



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

Virginia EV Road Show - PHEV Operations and Performance

Jim Francfort

**Virginia Clean Cities and Hampton Roads
Clean Cities Coalition - Virginia Electric
Drive Road Show
Poquoson, VA – August 2009**

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 by Technology

- **Plug-in hybrid electric vehicles (PHEV)**
 - 12 models, 188 vehicles, 800,000 fleet test miles
- **Hybrid electric vehicles (HEV)**
 - 17 models, 45 vehicles, 4.5 million test miles
- **Neighborhood electric vehicles**
 - 23 models, 200,000 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
- **Urban electric vehicles**
 - 3 models, 1 million test miles



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

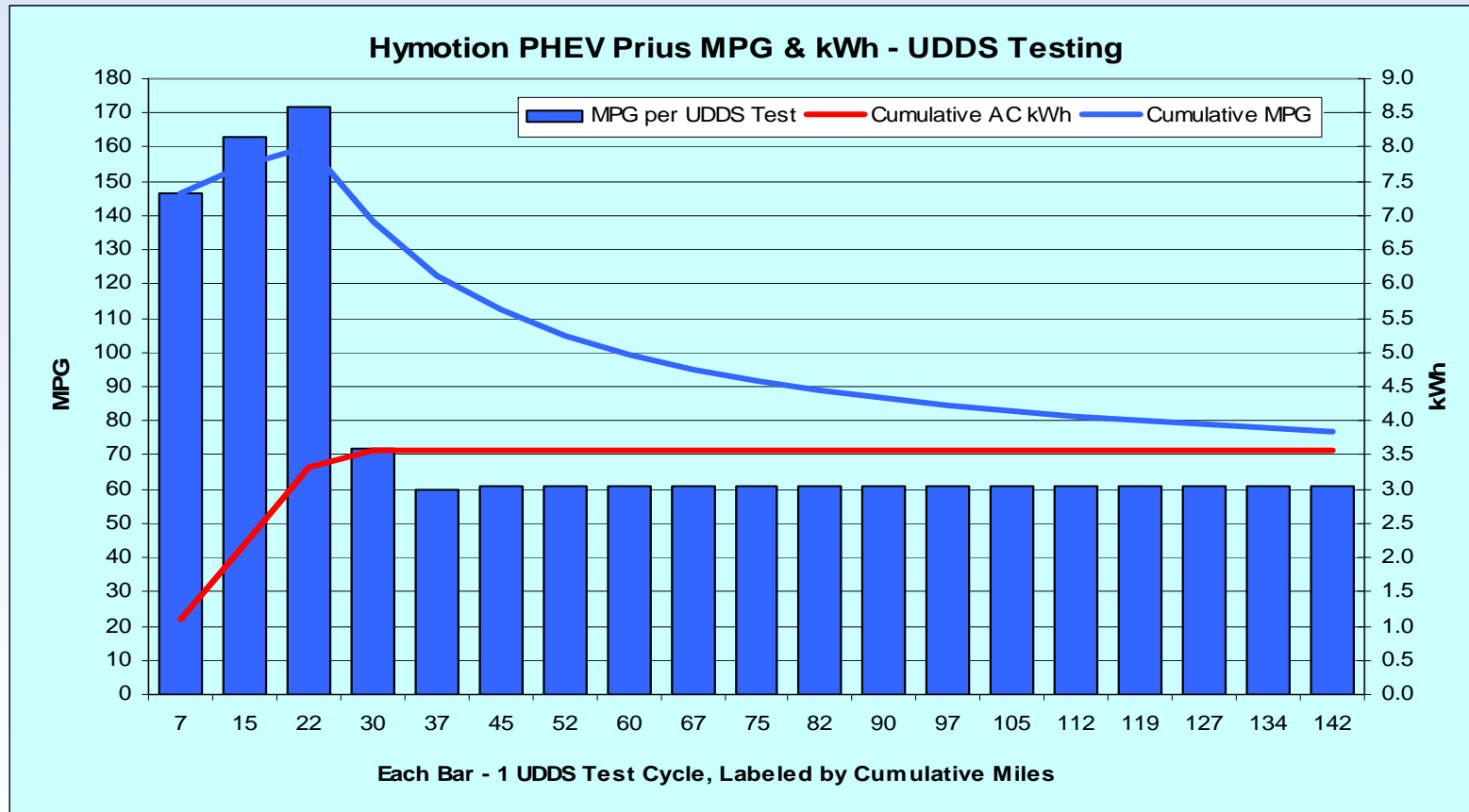
- **Perform independent testing of PHEVs, using:**
 - **Baseline performance testing: closed test tracks and dynamometers**
 - **Accelerated testing: dedicated drivers operating on defined onroad loops**
 - **Fleet testing: everyday unstructured \ non-directed fleet and public use, with onboard data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

