

The Transit Bus Niche Market For Alternative Fuels:

Module 3: Overview of Compressed Natural Gas as a Transit Bus Fuel

Clean Cities Coordinator Toolkit

Prepared by
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Options for Natural Gas Fueling in Transit

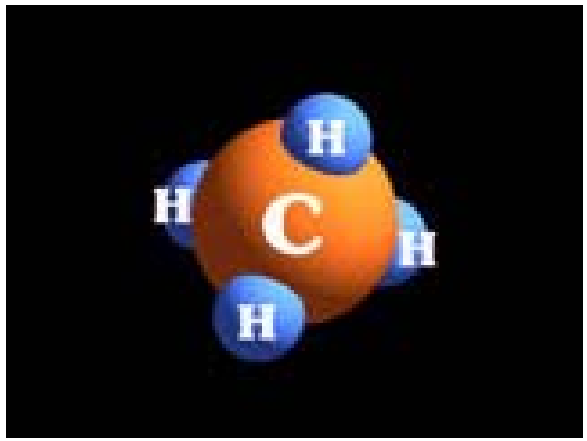
- Compressed Natural Gas (CNG)
  - Pipeline natural gas: methane with other hydrocarbons
  - Pressurized to 3,600 psi
  - Fueling accomplished by pressure transfer to vehicle
  - About 12% of transit buses in the U.S. now use conventional CNG
  - Largest users include LACMTA, MARTA, NY DOT, Pierce Transit, Washington D.C. (WMATA), Cleveland, Sacramento
- Liquefied Natural Gas (LNG)
  - Nearly pure methane (~98%) liquefied at very low temperatures
  - Liquid transfer to vehicle
  - Largest users are Phoenix, Orange County (CA), Dallas, and Tempe
  - Newer users include Santa Monica, Long Beach
- LNG to CNG ("LCNG")
  - Vaporized LNG (also nearly pure methane)
  - Liquid to gas conversion, then pressure transfer to vehicle
  - Sun Metro, OmniTrans, others use this approach

Methane Content in Pipeline Natural Gas Varies Regionally

Methane	CH_4	70-90%
Ethane	C_2H_6	0-20%
Propane	C_3H_8	
Butane	C_4H_{10}	
Carbon Dioxide	CO_2	0-8%
Oxygen	O_2	0-0.2%
Nitrogen	N_2	0-5%
Hydrogen sulphide	H_2S	0-5%
Rare gases	A, He, Ne, Xe	trace

Typical Composition of Pipeline Natural Gas

Methane Molecule



What are the Implications of the Resulting **CNG Fuel Quality** Variations?

- CNG with lower methane content (higher levels of ethane, propane, or butane) has resulted in some adverse affects on heavy-duty NG engine performance (e.g., misfire, stumble and underrated operation, engine knock, overheating)
- However, today's lean-burn closed-loop NG engines for transit (e.g., C Gas Plus and DDC S50G) are better able to tolerate and compensate for variations
- Compromises in emissions performance have been found to be modest

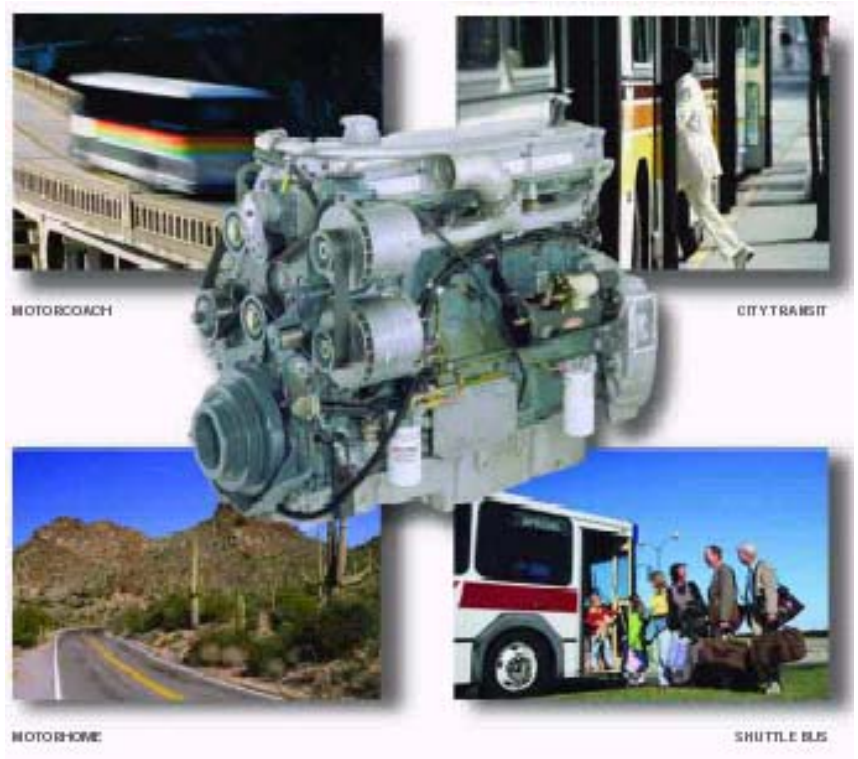
Numerous OEMs Offer Natural Gas Transit Buses and Paratransit Vehicles

Bus Manufacturer	Natural Gas Models Available
Champion Bus, Inc.	6
Neoplan USA Corporation	6
El Dorado National	5
Blue Bird Corporation	4
New Flyer of America	4
North American Bus Industries	4
Chance Coach, Inc.	2
Nova Bus, Inc.	2
Omnitrans	2
Freightliner Custom Chassis	2
Motor Coach Industries	1
Orion Bus Industries	1

