

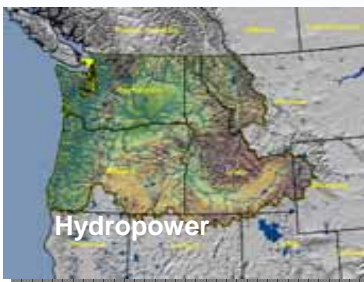
# **U.S. Department of Energy, Vehicle Technologies Program - Advanced Vehicle Testing Activity (AVTA)**

## **PHEV Testing and Demonstrations – NAFA Convention**

**Jim Francfort  
AVTA Principle Investigator  
NAFA, Portland International Auto Show  
February 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)**
  - 10 models, ~150 vehicles
- **Hybrid electric vehicles (HEV)**
  - 14 models, 4+ million test miles
- **Hydrogen ICE (internal combustion engine) vehicles**
  - 7 models, 400,000 test miles
- **Full-size electric vehicles**
  - 40 EV models, 5+ million test miles
- **Neighborhood electric vehicles**
  - 20 models, 200,000 test miles
- **Urban electric vehicles**
  - 3 models, 1 million test miles



# PHEV Questions

- Are PHEVs technically and economically feasible as a transportation option?
- What are the petroleum savings and electricity demands?
- Will fleets and the public adapt to plugging in (charging) PHEVs to maximize mpg?
- Is a two-fuel scenario a difficult transition?
- What are the charging infrastructure needs, including 110V versus 220V? Fast charging?
- V2Grid – economic and technical benefit or liability to the vehicle operator?
- To answer these questions, the AVTA is testing and field demonstrating ten different PHEV models, their batteries, and the charging infrastructure

# 10 PHEVs Models in Testing/Demonstrations

- Hymotion Prius (majority of PHEVs in testing/demo's)
- Hymotion Escape
- Ford E85 Escape
- EnergyCS Prius
- Electrovaya Escape
- Hybrids Plus Escape
- Hybrids Plus Prius
- Manzanita Prius (lead acid)
- Manzanita Prius (Thunder Sky - Lithium)
- Renault Kangoo (NiCad)
- (Lithium unless noted)

# PHEV Testing Objectives

- **Perform independent testing of PHEVs, using:**
  - **Baseline performance testing – closed test tracks and dynamometers**
  - **Accelerated testing – dedicated drivers operating on defined onroad loops**
  - **Fleet testing – everyday unstructured \ non-directed fleet and public use, with onboard data loggers**
- **Document battery life, charging patterns and demand profiles**
- **Document vehicle operations, fuel use (both gasoline and electricity) and infrastructure requirements (110V versus 220V, offpeak and V2Grid charging)**
- **Document driver influences on fuel use**
- **Document PHEV life-cycle costs**



# PHEV Baseline Performance Testing

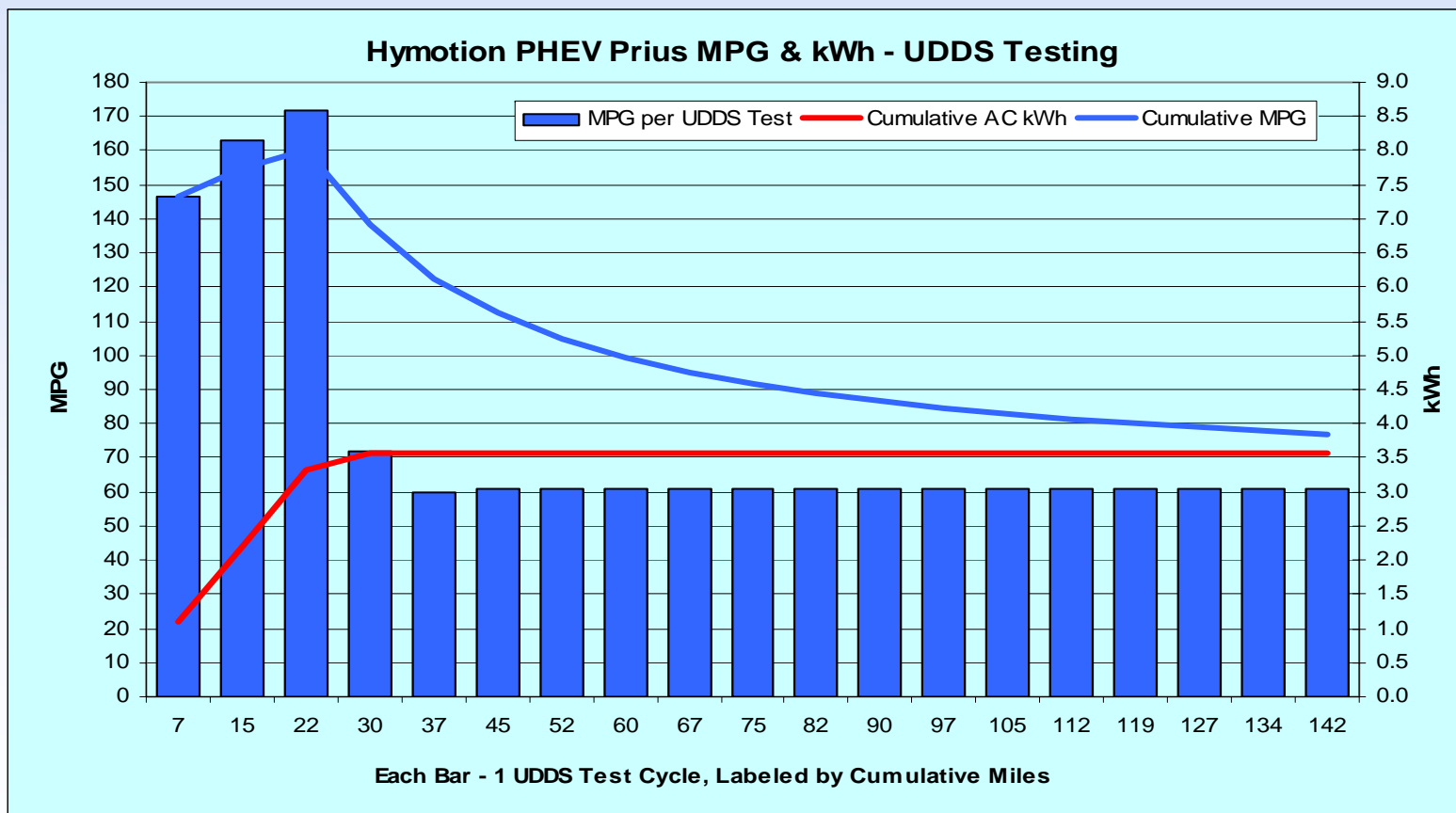
- **EETEC conducts initial track testing near Phoenix, AZ**
  - Includes coastdown (determination of dynamometer coefficients), acceleration, top speed, braking, charging, and durability testing
- **Argonne 5-day dynamometer testing regime includes:**
  - Charge depleting and sustaining test cycles, 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





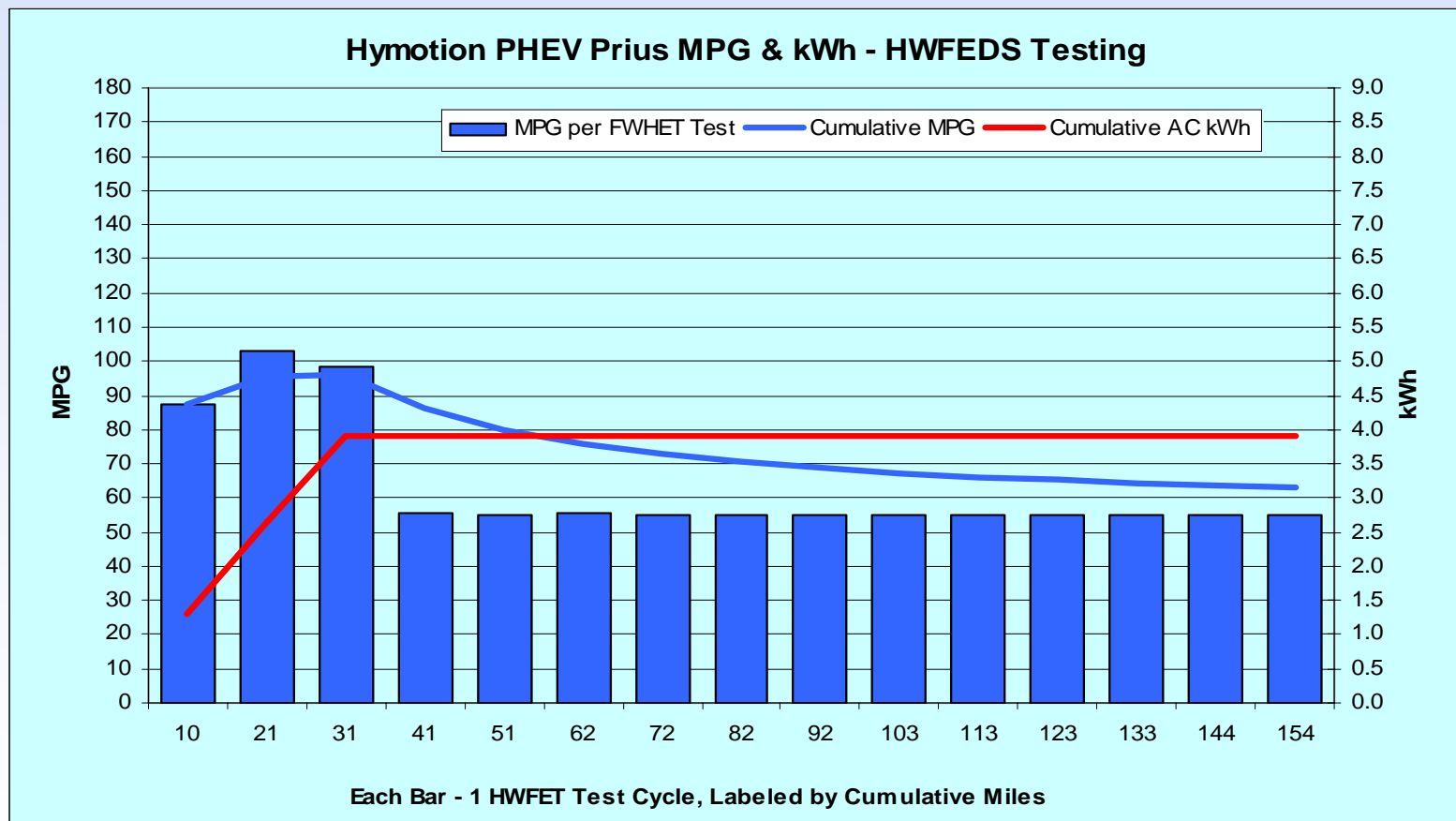
# Hymotion Prius – UDDS Fuel Use

- 5 kWh A123Systems (Li) V1 and Prius packs (AC kWh)