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

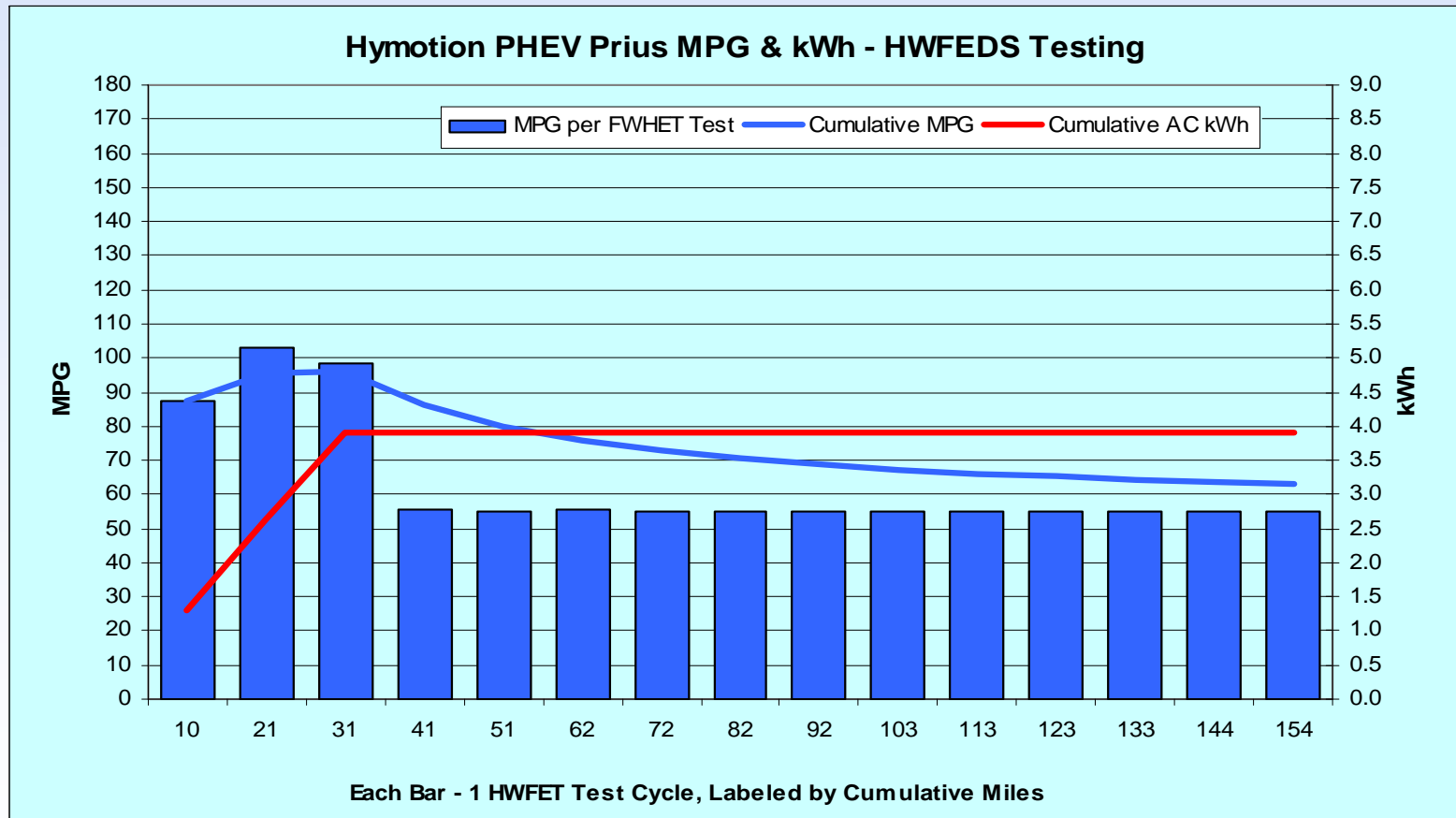
Hymotion Prius Gen I – UDDS Fuel Use

- 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

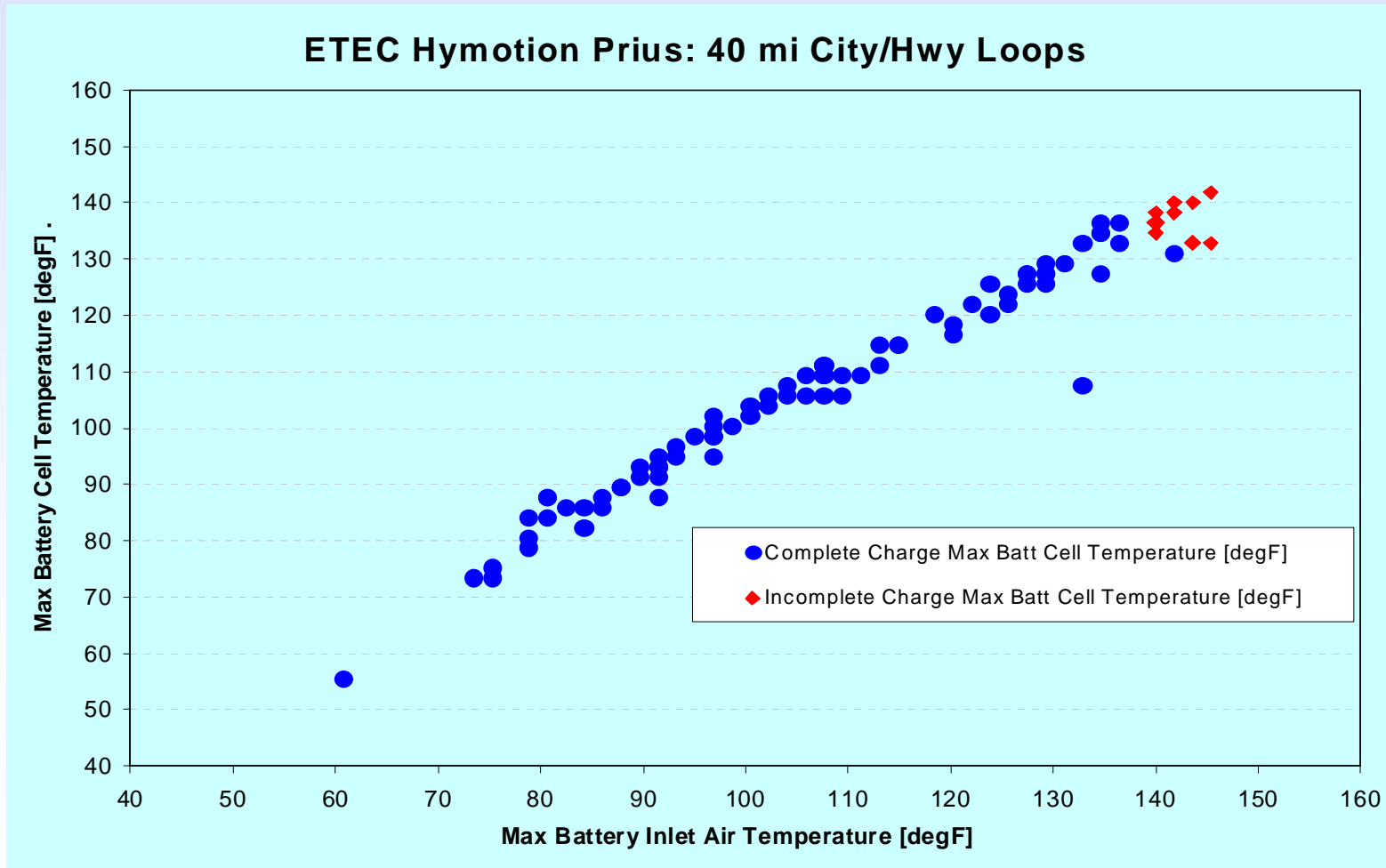
Hymotion Prius Gen II – Accelerated Testing

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	
20	1	1	8	30	600	124.50	8.105	80.1	
40	4	0	12	15	600	71.28	9.8	62.1	64.2
40	4	0	12	15	600	44.97	7.2	84.2	135.6
40	2	2	12	15	600	64.36	9.70	64.3	65.5
40	2	2	12	15	600	75.14	6.20	99.8	101.7
40	2	2	12	15	600	70.98	6.83	90.6	98.9
40	0	4	12	15	600	75.18	6.10	103.3	100.0
40	0	4	12	15	600	63.46	8.88	70.8	92.4
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	7,840	Weighted Average			

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

Hymotion Prius Gen II – Accelerated Testing

- 40 mile city/highway loops – high ambient temperatures results in incomplete charging



Energy CS Prius (Valance Bat.) Acc. 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)
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 (mi)	Urban (10 mi)	Highway (10 mi)	Charge (hr)	Reps (N)	Total (mi)	Electricity AC kWh	Gasoline	
							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 (mi)	Urban	Highway	Charge	Reps	Total	Electricity	Gasoline	
	(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