= Nearly 40 NG Models

The Detroit Diesel Series 50 Engine is Widely Used in Transit Applications

- Tens of thousands currently in use, nationwide (most are diesel version)
- 4 cylinder, inline engine with 8.5 liter displacement
- **Diesel version:**
  - 275 HP @ 890 lb-ft of torque
  - equipped with EGR system to meet 2002 / 2004 NOx standard
- **Natural gas version (Series 50G):**
  - 275 HP @ 900 lb-ft of torque
  - 2003 MY certified at 1.2 g/bhp-hr NOx and 0.01 g/bhp-hr PM (California)
  - Closed-loop DDEC controlled fuel system and coil-over-plug ignition system
  - Aftertreatment: oxidation catalyst
- Key users of the S50G include LACMTA, Cleveland Transit, Orange County Transit, and many others



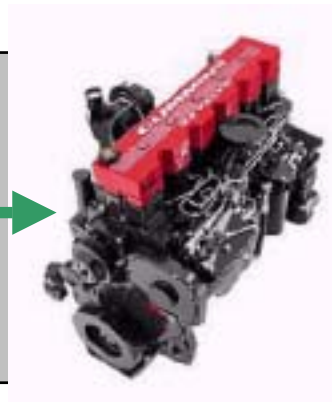
Photos from Detroit Diesel Corporation website

The Cummins-Westport C Gas Plus Engine is also a Key Transit Powerplant

- Launched in 2001
- Approximately 1,500 now in use
- Used by most major transit bus makers
- Designed primarily for 40-ft transit buses
  - 32,000 to 66,000 GVW
  - 280 HP / 850 lb-ft @ 1400 RPM
  - 6 cylinders, 8.3 L
- Easily meets 2004 U.S. and CARB standards for heavy-duty trucks and buses
  - Closed loop, lean burn and oxidation catalyst
  - Drive-by-wire technology, advanced electronic controls, improved sensors, knock detection and wider range fuel capability
- Up to 14 dBA quieter than diesel version of Cummins 8.3 engine (at idle, noise from 10 NG engines = 1 diesel engine)

Cummins-Westport C Gas Plus Heavy-Duty Natural Gas Engine (photo from Pierce Transit)

Note: Cummins-Westport will launch the larger (8.9 liter) "L Gas Plus" engine for transit buses in mid 2004



Cummins L Gas Plus

(For more info: see http://www.afdc.doe.gov/pdfs/32871.pdf)

Examples of Transit Users for the Cummins-Westport C Gas Plus Engine

CNG - **Pierce Transit, Seattle / Tacoma**

- 235 total buses, 176 on CNG
- 38 MY 2002 and MY 2003 buses with C Gas Plus engine
- Chassis: New Flyer C40 LF (low floor)
- Average miles per year on CNG buses: 42,000
- Range of CNG buses: 350 miles
- Improved durability, reliability, engine life over early versions of CNG engines

LNG - **Valley Metro Transit, Phoenix**

- 380 total buses, 296 on LNG
- 96 MY 2002 buses with C Gas Plus engine
- Average miles per year on CNG buses: 42,000
- Range of LNG buses: 350 miles

A CNG bus at Pierce Transit (photo from Pierce Transit)

EESI's National "Clean Bus Leaders"

Environmental and Energy Study Institute
EESI

The Environmental and Energy Study Institute (EESI) recently recognized several local initiatives for "leading the nation in investment of cleaner fuels and vehicle technologies in bus transit systems."

Awardees included:

- Pierce Transit Agency (Tacoma) -- 17 years of using **CNG** buses. Expected to be 100% CNG in the next few years. Clean Cities National Partner Award, 1999.
- Regional Transportation Commission of Southern Nevada, Citizens Area Transit -- 9 **CNG** buses have been put into operation and 48 more are on order. Considering options for purchase up to 600 more buses.
- SunLine Transit Agency -- 100% alternative fuel fleet, including **CNG**, Hythane, and fuel cell buses
- NYC Transit -- **CNG** and hybrid-electric buses
- New Haven -- electric bus trolley fleet. Beginning in 2002, deployed four 22-foot electric trolley. Greater New Haven Clean Cities Coalition is exploring the option to further deploy hybrid-electric or fuel cell buses in the area.

Cummins-Westport B Gas Plus: Key Powerplant for Smaller Buses

- Designed primarily for:
  - 32-foot transit buses and shuttle buses
  - specialty vehicles for paratransit
- 5.9 liter, 6 cylinder dedicated CNG engine
- Available in 250 HP, 275 HP and 280 HP for transit bus applications
- Easily meets 2004 U.S. and CARB standards for heavy-duty trucks and buses (same technologies as C Gas Plus engine)
- Up to 14 dBA quieter than diesel version of Cummins 5.9 engine (at idle, noise from 10 NG engines = 1 diesel engine)
- **Citizens Area Transit (Las Vegas)** was the first transit agency to order buses with the new B Gas Plus engine
  - 51 engines ordered for use in paratransit buses (mid '03 delivery)
  - 28-foot buses with Freightliner MB-45 shuttle bus chassis

