Early Results from DOE/NREL Transit Bus Evaluations

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NREL

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Battelle

APTA Bus and Paratransit Conference  
Columbus, Ohio  
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Overview

• Background
• Early Results from New York City Transit
• Early Results from King County Metro
• Questions
NREL Fleet Test & Evaluation Team

• Evaluate “real world” performance of advanced propulsion technologies

• Focus on medium and heavy duty fleet applications

• Main goals:
  – Facilitate the transition of advanced technologies from the R&D stage into the marketplace
  – Provide potential fleet users with accurate and unbiased information on vehicle performance and costs

• Funding is provided by the Department of Energy’s Office of Energy Efficiency and Renewable Energy
Fleet Evaluation: Goals

• Objectives:
  – Assess status of new technologies in real-world service
  – Establish a benchmark of current and near-term technologies
  – Provide unbiased information on vehicle performance
  – Share lessons learned about implementation experience

• Target Audience:
  – Fleet managers considering use of the technology
  – Manufacturers & system integrators
  – Department of Energy
  – Other interested parties
    (APTA, FTA, EPA, EDTA…)
Fleet Evaluation: Specifics

Selection of Specific Technology and Site for Evaluation

• Fuel and Technology Neutral
  – Alternative fuel - CNG, LNG, Biodiesel, LPG
  – Electric propulsion - hybrid-electric, fuel cell

• Site Selection Criteria include:
  – At least 5 advanced technology vehicles
  – Good record keeping
  – Motivated to participate
Fleet Evaluation: Specifics

Data collection plan based on existing and proven protocol developed for DOE heavy vehicle evaluations.

Data Collection includes:

• Vehicle specifications
• Vehicle expectations
• Vehicle usage and specific duty cycle
• Fuel and oil consumption
• Maintenance
• Fleet implementation experience
• Facility descriptions and capital cost
Fleet Evaluation: Specifics

Analysis and Reporting

The data collection typically covers one year of operation for both advanced vehicles and conventional comparison (if available).

Reports include:

• Two page fact sheet
• Early experience and results report
• Final Summary Report
Early Hybrid Bus Experience at NYCT in New York City

Leslie Eudy
National Renewable Energy Laboratory
Agenda

• Quick NYCT clean bus program description
• Plans for DOE/NREL evaluation
• Hybrid, Diesel, and CNG bus descriptions
• Early experience
• What’s next
NYCT Clean Bus Program

NYCT Goals

• Reduce bus fleet emissions
• Improve service (reliability and noise)
• Reduce cost of operations (improve fuel economy and reduce costs)
NYCT Clean Bus Program

- Repowering old 2-stroke diesel engines to new EGR-equipped 4-stroke diesel engines; to be completed in 2005
- All diesel engines to be equipped with diesel particulate filters (in progress)
- CNG buses – 481 in operation
- Hybrid buses – 325 in operation by mid-2005
NYCT Reasons for Hybrid Buses

- Emissions reductions
- Increased fuel economy
- Smooth and quiet operation
- Improved performance
- Avoids infrastructure costs of CNG
## CNG and Hybrid Buses

<table>
<thead>
<tr>
<th>Depot</th>
<th>CNG (260)</th>
<th>Hybrid (125)</th>
<th>Hybrid (200)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gleason</td>
<td>95</td>
<td></td>
<td></td>
</tr>
<tr>
<td>West Farms</td>
<td>165</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mother Clara Hale</td>
<td></td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>Queens Village</td>
<td></td>
<td>65</td>
<td></td>
</tr>
<tr>
<td>Fresh Pond</td>
<td></td>
<td>135</td>
<td></td>
</tr>
<tr>
<td>Manhattan-village</td>
<td></td>
<td>65</td>
<td></td>
</tr>
</tbody>
</table>
Planned DOE/NREL Evaluation

- Hybrid Order of 125 Orion VII Buses - 10 Hybrid Buses at Mother Clara Hale Depot in Manhattan Division (10 Orion V diesel buses chosen for comparison) – Average speed at depot of 6.5 mph
Planned DOE/NREL Evaluation

- CNG Order of Orion VII Buses – 10 CNG Buses at West Farms Depot in Bronx Division (10 NovaBus RTS diesel buses chosen for comparison) – Average speed at depot of 6.5 mph
Planned DOE/NREL Evaluation

- Hybrid Order of 200 Orion VII Buses – 10 Hybrid Buses at Fresh Pond Depot (10 diesel buses to be chosen for comparison)
Planned DOE/NREL Evaluation

• Collect and analyze operations data (bus usage, fuel, and maintenance) for 12 months
• Order of 125 Hybrid buses and CNG bus evaluations starting with October 2004
• Hybrid Order of 200 evaluation just getting underway
# Vehicle Descriptions

