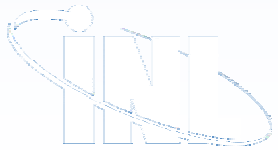
# U.S. Department of Energy, Vehicle Technologies Program, Advanced Vehicle Testing Activity (AVTA)

## Plug-in Hybrid Electric Vehicles (PHEVs) Overview

**Jim Francfort**
**AVTA Principle Investigator**
**Clean Cities Coalition Webcast**
**April 2009**

Idaho National Laboratory



# 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 for DOE. Argonne National Laboratory performs dynamometer testing for the AVTA**

- **The AVTA goals:**
  - **Provide benchmark data to DOE, technology modelers, research and development programs, vehicle manufacturers (via VSATT), and target and goal setters**
  - **Assist fleet managers in making informed early adaptor vehicle purchase, deployment and operating decisions**

# AVTA Testing History

- **Plug-in hybrid electric vehicles (PHEV)**
  - **12 models, ~150 vehicles, 400,000 fleet test miles**
- **Hybrid electric vehicles (HEV)**
  - **14 models, 39 vehicles, 4.5 million test miles**
- **Hydrogen ICE (internal combustion engine) vehicles**
  - **7 models, 400,000 test miles**
- **Full-size battery electric vehicles (BEVs)**
  - **40 EV models, 5+ million test miles**
- **Neighborhood electric vehicles**
  - **21 models, 200,000 test miles**
- **Urban electric vehicles**
  - **3 models, 1 million test miles**



# PHEV 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**

# 12 PHEVs Models in AVTA Testing / Demos

- **~400 Hymotion Prius (A123Systems) – only PHEV conversion crash tested and limited CARB exemption**
- **~2 Hymotion Escape (A123Systems)**
- **5 - 10 Ford E85 Escape (Johnson Controls/Saft)**
- **~35 EnergyCS Prius, 2 models (Valance and Altair Nano)**
- **~0 Electrovaya Escape (Electrovaya)**
- **~35 Hybrids Plus Escape, 2 models (Hybrids Plus and K2 Energy Solutions)**
- **~15 Hybrids Plus Prius (Hybrids Plus)**
- **~50 Manzanita types of Prius (lead acid)**
- **Couple Manzanita Prius (Thunder Sky)**
- **~0 Renault Kangoo (Saft NiCad)**
- **(All batteries are Lithium unless noted)**
- **(Numbers are believed deployment units)**

# PHEV Testing Methods and Reasons

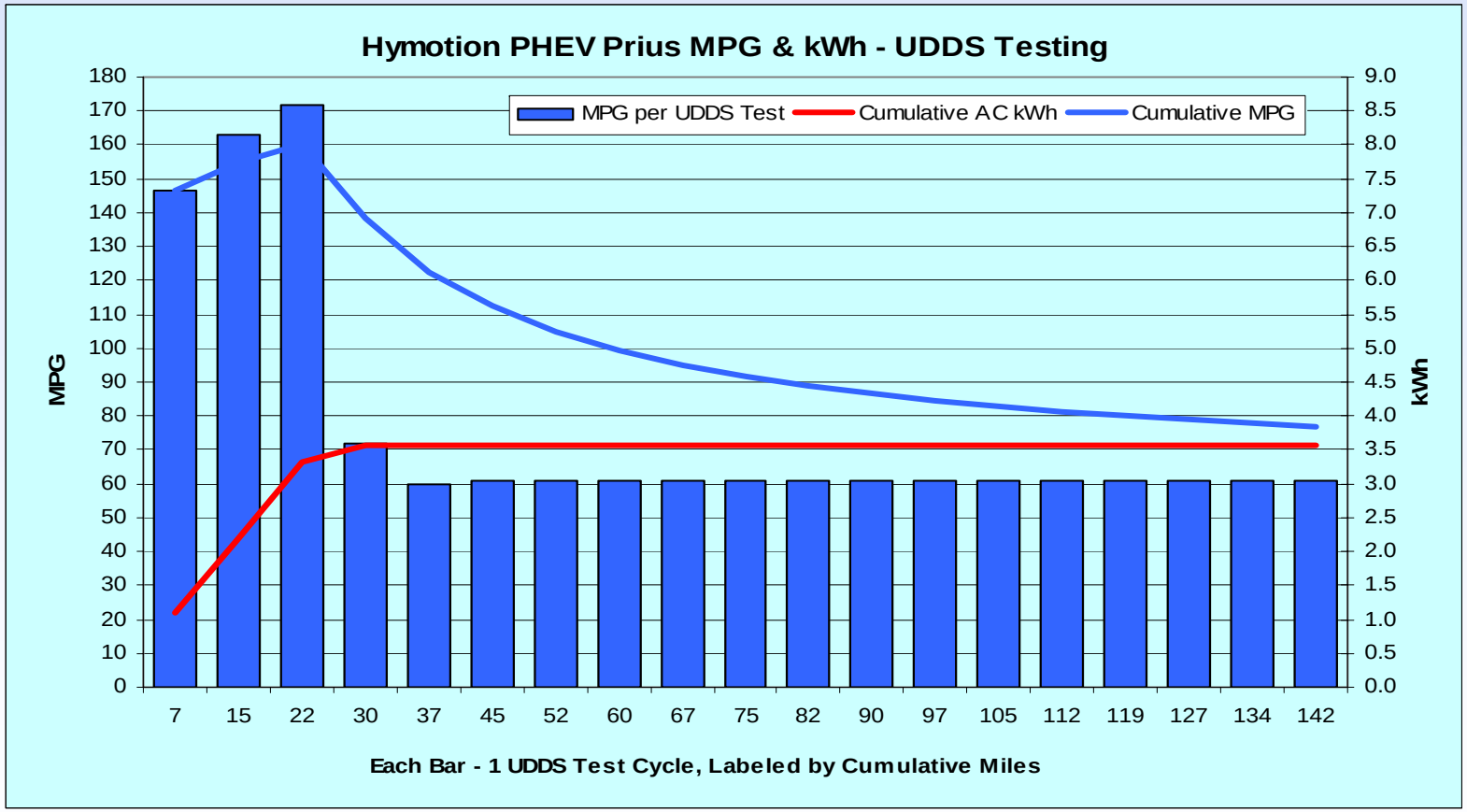
- Perform independent testing of PHEVs, using:
  - Baseline performance testing: closed test tracks and dynamometers
  - Accelerated testing: dedicated drivers operating on defined onroad loops
  - Fleet testing: everyday unstructured \ non-directed fleet and public use, with onboard data loggers
  - 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 Battery and Operating Modes

