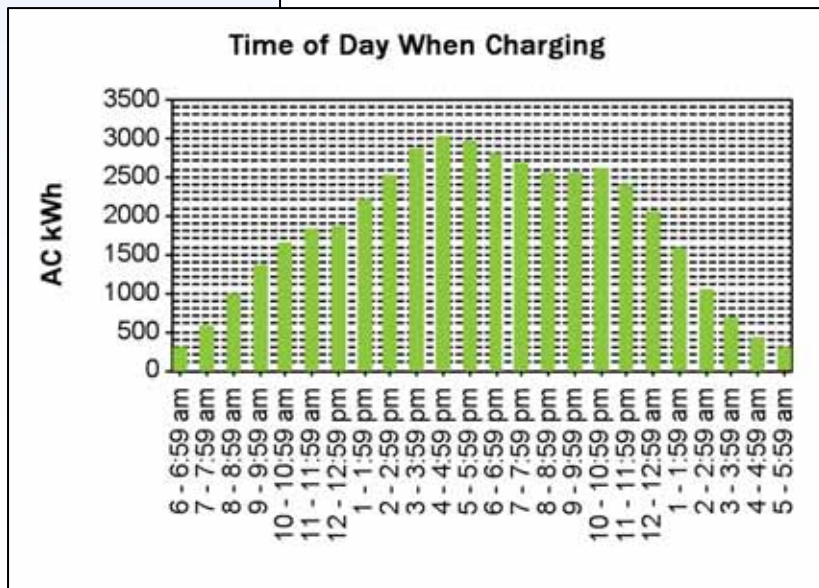
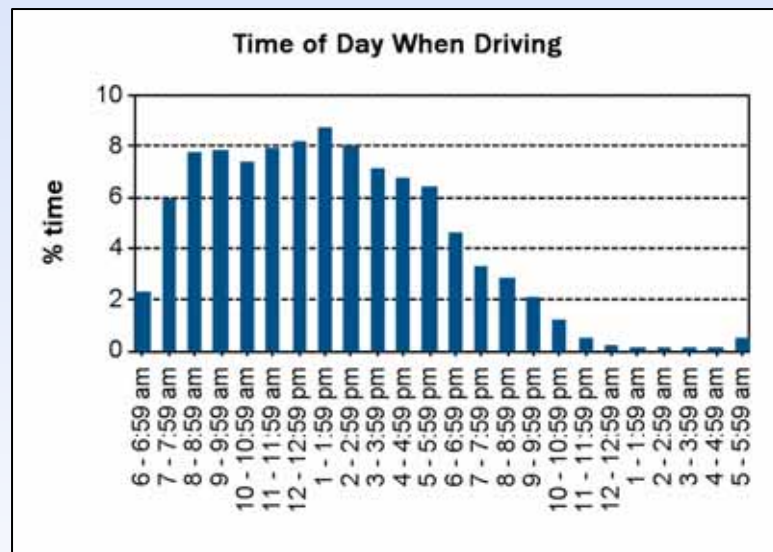
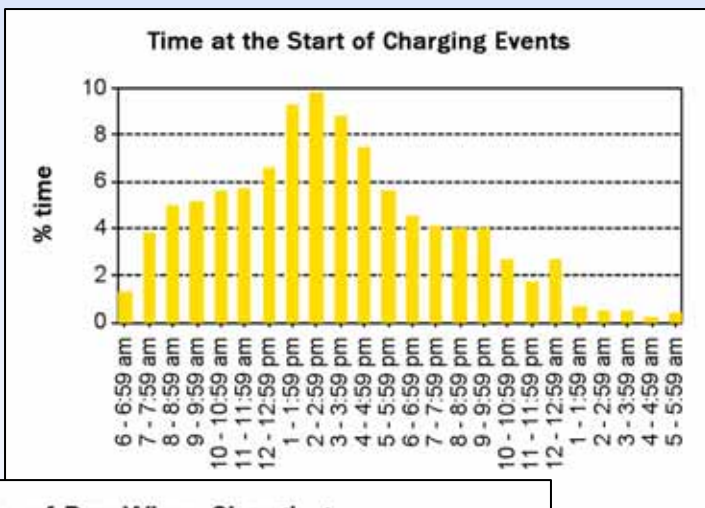
PHEV Fleet Testing Reports

- Summary reports posted monthly on the www
- Individual vehicle reports only go to the respective fleet owners each month, 1,340+ reports to date (Oct. 2009)
- 157 Hymotion Prius PHEVs, 981,000 miles, 108,297 trips, 26,000 charging events, 58,400 kWh used. GridPoint (V2Green) and Kvaser data loggers



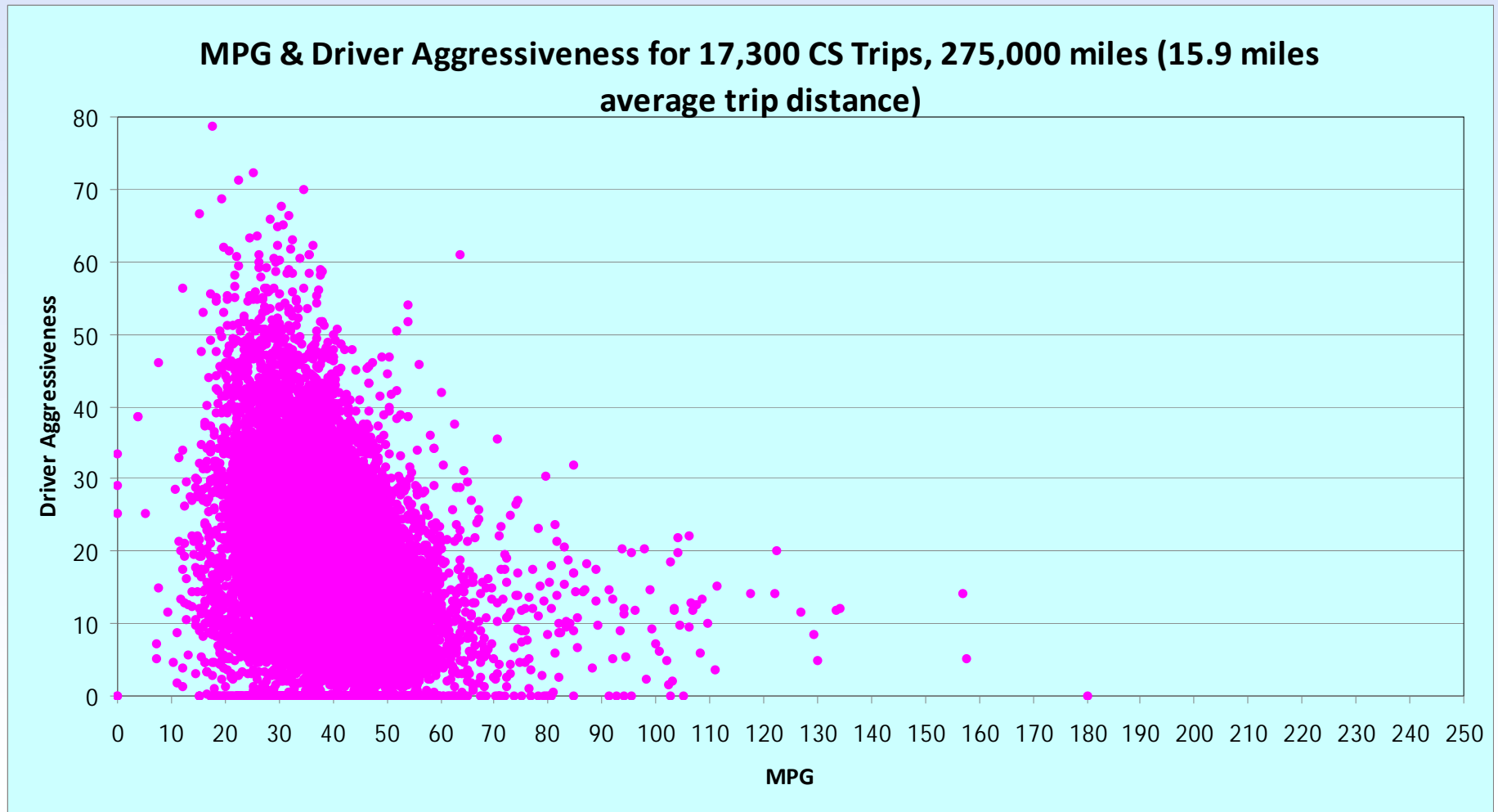
Hymotion Prius (GridPoint Log.) Fleet Tests

- March 2008 to Oct. 1, 2009. 116 PHEVs, 712,000 miles, 77,500 trips, 16,800 charging events and 44,000 kWh



