NYCT CLEAN FUEL BUS PROGRAMS

Clear Air Initiative Workshop
Lima, Peru
July 11, 2001

Outline
- Overview of NYCT Bus Operations
- NYCT Goals
- NYCT “Clean Fuel” Bus Plan
- Compressed Natural Gas Buses
- Hybrid Electric Buses
- Clean Diesel Technologies
NYCT Bus Operations

- Number of Depots: 18
- Employees: 12,159
- Bus Routes / Bus Stops: 234 / 14,000
- Ridership: 2.0 million weekday
- Revenue Miles: 102 million annually
- Diesel Fuel Used: 40 million US Gal. in 1999

NYCT Bus Fleet

<table>
<thead>
<tr>
<th>Model</th>
<th>2001</th>
<th>2006</th>
</tr>
</thead>
<tbody>
<tr>
<td>40' 2-stroke Diesel Transit</td>
<td>1,349</td>
<td>0</td>
</tr>
<tr>
<td>40' 4-stroke Diesel Transit</td>
<td>2,085</td>
<td>2,370</td>
</tr>
<tr>
<td>45' 4-stroke Diesel Coach</td>
<td>450</td>
<td>450</td>
</tr>
<tr>
<td>60' 4-stroke Diesel Articulated</td>
<td>370</td>
<td>630</td>
</tr>
<tr>
<td>40' CNG Transit</td>
<td>221</td>
<td>646</td>
</tr>
<tr>
<td>40' Hybrid Transit</td>
<td>11</td>
<td>390</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>4,486</td>
<td>4,486</td>
</tr>
</tbody>
</table>
NYCT Goals

1. Reduce Bus Fleet Emissions
   - Achieve levels below current U.S. mandates

2. Improve Service
   - Improve equipment reliability
   - Achieve quieter operation

3. Reduce the Cost of Operations
   - Improve fuel economy
   - Reduce maintenance costs
   - Avoid infrastructure costs

NYCT “Clean Fuel” Bus Commitment

- Program is technology neutral, and combines several different approaches
  - CNG Buses
  - Hybrid Buses
  - Clean Diesel Technologies
- Designed to give cost-effective emissions reductions as quickly as possible
- MTA 2000 - 2004 Capital Plan includes $304 million for Clean Fuel Programs
2000 - 2004 Capital Plan

- Expand CNG Bus Operations
  - Purchase 300 buses and convert 2 depots to CNG

- Expand Hybrid Bus Programs
  - Purchase 250 hybrid buses
  - Develop hybrid articulated and coach buses

- Expand the Use of Clean Diesel technologies
  - Retire all 2-stroke diesel engines by 2003
  - Convert entire fleet to reduced sulfur fuel
  - Retrofit 3,500 buses with catalyzed exhaust filters

NYCT CNG Bus Program

- Have operated 34 CNG buses since 1995
- In 2000, the program expanded to 221 buses at one depot
- Have installed one fast-fill CNG fuel station capable of fueling 30 buses/hour
- Over 8 million miles operated in revenue service to date
- A second CNG depot is under construction, and 255 CNG buses are on order
**CNG Lessons Learned**

- CNG Buses work - they can be used to successfully provide passenger service
- CNG Buses are 20% less reliable than comparable diesel buses
- CNG buses are 20-40% less energy efficient than diesel buses in urban service
- CNG buses are significantly more expensive to operate than diesel buses in NYC - *actual cost experience for others is highly dependent on local situation/conditions*

**CNG Bus Reliability**

![Graph showing mean distance (miles) between in-service failures for CNG and diesel buses from January 2000 to June 2001.](image)
NYCT CNG Bus Costs

<table>
<thead>
<tr>
<th>Additional Costs Compared to Diesel Buses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintenance</td>
</tr>
<tr>
<td>Fuel</td>
</tr>
<tr>
<td>Bus Purchase</td>
</tr>
<tr>
<td>Fuel Station</td>
</tr>
<tr>
<td>Depot Modifications</td>
</tr>
</tbody>
</table>

Infrastructure Changes for CNG

- Natural Gas “Fuel Station”
  - Compressors & equipment to raise gas pressure from pipeline (<500 psi) to 3,000 psi or more
  - Size & cost dependent on required fueling time

- Safety Modifications in Bus Depot
  - Methane detection
  - Increased ventilation and emergency purging
  - Removal of areas for gas “pocketing” at ceiling
  - Removal of ignition sources at ceiling level
  - *Cost depends on size of facility and is much greater for constrained urban environments*
Hybrid Electric Buses