- **Today's PHEVs either have a single battery pack, or a HEV battery and a PHEV pony battery pack**
- **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 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 battery is fully depleted before the trip ends**
- **Electric propulsion is either in the form of all-electric or electric-assist (ICE is also providing propulsion power)**

# Hymotion Prius Gen I – UDDS Fuel Use

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



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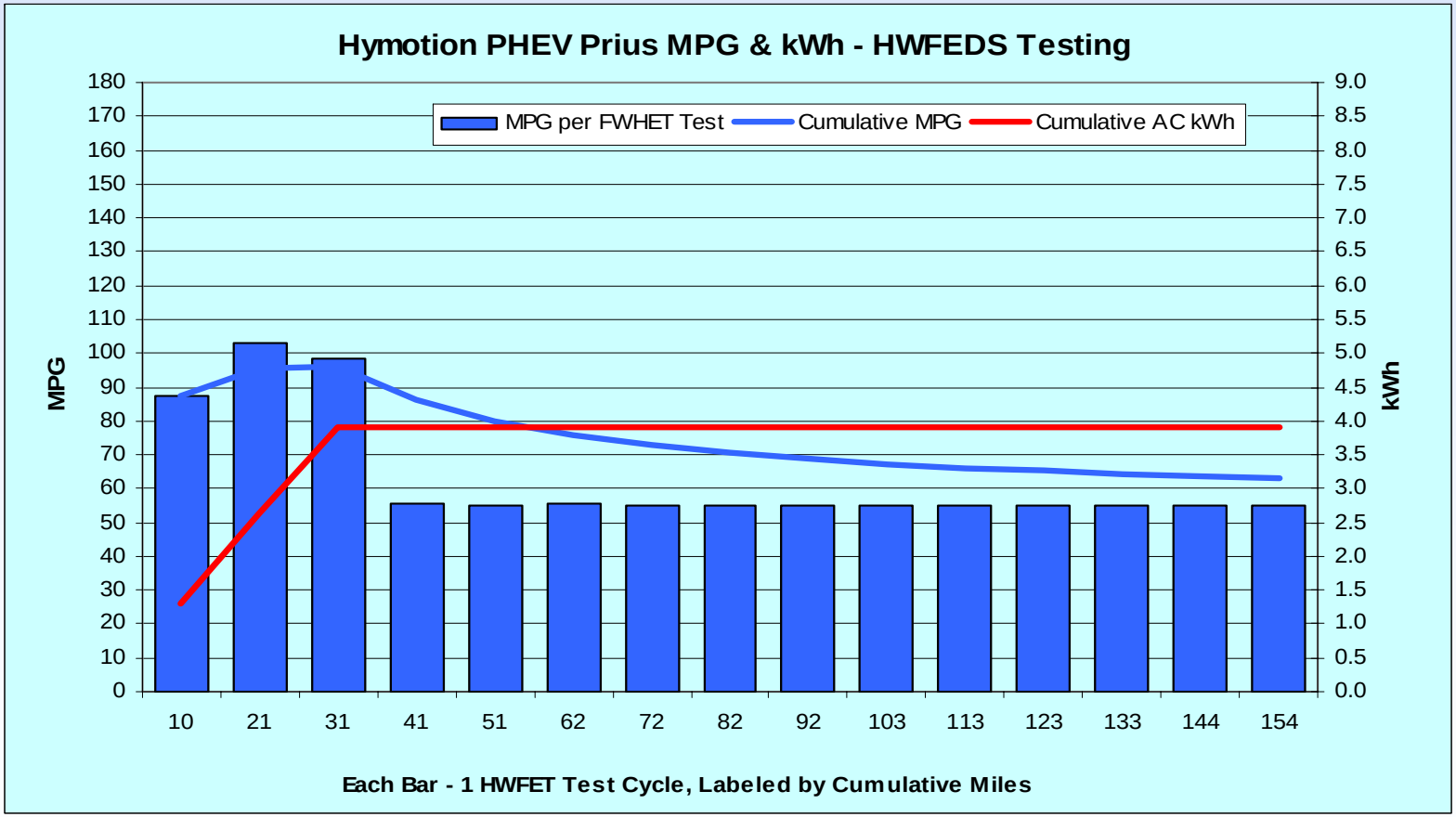


# Hymotion Prius Gen I – Accelerated Testing

| 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**

# Why Does PHEV MPG Vary So Much?

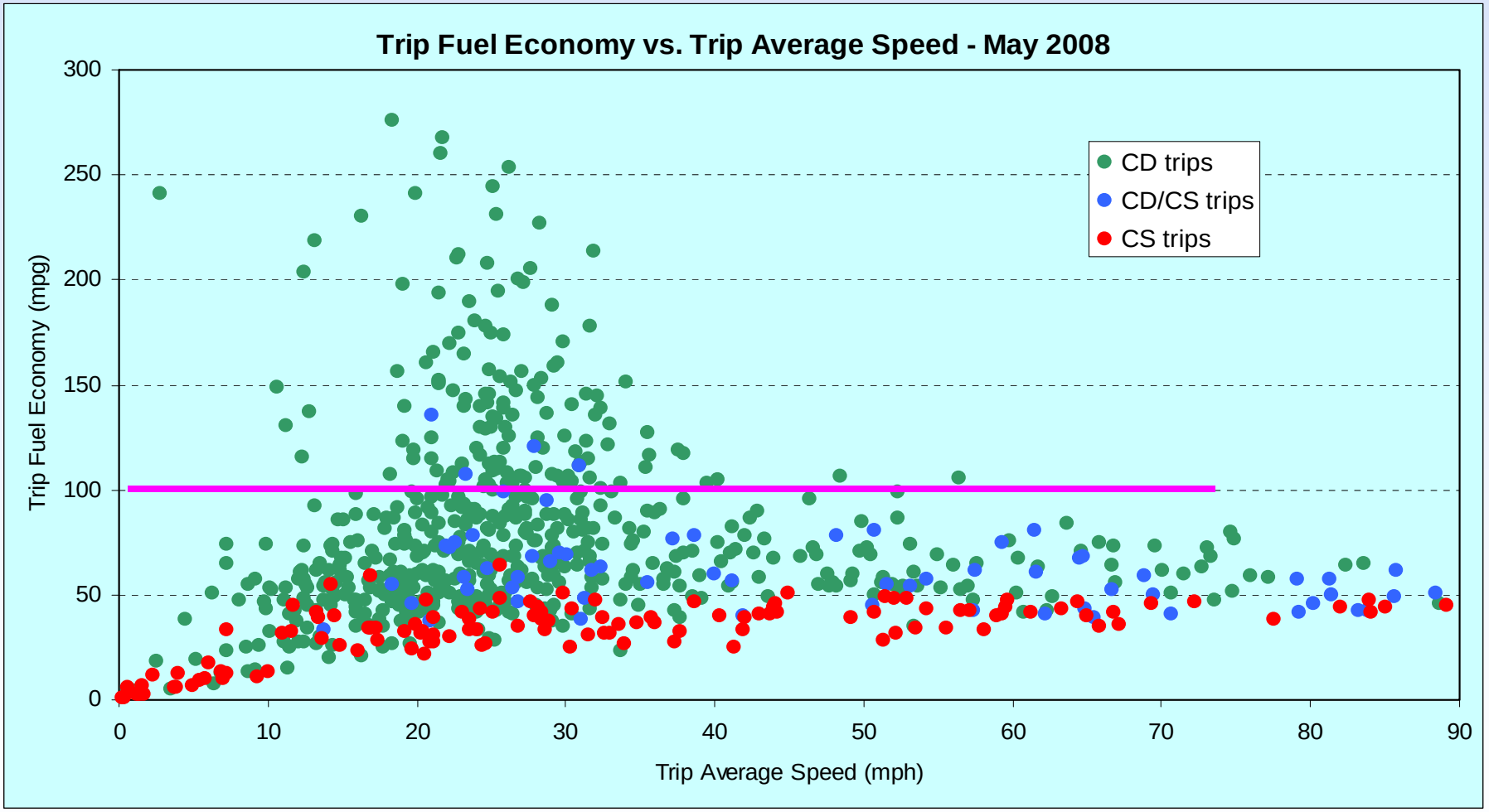
- **26 Hymotion Prius - January thru May 2008**

