Idaho National Laboratory

U.S. Department of Energy, Vehicle Technologies Program

Advanced Vehicle Testing Activity (AVTA) – North American and Seattle PHEV Testing and Demonstrations

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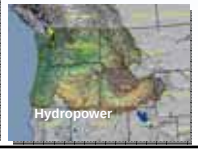
Seattle Chamber of Commerce
March 2009

This presentation does not contain any proprietary or sensitive information

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**



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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

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AVTA Testing History

- Plug-in hybrid electric vehicles (PHEV)
  - 12 models, ~150 vehicles, 360,000 fleet test miles
- 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
  - 21 models, 200,000 test miles
- Urban electric vehicles
  - 3 models, 1 million test miles

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PHEV Questions

- 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?
- Are PHEVs technically and economically feasible as a transportation option?
- To answer these questions, the AVTA is testing and demonstrating 12 different PHEV models (by battery), their batteries, and the charging infrastructure

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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)

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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
  - Laboratory testing of PHEV batteries
- Document battery life, charging patterns and profiles
- Document vehicle operations, fuel use (electricity and gasoline) and infrastructure requirements (110V versus 220V; Levels 1 and 2, offpeak, and V2Grid charging)
- Document driver influences on fuel use
- Document individual PHEV models and PHEV concept
- Document PHEV life-cycle costs

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PHEV Baseline Performance Testing

- ETEC 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

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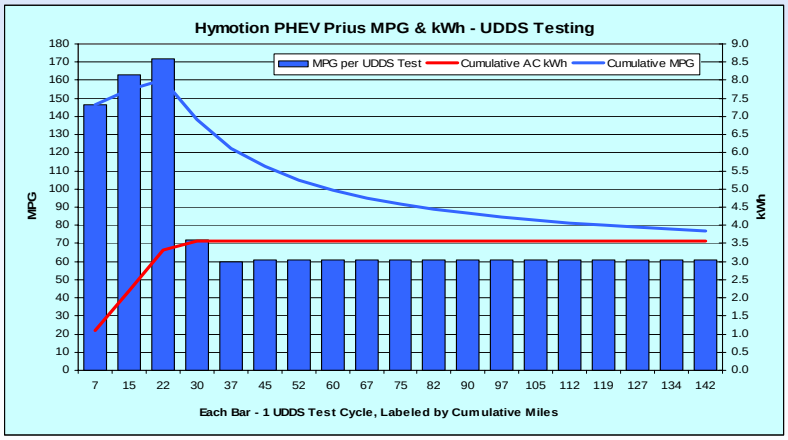
Hymotion Prius Gen I – UDDS Fuel Use

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



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Hymotion Prius Gen I – HWFEDS Fuel Use

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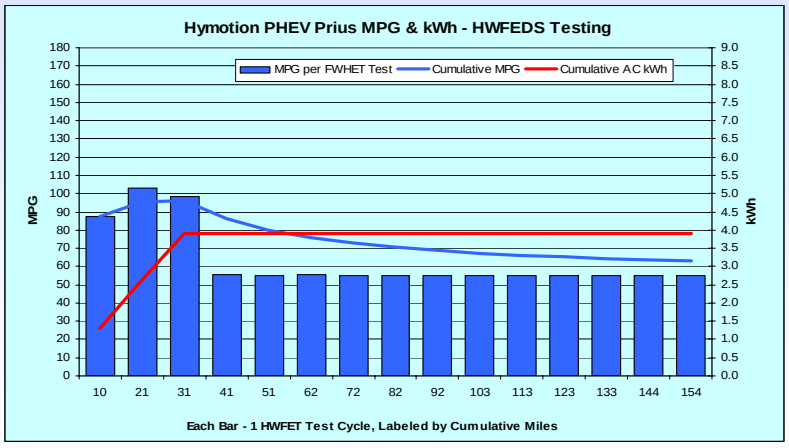

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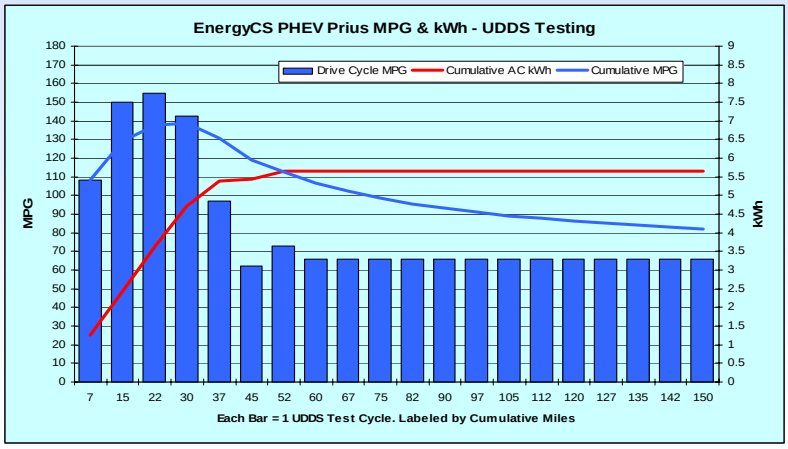
EnergyCS Prius Valence – UDDS Fuel Use

