



An Update on Plug-in Hybrids

COVES 2008

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Plug-in Hybrid School Bus

- > History
- > Implementation
- > Data Collection
- > Next Steps

Plug-in Hybrid Prius

- > History
- > Implementation
- > Data Collection
- > Next Steps



▶ Who is Advanced Energy?

- ▶ An independent non-profit located in Raleigh, NC
- ▶ Our mission is to create economic, environmental and societal benefits through innovative and market-based approaches to energy issues.
- ▶ Focus on solutions that are economically viable, environmentally responsible and reduce energy consumption
- ▶ We work in residential, commercial, industrial, and transportation markets



▶ Plug-in Hybrid School Bus Project

- ▶ Collaborative effort with manufacturers, operators and environmental agencies
- ▶ Identified market barriers and reduced risk where possible
- ▶ Funding support from NC utilities, NC DENR, NC SEO, US DOE, US EPA, and AE
- ▶ Goal is to change the marketplace

▶ How did we get here?

▶ 4 Phases

I. Feasibility Study (2003-2005)

II. Pre-Production Operation (2006-2009)

III. Fleet Testing (2008-2012)

IV. Full Market Deployment (2013)

- Technical Feasibility
 - Business Feasibility
 - Overall Feasibility
- Completed*

▶ How did we get here?

▶ 4 Phases

I. Feasibility Study (2003-2005)

II. Pre-Production Operation (2006-2009)

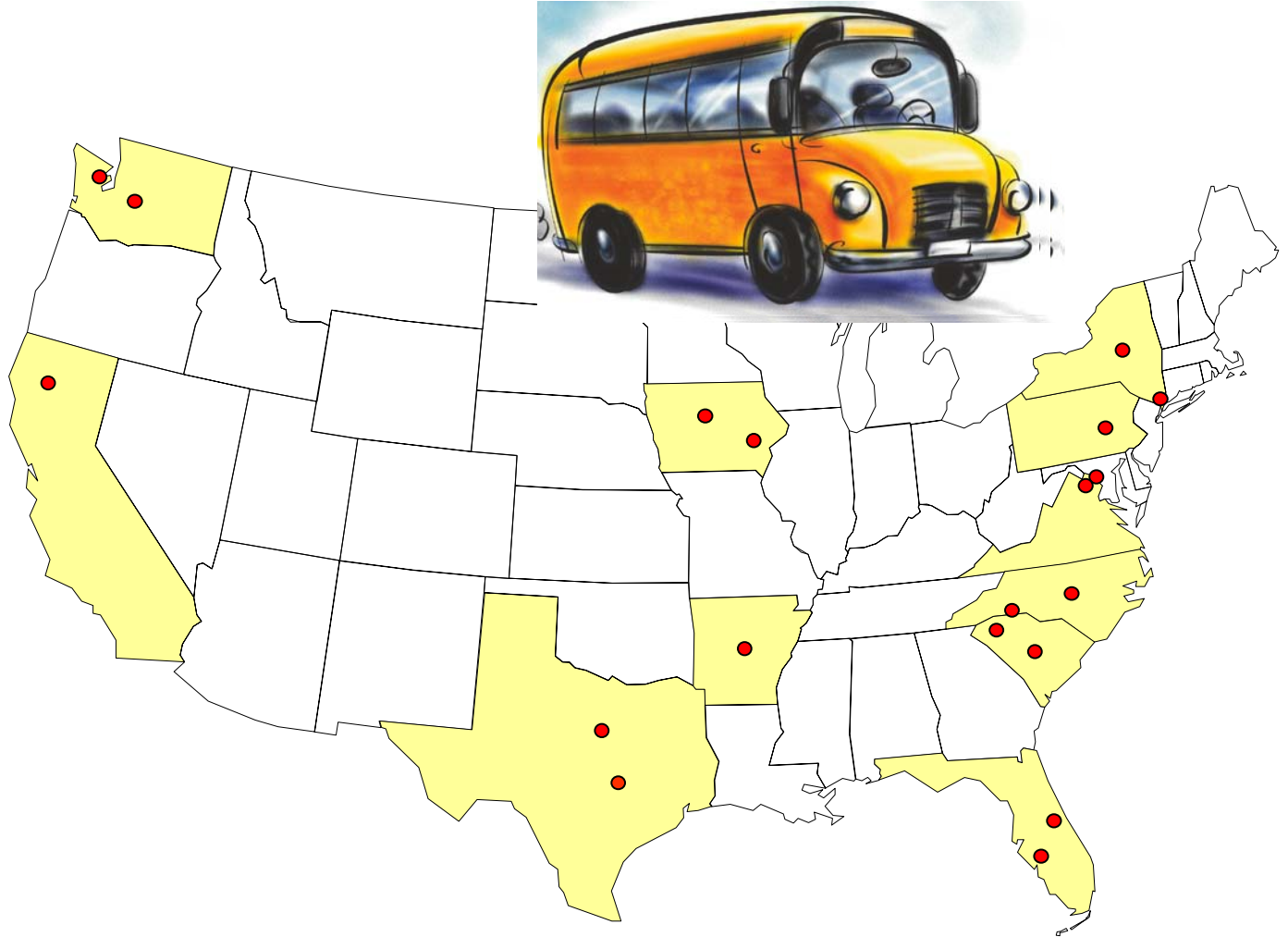
III. Fleet Testing (2008-2012)