Cummins-Westport B Gas Plus Heavy Duty Engine

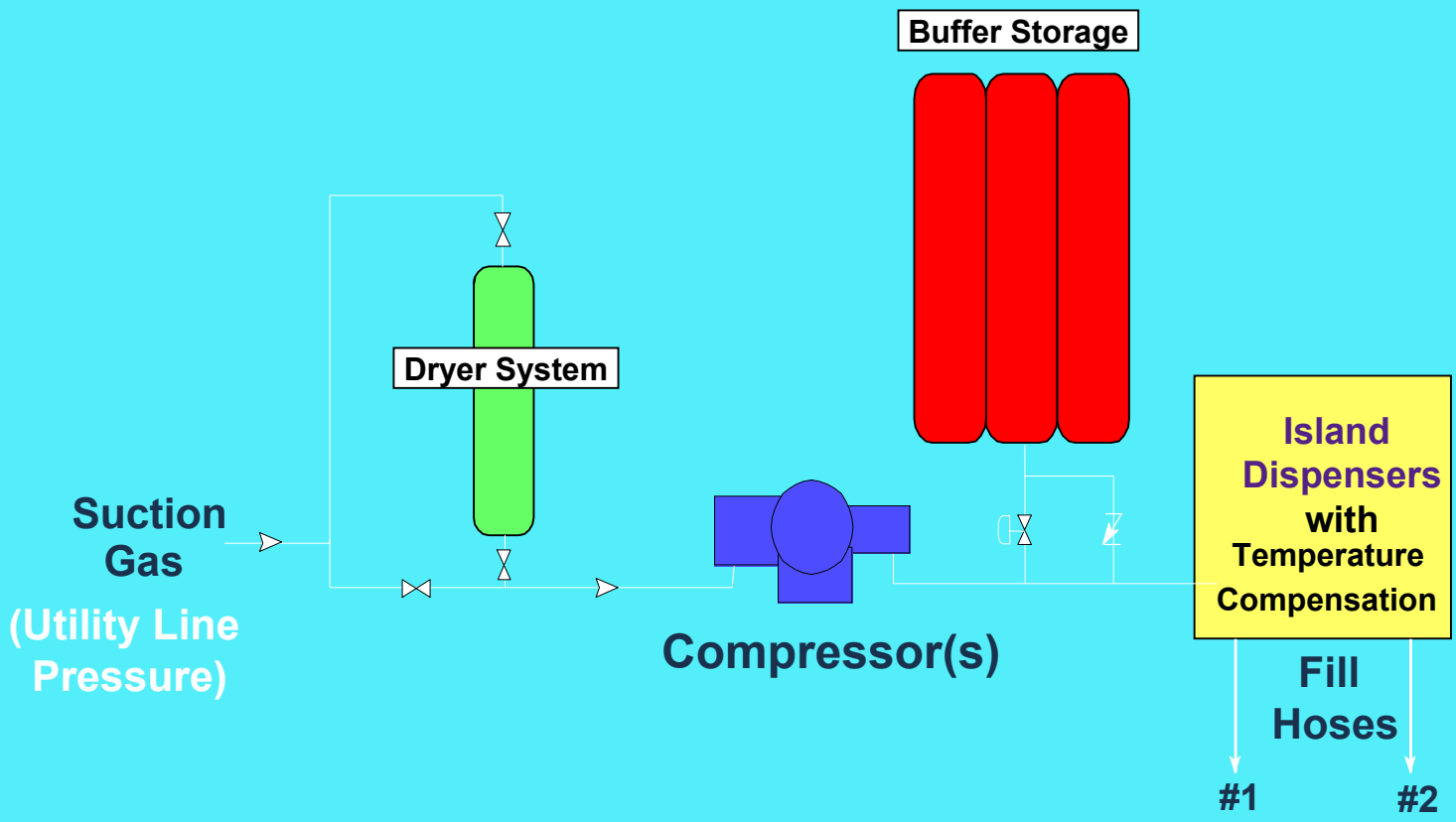
Photo from www.freightlinerchassis.com

Overview of CNG Fueling Infrastructure, and Examples of CNG Transit Bus Fleets

Functions of a Mainstream, Large-Scale CNG Station

- Remove undesirable constituents of pipeline natural gas (e.g., H20):
- Compress gas to above 3,600 psi
- Further remove moisture from compressed gas
- Remove oil carryover resulting from gas compression process (if any)
- Direct CNG to storage system
- Store CNG on site
- Dispense CNG to vehicles
  - Meter amount of fuel
  - Provide acceptable refueling time (close to diesel case)
  - Provide complete fuel fills
- Provide safety and emergency shutdown systems

Most CNG Stations for Large Transit Applications Use Buffer Fast-Fill Fueling Systems



Based on diagram from NGV Institute (www.ngvi.com)

Facilities Modifications for Natural Gas Stations (CNG or LNG):

- Facilities such as maintenance buildings, fueling structures, parking garages, and other support facilities may need modification
- All facilities where natural gas might be released inadvertently must be given special consideration
- Combustible gas detection and higher than usual capacity ventilation must be installed
- Proper mitigation strategies for natural gas must be developed in case of an accidental release. In general, the mitigation strategies will include:
  - Increased air flow/ventilation (more air exchanges per hour)
  - Combustible gas detectors
  - Visual and audible alarms
  - Upgraded electrical systems and explosion-proof lighting / fixtures
- In general, the older the facility, the higher the cost for upgrades due to more extensive work required to upgrade the ventilation and electrical systems
- Local fire marshals are often unfamiliar with NG fueling stations, and tend to rule strongly on the side of **over-engineering** safety measures

Source: Based on Battelle's *LNG Resources Guide*

Use of a Turnkey Fuel Provider in Transit Applications

- Advantages include:
  - Lower life-cycle cost
  - All technical risk assumed by private partner
  - Less demand on customer's resources; allows focus on transit business
  - Supported by Federal Transit Administration
  - Multiple options available for up-front costs
- Fuel Provider:
  - Permits, designs, builds, owns, operates, and maintains fueling station
  - Handles site preparation (e.g., gas supply) and customer training
- Customer:
  - Establishes performance requirements
  - Approves site layout
  - Responsible for building modifications
  - Provides fuel demand **(VOLUME, VOLUME, VOLUME)**

