The Transit Bus Niche Market For Alternative Fuels:

Overview of Clean Cities Coordinator Toolkit and Recent Trends with Alternative Fuel Buses

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Name and Objectives of the Project:

Official project name: "Market Analysis of Transit as an Alternative Fuel Niche Fleet"

Objectives:

- **Assess the current status** of alternative fuel use in transit bus applications
- **Provide** Clean Cities Coordinators with **the data and tools** necessary to:
  - **Better understand** transit fleet operations involving alternative fuels
  - **Identify opportunities and successful strategies** to increase AF use in the sector
  - **Work with the most-promising local transit agencies** to begin using alternative fuels, or expand existing operations

Deliverables:

- Workshops at regional Clean Cities meetings
- Cost evaluation tool for transit fleets
- Coordinator "toolkit" (Powerpoint modules on CD ROM)

The Electronic Toolkit Includes the Following "Modules" of Information:

MODULES BY DESCRIPTION

Module 1: ***Intro / Characterization of the Transit Bus Niche***

Module 2: ***Basics of Alternative Fuels for Transit Buses***

Module 3: ***CNG as a Transit Bus Fuel***

Module 4: ***LNG as a Transit Bus Fuel***

Module 5: ***Propane (LPG) as a Transit Bus Fuel***

Module 6: ***Biodiesel as a Transit Bus Fuel***

Module 7: ***Emerging Diesel Technology and Hybrids in Transit***

Module 8: ***Advanced Hybrid and Fuel Cell Bus Technologies***

Module 9a: ***Introduction to Transit Bus 1.0 Cost Model***

Module 9b: ***Transit Bus 1.0 Cost Model (MS Excel Program)***

Module 10: ***Emissions Benefits of Alternative Fuel and Advanced Technology Transit Buses***

Module 11: ***List of Contacts and Resources***

Mod01_Transit Intro.ppt
Mod02_AF Basics.ppt
Mod03_CNG.ppt
Mod04_LNG.ppt
Mod05_LPG.ppt
Mod06_Biodiesel.ppt
Mod07_AdvDiesel.ppt
Mod08_ZEBs.ppt
Mod09a_IntroCost.ppt
Mod09b_Transit Cost.xls
Mod10_Emissions.ppt
Mod11_Resources.xls

Modules by file name

Note: it takes about 2 hours to provide a full description of the complete toolkit!

A key premise for this toolkit is:

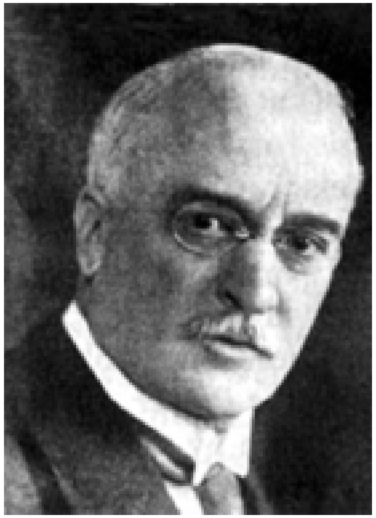
"Knowledge is power."

-Francis Bacon, 1597

The best approach to help a transit agency commit to alternative fuels / clean technologies is to gain as much knowledge as possible about:

- ***The transit "niche" in general,***
- ***The specifics of various available technologies, and***
- ***Unique circumstances and operational characteristics of that particular agency.***

A Key Basic Point: Diesel is the Standard Fuel of the Transit Niche *What is diesel?*



Rudolf Diesel (1858-1913)
Inventor of Diesel Engine

It's a liquid hydrocarbon fuel packed with energy . . .

. . . used in large heavy-duty engines

. . that power our heavy-duty transportation sector . . .

. . .while emitting harmful NOx and PM emissions.

The diesel engine is the backbone of our economy <u>and</u> a threat to our health.

Understanding the "competition" for alternative fuels is essential

Today's diesel engines offer many advantages . . .

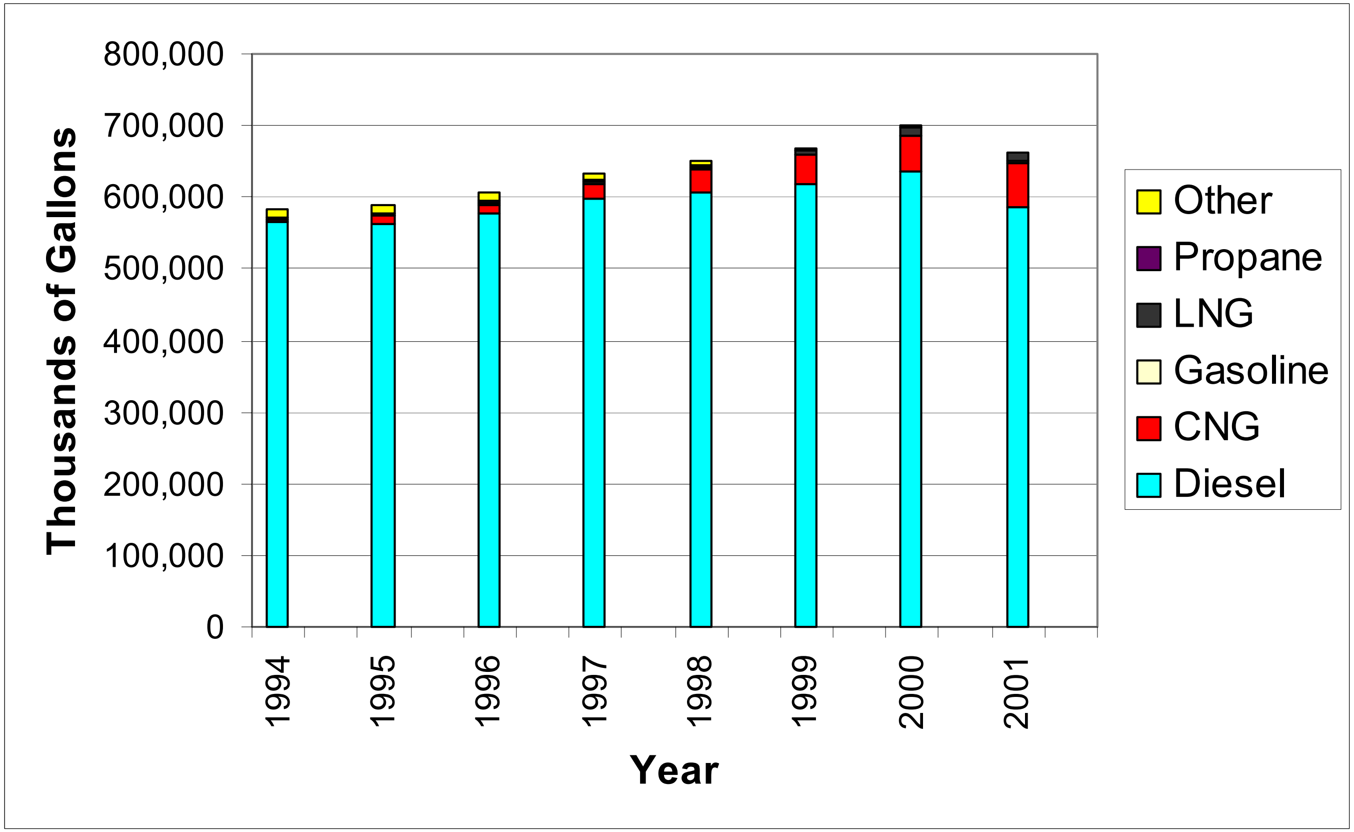
- **Safety** - Diesel is a safer fuel than gasoline and some of the alternatives (less flammable and explosive).
- **Energy Density** - Diesel fuel contains the highest energy per gallon of currently available transportation fuels. This delivers good vehicle range.
- **Efficiency** - diesel engines operate in a "lean" (excess air) combustion mode, which provides inherently high fuel efficiency and minimizes CO_2 emissions.
- **Performance** - Diesel technology has a greater power density than other fuels - it packs more power per unit volume than other fuels.
- **Durability** - Diesel engines are renowned for their durability, lasting hundreds of thousands of miles. This helps conserve resources.
- **Continuous Improvements** - Significant progress has been made in reducing emissions from diesel engines of all kinds. Today's trucks and buses are eight times cleaner than those built just a dozen years ago.

Key Questions: **1) Can H-D diesel engines meet the increasingly stringent 2007 to 2010 emissions standards? 2) At what cost?**