IV. Full Market Deployment (2013)

- 20 Bus Purchase
- Data Gathering
 - Emissions
 - Fuel Economy
 - Maintenance

► National Scope

- North Carolina (2)
- South Carolina (2)
- Florida (2)
- Virginia (1)
- Washington DC (1)
- Pennsylvania (1)
- New York (2)
- Arkansas (1)
- Iowa (2)
- Washington (2)
- California (1)
- Texas (2)

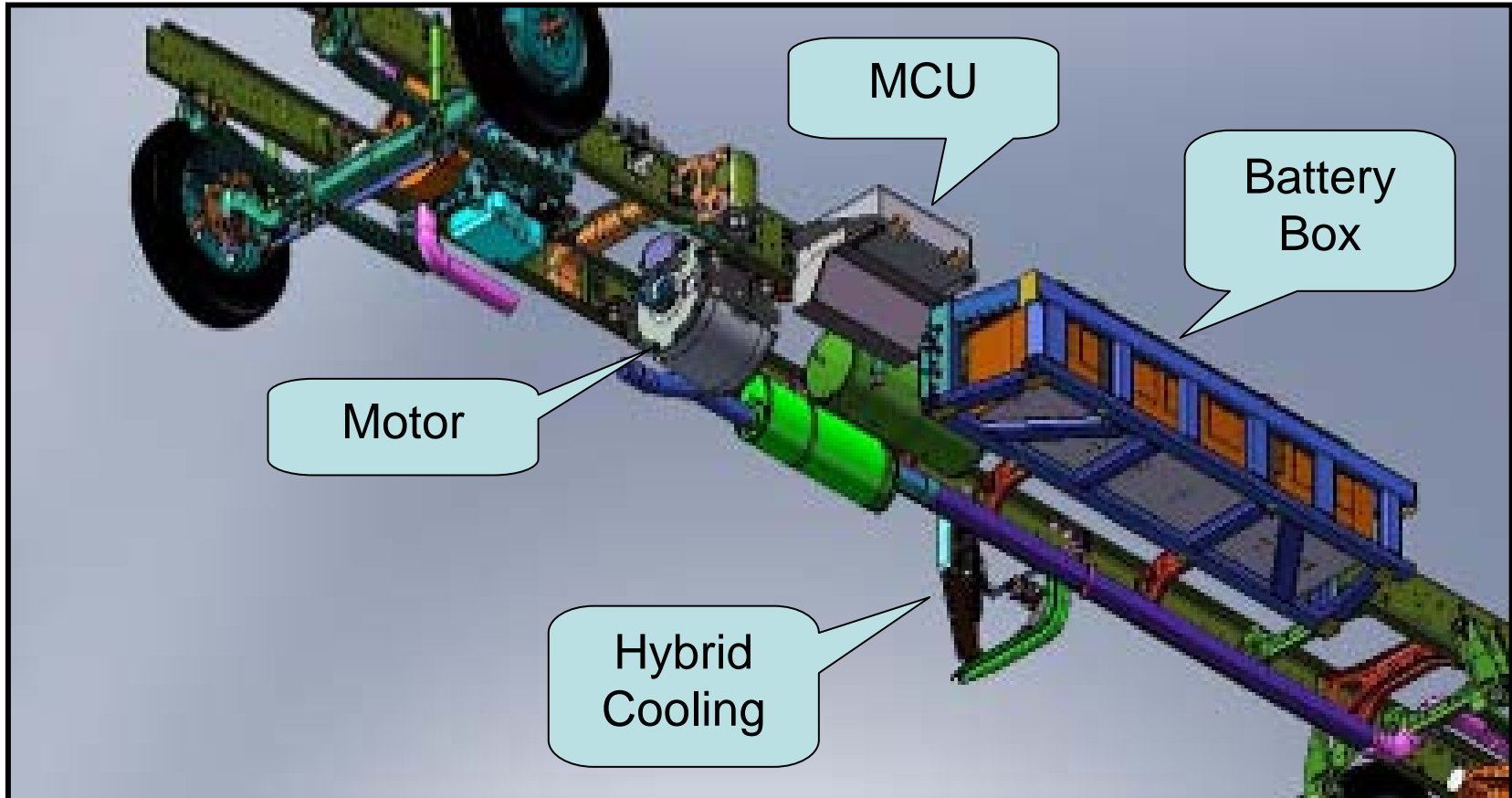


▶ Bid Award to Buses Delivered

- ▶ RFP for buses in June 2006
- ▶ IC Corporation selected based on specific criteria
 - > 80 kW parallel **plug-in** hybrid
 - > 28 kWh Li-Ion pack from Valence
 - > \$140k incremental cost
- ▶ First buses delivered to Bradenton, FL in March 2007



▶ Enova Systems Components



▶ Enova Systems Components



▶ Manatee County Charging



▶ Estimated Benefits

- ▶ Plugging-in is optional
- ▶ 90-100% increase in fuel economy for the first 45 miles
- ▶ 40% increase for remainder
- ▶ 90% reduction in PM
- ▶ 60% reduction in NOx
- ▶ Increased engine, transmission, and brake life
- ▶ Electricity cost of 60¢/gallon equivalent
- ▶ Option for renewable electricity at \$1 per gallon



