

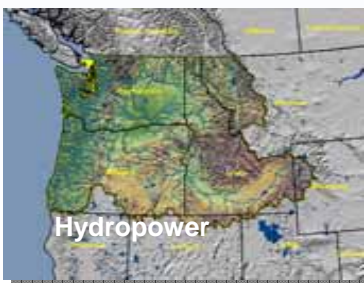
U.S. Department of Energy, Vehicle Technologies Program

PowerUp! Summit - AVTA North America and Washington State PHEV Testing Results

**Jim Francfort
AVTA Principle Investigator
2009 PowerUp! Summit
Wenatchee, Washington. May 2009**

Idaho National Laboratory

- Eastern Idaho based U.S. Department of Energy (DOE) Federal 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 and Goals

- The Advanced Vehicle Testing Activity (AVTA) is part of DOE's Vehicle Technologies Program
- The Idaho National Laboratory (INL) and Electric Transportation Engineering Corporation (ETEC) conduct the AVTA. Argonne National Laboratory performs dynamometer testing
- The AVTA goals:
 - Provide benchmark data to technology modelers, research and development programs, vehicle manufacturers (via VSATT), and target and goal setters
 - Assist fleet managers in making informed early adaptor vehicle purchase, deployment and operating decisions

AVTA Testing History

- **Plug-in hybrid electric vehicles (PHEV)**
 - 12 models, 168 vehicles, 600,000 fleet test miles
- **Hybrid electric vehicles (HEV)**
 - 14 models, 39 vehicles, 5 million test miles
- **Hydrogen ICE (internal combustion engine) vehicles**
 - 7 models, 400,000 test miles
- **Full-size battery electric vehicles (BEVs)**
 - 40 EV models, 5+ million test miles
- **Neighborhood electric vehicles**
 - 21 models, 200,000 test miles
- **Urban electric vehicles**
 - 3 models, 1 million test miles



PHEV Testing Objectives

- Document vehicle operating patterns, and fuel use (electricity and gasoline)
- Document charging patterns and profiles, as well as battery life
- Document driver influences on the dual-fuel scenario
- Document infrastructure requirements (110V versus 220V; Levels 1, 2 and 3; offpeak and V2Grid charging)
- Document individual PHEV models and more importantly, the PHEV concept
- Document the technical and economic feasibility of PHEVs as a transportation option
- Eventually, document PHEV life-cycle costs
- To answer these questions, the AVTA is testing and demonstrating 12 different PHEV models (by battery), their batteries, and the charging infrastructure

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)



AVTA's PHEV Testing Methods

- **Baseline performance testing**: dynamometer and closed test track test procedures (SAE) provide highly repeatable testing results
- **Accelerated testing**: dedicated drivers operate and charge PHEVs via defined onroad driving and charging cycles
- **Battery laboratory testing**: uses defined and repeatable laboratory test procedures (HPPC, static capacity) to characterize PHEV batteries
- **Fleet testing**: uses everyday, unstructured fleet and public PHEV use, with onboard data loggers, to document real-world vehicle operations and charging practices
- Above test methods balance testing costs versus repeatability (vehicle-to-vehicle comparisons) and sample size constraints to obtain real-world vehicle performance, fuel use, and charging profiles

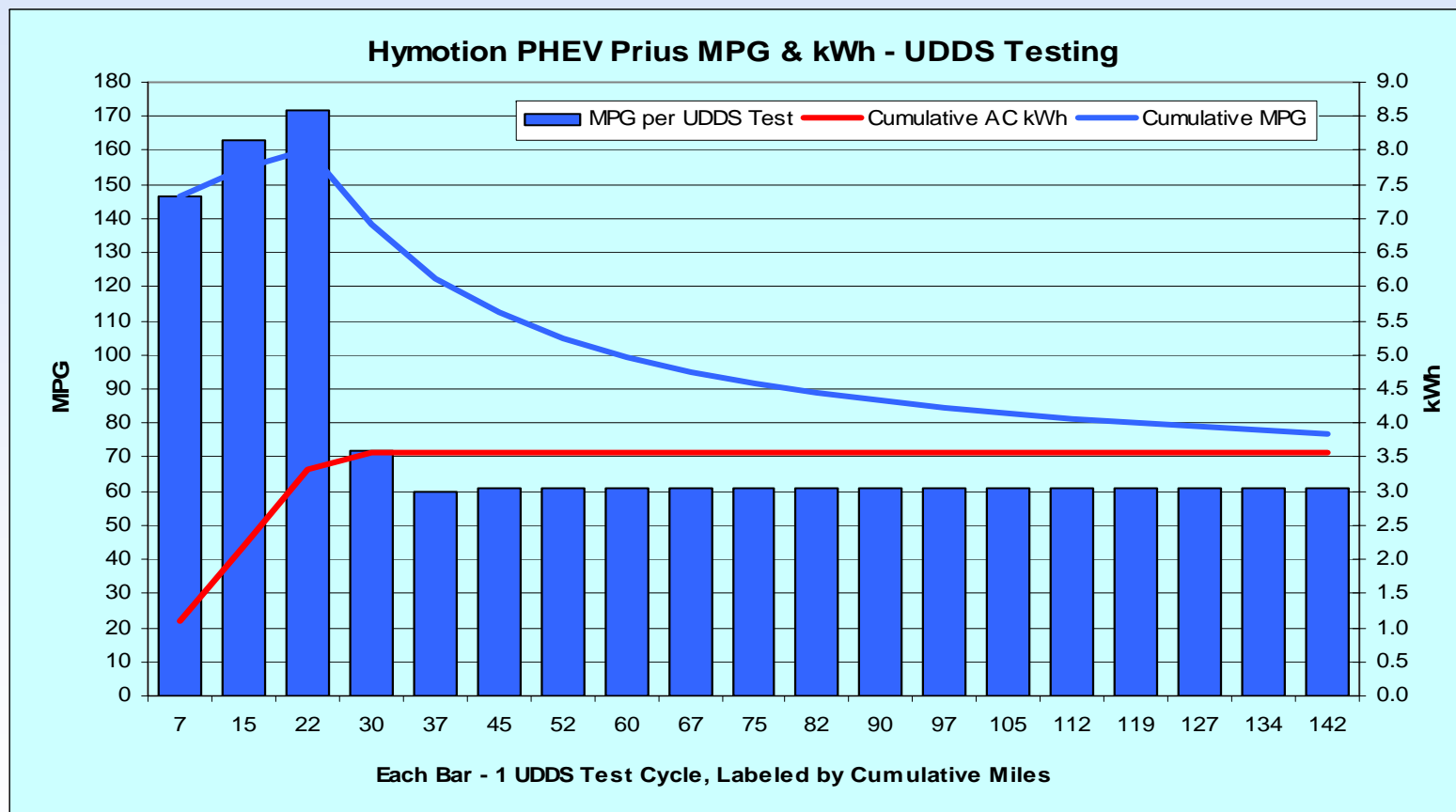
PHEV Baseline Performance Testing

- **ETEC conducts initial track testing near Phoenix, AZ**
 - Includes coastdown (determination of dynamometer coefficients), acceleration, top speed, braking, charging, durability, and fuel efficiency testing
- **Argonne 5-day dynamometer testing regime includes:**
 - Charge depleting and sustaining test cycles, as well as hot and cold starts
 - At least 26 UDDS (Urban Dynamometer Driving Schedule) and HWFEDS (Highway Fuel Economy Driving Schedule) dynamometer test cycles



