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

Advanced Electric Vehicle Testing and Evaluation Results

John Smart

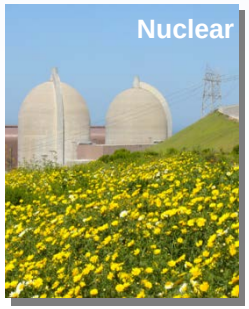
Idaho National Laboratory

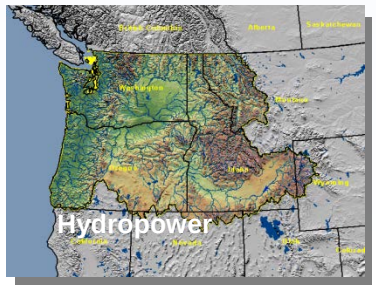
AT&T Fleet Operations Alternative Fuel Vehicle Planning Session
St. Louis, MO – Nov 11, 2009

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





Advanced Vehicle Testing Activity (AVTA)

- **Part of the U.S. Department of Energy's Vehicle Technologies Program**
- **INL and Electric Transportation Engineering Corporation (ETEC) conduct the AVTA's light-duty vehicle testing, with Argonne National Laboratory performing dynamometer testing**

AVTA Goals

- **Determine actual petroleum displacement and overall operating cost of advanced technology vehicles**
- **Provide benchmark data to industry and government research and development programs**
- **Assist fleet managers and consumers in making informed vehicle purchase, usage, and operating decisions**

AVTA Testing by Technology

- **Plug-in hybrid electric vehicles (PHEV)**
  - **12 models, 216 vehicles, 1.1 million test miles**
- **Hybrid electric vehicles (HEV)**
  - **18 models, 47 vehicles, 4.7 million test miles**
- **Full-size battery electric vehicles (BEVs)**
  - **40 EV models, 5+ million test miles**
- **Neighborhood electric vehicles**
  - **23 models, 200,000 test miles**
- **Urban electric vehicles**
  - **3 models, 1 million test miles**
- **Hydrogen internal combustion engine vehicles**
  - **7 models, 400,000 test miles**

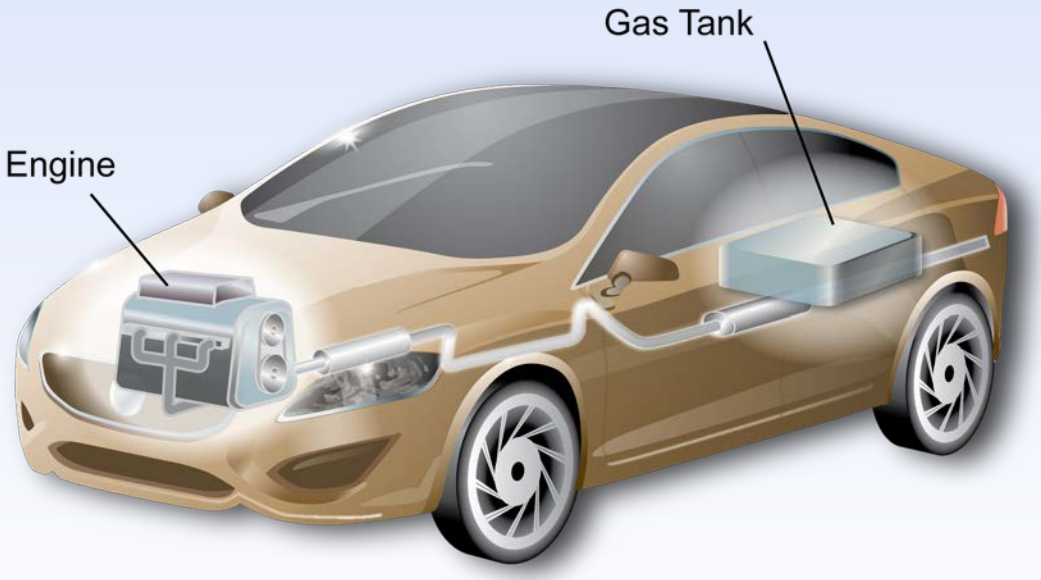
Focus on advanced electric vehicles

Outline

- Comparison of vehicle technology and operating characteristics
- Vehicles available today
- HEV and PHEV test results to date
- Big picture considerations for PHEVs
- Possible future vehicles

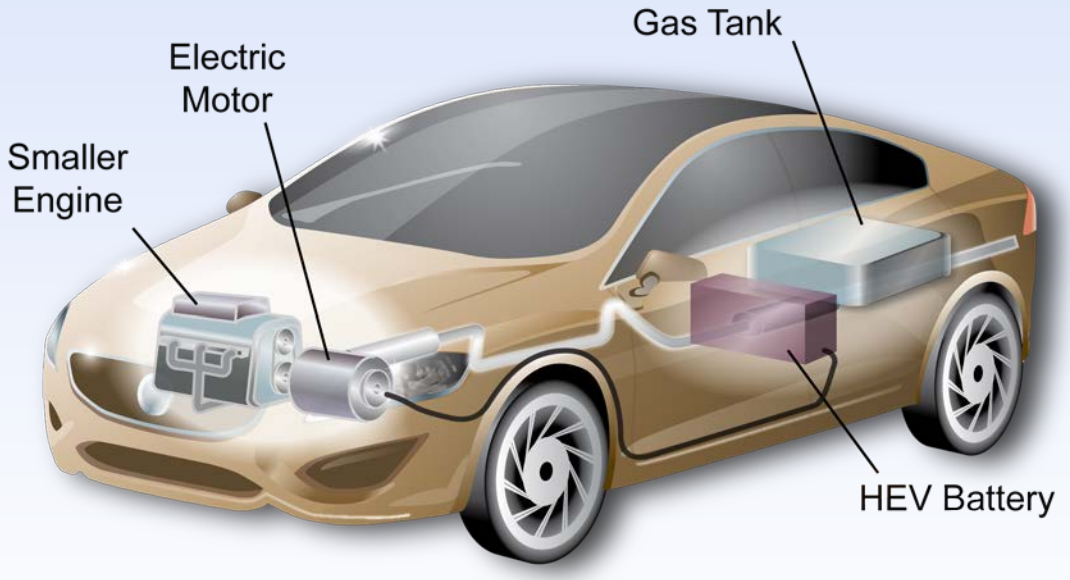
Comparison of Vehicle Technology

Conventional vehicle with internal combustion engine (ICE) only



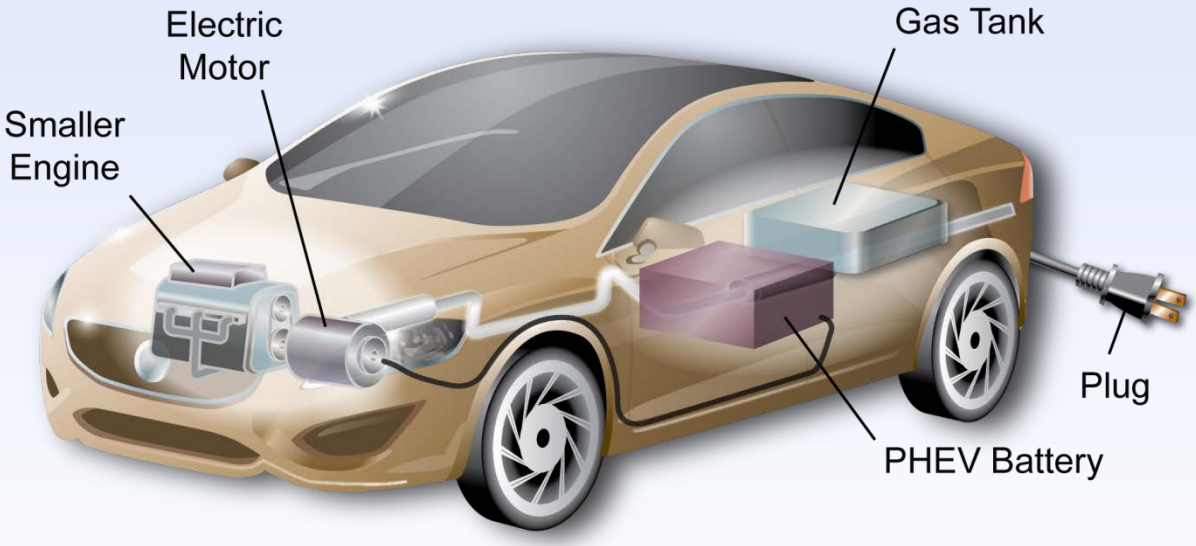
Comparison of Vehicle Technology

- **Hybrid Electric Vehicle (HEV) with ICE and electric drive**
- **Does not plug in to electric grid**