▶ Performance and Monitoring

- ▶ Web reporting
- ▶ Enova Logging
- ▶ Emissions Testing

Hybrid Electric School Bus Tier 1 Monitoring Form

School District

Bus Type

Bus ID #

Route Designation

Bus Driver

Maintenance Report

| DATE | MAINTENANCE AREA | EXPLANATION OF MAINTENANCE | PERFORMED BY | HOURS UNAVAILABLE | LIST OF MATERIALS |
|---|--|----------------------------|--|----------------------|----------------------|
| <input type="text"/> | <input type="text" value="Please Select"/> | <input type="text"/> | <input type="text" value="Please Sele"/> | <input type="text"/> | <input type="text"/> |
| ROAD CALL | ODOMETER READING | LABOR HOURS | MATERIAL COST | | |
| Yes <input type="radio"/> No <input checked="" type="radio"/> | <input type="text"/> | <input type="text"/> | <input type="text"/> | | |

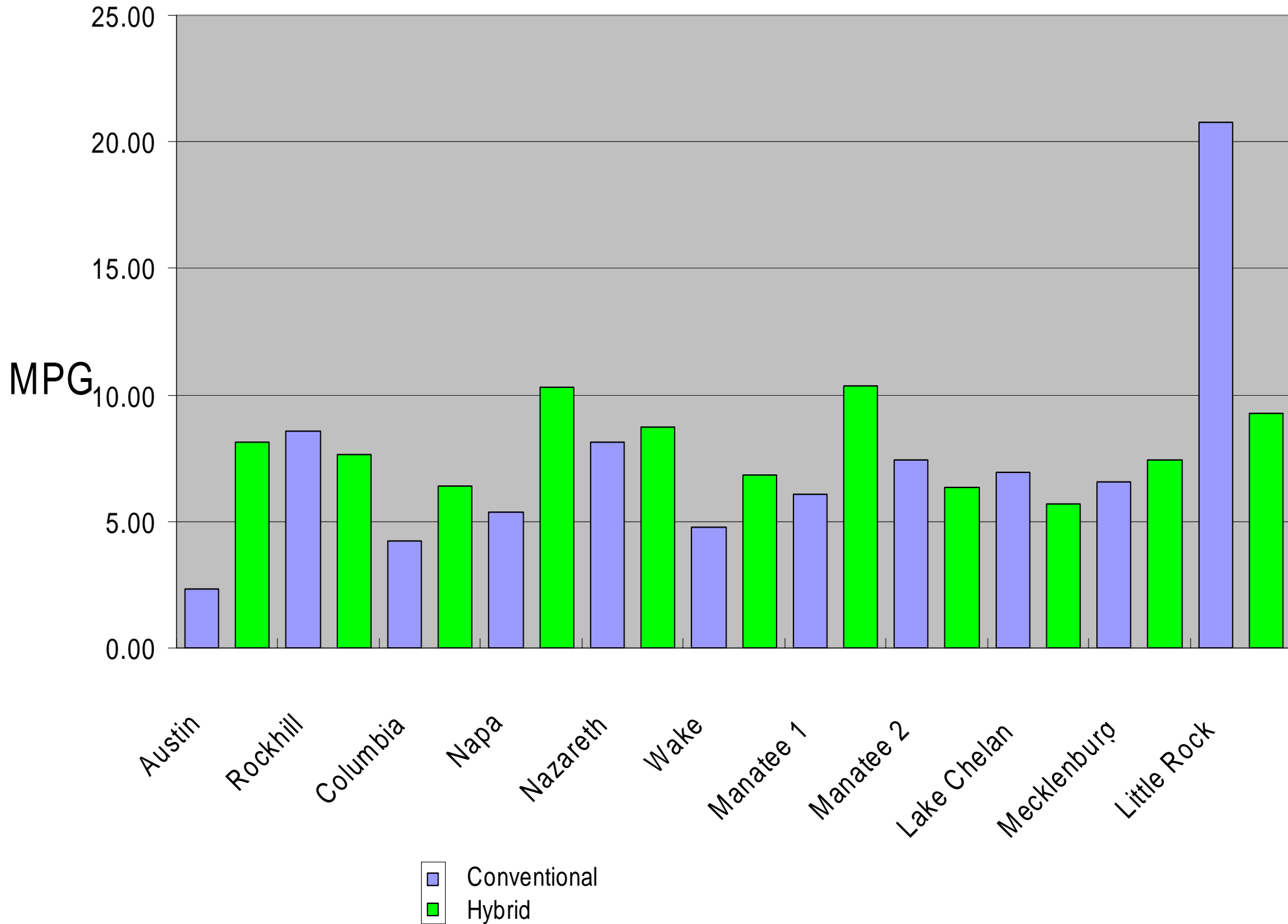
Submit

Fuel Report

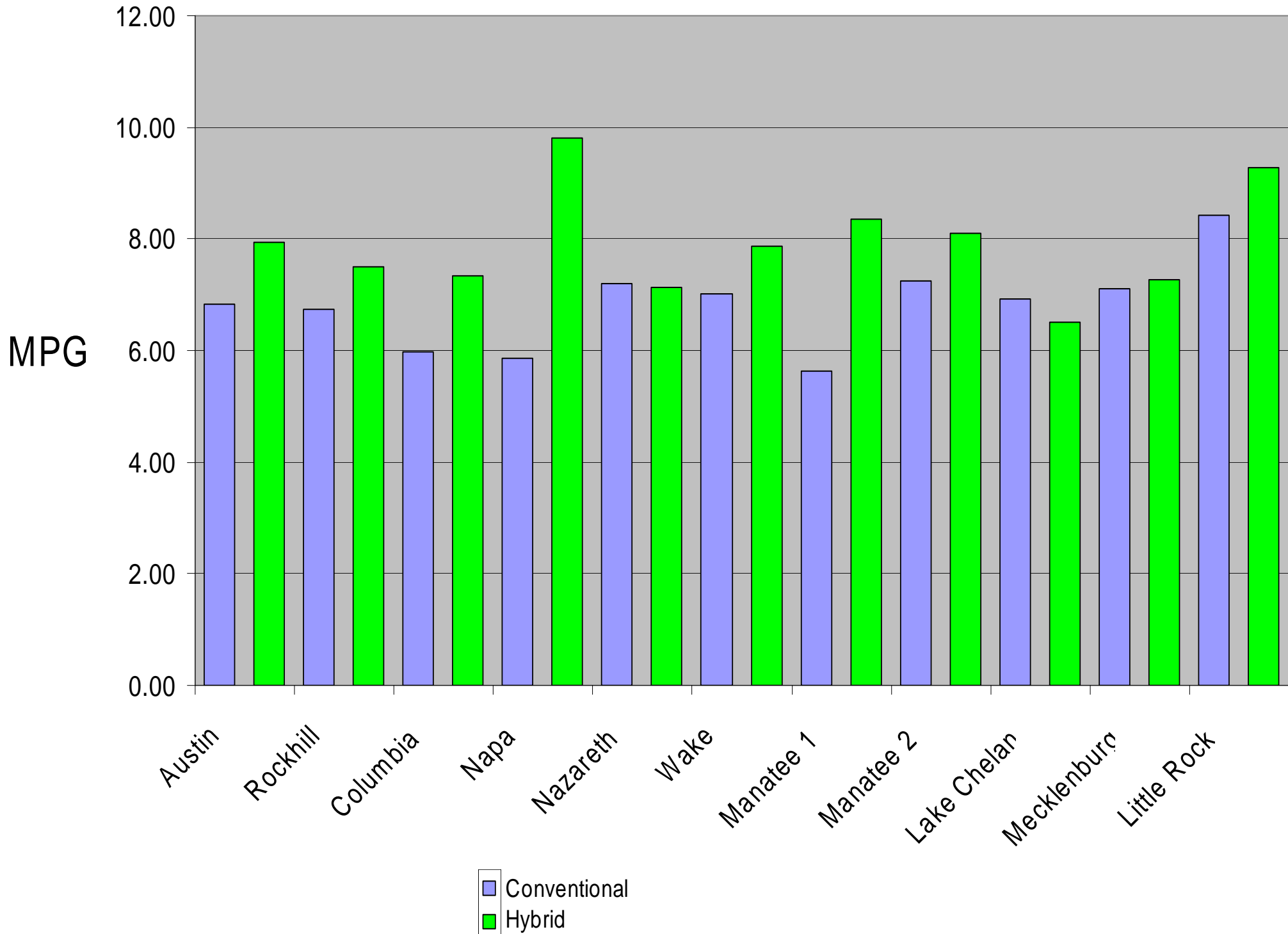
| DATE | ODOMETER READING | GALLONS | COST PER GALLON | KWH READING |
|----------------------|----------------------|----------------------|----------------------|----------------------|
| <input type="text"/> | <input type="text"/> | <input type="text"/> | <input type="text"/> | <input type="text"/> |
| NOTES | | | | |
| <input type="text"/> | | | | |

Submit

Recent MPG (last 3)