<table>
<thead>
<tr>
<th>System</th>
<th>Hybrid (125)</th>
<th>CNG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bus</td>
<td>Orion VII 40’</td>
<td>Orion VII 40’</td>
</tr>
<tr>
<td>Engine</td>
<td>Cummins ISB 270 hp 660 ft-lb</td>
<td>DDC S50G 275 hp 900 ft-lb</td>
</tr>
<tr>
<td>Emissions</td>
<td>4.0 g/bhp-hr NOx; 0.05 g/bhp-hr PM using a DPF</td>
<td>2.5 g/bhp-hr NOx+HC; 0.05 g/bhp-hr PM without Cat</td>
</tr>
</tbody>
</table>
# Vehicle Descriptions

<table>
<thead>
<tr>
<th>System</th>
<th>Hybrid (125)</th>
<th>CNG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric Propulsion</td>
<td>BAE SYSTEMS HybriDrive™</td>
<td>None</td>
</tr>
<tr>
<td>Energy Storage</td>
<td>Sealed lead acid</td>
<td>None</td>
</tr>
<tr>
<td>Regenerative Braking</td>
<td>Yes</td>
<td>None</td>
</tr>
</tbody>
</table>
Early Experience

- CNG Orion VII buses started arriving at NYCT in March 2003
- West Farms started getting their first CNG Orion VII buses in September 2003
- Hybrid buses started operation at Mother Clara Hale Depot in March 2004
- Hybrid buses started operation at Queens Village Depot in May 2004
Average Monthly Mileage per Bus
CNG Buses

Mar-03 May-03 Jul-03 Sep-03 Nov-03 Jan-04 Mar-04 May-04 Jul-04 Sep-04 Nov-04 Jan-05

Jackie Gleason
West Farms
Miles Between Roadcalls (MBRC)
CNG Buses

Graph showing miles between roadcalls for CNG buses from November 2003 to January 2005, with various lines representing different categories such as JG Total MBRC, JG Propulsion MBRC, WF Total MBRC, and WF Propulsion MBRC.
Miles Between Roadcalls (MBRC) Hybrid Buses

![Graph showing Miles Between Roadcalls (MBRC) for Hybrid Buses from April 2004 to February 2005. The graph compares MCH Total MBRC, MCH Propulsion MBRC, QV Total MBRC, and QV Propulsion MBRC.]
Fleet Campaigns – Orion VII
CNG and Hybrid

**Bus**
- Axle bolts coming loose
- Radiator baffle, surge tank overflowing
- Fuel lift pump
- Fuel injection pump
- PCS cooling pump seizure
- Water in wiring/ connectors
- Engine grid heater relay
- Water in engine from air intake

**Hybrid**
- PCS internal coolant leaks
- PCS board modification
- Software upgrade

**CNG**
- Cylinder kits
- Spark plugs
Early Results for Evaluation Buses

- Data period for results that follow:
  - West Farms Depot, 10/04-3/05
  - Mother Clara Hale Depot, 10/04-3/05

- The following information represents early experience, NOT final results
Early Results for Evaluation Buses
Fuel Economy – CNG and Diesel

![Graph showing fuel economy for CNG and Diesel buses from October 2004 to March 2005. The graph compares the fuel economy of CNG and Diesel buses with Farm W. The data is displayed with a linear scale from 0.00 to 4.00 on the y-axis and months from October 2004 to March 2005 on the x-axis. The CNG buses show a slight decrease in fuel economy, while the Diesel buses remain relatively flat.](image-url)
Early Results for Evaluation Buses
Fuel Economy – Hybrid and Diesel

Graph showing fuel economy over months for Hybrid Buses MCH and Diesel Buses MCH.
What’s Next

• Complete DOE/NREL evaluation - 12 months of operations for the Hybrid order of 125 and CNG buses starting October 2004

• Evaluation of Hybrid order of 200 just getting under way

• Reports
  - Fact sheet available
  - Interim report planned for Fall of 2005
  - Final report planned for mid-2006
Special Thanks

- New York City Transit
- Orion Bus
- BAE SYSTEMS
- U.S. Department of Energy
Early Hybrid Bus Experience at KC Metro in Seattle, WA

Kevin Chandler
Battelle
Agenda

• Quick KC Metro hybrid program description
• Hybrid and Diesel bus descriptions
• Early experience
• Plans for DOE/NREL evaluation
• What’s next
King County Metro Hybrid Bus Program

- Purchased 235 New Flyer/Allison Electric Drive articulated buses (October 2003) - $645,000 each
- Hybrid buses replacement for Breda dual-mode buses being retired
- Also purchased 30 diesel New Flyer articulated buses at the same time - $445,000 each
- Sound Transit received 22 hybrid (of the 235 buses) and 16 diesel articulated buses, all operated by KC Metro
# Vehicle Descriptions