Nearly 89% of the fuel consumed in the U.S. transit bus sector is diesel

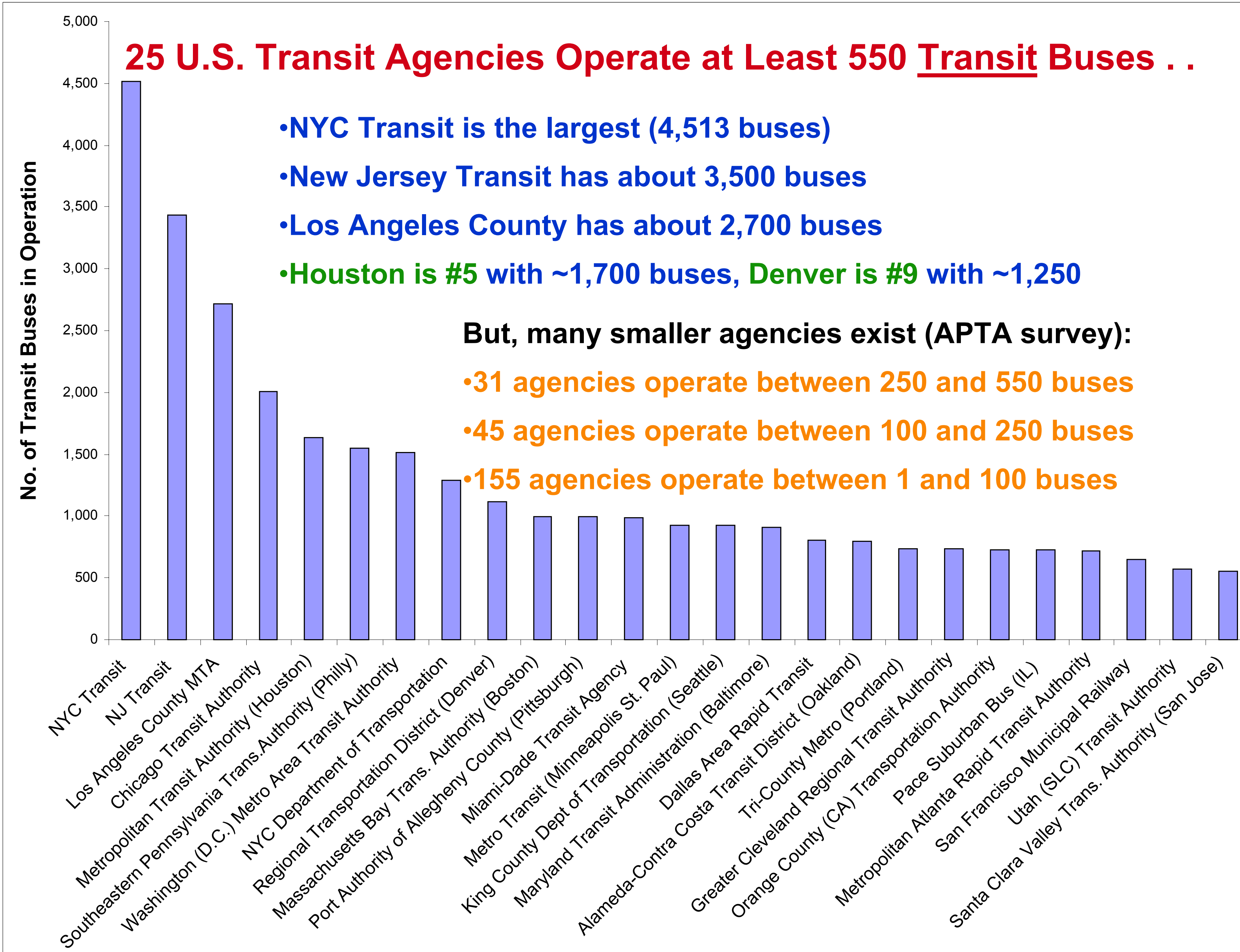
- Approximately **625 million gallons of diesel fuel** are used annually
- Approximately 78 million gallons (DGE) of **non-diesel fuels** are used annually
- ~58,000 transit buses are in active use; each vehicle consumes about 10k DGE/yr

U.S. Transit Bus Fuel Consumption, 1994-2001*



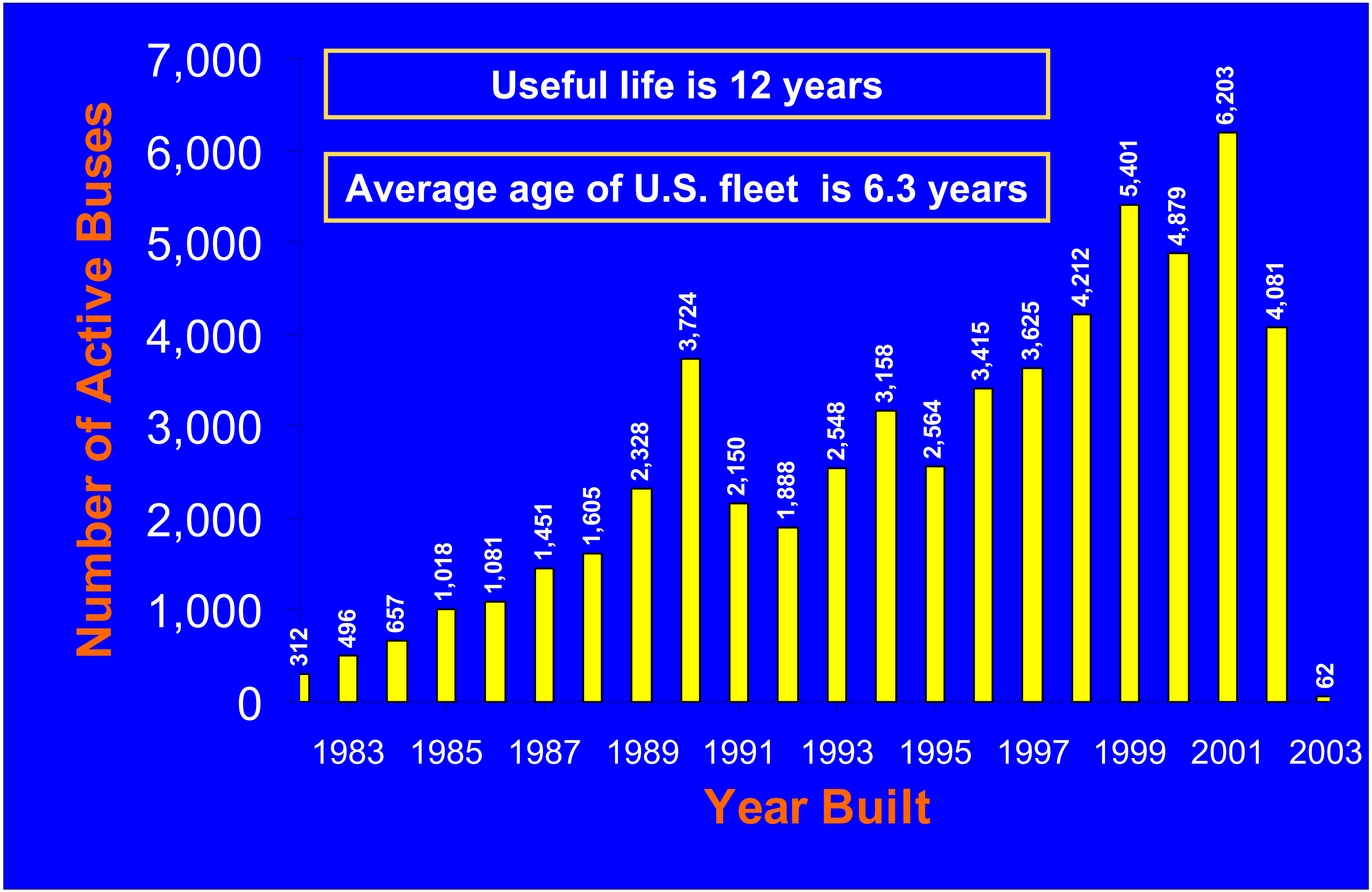
*Data includes passenger vehicles; excludes non-passenger-vehicle and non-vehicle consumption

2001 data are preliminary. **Source: APTA (http://www.apta.com/research/stats/bus/busfuel.cfm)**



25 U.S. Transit Agencies Operate at Least 550 Transit Buses . .
•NYC Transit is the largest (4,513 buses)
•New Jersey Transit has about 3,500 buses
•Los Angeles County has about 2,700 buses
•Houston is #5 with ~1,700 buses, Denver is #9 with ~1,250
But, many smaller agencies exist (APTA survey):
•31 agencies operate between 250 and 550 buses
•45 agencies operate between 100 and 250 buses
•155 agencies operate between 1 and 100 buses
No. of Transit Buses in Operation
0
500
1,000
1,500
2,000
2,500
3,000
3,500
4,000
4,500
5,000
NYC Transit
NJ Transit
Los Angeles County MTA
Chicago Transit Authority
Metropolitan Transit Authority (Houston)
Southeastern Pennsylvania Trans.Authority (Philly)
Washington (D.C.) Metro Area Transit Authority
NYC Department of Transportation
Regional Transportation District (Denver)
Massachusetts Bay Trans. Authority (Boston)
Port Authority of Allegheny County (Pittsburgh)
Miami-Dade Transit Agency
Metro Transit (Minneapolis St. Paul)
King County Dept of Transportation (Seattle)
Maryland Transit Administration (Baltimore)
Dallas Area Rapid Transit
Alameda-Contra Costa Transit District (Oakland)
Tri-County Metro (Portland)
Greater Cleveland Regional Transit Authority
Orange County (CA) Transportation Authority
Pace Suburban Bus (IL)
Metropolitan Atlanta Rapid Transit Authority
San Francisco Municipal Railway
Utah (SLC) Transit Authority
Santa Clara Valley Trans. Authority (San Jose)

Breakout of Active U.S. Transit Buses (~58,000 in Total), by Year Built



Source: Table 16 from APTA 2003 Database. Note: 2003 is a partial year.