Hymotion Prius PHEVs – CS Trips

- **MPG and aggressive driving impacts March '08 – May '09**

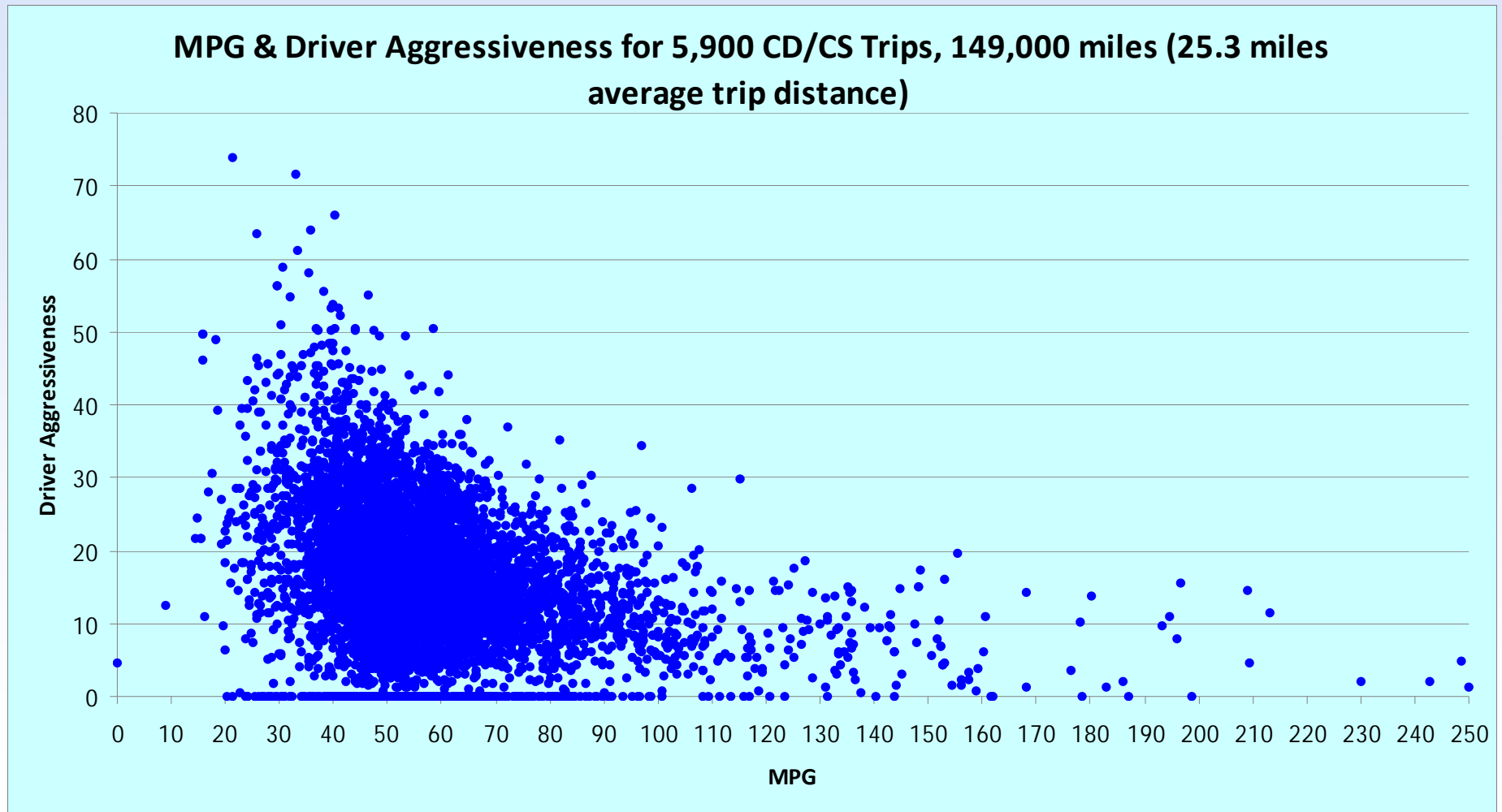


Data from 150 Hymotion Prius with V2Green and Kvaser loggers



Hymotion Prius PHEVs – CS/CD Mixed Trips

- **MPG and aggressive driving impacts March '08 – May '09**

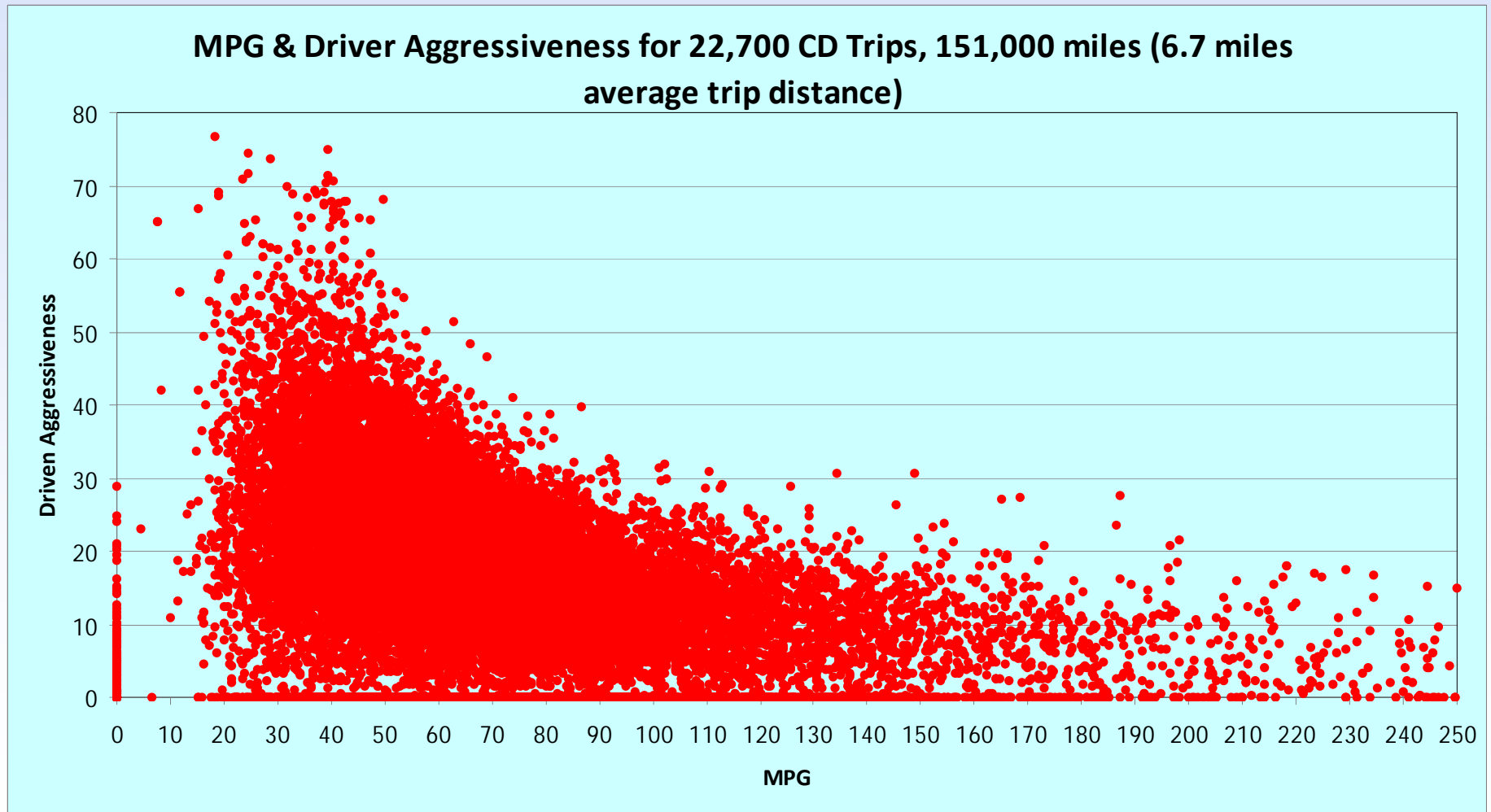


Data from 150 Hymotion Prius with V2Green and Kvaser loggers



Hymotion Prius PHEVs – CD Trips

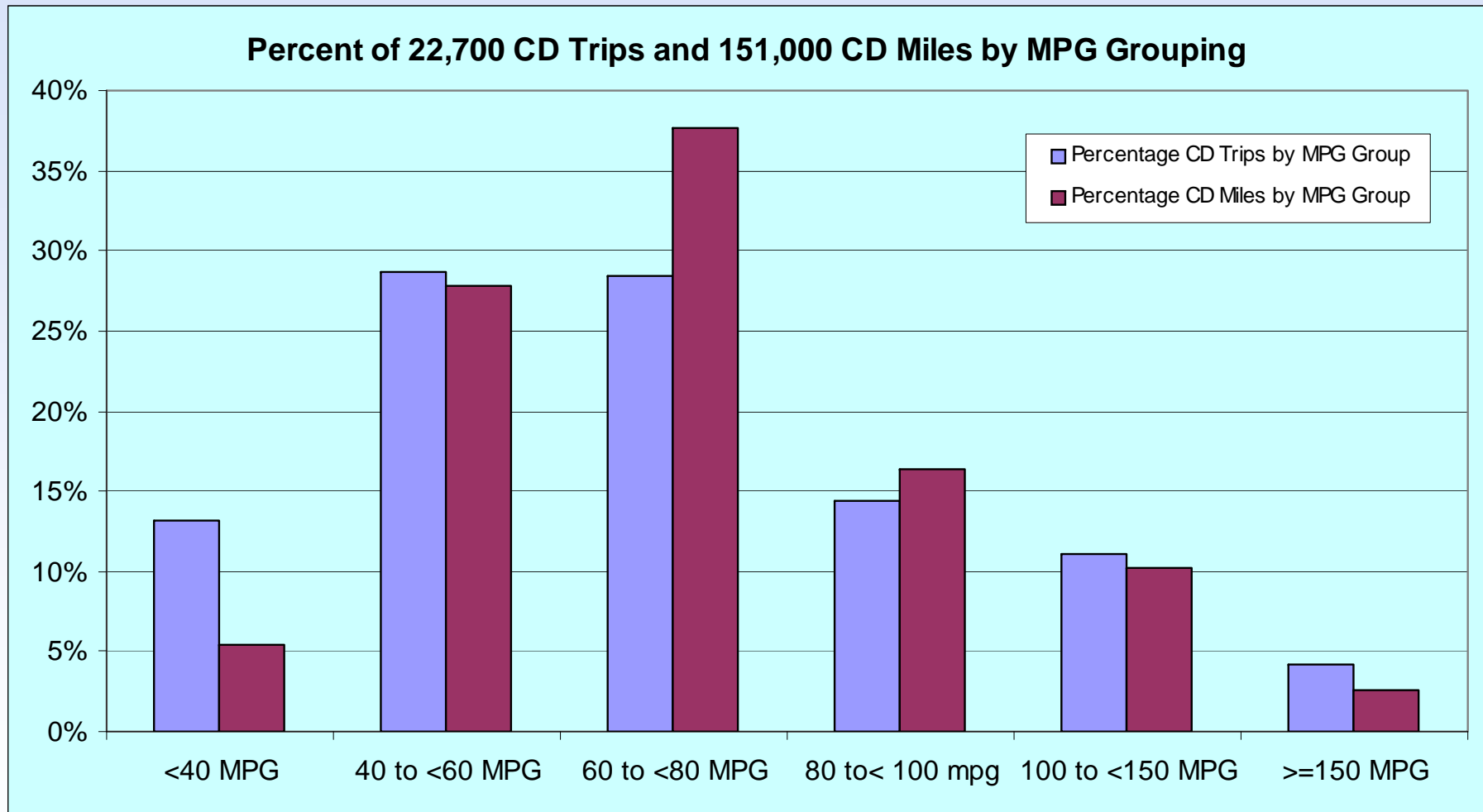
- MPG and aggressive driving impacts March '08 – May '09