| Charge / Operating Mode | # Trips | Distance (Miles) | MPG |
|---|---|---|---|
| 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 - May 2008**

| Charge / Operating Mode | # Trips | Distance (mi.) | Average (mi.) | MPG | DC kWh\mi. |
|---|---|---|---|---|---|
| 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 | 775 | 6,291 | 8.1 | 55.9 | |

# Why Does PHEV MPG Vary So Much?




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

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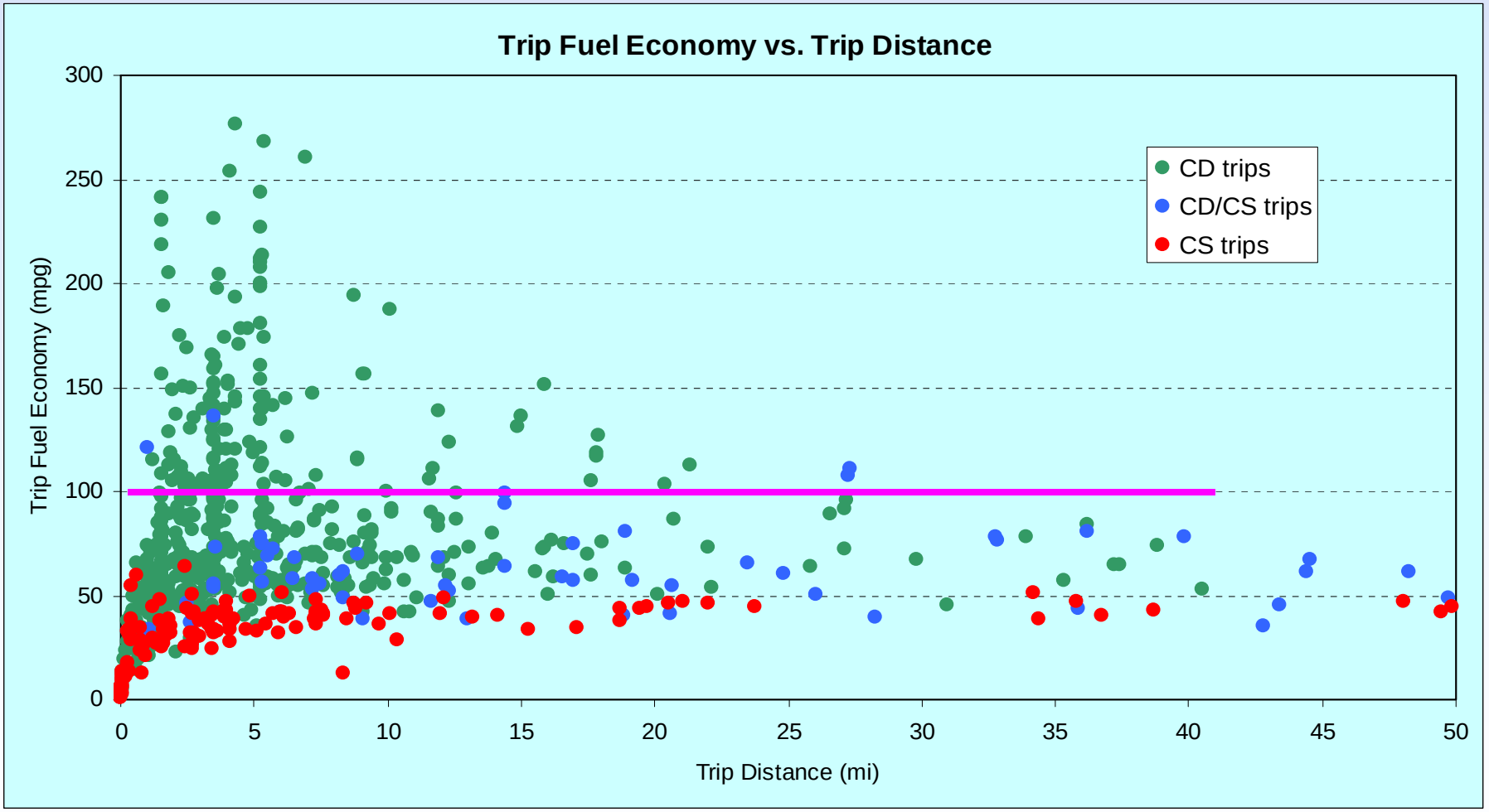
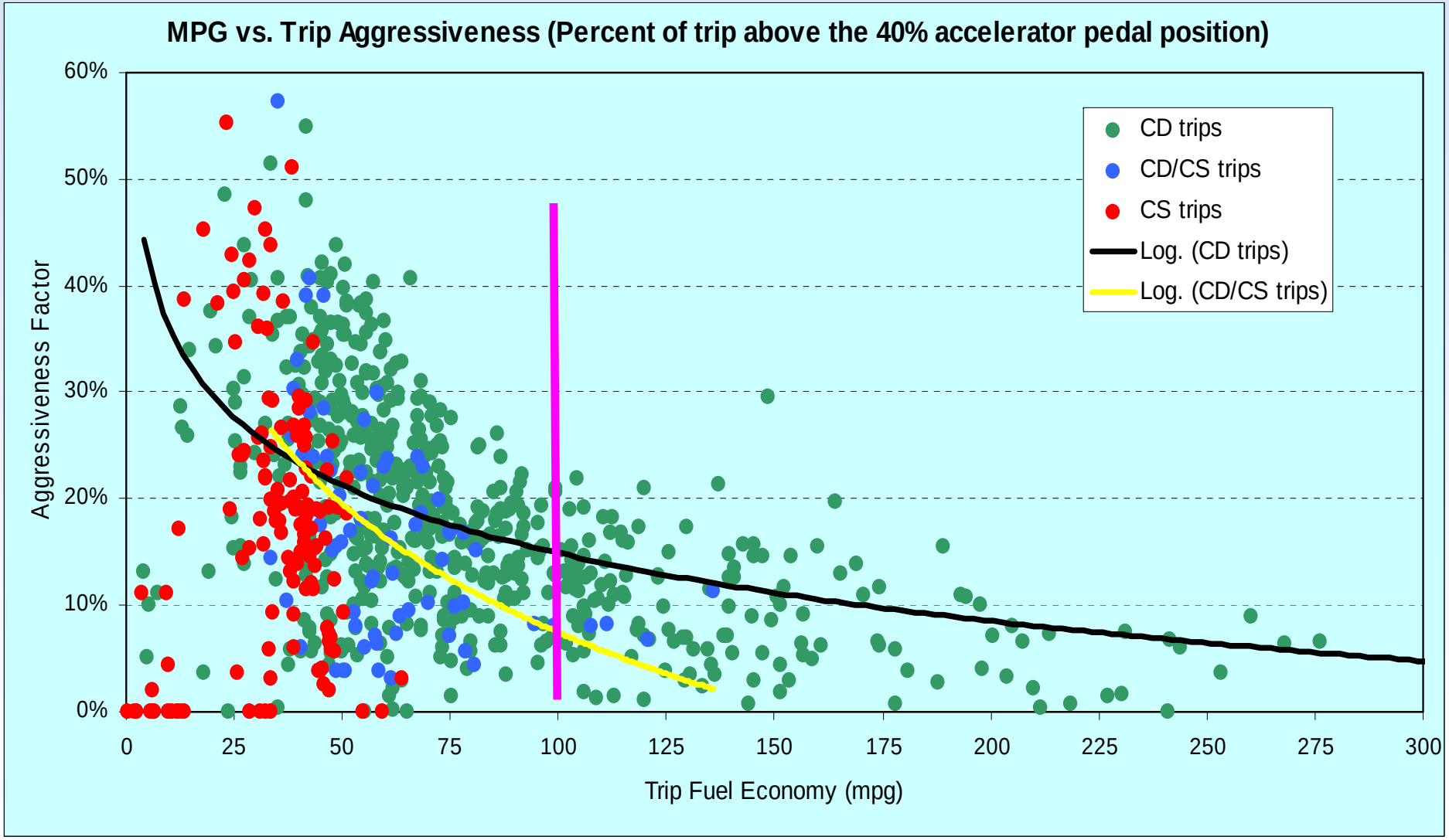