New Bus and Trolleybus Market by Power Source, 2002-2007

	Built in 2002		On Order January 2003		Potential Orders(a)	
	Number	Percent	Number	Percent	Number	Percent
Diesel ICE	3,389	80.1%	4,026	68.8%	5,275	58.7%
Dedicated CNG	641	15.2%	1,216	20.8%	2,432	27.0%
Dual-Power*	44	1.0%	403	6.9%	307	3.4%
Electric Catenary	88	2.1%	141	2.4%	0	0.0%
Gasoline ICE	11	0.3%	1	0.0%	48	0.5%
Dedicated LNG	52	1.2%	56	1.0%	154	1.7%
Dedicated Propane	4	0.1%	3	0.1%	41	0.5%
All others	2	0.0%	0	0.0%	73	0.8%
Undecided	NA	NA	NA	NA	666	7.4%
Total	**4,231**	**100.0%**	**5,846**	**100.0%**	**8,996**	**100.0%**

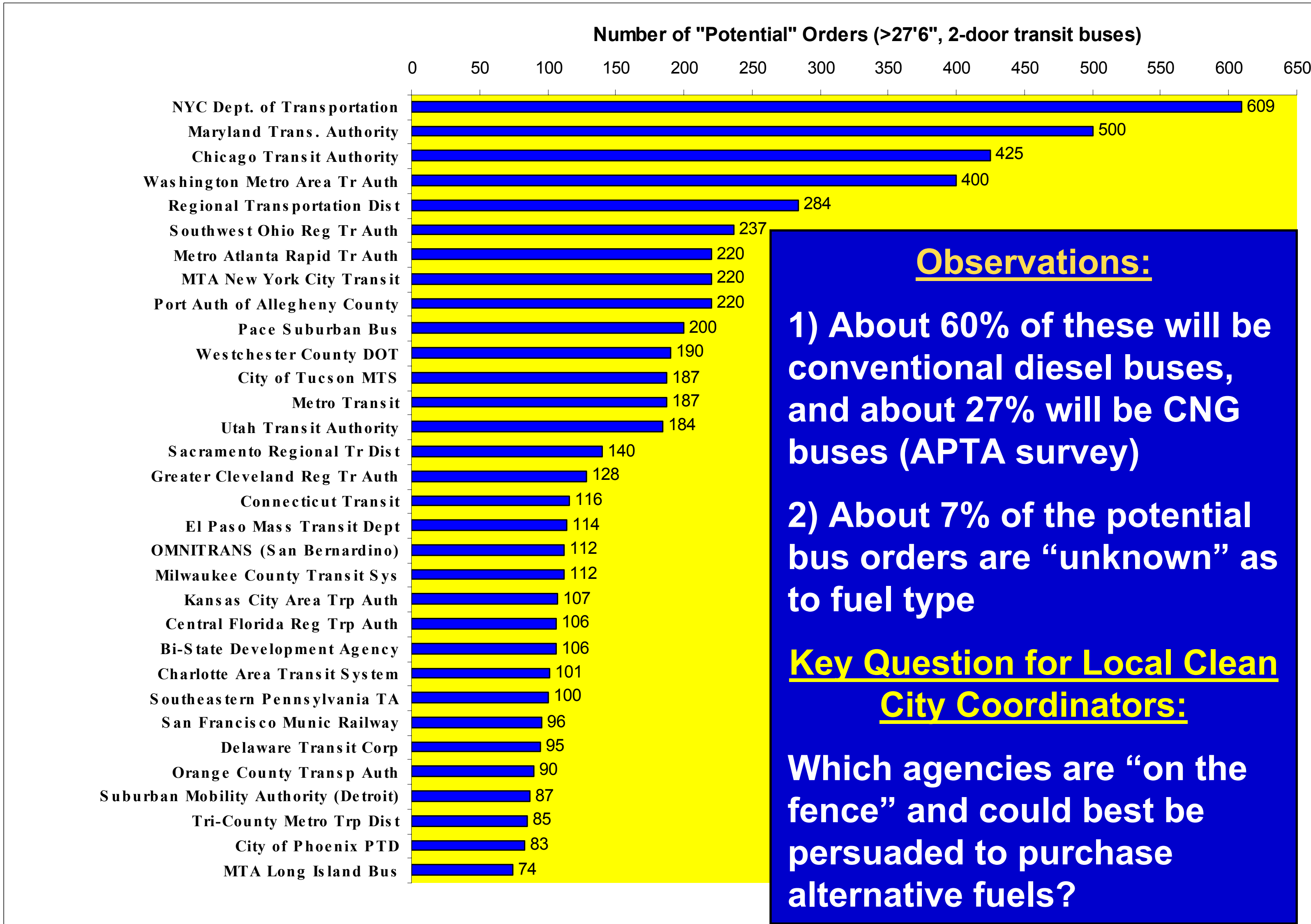
Source: APTA survey, Table 60. Bus and trolleybus data are about 67% and 100%, respectively, of national totals.
(a) Data are tentative. Some potential orders may not occur.

*"Dual-power " means hybrid buses in this case.

APPARENT TRENDS:

- **Market share for conventional diesel ICE buses is declining**
- **Market share for CNG buses is increasing**
- **Market share for hybrid diesel-electric buses (referred by APTA as "Dual-Power") will increase, but "undecided" potential orders probably reflect this**
- **Trend for LNG buses is less clear, but market share appears to be increasing**

APTA: more than 7,600 transit buses are "potential"orders (next few years)



Observations:

1) About 60% of these will be conventional diesel buses, and about 27% will be CNG buses (APTA survey)

2) About 7% of the potential bus orders are "unknown" as to fuel type

Key Question for Local Clean City Coordinators:

Which agencies are "on the fence" and could best be persuaded to purchase alternative fuels?

Why are transit buses a very good niche application for alternative fuels?

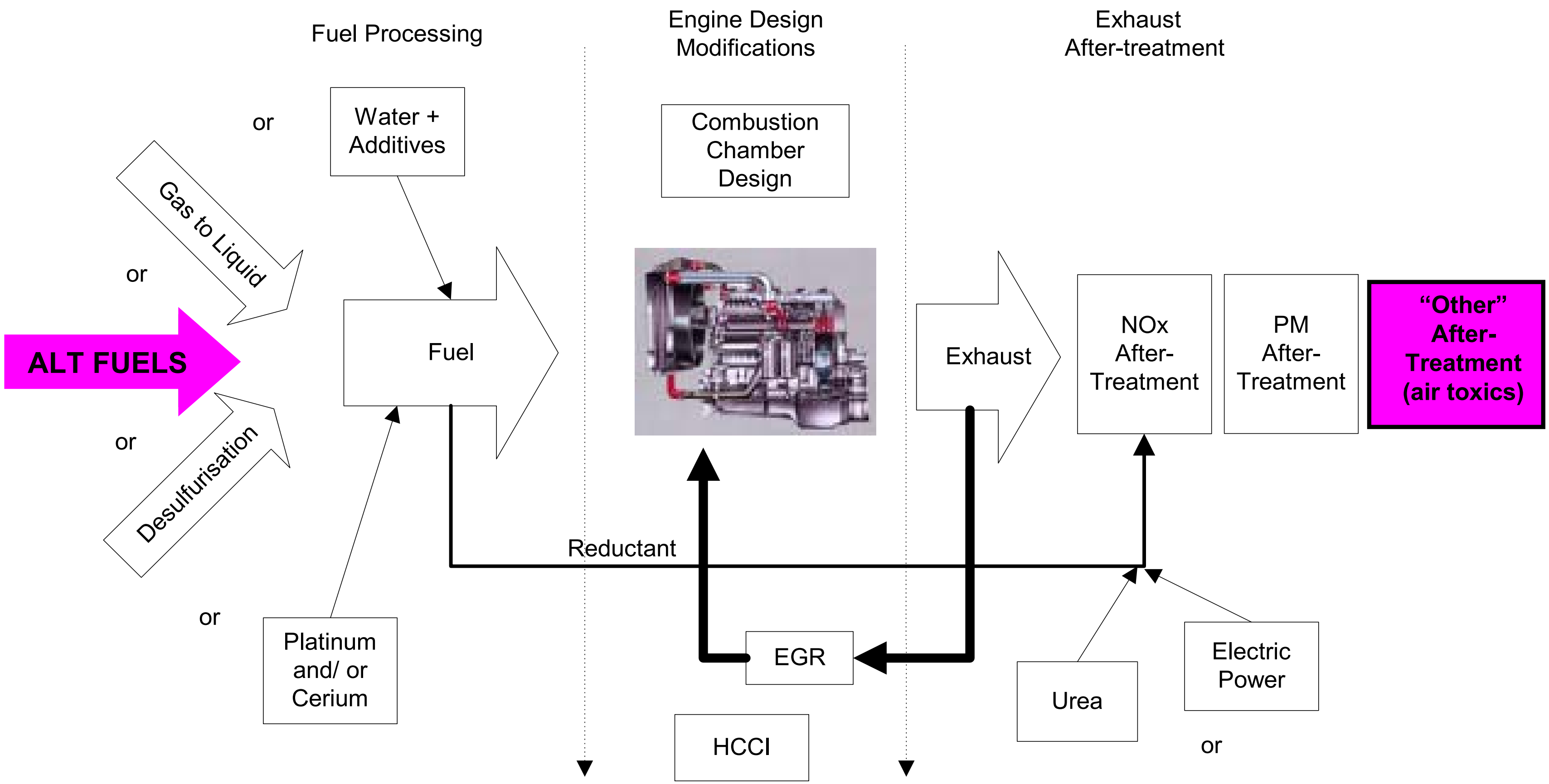
- **Motivating Factors:**
  - **Location:** transit buses are often operated in CAA "non-attainment" urban environments, and serve as symbols for the need to eliminate "dirty diesels"
  - **Public sector:** transit agencies are quasi-government entities under intense pressure to **lead** towards clean air and environmental justice
- **Application:** high fuel use and centralized fueling allow volume purchasing of fuels at lower cost and leveraging of infrastructure investments
- **OEM support:** numerous low-emission alternative engines and chassis are commercially available for the application
- **Other key success factors:**
  - Legislation promoting or mandating the use of alternative fuels in application
  - Availability of incentives for capital investments (vehicles, infrastructure)
  - Strong community support

The Upshot - transit fleets are **among the most viable alternative fuel applications** because they frequently offer many (or all) of these elements . . .

. . . but often the most important ingredients are 1) ***the desire to achieve success***, and 2) ***determination*** to make it happen.

Emission Reduction Approaches for Heavy-Duty Vehicles

- Strategies to reduce NOx, PM and toxics are implemented at 3 basic levels:



- To date, using alternative fuels <u>(w/ minimal after-treatment)</u> has been very effective.