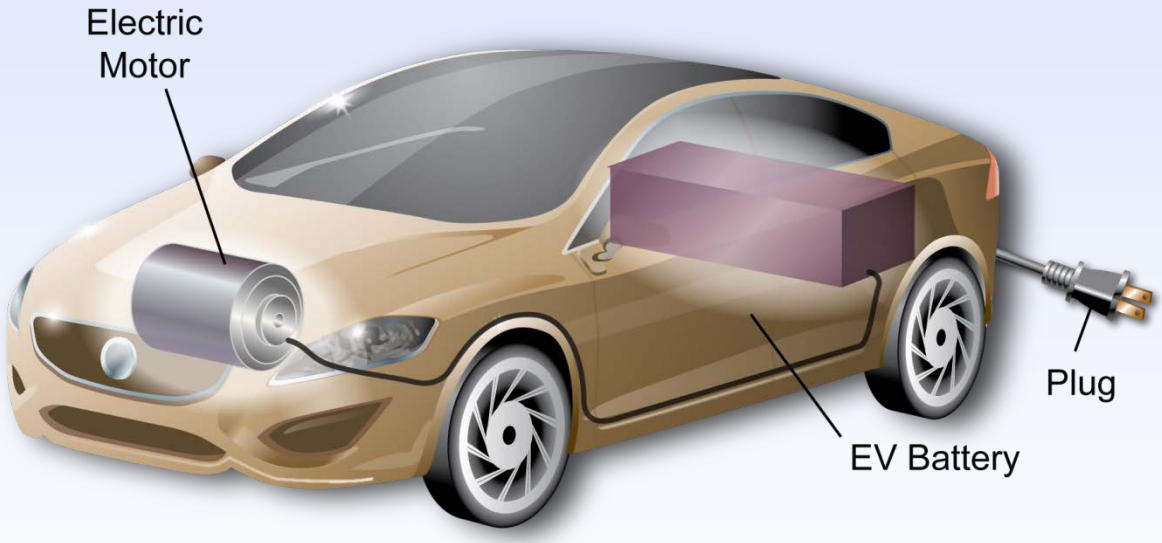
Comparison of Vehicle Technology

- **Plug-in Hybrid Electric Vehicle (PHEV) with ICE and electric drive**



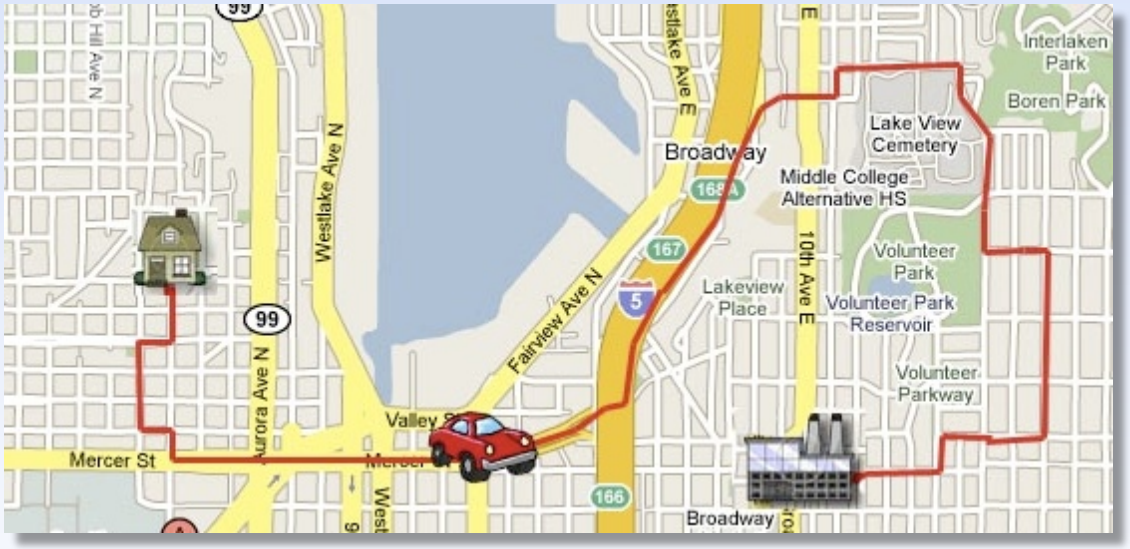
Comparison of Vehicle Technology

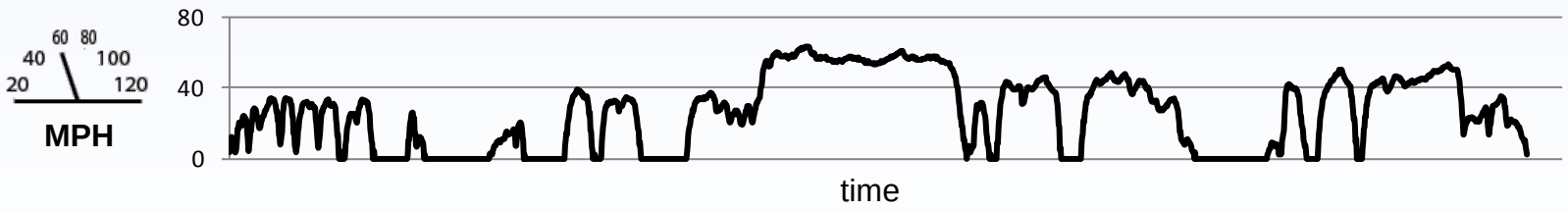
- **Battery Electric Vehicle (BEV) with electric drive only**



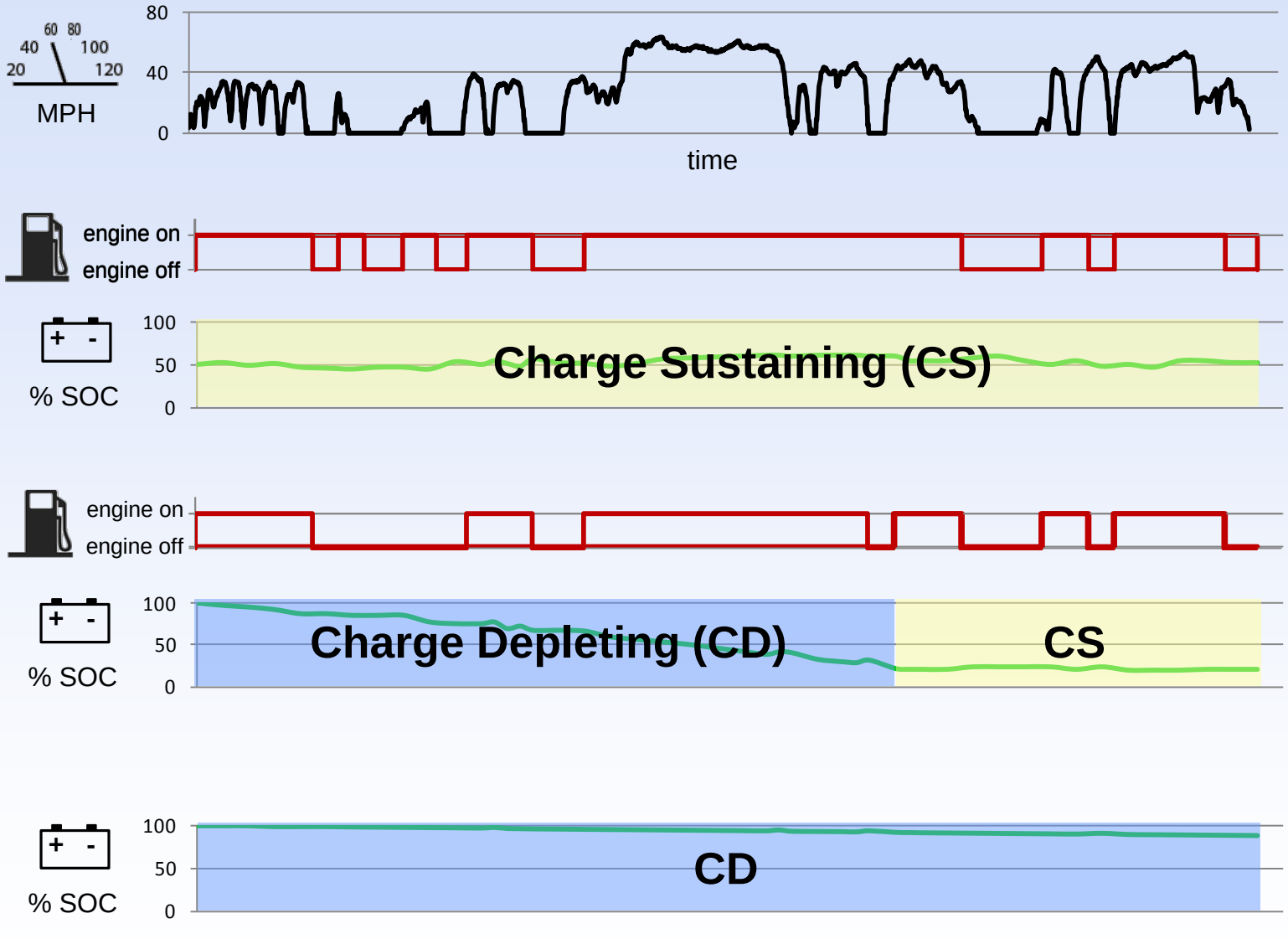
Conceptual Comparison of Vehicle Operation

Hypothetical 15 mile drive cycle



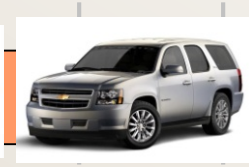


Conceptual Comparison of Vehicle Operation



Timeline of Advanced Electric Vehicle Availability





Production OEM HEVs

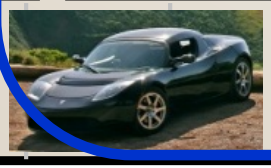
Conversion PHEVs

AVTA has done extensive testing of vehicles available to date

Production OEM PHEVs*


AVTA is collaborating with auto makers to begin testing OEM PHEVs and BEVs. HEV and conversion PHEV testing continues.

Production OEM BEVs*




2004 2006 2008 2010 2012 2014

* Refers to PHEVs and BEVs produced for the mass market. OEMs have produced PHEVs and BEVs in low volume intermittently since the 1990's.