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



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EnergyCS Prius Valence – HWFEDS Fuel Use

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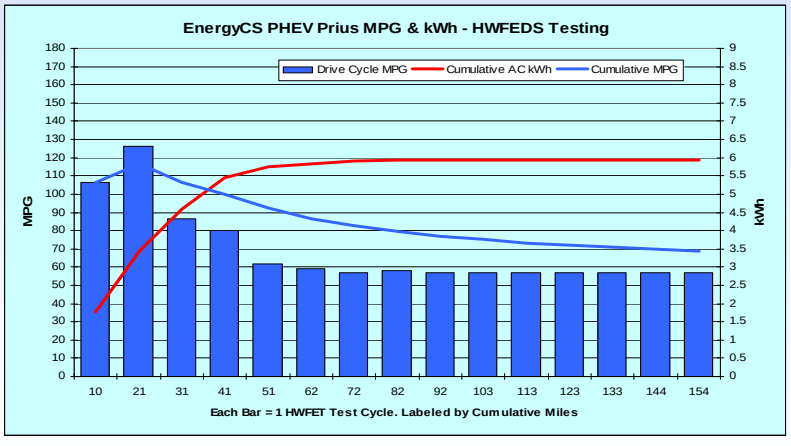

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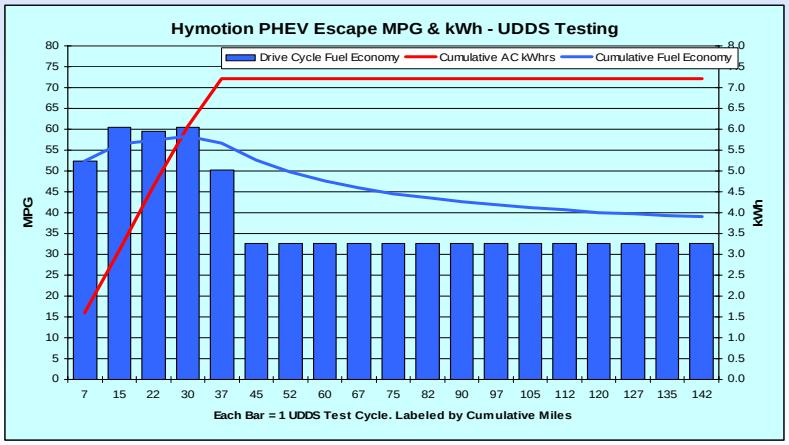
Hymotion Escape – UDDS Fuel Use

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



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Hymotion Escape – HWFEDS Fuel Use

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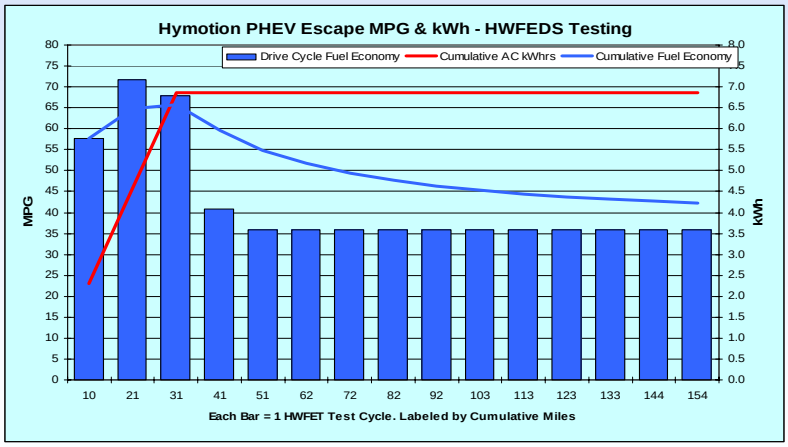

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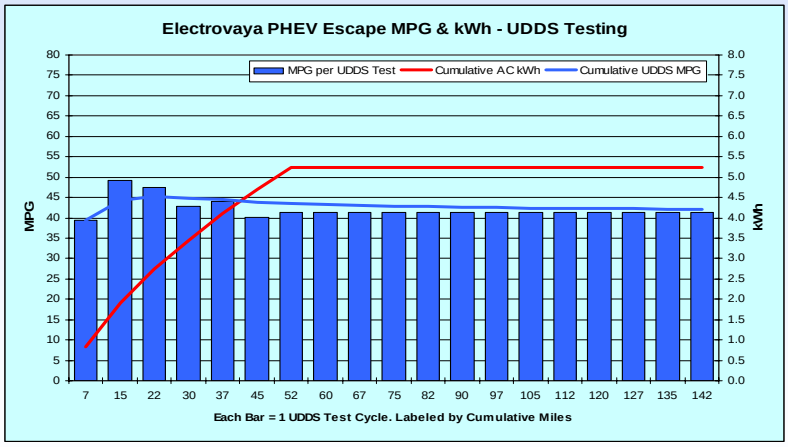
Electrovaya Escape – UDDS Fuel Use