Trillium USA is One "Turnkey" CNG Provider for the Transit Bus Niche

- Currently responsible for daily fueling of 1,000 CNG buses, nationwide
- Reports delivering 148 site-months of CNG transit fueling with no failure of service (through August 2003)
- "Performance clauses" apply on both sides of the agreement
- Trillium supports user fleets to keep buses rolling out:
  - "24 / 7" remote support, diagnostics and control from headquarters
  - Automatically responds to shut downs
  - Provides web cameras at each CNG dispenser and compressor compound
  - Deploys locally based technicians to operate and trouble shoot stations
  - Maintains extensive on-site inventory of spare parts and equipment

Trillium USA

Los Angeles County Metro Transportation Authority

- Third largest U.S. transit bus fleet by total number of buses (2,714)
- 2nd largest U.S. transit bus fleet by number of passenger miles
- Most CNG transit buses in America (1,945 existing 40ft. CNG buses, 102 on order)
- 400 new 60' articulated CNG buses (NABI) will be phased in from 2005-2007
- To be powered by the Cummins-Westport L Gas Plus engine (launch in 2004)
- Motivating factors towards CNG include: So. Coast AQMD Rule 1192 and CARB's statewide transit bus fleet rule

Average price paid by LACMTA for 40 ft. CNG bus: **$320,000**

2002 NABI 40 ft low floor CNG transit bus used by Los Angeles County MTA

Los Angeles County MTA: Typical Large CNG Station for Transit Buses

- Each division uses 3 gas-drive compressor skids (1 redundant)
- Three to four fuel dispensers
- No single failure will shut down the whole station

LACMTA Div 7, West Hollywood, CA. Close-up of compressor compound

LACMTA Div 7, West Hollywood, CA. CNG station (fueling area partially visible on the left)

Sacramento RT Owns, Operates and Maintains its CNG station

- Station cost w/ upgrades since 1993: $8.4 million
- Inlet gas supplied at 400 psi
- A total of five 3-stage Ariel electric-drive compressors increase gas pressure to 4,250 psi
- Relatively high “suction” pressure allows fewer stages of compression
- Moisture is removed in twin-tower regenerative driers

Photos courtesy of Charles Powars

- CNG then sent to buffer storage vessels rated at 60,000 scf @ 5,000 psi
- This equates to CNG for about 50 buses @ 3,600 psi
- Refueling time per bus is 4 to 5 minutes
- Fuel fills are about 93% (using heat- of-compression compensation)
- Initial fuel quality issues resolved
- Total CNG cost = $0.45 / therm or $0.63 per DGE

Sacramento RT Uses a Typical CNG Fueling Island for Transit Buses

Sacramento uses 4 CNG dispensers on 2 fueling islands.

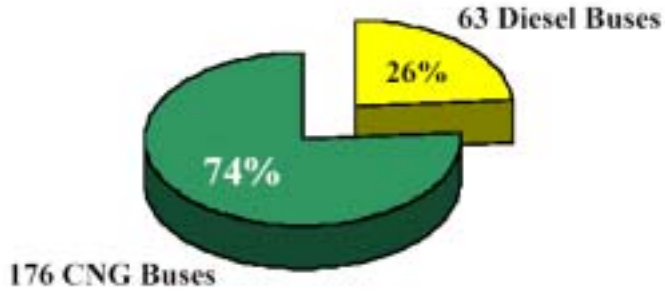
Other CNG Transit Bus Users in California Include (Existing & Ordered):

- **Golden Empire Transit (Bakersfield):** 41 of 73 transit buses
- **Chula Vista Transit:** 25 of 37 transit buses
- **Culver City Municipal Bus Lines:** 38 of 45 transit buses
- **Fresno Area Express:** 25 of 102 transit buses
- **City of Glendale Beeline:** 31 of 35 transit buses
- **South Coast Area Transit (Oxnard):** 43 of 48 transit buses
- **North County (San Diego) Transit District:** 52 of 169 transit buses
- **San Diego Transit Corporation:** 249 buses of 299 transit / articulated buses
- **Riverside Transit Agency:** 105 of 238 transit buses
- **Foothill Transit:** 112 of 299 transit buses
- **Sunline Transit:** 58 of 65 transit buses (including 2 CNG / Hydrogen buses)

Source: 2003 APTA survey

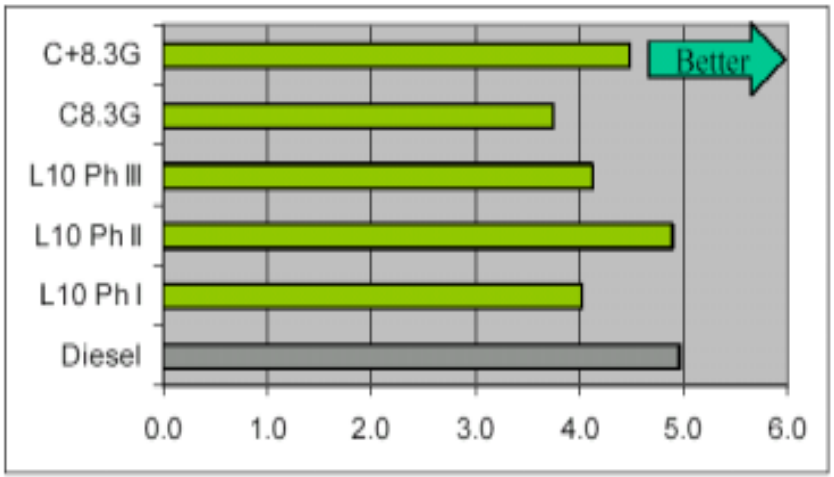
Pierce Transit: a Case Study in Making CNG Transit Buses Successful