etec electric transportation engineering corporation

INL Idaho National Laboratory

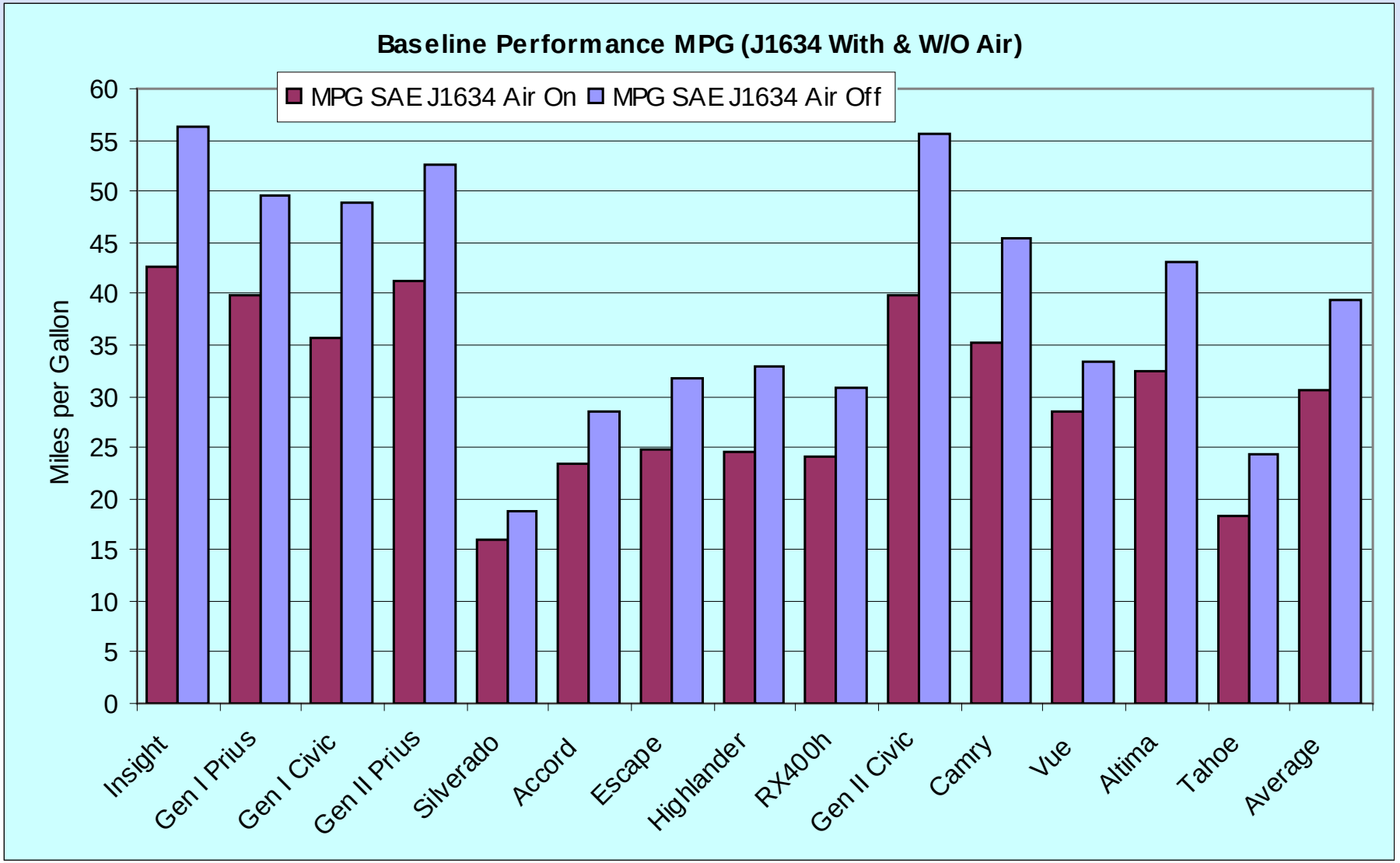
U.S. DEPARTMENT OF ENERGY

HEV TESTING

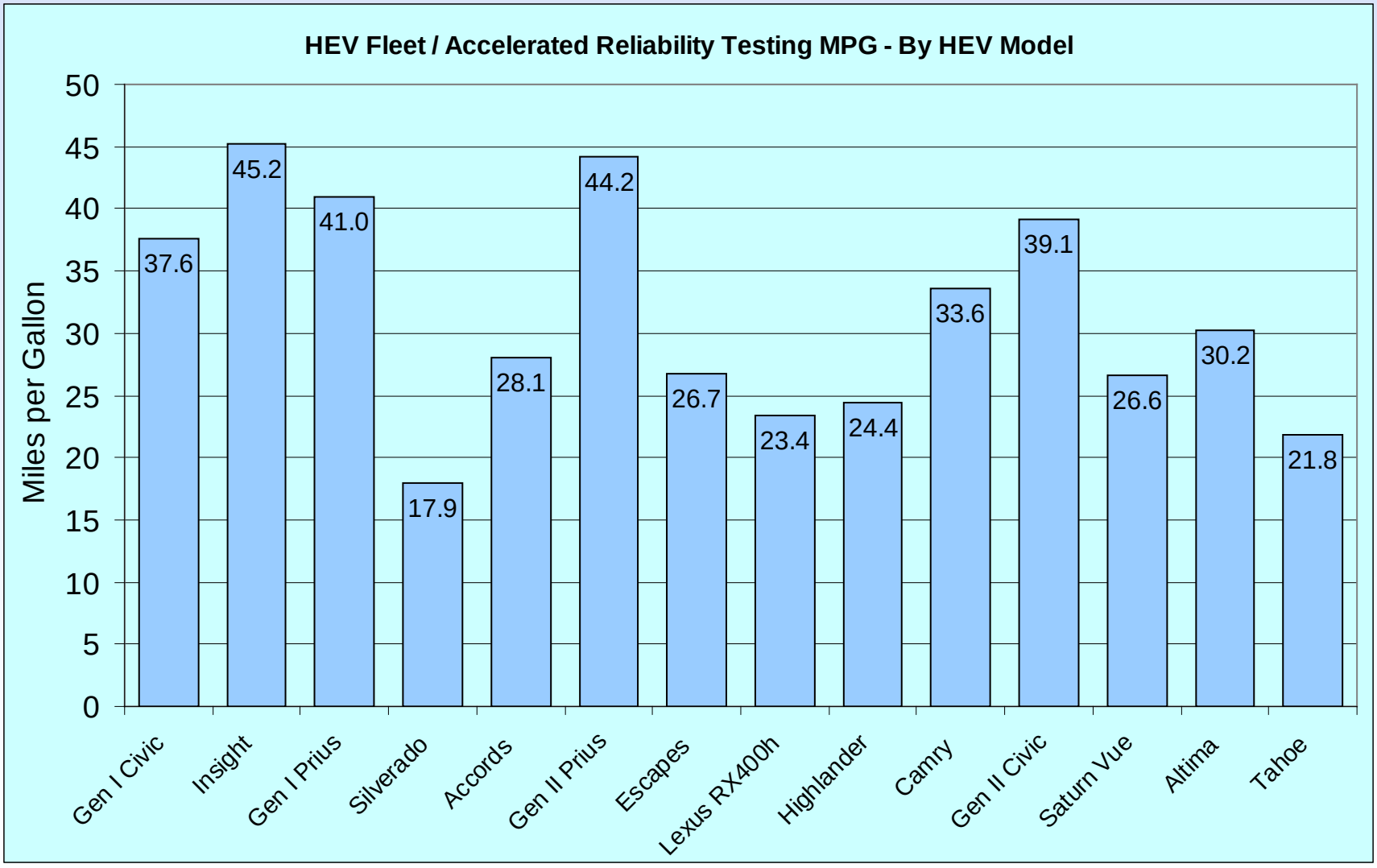
Hybrid Electric Vehicles (HEVs) in Testing

2001 Honda Insight	6	Completed
2002 Gen I Toyota Prius	6	Completed
2003 Gen I Honda Civic	4	Completed
2004 Chevrolet Silverado (2- & 4-WD)	2	Completed
2004 Gen II Toyota Prius	2	Completed
2005 Ford Escape (front & 4-WD)	2	Completed
2005 Honda Accord	2	Completed
2006 Lexus RX 400h (front & 2 AWD)	3	Completed
2006 Toyota Highlander (AWD)	2	Completed
2006 Gen II Honda Civic	2	Completed
2007 Saturn Vue	2	Ongoing
2007 Toyota Camry	2	Completed
2008 Nissan Altima	2	Ongoing
2008 GM 2-mode Tahoes	2	Ongoing
2010 Toyota Prius	2	Ongoing
2010 Honda Insight	2	Ongoing
2010 Ford Fusion	2	Ongoing
2010 Mercedes S400	2	Ongoing
Total	47 to date	

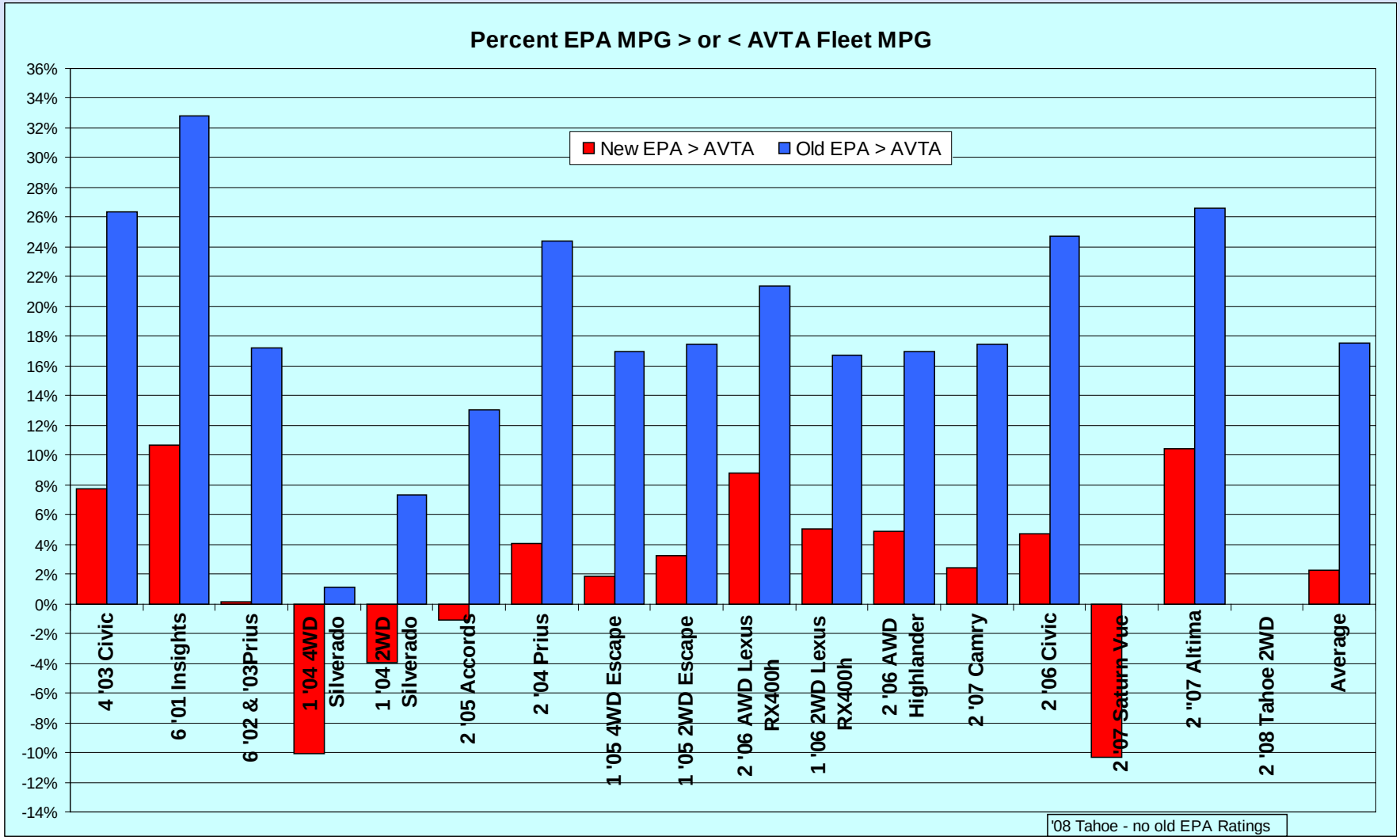
HEVs Dynamometer Testing



160,000-Mile HEV Accelerated Testing - MPG



AVTA HEV Fleet MPG and EPA MPG



HEV Maintenance and Repairs

FREEDOMCAR & VEHICLE TECHNOLOGIES PROGRAM

HEV Fleet Testing

Advanced Vehicle Testing Activities

Maintenance Sheet for 2006 – Highlander

FreedomCAR & Fuel Partnership

VIN # JTEDW21A160006395

Date	Mileage	Description	Cost
12/14/2005	4,855	Changed oil, rotated tires	$31.99
1/5/2006	9,952	Changed oil, rotated tires	$28.04
1/31/2006	15,749	15K service	$187.05
2/22/2006	20,783	Changed oil, rotated tires	$28.07
3/15/2006	26,197	Changed oil, rotated tires	$28.10
4/17/2006	31,578	30K service	$321.80
4/26/2006	36,682	Changed oil, rotated tires	$28.99
5/18/2006	42,113	Changed oil, rotated tires	$28.99
6/9/2006	47,475	15K interval service, 45K preventative maintenance	$200.67
7/5/2006	53,711	Changed oil	$38.44
7/26/2006	59,632	60K service	$346.86
8/21/2006	65,947	Changed oil	$38.31
9/12/2006	71,030	Changed oil, replaced wiper blades	$57.20
9/14/2006	71,053	Check engine light on - Code PA93 Inverter cooling system malfunction inverter coolant low	warranty
9/29/2006	73,015	Replaced windshield	$272.87
10/6/2006	75,949	75K service	$200.67
12/6/2006	90,270	Changed oil	$39.60

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HEV Per Mile Costs and Per Month MPGs

FREEDOMCAR & VEHICLE TECHNOLOGIES PROGRAM

HEV Fleet Testing

Advanced Vehicle Testing Activities

2005 Honda Accord
VIN #
JHMCN36495C000657

Fleet Performance

Description:
This vehicle is operated throughout the valley of Phoenix, Arizona by JP Morgan Chase Bank of Arizona's courier fleet. It is operated six days a week, transferring documents between branches and a central processing center on city streets and urban freeways as well as intrastate courier routes.