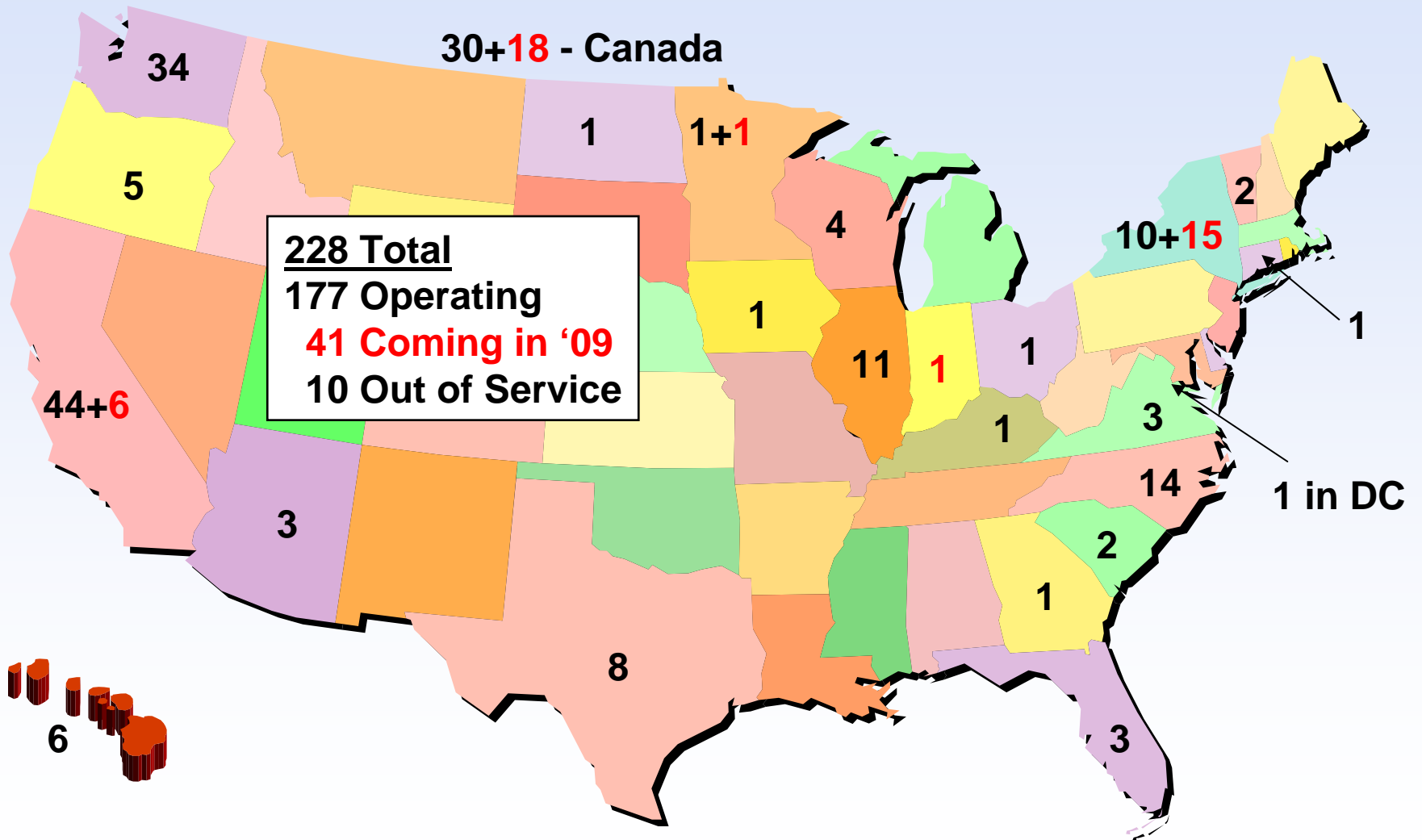
Each total distance slightly greater than 600 miles. HEV version = 27 mpg

PHEV Fleet Testing Partners



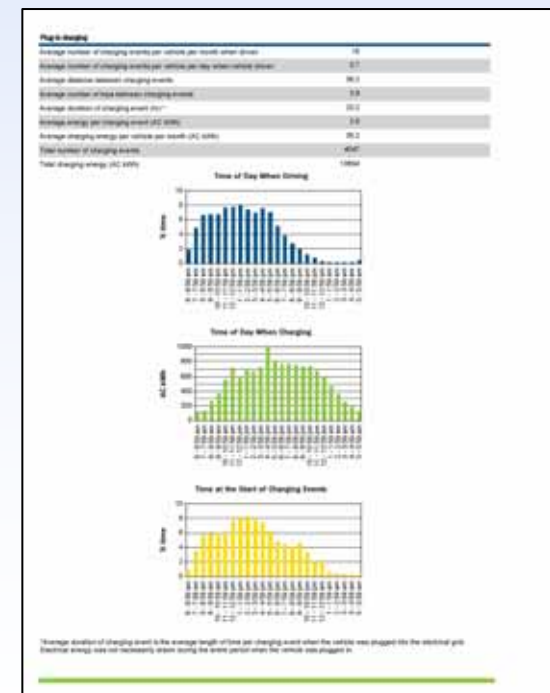
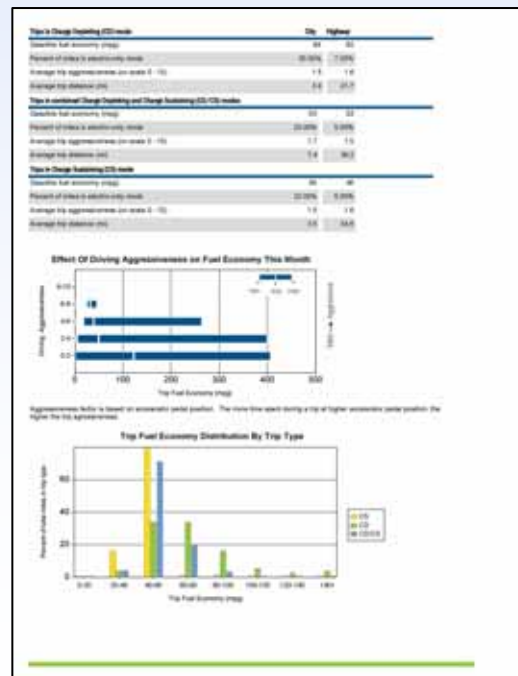
- **75+ testing partners in the U.S. and Canada:**
 - 36 Electric utilities and 2 clean-air agencies
 - 10 City, county and state governments
 - 7 Private companies and advocacy organizations
 - 8 Universities and colleges and 4 Canadian provinces
 - 2 PHEV companies 1 sea port and 1 DOD facility
- **Testing 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

PHEVs and Demonstration Locations



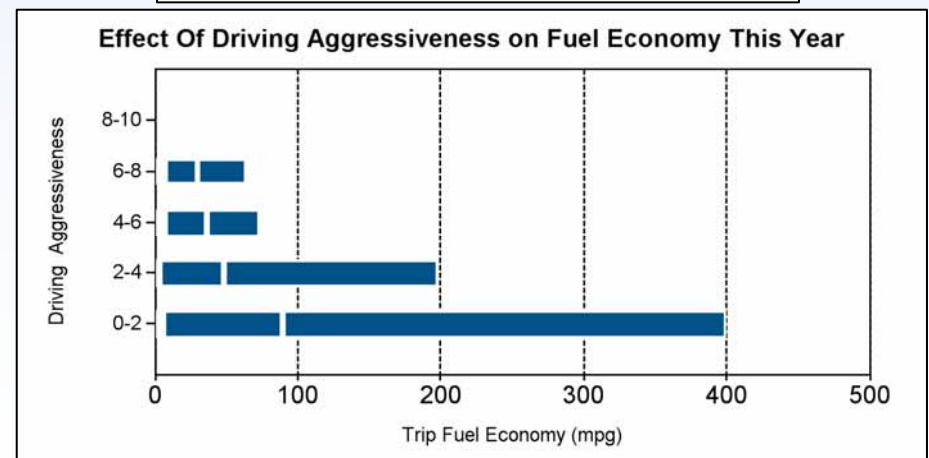
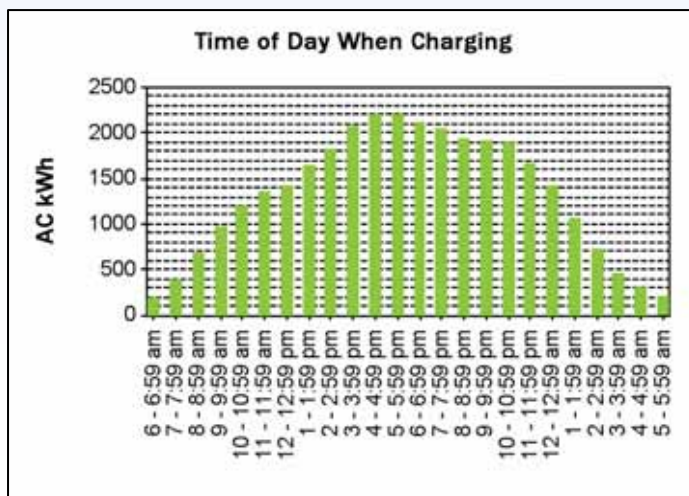
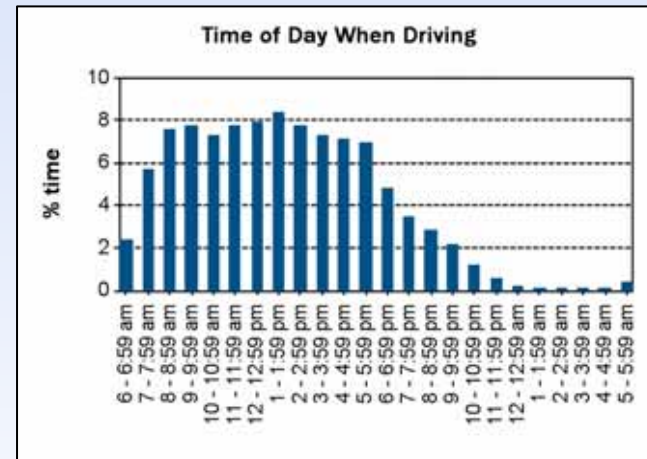
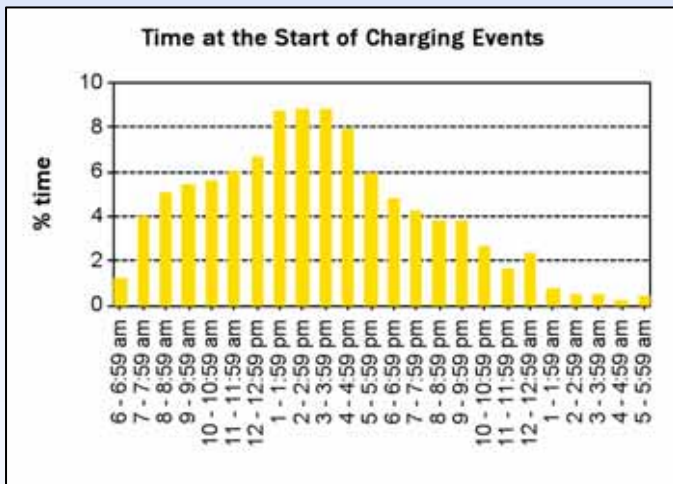
PHEV Fleet Testing Reports