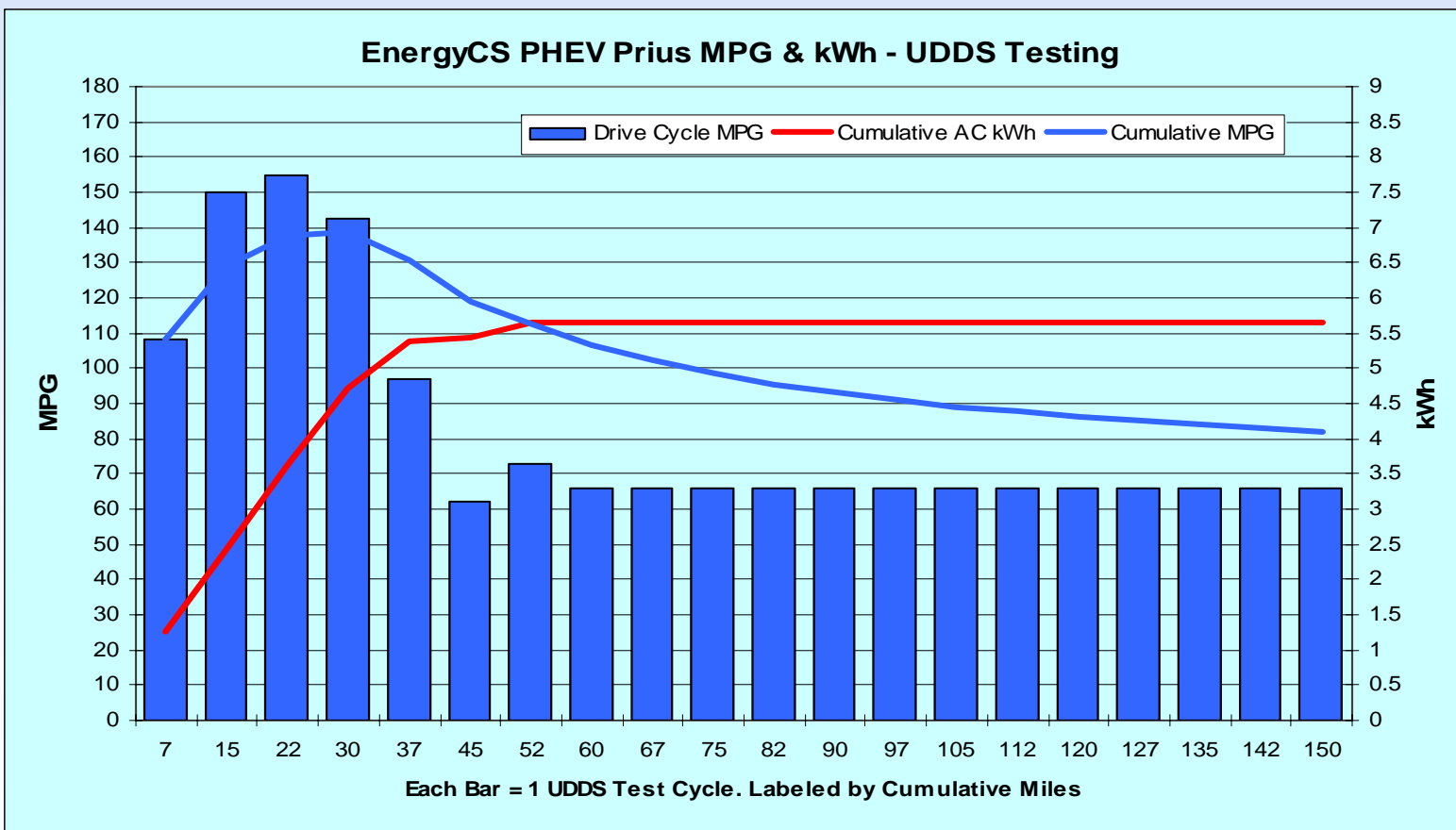
# Hymotion Prius – HWFEDS Fuel Use

- 5 kWh A123Systems (Li) V1 and Prius packs (AC kWh)



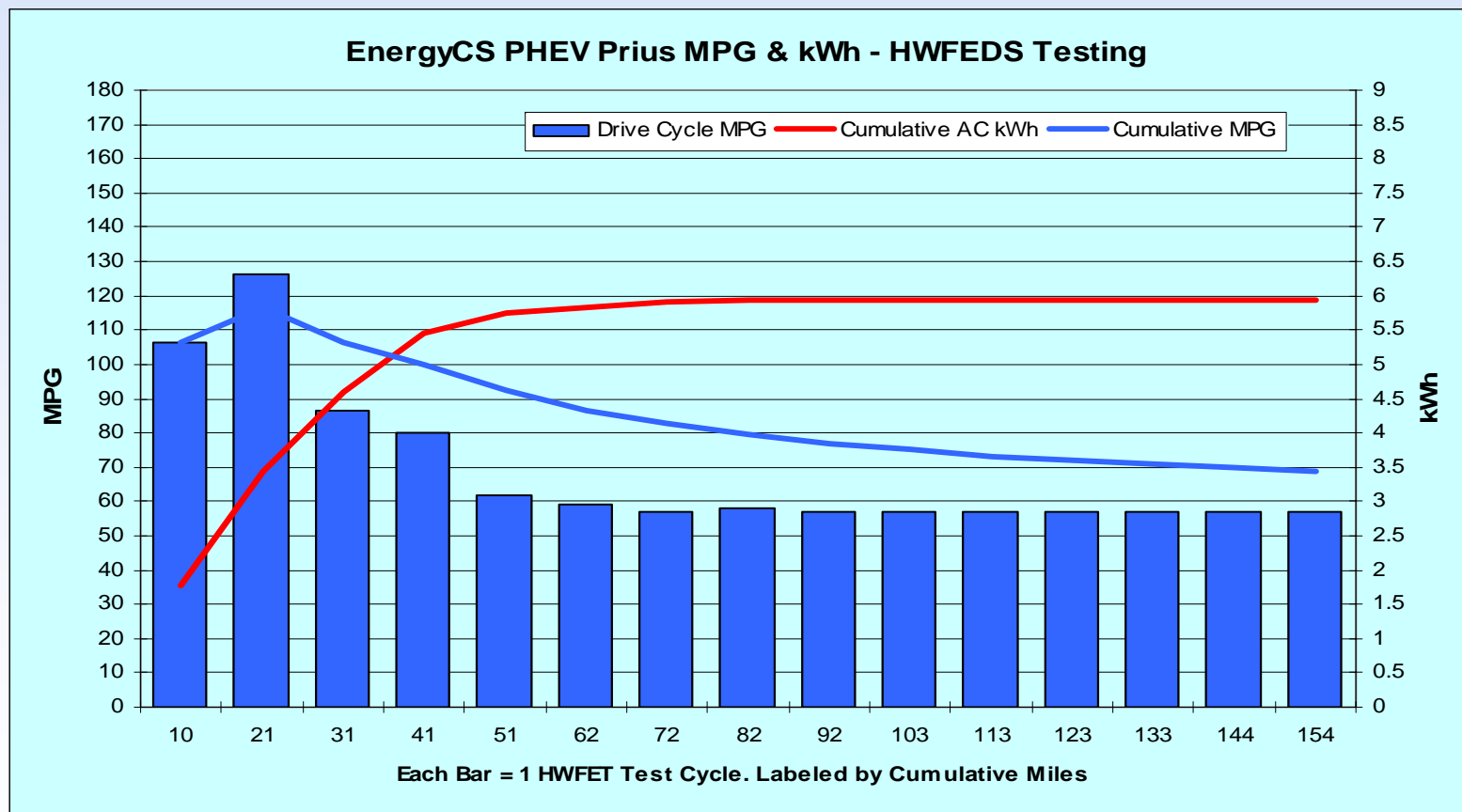
# EnergyCS Prius – UDDS Fuel Use

- 9 kWh Valence (Li) pack only (AC kWh)