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



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Electrovaya Escape – HWFEDS Fuel Use

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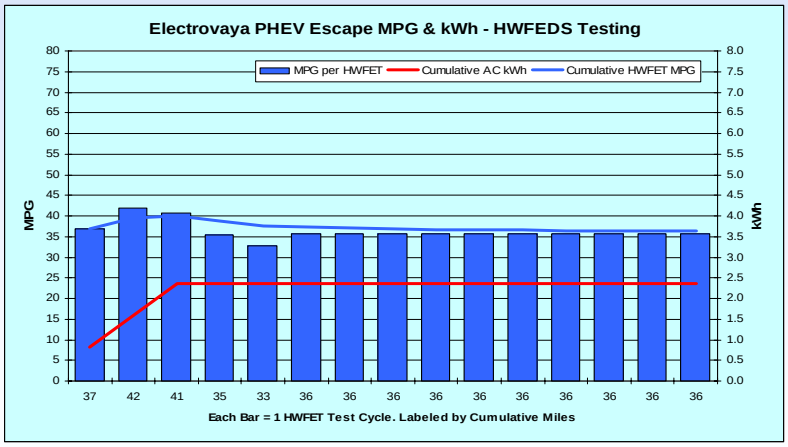

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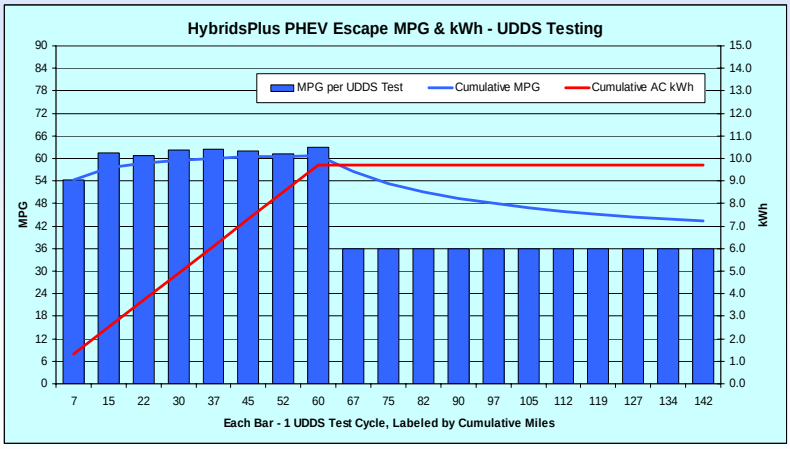
Hybrids Plus Escape – UDDS Fuel Use

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



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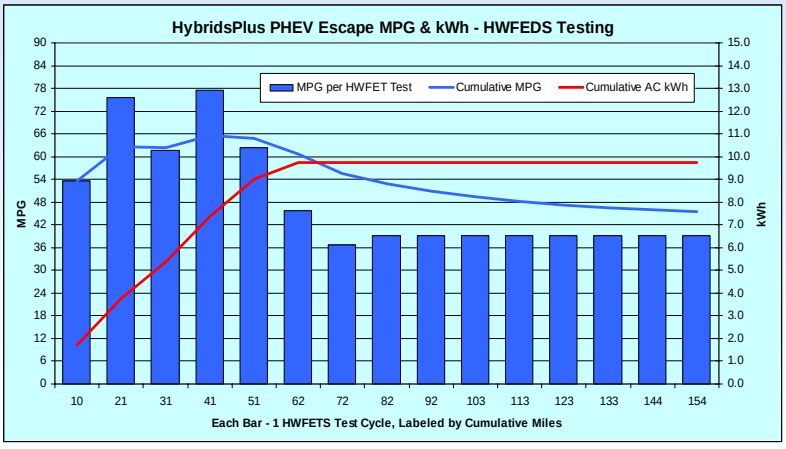
Hybrids Plus Escape – HWFEDS Fuel Use

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



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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

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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%
Total	2,340	3,100	1,344	162	5,440		
Average	43%	57%	8.3	18			

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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

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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	62.13
40	2	2	12	15	600	retesting		
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

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EnergyCS Prius Val. – 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	4840	Weighted Average		66.1

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

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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.