- Summary reports posted monthly on web
- Individual vehicle reports only go to the respective fleets each month, 950+ reports to date (July 1, 2009)
- 150 Hymotion Prius PHEVs, 710,000 miles, 76,000 trips, 18,000 charging events, 43,000 kWh used. V2Green and Kvaser data logger reports



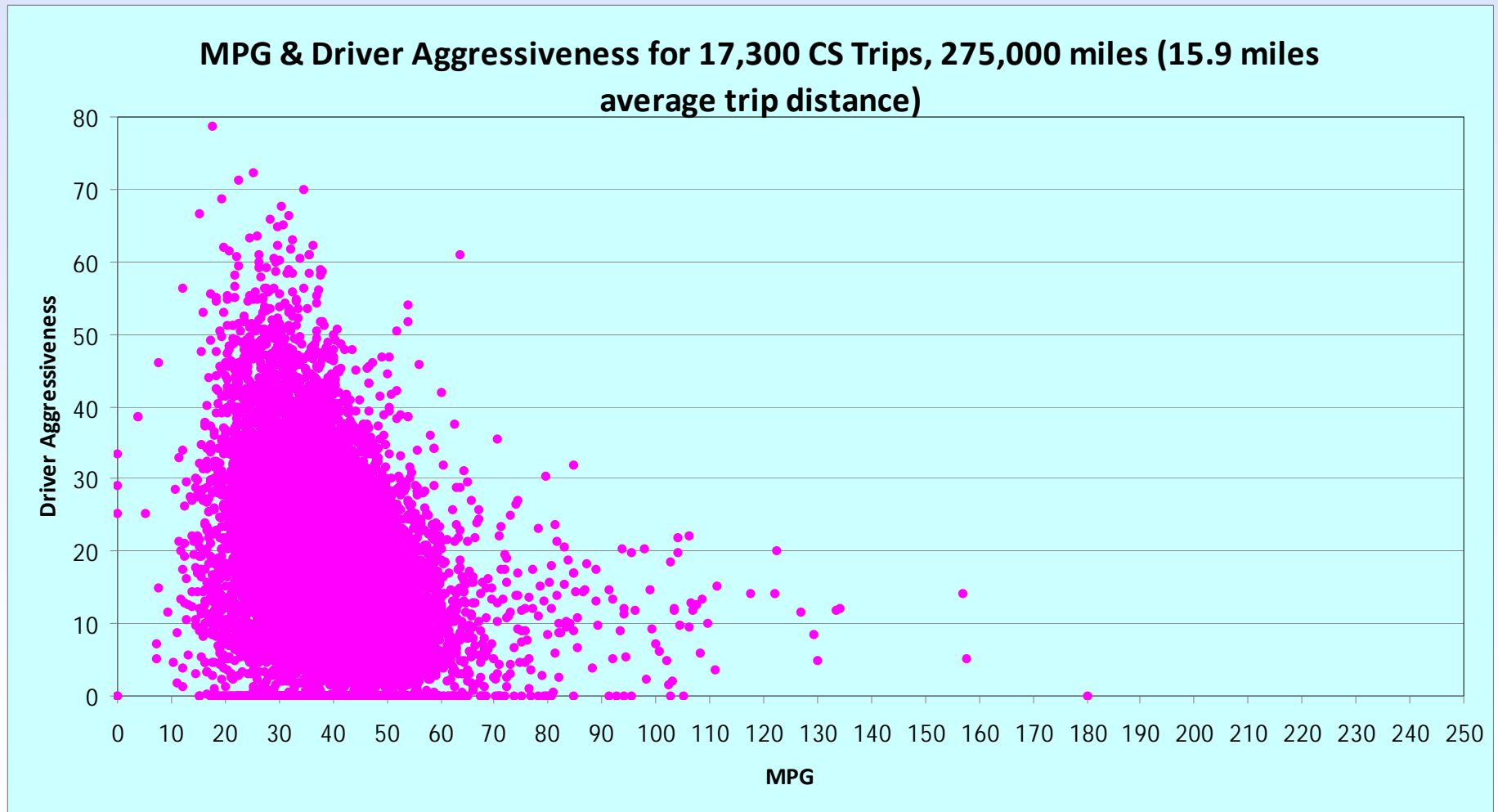
Hymotion Prius (V2Green Logger) Fleet Tests

- March 01/08 to July 01/09. 110 PHEVs, 498,000 miles, 54,000 trips, 12,400 charging events and 31,000 kWh used