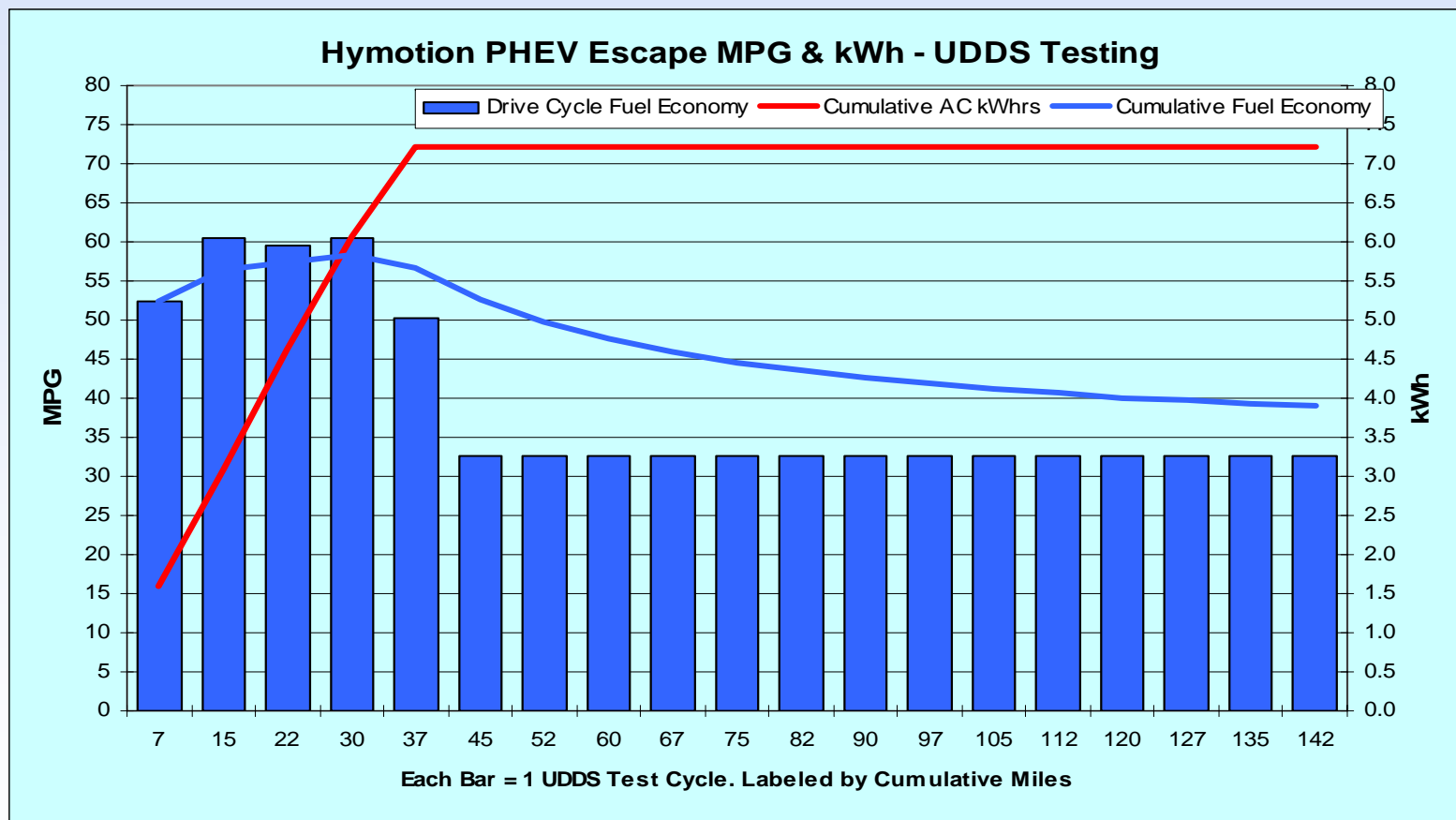
# EnergyCS Prius – HWFEDS Fuel Use

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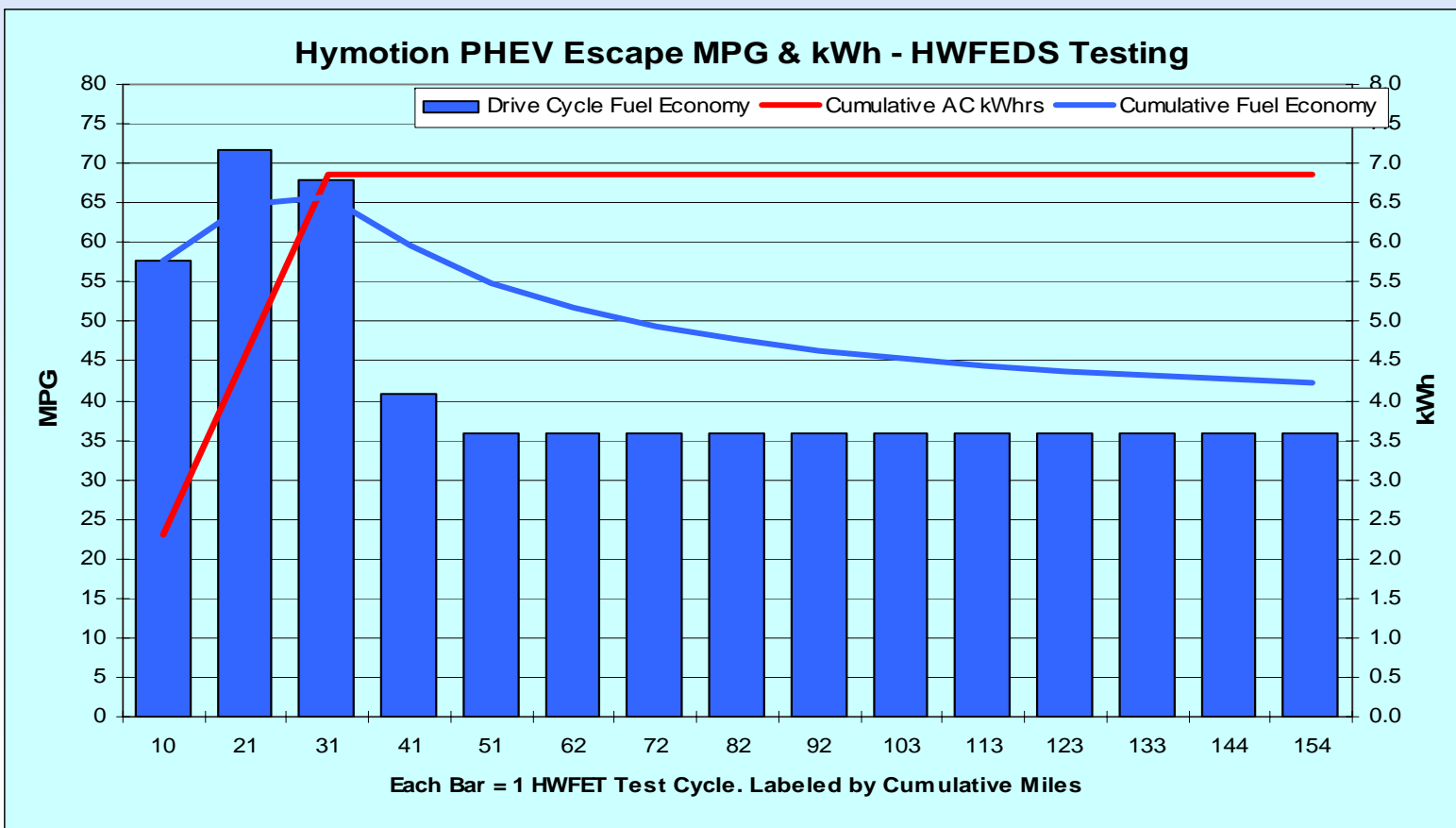
# Hymotion Escape – UDDS Fuel Use

- 8.5 kWh A123Systems (Li) and Escape packs (AC kWh)



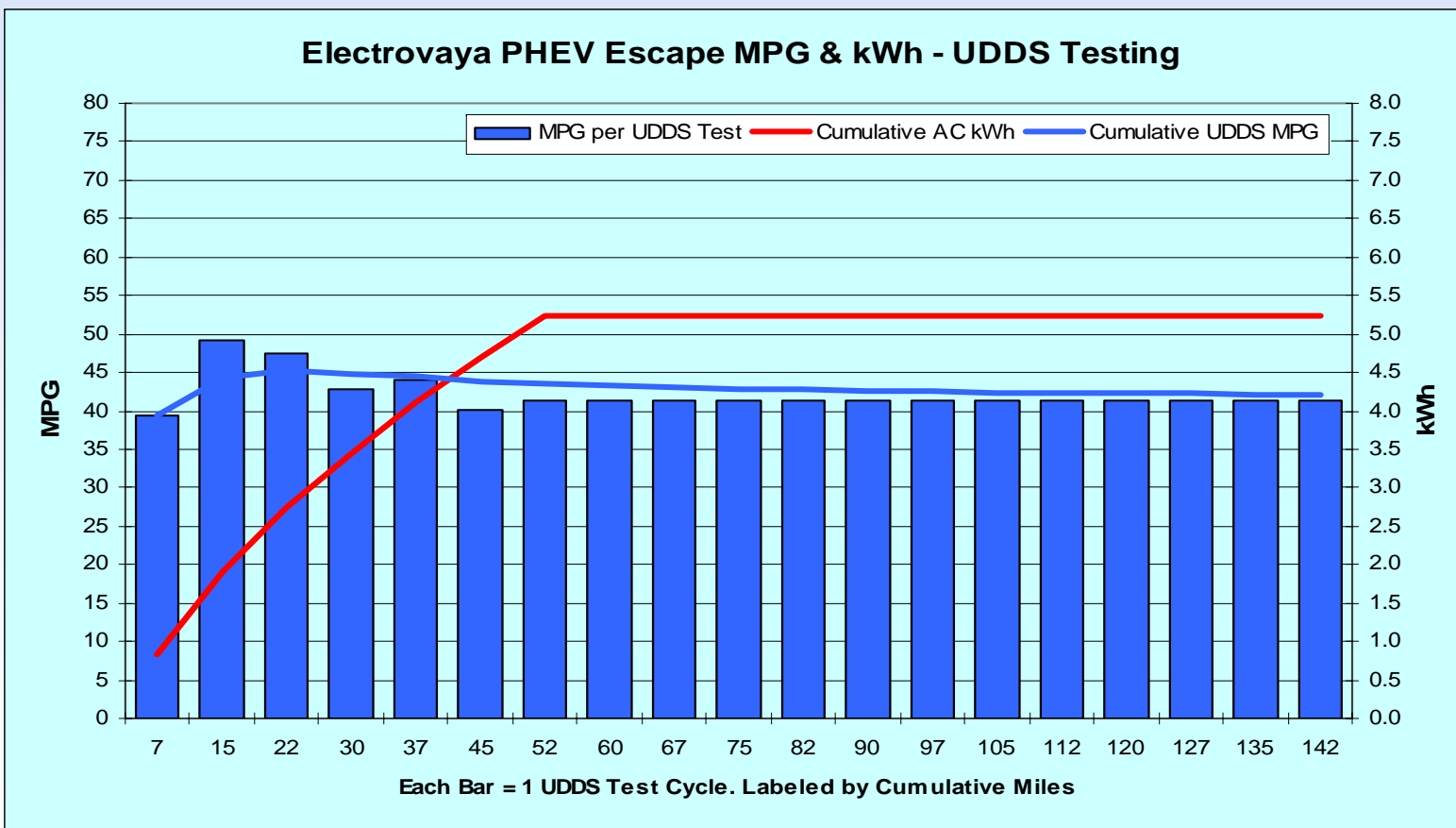
# Hymotion Escape – HWFEDS Fuel Use

- 8.5 kWh A123Systems (Li) and Escape packs (AC kWh)



# Electrovaya Escape – UDDS Fuel Use

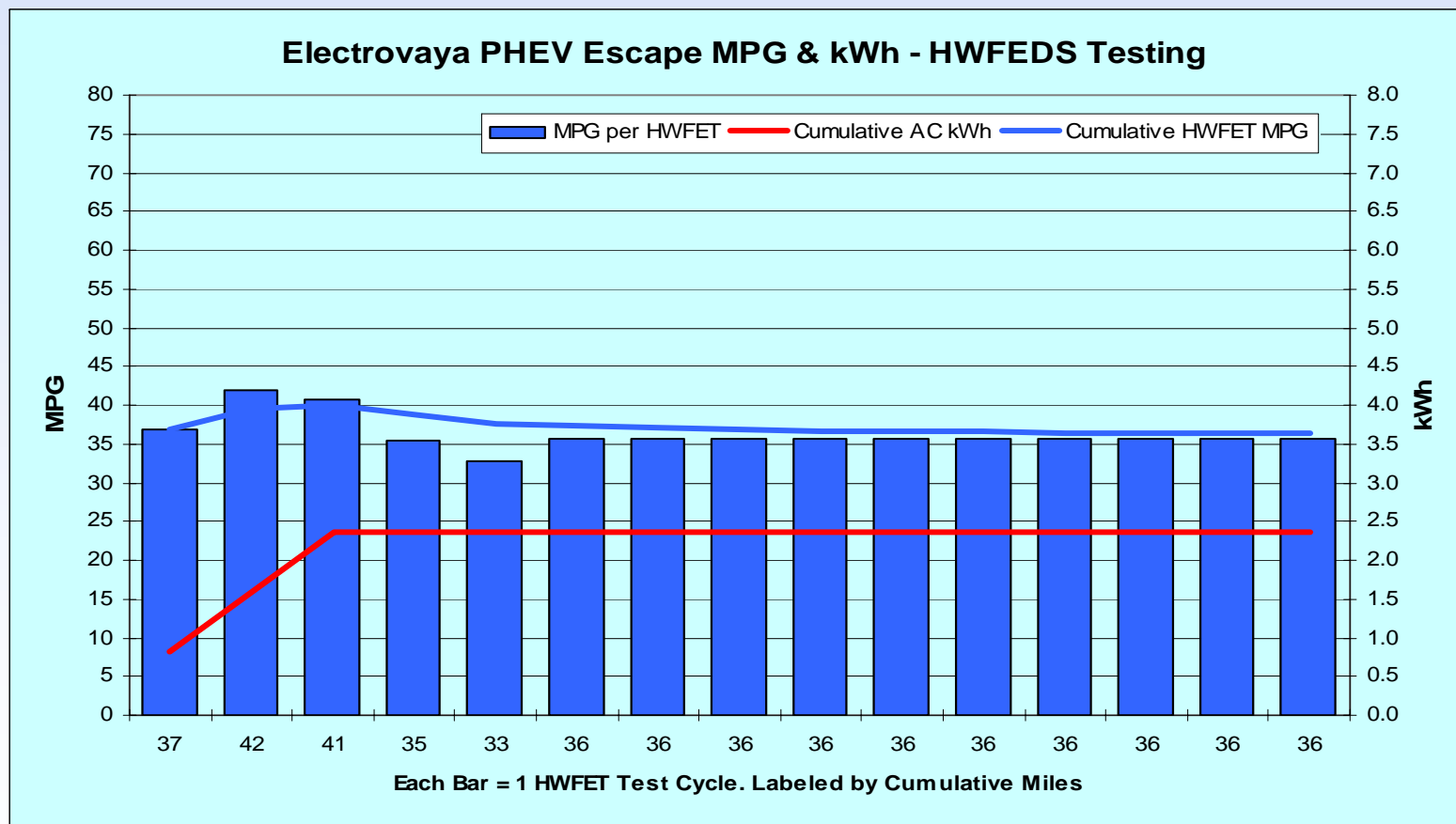
- 12 kWh Electrovaya (Li) and Escape packs (AC kWh)