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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

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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

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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, with data lags
- Onboard data includes vehicle performance, fuel use, and charging and driving profiles
- Started 2007

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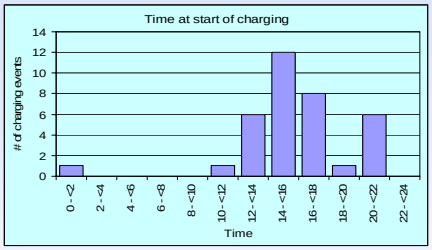
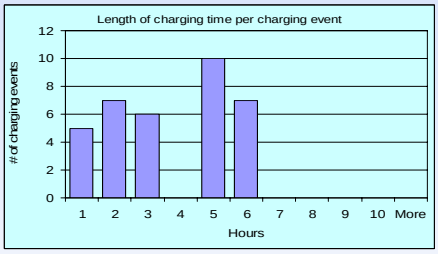
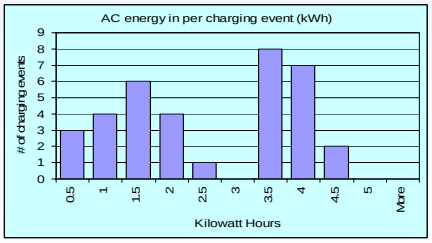
Single Hymotion Prius Charging Profiles

- 3 months, 2212 miles, 35 charges







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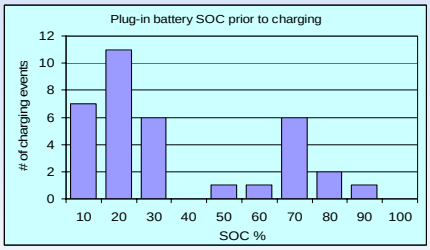
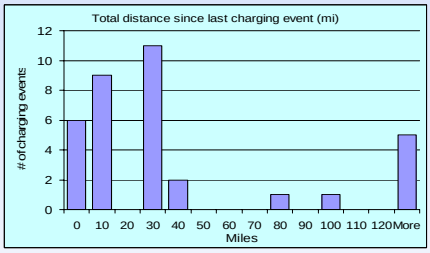
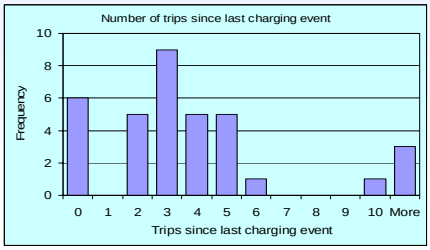
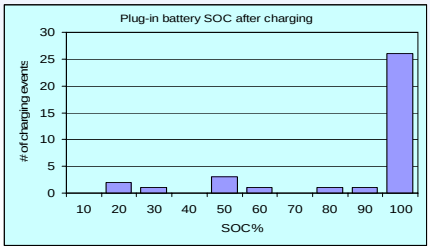
Single Hymotion Prius Charging Profiles

- **3 months, 2212 miles, 35 charges**









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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

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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	

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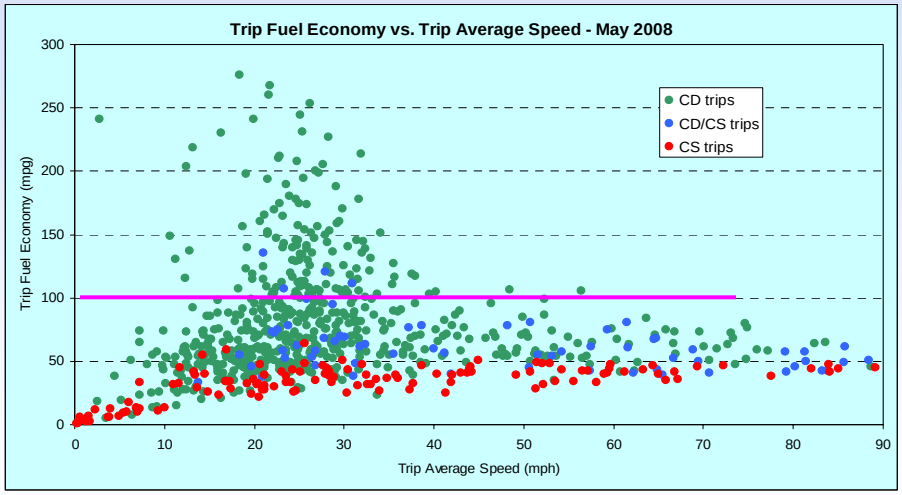
13 Hymotion Prius MPG Vs. Speed