- Operates 176 CNG buses (239 total)
- Moving towards 100% CNG fleet
- '91 to '03 MY buses; 5 generations of Cummins NG engines
- Newest engine (280 HP / 850 ft.lb. C Gas Plus) used in two distinct services:
  - 2002 New Flyer C40LF (20 buses) in **express service**, averaging 64,000 miles per year per bus
  - 2003 New Flyer C40LF (18 buses) in **local service**, averaging 17,000 miles per year per bus
- Station expansion to include LCNG
- **Pierce Transit future goal:** procure and test CNG-fueled hybrids

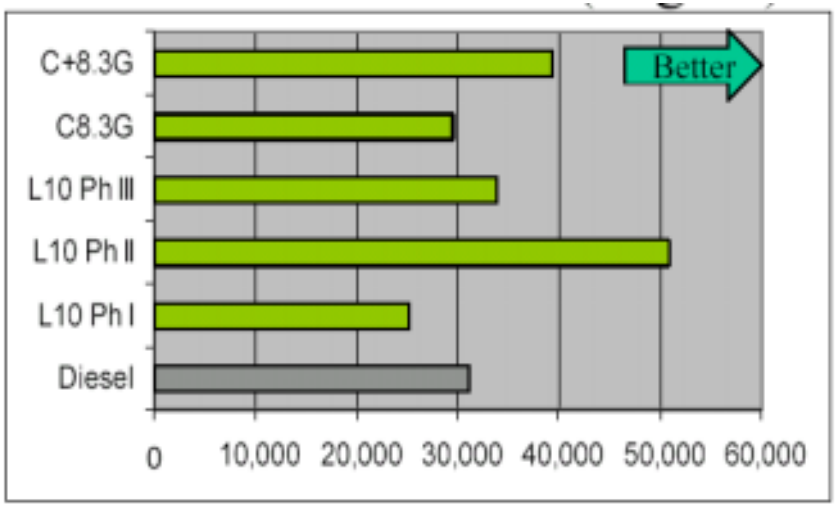


Source of information and photos: Don S. Monroe, CEO Pierce Transit, "Transitioning to CNG," presentation at 9th National Clean Cities Conference, Palm Springs, CA, May 2003.

Comparisons of CNG and Diesel Buses at Pierce Transit



Miles per diesel gallon equivalent at 137,000 BTU/diesel gallon



Miles between engine-related road failures

Summary of Findings

NG buses achieve 10% to 25% lower fuel efficiency than diesel buses.

NG engines have been very reliable (miles between road failures)

Newest NG buses have lower **total cost per mile** than diesel buses.

NOTES: 1) Various generations of Cummins NG engines were tested. 2) Diesel baseline were not defined in report.

Source : Don S. Monroe, CEO Pierce Transit, "Transitioning to CNG," presentation at 9th National Clean Cities Conference, Palm Springs, CA, May 2003.

Washington Metro Transit: An Emerging, Customized CNG Success Story

- Currently owns 164 **CNG transit buses**:
  - MY 2001 New Flyer C40LG (low floor)
  - Cummins C Gas Plus engine w/ oxy cat
  - 7 roof-mounted CNG tanks, holding a total of 21,161 scf natural gas (152 DGE)
  - All 164 are fueled and maintained at the $8 million Bladensburg Garage
- 250 more CNG buses on order or planned
  - New Four Mile facility was originally intended to dispense LCNG from **LNG** stored in 30,000 gallon bulk tank (to avoid a 3.5 mile NG pipeline expansion)
  - However, conventional CNG was ultimately decided upon
- WMATA's main fleet consists of about 1,400 **diesel transit buses**
  - MY 2000 Orions (low floors) with DDC Series 50 engines
  - Most equipped with oxy cats, all using 18 ppm sulfur diesel

WMATA's Activities to Complete CNG Fueling Facilities

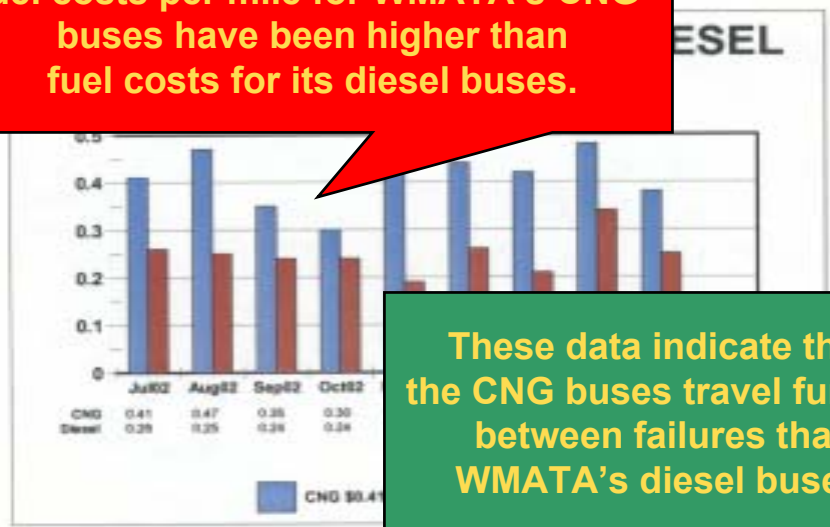
- **Renovations are underway to make the existing facility meet local code**
  - **Enhanced ventilation and heating**
  - **New generators for backup emergency power**
  - **Upgrades and the addition of doors and walls to achieve more stringent fire ratings**
  - **Installation of methane detection / control system**
  - **Emergency lighting system**
- **March 2004 targeted for completion**
- **High cost to upgrade Four Mile facility includes asbestos abatement**

WMATA will host emissions testing in 2004 by DOE/WVU. This will be one of the first "apples to apples" test programs of CNG and diesel buses optimized for NOx / PM control.