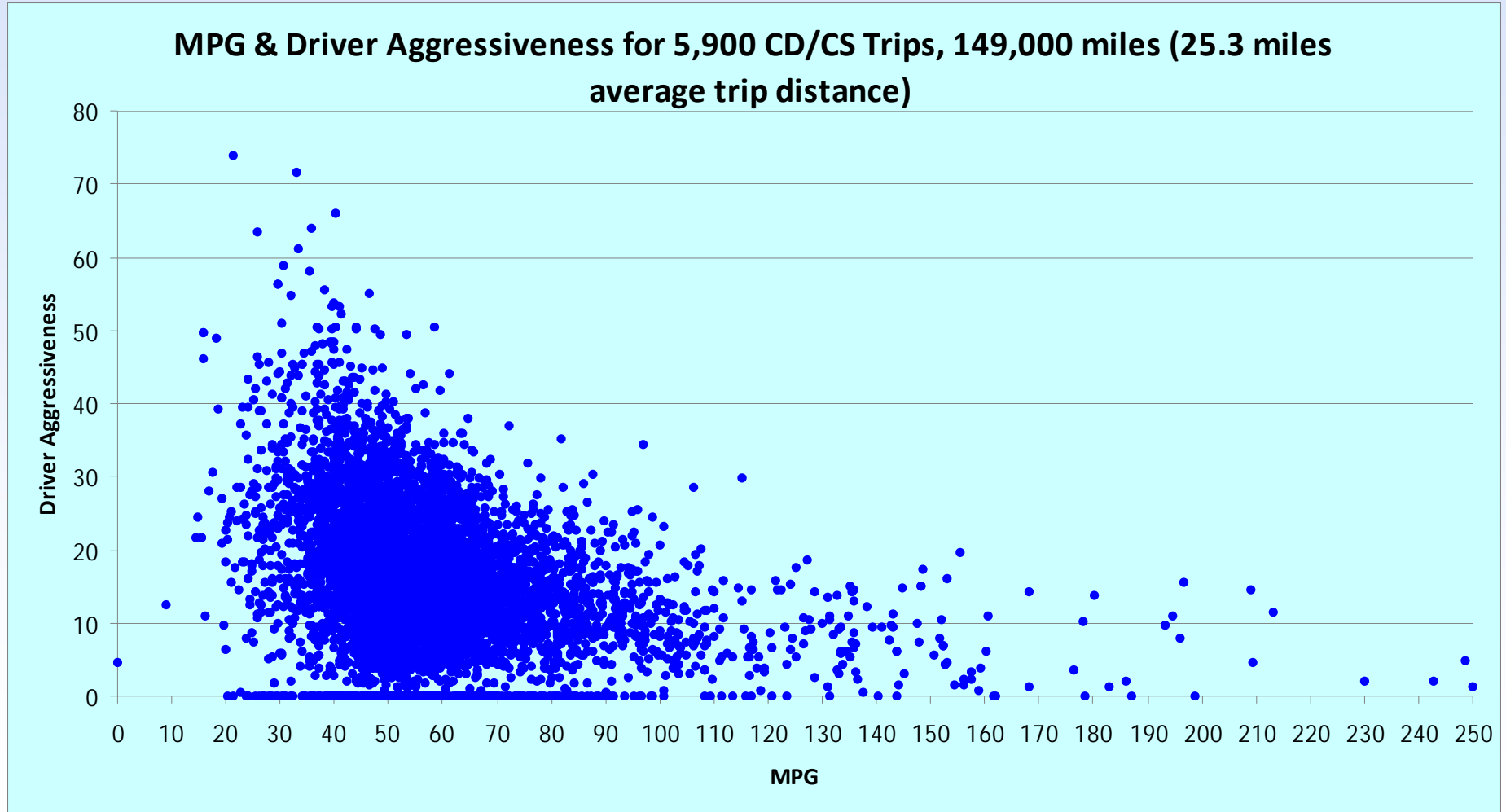
Hymotion Prius PHEVs – CS Trips

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



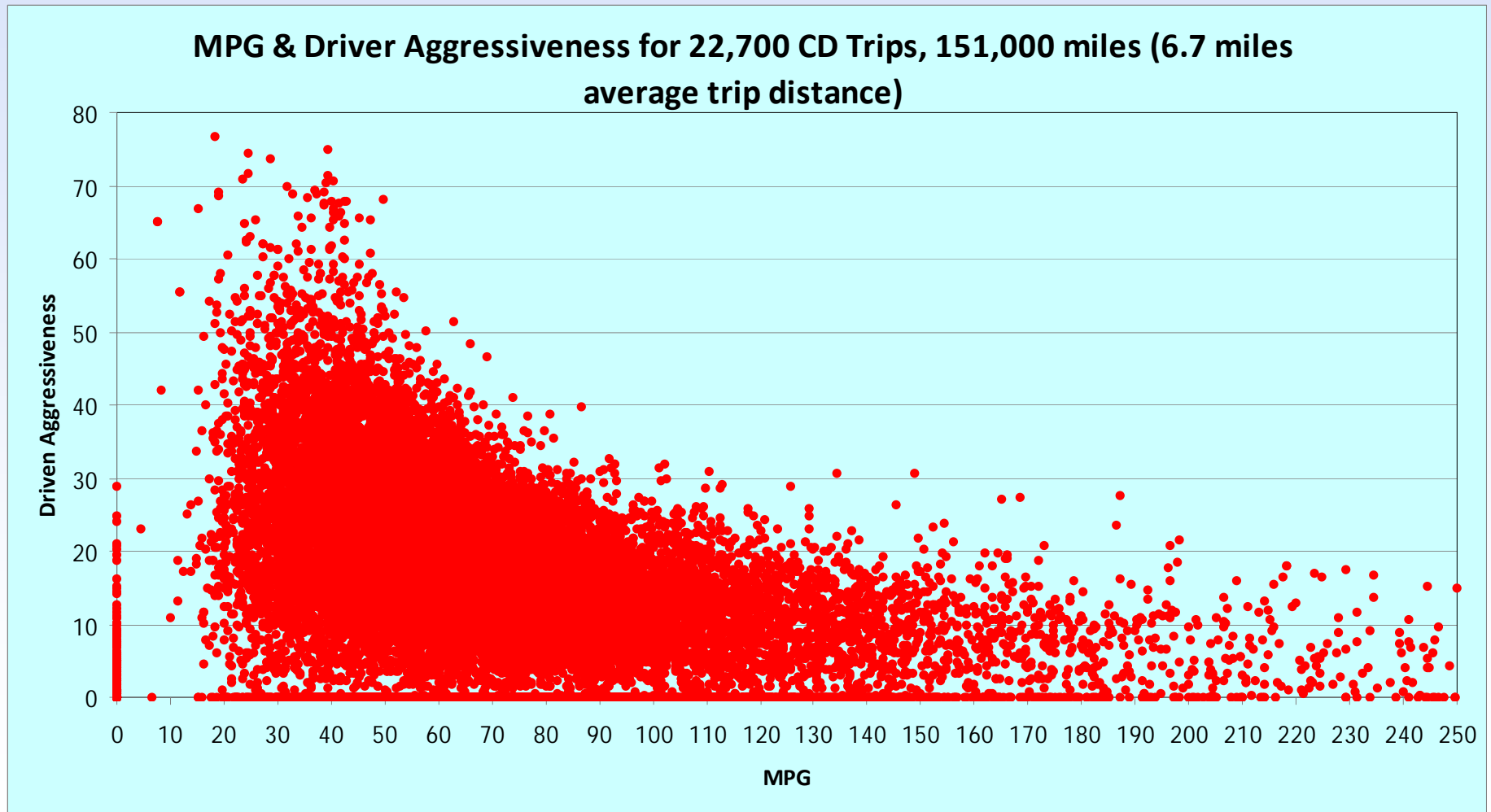
Hymotion Prius PHEVs – CS/CD Mixed Trips