Major Operations & Maintenance Events:
Repaired electrical door lock @ 79,722
Cost: $321.17

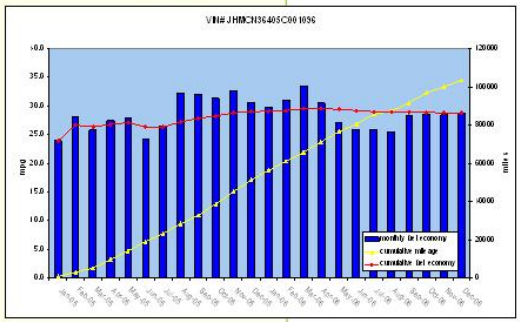
Operating Cost:
Purchase Cost: $32,945 (12/04)*
Kelly Used Vehicle Price: $16,935 (1/07)
Sale Price: In Operation
Maintenance Cost: $0.038/mile
Operating Cost: $0.13/mile
Total Ownership Cost: $0.32/mile

Operating Performance:
Total miles driven: 103,646
Cumulative MPG: 29.5

Vehicle Specifications

Engine: I-VTEC V6
Electric Motor: 11.9 kW
Battery: Nickel metal hydride
Seatbelt Positions: Five
Payload: 952 lbs
Features: Front wheel drive, regenerative braking

See HEVAmerica Baseline Performance Fact Sheet for more information.

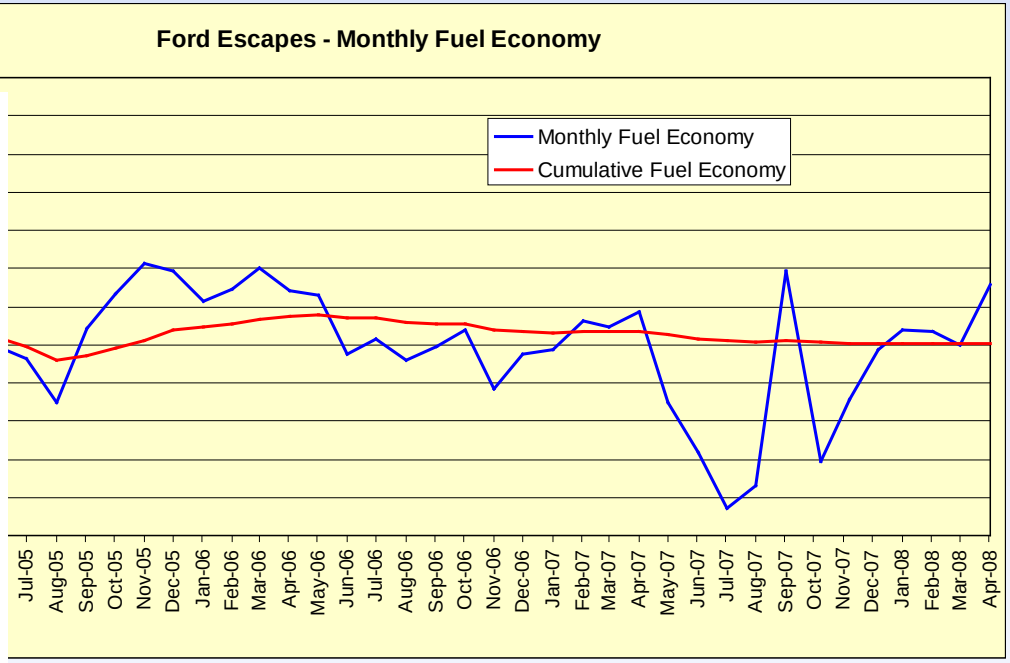


FreedomCAR & Fuel Partnership

A Strong Energy Portfolio for a Strong America
Energy efficiency and clean, renewable energy will mean a stronger economy, a cleaner environment, and greater energy independence for America. Working with a wide array of state, community, industry, and university partners, the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy invests in a diverse portfolio of energy technologies.

For more information contact:
EERE Information Center
1-877-EERE-INF (1-877-337-3463)
www.eere.energy.gov

*Purchase includes dealer price with options plus taxes. It does not include title, license, registration, extended warranty or delivery fee costs. Gas figured at $2.45/gallon.



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PHEV TESTING

12 PHEVs Models in Testing/Demonstrations

Aftermarket PHEV conversions

- Hymotion Prius (A123Systems)
- Hymotion Escape (A123Systems)
- EnergyCS Prius, 2 models (Valence and Altairnano)
- 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)

OEM PHEVs

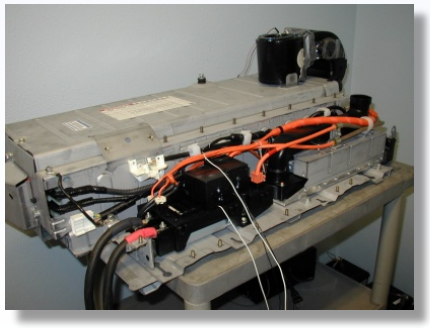
- Renault Kangoo (Saft NiCad)
- Ford E85 Escape prototype (Johnson Controls/Saft)

(All batteries are Li-Ion unless noted)

PHEV Testing Methods

Perform independent testing of PHEVs using:

- **Baseline performance testing:**
  - **closed test tracks and dynamometers**
- **Accelerated testing:**
  - **dedicated drivers operating on defined on-road loops**
- **Fleet testing:**
  - **everyday non-directed fleet and public use, with onboard data loggers**
- **Laboratory testing of PHEV batteries**



PHEV Testing Objectives

Quantify the following:

- **Energy consumption (gasoline and electricity)**
- **Driving and charging patterns**
- **Effect of use on vehicle energy consumption, battery life, and the electrical grid**
- **Infrastructure requirements …**

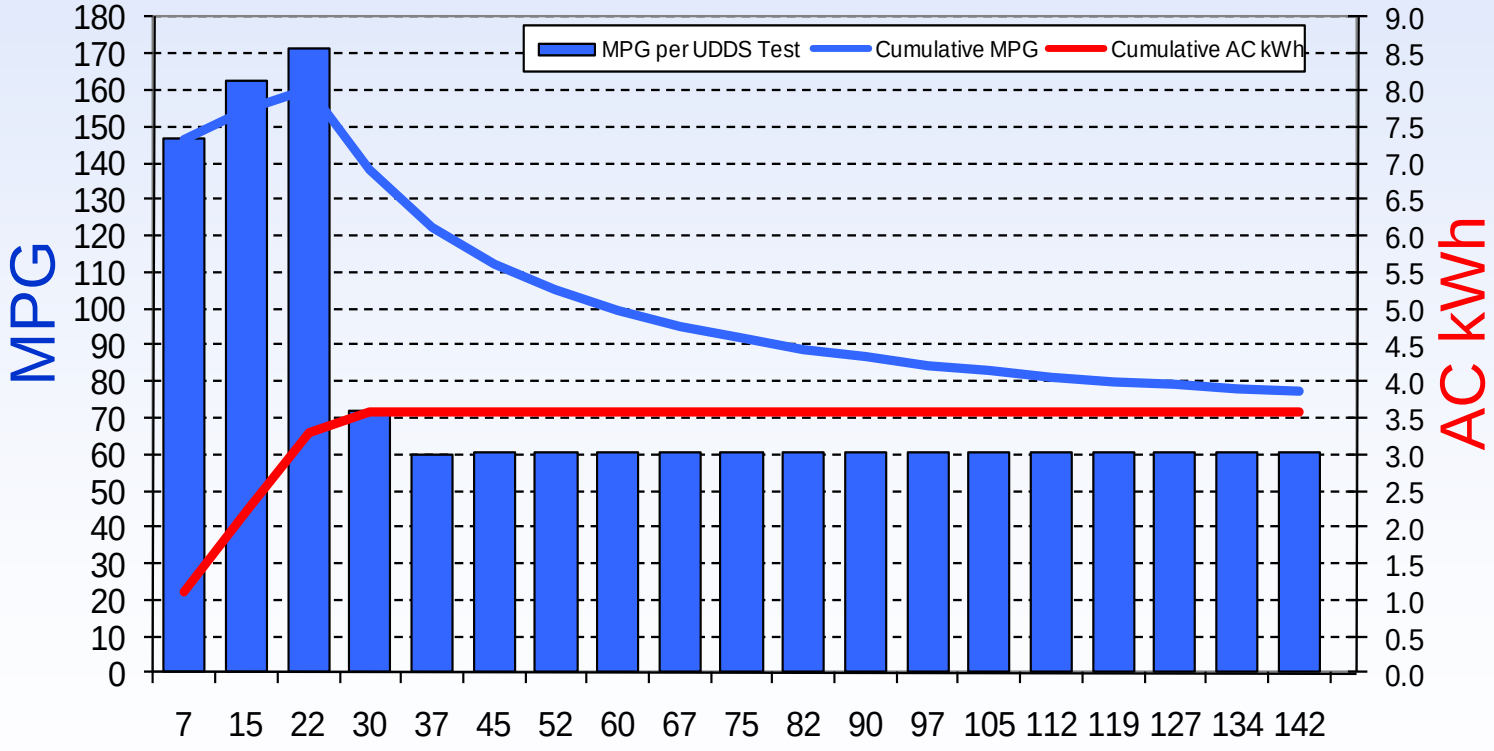
PHEV Testing Objectives

… to answer the following:

- **What are the potential petroleum savings and electricity demands?**
- **Will drivers adapt to plugging in (charging) PHEVs to maximize mpg?**
- **What are the charging infrastructure needs, including 110V versus 220V? Fast charging?**
- **Is vehicle-to-grid (V2G) charging a benefit or liability to the vehicle operator? To automakers and utilities?**
- **Are PHEVs technically and economically feasible as a transportation option?**