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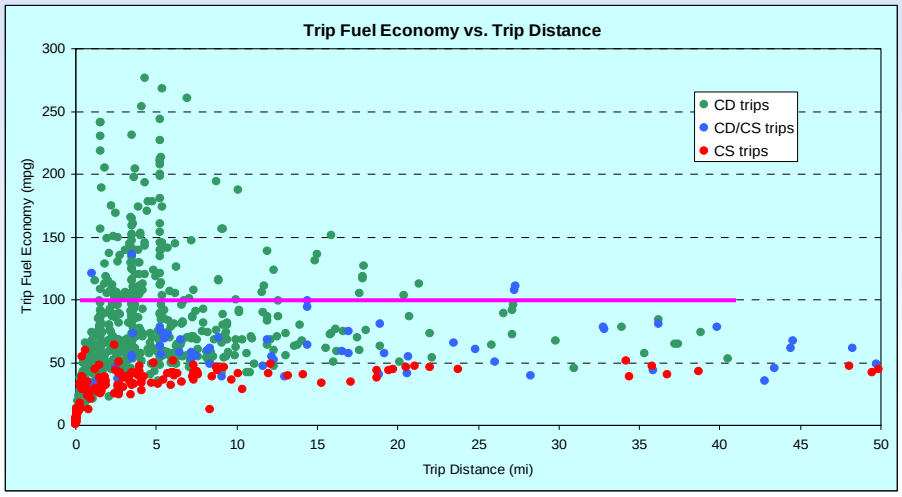
13 Hymotion Prius MPG Vs. Distance



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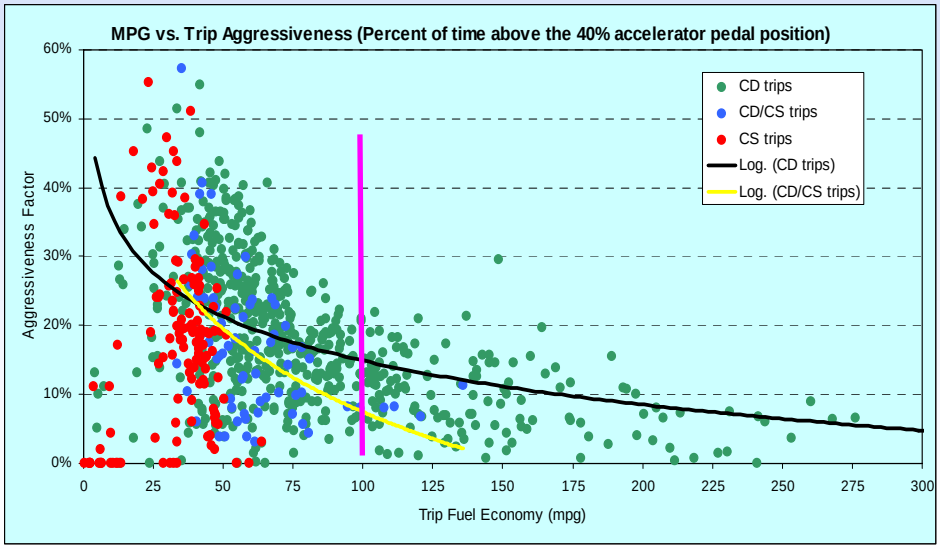
13 Hymotion Prius and Aggressive Driving



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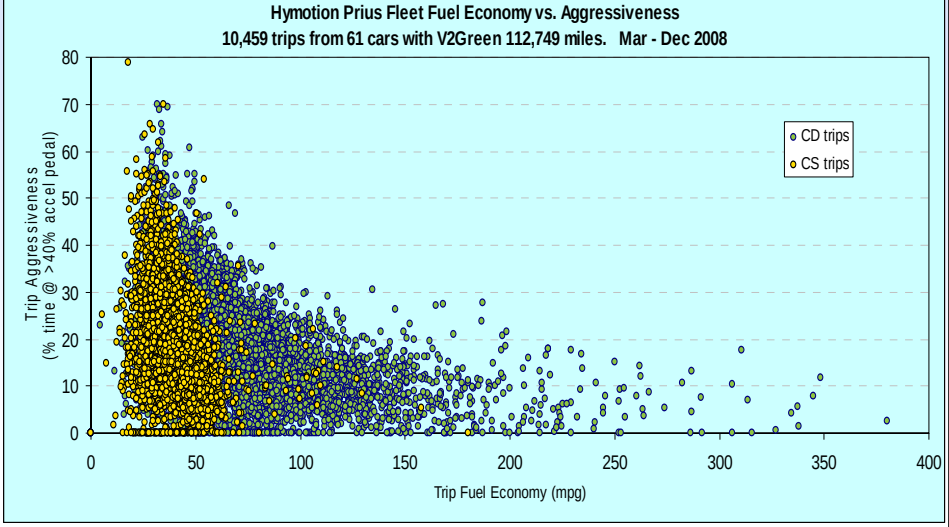
61 Hymotion Prius and Aggressive Driving



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NYSERDA Testing Partnership

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

Model	Baseline Testing	Accelerated Testing
EnergyCS Prius	Completed	Completed
Hymotion Prius	Completed	Completed
Hymotion Escape	Completed	Completed
Electovaya Escape	Completed	Completed (But…)
HybridsPlus Escape	Suspended (?)	Suspended (?)