**13 Hymotion Prius, 775 trips, 6,291 miles, May 2008**

# PHEV MPG and Aggressive Driving

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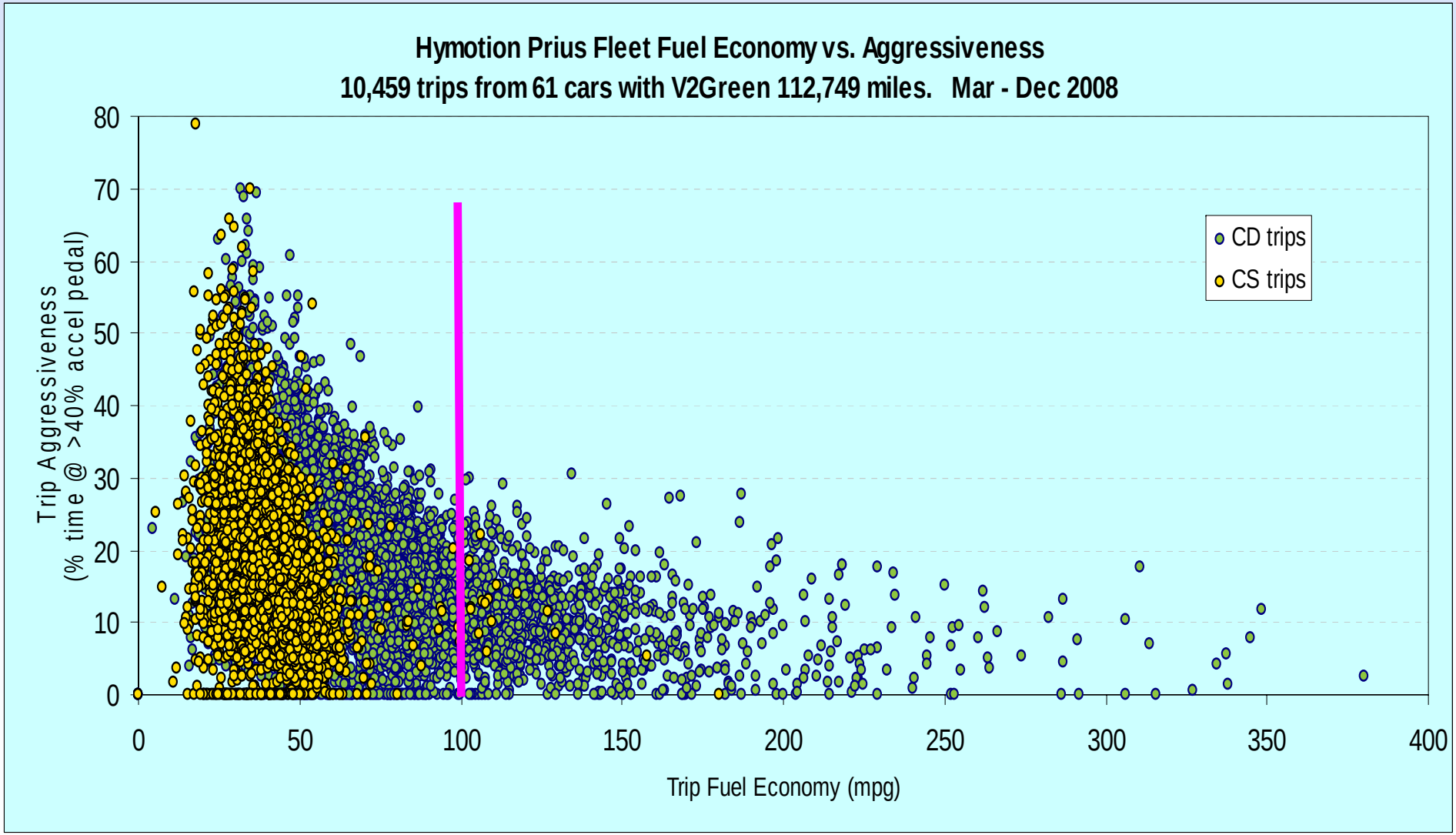
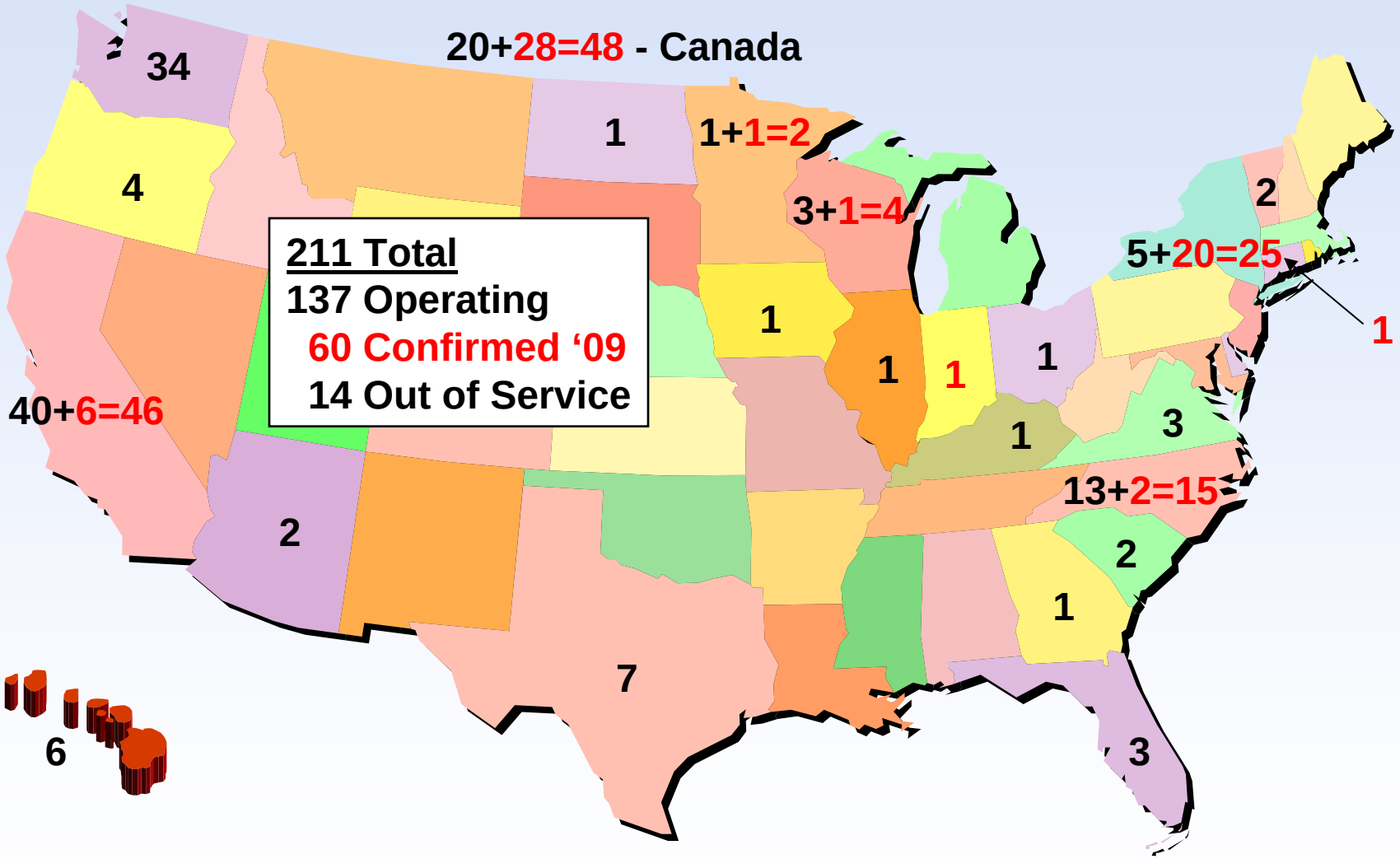


# PHEV Fleet Testing Partners

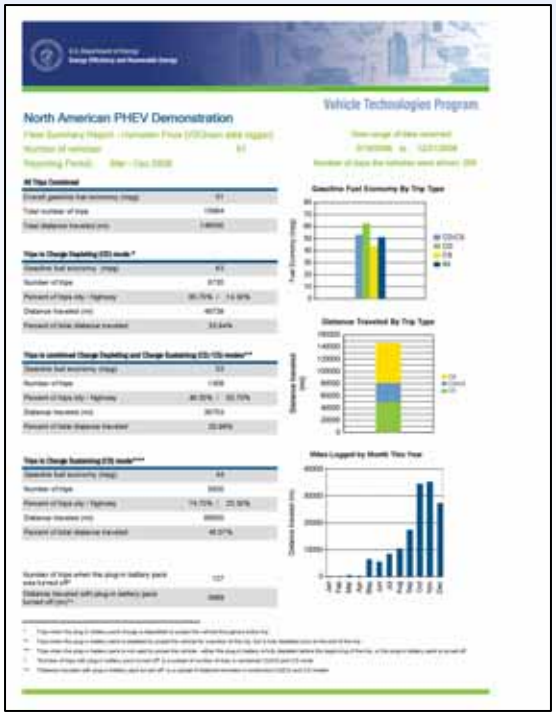
- 75+ testing partners in the U.S. and Canada:
  - 36 Electric utilities and 2 clean-air agencies
  - 10 City, county and state governments
  - 7 Private companies and advocacy organizations
  - 8 Universities and colleges and 4 Canadian provinces
  - 2 PHEV conversion companies 1 sea port and 1 DOD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