Dynamometer Testing - City

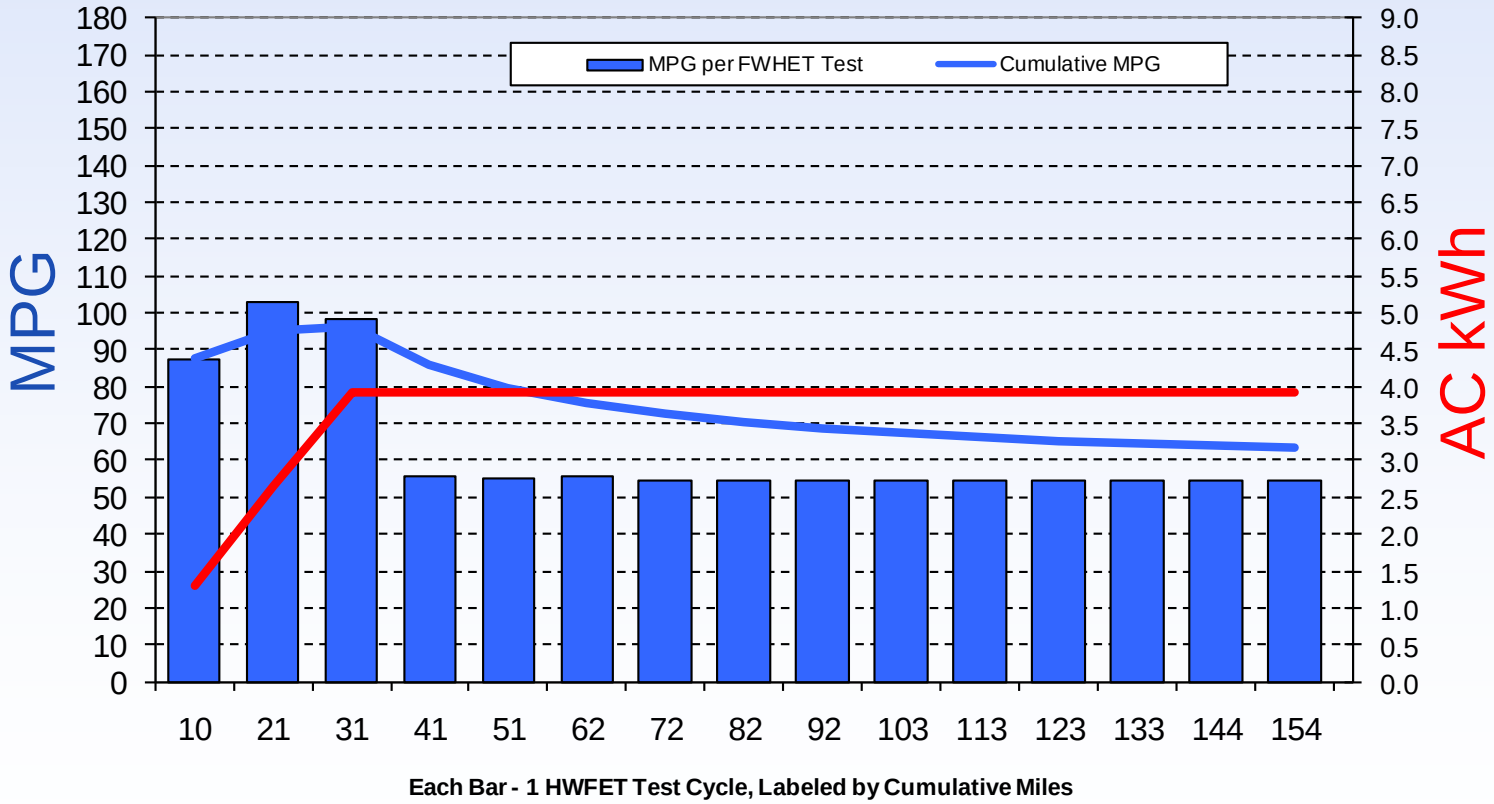
- **Hymotion Prius Gen I**
- **5 kWh supplemental A123Systems (Li-ion) battery pack**
- **Urban Dynamometer Driving Schedule (UDDS)**



Each Bar - 1 UDDS Test Cycle, Labeled by Cumulative Miles

Dynamometer Testing - Highway

- Hymotion Prius Gen I
- 5 kWh supplemental A123Systems (Li-ion) battery pack
- Highway Fuel Economy Driving Schedule (HWFEDS)



PHEV On-road 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	136.3	4.81	127.2
20	1	1	8	30	600	122.0	5.37	115.9
40	4	0	12	15	600	84.1	6.05	101.1
40	2	2	12	15	600	87.2	5.78	106.9
40	0	4	12	15	600	79.8	8.54	73.1
60	2	4	12	10	600	55.3	8.98	68.9
80	2	6	12	8	640	43.9	11.36	58.3
100	2	8	12	6	600	35.9	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

EnergyCS Prius (Valence) – 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	115.5	4.78	128.1
20	1	1	8	30	600	86.2	7.95	77.9
40	4	0	12	15	600	25.0	14.29	42.7
40	2	2	12	5	600	31.5	11.05	56.1
40	0	4	12	5	600	32.4	11.36	55.5
60	2	4	12	10	600	65.0	5.90	103.7
80	2	6	12	8	640	39.0	10.09	65.8
100	2	8	12	6	600	22.6	8.81	70.8
200	2	18	12	3	600	12.9	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

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	198.9	11.52	53.1
20	1	1	8	30	600	163.3	13.51	45.7
40	4	0	12	15	600	57.5	14.91	41.1
40	2	2	12	15	600	76.3	15.99	38.7
40	0	4	12	15	600	114.1	11.92	51.5
60	2	4	12	10	600	97.2	13.70	45.3
80	2	6	12	8	640	77.7	16.05	41.3
100	2	8	12	6	600	58.6	15.69	39.8
200	2	18	12	3	600	26.1	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

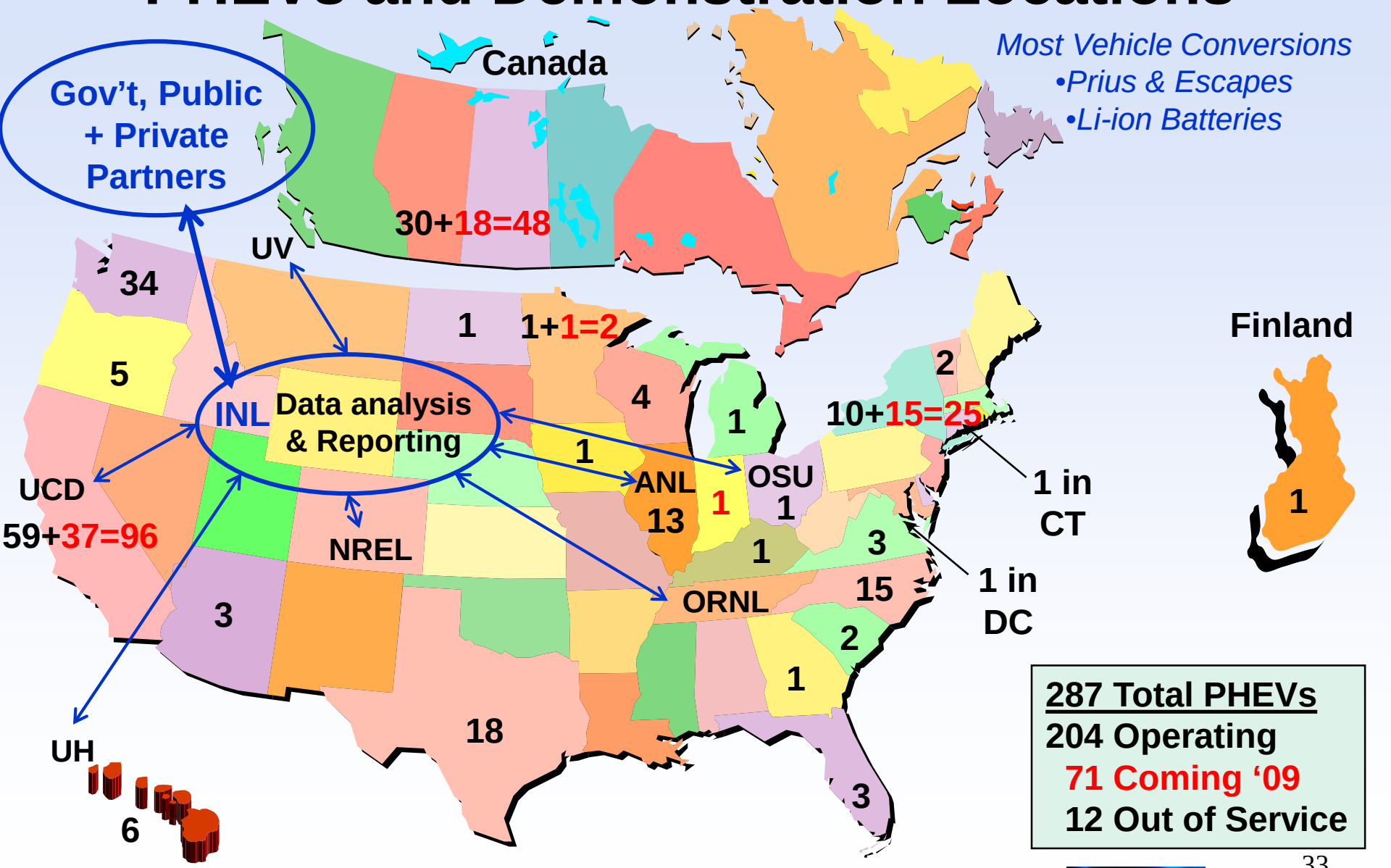
Cycle	Urban	Highway	Charge	Reps	Total	Electricity	Gasoline	
(mi)	(10 mi)	(10 mi)	(hr)	(N)	(mi)	AC kWh	Gals	MPG
10	1	0	4	60	600	135.2	9.55	65.1
20	1	1	8	30	600	101.1	17.54	34.7
40	4	0	12	15	600	71.3	16.42	37.3
40	2	2	12	15	600	69.8	14.34	43.1
40	0	4	12	15	600	55.8	20.73	29.8
60	2	4	12	10	600	44.8	16.64	37.3
80	2	6	12	8	640	42.7	16.30	40.8
100	2	8	12	6	600	20.9	21.17	29.2
200	2	18	12	3	600	13.3	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

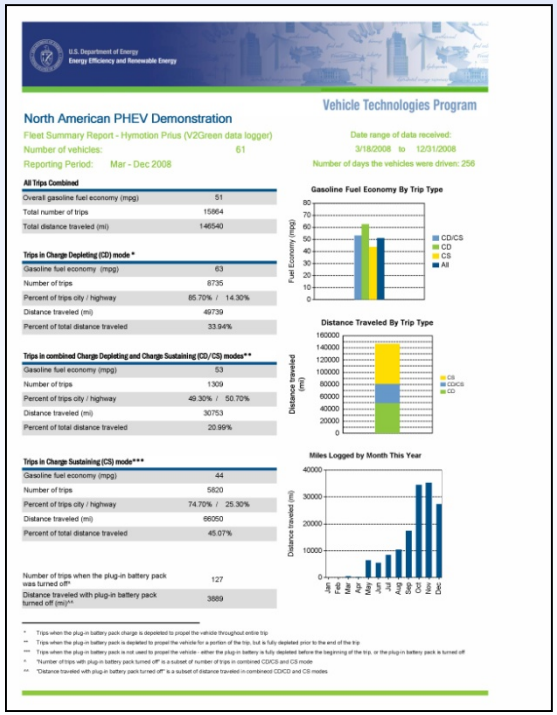
- 75+ testing partners in the U.S. and Canada:
  - 36 Electric utilities and 2 clean-air agencies
  - 10 City, county and state governments
  - 7 Private companies and advocacy organizations
  - 8 Universities and colleges and 4 Canadian provinces
  - 2 PHEV companies 1 sea port and 1 DOD facility
-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