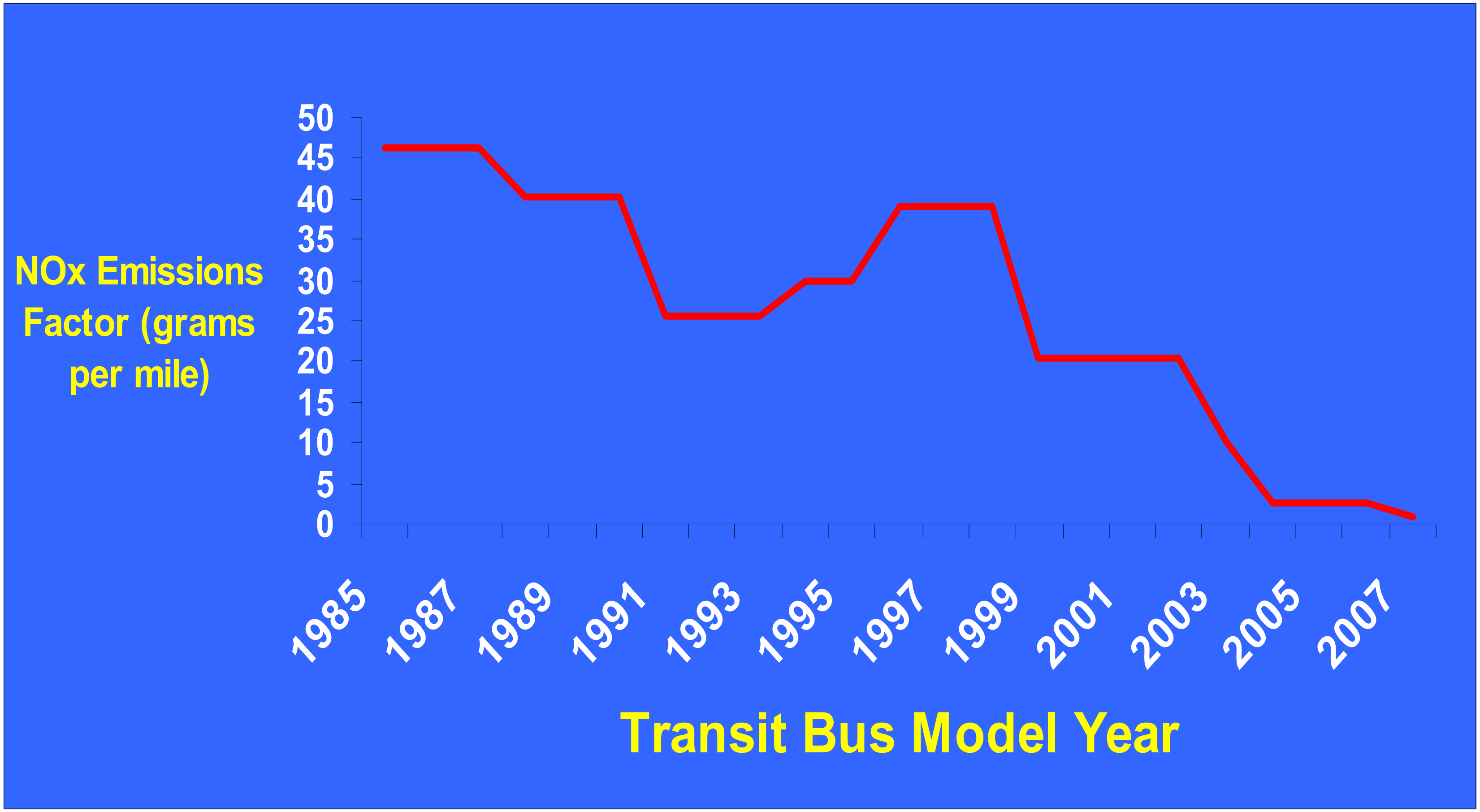
- Advanced AF technology and after-treatment is now providing greater benefits.

How Much Longer Will Air Quality Be A Major Driver for Alternative Fuels?

- California's South Coast AQMD has been strongly challenged on the legality of its Rule 1192 transit bus fleet rule (and other fleet rules)
- California's statewide transit bus fleet rule and other potential AQMD fleet rules (e.g., Sacramento) may hinge on the Supreme Court's decision, announced in April 2004
- As long as **emission benefits** are clear, public funding may be available to support incremental capital costs (vehicles, infrastructure) for AFVs
- But, as progressively cleaner diesel technologies are deployed to meet the 2007 / 2010 standards, justification for such funding is likely to diminish
- Now more than ever, the **petroleum-displacement benefits** of using alternative fuels in transit must be recognized and emphasized, if not **monetized**

Arizona and California have implemented legislation requiring alternative fuel use in urban transit buses

NOx Emissions Factors for Urban Transit Buses (EMFAC 2002)



- A Pre-1987 urban transit bus emitted about 46 grams of NOx per mile
- By 2007 time frame, newly purchased urban buses will emit only 1 gram of NOx per mile

Source: California Air Resources Board

Snapshot of Alternative Fuels in Transit, 2003

APTA 2003 Data: Conventional (ICE) diesel buses continue to dominate the in-use fleet (~87%), but dedicated CNG and LNG collectively account for 12%

Propulsion Fuel / Technology	APTA 2003 Survey for In-Use Transit Buses	% of U.S. Fleet
Diesel ICE	49,755	86.59%
Dedicated CNG	6,052	10.53%
Dedicated LNG	910	1.58%
Gasoline ICE	241	0.42%
Jet Fuel	108	0.19%
Propane (LPG)	90	0.16%
Battery Electric	70	0.12%
CNG Electric Hybrid	59	0.10%
CNG w/ Diesel Pilot	57	0.10%
Diesel Electric Hybrid	50	0.09%
Gas Turbine Electric	20	0.03%
LNG w/ Diesel Pilot	18	0.03%
Methanol ICE	11	0.02%
Bi-Fuel CNG / Gasoline	8	0.01%
Propane Microturbine Hybrid	6	0.01%
Biodiesel (B20 or B100)	4	0.01%
Hythane (CNG & Hydrogen)	2	0.00%
TOTAL	57,461	100.00%