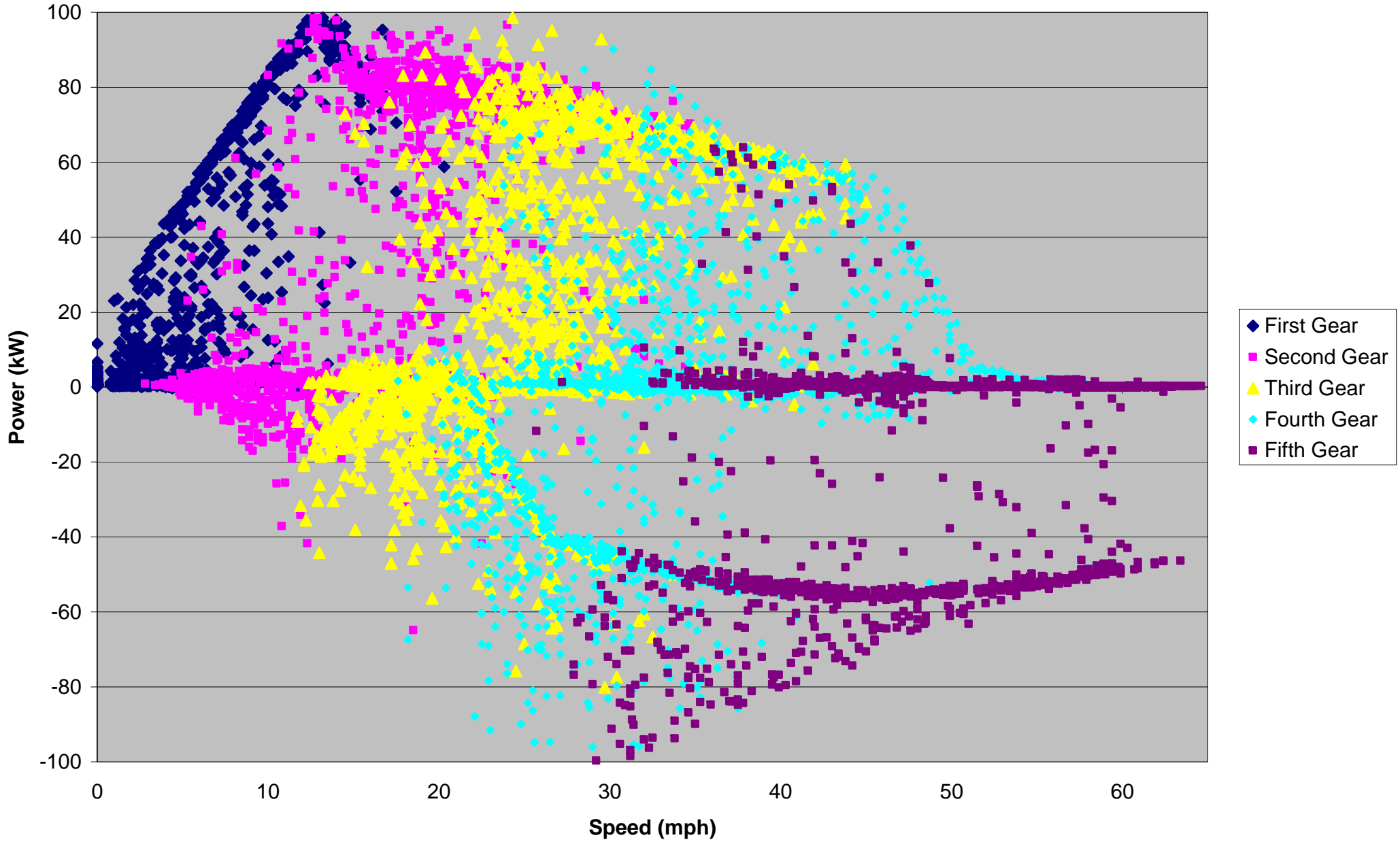
Overall MPG



▶ Enova Logging

- ▶ Monitors hybrid system operation
- ▶ Detailed output every second
 - > Speed, SOC, Voltage, Current, Gear, RPM, Motor Temperature, Brakes, Throttle, etc.

Power Versus Speed



▶ Emissions Testing

- ▶ Portable analyzer and Large Chassis Dynamometer
- ▶ Correlate engine operations and drive cycle with emissions

► Dynamometer Testing

Cycle Specific Results: West-Virginia Suburban Cycle

| Test | MPG* | MM MPG** | THC | CO | NO _x | CO ₂ | PM | NO | NMHC | NO ₂ |
|---------------|-------|----------|-------|--------|-----------------|-----------------|--------|--------|-------|-----------------|
| <u>Diesel</u> | 7.1 | 6.8 | 0.479 | 2.773 | 6.043 | 1435.1 | 0.158 | 5.64 | 0.479 | 0.404 |
| <u>Hybrid</u> | 12.9 | 12.8 | 0.624 | 2.401 | 3.64 | 793.8 | 0.105 | 3.08 | 0.624 | 0.564 |
| % Imp | 82.3% | 88.8% | 30.4% | -13.4% | -39.8% | -44.7% | -33.5% | -45.5% | 30.4% | 39.8% |