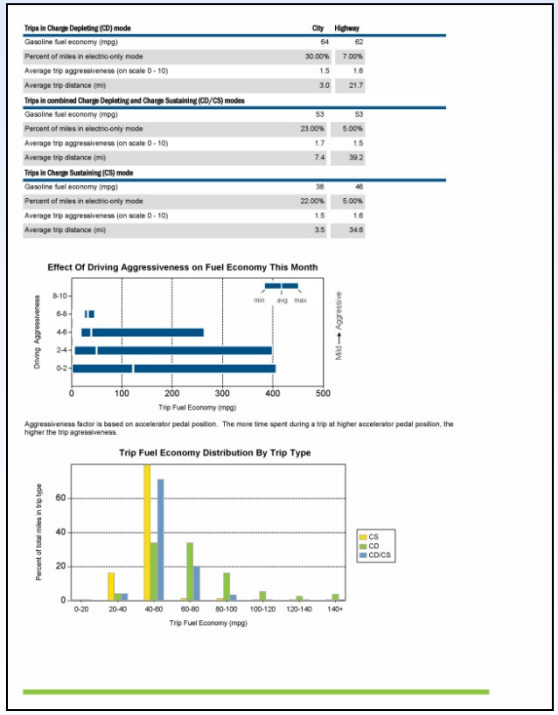
PHEVs and Demonstration Locations

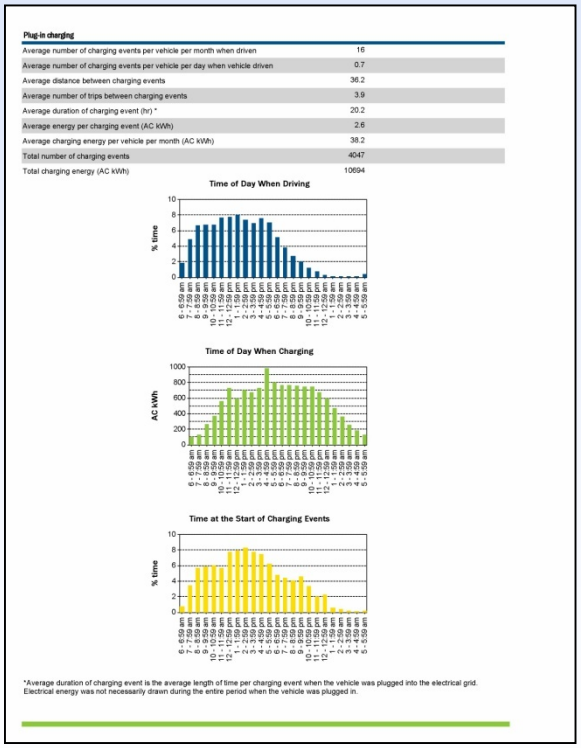


Hymotion Prius PHEV Fleet Testing Reports

- **Summary reports posted monthly on web**
- **Individual vehicle reports only go to the respective fleets each month**



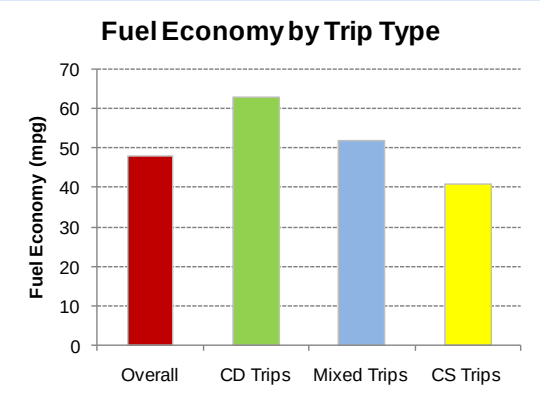


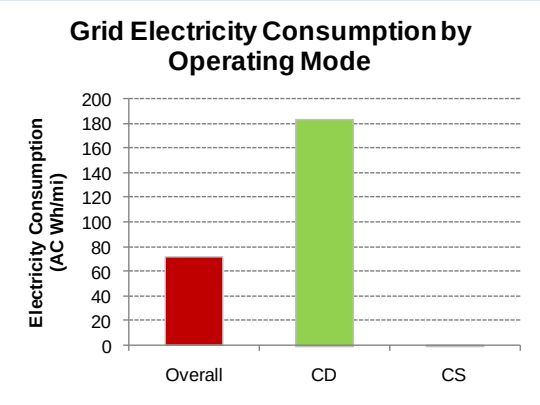


Hymotion Prius – 2008

Energy Consumption and CD Range

	Gasoline Fuel Economy (mi/gal)	Electrical Energy Consumption (AC Wh/mi)
Overall	48	72
CD Trips	63	183*
Mixed Trips	52	
CS Trips	41	0





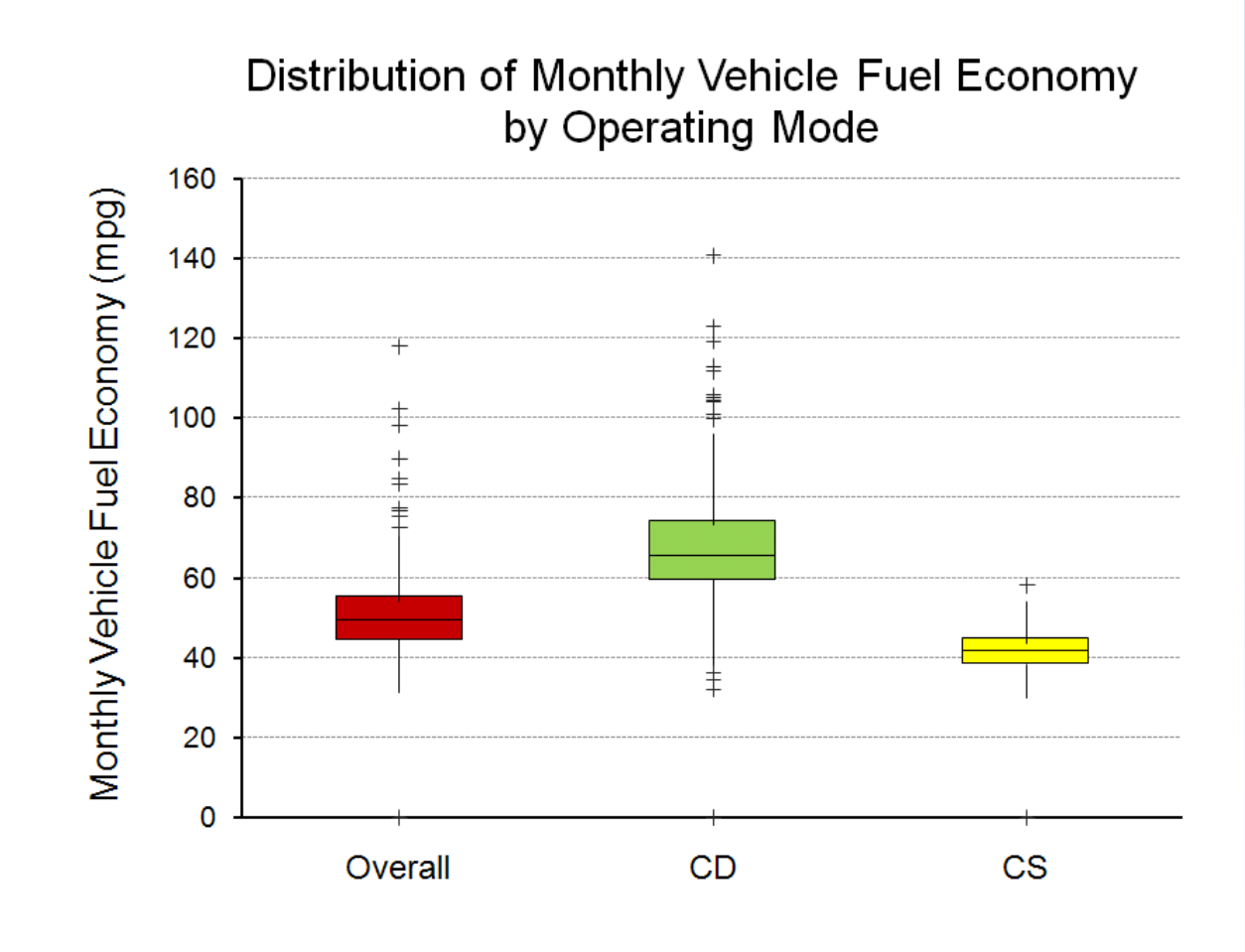
* Includes miles from CD trips and CD portion of mixed trips

Average Charge Depleting Range (mi)	31.6

Definition of Trip Types

- CD Trip = trip that begins and ends in charge depleting mode
- Mixed Trip = trip that begins in charge depleting mode and ends in charge sustaining mode
- CD Trip = trip that begins and ends in charge sustaining mode

Hymotion Prius – 2008



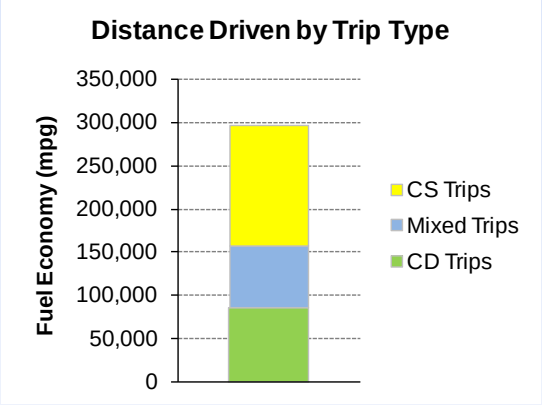
Monthly fuel economy shown for all vehicle months in 2008 when a vehicle drove > 300 mi

Hymotion Prius – 2008

Distance Driven Relative to Charging

Trip Type	Trips	Distance (mi)	Percent of Total Distance
CD	17,913	85,225	29%
Mixed	2,894	72,737	24%
CS	12,007	138,642	47%

Average number of charging events per vehicle per month when driven	17.8
Average number of charging events per vehicle per day when driven	1.1
Average distance between charging events	39.0
Average number of trips between charging events	4.3