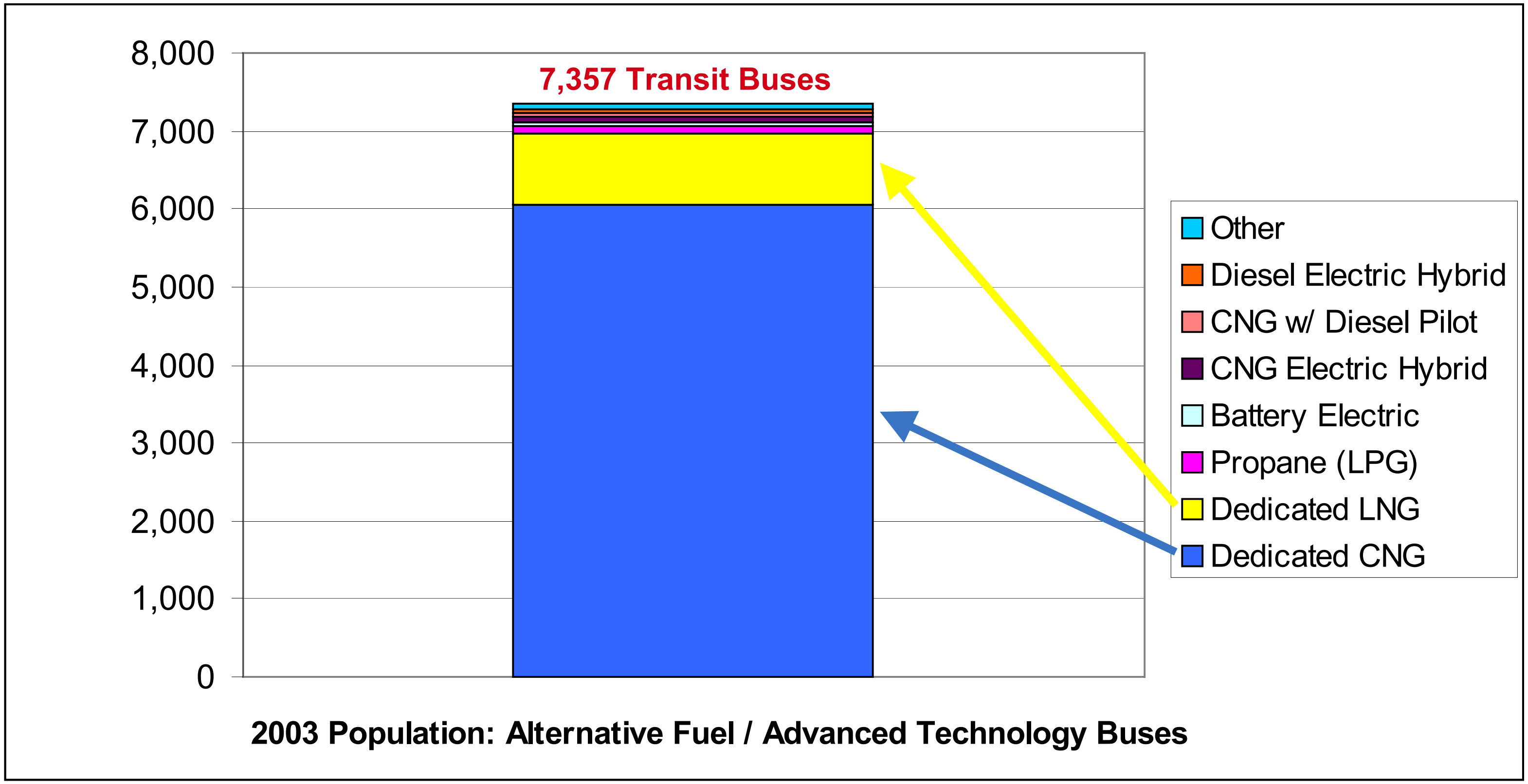
Soure: Table 14 of APTA 2003 Database

*Represents data for approximately 67% of all U.S. Transit Buses

TIAX

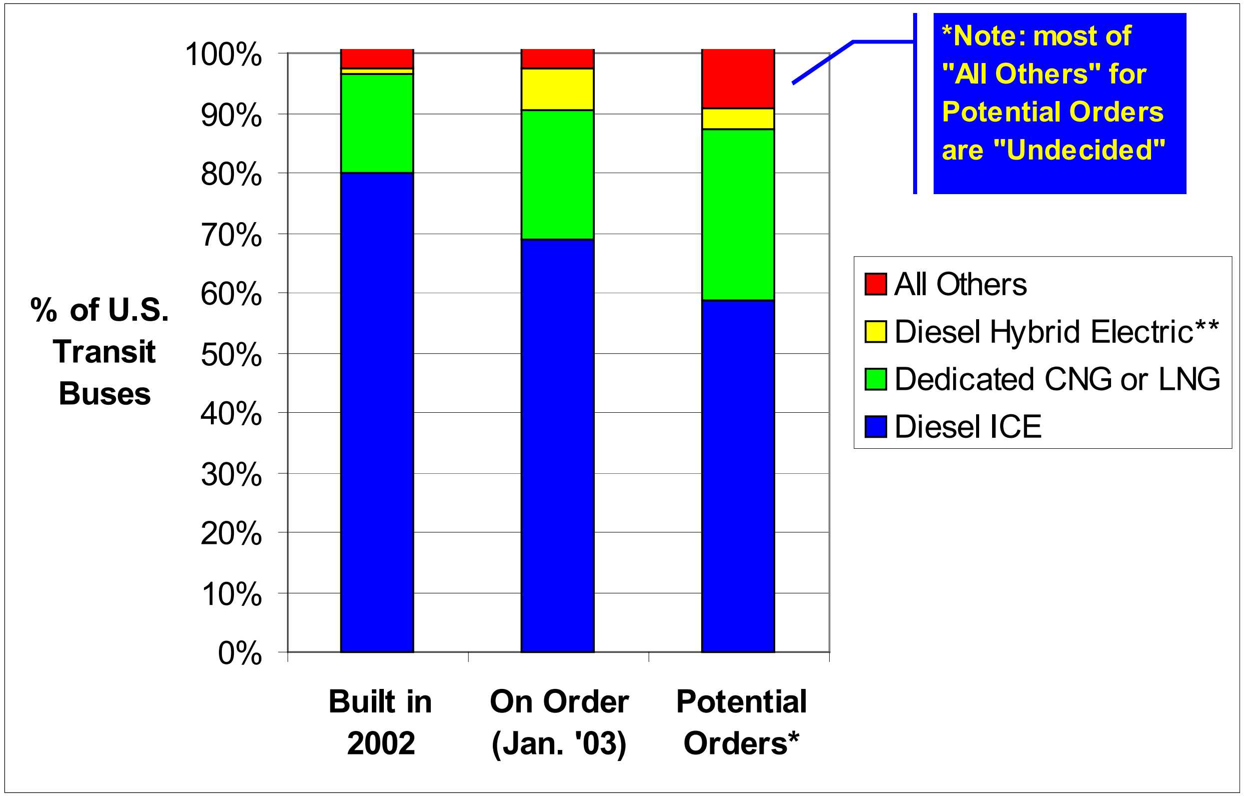
Alternative Fuels in Transit Today: Break Out of Alternative Fuel and Advanced Propulsion

- **Approximately 7,400 transit buses in the U.S. are now powered by alternative fuels and/or advanced technologies**
- **This is about 13% of the 57,500 active transit buses in the U.S.**
- **APTA's 2003 survey: dedicated CNG and LNG buses account for 82% and 12%, respectively, of the alternative fuel / technology transit buses**



Source: 2003 APTA Survey, Table 14

Transit: What Are the Key Current and Expected Short-Term Trends?



- Overall market share for conventional diesel buses (ICEs, including “green” types) is declining
- Natural gas buses are increasing in number (still mostly CNG)
- Diesel electric hybrid buses will increase with ‘04 orders, and likely will increase beyond then (i.e., “undecided” portion of All Others)

Source: APTA 2003 Survey, Table 60. Represents survey of about 67%of transit districts, but includes high % of orders. Potential Order data are tentative and may not come to fruition.

Overview of Cost Issues Related to Alternative Fuel Use in Transit Applications

(See Module 9a and 9b for Detailed Comparative Economics)

Transit Bus Pricing: Many Variations Specific to Bus Type and Agency

- Many factors dictate the price for transit bus procurements, e.g.,:
  - Bus size, type, fuel, technology, features (e.g., floor type), and options
  - Number purchased, and “piggybacked” procurements
- Generally, bus types produced and sold in the highest quantities are sold for the lowest price (40 ft. conventional diesel ICE buses)
- Low-volume / highly customized buses (e.g., NJ Transit and King County hybrids) are the most expensive

Bus Size / Type	Fuel / Technology	Floor Height Type	Total Quantity Purchased (U.S.)	District Placing Largest Order (Number Ordered)	Average Cost
40 ft. Transit	Diesel Hybrid	High Floor	3	New Jersey Transit (3)	$ 1,034,000
60 ft. Articulated	Diesel Hybrid	Low Floor	1	King County DOT (1)	$ 963,328
60 ft. Articulated	Diesel ICE	High Floor	149	Minneapolis Metro Transit (25)	$ 467,398
60 ft. Articulated	Diesel ICE	Low Floor	380	Chicago Transit Authority (380)	$ 438,084
40 ft. Transit	Diesel Hybrid	Low Floor	145	NY City Transit (125)	$ 401,804
40 ft. Transit	CNG ICE	Low Floor	612	NY City Transit (255)	$ 314,700
40 ft. Transit	CNG ICE	High Floor	179	Foothill Transit, CA (66)	$ 314,207
40 ft. Transit	LNG ICE	High Floor	45	Dallas Area Rapid Transit (45)	$ 313,774
40 ft. Transit	LNG ICE	Low Floor	7	City of Tempe Trans Div (4)	$ 296,927
40 ft. Transit	Diesel ICE	High Floor	599	Maryland Transit Authority (100)	$ 287,726
40 ft. Transit	Diesel ICE	Low Floor	2166	Chicago Transit Authority (125)	$ 281,196

Operating Costs: Good Comparative Data Are Beginning to Emerge

- Some **"apples-to-apples" comparisons** of CNG and diesel engine maintenance and repair costs **are beginning to emerge**
- Natural gas buses have not been on the road long enough in large numbers to provide an ideal comparison
- Early adopters were subject to a fairly steep learning curve, but significant improvements have occurred
- Early buses were under warranty -- agencies were not responsible for many of the high repair costs
- Many in-use CNG buses are now out of warranty, but are only now reaching the point where normal engine overhauls are needed
- More experience may be needed to compare CNG and diesel buses for time between overhauls
- Generally, incentive funding is not available to subsidize any increased operating costs
- **Fuel costs are a major issue to transit districts**
  - Alternative fuels have been cheaper than diesel in many cases
  - But, **price volatility for all transportation fuels** has become commonplace

Diesel Prices for On-Highway Applications Have Been Especially Volatile . . .

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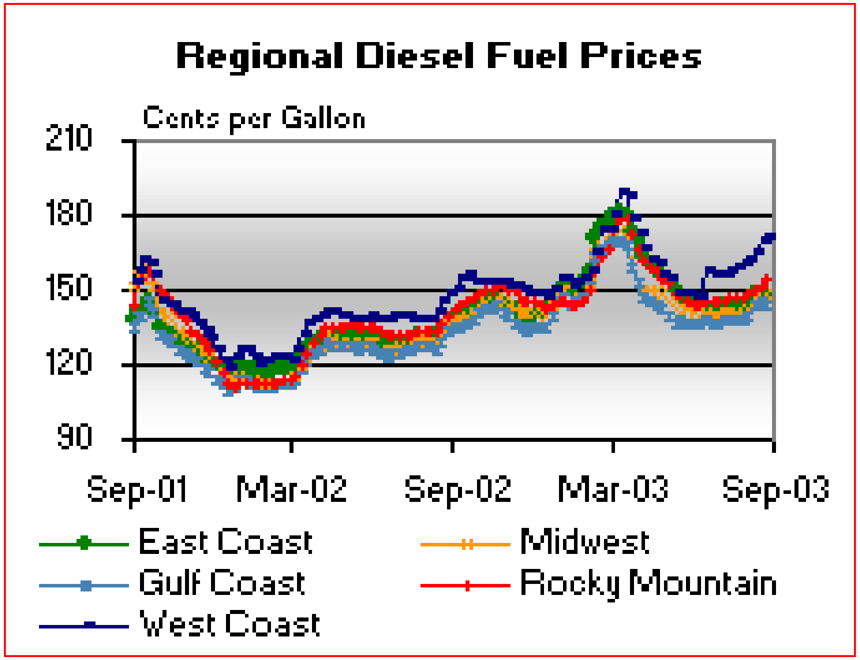
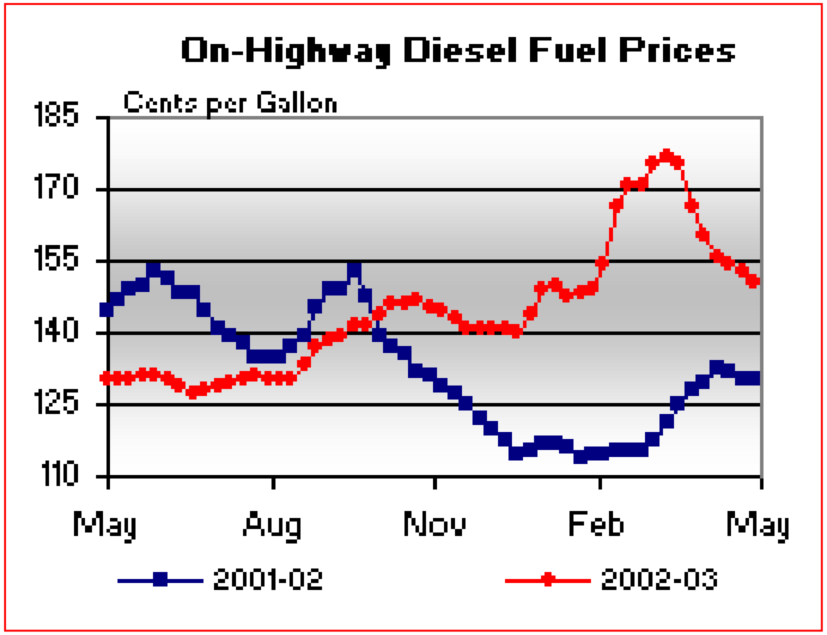