Data from 150 Hymotion Prius with V2Green and Kvaser loggers



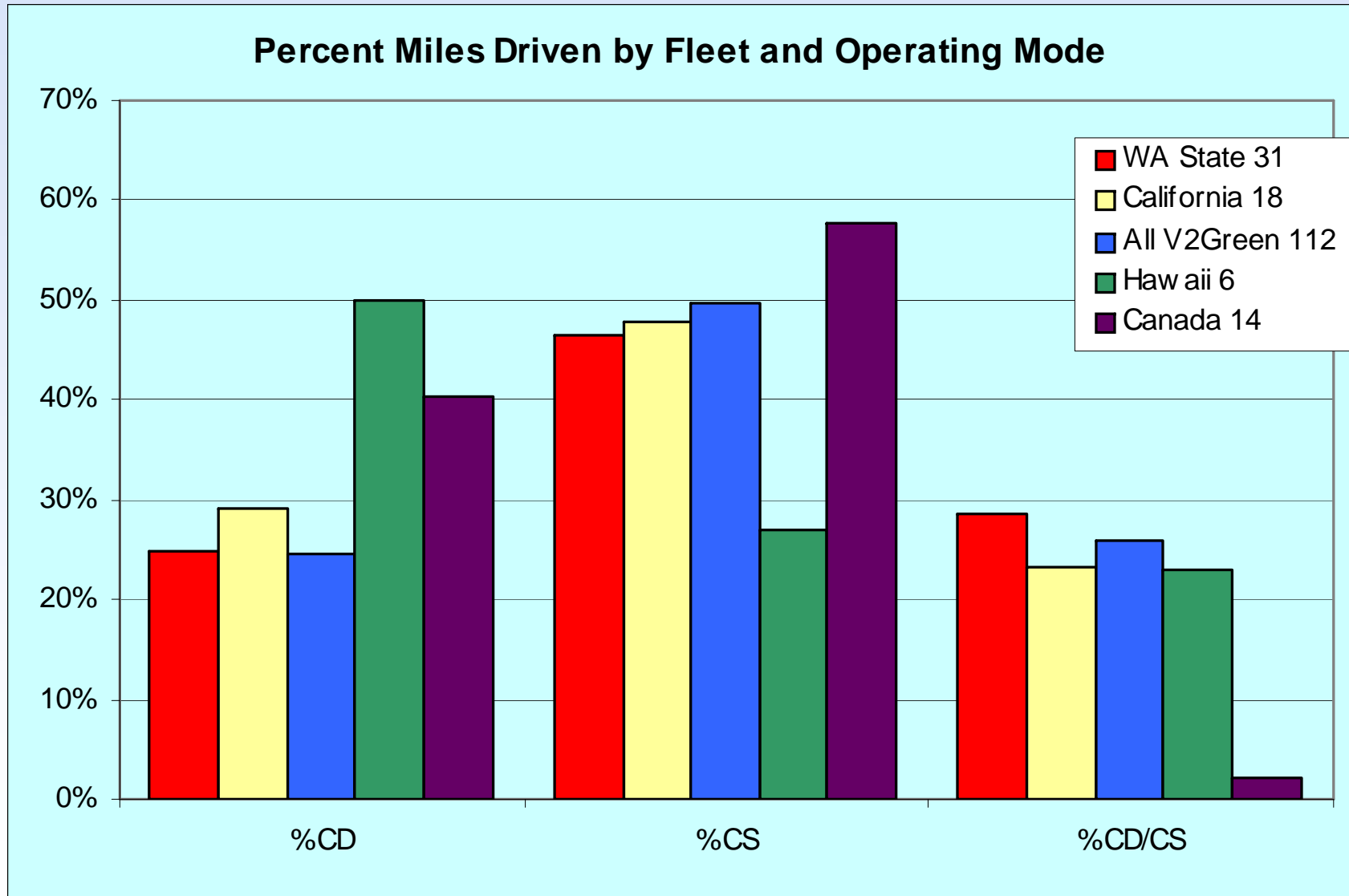
MPG Results - Charge Depleting (CD) Mode



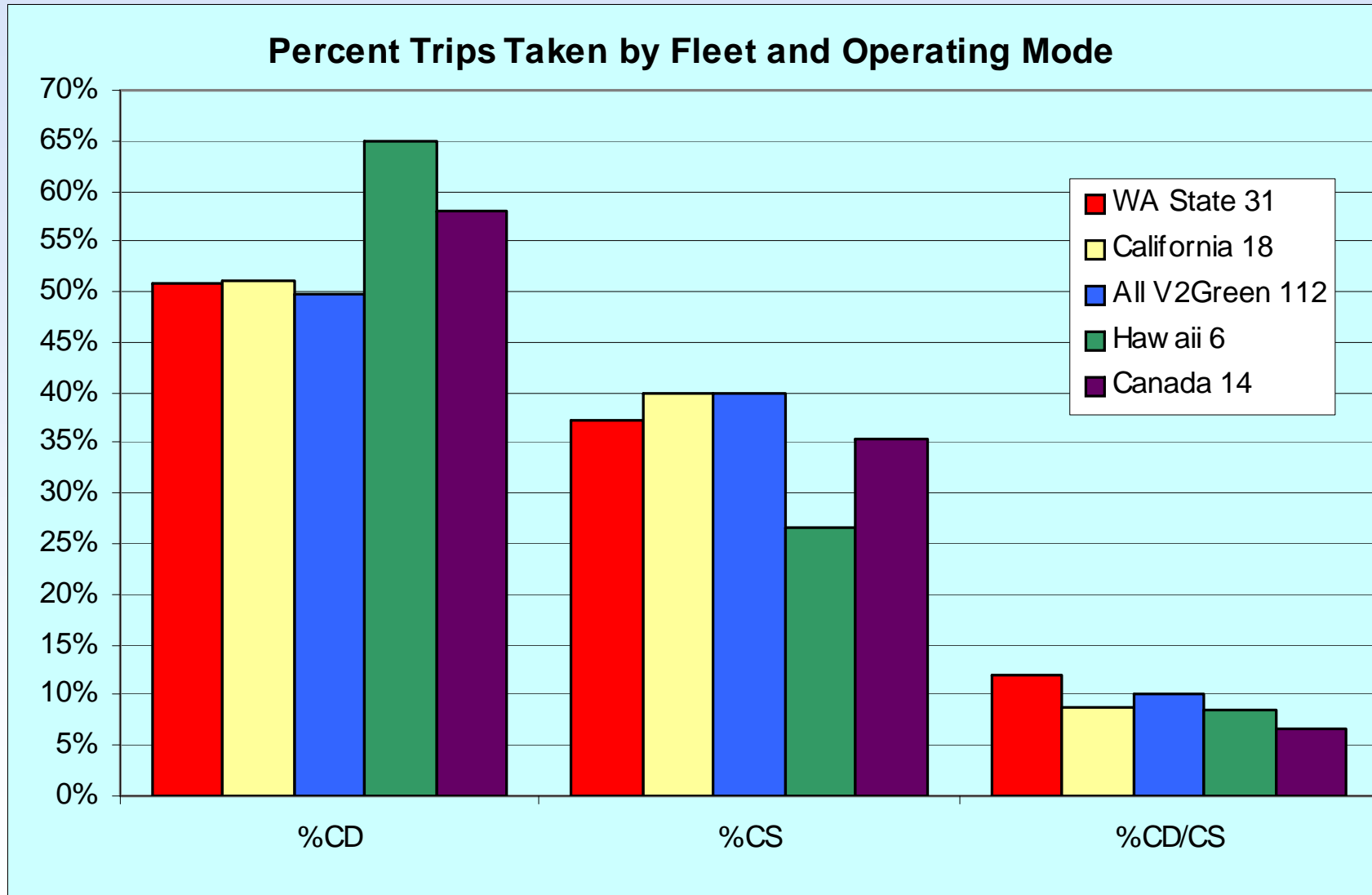
Data from 150 Hymotion Prius with V2Green and Kvaser loggers