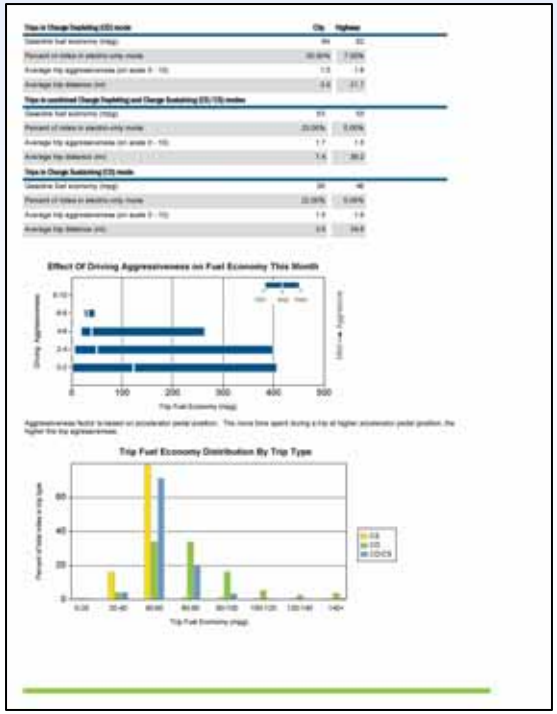
# PHEV Fleet Testing

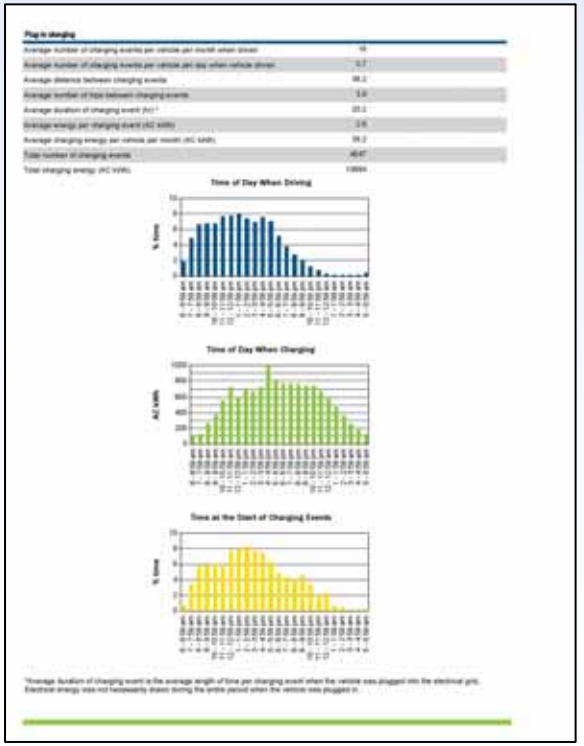


# PHEV Fleet Testing Reports

- **Summary reports posted monthly on web**
- **Individual vehicle reports only go to the respective fleets each month, 570+ reports to date**
- **104 Hymotion Prius PHEVs, 297,669 miles, 33,014 trips, 7,627 charging events, 18,031 kWh used. V2Green and Kvaser data logger reports**