- Hybrid Electric buses combine a diesel engine and electric drive components
- Improved performance
  - Significant emissions reduction
  - Increased fuel economy
  - Smooth and quiet operation
- Avoids the infrastructure costs of CNG - no special fuel handling is required

BAE Hybrid System

- Lead Acid Battery Packs
- Power Electronics
- Diesel Engine
- Generator
- Electric Traction Motor
NYCT Hybrid Bus Programs

- Successful prototype in 1996 (Orion/GE)
- Hybrid retrofit for RTS bus - revenue service testing completed March 2000 (Allison/Nova)
- Two pilot fleets of hybrid buses ordered
  - 5 Orion/Lockheed buses entered revenue service 9/98; 5 more entered service 5/00
  - 5 Nova/Lockheed buses due by late 2001
- 325 additional Orion/Lockheed buses ordered for delivery in 2001 and 2003

Orion Hybrid Bus
Hybrid Revenue Service Experience

- Hybrid buses in service since Sept. 1998
- Over 340,000 revenue miles accumulated to date
- Very positive - for a brand new technology, have exceeded expectations
- Experience to date compares favorably to other new technology introductions
- NYCT is very encouraged for the future

Hybrid Emissions Testing

- Diesel hybrid electric buses offer emissions comparable to CNG buses
- 50-90% lower PM than standard diesel buses
- 30-60% lower NOx and HC
- 20-40% lower greenhouse gases than CNG or standard diesel
- Significantly better fuel economy than CNG or standard diesel
- Emissions testing data is available online at www.navc.org/emissionsreport.html
New York City Transit

Hybrid Bus Fuel Economy (mi/gallon)

- 8% increase in Manhattan
- 19% decrease in Brooklyn

Hybrid Bus Reliability (MDBF*)

- Hybrid Buses show improved reliability compared to Diesel Buses
- Mean Distance (Miles) Between In-Service Failures
**Hybrid Lessons Learned - Operational**

- Bus operators and passengers like hybrids
  - Quiet, smooth operation
  - Excellent acceleration/smooth braking
  - “Feels” like a standard bus
  - Little or no operator training required
- Able to be used on all NYCT routes
- Bus does not roll back on hills
- Performance can be customized

**Hybrid Lessons Learned - Technical**

- Premature motor & generator failures
  - Addressed through re-design
- Premature battery failures
  - Retrofit with batteries from a different manufacturer
  - Long-term solution is ultra-capacitors
- Integrated Diagnostic System (IDS) is being revised to flag problems sooner and troubleshoot problems more easily
Clean Diesel Fleet Replacement

- Modern diesel engines are 94% cleaner than engines purchased 10 year ago

- Retirement of older diesel buses, and replacement with new buses is an effective and cost-effective emissions reduction strategy

- As part of its clean fuel commitment, NYCT will retire all pre-1990 2-stroke diesel engines by 2003, either by retiring the bus, or by re-powering with a modern engine

NYCT Fleet PM Emissions

% of 1986 Baseline

Based on engine certification data
Advanced Exhaust After-Treatment

- Catalyzed Exhaust Filters
  - Oxidation catalyst and wall-flow ceramic filter
  - Packaged to replicate OEM muffler dimensions
  - No moving parts
  - No external energy requirements

- Reduced Sulfur Diesel Fuel
  - Base specification similar to #1 Diesel
  - Sulfur level of 30 ppm (350 - 500 ppm standard)
  - Lubricity enhancement

Johnson Matthey CRT™
**CRT™ Fleet Demonstration**

- 25 buses equipped with CRT catalyzed filters in revenue service in Manhattan for one year
- One entire depot (140 buses) operated on reduced sulfur fuel for one year (1.2 mill gallons)
- 4 buses equipped with continuous data loggers; others monitored monthly for changes in engine back-pressure, and fuel economy
- Emissions test program

**Operational Results**

- Prototype testing showed in-service exhaust temperatures to be acceptable for CRT
- Nine month Fleet demonstration Completed
  - CRT buses have logged over 750,000 miles (up to 40,000 miles/bus)
  - No CRT-related road calls; MBDF of CRT fleet is equivalent to non-CRT buses
  - No back-pressure problems
  - No measured loss of fuel economy
  - 24 CRT buses still in service
REGULATED EMISSIONS
Series 50 Bus on CBD Cycle