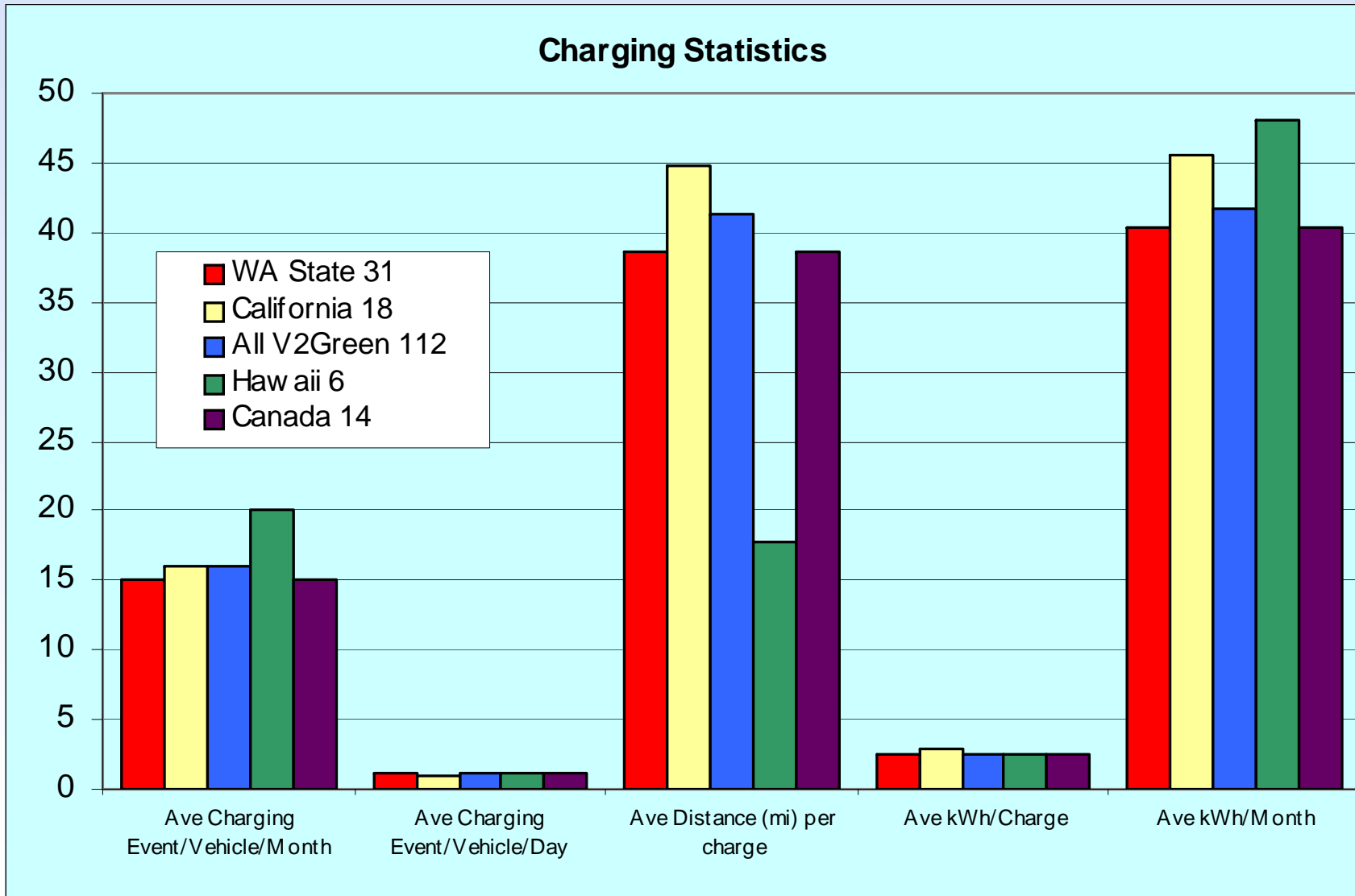
Testing Results by Fleet



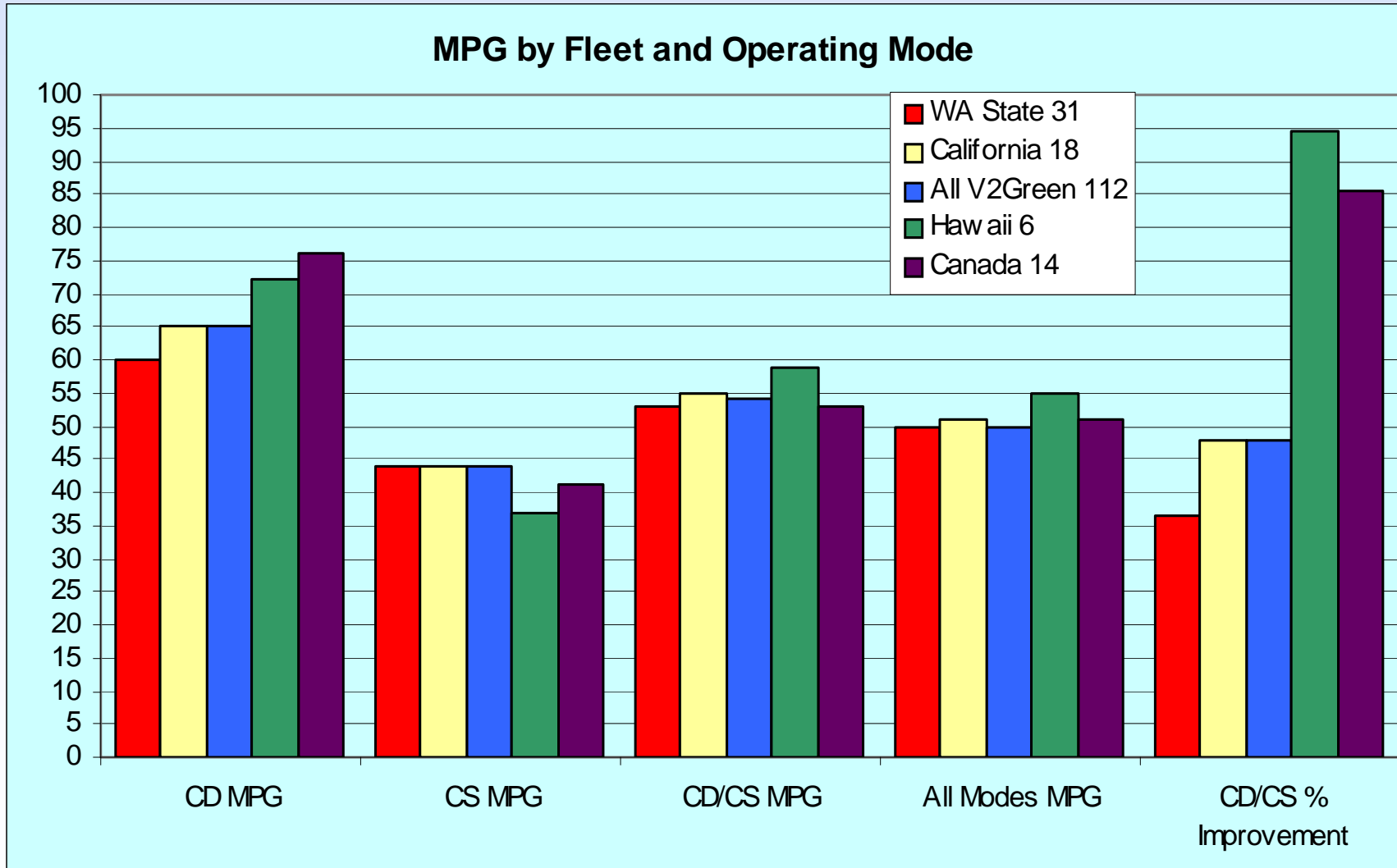
Testing Results by Fleet – cont'd



Testing Results by Fleet – cont'd



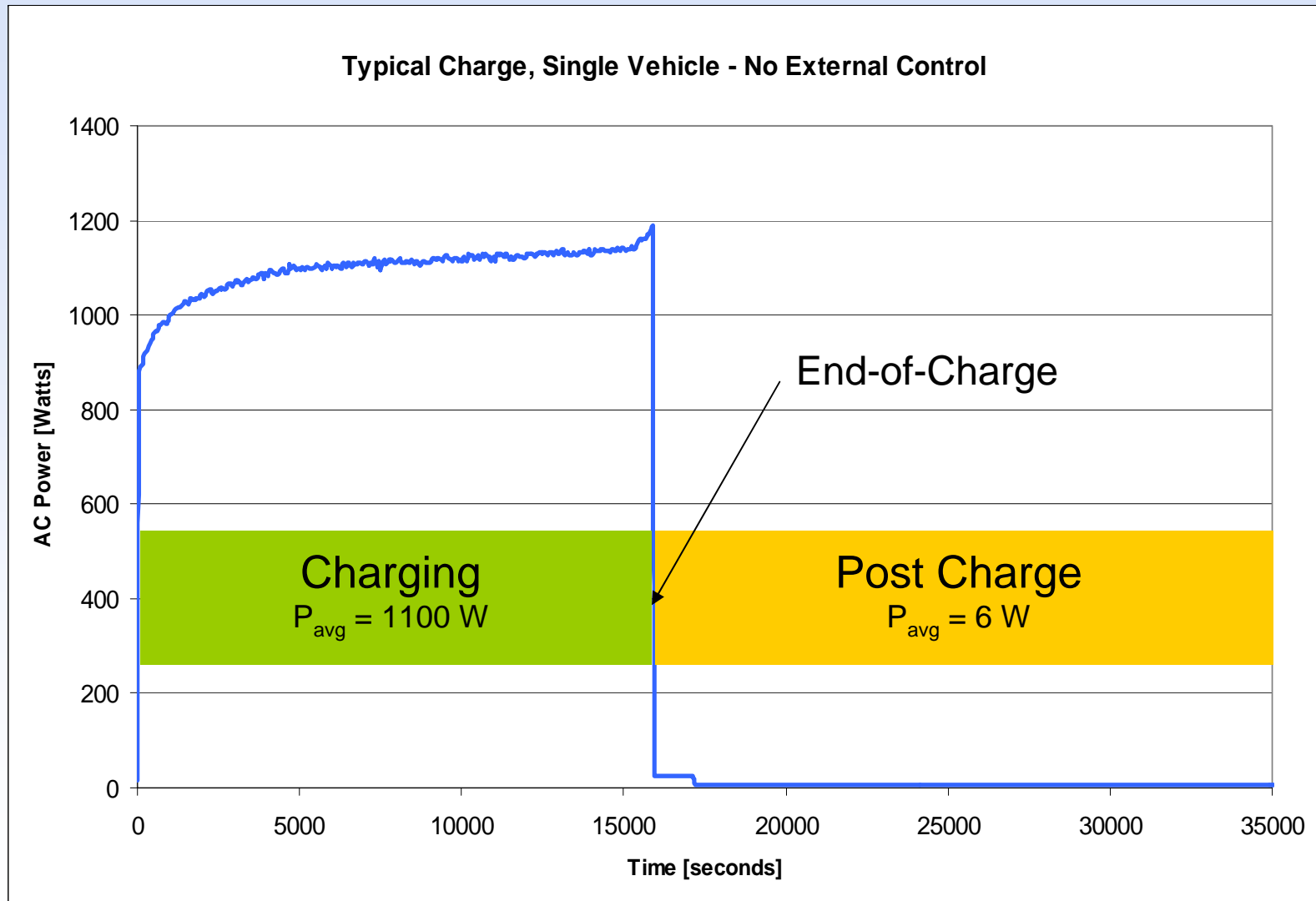
Testing Results by Fleet – cont'd



Seattle Area PHEV Smart Charging Trials

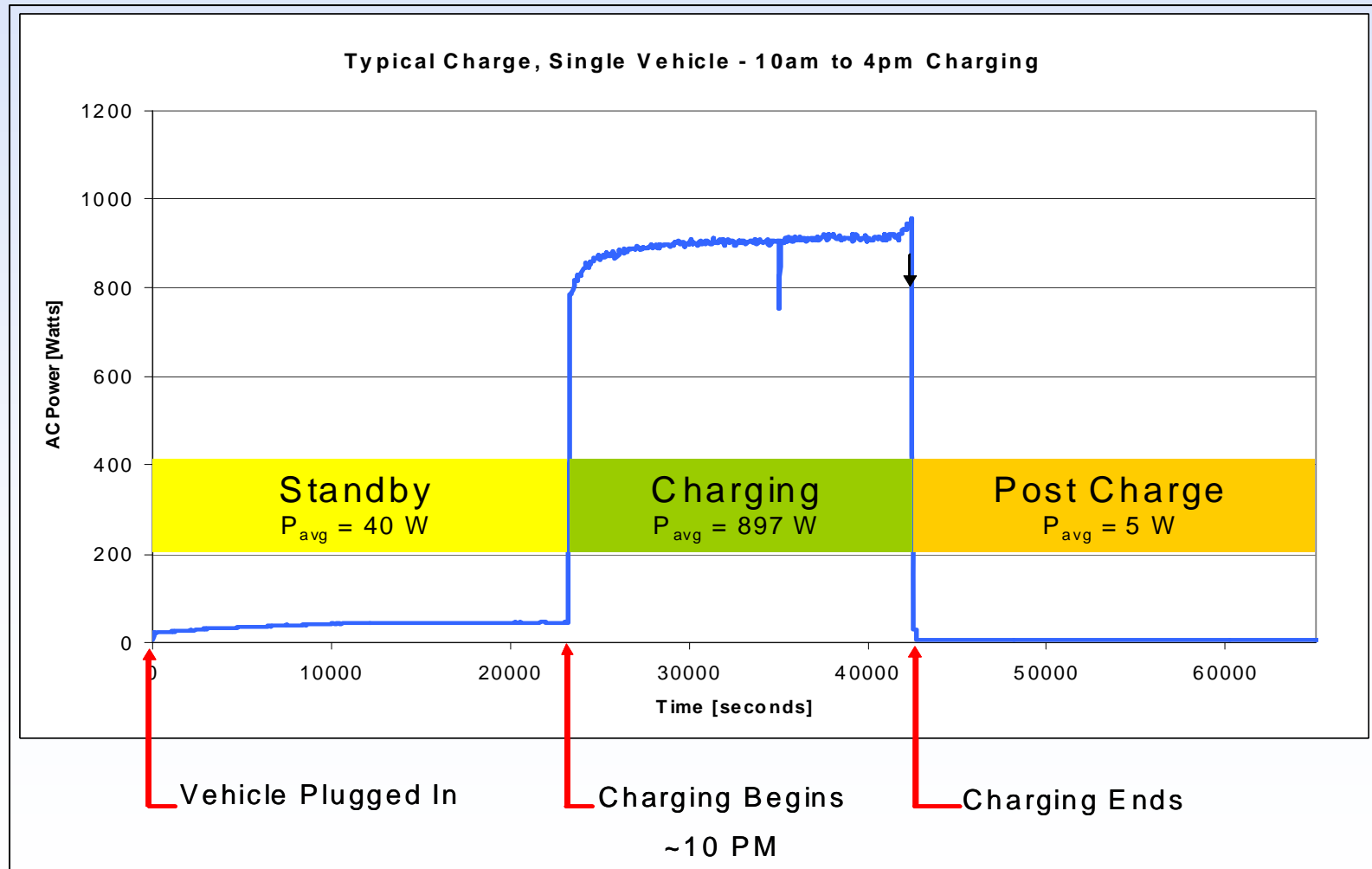
- 13 Hymotion PHEVs, sponsored by Seattle City Light using GridPoint's *Electric Vehicle Management Solution*
- Types of Trials:
 - Time of Day Charging – Vehicle charging only allowed during certain hours of the day
 - Goal Based Charging – Normalize power demand for vehicle charging around a kW goal 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