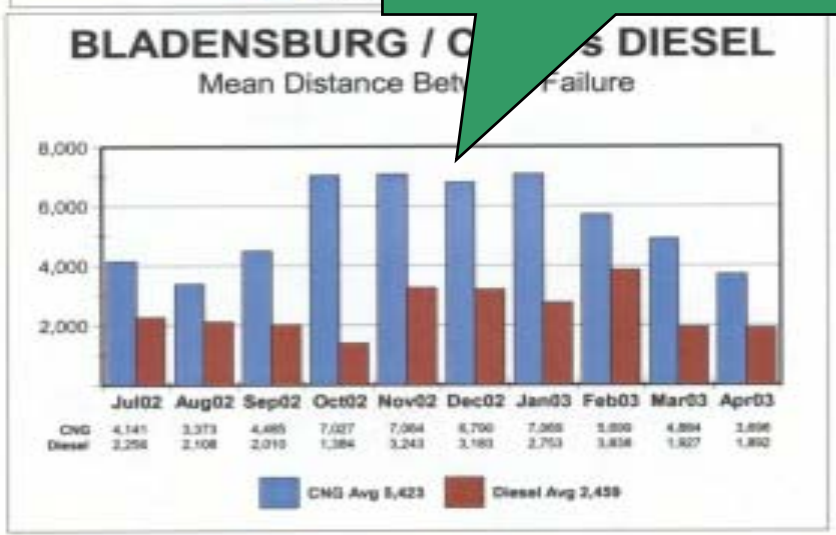
Sources: WMATA press releases from website http://wmata.com and NREL

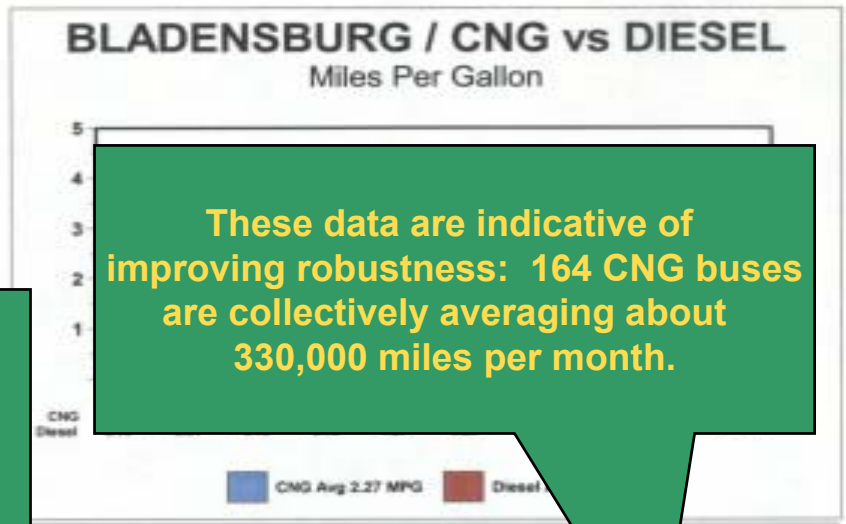
WMATA Data on CNG vs. Diesel Bus Fleets

These data indicate that fuel costs per mile for WMATA's CNG buses have been higher than fuel costs for its diesel buses.

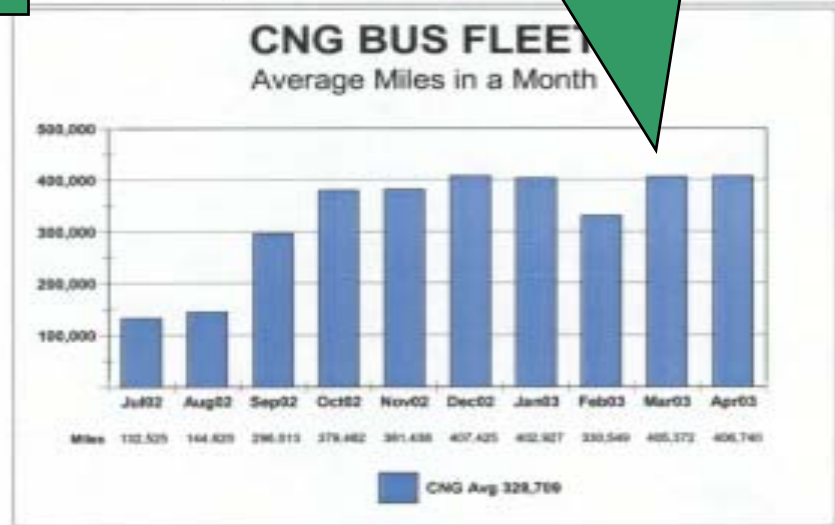


These data indicate that the CNG buses travel further between failures than WMATA's diesel buses.





These data are indicative of improving robustness: 164 CNG buses are collectively averaging about 330,000 miles per month.