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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 No. America and 15 Europe)
- AVTA supporting data logger improvements

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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, used in 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

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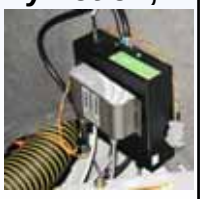
Fleet Demonstration Partners – cont'd

- University of California Davis, with 13 Hymotion Prius
  - Up to 70 AAA of California public drivers will each operate a Hymotion Prius for ~2 months
  - First study of public use of PHEVs, charging practices and locations, started April 2008
- Oregon State Government fleets
  - Three Hymotion Prius
- 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
- Above all using V2Green data loggers



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Fleet Demonstration Partners – cont'd

- Hawaii, 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

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Canada Specific Activities

- Testing/Demo activities with 20 Canadian universities, governments, private companies and energy companies
- PHEV data collection activities include
  - 20 Hymotion Prius PHEVs with data loggers currently in Canadian fleet operations
  - Adding 28 more Hymotion Prius PHEVs with data loggers, mostly in British Columbia
  - AVTA will provide PHEV data to University of Victoria
- Hydrogen ICE activities in Vancouver BC area
  - Eight HICE pickups with data loggers fueled at IWHUP
  - Studying HICE specific maintenance/repair issues
- BC Hydro PHEV and data logger procurement support, and developing charging infrastructure guidelines for BC PHEV deployment and future electric drive deployments

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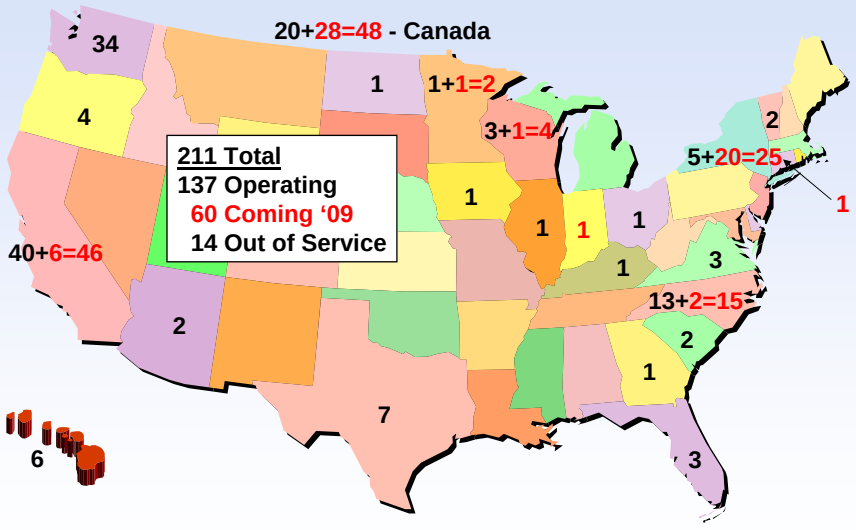
PHEVs and Demonstration Locations



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Fleet Data Collection \ Reporting Processes

- Along with testing partners, implemented onboard data logging for 150+ PHEVs, 16 HEVs, 8 HICE vehicles
- Created automated data warehousing, analysis, and reporting process for fleet data
- Accommodates 4 different data transfer methods from a multitude of vehicle / data logger combinations:
  - 8 PHEV, 8 HEV and 1 HICE models
  - 4 data logger manufacturers / designs
- Reporting formats include 69 metrics describing energy use, driving and charging patterns, and status monitors
- Developed quality assurance \ exploratory analysis tools
- Created flexible automated report generation processes for individual and multiple vehicle reports

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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

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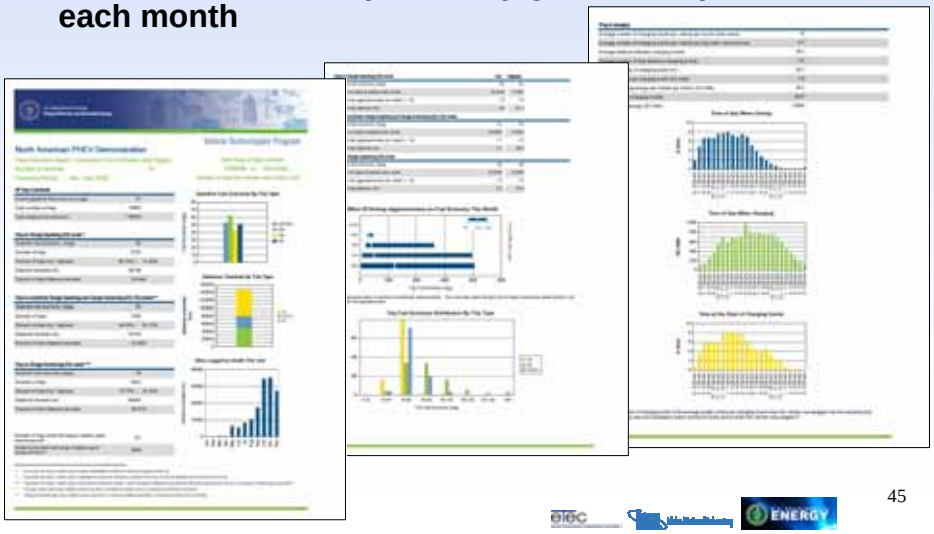
Database Generated PHEV Reports