* MPG is calculated from exhaust carbon

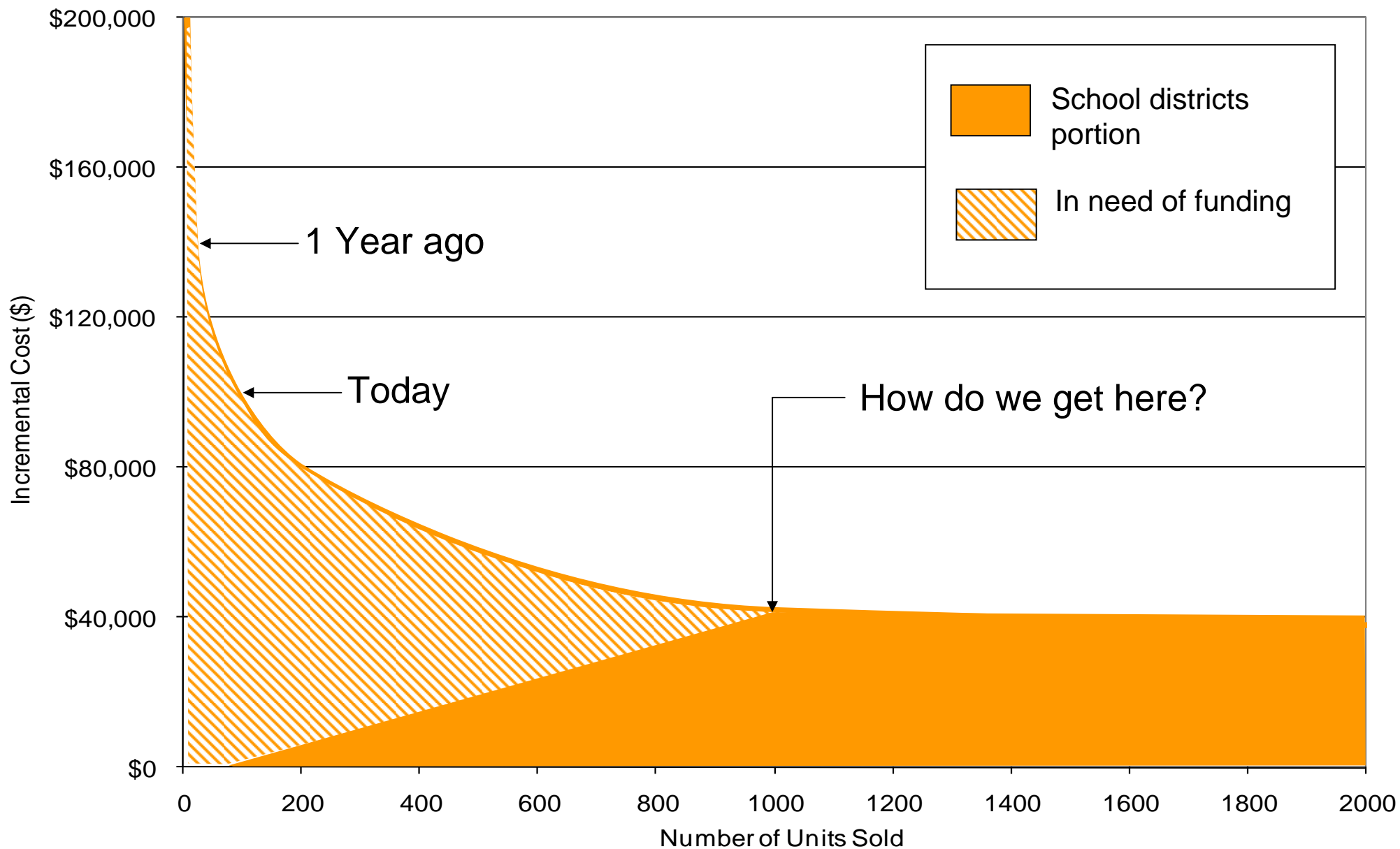
** MM MPG is Micro Motion, calculated by fuel flow rate

▶ Next Steps

- ▶ 2 Year monitoring period: fuel economy, maintenance, general operation and driving performance.
- ▶ Hybrid system improvements
 - > Engine off, All electric range, Improved component interaction
- ▶ 300 Bus Purchase
- ▶ Form on website for emailed program updates

www.hybridschoolbus.org

► Incremental cost per unit





▶ Plug-in Prius Project

- ▶ Basics
- ▶ History
- ▶ Conversion Process
- ▶ Monitoring

▶ Why a Plug-in Prius?

- ▶ Plug-in Benefits
 - > Domestic Fuel, Reduced CO₂
- ▶ Prius Transmission Design
- ▶ Need to understand technology through demonstration

▶ Plug-in Prius History

- ▶ Project with Utility Partners: Duke, Progress and NCEMC
- ▶ Kit from A123/Hymotion
- ▶ Work with local shop to perform conversions
- ▶ Dec 2006: Ordered kits
- ▶ Feb 2007: Initial delivery date
- ▶ Apr 2007: Revised delivery
- ▶ Jul 2007: Actual delivery and installation



▶ Hymotion Specs

- ▶ Battery Type: Lithium Polymer
- ▶ Battery Energy: 5 kilowatt hours
- ▶ Battery Weight: 160 pounds
- ▶ Charging Voltage: 110
- ▶ Charging Current: 15 Amp
- ▶ Charging Duration: 5 to 6 hours
- ▶ All Electric Range: 20 to 40 miles

▶ Electric Criteria

- ▶ Speed < 35 mph
- ▶ Pack SOC > 20% for Hymotion, > 45% for Prius
- ▶ Throttle Position < 25% (?)
- ▶ Motor Temperatures
- ▶ Pack Temperatures