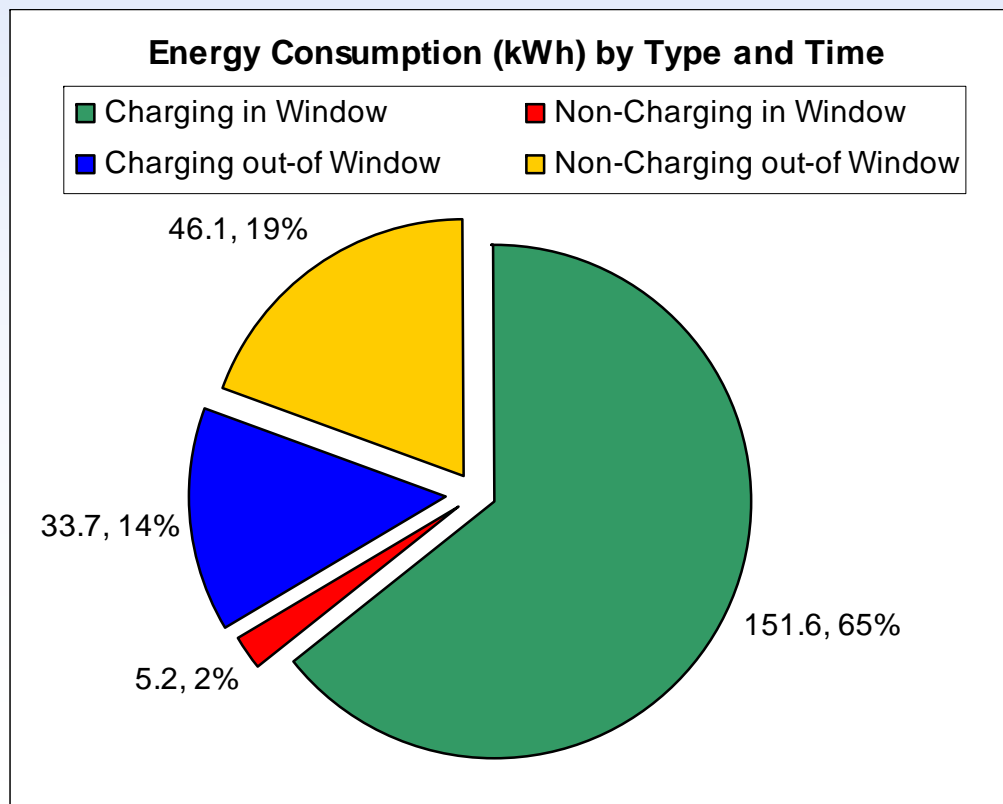
Results of Time of Day Charging Trials

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



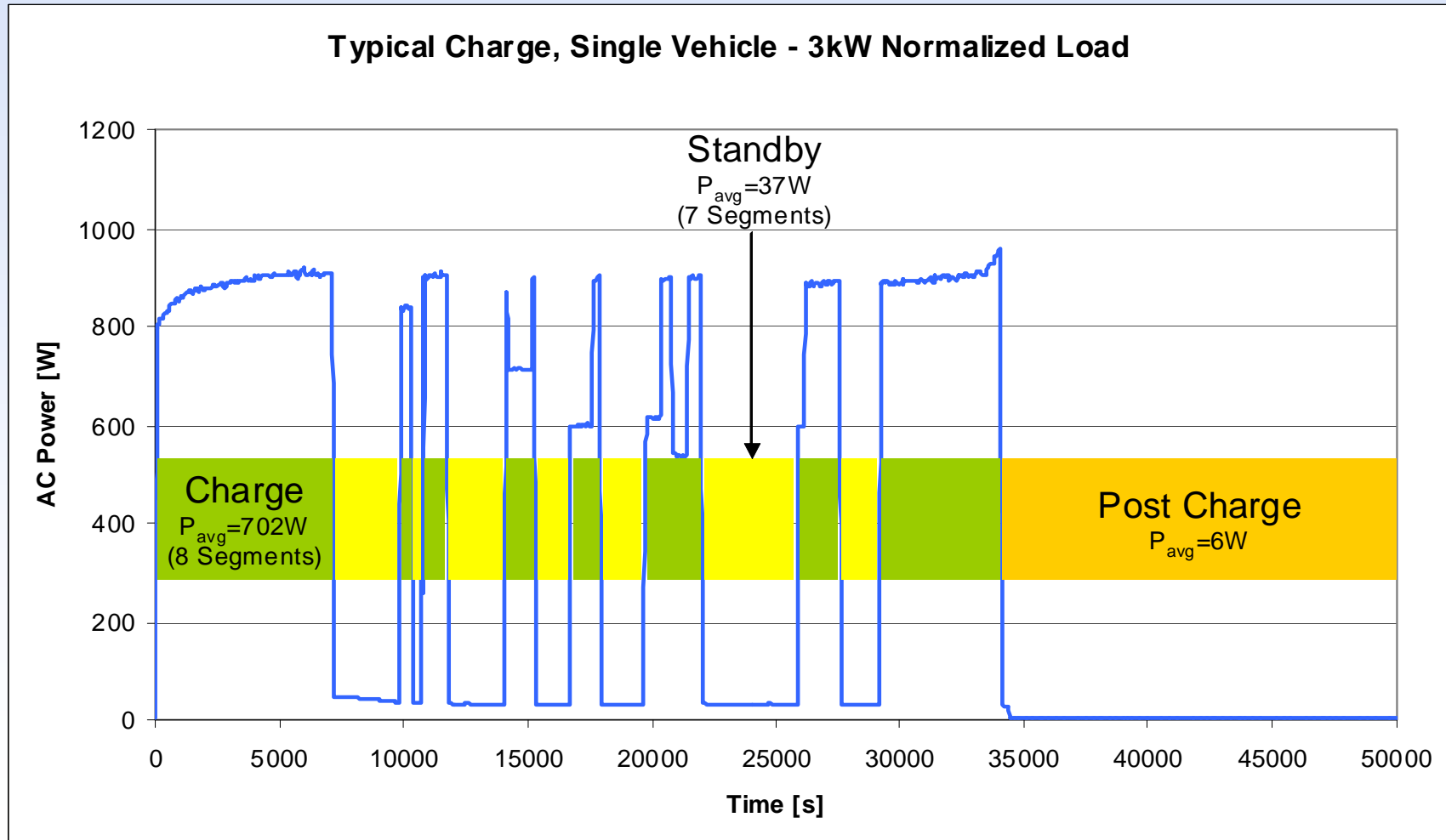
Results of Time of Day Charging Trials

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



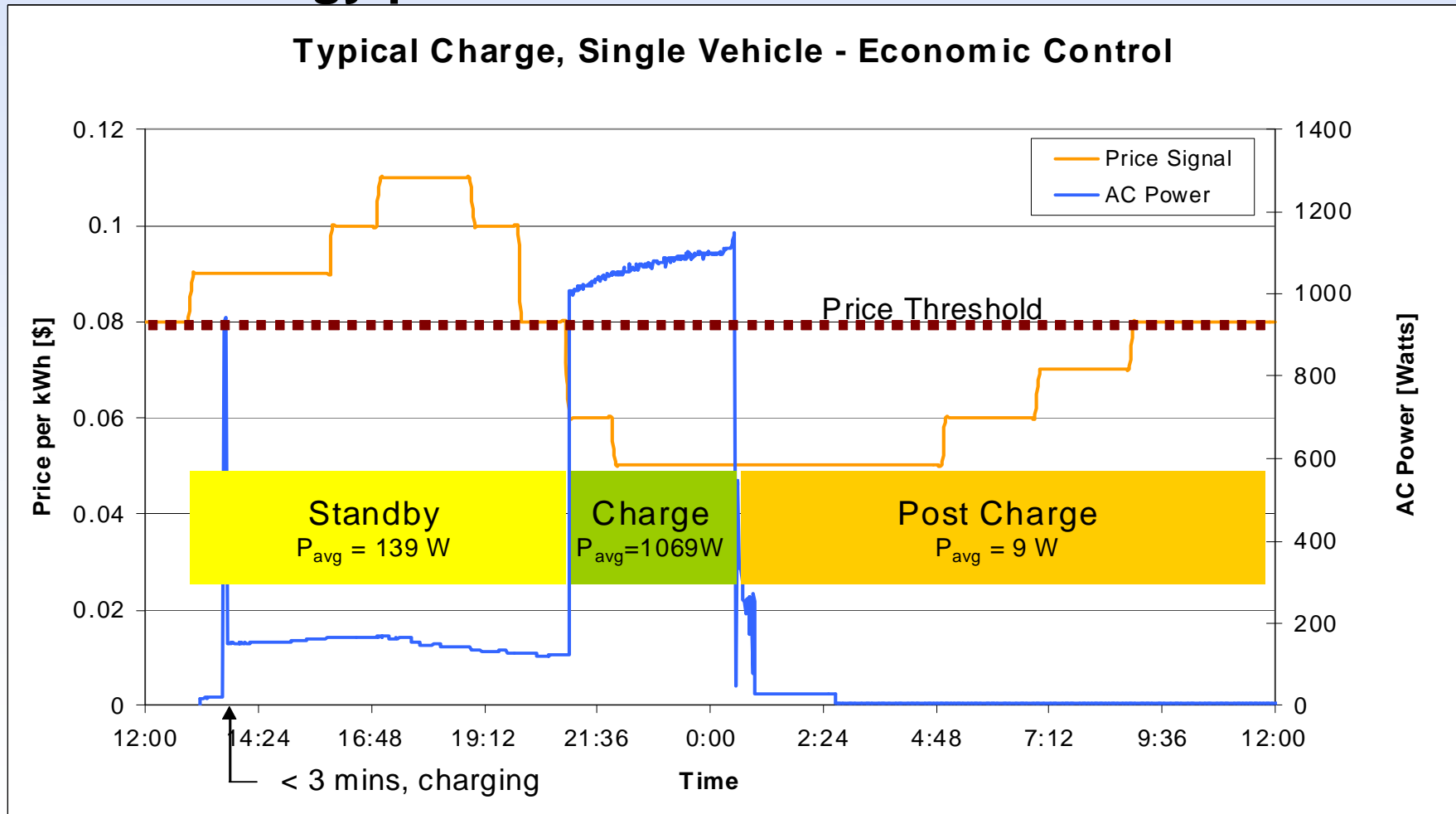
Results of kW Goal Charging Trials

- Vehicle charging controlled to normalize the resource load around 3 kW (Typical 7 Vehicle Max, 13 Possible)