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



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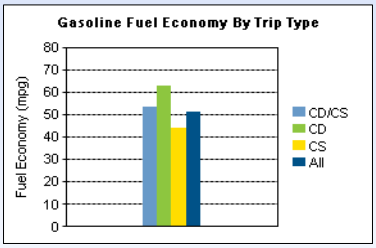
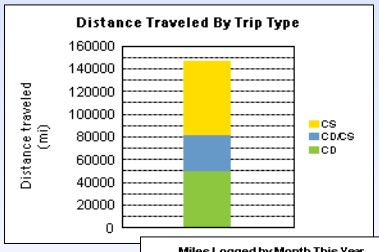
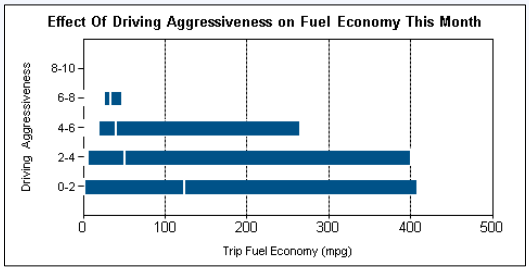
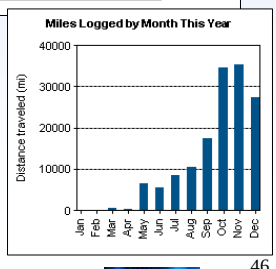
Database Generated PHEV Reports

- 61 Hymotion Prius PHEVs, 147,000 miles, 15,900 trips, 4,047 charging events – Mar/Dec 2008, V2Green collected









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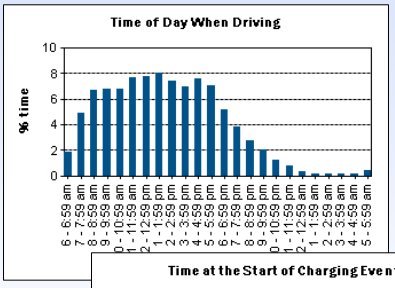
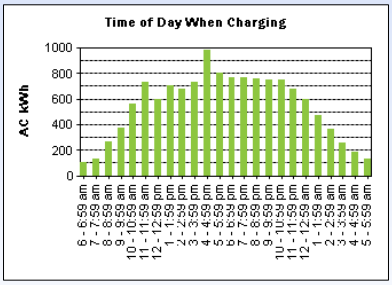
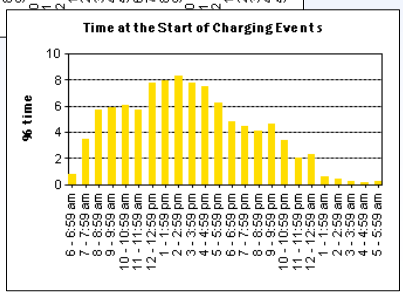
Database Generated PHEV Reports – cont'd

- 61 Hymotion Prius PHEVs, 147,000 miles, 15,900 trips, 4,047 charging events – Mar/Dec 2008, V2Green collected







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North American PHEV Demonstration

Vehicle Technologies Program

Seattle PHEV Report – page 1

- 13, not 14 PHEVS
- V2Green data loggers
- 51 mpg all modes
- 59 mpg CD mode
- 54 mpg CD/CS mode
- 40 mpg CS mode
- 17,636 miles
- CD trips = 8,886 CD miles
- CD/CS trips = 2,877 miles & 1,586 CD mi.
- Total 10,472 CD miles

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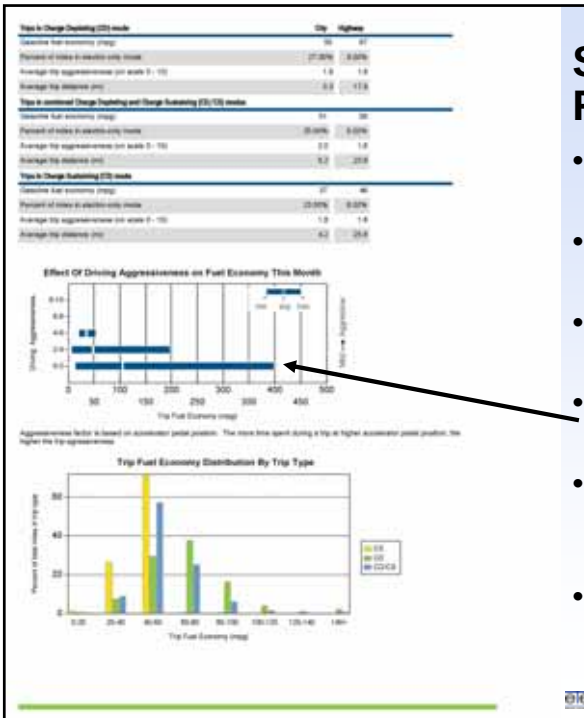