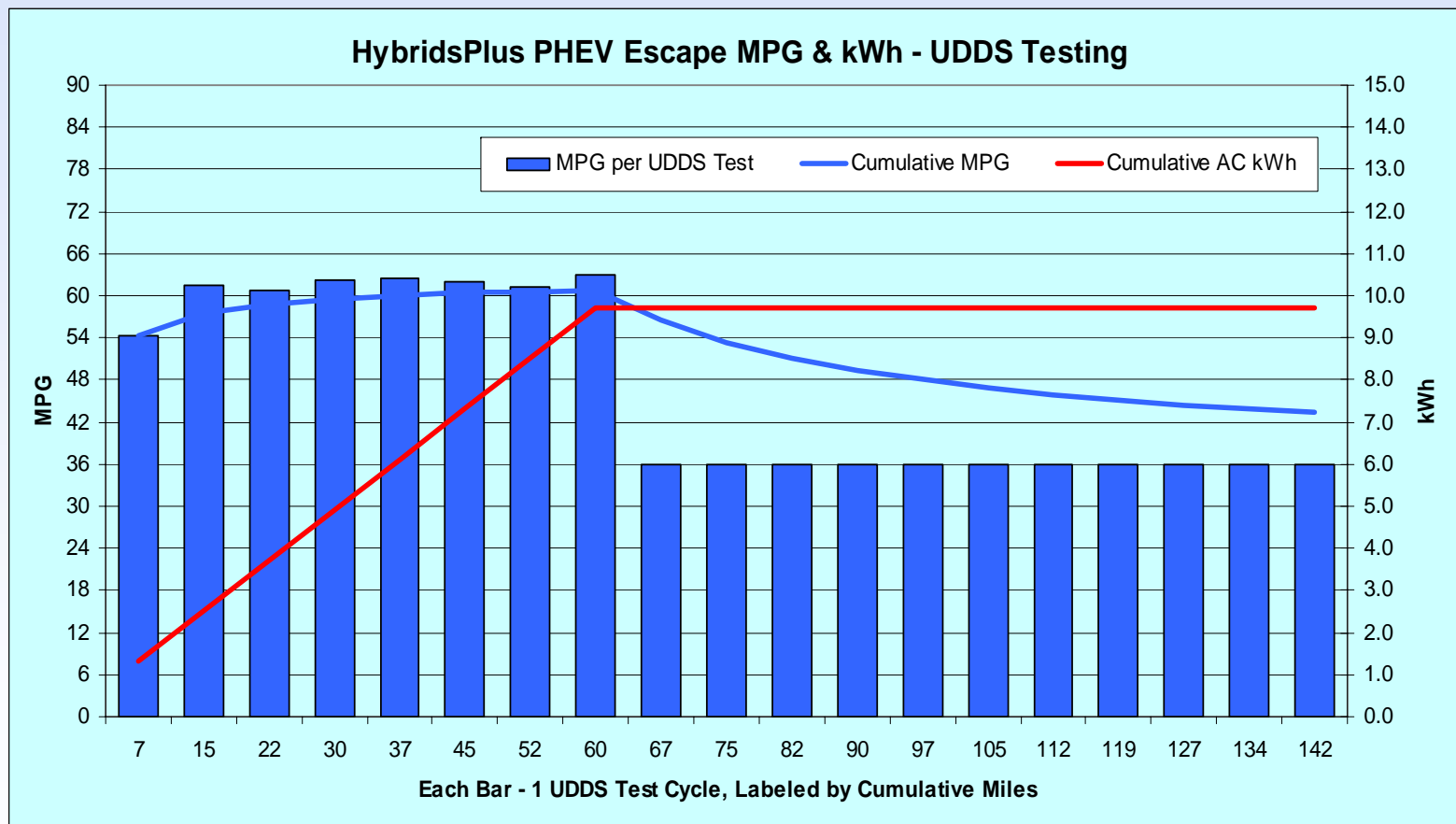
# Electrovaya Escape – HWFEDS Fuel Use

- 12 kWh Electrovaya (Li) and Escape packs (AC kWh)



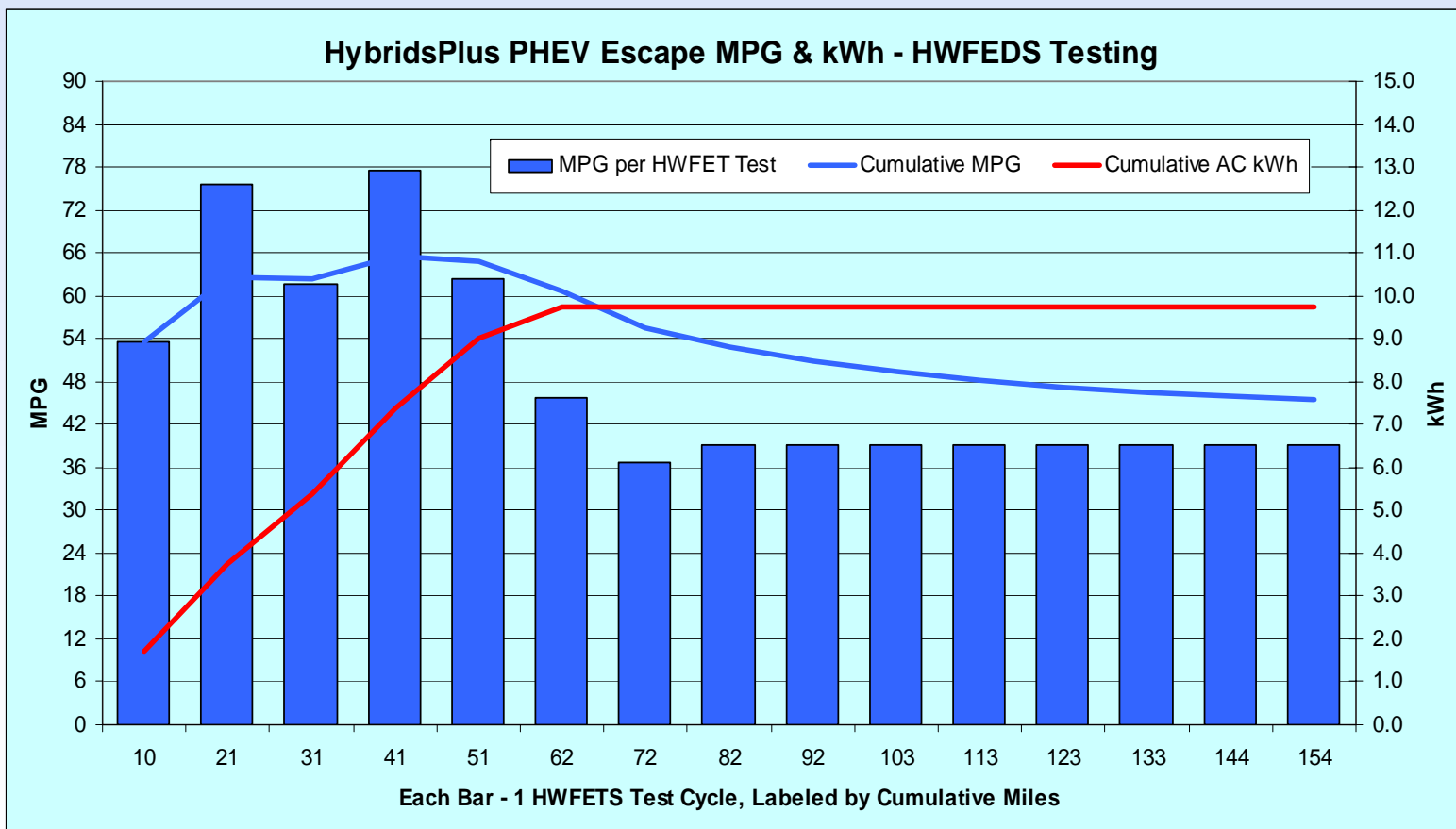
# Hybrids Plus Escape – UDDS Fuel Use

- 12 kWh Hybrids Plus (Li) pack (AC kWh)



# Hybrids Plus Escape – HWFEDS Fuel Use

- 12 kWh Hybrids Plus (Li) pack (AC kWh)



# Renault Kangoo Test Results

- First OEM series PHEV with 9.6 kWh (usable) Saft NiCad pack and 650cc gasoline engine

Test Cycle	AC kWh per Mile	Miles per Gallon
Battery Only – UDDS	0.268	
Battery Only - HWFEDS	0.155	
Battery Only @ Constant 45 mpg	0.271	
Battery and Gas Cold UDDS	0.144	42.3
Battery and Gas Hot UDDS	0.110	39.4
Battery and Gas Hot HWFEDS	0.042	40.9



# PHEV Accelerated Testing

- Accelerated testing in Phoenix over 5,440 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%
<b>Total</b>	<b>2,340</b>	<b>3,100</b>	<b>1,344</b>	<b>162</b>	<b>5,440</b>		
<b>Average</b>	<b>43%</b>	<b>57%</b>	<b>8.3</b>	<b>18</b>			

# 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
<b>Total</b>	<b>2340</b>	<b>3100</b>	<b>1404</b>	<b>167</b>	<b>5,440</b>	<b>Weighted Average</b>		<b>79.5</b>

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			
40	4	0	12	15	600		testing	
40	2	2	12	15	600	64.36	9.7	64.26
40	0	4	12	15	600			
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	5,440	Weighted Average		

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



# EnergyCS Prius – 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
<b>Total</b>	<b>2340</b>	<b>2500</b>	<b>984</b>	<b>147</b>	<b>4840</b>	<b>Weighted Average</b>		<b>66.1</b>

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*			
<b>Total</b>	<b>1560</b>	<b>1480</b>	<b>876</b>	<b>123</b>	<b>3,040</b>				

\* 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
<b>Total</b>	<b>2340</b>	<b>3100</b>	<b>1344</b>	<b>162</b>	<b>5440</b>	<b>Weighted Average</b>		<b>42.5</b>

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		testing	
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
<b>Total</b>	<b>2340</b>	<b>3100</b>	<b>1344</b>	<b>162</b>	<b>5440</b>	<b>Weighted Average</b>		

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

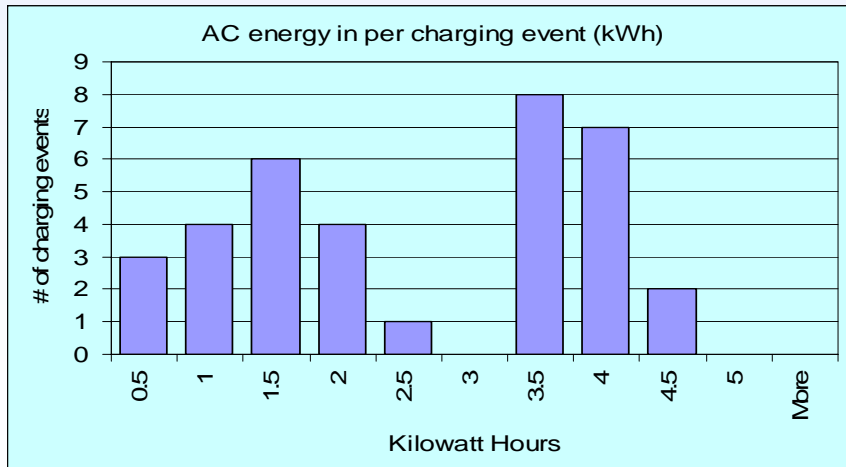
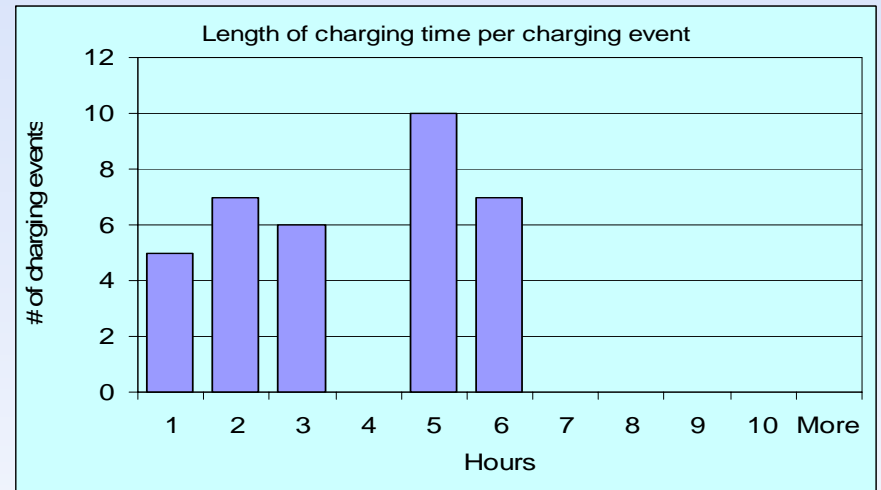
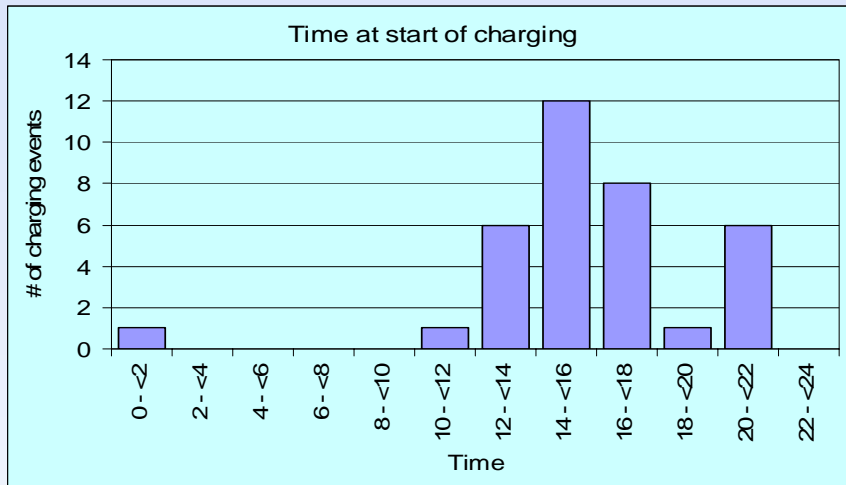
# Hymotion Joint Data Collection