<table>
<thead>
<tr>
<th>System</th>
<th>Diesel</th>
<th>Hybrid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bus</td>
<td>New Flyer 60’</td>
<td>New Flyer 60’</td>
</tr>
<tr>
<td>Engine</td>
<td>Caterpillar C9</td>
<td>Caterpillar C9</td>
</tr>
<tr>
<td></td>
<td>330 hp</td>
<td>330 hp</td>
</tr>
<tr>
<td></td>
<td>1150 ft-lb</td>
<td>1150 ft-lb</td>
</tr>
<tr>
<td>Emissions</td>
<td>2.5 g/bhp-hr NOx+HC; 0.05 g/bhp-hr PM using a DPF</td>
<td>2.5 g/bhp-hr NOx+HC; 0.05 g/bhp-hr PM using a DPF</td>
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<thead>
<tr>
<th>System</th>
<th>Diesel</th>
<th>Hybrid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric Propulsion</td>
<td>None</td>
<td>Allison E(^P)50 Parallel Hybrid System</td>
</tr>
<tr>
<td>Energy Storage</td>
<td>None</td>
<td>Nickel metal hydride batteries</td>
</tr>
<tr>
<td>Regenerative Braking</td>
<td>None</td>
<td>Yes</td>
</tr>
</tbody>
</table>
New Flyer Articulated Buses at KC Metro
Early Experience

• Introduction of 235 hybrid buses started in June 2004 and was completed by December 2004
• Hybrid buses reported as easy to put into service within 2-3 days after delivery
• By end of February 2005, fleet have completed ~4 million miles (~6 million miles as of today)
Average Monthly Mileage per Bus

![Graph showing average monthly mileage for different types of buses. The x-axis represents months from June 2004 to February 2005, and the y-axis represents mileage in thousands. Three types of buses are compared: Hybrid, ST Hybrid, and Diesel. The graph shows fluctuations in mileage for each type throughout the months.]
Roadcalls

The chart shows the trend of road calls from June 2004 to February 2005, categorized by fuel type: diesel and hybrid. The vertical axis represents the number of road calls ranging from 0 to 30,000. The horizontal axis represents the months from June 2004 to February 2005.

- **Diesel Total MBRC**: This line represents the total number of road calls involving diesel vehicles.
- **Diesel Propulsion MBRC**: This line indicates the number of road calls related to diesel propulsion.
- **Hybrid Total MBRC**: This line shows the total number of road calls involving hybrid vehicles.
- **Hybrid Propulsion MBRC**: This line represents the number of road calls related to hybrid propulsion.

The data suggests an increasing trend in road calls over the period, with diesel and hybrid vehicles showing notable increments.
Fleet Campaigns

- Axle snap rings – 8/04
- Soot filter replacement – 8/04
- Communication modules – 8/04
- Allison/CAT software upgrade – 9/04
- Door proximity switches – 10/04
- Center axle radius rod bolts – 11/04
- Wire chaffing over rear door – 12/04
- Master switch – 12/04
- Mirror drain holes – 1/05
Planned DOE/NREL Evaluation

• 10 Hybrid Buses at Atlantic Base (best match in operation compared to diesel buses) – Average speed of 11.2 mph
• 10 Hybrid Buses at South Base (first base to put hybrids into service) – Average speed of 19.2 mph
• 10 Diesel Buses at Ryerson Base – Average speed of 13.3 mph
• Collect and analyze operations data (bus usage, fuel, and maintenance) for 12 months starting with April 2005
Early Results for Evaluation Buses

- Data period for results that follow:
  - South Base Hybrids, 7/04-2/05
  - Atlantic Base Hybrids, 12/04-2/05
  - Ryerson Base Diesels, 7/04-2/05

- The following information represents early experience, NOT final results
Early Results for Evaluation Buses
Fuel Economy

- Diesel RB
- Hybrid SB
- Hybrid AB
Early Results for Evaluation Buses
Maintenance Costs per Mile

**Graph:**
- **Axis X:** Dates from Jul-04 to Feb-05
- **Axis Y:** Maintenance Costs per Mile (0.00 to 0.50)

Legend:
- **AB Cumulative Cost/Mile** (Red Diamond)
- **SB Cumulative Cost/Mile** (Blue Square)
- **RB Cumulative Cost/Mile** (Green Triangle)
### Early Results for Evaluation Buses

#### Fuel and Maintenance Cost/Mile

<table>
<thead>
<tr>
<th></th>
<th>Diesel RB</th>
<th>Hybrid AB</th>
<th>Hybrid SB</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fuel</strong> ($1.47/gal)</td>
<td>$0.614/mi</td>
<td>$0.466/mi</td>
<td>$0.396/mi</td>
</tr>
<tr>
<td></td>
<td>2.39 mpg</td>
<td>3.15 mpg</td>
<td>3.72 mpg</td>
</tr>
<tr>
<td><strong>Maintenance</strong></td>
<td>$0.433/mi</td>
<td>$0.456/mi</td>
<td>$0.396/mi</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>$1.047/mi</td>
<td>$0.922/mi</td>
<td>$0.791/mi</td>
</tr>
</tbody>
</table>
What’s Next

• Complete DOE/NREL evaluation - 12 months of operations for the 30 study buses starting April 2005
• Chassis Dynamometer Emissions Testing
• Reports
  - Fact sheet available
  - Interim report planned for end of 2005
  - Final report planned for mid-2006
Special Thanks

- King County Metro
- New Flyer
- Allison Electric Drives
- Caterpillar
- U.S. Department of Energy