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

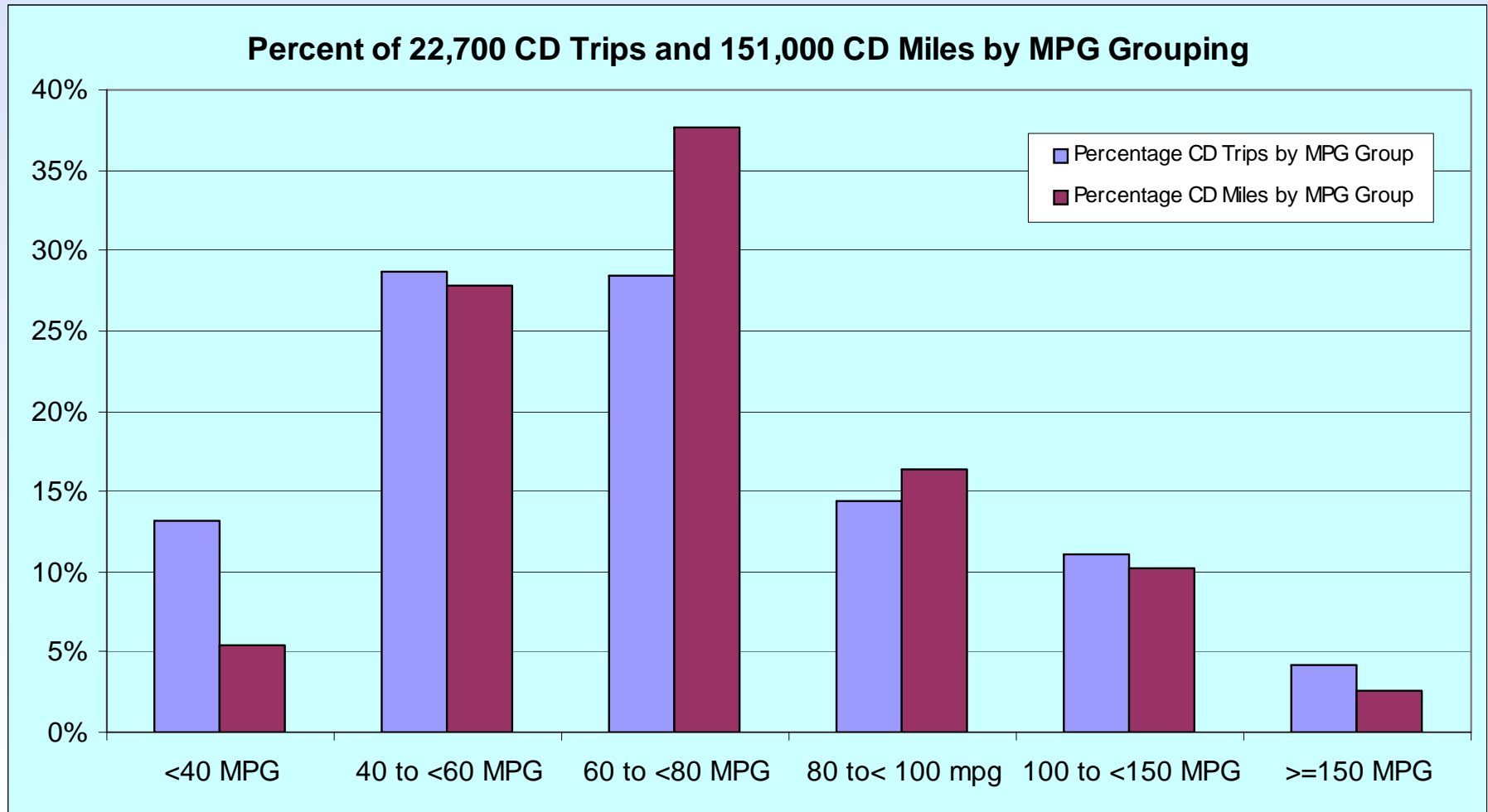


Hymotion Prius PHEVs – CD Trips

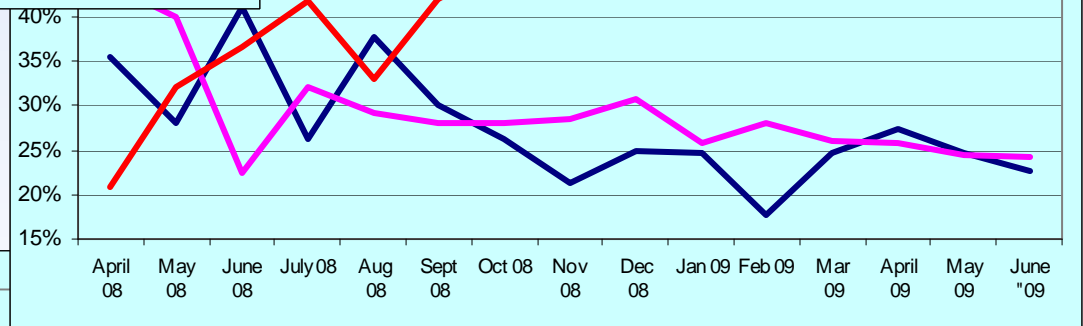
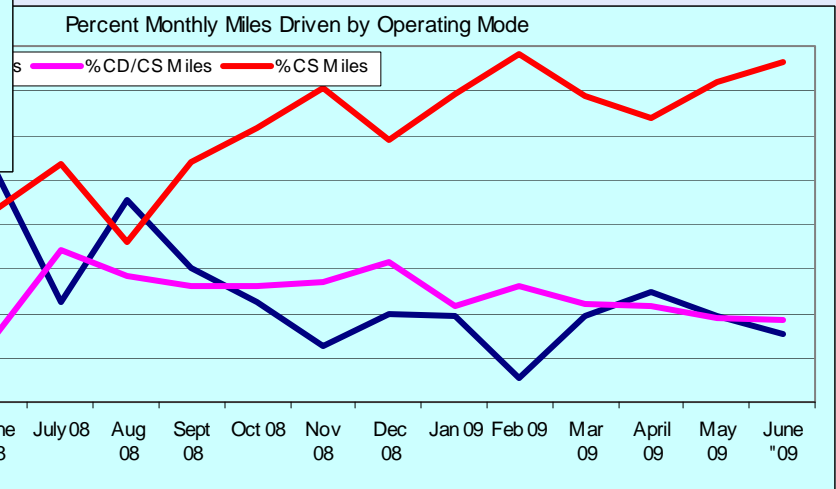
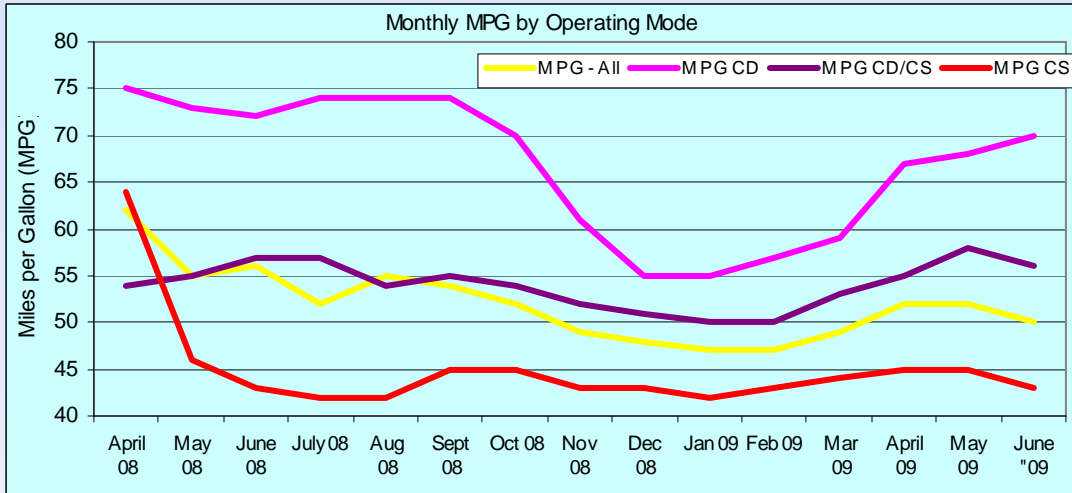
- MPG and aggressive driving impacts March '08 – May '09