- Kvaser data loggers installed onboard ~50 Hymotion Prius PHEVs in North America
  - Requires manually pulling data cards and downloading via web or mailing cards in
  - About 70% response rate
- Onboard data includes vehicle performance, fuel use, and charging and driving profiles
- Started 2007



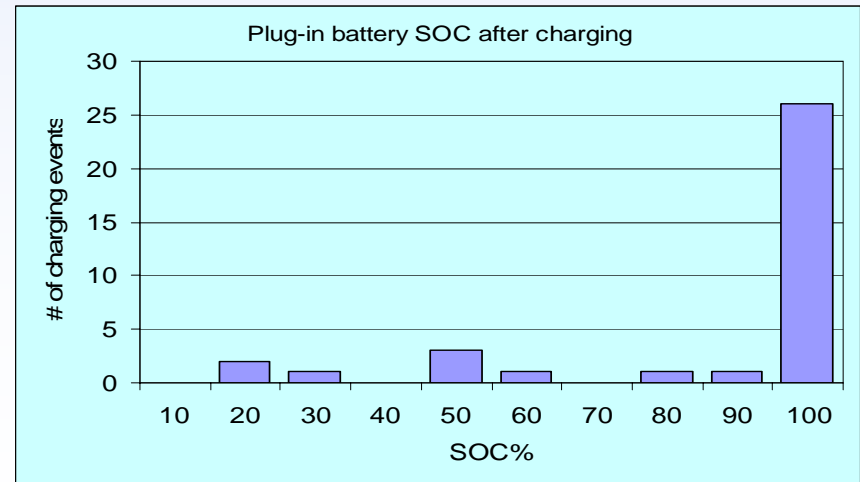
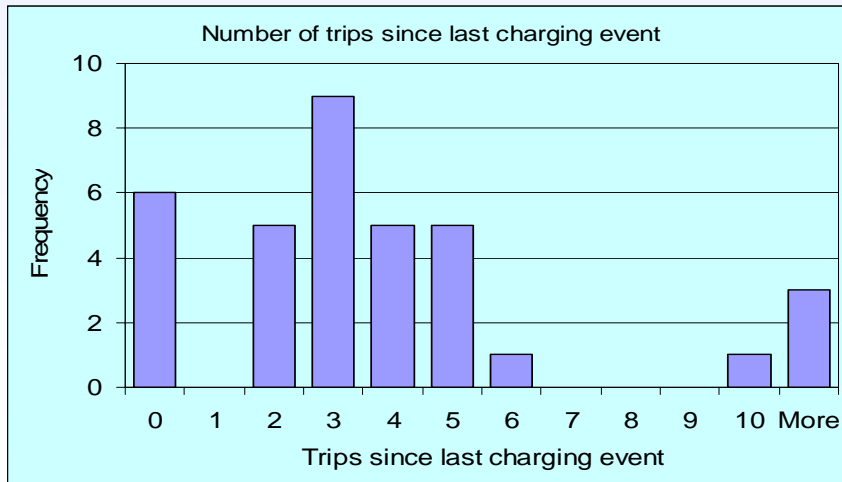
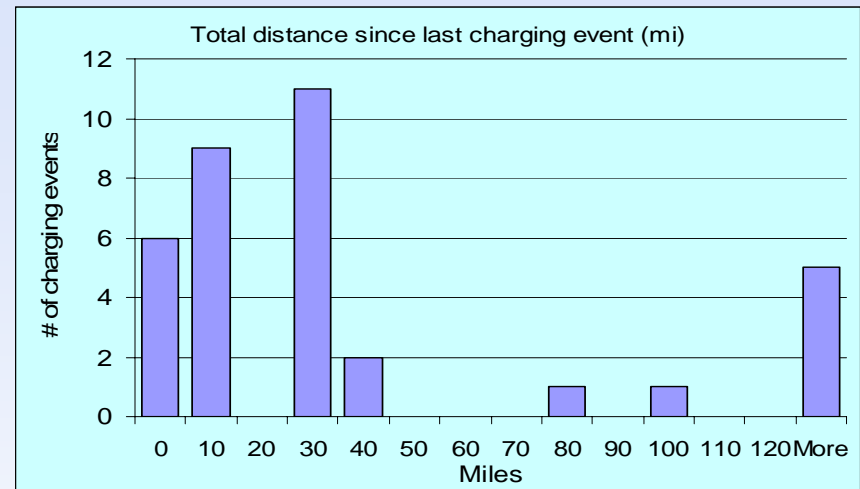
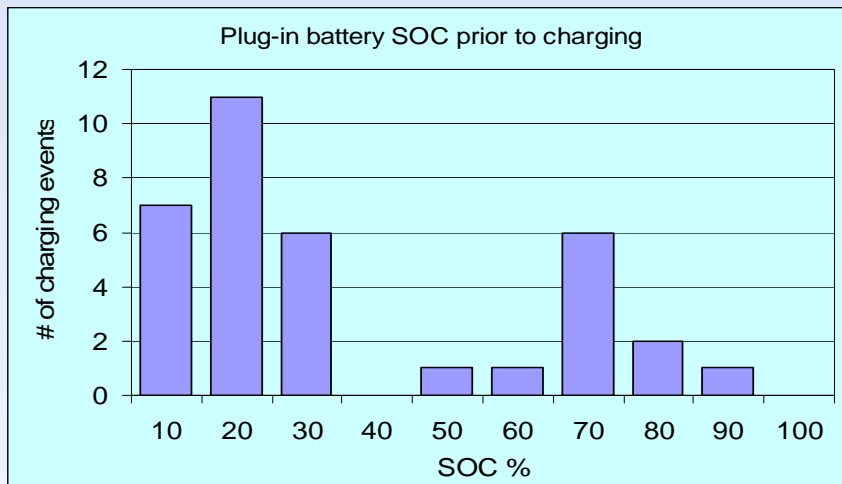
# Single Hymotion Prius Charging Profiles

- 3 months, 2212 miles, 35 charges



# Single Hymotion Prius Charging Profiles

- 3 months, 2212 miles, 35 charges





## 26 Hymotion Prius - January thru May 2008

- Below averages do NOT tell the whole PHEV energy-use potential – see following slides