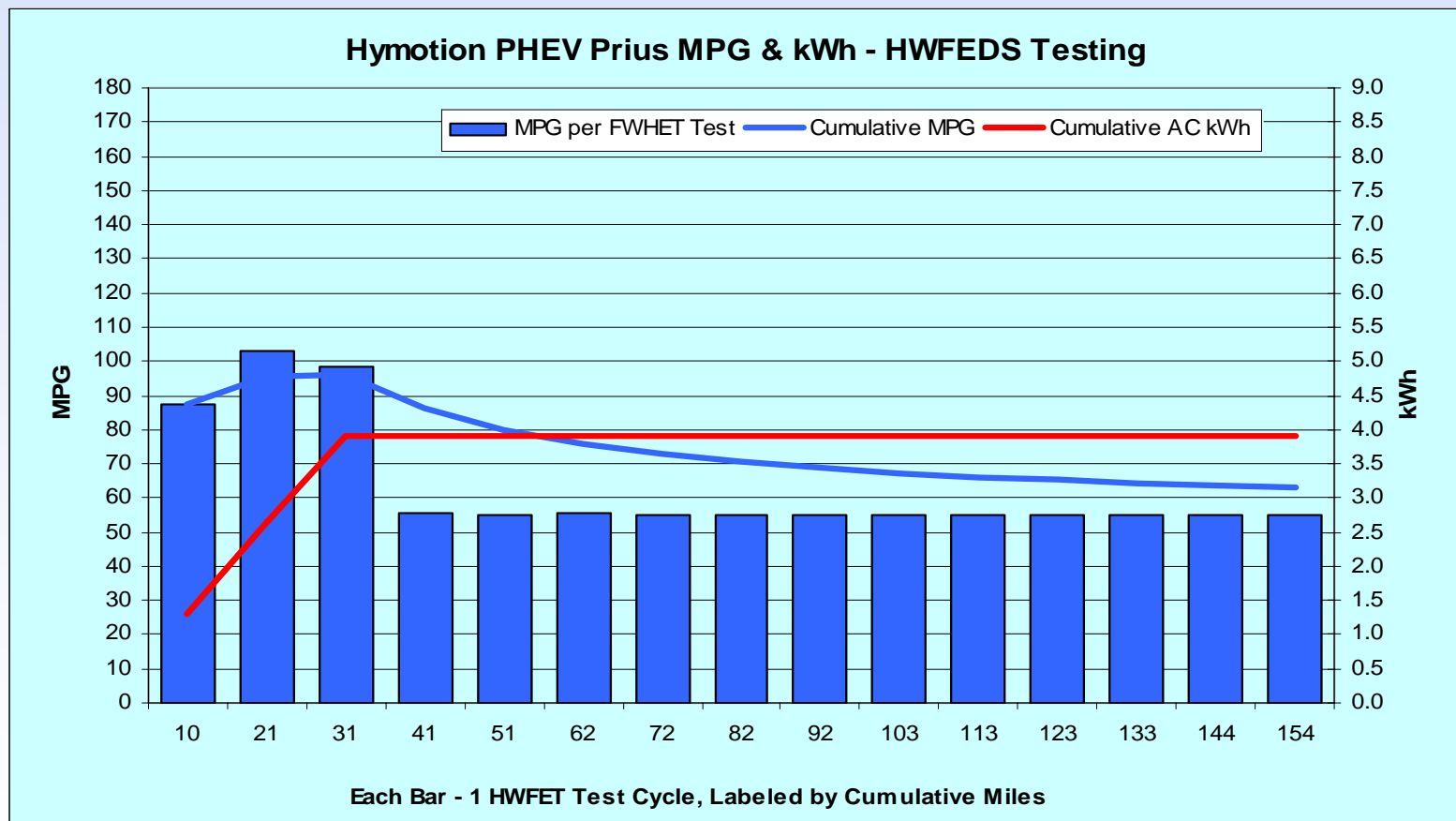
Hymotion Prius Gen I – UDDS Fuel Use

- 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	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	111.43	5.205	117.6
20	1	1	8	30	600	124.50	8.105	80.1
40	4	0	12	15	600	71.28	9.8	62.1
40	2	2	12	15	600	64.36	9.70	64.3
40	2	2	12	15	600	75.14	6.20	99.8
40	2	2	12	15	600	70.98	6.83	90.6
40	0	4	12	15	600	75.18	6.10	103.3
60	2	4	12	10	600	33.38	10.54	58.8
80	2	6	12	8	640	41.38	10.71	61.8
100	2	8	12	6	600	26.48	10.91	56.5
200	2	18	12	3	600	16.01	10.41	57.7
Total	2340	3100	1404	167	6,040	Weighted Average		

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

EnergyCS Prius (Valance) – Accelerated Testing

Cycle	Urban	Highway	Charge	Reps	Total	Electricity	Gasoline	
(mi)	(10 mi)	(10 mi)	(hr)	(N)	(mi)	kWh	Gals	MPG
10	1	0	4	60	600	115.58	4.78	128.1
20	1	1	8	30	600	86.21	7.95	77.9
40	4	0	12	15	600	25.00	14.29	42.7
40	2	2	12	5	600	31.52	11.05	56.1
40	0	4	12	5	600	32.44	11.36	55.5
60	2	4	12	10	600	65.00	5.90	103.7
80	2	6	12	8	640	39.04	10.09	65.8
100	2	8	12	6	600	22.67	8.81	70.8
200	2	18	12	3	600	12.98	10.46	57.8
Total	2340	2500	984	147	5440	Weighted Average		66.1

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

Renault Kangoo – Accelerated Testing

Cycle	Urban	Highway	Charge	Reps	Total	Electricity		Gasoline	
(mi)	(10 mi)	(10 mi)	(hr)	(N)	(mi)	AC kWh	Mi/kWh	Gals	MPG
10	1	0	4	60	600	359.60	1.7	0	
20	1	1	8	30	600	131.96	4.6	0	
40	4	0	12	5	200	35.18	5.6	0	
40	2	2	12	5	200	33.22	6.0	0	
40	0	4	12	5	200	28.60	7.0	0	
60	2	4	12	10	600	57.96	10.4	13.3	45.1
80	2	6	12	8	640	44.62	14.4	16.6	38.6
100	2	8	12	6	600	Deleted*			
200	2	18	12	3	600	Deleted*			
Total	1560	1480	876	123	3,040				

* Testing ended when gasoline engine and inverter failed. Each total distance slightly greater than 600 miles.

Hymotion Escape – 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	198.93	11.52	53.1
20	1	1	8	30	600	163.29	13.51	45.7
40	4	0	12	15	600	57.51	14.91	41.1
40	2	2	12	15	600	76.29	15.99	38.7
40	0	4	12	15	600	114.14	11.92	51.5
60	2	4	12	10	600	97.18	13.70	45.3
80	2	6	12	8	640	77.69	16.05	41.3
100	2	8	12	6	600	58.64	15.69	39.8
200	2	18	12	3	600	26.09	17.72	33.5
Total	2340	3100	1344	162	5440	Weighted Average		42.5

Each total distance slightly greater than 600 miles. HEV version = 27 mpg

Electrovaya Escape – 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	135.24	9.55	65.1
20	1	1	8	30	600	101.13	17.54	34.7
40	4	0	12	15	600	71.3	16.42	37.3
40	2	2	12	15	600	69.8	14.34	43.1
40	0	4	12	15	600	55.84	20.73	29.8
60	2	4	12	10	600	44.79	16.64	37.3
80	2	6	12	8	640	42.72	16.30	40.8
100	2	8	12	6	600	20.85	21.17	29.2
200	2	18	12	3	600	13.31	19.01	30.9
Total	2340	3100	1344	162	5440	Weighted Average		36.7

Each total distance slightly greater than 600 miles. HEV version = 27 mpg

Hybrids Plus Escape (K2) – Accel. 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			
20	1	1	8	30	600			
40	4	0	12	15	600			
40	2	2	12	15	600	123.35	11.13	55.2
40	0	4	12	15	600			
60	2	4	12	10	600			
80	2	6	12	8	640			
100	2	8	12	6	600			
200	2	18	12	3	600			
Total	2340	3100	1404	167	5,440	Weighted Average		

Each total distance slightly greater than 600 and 640 miles. HEV version = 27 mpg

PHEV Fleet Testing Partners



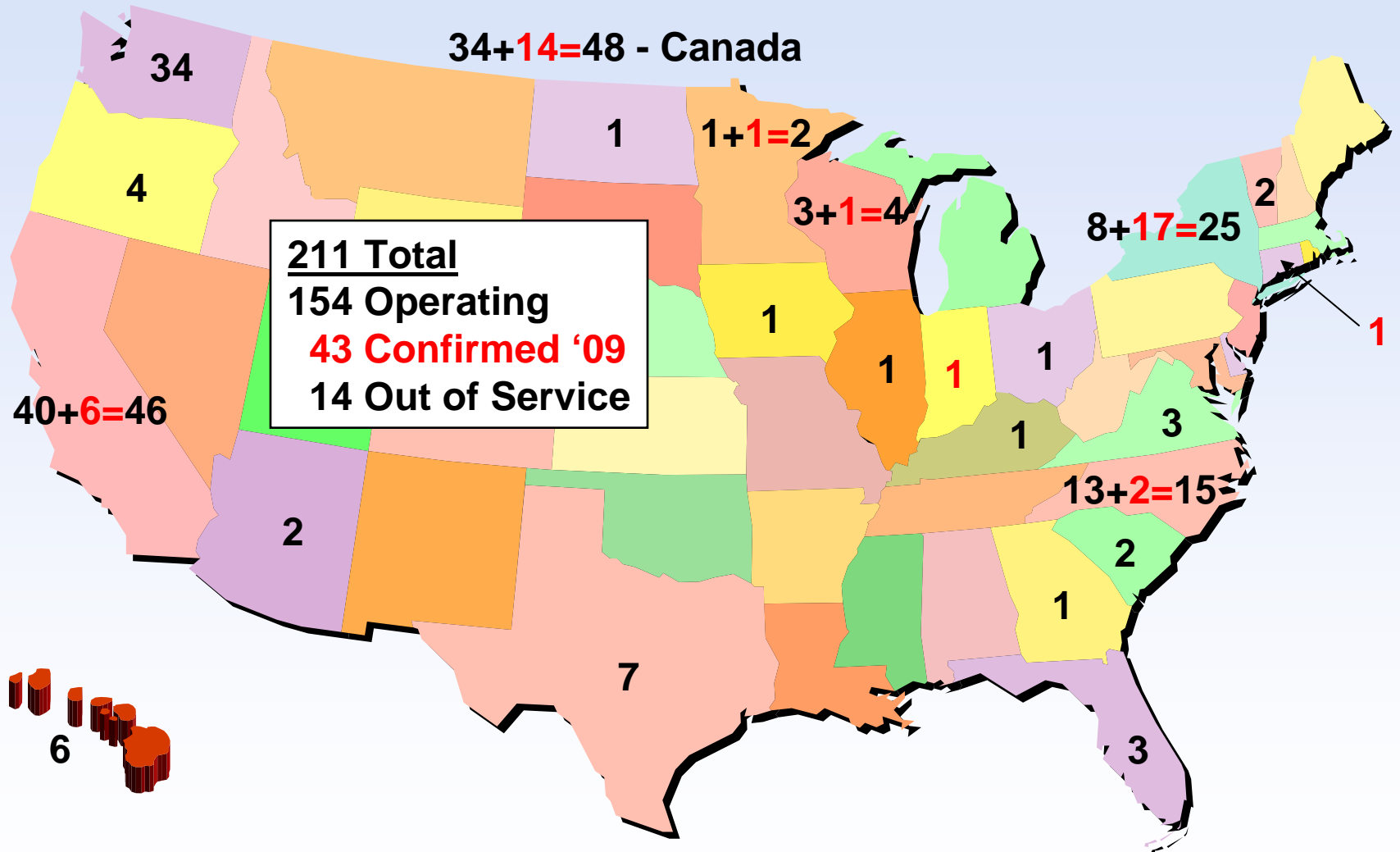
- **75+ testing partners in the U.S. and Canada:**
 - 36 Electric utilities and 2 clean-air agencies
 - 10 City, county and state governments
 - 7 Private companies and advocacy organizations
 - 8 Universities and colleges and 4 Canadian provinces
 - 2 PHEV companies 1 sea port and 1 DOD facility
- **Testing partners include:**
 - A123Systems, EnergyCS, NYSERDA, NRECA, UC Davis, Fairfax County, Google.org, Austin Energy, Central Vt PSC, Duke Energy, Advanced Energy, Progress Energy, SDGE, Basin Electric, Buckeye Power, WI Public Power Inc., Madison GE, SCANA Corp., HCATT, BC Hydro, BC Government, various Washington State groups (next slide)

Washington State Demonstrations

- **Greater Seattle area 13 Hymotion Prius**
 - City of Seattle, King County, Port of Seattle and Puget Sound Clean Air Agency
 - Initial use of V2Green data loggers, GPS and cellular communications, used in all PHEV fleets going forward due to timely 100% response rate
- **Tacoma Power**
 - 2 Manzanita lead acid Prius
 - 2 Hymotion Prius
- **Port of Chelan lead 14 Hymotion Prius**
 - Benton, Chelan and Douglas Counties, City of Wenatchee, Energy Northwest, Green IT Alliance, McKinstry, Port of Chelan, Univ. of Washington, Walla Walla Community and Wenatchee Valley Colleges
- **Puget Sound Energy 2 Hymotion Prius**



PHEV Fleet Testing



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) 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 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
- **Electric propulsion** is either in the form of all-electric or electric-assist (the internal combustion engine [ICE] is also providing propulsion power)

Why Does PHEV Fleet MPG Vary So Much?