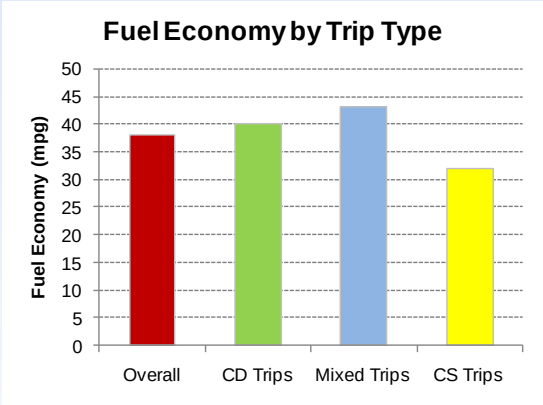
Hybrids Plus Escape – 2008

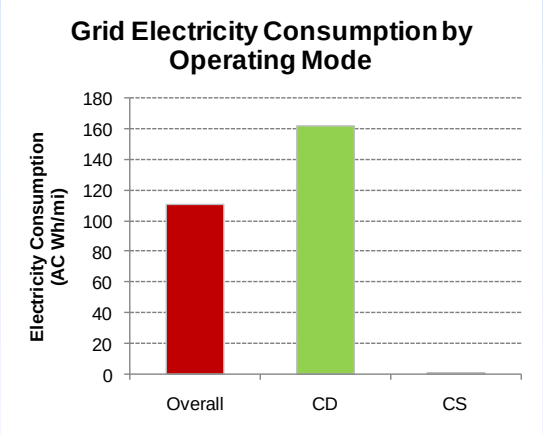
Energy Consumption and CD Range

	Gasoline Fuel Economy (mi/gal)	Electrical Energy Consumption (AC Wh/mi)
Overall	38	111
CD Trips	40	162*
Mixed Trips	43	
CS Trips	32	0

* Includes miles from CD trips and CD portion of mixed trips

Average Charge Depleting Range (mi)	63.8



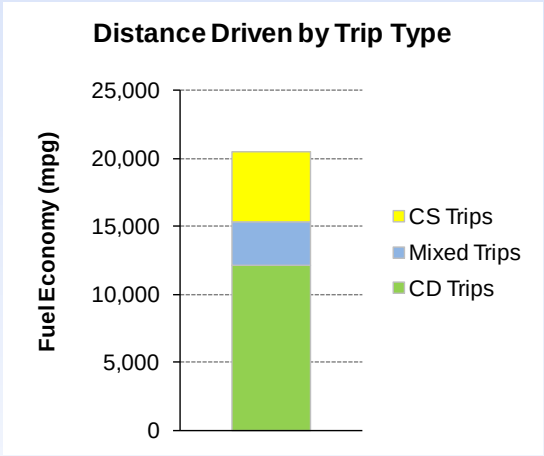


Hybrids Plus Escape – 2008

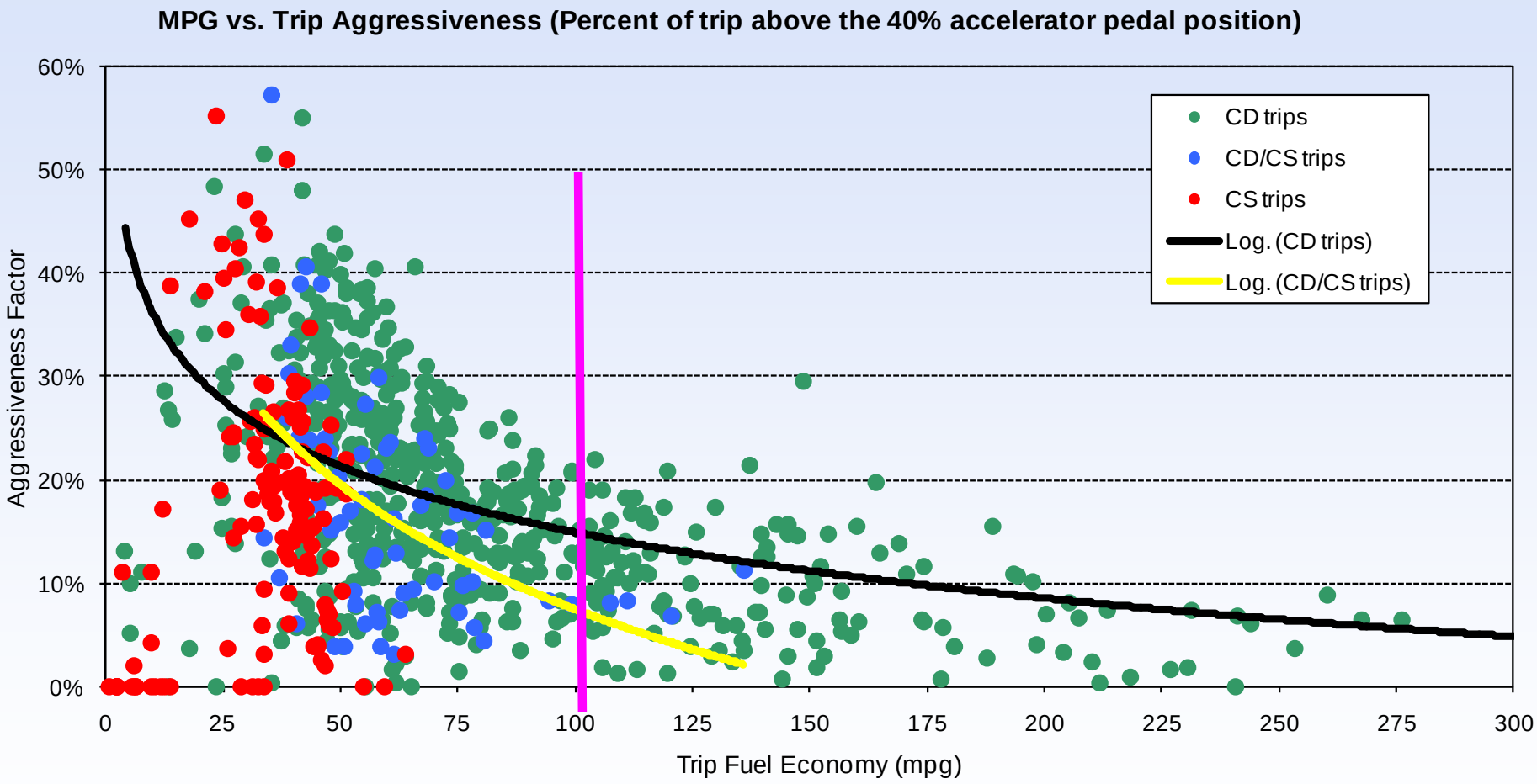
Distance Driven Relative to Charging

Trip Type	Trips	Distance (mi)	Percent of Total Distance
CD	2,104	12,130	59%
Mixed	57	3,164	15%
CS	576	5,180	25%

Average number of charging events per vehicle per month when driven	30.7
Average number of charging events per vehicle per day when driven	2.0
Average distance between charging events	29.3
Average number of trips between charging events	3.9

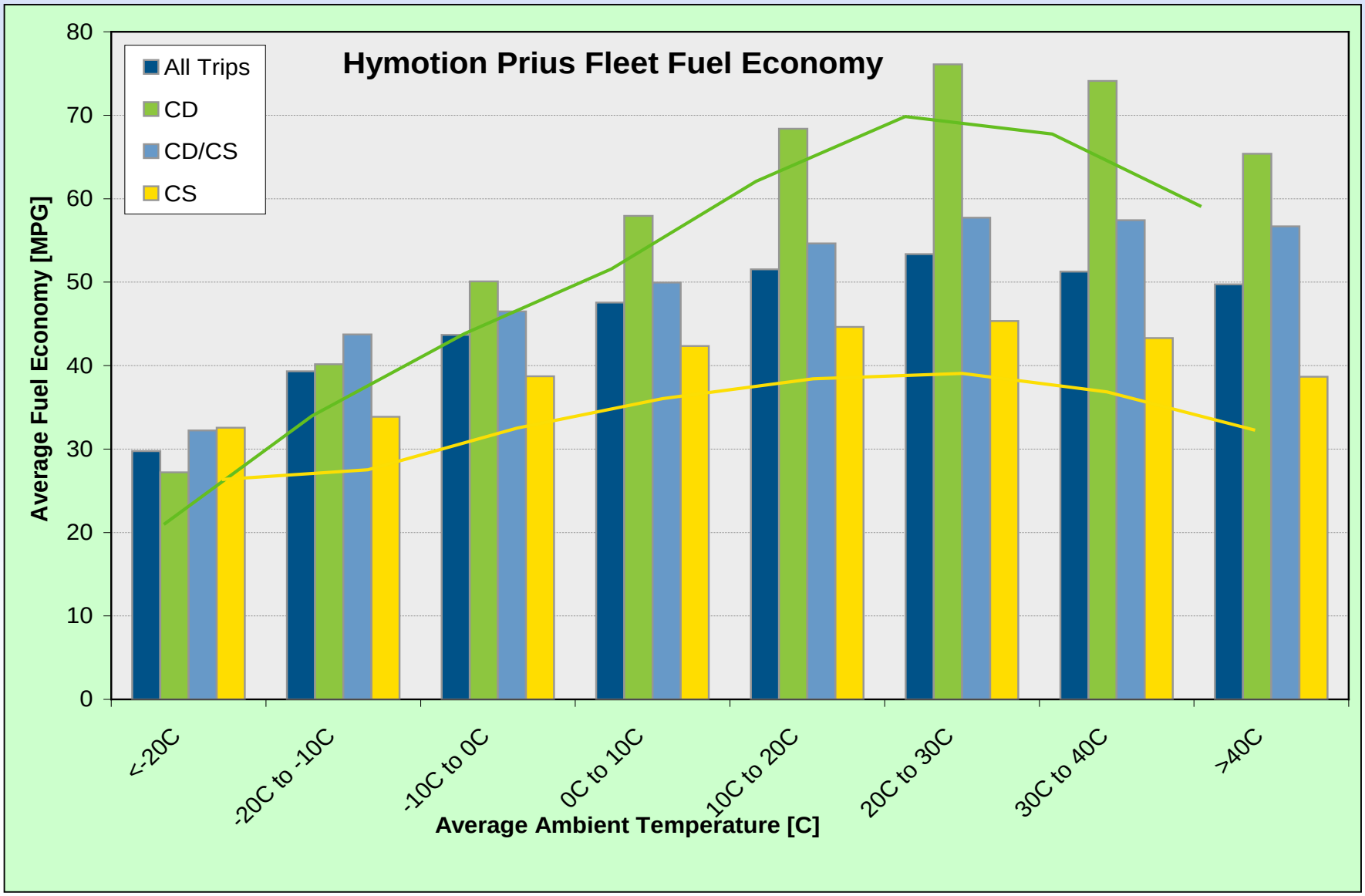


Effect of Aggressive Driving on MPG



From 13 Hymotion Priuses, 775 trips, 6,291 miles, May 2008

Effect of Ambient Temperature on MPG



BIG PICTURE CONSIDERATIONS FOR PHEVS

PHEV Advantages

- **Reduced petroleum consumption and emissions**
  - **Displace combustible fuel with electricity**
  - **Recover energy during regenerative braking and other benefits of HEV technology**
- **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 (all-electric capable vehicles in CD mode)**
- **Lower fuel costs compared to HEVs**
- **Potential for off-peak charging**
- **Potential for V2G charging (this is a 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-fuel 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