Charge / 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

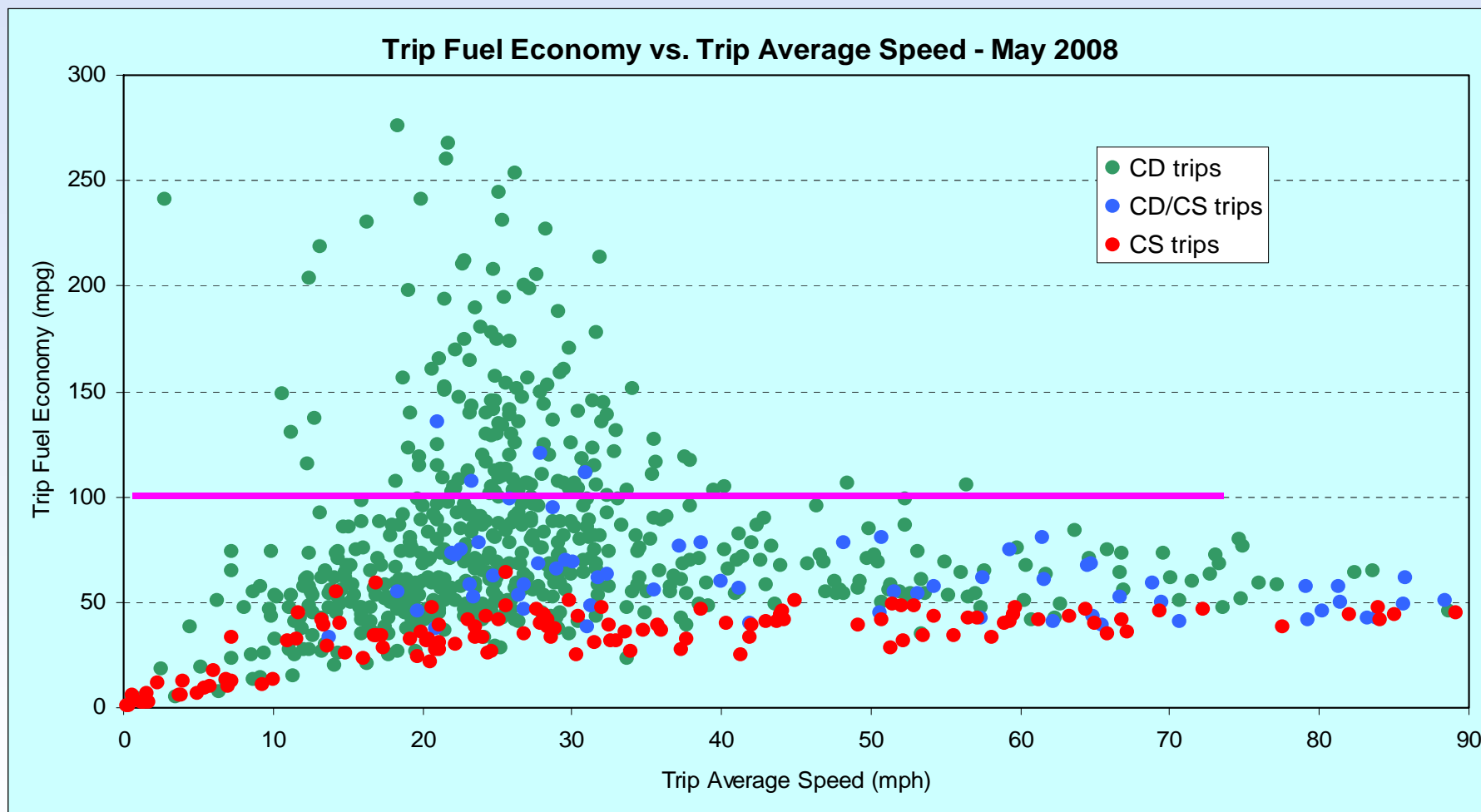


# 13 Hymotion Prius in May 2008 - MPG

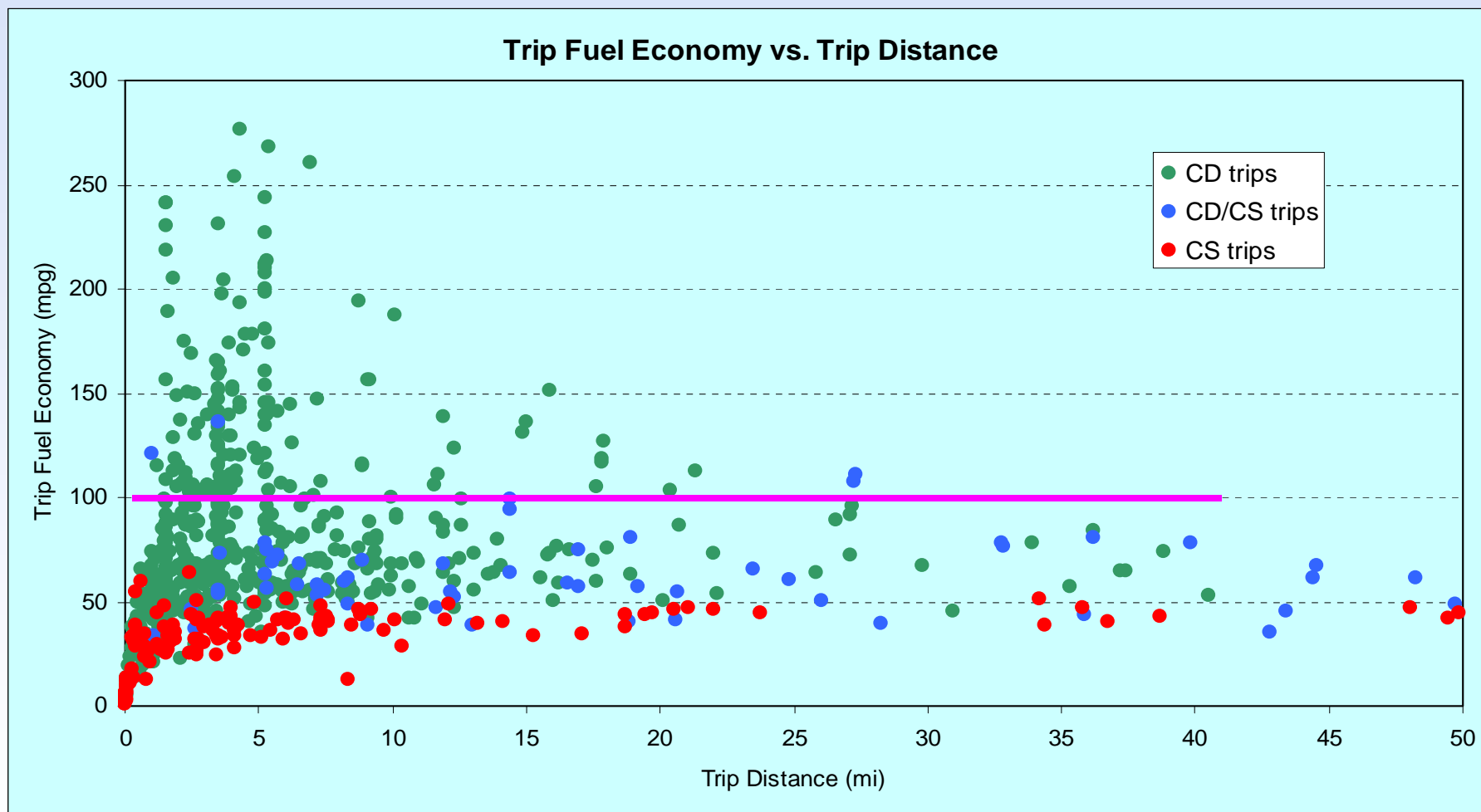
- Below averages do NOT tell the whole PHEV energy use potential – see following slides

Charge / Operating Mode	Number of Trips	Total Distance (Miles)	Average Trip Distance (miles)	MPG	DC kWh per Mile
Charge Depleting (CD)	575	3,040	5.3	72.0	0.138
Mixed CD / CS	67	1,840	27.5	52.1	0.050
Charge Sustaining (CS)	133	1,411	10.6	40.2	
Electric vehicle only (EV)	137	127	0.9		0.236
Total	912	6,417	7.0		
CD, CS, CD/CS results (excludes EV results)	775	6,291	8.1	55.9	

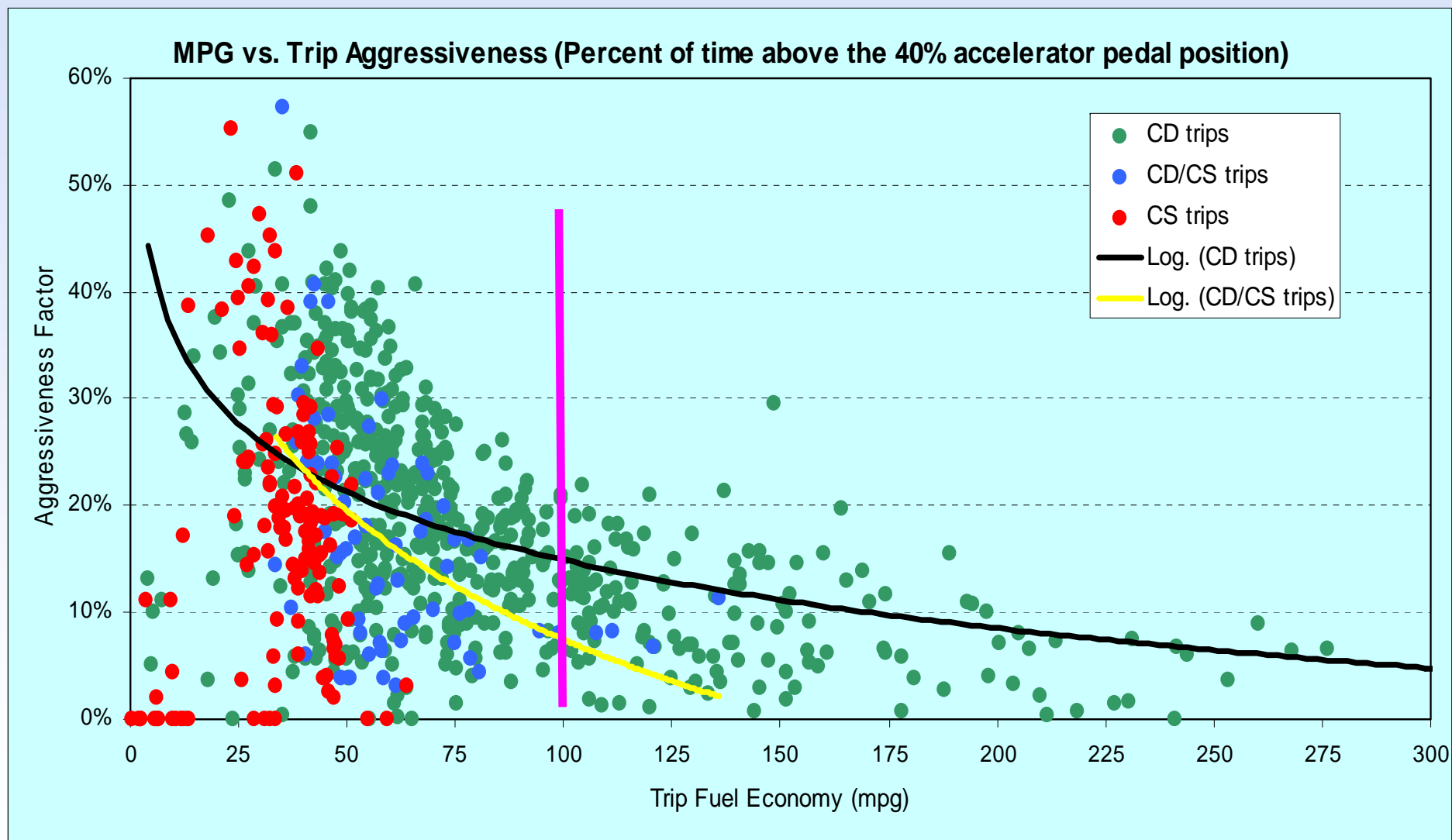
# 13 Hymotion Prius MPG Vs. Speed



# 13 Hymotion Prius MPG Vs. Distance



# 13 Hymotion Prius and Aggressive Driving



# NYSERDA Testing Partnership

- AVTA is testing New York State Energy Research and Development Agency's PHEV conversions, started 2007
- Fleet testing of 20 PHEVs starting 1<sup>st</sup> quarter CY09

Model	Baseline Testing	Accelerated Testing
EnergyCS Prius	Completed	Completed
Hymotion Prius	Completed	Completed
Hymotion Escape	Completed	Completed
Electrovaya Escape	Completed	Ongoing
HybridsPlus Escape	Suspended	Suspended





# EnergyCS Prius Data Collection

- Provided AVTA onboard data for 12 vehicles operating in fleets in the U.S. and Canada with Valence packs
- Going forward, EnergyCS is using lithium batteries from various manufacturers (including Altair Nano)
- ~ 30 vehicles deployed (~15 North America and ~15 Europe)





# Washington State Demonstrations

- **13 Hymotion Prius in Seattle area:**
  - **City of Seattle and King County**
  - **Port of Seattle and Puget Sound Clean Air Agency**
  - **Initial use of V2Green data loggers, GPS and cellular communications – all PHEV fleets going forward**
- **Tacoma Power**
  - **2 Manzanita lead acid Prius**
  - **2 Hymotion Prius**
- **Washington State-wide, Port of Chelan leading, with 14 Hymotion Prius with :**
  - **Benton County PUD, Chelan County Public Works, City of Wenatchee, Douglas County PUD, Energy Northwest, Green IT Alliance, McKinstry, Port of Chelan, University of Washington, Walla Walla Community College and Wenatchee Valley College**

# Fleet Demonstration Partners – cont'd

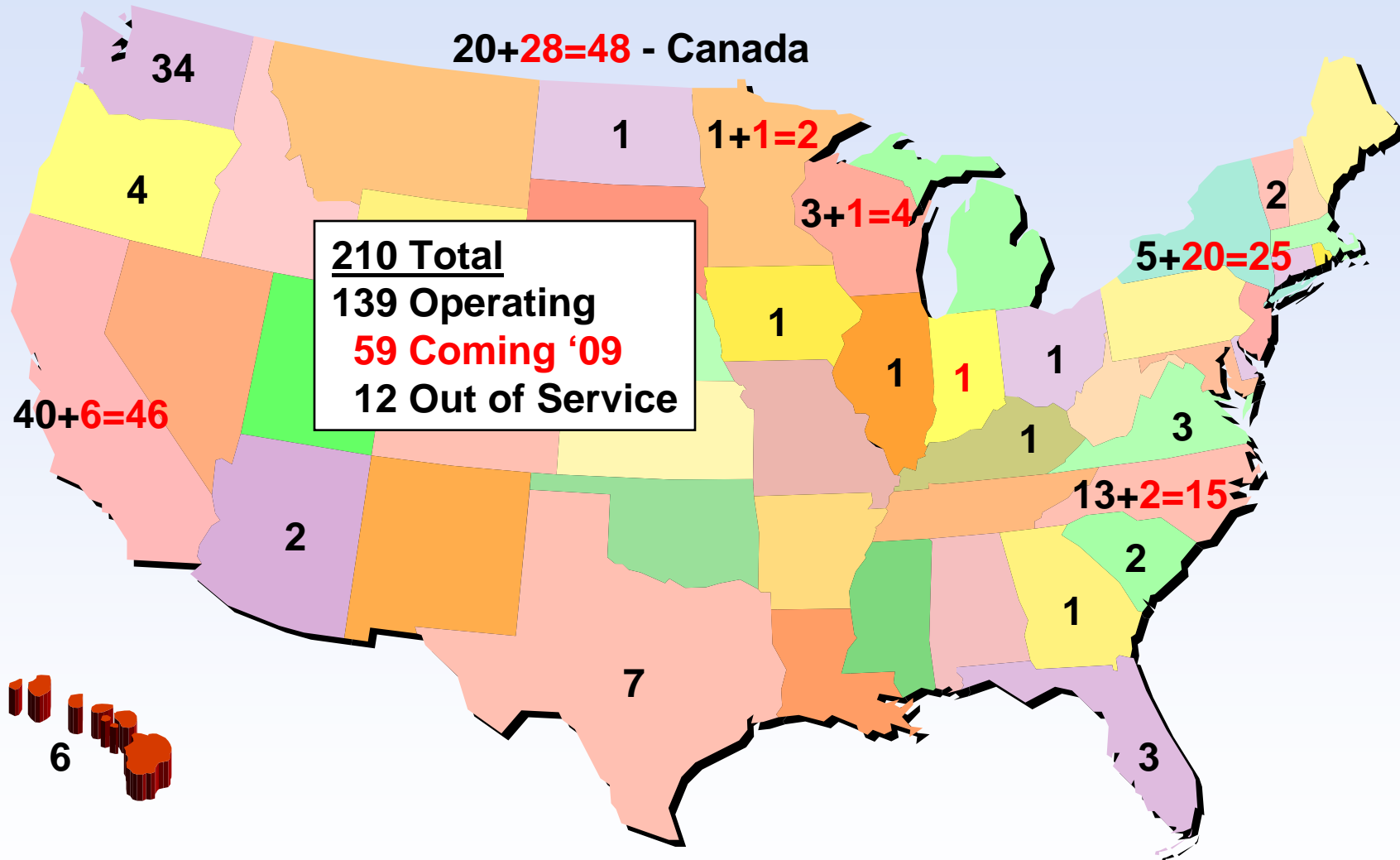
- **University of California Davis, with 13 Hymotion Prius**
  - Up to 70 AAA of California public drivers will each operate a vehicle for ~2 months
  - First study of public use of PHEVs, charging practices and locations, started April 2008
- **Oregon State fleets**
  - Three Hymotion Prius with V2Green data loggers
- **National Rural Electric Cooperative Association**
  - Total of ten Prius and Escape PHEVs from Hymotion, EnergyCS, and Hybrids Plus
  - Problems with vehicle recalls and a fire