- 26 Hymotion Prius – January thru May 2008

PHEV Operating Mode	Number of Trips	Distance Traveled (Miles)	Miles per Gallon
Charge Depleting (CD)	3,073	14,820	59
Mixed CD / CS	404	11,121	49
Charge Sustaining (CS)	1,358	16,059	40
All trips combined	4,835	42,000	48

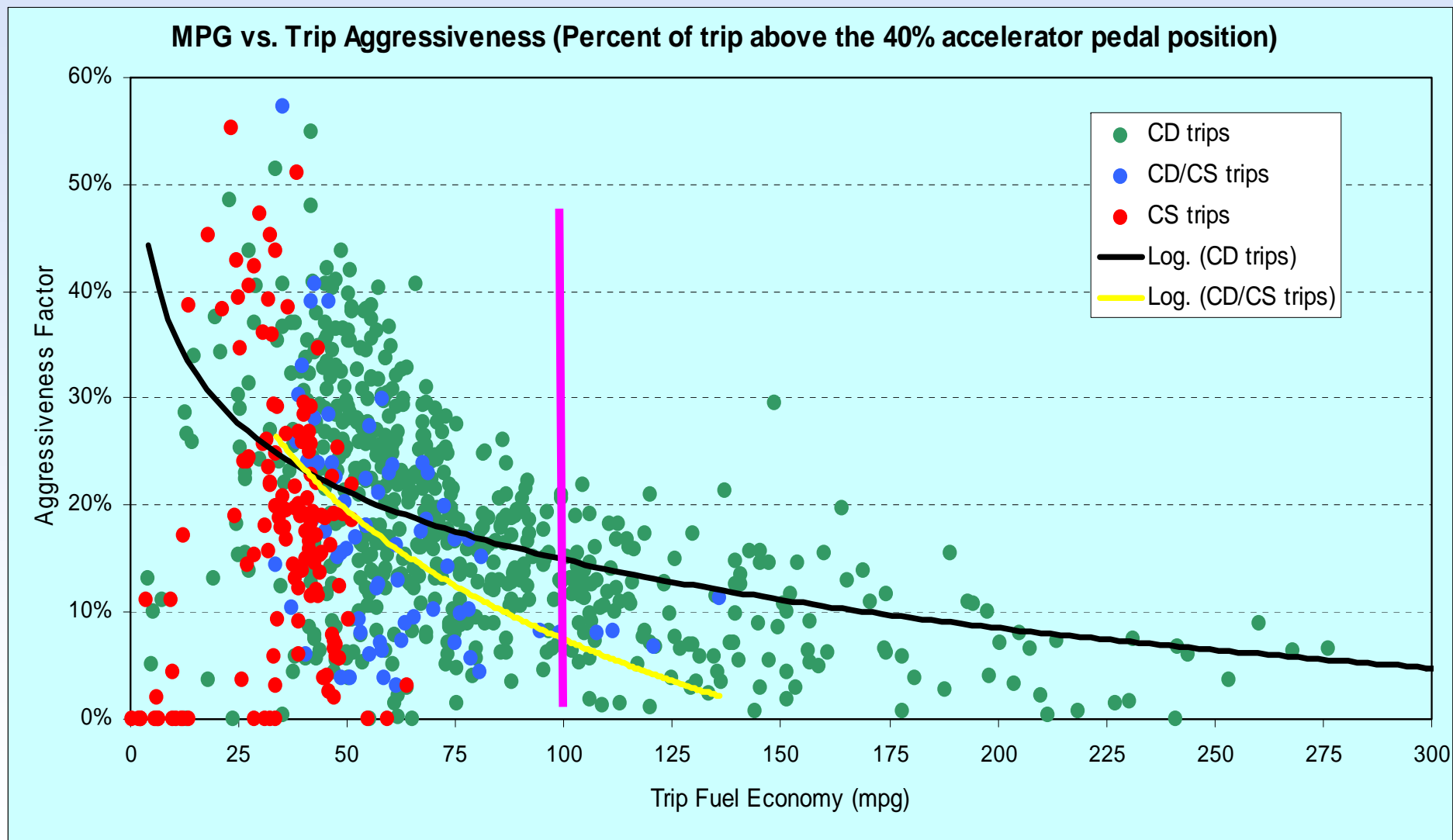


Why Does PHEV Fleet MPG Vary So Much?

- 13 Hymotion Prius - May 2008

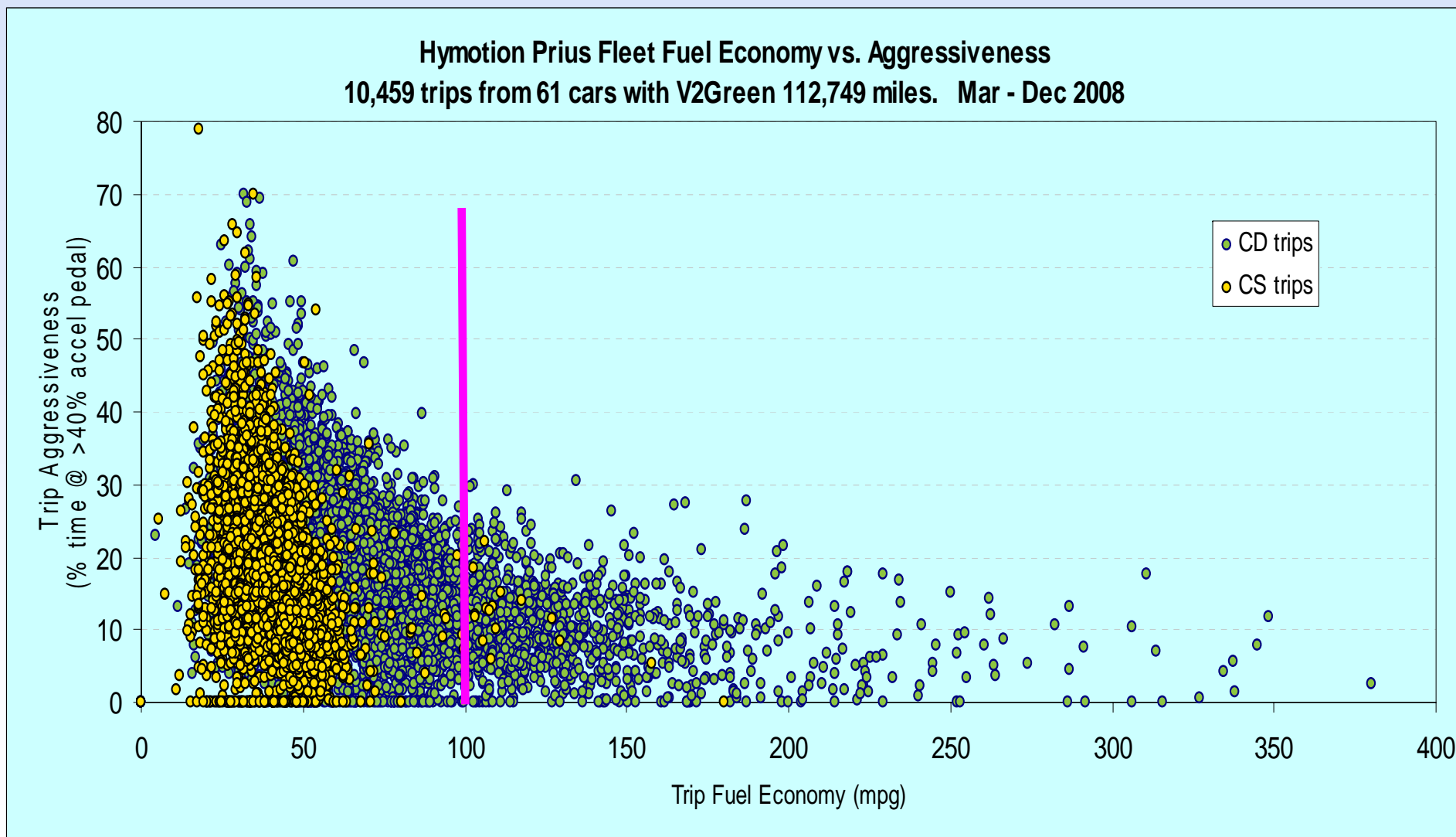
PHEV Operating Mode	# Trips	Total Distance (mi.)	Average Trip (mi.)	MPG	DC kWh\mi.
CD	575	3,040	5.3	72.0	0.138
Mixed CD / CS	67	1,840	27.5	52.1	0.050
CS	133	1,411	10.6	40.2	
All-electric	137	127	0.9		0.236
Total	912	6,417	7.0		
CD, CS, CD/CS only total	775	6,291	8.1	55.9	

PHEV MPG and Aggressive Driving



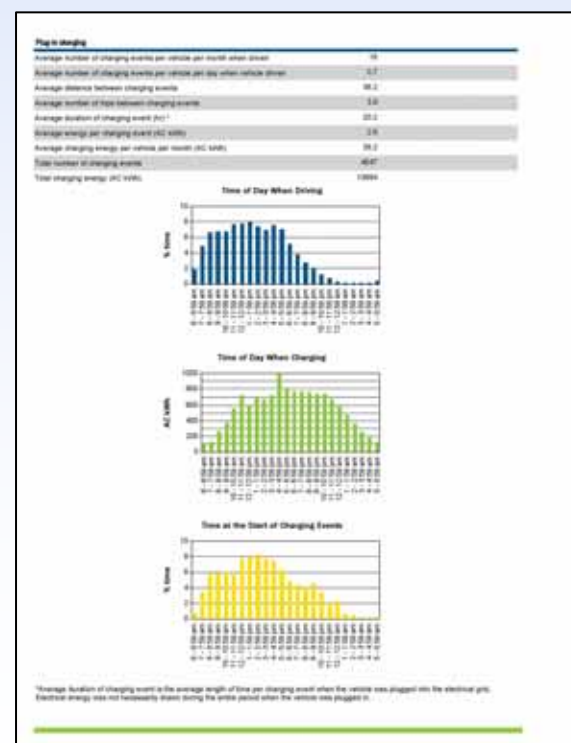
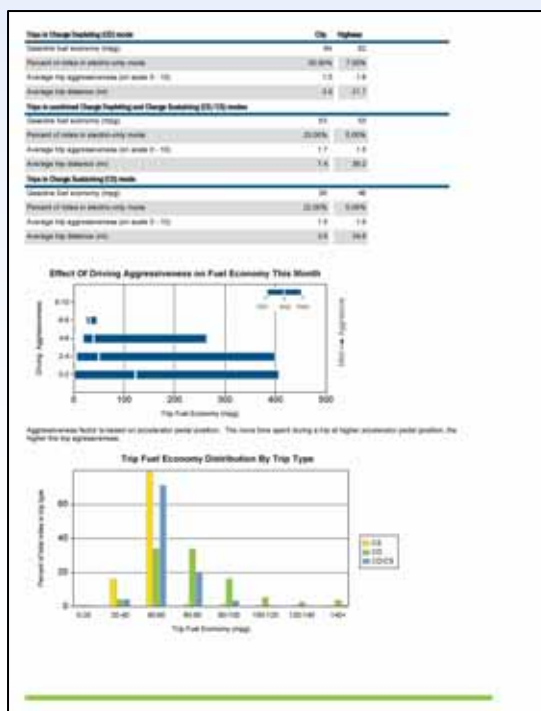
13 Hymotion Prius, 775 trips, 6,291 miles, May 2008