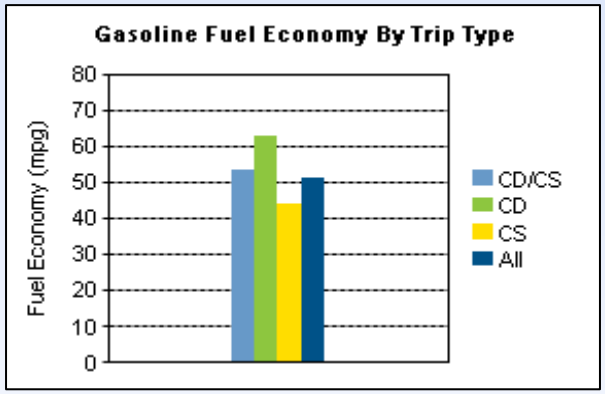


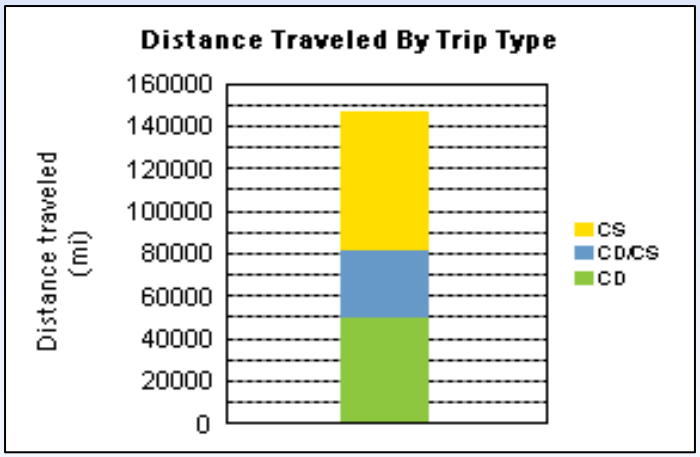



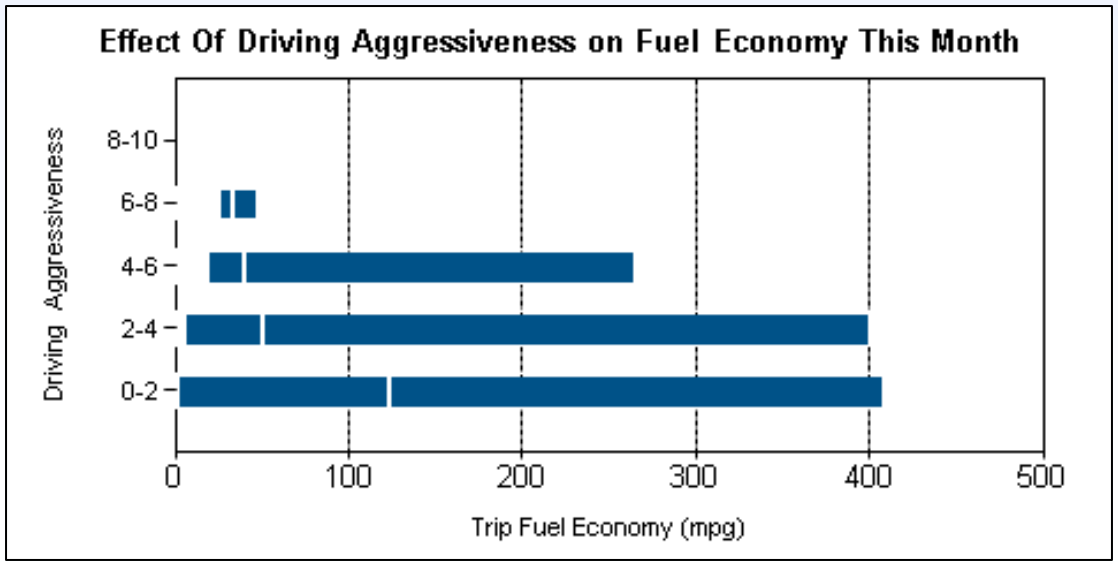



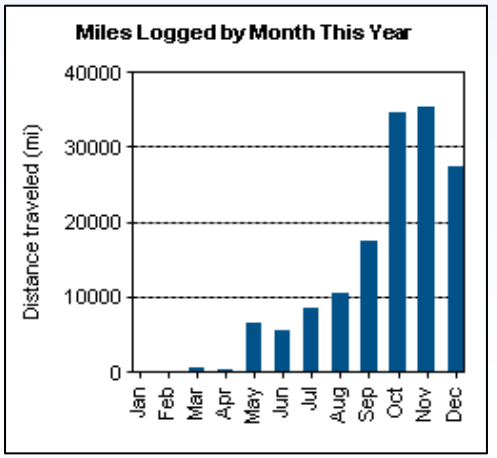
# Fleet Testing Results

- **Hymotion Prius, with V2Green Data Logger. 03 to 12 / 2008. 65 PHEVs, 144,763 miles, 15,926 trips, 4,219 charging events and 10,514 kWh used**