# Fleet Demonstration Partners – cont'd

- **Hawaii, with 6 Hymotion Prius on Maui and Oahu**
  - **State of Hawaii, University of Hawaii, Hawaiian Electric Company, Maui Electric Company, Maui County, U.S. Air Force**
- **~75 Total testing partners in the U.S. and Canada:**
  - **36 Electric utilities and 2 clean-air agencies**
  - **6 City, 2 County and 2 state governments**
  - **8 Universities and colleges**
  - **7 Private companies and advocacy organizations**
  - **4 Canadian provinces, 1 sea port and 1 DOD**
  - **2 PHEV conversion companies**



# PHEVs and Demonstration Locations



# Fleet Data Collection \ Reporting Processes

- Along with testing partners, implemented onboard data logging to acquire time stamped data from fleets of 150+ PHEVs, 16 HEVs, 8 HICE vehicles
- Created automated data warehousing, analysis, and reporting process for fleet data
  - Accommodates 4 different data transfer methods
  - Accepts data from a multitude of vehicle / data logger combinations:
    - 6 PHEV conversion models, 8 HEV models, and 1 HICE model
    - 4 data logger manufacturers / designs
- Developing data processing routines for additional PHEV / data logger combinations

# Fleet Data Collection \ Reporting Processes

- Created flexible automated report generation processes for individual and multiple vehicle reports
- Reporting formats include 69 metrics describing vehicle energy usage, driving and charging patterns, and vehicle status monitors
- Developed additional database tools to perform quality assurance and exploratory analysis on the above and additional vehicle data
- Numerous additional metrics under development



# Database Statistics

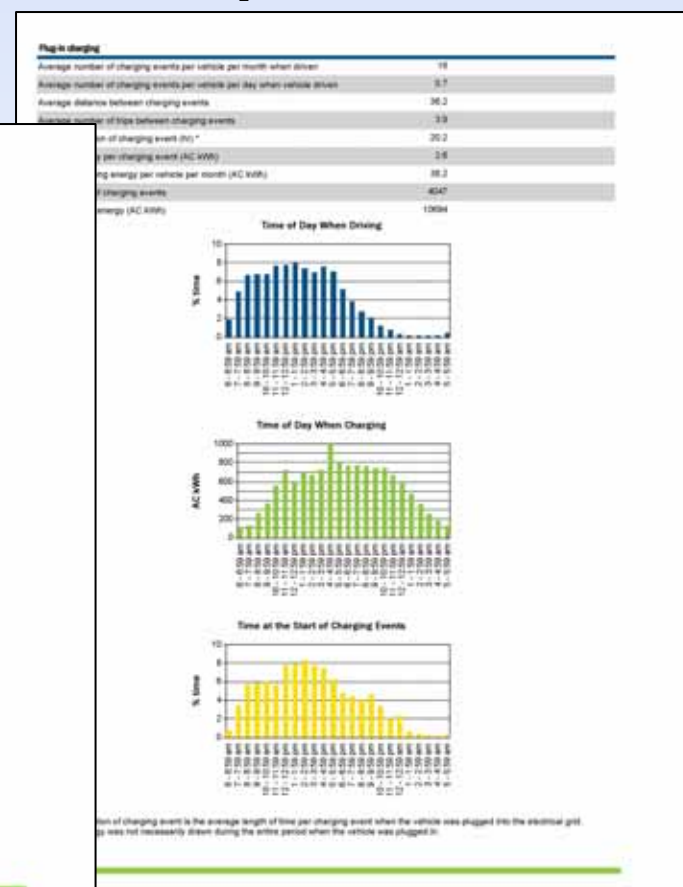
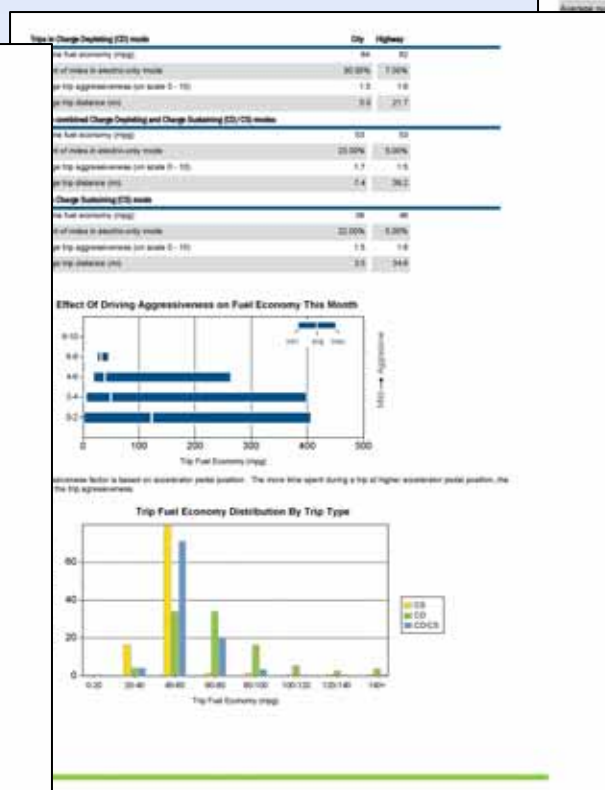
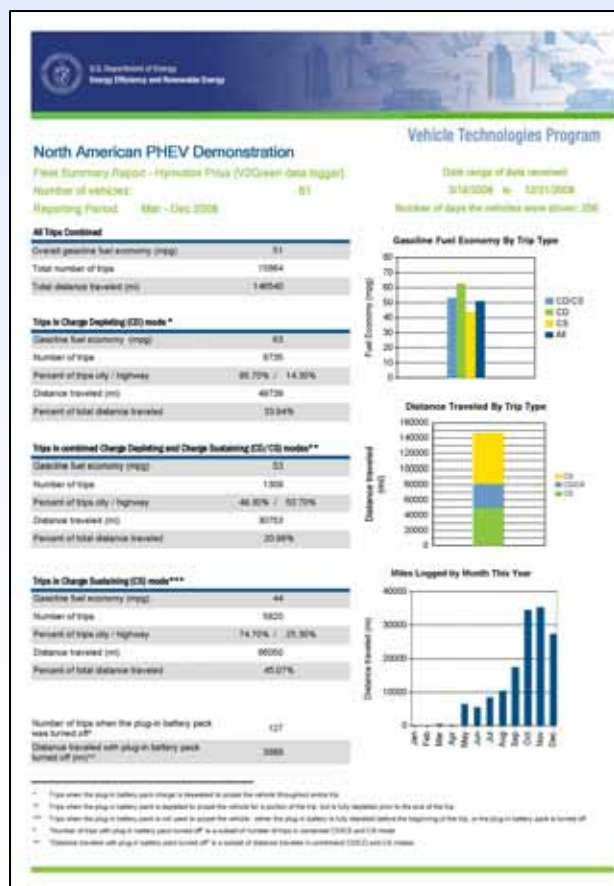
- As of December 2008, the data warehouse has grown to:
  - 5 different databases
  - 80 GB of vehicle data
  - Approximately 1 billion records
  - Approximately 120 vehicles (95 Hymotion Prius PHEVs) representing 700,000 vehicle miles and 53,000 trips (only includes downloaded and processed data from the onboard data loggers)
- The fleet onboard data collection system is growing at approximately 40 million records per month





# Database Generated PHEV Reports

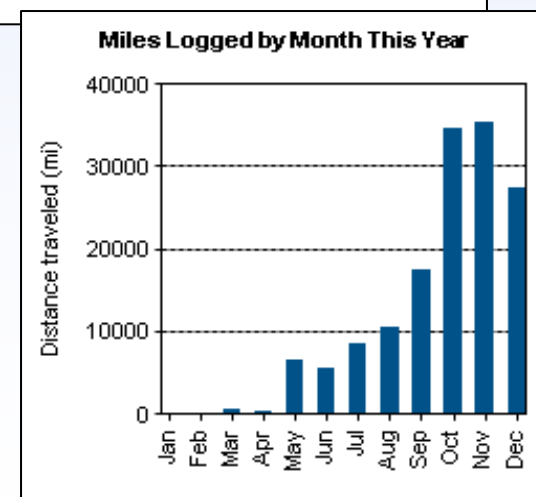
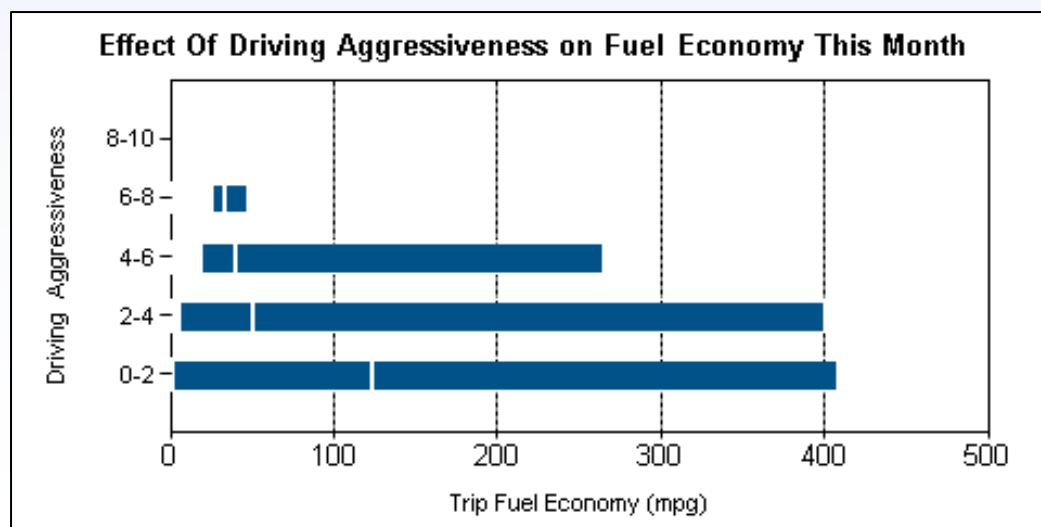
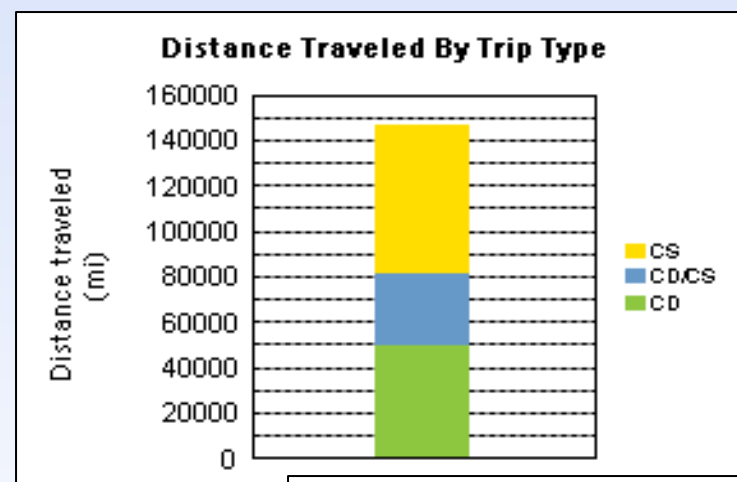
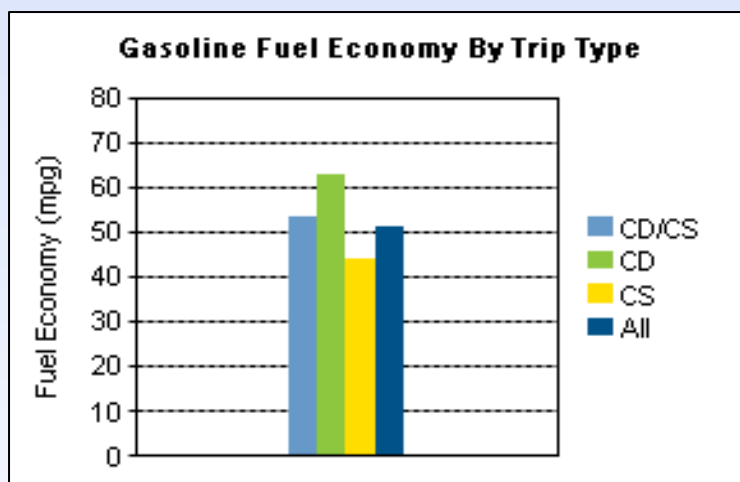
- Summary reports posted monthly on web
- Individual vehicle reports only goes to respective fleets each month