Diesel price trends by region since Sept. 2001

Diesel price volatility: two similar 12-month periods



But . . . the days of very cheap natural gas (~$2.50 per MMBtu) appear to be over -- negating a major early advantage for CNG buses

Operational Costs for Diesel Technologies Will Increase

- **New components** may be needed for all diesel buses, as progressively more stringent NOx and PM standards are phased in
  - New fuel management systems
  - Aftertreatment devices such as particulate traps and catalysts
  - Careful **INTEGRATION** of engine strategies (EGR, etc.), cleaner fuels, and aftertreatment devices
- These devices and technologies will **increase the maintenance costs** of diesel engines
- This trend is already being seen in field trials of DPFs (e.g., NYC Transit)
- These increases may tend to close any gap between the maintenance costs of diesel engines and alternative-fuel engines
- Natural gas engines already approach 2007 NOx levels (with averaging) -- and therefore **may not require extensive redesign and improvements by manufacturers** (at least until the 2010 time frame)
- **Diesel fuel price increases (transition to ULSD)** will add to diesel bus operational costs

Summary Outlook: Life-Cycle Costs for Alternative Fuel Transit Buses

- Costs for natural gas buses are best documented, due to numbers deployed
- Initially, CNG and LNG bus fleets are likely to have higher maintenance costs
- Availability of more reliable NG engines, and operation of diesel engines meeting future lower emission standards, will tend to decrease this difference
- Together, these changes should close the gap, and result in **equivalent to slightly higher maintenance costs for NG transit buses**
- Special fuel-purchasing deals are available for transit - **VOLUME** is the key
- Fuel costs per mile, including NG compression or liquefaction, can be lower for NG fleets (except in times of extreme NG price spikes)
- The increased price of ULSD needed for future diesel engines, or fuel costs associated with the possible use of SCR systems (e.g., urea) should accentuate this difference
- Total operating costs of new NG fleets in the future are estimated to be only slightly higher than new diesel fleets (assuming reasonable fuel prices)
- The capital costs for NG fleets -- initial bus purchase price and the refueling and facility modification costs -- will continue to be higher than diesel fleets
- Incentive funds exist to help offset these costs, and <u>will be needed in the future</u>

Ultra-low Sulfur Diesel and Advanced Diesel Technologies

Progress Towards 2007 Emissions Standards (According to EPA)

1) Engines

- Focus has shifted from R&D programs to product development
- Engine companies have reached (or are approaching) technology down-select
- Most companies have multiple technology paths capable of achieving 2007 std.
- NOx control options focus will be on “heavy EGR” with engine mods
- Aftertreatement (NOx adsorber or urea-SCR) may not be needed, because provisions of 2007-2009 standards effectively allow OEMs to achieve engine family **average** of 1.2 g/bhp-hr NOx
- Companies now choosing final 2007 package

2) Diesel Fuel

- Industry is on target to comply -- 15 ppm fuel will be “widely available”
  - >95% of highway diesel fuel volume produced in 2006 will be ULSD
  - Highway diesel fuel supply will be “sufficient”
- EPA will summarize the results and publish a report soon

Source: Presentation by Bill Charmley, US EPA Office of Transportation and Air Quality, 2003 DEER Conference, August 24, 2003

NYCT’s Challenges with“Clean Diesel” Technology in Transit Applications

Particulate Filters (Available Today)

- “Standard” installations are elusive
- Need duty cycle that’s generates sufficient heat profile
- Filters create backpressure problems and mask underlying engine problems
- New replacement filters are expensive ($2,500 to $5,000)

EGR Engines (Available Today)

- Immature in HDVs: durability and maintenance can be poor (but are improving)
- Space and packaging issues
- Adds more heat load to “already marginal” engine cooling system

EGR + Particulate Filters (Post 2004 Technology)

- Reduced NOx from EGR negatively affects PM filter’s catalysis
- Difficulties with engine programming to control smoke and provide good power
- Initial EGR system failures caused a high incidence of PM filter failures
- New EGR engines and plugged filters show a high correlation

Source: Dana Lowell, “NYCT Experience with Clean Diesel Technologies,” January 17, 2003, online at http://www.worldbank.org/cleanair/global/learningactivities/diesel_days/presentations/dlowell_nymta.pdf

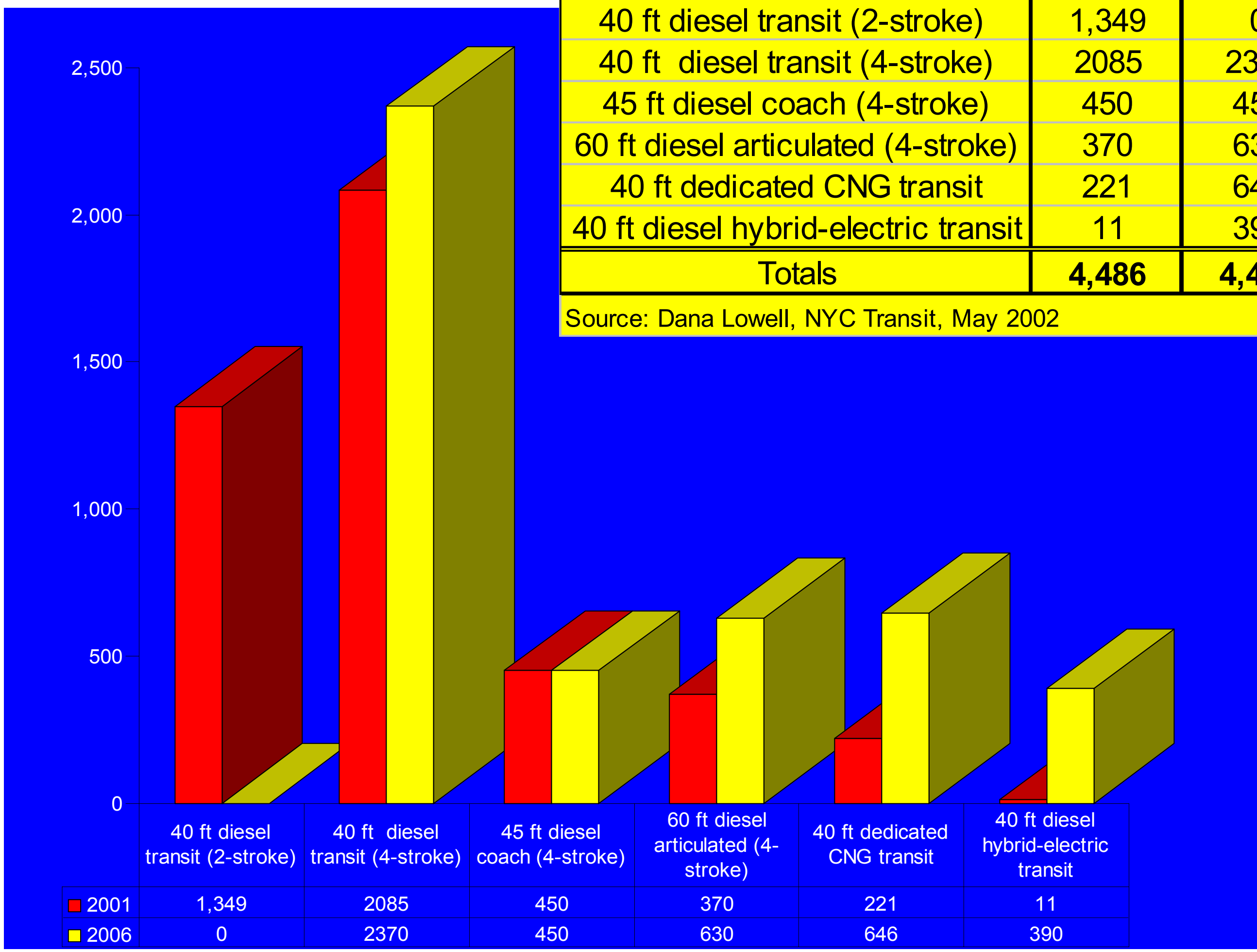
NYCT's Conclusions on "Clean Diesel" in Transit Applications

- "Clean diesel" technologies can significantly reduce in-use diesel emissions
- Some technologies are quite mature and present little challenge (4-stroke engine, catalyst mufflers, reduced sulfur fuel)
- More aggressive technologies provide much higher benefits but are less mature, more costly, and more complex (catalyzed filters, EGR, hybrid)
- **There is no "free lunch" - all emissions reduction technologies increase engine/system complexity, resulting in increased maintenance costs**
- Capital and operational costs for ULSD
  - Purchase price at $0.12 more per gallon (CARB, NYCT)
  - Incremental cost of $0.04 / mile
- Capital and operational costs for catalyzed PM filter
  - $5,000 to $7,000 (including installation and back-pressure monitoring)
  - Annual maintenance: $300 to $600 / year / bus to remove, clean and replace @ 2 to 4 hours each (NYCT)

Source: Dana Lowell, "NYCT Experience with Clean Diesel Technologies," January 17, 2003, online at http://www.worldbank.org/cleanair/global/learningactivities/diesel_days/presentations/dlowell_nymta.pdf