▶ Conversion Process



▶ Conversion Process



► Conversion Process



► Conversion Process





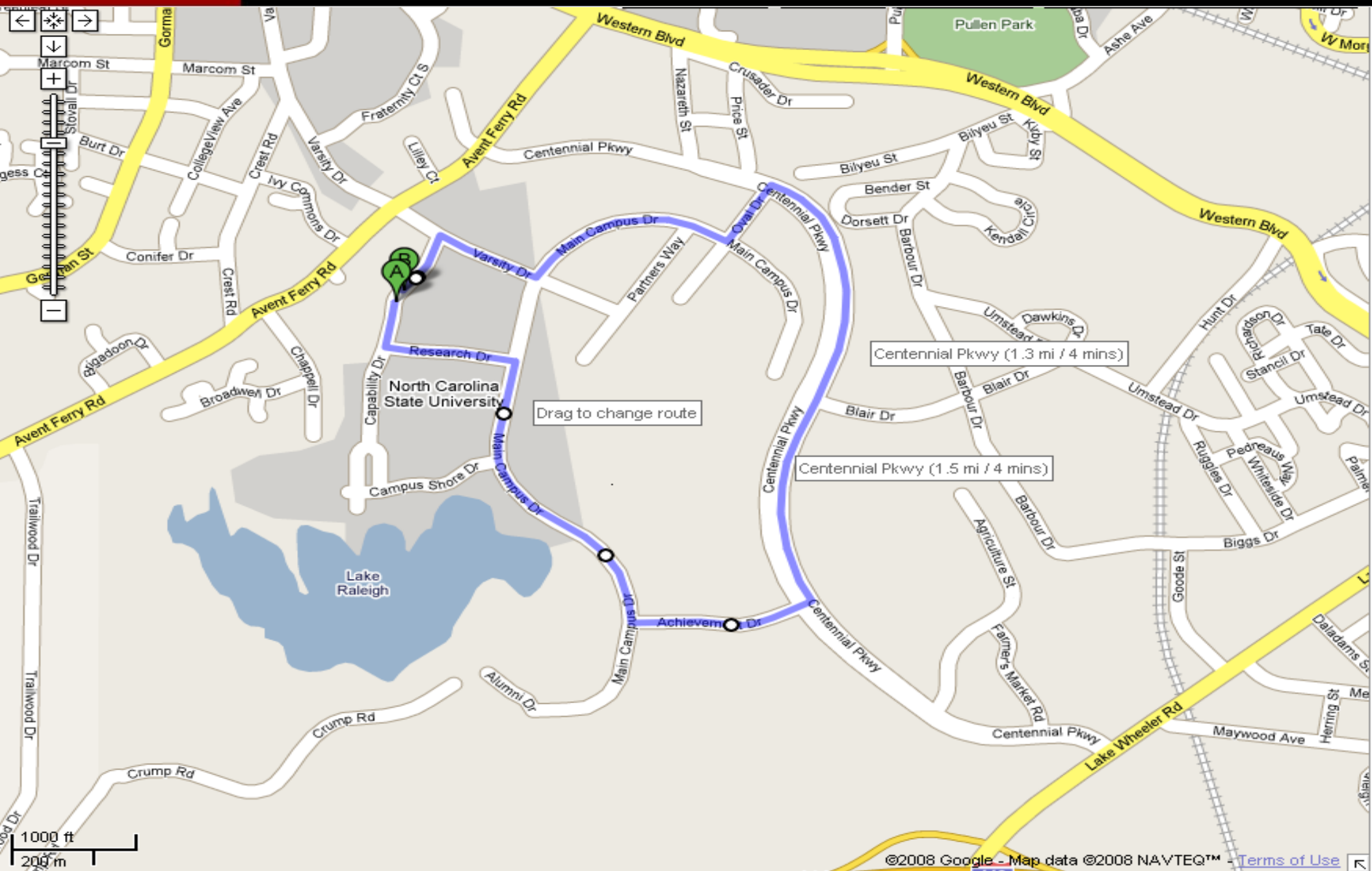
▶ Monitoring

- ▶ PHEV Prius spoofs existing engine controls using CAN
- ▶ V2Green unit filters and logs data then interprets through database
- ▶ Data is transmitted on Verizon Network
- ▶ Web access allows for real time performance monitoring
- ▶ GPS capabilities log trips and displays on Microsoft Virtual Earth.