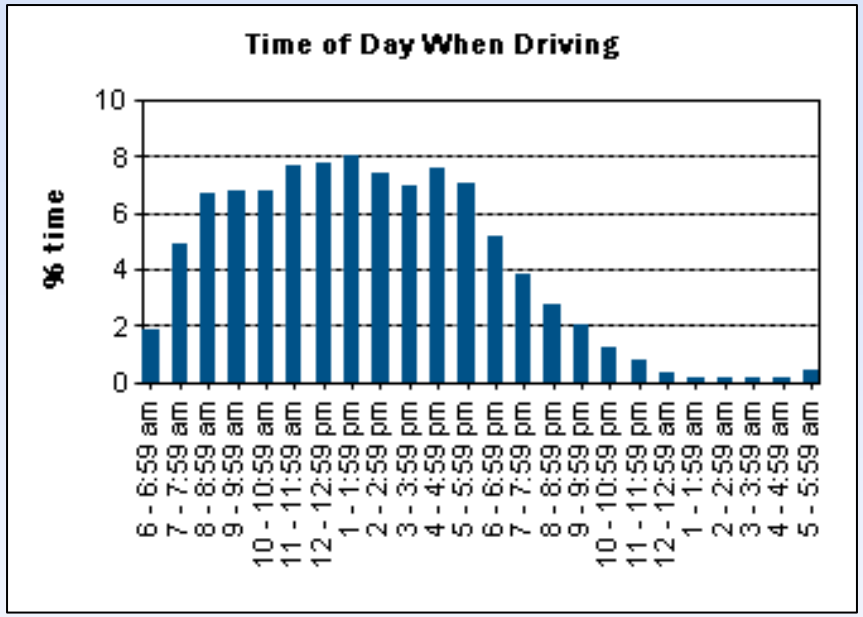


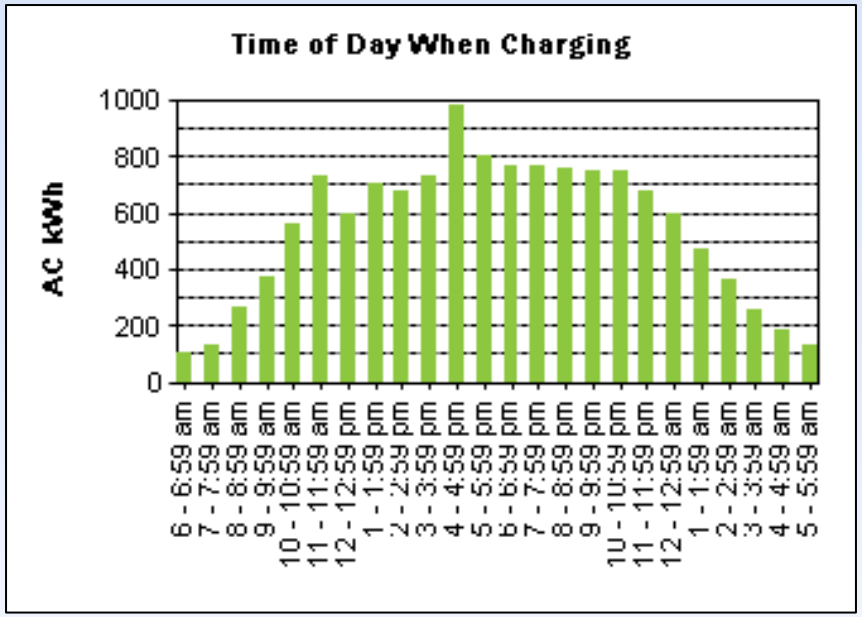



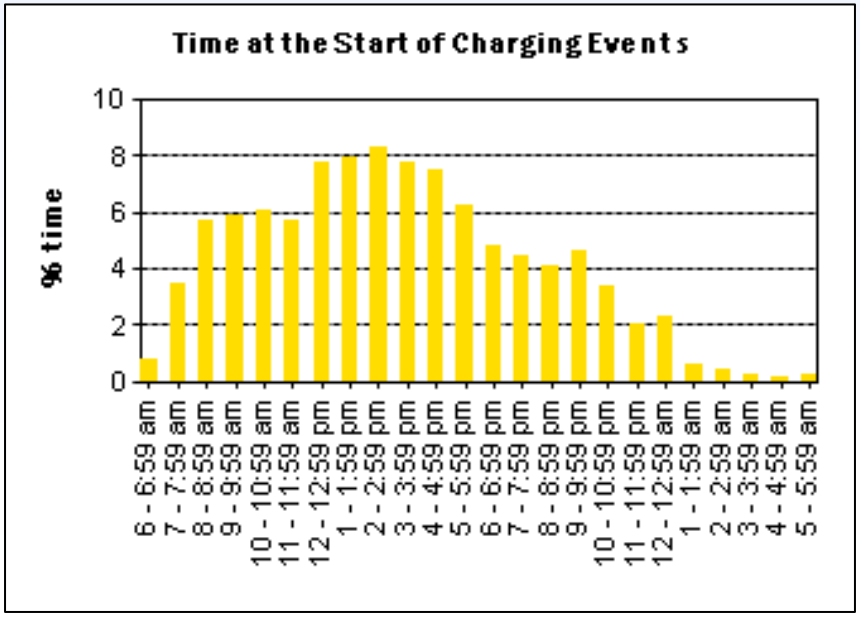



# Fleet Testing Results – cont'd



# Charging Infrastructure Terms

- **Level I – 110 / 120 VAC, 15 amp (12 amp continuous). Maximum 1.44 kW continuous. Onboard charger. NEMA5-15R receptacle, with GFCI**
- **Level II – greater than Level I, with 208-240 VAC and up to 40 amp (32 amp continuous). Maximum 9.6 kW (7.68 kW continuous). Generally onboard charger. EVSE, mated to AC input and SAE J1722 connector to vehicle (the "plug")**
- **Level III – greater than Level II, generally off-board charger supporting more than one vehicle. Energy to vehicle can be 440 VDC or higher**
- **Fast Charge – Not definitively defined. Generally returns 50% of a battery's capacity in under 10 minutes. For large batteries, usually at Level III charge level**
- **SAE J1722 – scheduled June 2009 vote. Defines standard connector up to ~70 amps**

# Charging Infrastructure Considerations

- Match infrastructure to vehicle requirements
- New construction, run conduit in anticipation of 240 Volt, Level II charging
- Avoid being “connected” to one company
- Follow J1722 when published
- National Electric Code requirements for 120V
  - Dedicated branch circuit
  - GFCI (ground fault circuit interrupt)
  - “EV” extension cord
  - Unique connector “plug”

# Charging Infrastructure Cost Report

- Analyzes charging 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 |