NYC Transit's Changing Fleet Profile

Bus Size / Type / Technology	2001	2006	Increase / Decrease	% Change
40 ft diesel transit (2-stroke)	1,349	0	-1,349	-100%
40 ft diesel transit (4-stroke)	2085	2370	285	14%
45 ft diesel coach (4-stroke)	450	450	0	0%
60 ft diesel articulated (4-stroke)	370	630	260	70%
40 ft dedicated CNG transit	221	646	425	192%
40 ft diesel hybrid-electric transit	11	390	379	3445%
Totals	**4,486**	**4,486**	**0**	**0**
Source: Dana Lowell, NYC Transit, May 2002				



Results of DART Review (2002): Top Technologies to Demo and Evaluate

- 1. **Diesel Hybrid** – technologically mature compared to others, easily integrated into DART operations
- 2. **NOx Adsorber or SCR (not both)** – Unknown which technology to choose; allow engine manufacturer to determine
- 3. **Turbine Hybrid (Diesel or natural gas, not both)** – demonstrating microturbine technology should suffice for DART's knowledge, but to meet 2007 emissions standards, natural gas may also be required
- 4. **Natural Gas ICE and Natural Gas Hybrid –** Test advanced natural gas ICE as fourth option, but test natural gas hybrid technology as part of the diesel hybrid testing
- 5. **Fuel Cell** – Most benefits, but entails highest capital investments to accommodate fuel cell buses and hydrogen infrastructure
- 6. **Hydrogen / CNG Blend ICE** – As a alternative to fuel cells that can transition to hydrogen fuel cells

Note: **for DART's needs** (40-ft. buses with a range of 350 to 400 miles), battery electric technology was found to be an unrealistic option

Hybrid Electric Buses

Overview of Diesel Hybrid-Electric Buses

- HEBs (unlike battery electric buses) are **not limited to smaller vehicles**
- Developed in a wide range of vehicle sizes, including shuttle buses, 40-foot transit buses, 60-foot articulated buses, and over-the-road coaches
- **More than 30 organizations** in the United States are currently demonstrating hybrid bus technologies
- Early hybrid bus demonstration projects involved small numbers of vehicles, but **interest has grown recently**
- The promising results from early projects have led several agencies to place **large orders for hybrid buses**
- More than 600 hybrid buses could be placed into service around the country during the next few years
- A system that uses a "clean fuel" (e.g., NG or ULSD) and advanced NOx exhaust aftertreatment, in conjunction with an optimized hybrid electric system, has the **potential** to achieve near-zero emissions
- **Hybrid buses can be stepping stones to fuel cell propulsion systems, which show promise for zero or near-zero emission transit buses**

Numerous Transit Agencies in Pacific States Are Testing Diesel HEBs

Washington:

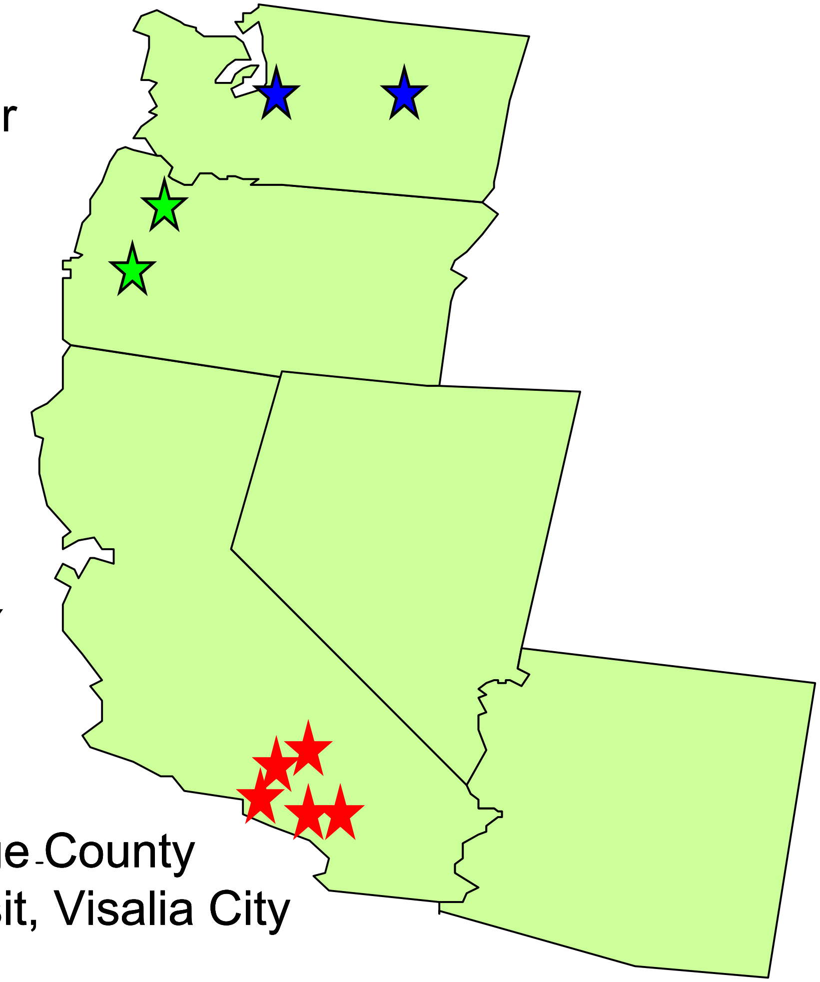
- King County Metro - 1 existing, 200 on order (60 ft. articulated dual mode buses)
- Spokane Transit - 4 to be purchased (2005 MY transit buses)

Oregon:

- Tri County Metro (Portland) - 2 existing 2002 MY transit buses
- Lane Transit (Eugene) - 6 existing 2001 MY paratransit vehicles

California:

- Users include: Fresno Area Express, Orange County Transit, Torrance Transit, Long Beach Transit, Visalia City Coach, and Santa Barbara MTD
- Users in South Coast are currently subject to Rule 1192 limitations



Note: based on 2003 APTA database for reporting transit agencies

Summary on Emerging Diesel Technologies in Transit Applications

- Multiple technology paths are being pursued by OEMs to meet 2007/2010, in conjunction with ULSD fuel
- Progressively more aggressive “clean diesel” technologies will be needed, which are likely to result in **more-costly and less-reliable** diesel buses
- Hybrid-electric buses are being deployed across the U.S. in field trials: results are **promising, and commercialization is rapidly moving forward**
- Diesel HEBs provide **increased fuel efficiency** (15% to 18%) over conventional diesel buses, and they also provide **emissions benefits**
- Diesel HEBs have **higher capital costs, higher operational costs, and reduced durability**, but this is expected to improve
- **Alternative-fueled HEBs** are being tested that **further accentuate emissions benefits** associated w/ electric drive and hybridization (Module 8)
- Many transit agencies appear to be delaying near-term bus procurements to see if HEBs will become less expensive and more reliable
- Strong training programs are essential (internal, or from the outside)
- Diesel HEBs are “bridge technology” to advanced technology transit buses, including those powered by hydrogen fuel cells (see Module 8)

Snapshots of Advanced Transit Technologies: Clean-Fueled Hybrids and Fuel Cells

Hybrid Buses with Twin Capstone 30 kW Microturbine Engines

- Certified by California Air Resources Board on diesel, natural gas and propane

LA DOT bus powered by Capstone's microturbine engine fueled by propane

- **Series hybrid**: each bus has two 30-kW microturbines, which recharge battery packs

Photos from Capstone Turbine Corp. at [www.microturbine.com.](http://www.microturbine.com)

- Field trial by Los Angeles DOT in revenue service
- Proceeding to Phase 2
- Tempe reportedly interested in large procurement

Advantages of Fuel Cells for Transit Bus Applications

- Fuel cells offer a number of potential benefits that make them appealing for transportation use:
- **Efficiency**: FC buses are more efficient than ICE buses
- **Near-Zero or Zero Emissions**: Depending on the source fuel
- **Greenhouse Gas Reductions**: greatly reduced CO_2 emissions (depending on fuel). Hydrogen generated using renewables will have zero greenhouse gas emissions.
- **Energy Security**: Reduced dependence on petroleum and allow greater energy diversity. Natural gas, ethanol, electrolysis -- different regions could choose a hydrogen source based on the most available and economical source for that region
- **Quiet and smooth operation**: Fuel cells may offer significantly more pleasant operation for transit riders. The fuel cell itself has no moving parts, although the fuel cell system will have pumps and fans. Quieter than diesel engine. Electric motors: smoother starts and stops than a typical diesel-engine buses.