Seattle PHEV Report – page 2

- CD mode - 55 mpg city, 67 mpg highway
- CD/CS mode - 51 mpg city, 58 mpg highway
- CS mode - 37 mpg city, 46 mpg highway
- 0 to 20% aggressive driving = 100+ mpg
- Aggressive = percent of trip pedal position 40% or deeper
- Vehicle response controlled in future?

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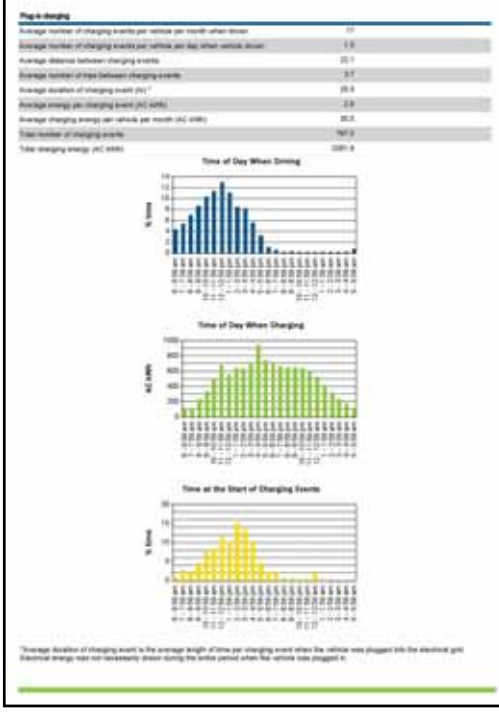

Seattle PHEV Report – page 3

- 17 charging events per vehicle per month when driven
- 797 charging events
- 2,082 kWh used
- 10,472 miles / 2,082 kWh = 5.03 miles/kWh
- 2.6 kWh average per charging event
- 35.5 kWh average per vehicle per month
- Lots of onpeak charging

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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

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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

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PHEV Charging Infrastructure Costs Report

- Report analyzes PHEV infrastructure requirements in single family & multi-family residential, & commercial facilities as well as driving trends. No site specific costs
- Charging infrastructure equipment/administrative costs:
  - Levels 1 (120V, 15 or 20 amp) & 2 residential
  - Levels 1 & 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

Report @ http://avt.inl.gov/pdf/phev/phevInfrastructureReport08.pdf

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Charging Infrastructure

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





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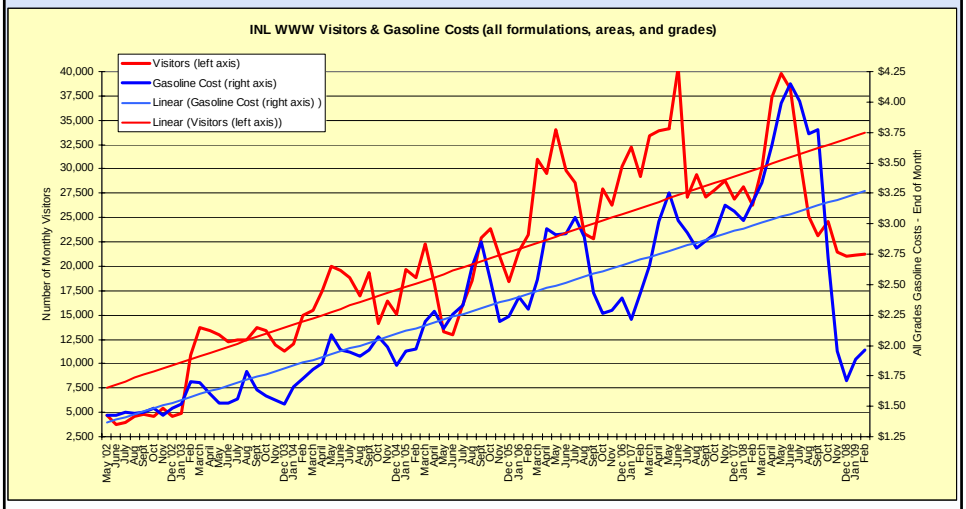
AVTA Webpage Use and Gasoline Costs



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Acknowledgement

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Additional Information

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

INL/CON-09-15561

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