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

# PHEV Purchase Considerations

- Has the vehicle emissions been certified by CARB or the EPA, or received an exemption?
- Has the vehicle been crashed testing and FMVSS certified per NHTSA reporting requirements?
- Has converter made the vehicle available to DOE's AVTA for testing?
- "Rich" charging environment may be less costly than increasing per vehicle battery size
- Current PHEVs have the potential to provide greater than 100 mpg – but maybe needs a "better" PHEV driver
- Future PHEVs may provide controlled response to power demands
- Match mission to PHEV capabilities
- Consider the vehicle's ambient operating temperature
- Conversions need crash testing – Don't believe "its just another piece of luggage in the trunk"

# Lithium Battery Performance

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

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

# 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 Hyundia 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
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**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 Toshibia EV develop letter of intent
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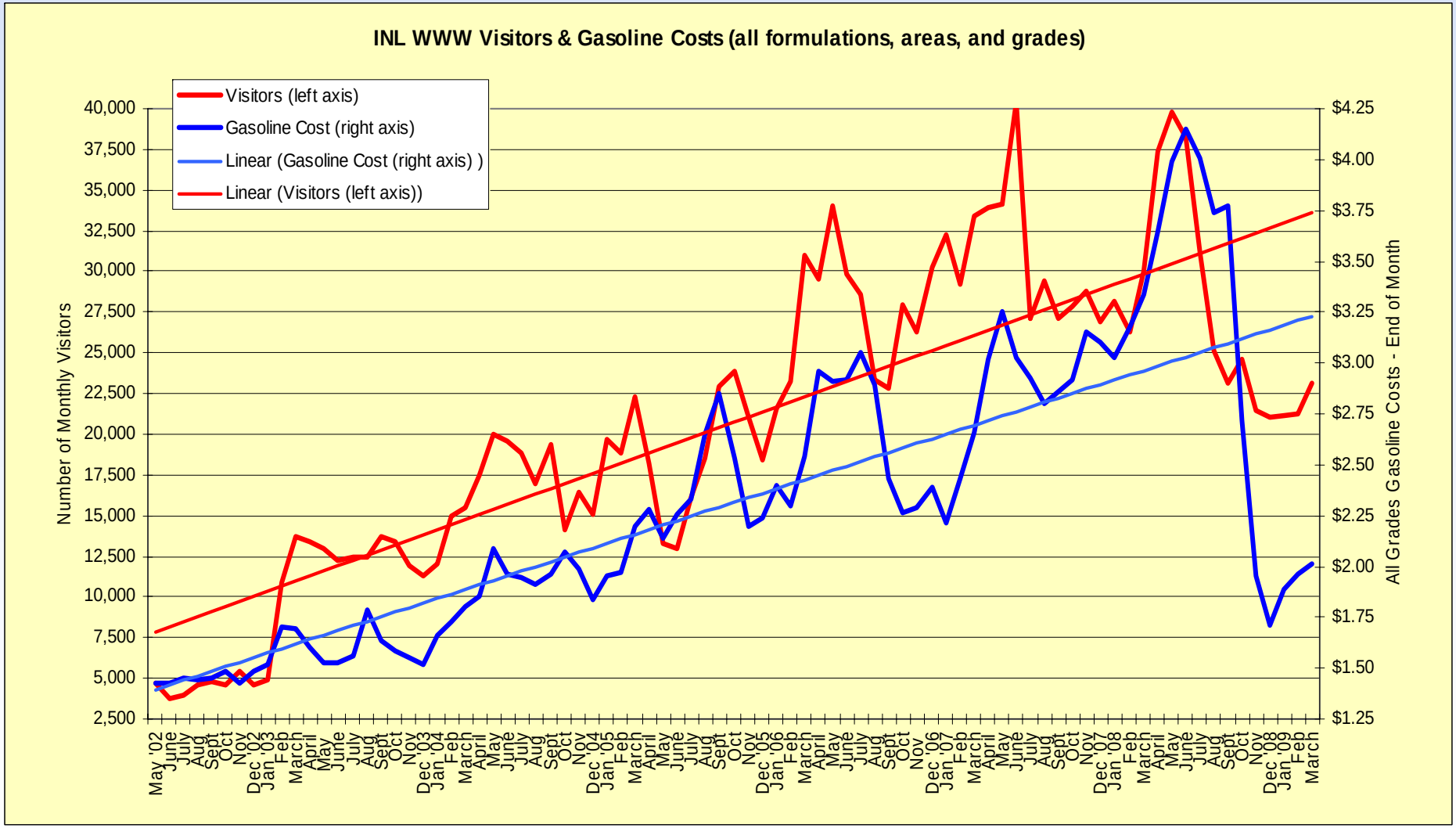
# AVTA Webpage Use and Gasoline Costs



# 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-09-15561**