PHEV MPG and Aggressive Driving



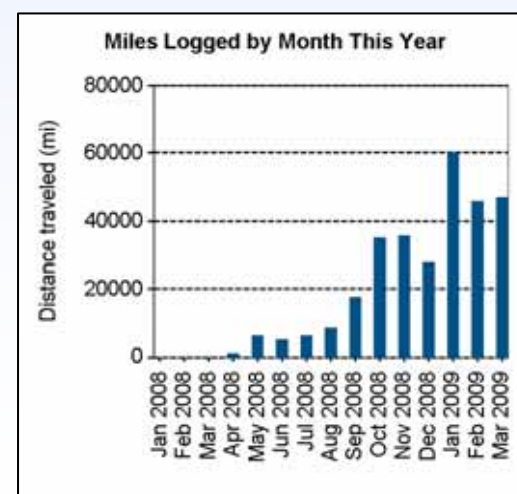
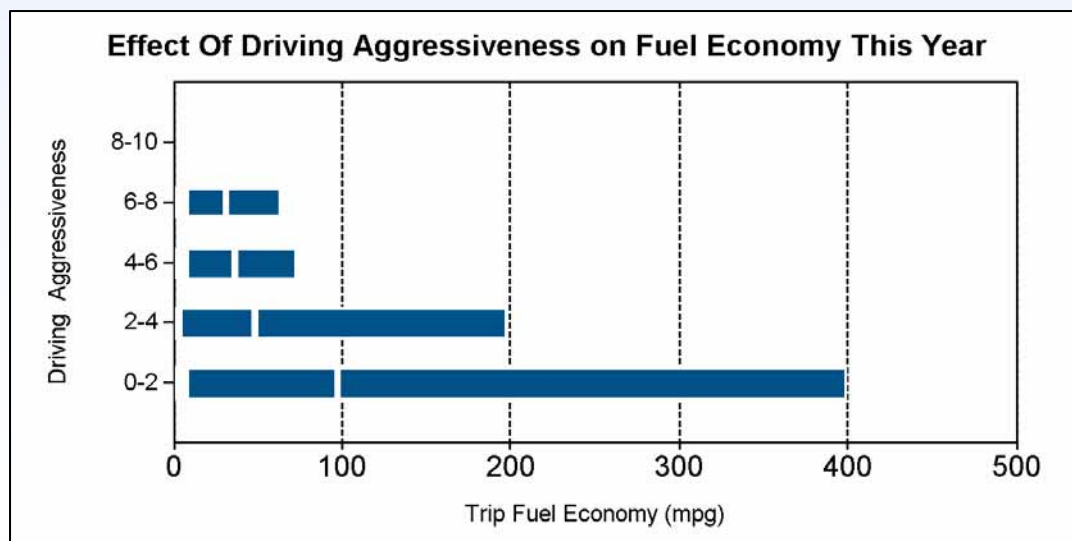
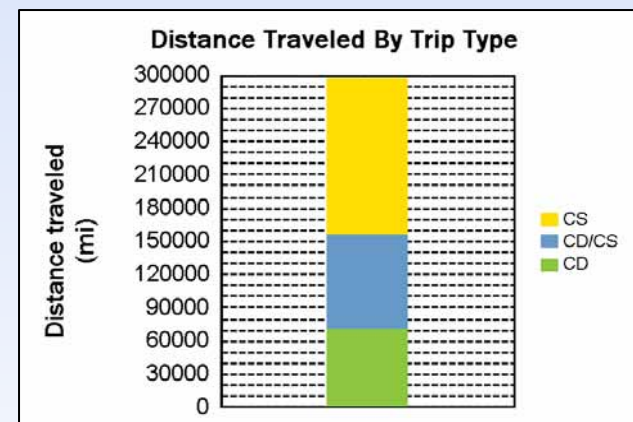
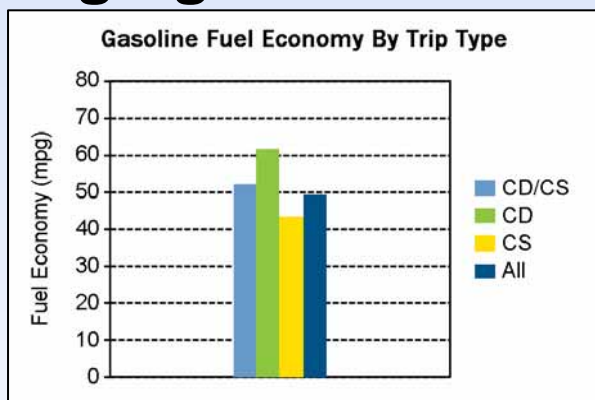
PHEV Fleet Testing Reports

- Summary reports posted monthly on web
- Individual vehicle reports only go to the respective fleets each month, 740+ reports to date (April 1, 2009)
- 115 Hymotion Prius PHEVs, 484,682 miles, 50,501 trips, 12,754 charging events, 28,663 kWh used. V2Green and Kvaser data logger reports



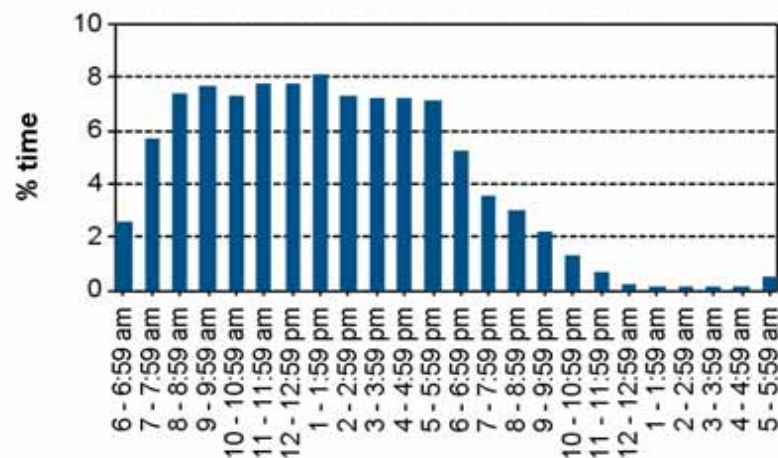
Fleet Testing Results

- Hymotion Prius, with V2Green Data Logger. 03/08 to 03/09. 65 PHEVs, 296,558 miles, 30,099 trips, 7,290 charging events and 118,755 kWh used

