Plug-in Hybrid
School Bus Update

Ken Dulaney
Advanced Energy

www.hybridschoolbus.org
Presentation Outline

- Project History
- Why plug-in hybrids?
- Performance and Monitoring
- Next Phases

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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

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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

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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

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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)

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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

- Battery Box
- MCU
- Motor
- Hybrid Cooling
Manatee County Charging

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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

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Performance and Monitoring

- Web reporting
- IC Aware
- Enova Logging
- Emissions Testing
## Hybrid Electric School Bus Tier 1 Monitoring Form

**School District**: [Please Select]

**Bus Type**: [Please Select]

**Bus ID #**: [Please Select]

**Route Designation**: [Please Select]

**Bus Driver**: [Please Select]

### Maintenance Report

<table>
<thead>
<tr>
<th>DATE</th>
<th>MAINTENANCE AREA</th>
<th>EXPLANATION OF MAINTENANCE</th>
<th>PERFORMED BY</th>
<th>HOURS UNAVAILABLE</th>
<th>LIST OF MATERIALS</th>
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</thead>
<tbody>
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<td></td>
<td>Please Select</td>
<td>Please Select</td>
<td>Please Select</td>
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**ROAD CALL**: [Yes] [No]

<table>
<thead>
<tr>
<th>ODOMETER READING</th>
<th>LABOR HOURS</th>
<th>MATERIAL COST</th>
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### Fuel Report

<table>
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<tr>
<th>DATE</th>
<th>ODOMETER READING</th>
<th>GALLONS</th>
<th>COST PER GALLON</th>
<th>KWH READING</th>
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<tbody>
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</table>

**NOTES**: [Please Select]

[Submit]

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Fuel Economy Comparison

MPG

Manatee H 1
Manatee H 2
Manatee C 1
Manatee C 2

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Wake County, N.C., Hybrid School Bus

Not Plugged In

Plugged In

Date

July 17, 2007 to October 5, 2007

MPG

0.00 1.00 2.00 3.00 4.00 5.00 6.00 7.00 8.00 9.00 10.00

Average Fuel Economy

AVG MPG

Columbia H
Columbia C
Nazareth H 1
Nazareth C 1
Nazareth H 2
Nazareth C 2
Napa H
Wake H
Manatee H 1
Manatee C 1
Manatee H 2
Manatee C 2
IC Aware

Parameters

- Fuel economy
- Speeds
- Stops
- Fleet location
- Odometer

- Engine run time
- Brake count and duration
- Alert reports
  - Fault conditions
  - Out of range parameters
    (rapid accelerations or decelerations)

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ATTENTION: An AWARE™ Software Upgrade is now available for the vehicle installed modules. We recommend that you upgrade all of your vehicles to the latest version of software as soon as possible to ensure continued communication and access to your vehicle data on the website. Customer Administrators for the accounts requiring this upgrade have been notified through email. If you have any questions please contact AWARE™ Customer Support at 1-888-883-5362, option #4.

NOTICE
With each Module Replacement or Software Upgrade please ensure that your service technician has contacted AWARE™ Customer Support at 1-888-883-5362, option #4 as part of the upgrade process. This is necessary to confirm that your modules are communicating correctly and resolve any issues at the time of service.

AWARE™ Customer Support is available from 7:00am to 7:00pm Central Daylight Time, Monday - Friday: 1-888-883-5362, option #4.
Average Fuel Economy

IC Aware vs Web Reporting

AVG MPG

IC Aware Data

Columbia H
Columbia C
Nazareth H 1
Nazareth C 1
Nazareth H 2
Nazareth C 2
Napa H
Wake H
Manatee H 1
Manatee C 1
Manatee H 2
Manatee C 2
Enova Logging

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

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Power Versus Speed

-100 -80 -60 -40 -20 0 20 40 60 80 100

0 1 02 03 04 05 06 0

-100 -80 -60 -40 -20

0 10 20 30 40 50 60

First Gear
Second Gear
Third Gear
Fourth Gear
Fifth Gear

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Emissions Testing

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

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Next Steps

- 2 Year period of watching and recording emission, fuel economy, maintenance, general operation and driving performance.
- Program will be expanding with utility support
  - Approximately 300 buses
  - Estimated $80,000 incremental cost
- Form on website for emailed program updates
Incremental Cost per Unit

The graph shows the incremental cost per unit as a function of the number of units sold. The cost decreases as the number of units sold increases, with the incremental cost starting at $200,000 for 0 units sold and dropping to $0 as the number of units sold approaches 2000.
Push vs. Pull Methodology

Level of Activity and Funding

R&D

Deployment

Time (Years)

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Push Methodology

Level of Activity and Funding

Time (Years)

R&D

Deployment

Insert Money and Effort Here

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Pull Methodology

Level of Activity and Funding

R&D

Deployment

Insert Money and Effort Here

Time (Years)

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Balanced Methodology

Level of Activity and Funding

R&D

Deployment

Insert Money and Effort Here and Here

Advanced Energy
Hybrid Buses
Plug-In Conversions

Time (Years)

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AE as Facilitator

- School Districts
- Bus Manufacturers
- Drive Manufacturers
- Battery Manufacturers
- Government Agencies

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