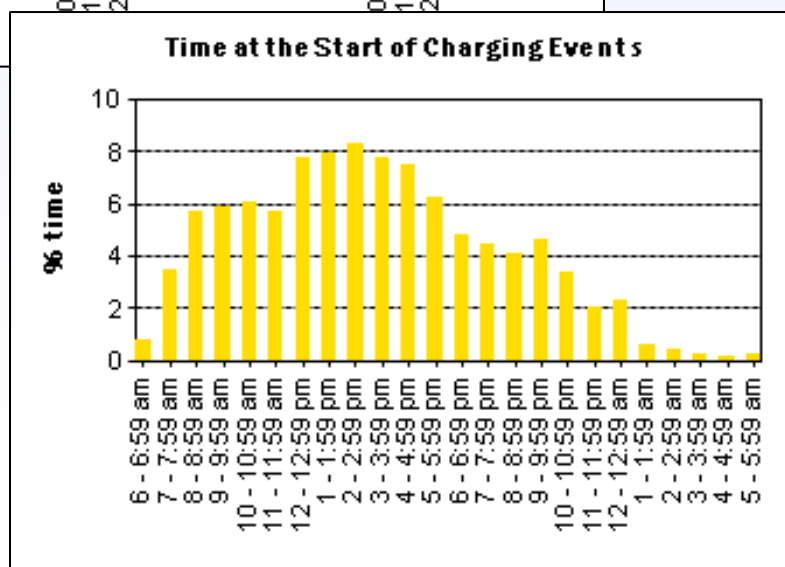
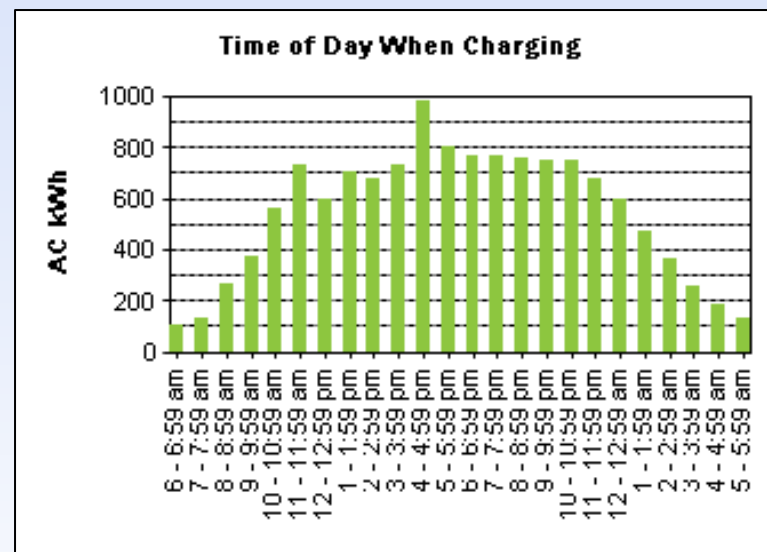
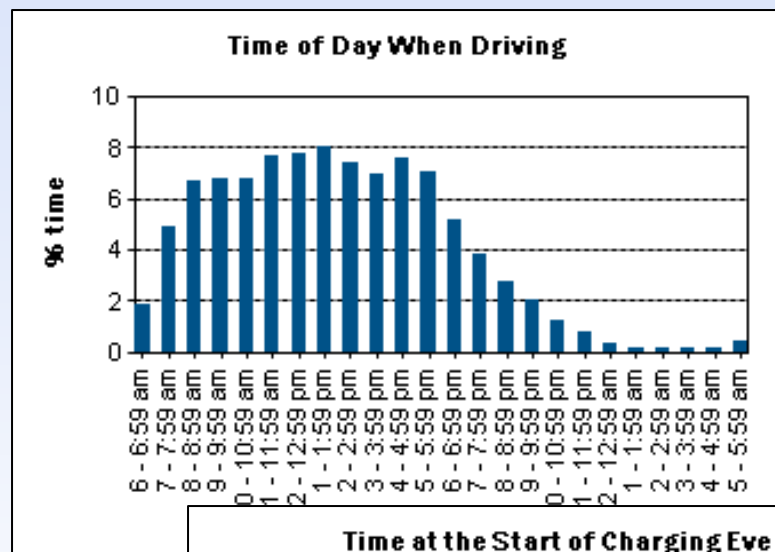
# Database Generated PHEV Reports

- 61 Hymotion Prius PHEVs, 147,000 miles, 15,900 trips, 4,047 charging events – Mar/Dec 2008



# Database Generated PHEV Reports – cont'd

- 61 Hymotion Prius PHEVs, 147,000 miles, 15,900 trips, 4,047 charging events – Mar/Dec 2008



## Other PHEV Testing

- **Hymotion/A123Systems Gen 2 Prius battery hot weather vehicle / battery 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**
- **Will consider other suitable PHEV conversions for vehicle/battery testing**
- **Developing batteries / mule vehicles testing regimes**

# PHEV Infrastructure Demonstrations

- **City of Seattle lead time-of-day charging demonstration on 13 or more Seattle-area PHEVs. Includes INL battery impact analysis. Uses V2Green wireless charging control**
- **Charging infrastructure study**
  - **Tacoma - Collect 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**

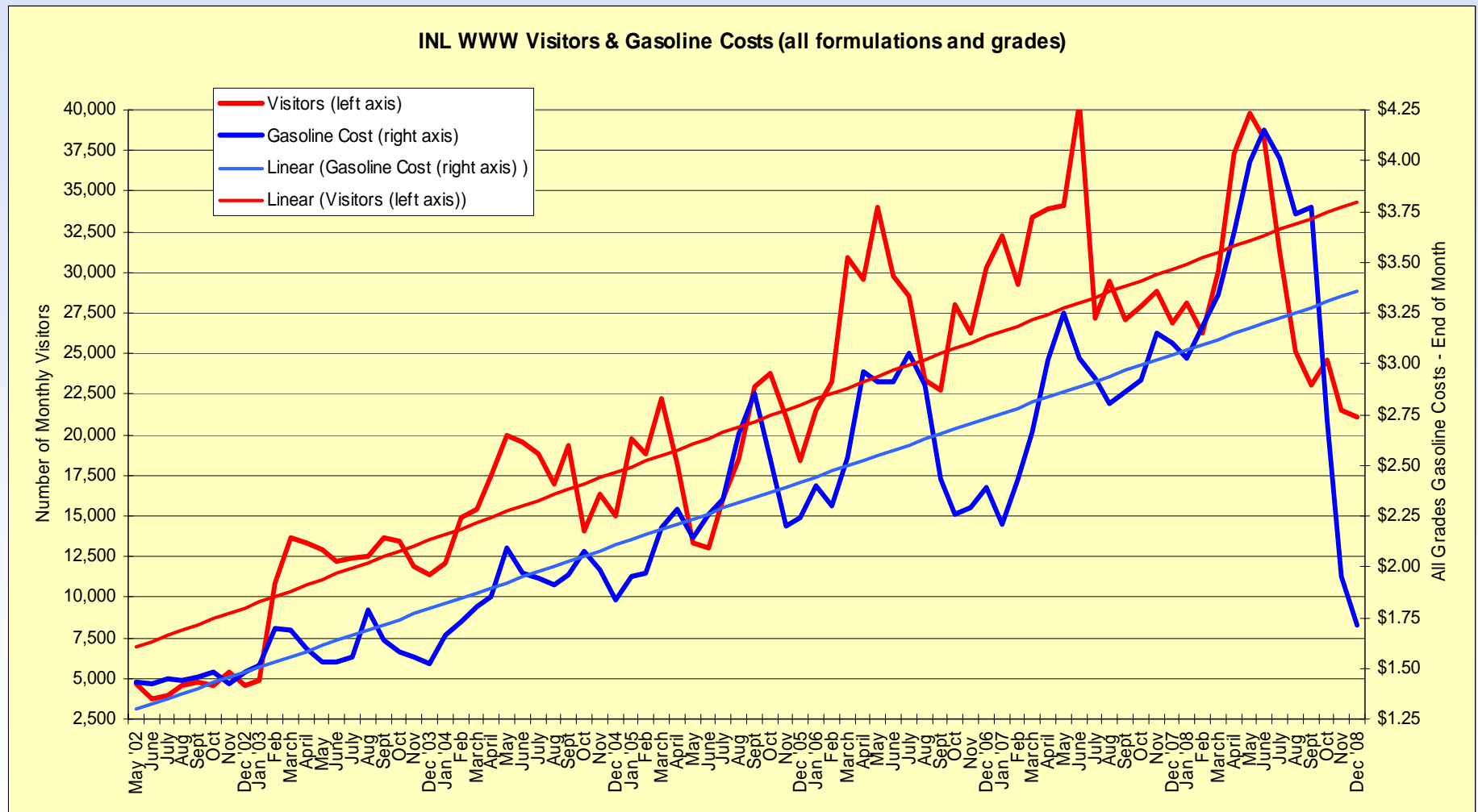


# Charging Infrastructure

- National Electric Code requires
  - Dedicated branch circuit
  - GFCI (ground fault circuit interrupt)
  - “EV” extension cord
  - Unique connector “plug”
- NEC being updated



# AVTA Webpage Use and Gasoline Costs



# Acknowledgement

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

**Lee Slezak, David Howell, and Pat Davis**

## Additional Information

**<http://avt.inl.gov>**

**or**

**<http://www1.eere.energy.gov/vehiclesandfuels/avta/>**

INL/CON-09-15358