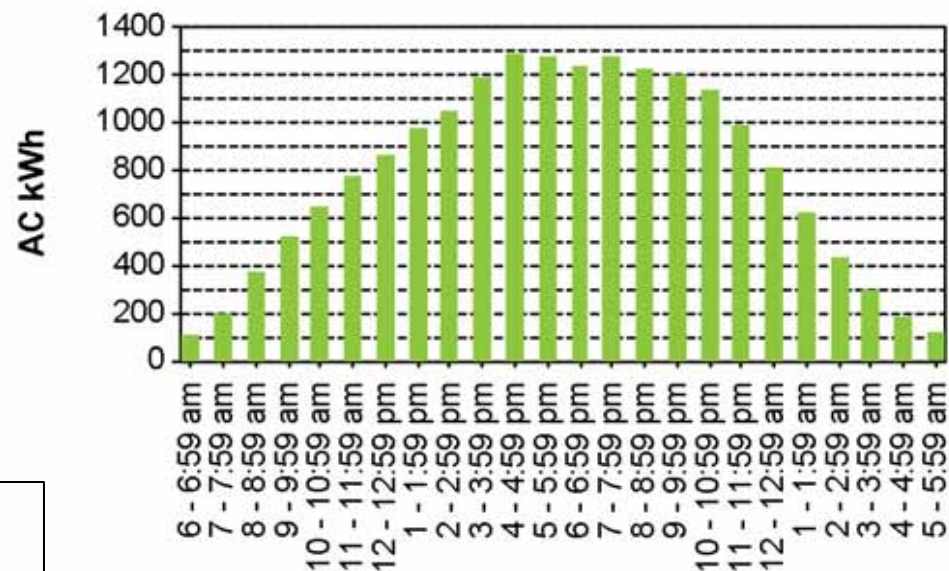


Fleet Testing Results – cont'd

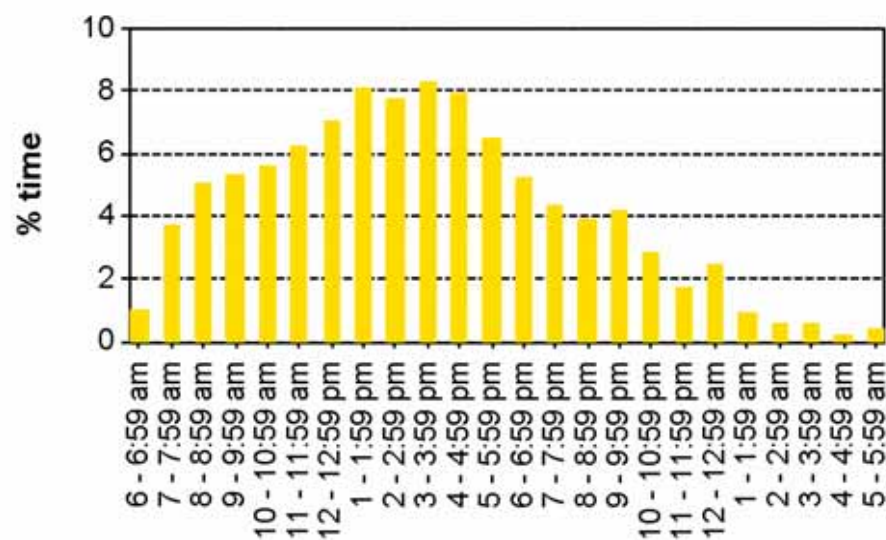
Time of Day When Driving



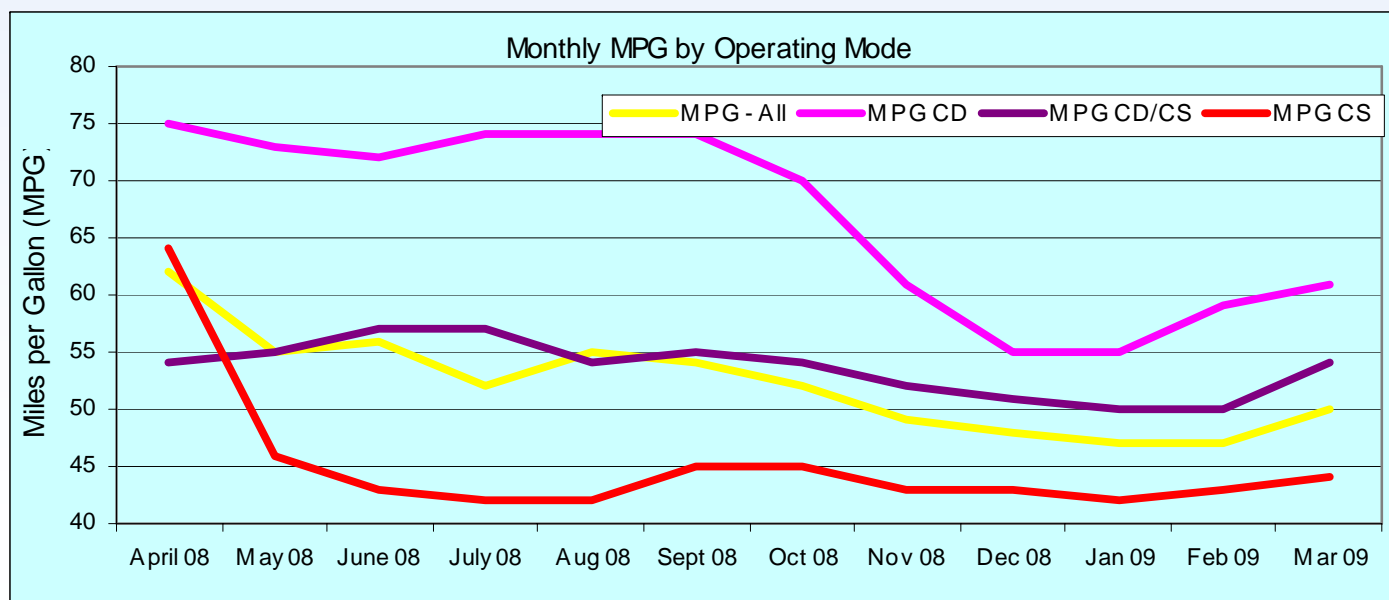
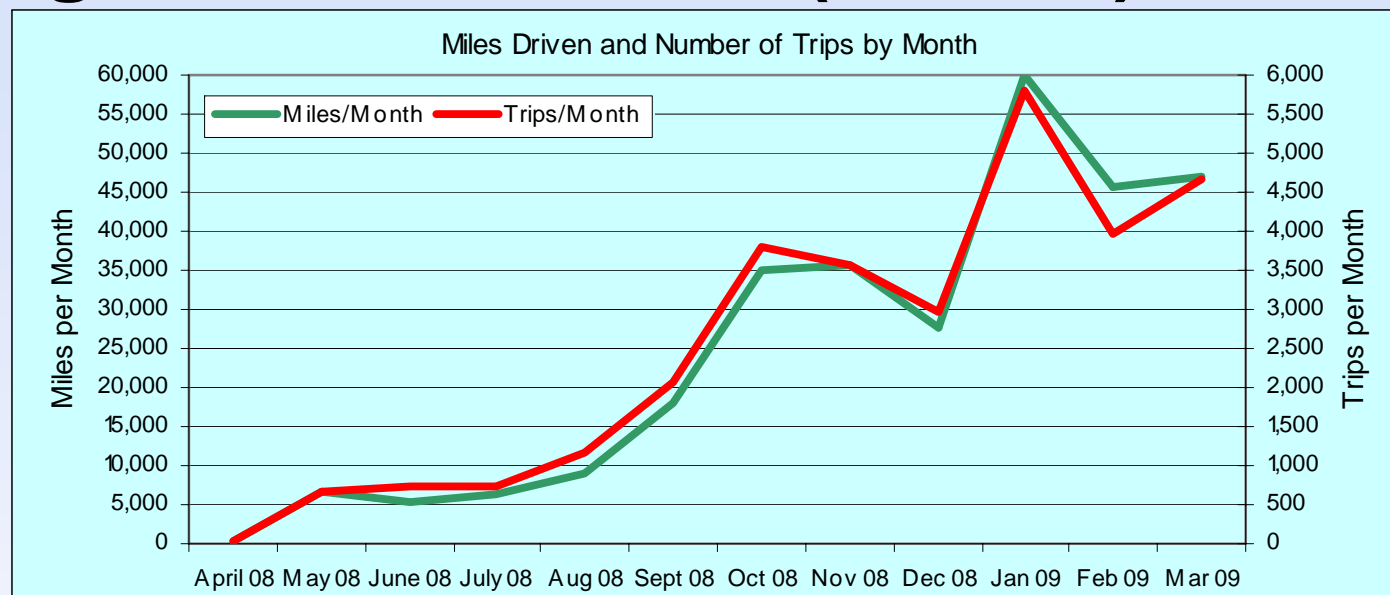
Time of Day When Charging



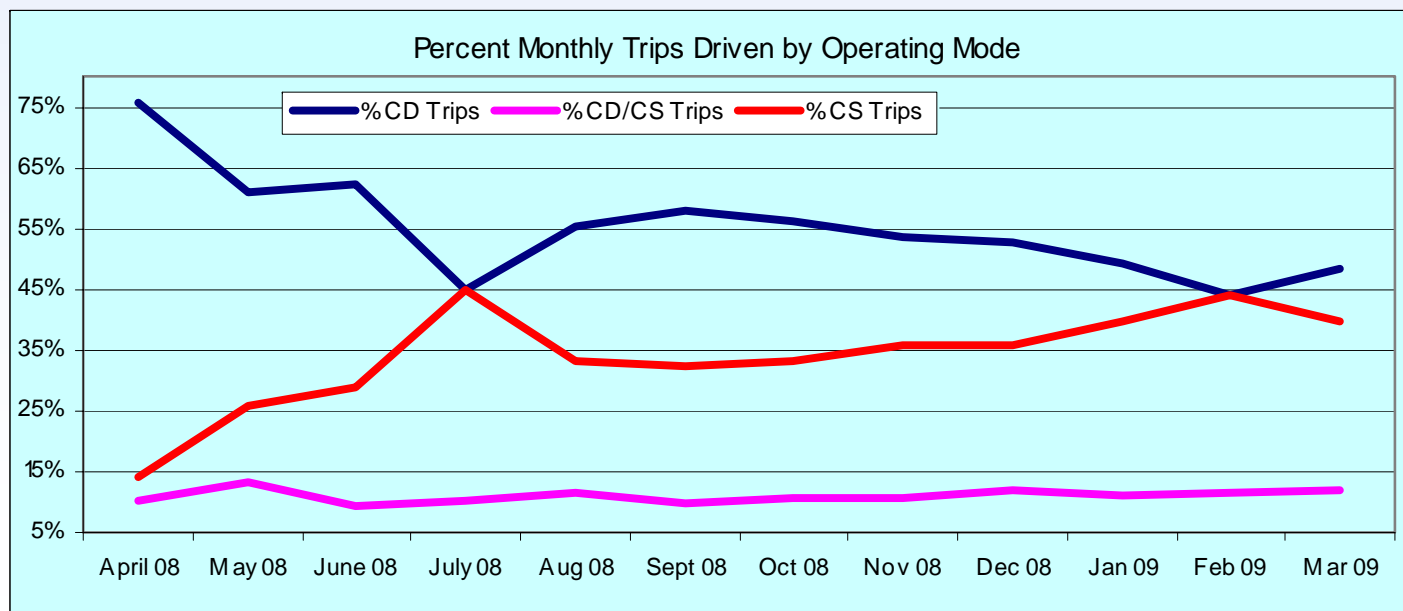
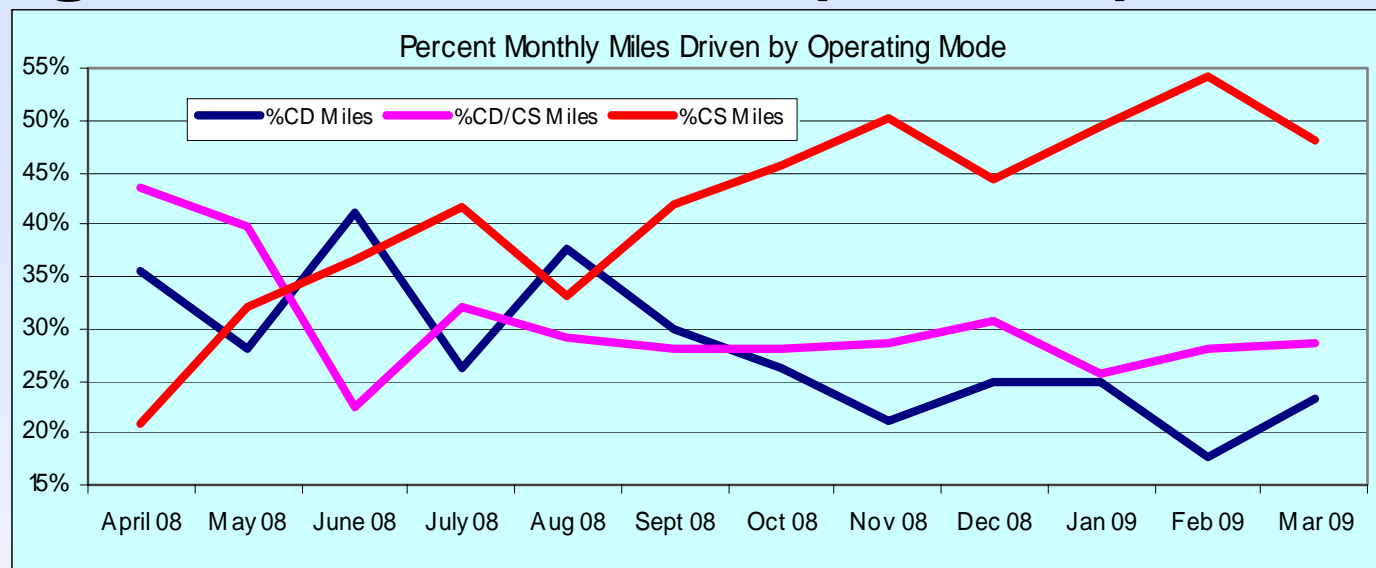
Time at the Start of Charging Events