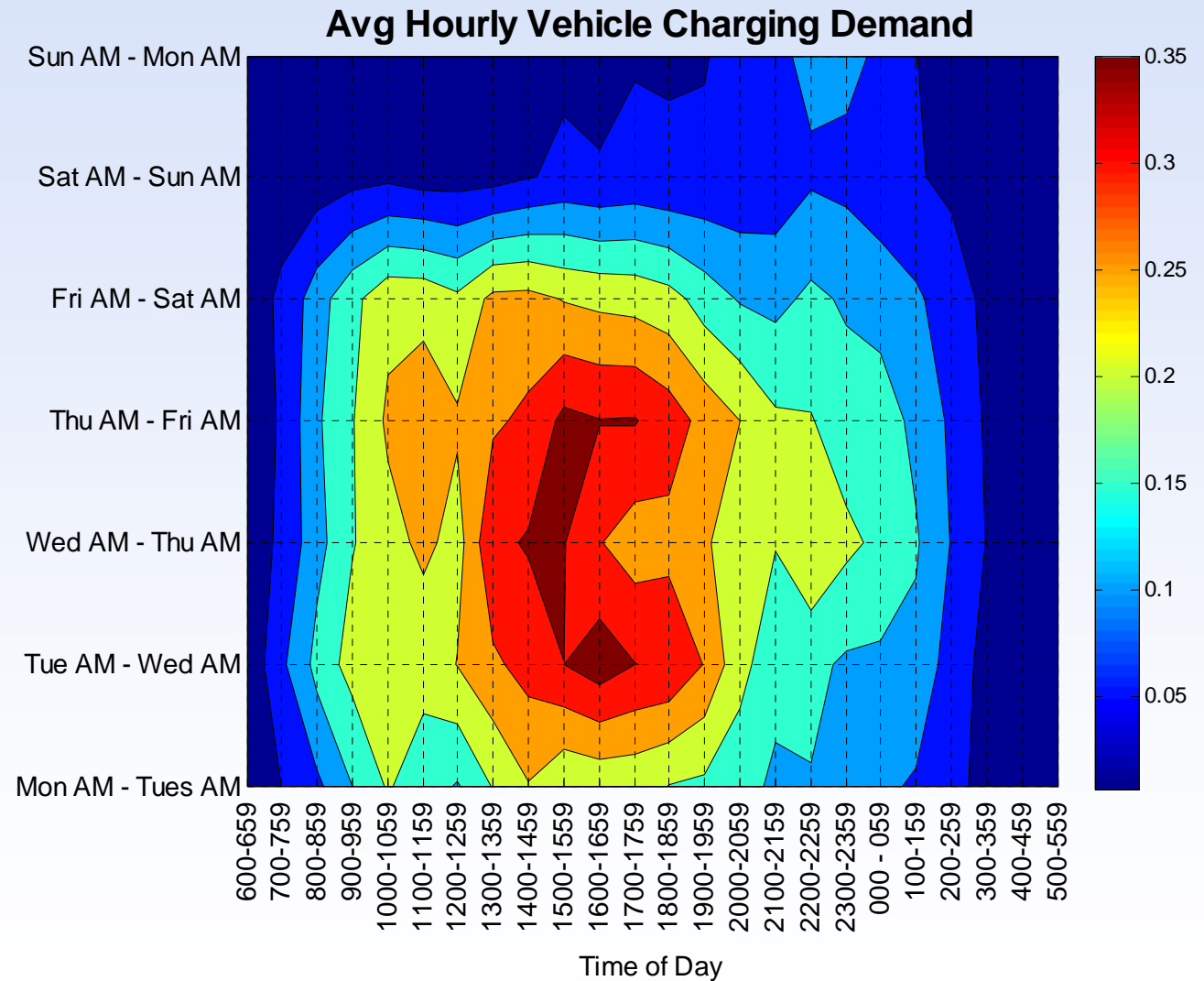


Results of Economic (\$/kWh) Charging Trials

- Artificial price signal supplied and vehicles only charged when energy price < \$.08/kWh