ULSD = 29 - 78% Reduction
ULSD + CRT = 88 - 94% Reduction

TOXIC EMISSIONS
Series 50 Bus on NYB Cycle - PAH

New York City Transit
**PM PARTICLE SIZE**  
Series 50 Bus on CBD Cycle (ELPI)

```
  1.0E+00  1.0E+01  1.0E+02  1.0E+03  1.0E+04  1.0E+05
  1.0E+06  1.0E+07  1.0E+08  1.0E+09  1.0E+10
```

<table>
<thead>
<tr>
<th>Size (nm)</th>
<th>dN/dlog(DP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>1.0E+00</td>
</tr>
<tr>
<td>60</td>
<td>1.0E+01</td>
</tr>
<tr>
<td>110</td>
<td>1.0E+02</td>
</tr>
<tr>
<td>180</td>
<td>1.0E+03</td>
</tr>
<tr>
<td>270</td>
<td>1.0E+04</td>
</tr>
<tr>
<td>420</td>
<td>1.0E+05</td>
</tr>
<tr>
<td>680</td>
<td>1.0E+06</td>
</tr>
<tr>
<td>1100</td>
<td>1.0E+07</td>
</tr>
<tr>
<td>1700</td>
<td>1.0E+08</td>
</tr>
<tr>
<td>2600</td>
<td>1.0E+09</td>
</tr>
<tr>
<td>4200</td>
<td>1.0E+10</td>
</tr>
</tbody>
</table>

Average Reduction 98.8%

**CRT FILTER AFTER 9 MONTHS**

- **CRT Inlet Section**
- **CRT Outlet Section**

New York City Transit
Clean Diesel Implementation

- Based on success of pilot program, NYCT has committed to aggressive implementation of Clean diesel technology fleet-wide
  - Convert entire fleet to ULSD (completed 9/00)
  - Retrofit entire fleet with catalyzed filters (450+ installed to date; 3,500+ NLT 12/03)
- In addition, NYCT will retire all 2-stroke engines NLT 12/03
  - Will require “re-powering” up to 800 buses with new 4-stroke EGR engines

Clean Diesel Costs

- Ultra Low Sulfur Diesel Fuel
  - $0.12/gallon incremental cost ($0.04/mile)
- Catalyzed Filter Installation
  - $5,000 - $7,000/bus with back-pressure monitoring
- Annual Maintenance
  - Remove filter, clean, and replace
  - 2 - 4 hour job
  - $100 - $200 per year per bus
# Clean Diesel Emissions Effects

<table>
<thead>
<tr>
<th>EPA Certified Emission levels (gm/bhp-hr)</th>
<th>HC</th>
<th>CO</th>
<th>NOx</th>
<th>PM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-1993 2-Stroke (6V92)</td>
<td>0.66</td>
<td>3.10</td>
<td>10.20</td>
<td>0.31</td>
</tr>
<tr>
<td>1993 2-Stroke (6V92)</td>
<td>0.23</td>
<td>0.81</td>
<td>4.30</td>
<td>0.17</td>
</tr>
<tr>
<td>1998 4-Stroke (Series 50)</td>
<td>0.10</td>
<td>0.90</td>
<td>3.80</td>
<td>0.04</td>
</tr>
<tr>
<td>2000 4-Stroke (Series 50) w/ EGR</td>
<td>0.02</td>
<td>0.16</td>
<td>3.47</td>
<td>0.03</td>
</tr>
<tr>
<td>1998 4-Stroke (Series 50) + Catalyzed Filter</td>
<td>0.01*</td>
<td>0.09*</td>
<td>3.80</td>
<td>0.004*</td>
</tr>
<tr>
<td>2002 4-Stroke (Series 50) w/ EGR + Catalyzed Filter</td>
<td>0.002*</td>
<td>0.016*</td>
<td>2.40**</td>
<td>0.003*</td>
</tr>
</tbody>
</table>

* Assumed levels based on chassis testing. Numbers represent a 90% reduction
** Assumed level in accordance with new EPA standards in effect October 2002

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# Further Information

- **Speaker Contact:**
  - Dana Lowell
  - MTA New York City Transit
  - (718) 927-8620; dalowel@nyct.com

- **Hybrid/CNG/Diesel Emissions Report**
  - www.navc.org/emissionsreport.html

- **Clean Diesel Emissions Report:**
  - Available from SAE at www.sae.org
  - Paper Number 2001-01-0511