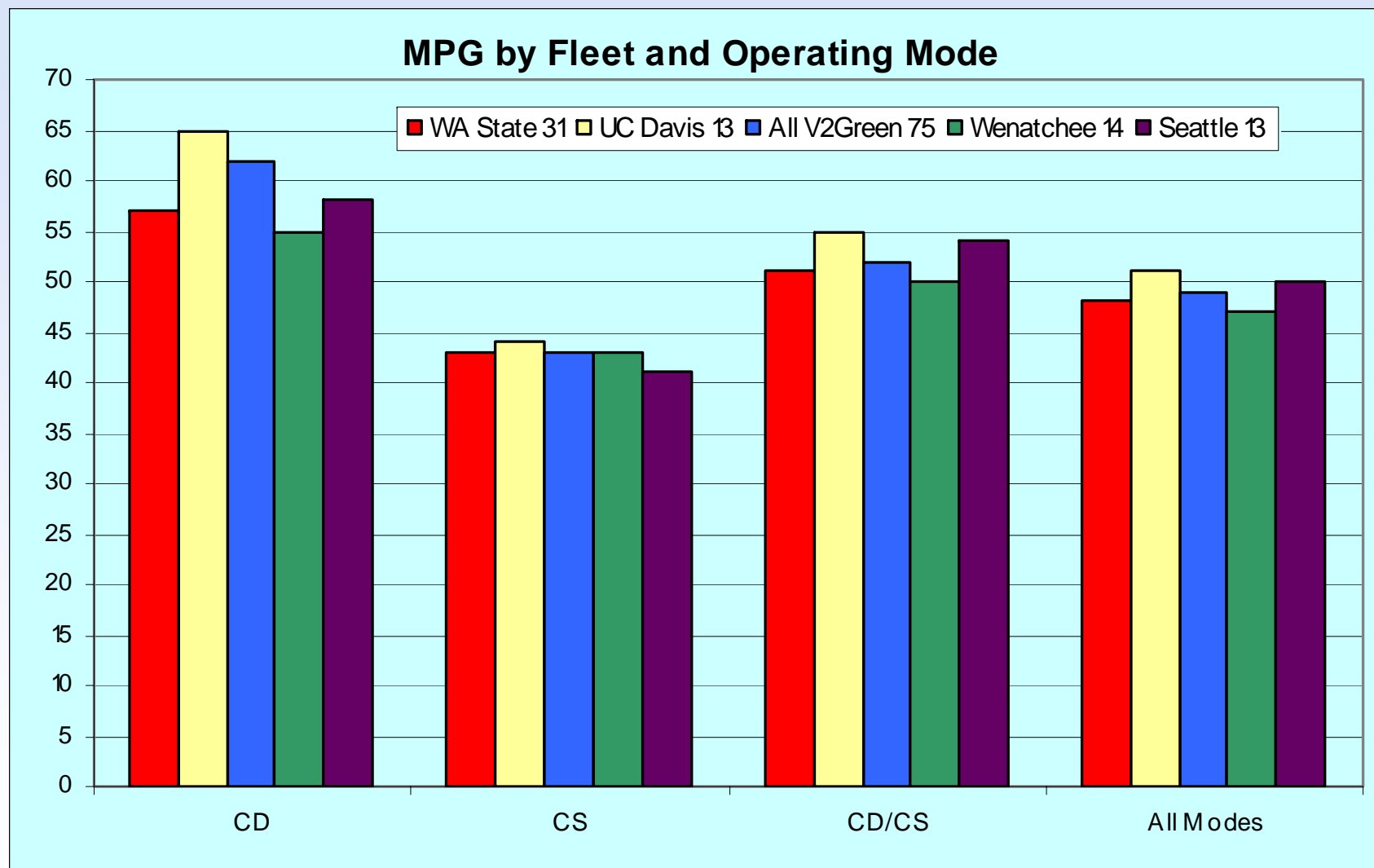
Fleet Testing Results – cont'd (Trends)



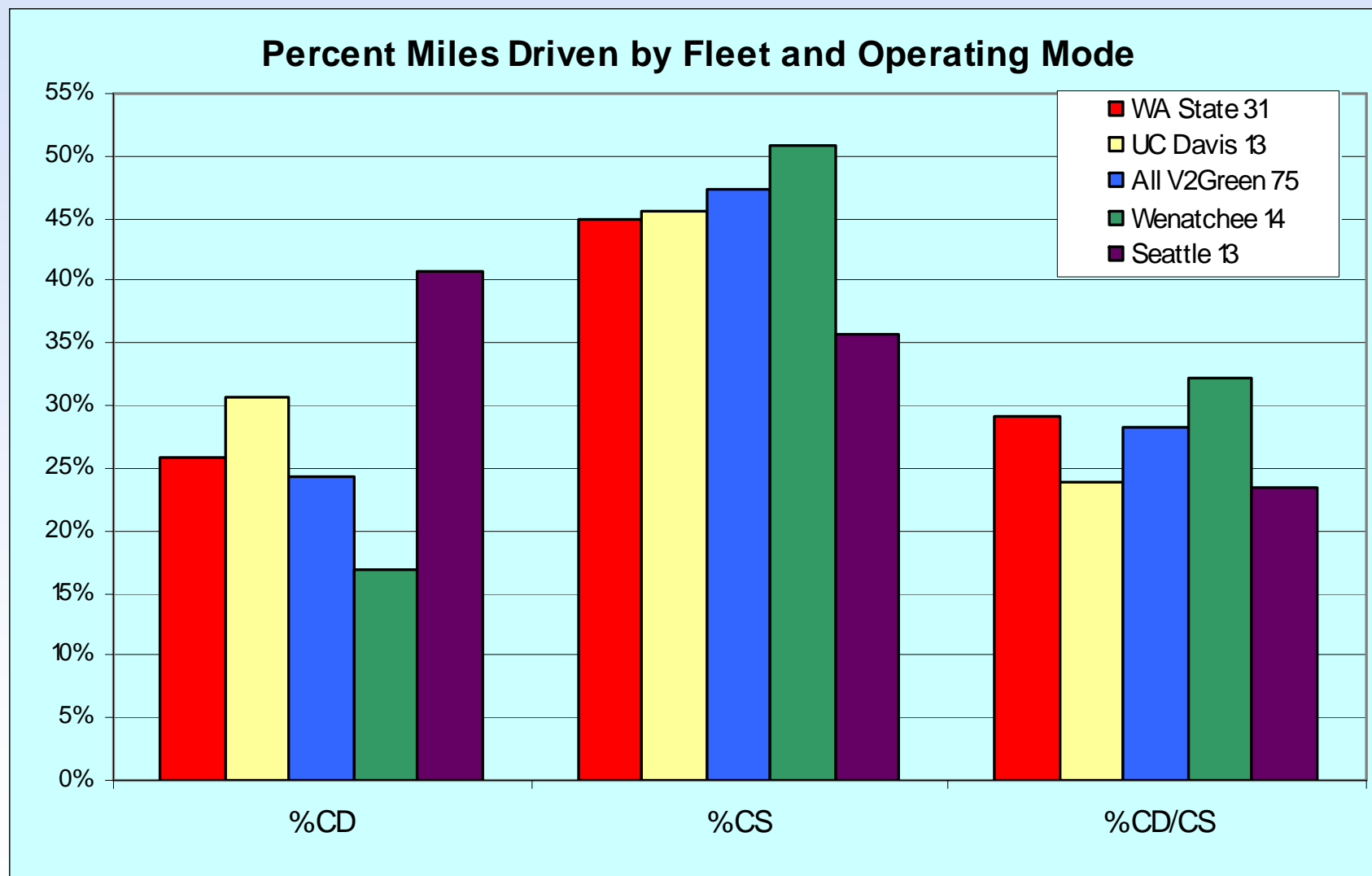
Fleet Testing Results – cont'd (Trends)