Massachusetts Bay Transportation Authority (MBTA) is Moving Into CNG

Bus Fleet

- About 1,000 active transit buses
- 2003 model CNG buses are being purchased, consisting of:
  - 44 articulated (60-ft) CNG buses
  - 74 transit (40-foot) CNG buses
- Up to 580 new CNG buses may be phased in over next several years

Fueling Infrastructure

- **Clean Energy** has been contracted for 2 new transit bus CNG fueling facilities
- $30 million, 10-year agreement will include
  - Design, construction and equipping of the two new stations
  - Operating and fueling for approximately 250 buses initially
- The facilities are designed to accommodate more buses in the future as MBTA's CNG bus program expands

Maintenance Facility

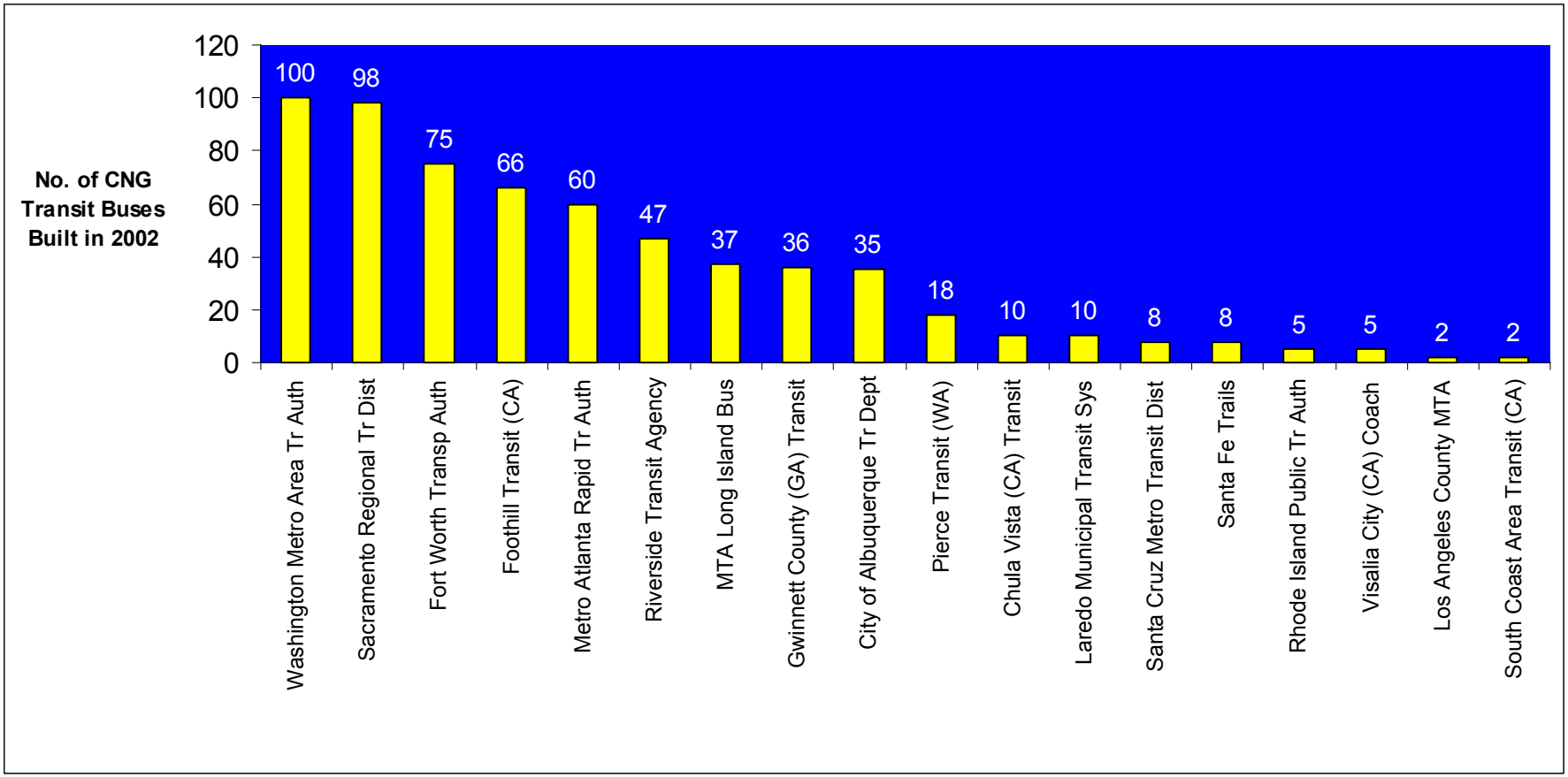
- MBTA is building a 342,470 sq.ft. CNG bus storage and repair facility

Other CNG Users in the Northeastern and Mid-Atlantic U.S. Include:

- MTA Long Island Bus: ~275 transit buses (40 ft. Orion Bus Industries)
- CNY Centro (Syracuse): 5 transit buses (35 ft. Orion Bus Industries)
- Rhode Island Public Trans.Authority: 5 transit buses (35 ft. New Flyer)
- New Jersey Transit: 77 intercity buses (40 ft. MCI)
- Centre Area Transportation Authority (State College, PA): 44 (undefined type)
- Montgomery County (MD) Transportation Services: 38 (undefined type)
- Berks Area Reading Transportation Authority: 12 (undefined type)
- Arlington County (VA) Dept. of Public Works: 8 (undefined type)
- Allegheny County (Pittsburgh) and Indiana Co. (PA): 5 each (undefined type)
- Niagara Frontier Transportation Authority:
  - 5 transit buses (40 ft. Bus Industries of America)
  - 15 bi-fuel (CNG/gasoline) trolley buses (30 ft. GM)
- Greater Portland (Maine) Transit District:
  - Up to 25 CNG buses planned for the immediate term

Which Transit Districts Ordered CNG Buses in 2002? WMATA and Others

APTA Survey Data on Number of CNG Buses Built in 2002 for Specific Transit Districts



Source: 2003 APTA Survey, Table 82.