▶ Driving Behaviors

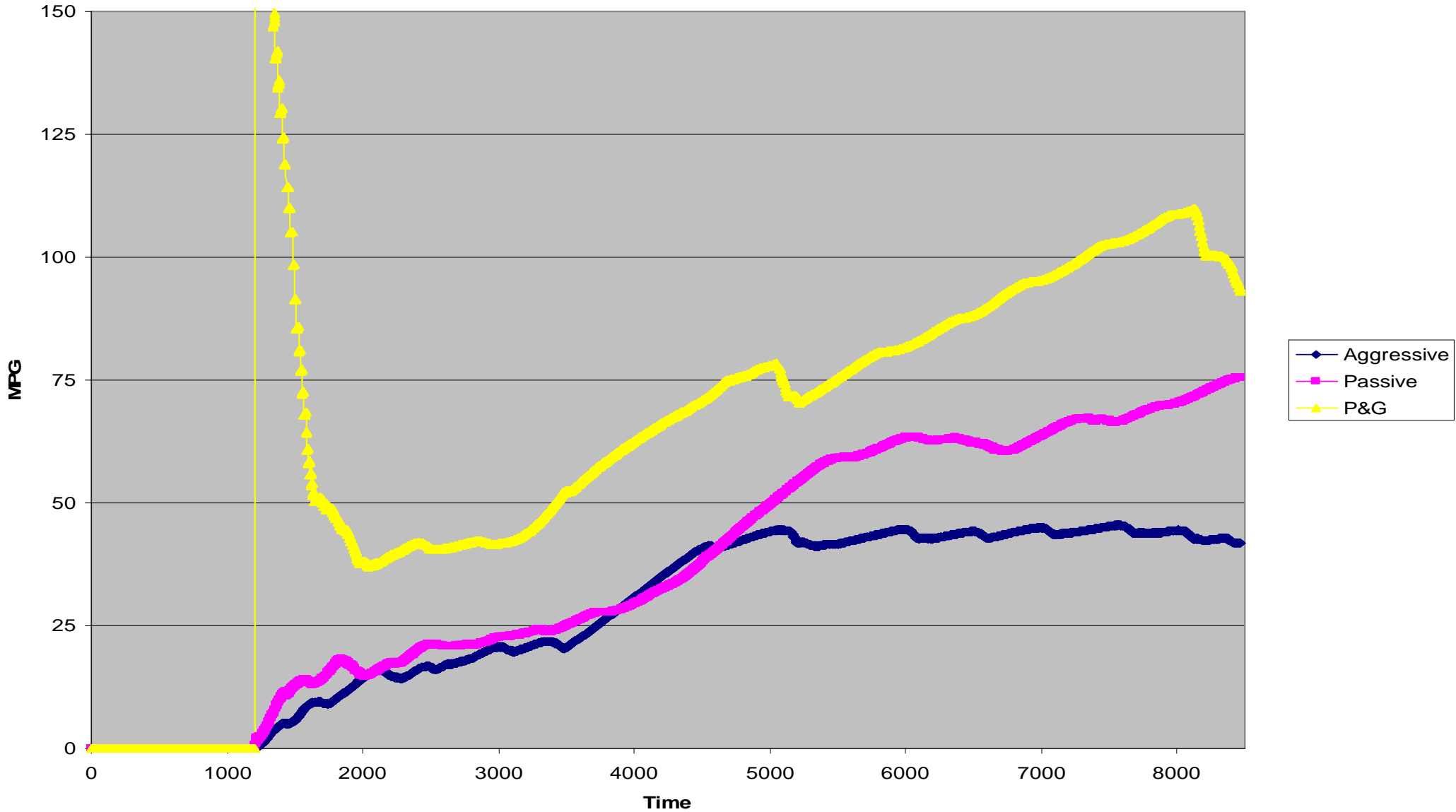
- ▶ In order to maximize fuel economy, several different driving behaviors were tested:
 - Aggressive behavior
 - Passive behavior
 - Pulse & Glide Technique

▶ Driving Behaviors



▶ Driving Behaviors

Fuel Economy of Different Driving Behaviors



▶ Review of PHEV Project

▶ Lessons learned

- > Works better when plugged in to working outlet
- > Adapted behavior with new technology
- > Important to utilize ICE when on and avoid fluctuation of engine on/off
- > Engine warming reduces fuel economy
- > Long trips (> 40 miles) eliminates PHEV benefit



▶ Other Studies and Projects

- ▶ Idaho National Labs
 - > Partnership with Hymotion to gather data on entire fleet
- ▶ Cooperative Research Network
 - > Conversions from Hymotion, Energy CS, Hybrids Plus
- ▶ Google
 - > www.rechargeit.org

► Other Studies and Projects

google.org RechargeIT.org: A Google.org Project

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Comoe

Toyota Prius Plug-in



This car is a gasoline-powered Toyota Prius that has been modified by adding a second, larger battery. The additional battery can be charged using a normal 120-volt outlet, ideally at night when electricity demand (and cost) is at its lowest.

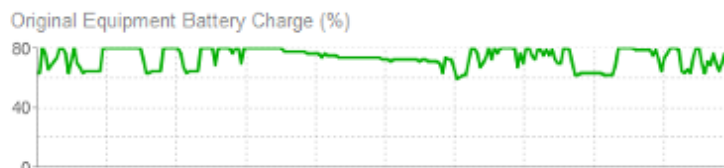


69.9 MPG



123.8 Wh/mile

Event Data



Event Summary

| | |
|-----------------|------------------|
| Start Time | April 2 11:16 am |
| End Time | April 2 11:28 am |
| Elapsed Time | 12 minutes |
| Distance Driven | 8.343 miles |
| Fuel Used | 0.192 gallons |
| Fuel Economy | 43.4 MPG |

Events for Wednesday, April 2, 2008

| | |
|----------|---|
| 12:00 am | Daily summary |
| 11:16 am | Drive 8.3 miles in 12 minutes |
| 2:33 pm | Drive 6.8 miles in 11 minutes |
| 2:47 pm | Charge for 8 hours 27 minutes |

Calendar

| April 2008 | | | | | | | |
|------------|----|----|----|----|----|----|----|
| « | S | M | T | W | T | F | » |
| | | | 1 | 2 | 3 | 4 | 5 |
| | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
| | 20 | 21 | 22 | 23 | 24 | 25 | 26 |
| | 27 | 28 | 29 | 30 | | | |



▶ North Carolina Activities

- ▶ Advanced Vehicle Research Center
 - > Certified installers for Hymotion conversions
- ▶ Progress Energy & Duke Energy
 - > Evaluating V2Green concept to control charging and provide benefit to local grid
- ▶ Advanced Transportation Energy Center
 - > PHEV and EV research/demo center at NCSU

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