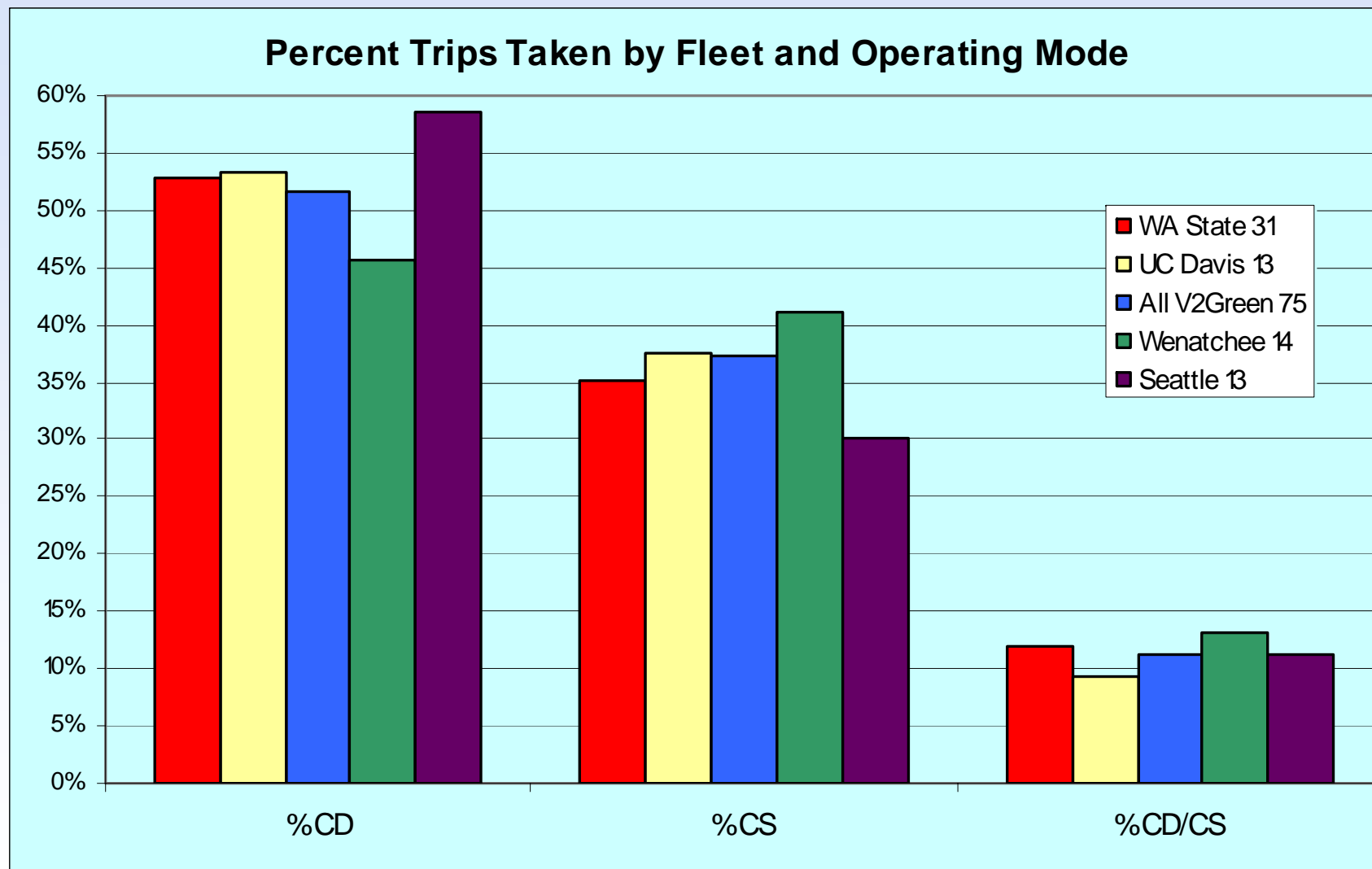
Fleet Testing Results by Fleet



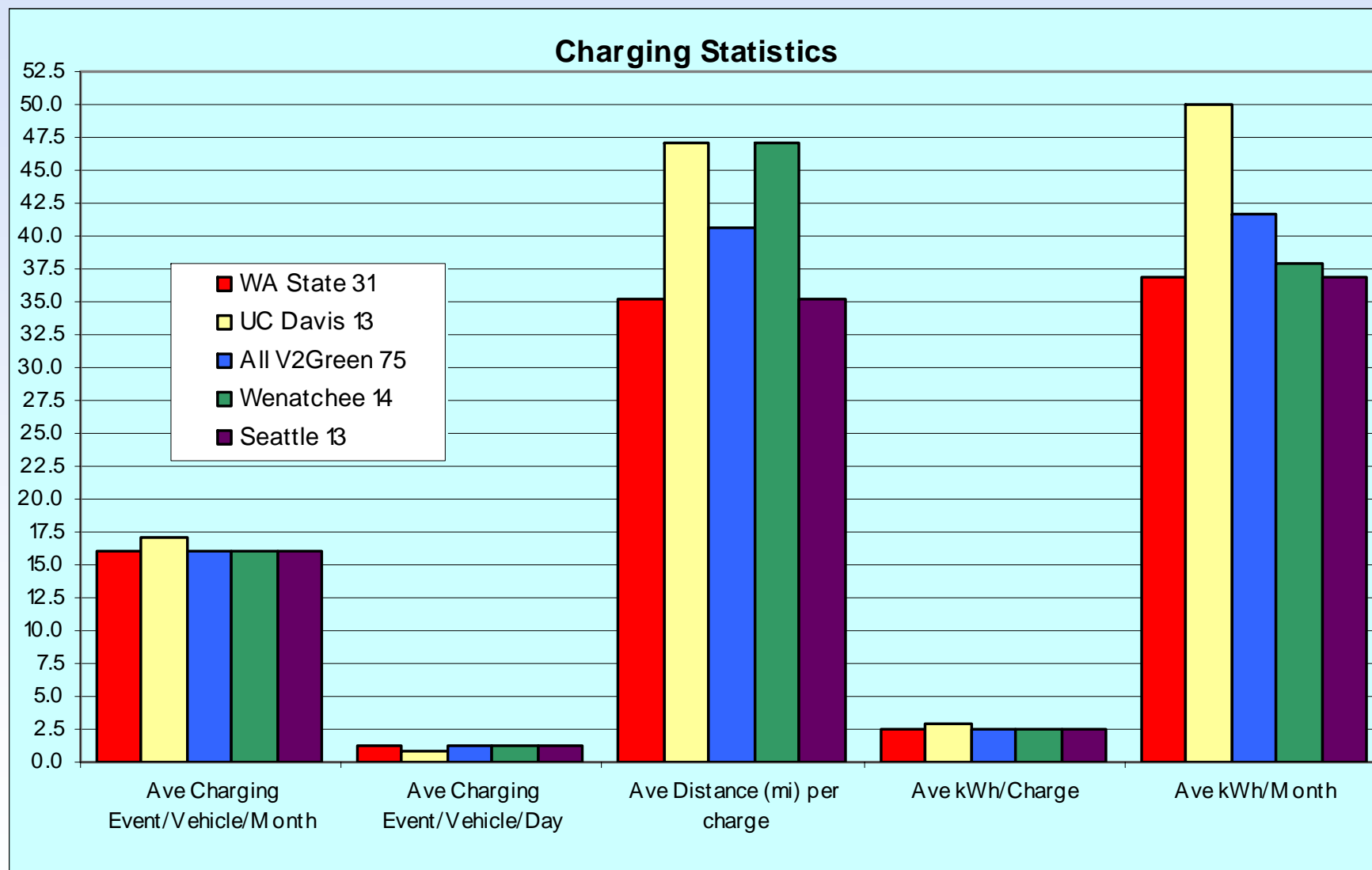
Fleet Testing Results by Fleet



Fleet Testing Results by Fleet – cont'd

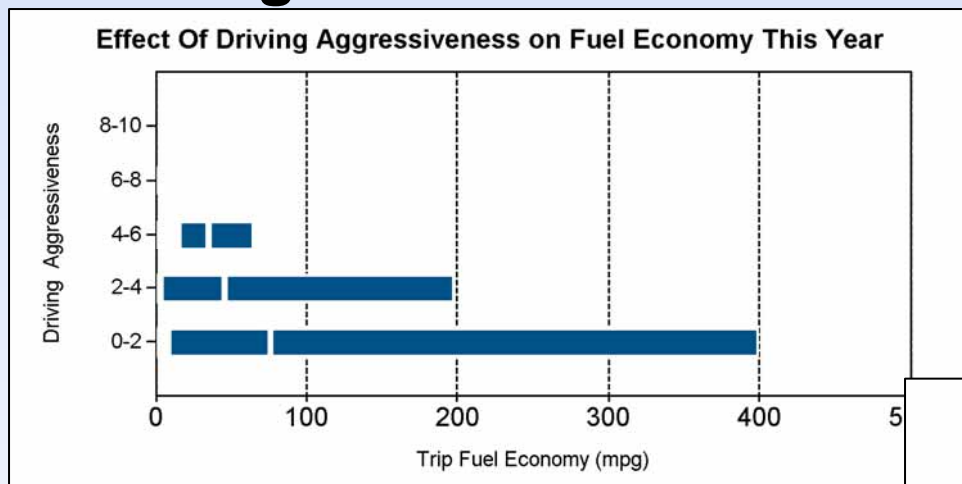


Fleet Testing Results by Fleet – cont'd

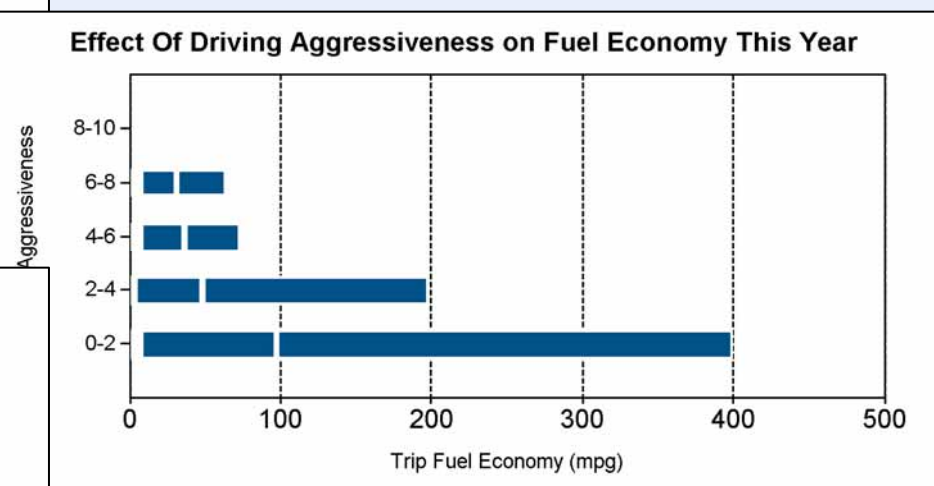


Aggressiveness Impacts on MPG

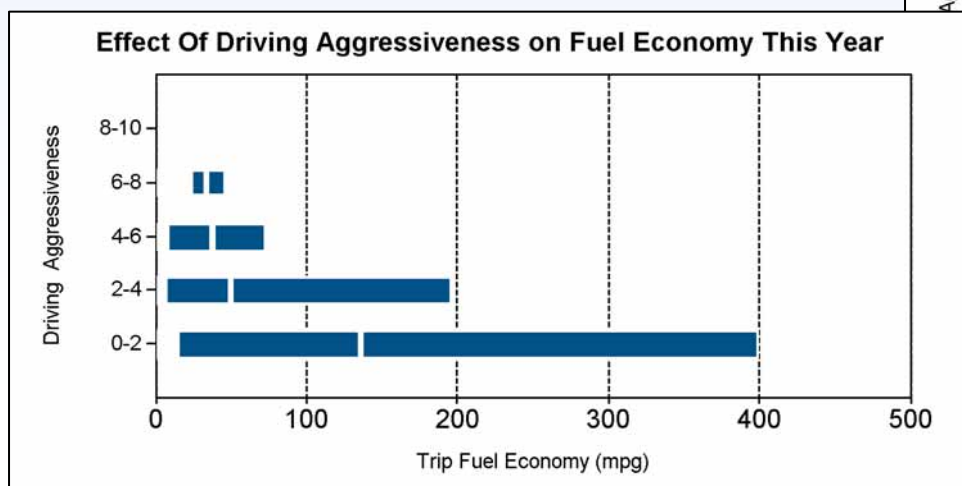
Washington State



All Fleets



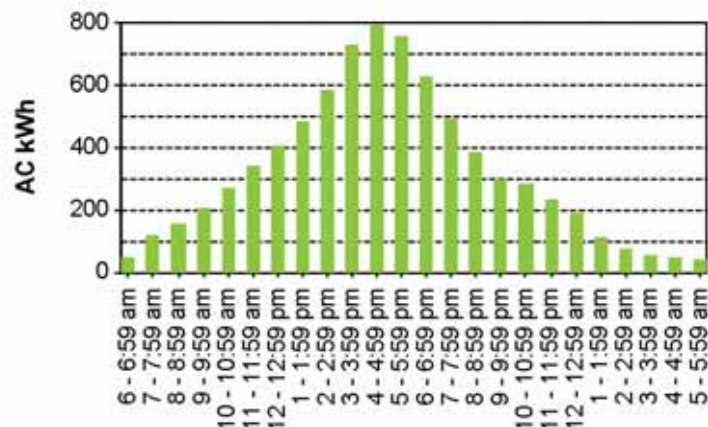
UC Davis



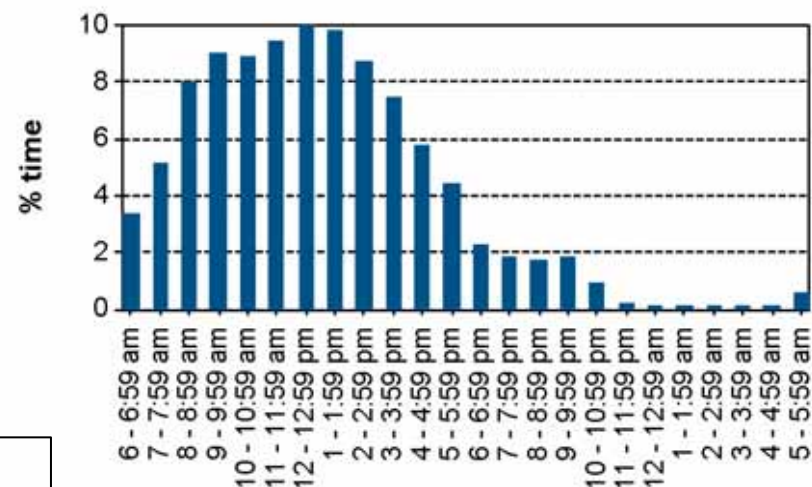
Washington State Fleet Testing Reports

- 31 Hymotion Prius PHEVs, 114,359 miles, 12,912 trips, 3,248 charging events, 7,719 kWh used

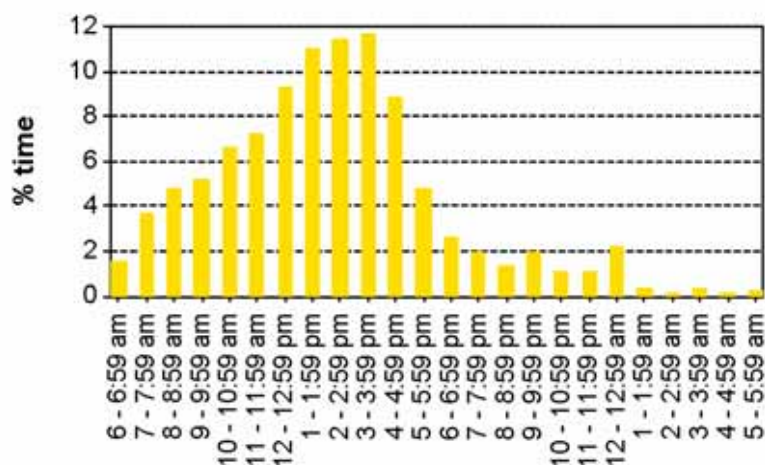
Time of Day When Charging



Time of Day When Driving



Time at the Start of Charging Events



Charging Infrastructure Terms

- **Level I** – 110 / 120 VAC, 15 amp (12 amp continuous). Maximum 1.44 kW continuous. Onboard charger. NEMA5-15R receptacle, with GFCI
- **Level II** – greater than Level I, with 208-240 VAC and up to 40 amp (32 amp continuous). Maximum 9.6 kW (7.68 kW continuous). Generally onboard charger. EVSE, mated to AC input and SAE J1722 connector to vehicle (the “plug”)
- **Level III** – greater than Level II, generally off-board charger supporting more than one vehicle. Energy to vehicle can be 440 VDC or higher
- **Fast Charge** – Returns 50% of a battery’s capacity in under 30 minutes. For large batteries, usually at Level III
- **SAE J1722** – scheduled June 2009 vote. Defines standard connector up to ~70 amps