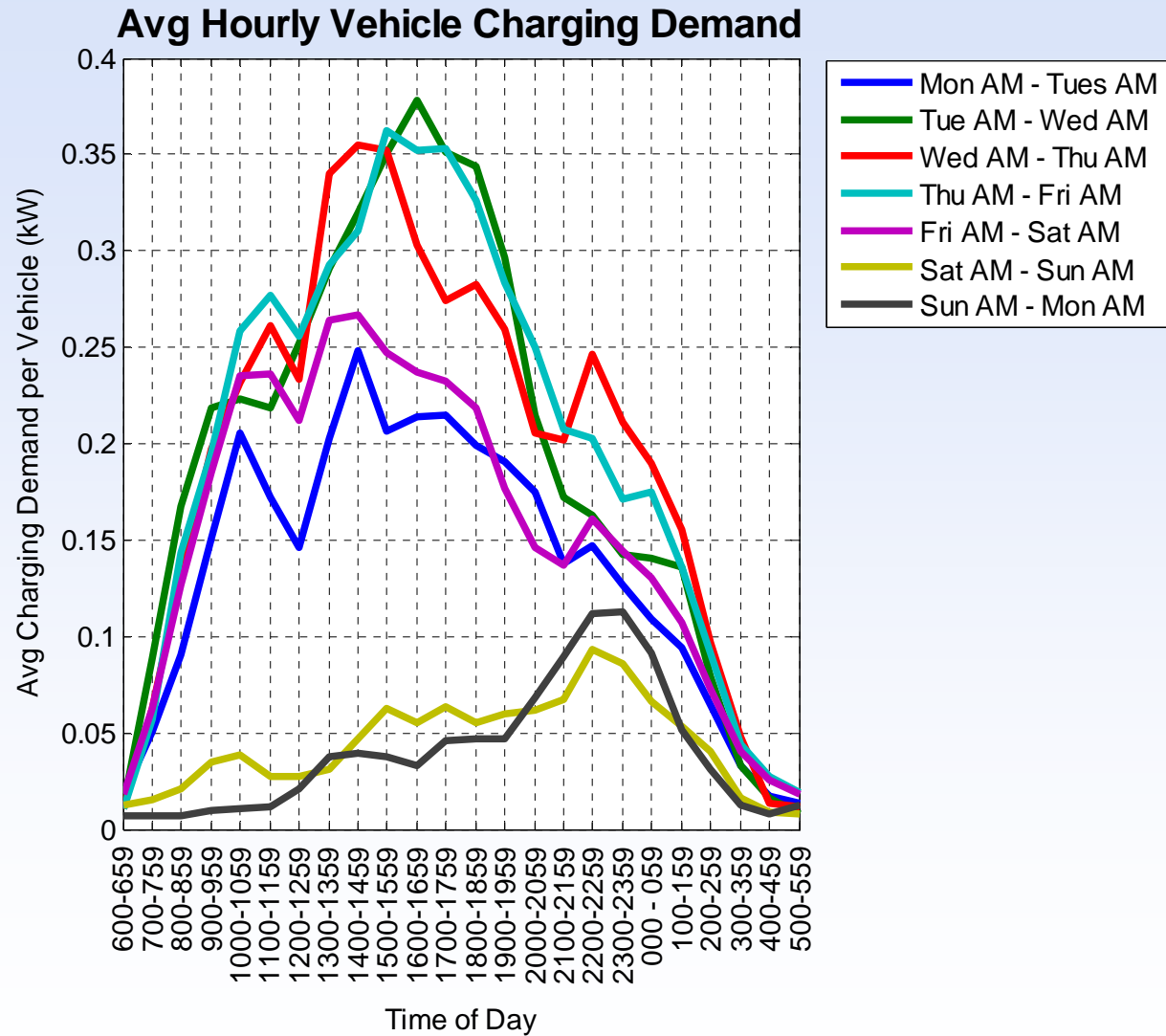


Commercial Fleet Average Charge Demand

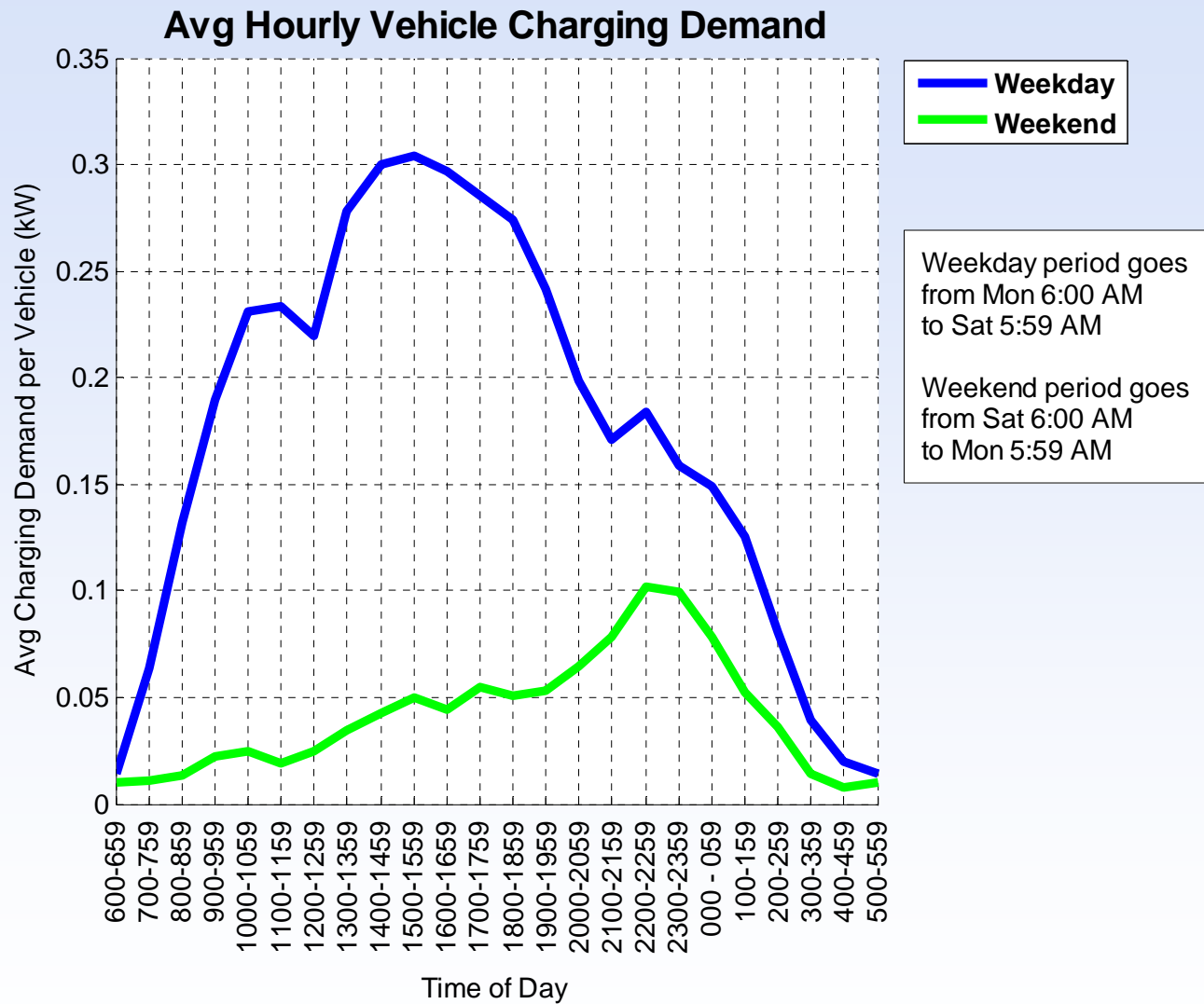


Commercial fleet
 67 Hymotion Prius PHEVs
 May 2009
 1,218 Level I charging events

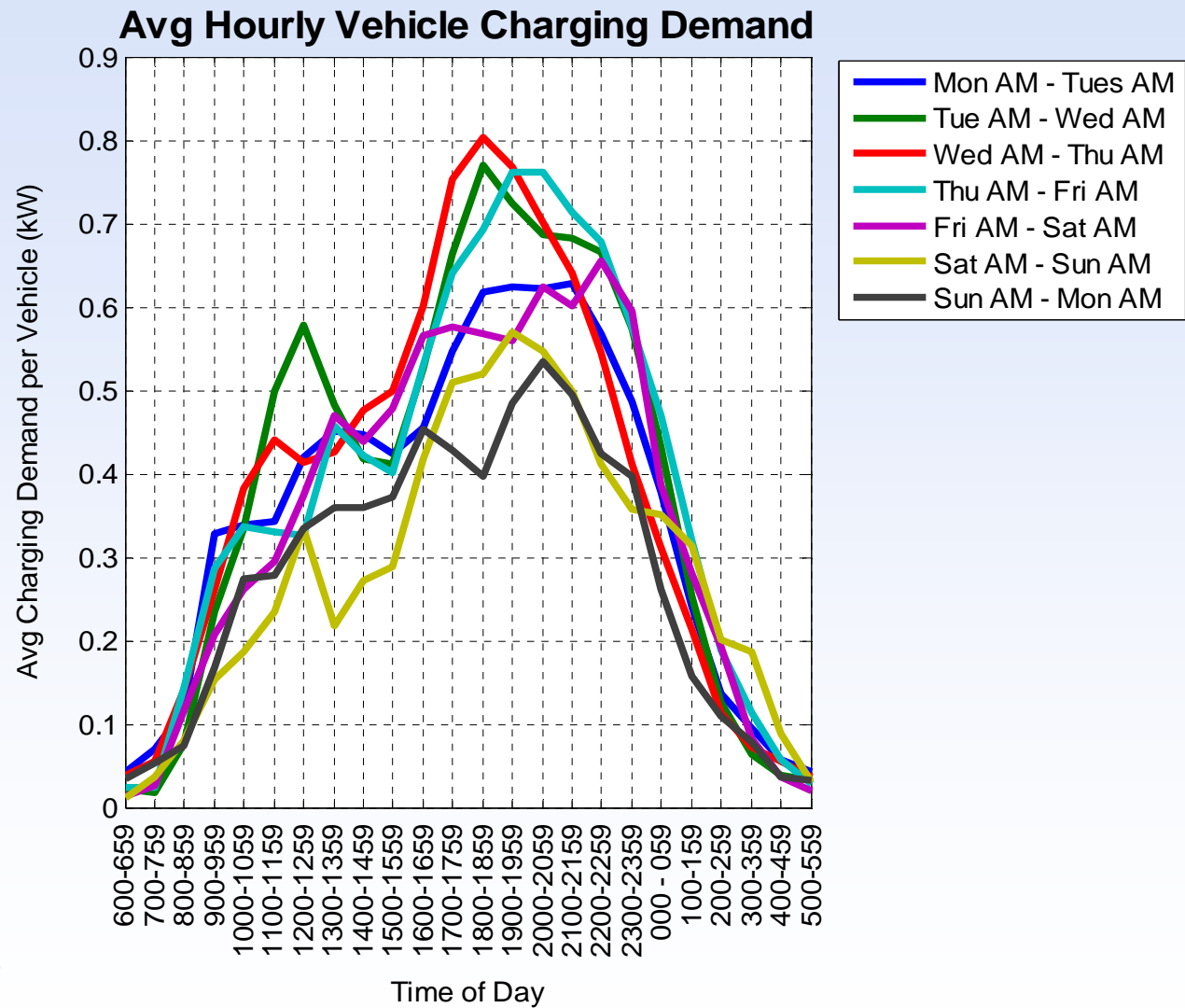
Commercial Fleet Average Charge Demand



Commercial Fleet Average Charge Demand



Private Fleet Average Charging Demand



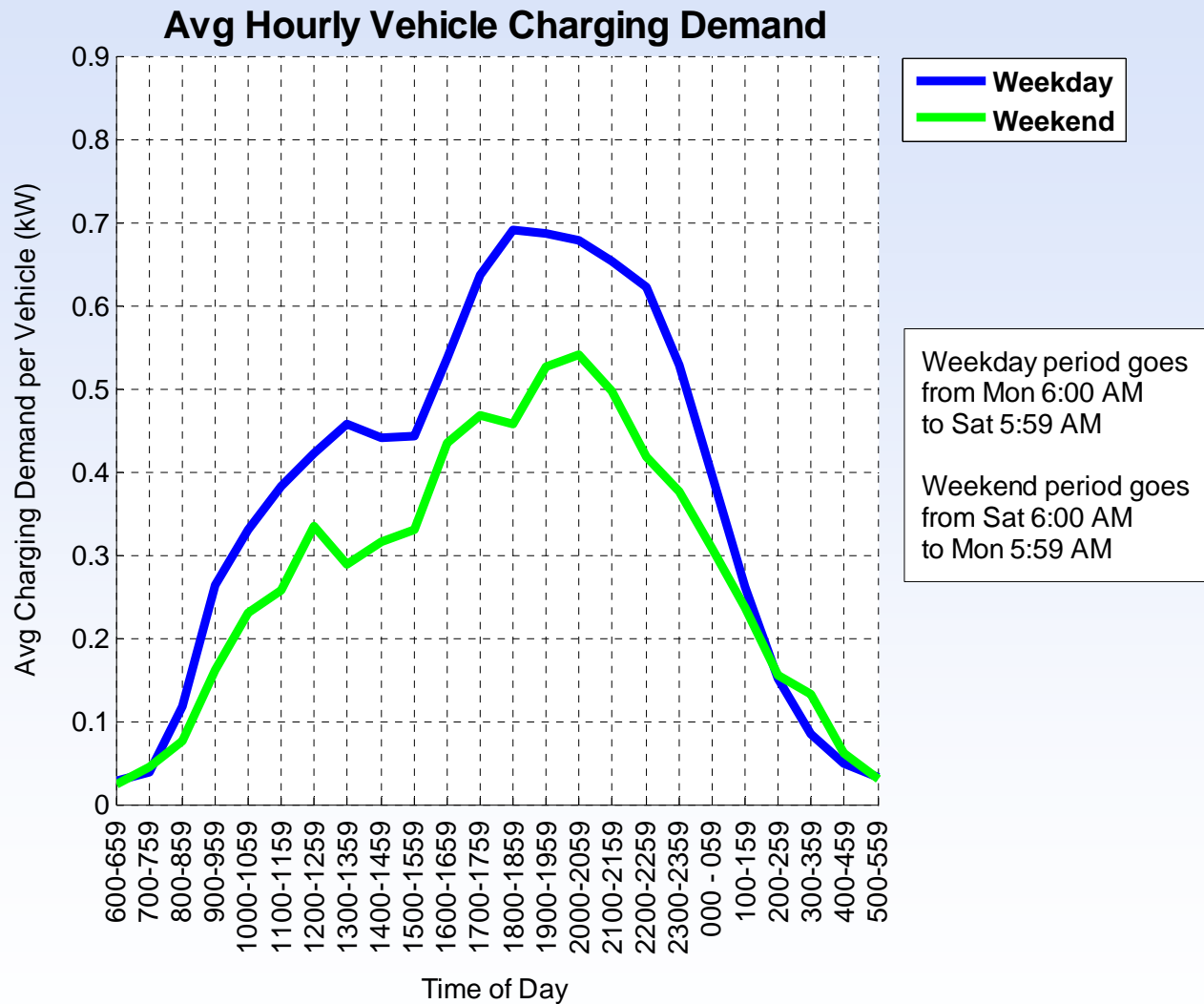
Private fleet

39 Hymotion Prius PHEVs

Jan – Sep 2009

1,014 charging events

Private Fleet Average Charging Demand



Vehicle to Grid (V2G) Regulatory Study

- **Study of regulations, standards, and codes related to charging/discharging electric drive vehicles from/to the grid**
 - **Examine governmental regulations, standards and building code requirements potentially impacting V2G**
 - **Identify regulations, standards and codes requiring modification if V2G is implemented**
 - **Develop a common set of regulations, standards and codes for applying in a broad geographic area**
 - **Conducted with an OEM**
 - **Base study on practices in Phoenix, Orlando, Boston, Detroit, Raleigh, Maui, San Diego, Dallas, Seattle, Washington DC, Portland OR, and New York**