PHEV Purchase Considerations

- **Has the vehicle emissions been certified by CARB, the EPA, or received an exemption?**
- **Has the vehicle been crashed tested and FMVSS certified per NHTSA requirements?**
  - **Conversions need crash testing – Don't believe "its just another piece of luggage in the trunk"**
- **Has the manufacturer or vehicle converter made the vehicle available to DOE's AVTA or other third party evaluator for testing?**
- **Current PHEVs have the potential to provide greater than 100 mpg – but may need "better" PHEV drivers**
- **Future PHEVs may be more robust to driving style and environment, but will always need to be charged**
- **Match mission to PHEV capabilities. Consider:**
  - **distance between charging opportunities**
  - **vehicle's ambient operating temperature**
  - **trip distance (avoid very short trips in blended PHEVs)**

POSSIBLE FUTURE VEHICLES

Announced PHEV Introductions*

- Chevrolet Volt Extended Range Electric Vehicle (EREV)
- Ford Escape PHEV
- Chrysler Town & Country PHEV/EREV
- Buick (formerly Saturn Vue) PHEV
- Toyota Prius PHEV
- Fisker Karma S PHEV/EREV
- Kia Forte LPG PHEV
- Hyundai PHEV
- BYD F3DM PHEV
- AFS Trinity SUV PHEV
- Raser/FEV SUV PHEV/EREV

* It's not in production until it's in production! Presenter makes no accuracy claim for the above information. 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*

- BMW Mini E BEV
- Nissan Leaf BEV
- Mitsubishi / Peugeot iMiEV BEV
- Subaru Stella and R1e BEVs
- ZENN city BEV
- Tesla / Daimler Smart Fortwo BEV
- Renault Kangoo BEV and others
- Ford Transit Connect and Focus BEVs
- Tesla Model S BEV
- BYD e6 BEV
- Toyota sedan BEV
- Volkswagen and Toshiba BEV
- …

*** Presenter makes no accuracy claim for the above information. Some info based on media reports**

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

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/MIS-09-17280

BACKUP SLIDES

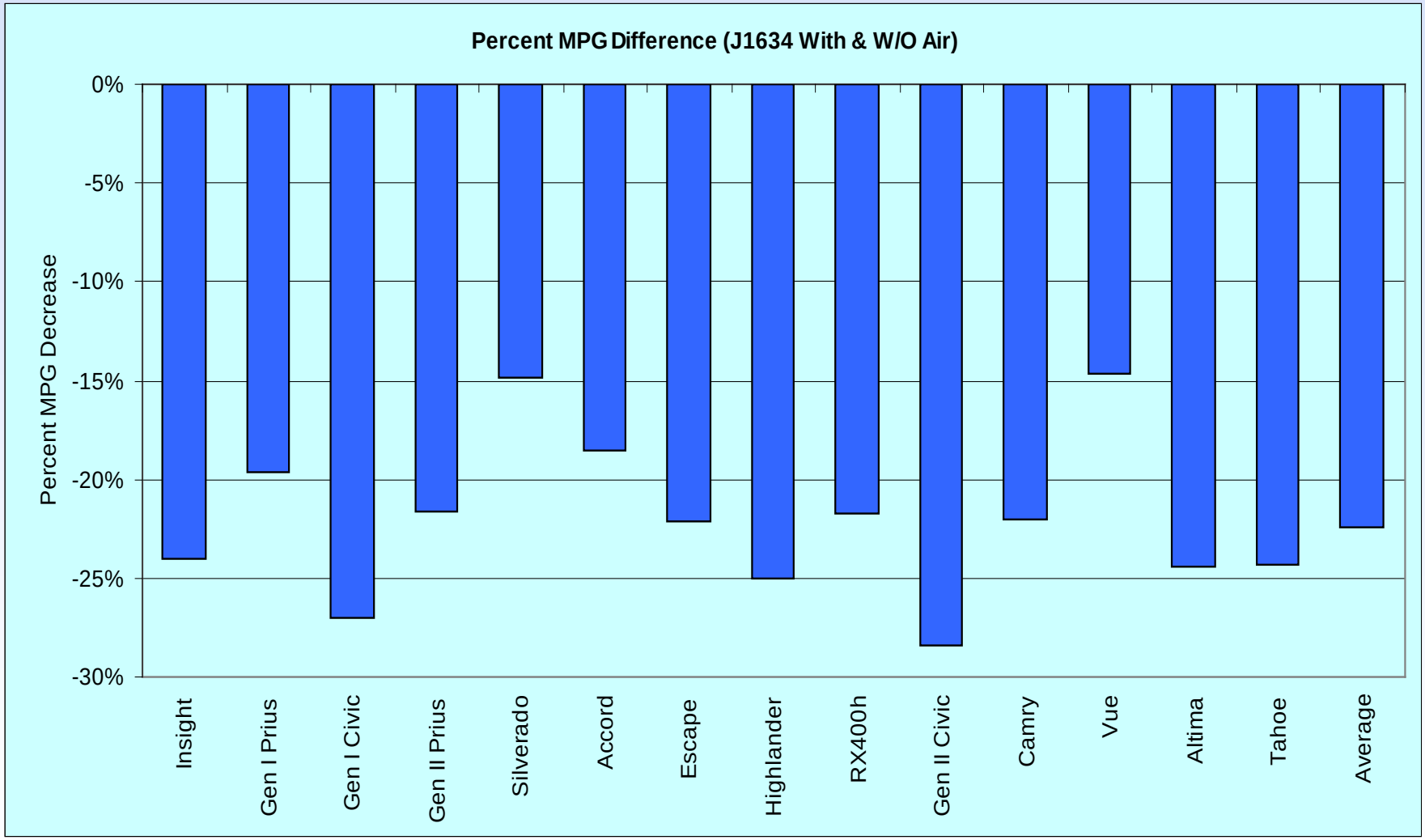
Survey of Major Vehicle Technologies

- Internal Combustion
  - Gasoline
  - Diesel
  - Biodiesel
  - "Flex Fuel" gas + ethanol or methanol
  - Natural Gas
  - Hydrogen

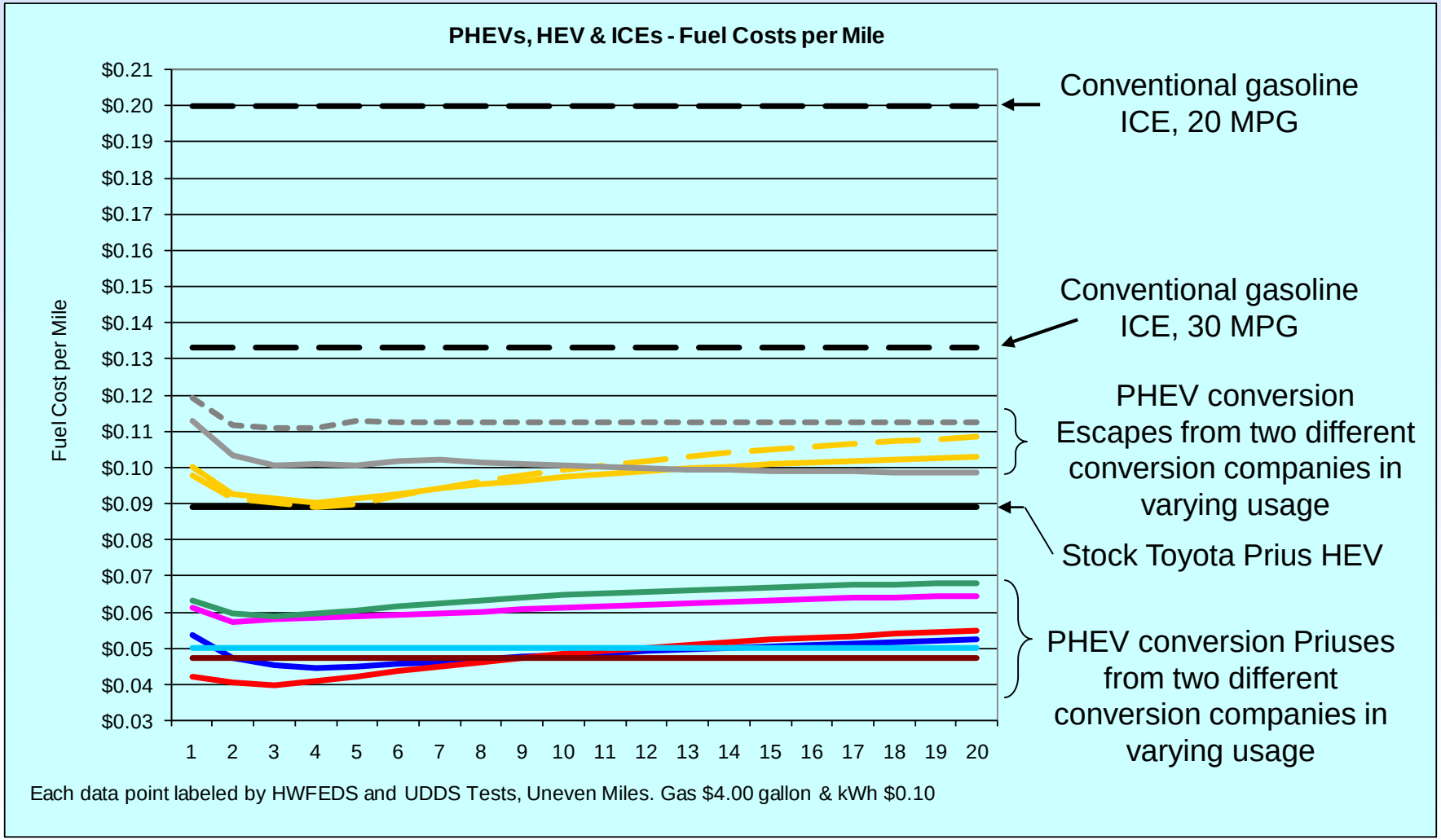
- Electric Drive
  - Small "neighborhood" or "urban" battery electric vehicles (NEV or UEV)
  - Hybrid electric vehicle (HEV)
  - Plug-in hybrid electric vehicle (PHEV) or Extended range electric vehicle (EREV)
  - Full size battery electric vehicle (BEV)
  - Fuel Cell Vehicle (FCV)

Black = currently on market
Blue = entering market as aftermarket conversions
Red = under development, limited number of vehicles in market

HEV Dynamometer A/C MPG % Decrease



Comparing Fuel Cost



Hymotion Prius – Fuel Costs