Other PHEV Testing

- **Bidirectional vehicle-to-grid (V2G) charging study with electric utilities participating**
 - 6 kW and 20 kW levels, using two lithium PHEV batteries, V2Green cellular charging control, documenting infrastructure requirements and costs
- **Conduct vehicle \ battery testing on PHEVs when received via DOE's OEM PHEV Technology Assistance and Demonstration Activity**
- **Developing batteries \ mule vehicles testing projects**
- **City of Seattle \ V2Green lead time-of-day charging demonstration on 13 Seattle-area PHEVs. Includes INL battery impact analysis. Uses V2Green wireless charging control**

Other PHEV Testing – cont'd

- Tacoma Power charging infrastructure study
 - AVTA and Tacoma Power are collecting data on one section of administration building (800 amp, 480 volt, 3 phase load) and PHEV charging infrastructure
 - Document demand and energy profiles of PHEV charging as portion of facility profiles
 - WiFi local energy meter (LEM) data collection system



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

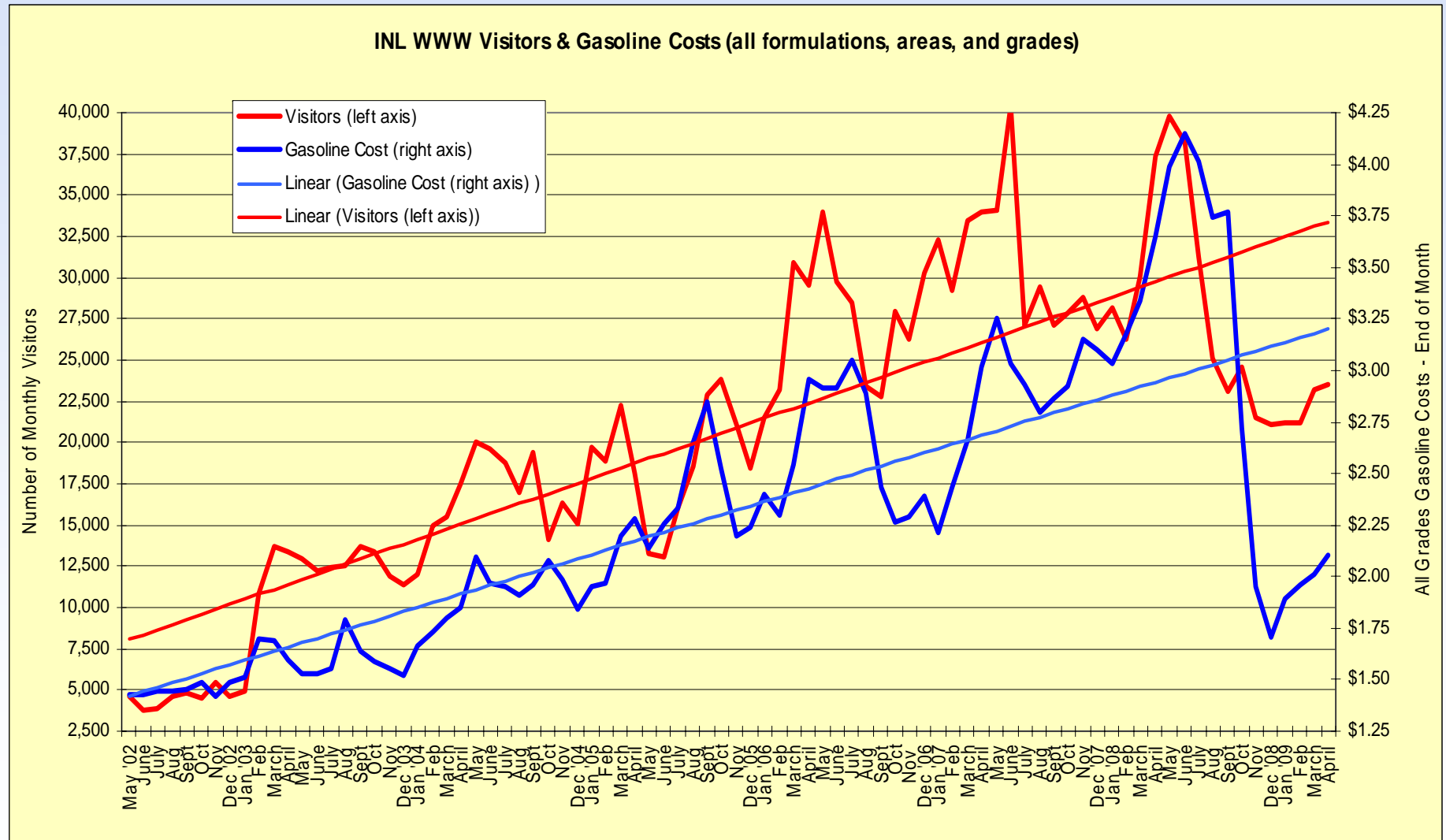
Lithium Battery Performance

- Applicable to NiMH and Lithium chemistries, the DOE / USABC HEV and PHEV battery goals are listed below
- Most lithium batteries are performing to or near the goals

Temperature	Capacity based on performance at 30°C
0°C (32°F)	50%
-10°C (14°F)	30%
-30°C (-22°F)	10%
+50°C (122°F)	>100%



AVTA Webpage Use and Gasoline Costs



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-09-16044