Other PHEV Testing

- **Bidirectional vehicle-to-grid (V2G) charging study**
 - 6 kW and 20 kW levels, using lithium PHEV batteries, V2Green cellular charging control. Document infrastructure requirements and costs for V2G
- **Developing vehicle-based battery test bed research project for testing battery electric vehicle and PHEV batteries in various vehicle and charging operating scenarios, including:**
 - High mileage applications that introduce testing uncertainties such as high heat, extreme cold, vibration, irregular charging profiles and the most dangerous influence of all – the vehicle operator
 - Testing will include dynamometer and battery laboratory testing

PHEV Charging Infrastructure Cost Report

- Analyzes PHEV infrastructure requirements in single and multi-family residential, and commercial facilities as well as driving trends. No site specific costs
- Charging infrastructure equipment/administrative costs:
 - Levels 1 (120V, 15 or 20 amp) and 2 residential
 - Levels 1 and 2 (208/240V ~40 amp) apartment complex
 - Level 2 commercial facility
- Battery sizes & charge times for various PHEV platforms
- Power electronics & battery costs for PHEV platforms

Level 1 Residential	Labor	Material	Permits	Total
EVSE (charge cord)	--	\$250	--	\$250
Residential circuit installation (20A branch circuit, 120 VAC/1-Phase)	\$300	\$131	\$85	\$516
Administration costs	\$60	\$43	\$9	\$112
Total Level 1 Cost	\$360	\$424	\$94	\$878

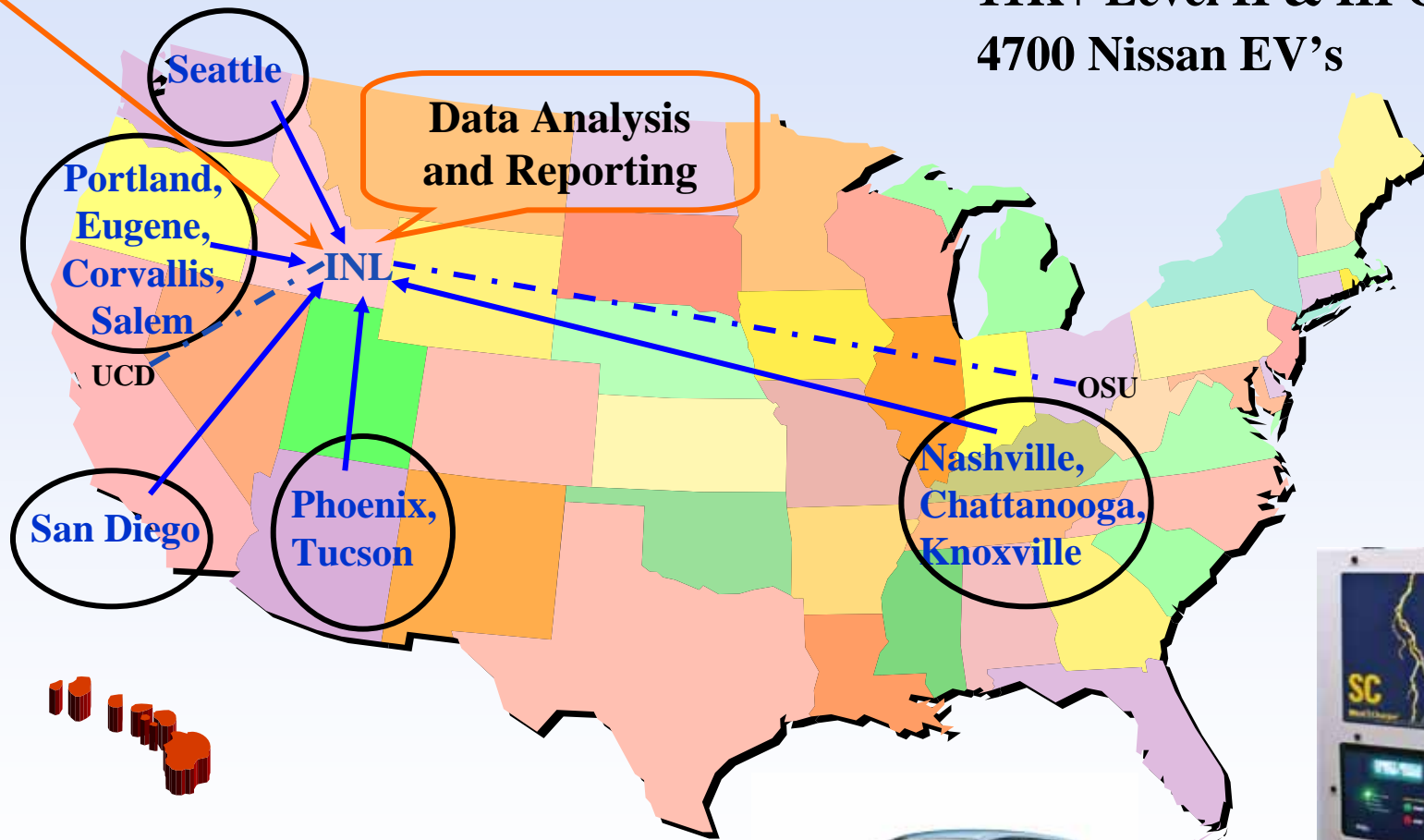
eTec/Nissan EV Infrastructure Demonstration

- INL is a principle participant with eTec and Nissan in the deployment of 4,700 battery electric Nissan Leaf vehicles in 5 greater metropolitan statistical areas:
 - **Portland OR., Seattle WA, San Diego CA, Phoenix / Tuscan AZ, and several Tennessee locals**
 - **INL will collect, analyze and report on charging infrastructure utilization for 11,000 Level II electric vehicle supply equipment (EVSE) and 260 Level III chargers**
 - **INL will report on vehicle charging patterns**

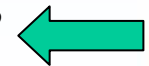
eTec/Nissan EV Infrastructure Demonstration

eTec/Nissan/Regional Partners

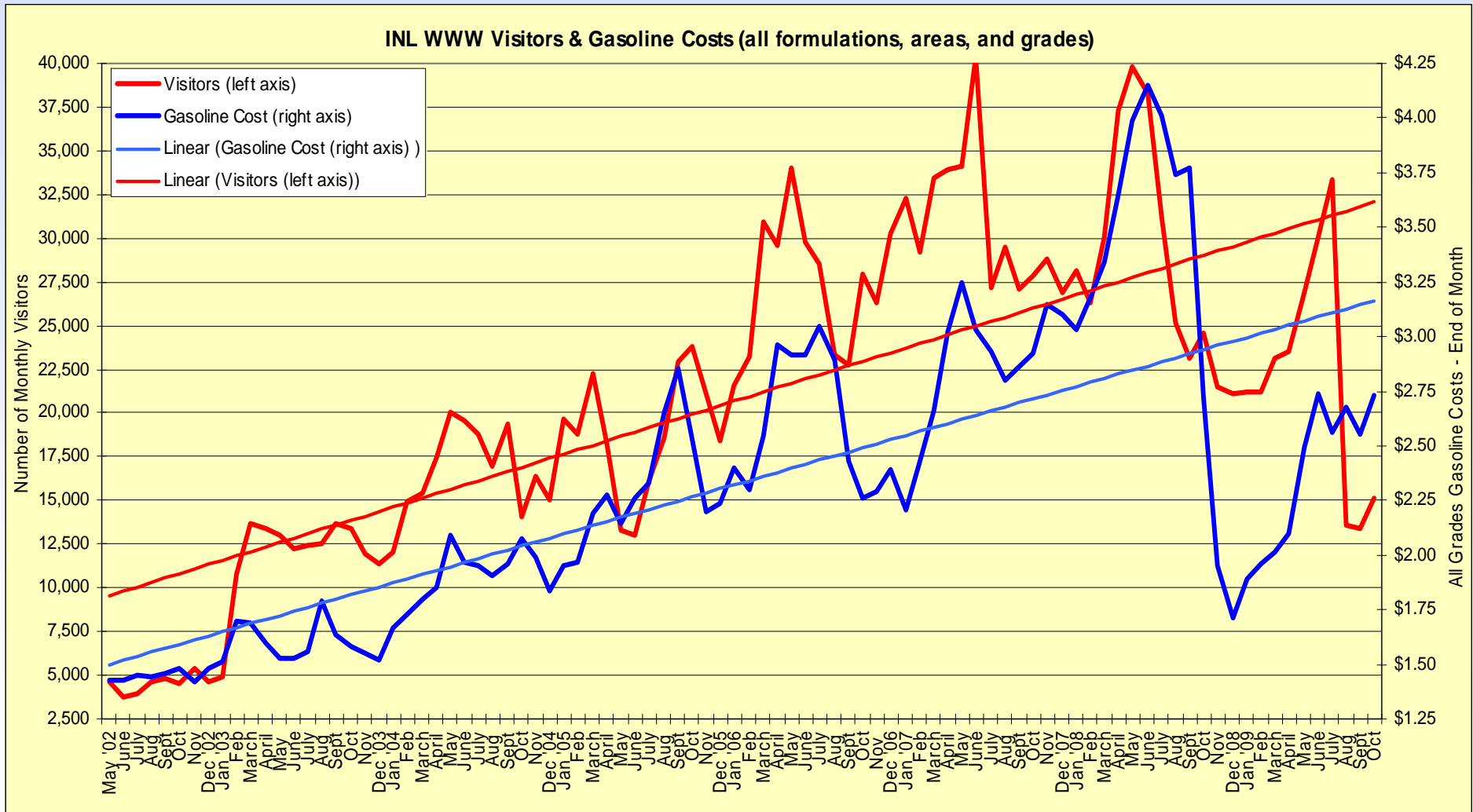
11K+ Level II & III Chargers
4700 Nissan EV's



Battery – 24+ kWh Li-ion,
Projected 100 Mile Range



AVTA Webpage Use and Gasoline Costs



Summary

- INL/AVTA PHEV Demonstration has provided 1.1 million miles and 26,000 charging events of data (knowledge?)
- Driver behavior, charging frequency, and environmental conditions have significant impacts on electric drive vehicles' 80-85% energy efficiencies and mpg results
- PHEV drive patterns suggest shorter distances per day driving patterns than previously documented
- PHEV operations often occur with minimal pre-trip charge events – “they run even if not plugged in”
- Non-charging energy use (hotel loads) may be significant
- The eTec/Nissan project will document more than 70 million miles of electric drive vehicle operations and more than 1.8 million charging events
- **We (in this room) have the opportunity to help drive the future of electric drive transportation and infrastructure**

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/CON-09-17242