MPG Results - Charge Depleting (CD) Mode



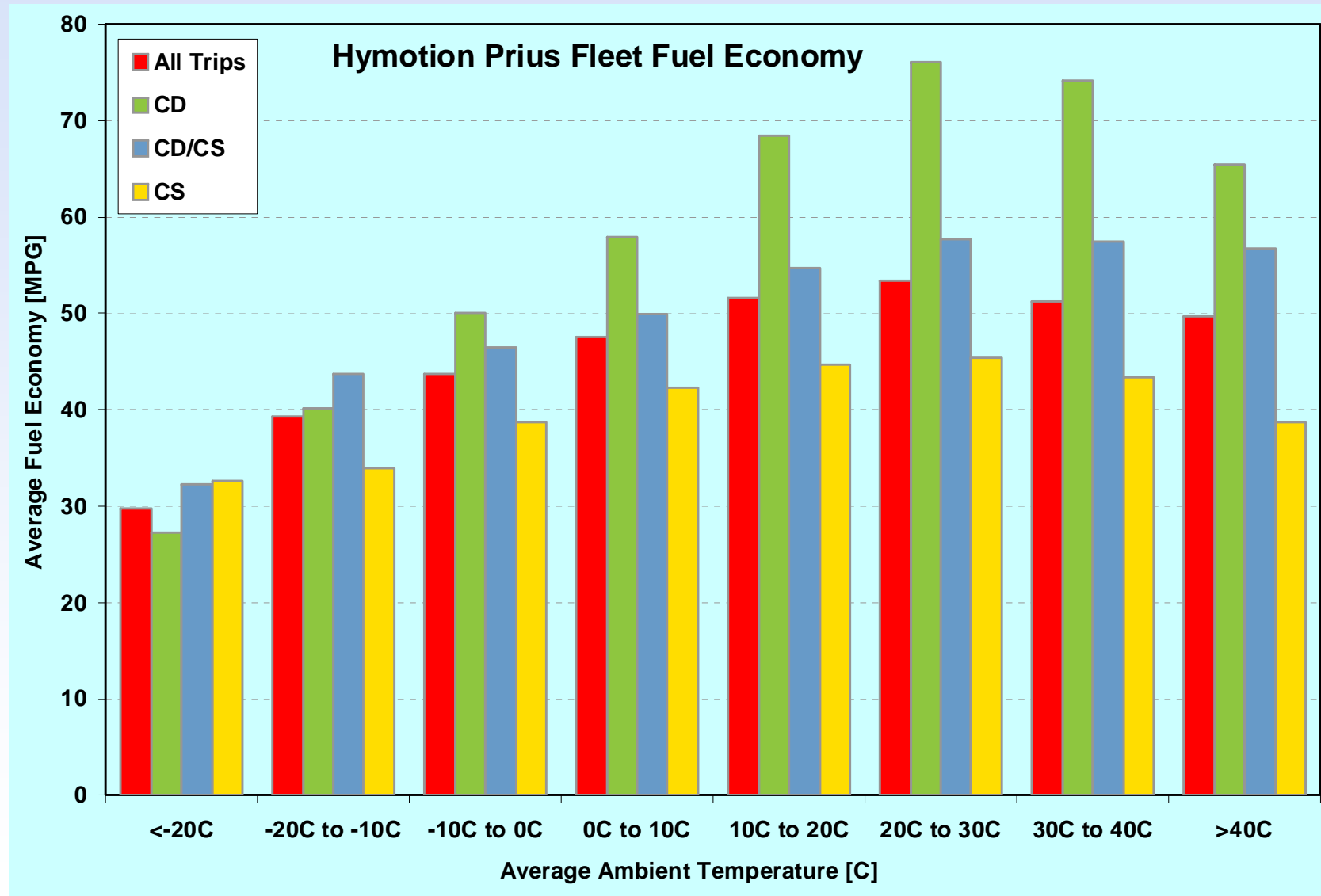
Fleet Testing Results – Monthly Trends



Data from 110 Hymotion Prius with V2Green loggers



Hymotion Prius PHEV MPG by Temperature

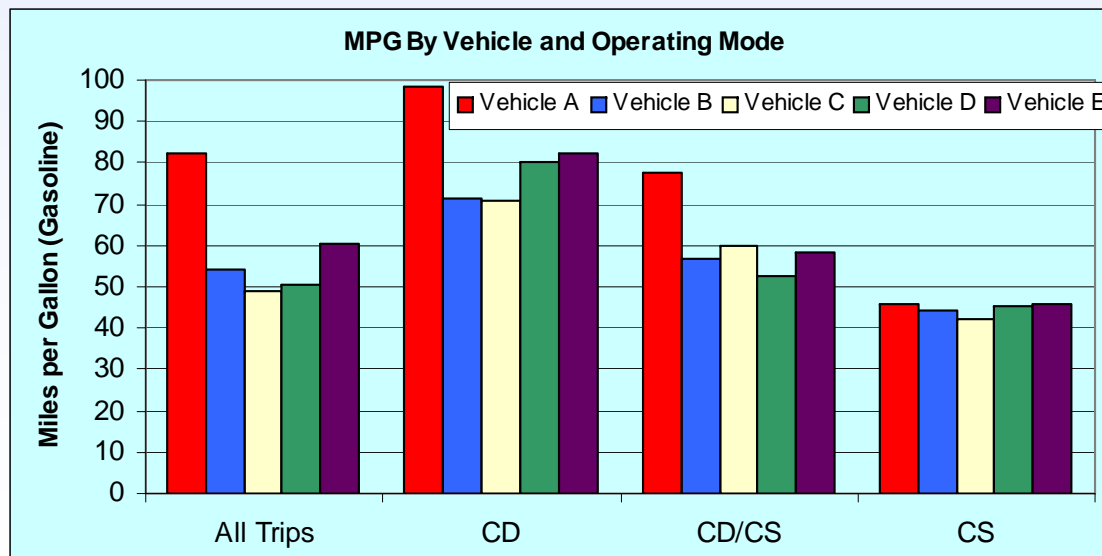
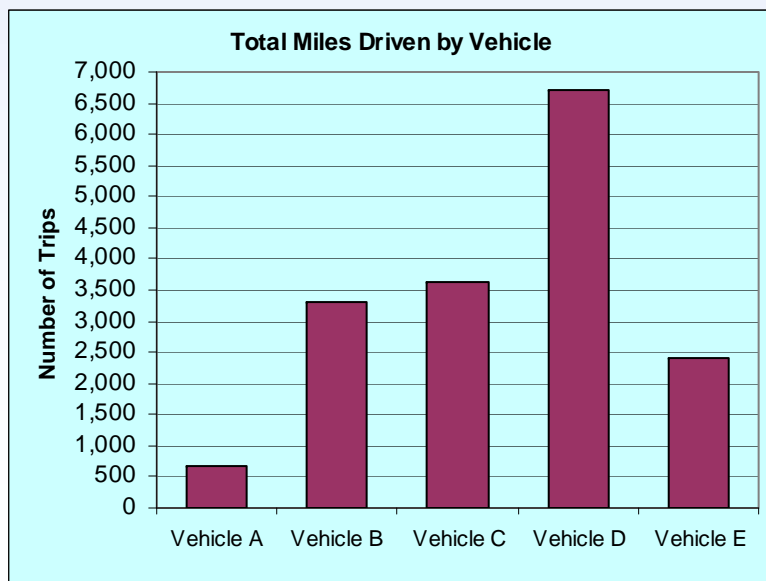


Data from 150 Hymotion Prius with V2Green and Kvaser loggers



EnergyCS Prius (Valance Battery) Fleet Tests

Trip Type	Fuel Economy (mpg)	Number of Trips	Percent of Trips	Miles Driven	Percent Total Distance
All	53.0	1,966		16,470	
CD	78.1	953	48%	3,911	24%
CD/CS	56.1	184	9%	4,896	30%
CS	44.4	829	42%	7,933	48%



EnergyCS Prius (Altairnano Bat.) Fleet Tests

Trip Type	Fuel Economy (mpg)	Number of Trips	Percent of Trips	Miles Driven	Percent Total Distance
All	60	915		7,312	
CD	73	475	52%	1,724	24%
CD/CS	68	101	11%	3,156	43%
CS	47	339	37%	2,431	33%