NOTES: Refers to Transit Buses >27'6" in length with 2 doors.
Some vehicles were built late in the year and delivered in 2003.

Overview of Safety and Training Issues

CNG Tanks Can Be Installed On Rooftop or Under the Floor

Fiberglass "Gull Wing" Shrouds

Roof Mount NGV tanks.

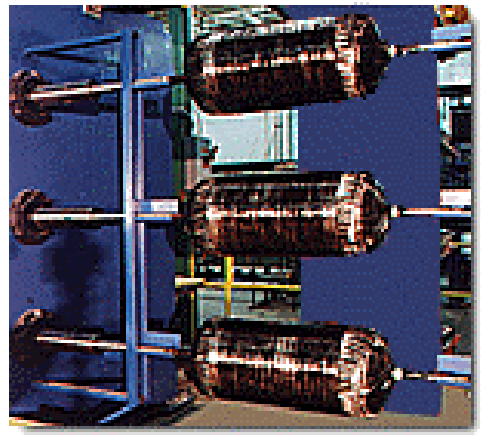
Chassis Mount NGV tanks.

Sacramento RT's 152 CNG buses use roof-mounted CNG cylinders. This enables purchase of low-floor buses, which many transit agencies prefer.

Other agencies mount their CNG cylinders to the chassis under the floor, which requires high-floor buses.

CNG Tanks are getting safer, lighter, and holding more natural gas

- The high pressure (typically 3,600 psi) of CNG fuel systems requires special tanks constructed from either steel, carbon composite, or aluminum
- CNG composite fuel cylinders offer the best combination of light weight and durability
- The weight and costs of CNG tanks are important factors to consider when specifying the number and types of tanks to be put on a bus (range issue)
- Higher pressure systems are being developed, but primarily for hydrogen applications
- 3,600 psi is likely to remain the limit for CNG transit bus applications (according to the NGV Coalition)
- Current state-of-art cylinder construction:
  - Aluminum collar interlocking with high-density polyethylene thermoplastic liner
  - Wound using carbon/glass and fiberglass outer skin
  - Final outer shell has an energy absorbing material that protects cylinder from abrasion



High rate three spindle filament winding.

CNG Cylinder Safety

- CNG fuel containers (cylinders) should be visually inspected for damage or deterioration at least every 36 months or 36,000 miles, whichever comes first
- Qualified inspector must note cuts, cracks, gouges, abrasions, discoloration, broken fibers, loose brackets, dam-aged gaskets or isolators, heat damage or other problems, and recommend proper action to assure safety
- In addition to the regular 3-year/36,000 mile inspection, CNG containers should undergo a detailed visual examination for damage or deterioration after a motor vehicle accident
- All CNG vehicle fuel containers now in use are required to meet Federal Motor Vehicle Safety Standard 304 (Compressed Natural Gas Fuel Container Integrity)
- Almost all vehicle fuel containers currently meet the natural gas vehicle (NGV) industry standard ANSI/IAS NGV2 (Basic Requirements for Compressed Natural Gas Vehicle Fuel Containers)
- Both standards specify a detailed visual examination every three years. NGV2 further states that the inspection follow the procedures in Compressed Gas Association (CGA) pamphlet C-6.4 (Methods for External Visual Inspection of Natural Gas Vehicle Fuel Containers and Their Installations) and the container manufacturer's recommendations
- However the container shall not be removed from the vehicle unless damage or deterioration is seen on the exposed container surface.

Good Training is Absolutely Essential for Transit Districts Using Alternative Fuels and New Technologies

- Fueling station design, procurement, and installation
- Fueling station operation including monitoring
- Fueling station maintenance
- Driver/fueler safety
- Vehicle mechanic technical and safety
- Vehicle fuel cylinder inspection
- Facility modifications

Station vendors offer training, but many transit agencies using NG offer their own programs or send employees to training schools (e.g.,NGV Institute)

Fueling monitors from the control room must be trained also

For CNG Training Issues Nationwide:

- The **NGV Institute** conducts regular training workshops for CNG users on:
  - Fueling station design, procurement and installation
  - Fueling station operation and maintenance
  - Driver and fueler safety
  - Vehicle mechanic safety
  - Vehicle fuel cylinder inspection
  - Facility modifications
- NGVI is a DOE / NREL Tiger Team member with services available to Clean Cities Coordinators
- NGVI prepared Alternative Fuels and Vehicles Training Resource Guide for Transit Districts, April 2003 (http://www.ccities.doe.gov/pdfs/32534.pdf)

NGV Institute
Leo Thomason
Executive Director
3802 Ruskin Street
Las Vegas, NV 89147-1071
www.ngvi.com

- The National Alternative Fuel Training Consortium (WVU) also conducts NGV training

Summary: CNG works very well as a transit bus fuel (in the right situations)

- CNG is the dominant alternative fuel used in transit applications today
- CNG transit vehicles are now successfully displacing nearly 70 million gallons of diesel per year across America
- Many transit agencies are moving towards 100% CNG fleets
- AQ benefits are strong and well documented (Module 10), but diminishing
- High capital and operational costs make grant funding essential
- Use of “turnkey” CNG providers may be the most cost-effective choice for transit operations -- if they use large volumes of fuel, and/or share a station
- Challenging operational issues (e.g., reduced energy efficiency and bus range) can all be managed through commitment to success
- Life-cycle costs for CNG buses appear to be decreasing, while life-cycle costs for diesel buses are likely to increase
- Strong training programs are essential (internal, or from the outside)
- Valuable support exists for Clean City Coordinators to work with transit agencies (see Module 11 for lists of resources)
- CNG is “bridge technology” to hydrogen fuel cells (20+ years; see Module 8)