Average number of charging events per vehicle per month when driven	17.7
Average number of charging events per vehicle, per day, when driven	1.2
Average distance between charging event (miles)	33.7
Average number of trips between charging event	4.2
Average energy per charging event (DC kWh)	2.0
Average charging event duration (hours)	21.9
Total number of charging events	217
Total charging energy (AC kWh)	590

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

PHEV Advantages

- **Reduced petroleum consumption and emissions**
- **Optimized fuel efficiency and performance**
- **Recover energy during regenerative braking**
- **Use existing gas station infrastructure**
- **Minimal electric grid changes needed - add connector and electric vehicle supply equipment (EVSE)**
- **At home battery charging, well below cost of gasoline**
- **Zero emission potential (local)**
- **Lower fuel costs compared to HEVs**
- **Energy security by displacing imported petroleum with domestically generated electricity**
- **Potential for off-peak charging**
- **V2Grid (big maybe)**

Primary Source Electric Drive Transportation Association (EDTA)
http://www.electricdrive.org/index.php?ht=d/Articles/cat_id/5599/pid/9673



PHEV Challenges

- Cost and complexity of two powertrains
- Drivers adapting to dual-fueling scenario
- Component availability - batteries, powertrains, power electronics (early challenge)
- Higher initial capital cost
- Cost of batteries and potential battery replacements
- Added weight
- Probable need for public recharging infrastructure
- Challenge to move charging to off-peak times
- If large PHEV batteries are successful, will BEVs replace PHEVs?



Primary source EDTA

http://www.electricdrive.org/index.php?ht=d/Articles/cat_id/5599/pid/9673

Announced PHEV Introductions*

- 2009 Fisker Karma S Plug-in Hybrid (maybe 2010)
- 2010 Saturn VUE Plug-in Hybrid
- 2010 Toyota Plug-in Hybrid (?)
- 2010 Chevrolet Volt Extended Range BEV
- 2010 Kia LPG and Electric “hybrid”
- 2009 Chery (China, Berkshire Hathaway) BYD PHEV in Europe
- 2011 BYD F3DM Plug-in Hybrid
- 2012 Ford Escape Plug-in Hybrid
- 2012 Hyundai PHEV
- ? AFS Trinity SUV
- * Presenter makes no accuracy claim for the above dates and products. Some info based on media reports



Primary source: EDTA <http://www.electricdrive.org/index.php?ht=d/sp/i/11551/pid/11551>

Announced BEV Introductions*

- 2009 Subaru 4 seat Stella or R1e (2 in New York now)
- 2009 Chrysler EVs (showing concepts)
- 2009 Smart for Two EV
- 2009 ZENN city BEV
- 2009 Chery (China, Berkshire Hathaway) BYD EV in China
- 2009 Tesla / Daimler Smart Car BEV
- 2010 BMW electric Mini (maybe 2009)
- 2010 Chrysler EV
- 2010 Miles EV
- 2010 Mitsubishi \ Peugeot iMiEV BEV
- * Presenter makes no accuracy claim for the above dates and products. Some info based on media reports

Primary source: EDTA <http://www.electricdrive.org/index.php?ht=d/sp/i/11551/pid/11551>

Announced BEV Introductions* – cont'd

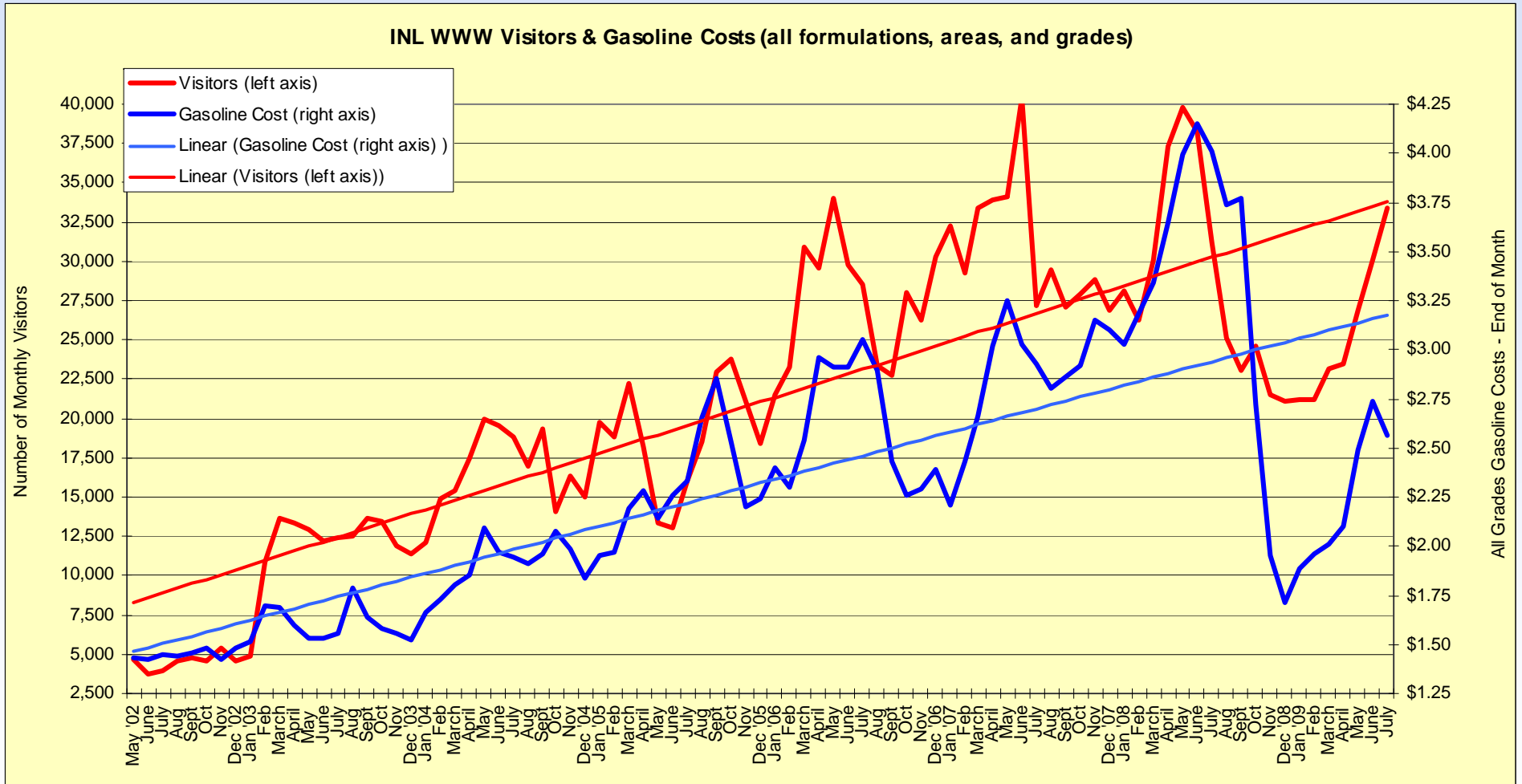
- 2010 Nissan BEV
- 2010 Ford Battery Electric Van
- 2011 Tesla Model S sedan
- 2011 BYD e6 Electric Vehicle
- 2011 Ford Battery Electric Sedan
- 2011 Opel Ampera Extended Range BEV (Europe)
- 2012 Toyota EV sedan
- ? Volkswagen and Toshiba EV develop letter of intent
- * Presenter makes no accuracy claim for the above dates and products. Some info based on media reports



Primary source: EDTA

<http://www.electricdrive.org/index.php?ht=d/sp/i/11551/pid/11551>

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-09-16608