Preliminary testing of XCELLSiS P4 Direct-H2 FC bus at Sunline Transit

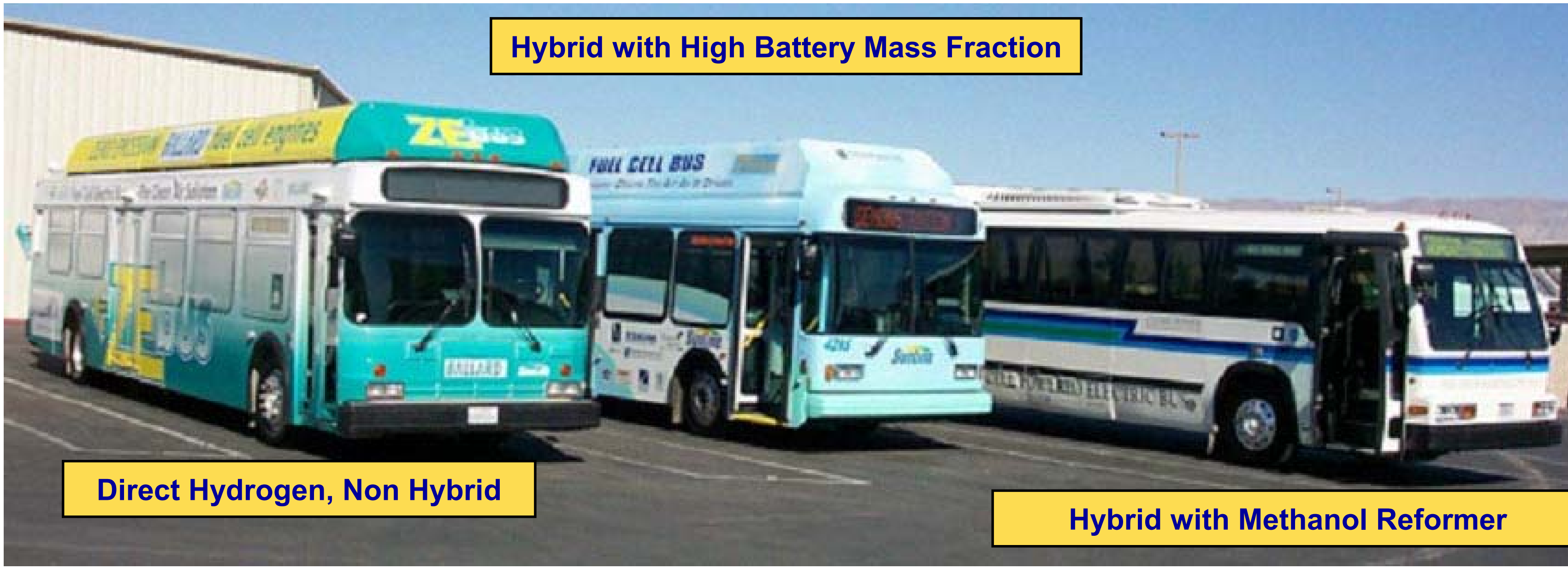
Refueling using Stuart Energy's prototype hydrogen bus refueler

Non-revenue-service testing with water tanks to simulate curb weight

Photos by R. Barnitt, TIAX LLC

TIAX

Three Types of Prototype Fuel Cell Buses



- SunLine Transit Agency has demonstrated three fuel cell buses: Ballard’s Zebus, ISE Research’s ThunderPower bus, and Georgetown University’s methanol fuel cell bus.
- Each bus and technology type has a different approach involving fueling and hybridization -- to achieve different operational characteristics

Summary: Advanced Transit Bus Technologies and Fuel Cell Buses

- Wireless electric propulsion is an important step forward for the future of transit buses across America
- Depending on regional needs and operational characteristics of the user transit agency, a variety of zero-emission or near-zero emission technologies are commercially available or undergoing testing:
  - **Battery electric:** available now as a ZEB technology, for 22 foot bus applications not requiring long driving ranges (downtown shuttle routes)
  - **Hybrid electric using clean fuels and/or advanced prime movers:** available now as near-ZEB technology, in demonstration capacity
  - **Fuel cell electric:** available now as near-ZEB or ZEB technology, but strictly in an R&D capacity
- **Today's alternative fuel buses and hybrid-electric buses are "bridge technologies" to these buses of the future**
  - Powertrains, fuel storage, safety systems, aftertreatment for exhaust, etc.
  - Fueling infrastructure
- New codes and standards, training programs, etc. will be essential as commercialization proceeds and new deployments are made
- Resources are available to Coordinators to assist deployment (Module 11)

How do Transit Buses Compare for Emissions in "Real-World" Testing?

(Chassis Dynamometer Testing of Diesel, Alternative Fuel, and Hybrid-Electric Transit Buses)

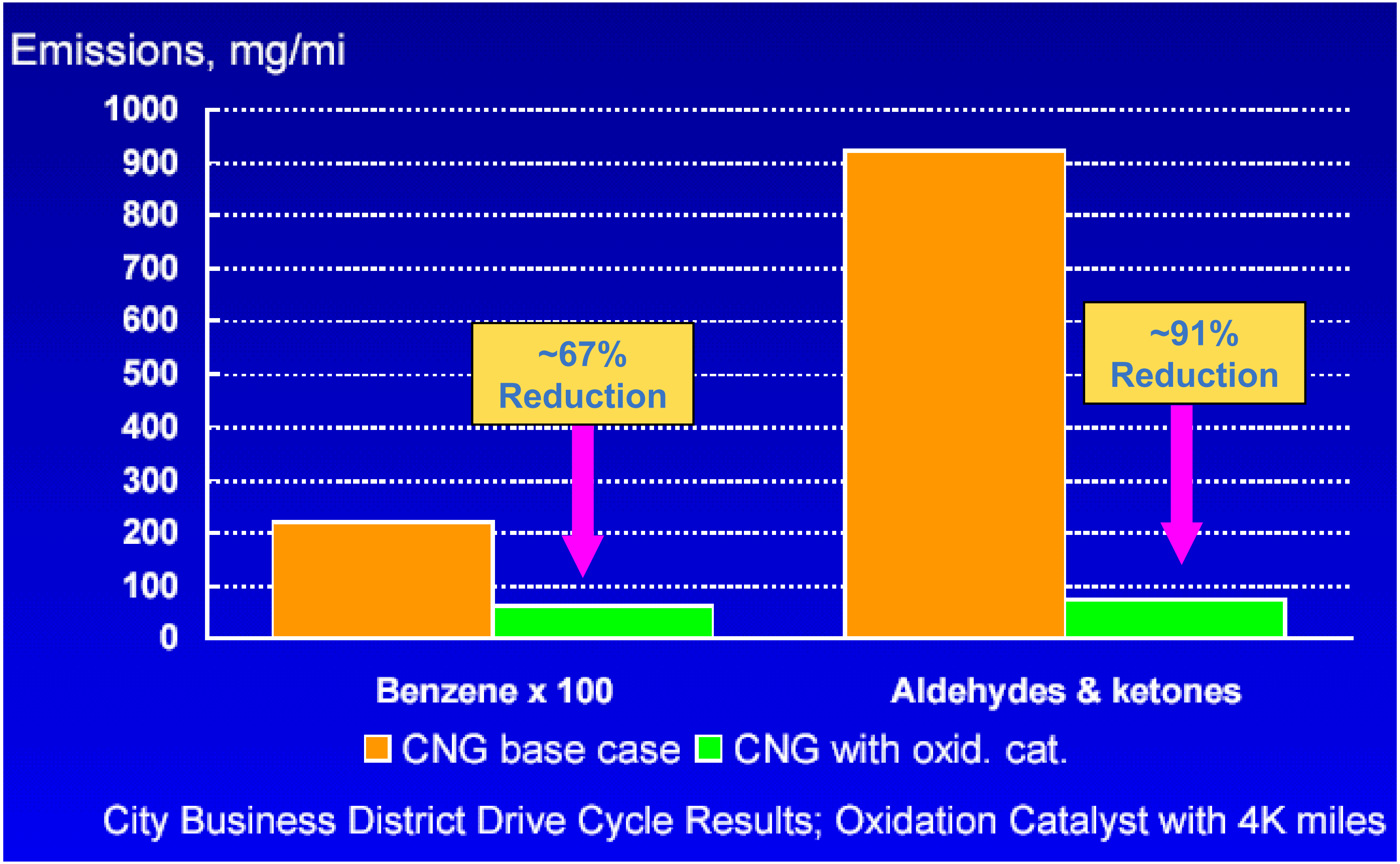
What “Apples to Apples” In-Use Emissions Testing Has Been Done?

- So far, ***not much***
- While various sources have cited emissions data of alternative fuels vs. diesel . . .
- . . . past comparisons have usually involved too many variables:
  - bus age, manufacturer, model, etc.
  - iterations of engine technology (e.g., various phases of Cummins L10 G technology)
  - use of after-treatment on buses
- The issues are complex -- objective parties should be leary when assessing data cited by special interests *on either side of the debate*
- Some good comparative data are beginning to emerge
- More chassis dynamometer emissions tests of emerging transit bus technologies are needed . . . . . and planned

Early Studies Indicated Both CNG and Clean Diesel Needed Improvement

- In 2001, California Air Resources Board tested two transit bus technologies:
  - 2000 MY CNG bus with a DDC Series 50G engine (no catalyst)
  - 1998 MY diesel bus with a DDC Series 50 engine using ULSD and a Johnson-Matthey Continuously Regenerating Technology (CRT) PM trap
- Results indicated that
  - the CNG bus had high emission levels for aldehydes and air toxics (e.g., 1,3 butadiene), suggesting that further control (aftertreatment) was needed
  - the CRT-equipped LSD bus had encouraging overall emissions, but exhibited a substantial increase in the amount of NOx emitted as NO_2 (which has negative air quality implications)
- In 2002, CARB installed an oxidation catalyst and re-tested the CNG bus
- Conclusion: "oxidation catalysts for CNG applications offer significant benefits" and are "significantly superior" to CRT-equipped ULSD buses in terms of controlling total PM ***mass***
- More work needs to be done on both technologies to target "ultra-fine" PM
- More work needs to be done on diesel traps to **keep NO_2 levels low**
- Full study at: http://www.arb.ca.gov/research/cng-diesel/cng-diesel.htm

Oxidation Catalysts Have Greatly Reduced Air Toxics from CNG Buses



Source: graph form Manufacturers of Emissions Controls (MECA), citing California Air Resources Board data

Emissions Testing at Washington Metro Area Transit Authority (July '02)

- Five CNG and 4 "green" diesel transit buses were emissions tested on the WVU portable chassis dynamometer
- CNG Buses:
  - 2001 MY New Flyer with 280 HP Cummins C-Gas Plus (8.3 L) engines
  - each equipped with an oxidation catalyst
  - All buses were low mileage
- Diesel Buses
  - 2000 MY Orion with 320 HP DDC Series 50 diesel (8.5 L) engines
  - Operated on ULSD (19 ppm)
  - Each equipped with an oxidation catalyst
  - Two of 4 buses were low mileage

On Average:

- **NOx reduced 53% for CNG**
- **TPM reduced 85%for CNG**
- **CO reduced 89%for CNG**

Next: more advanced buses of both kinds will be tested in mid 2004

WMATA's CNG bus fleet (photo by Leslie Eudy of NREL)

How “Clean” Are Hybrid-Electric Buses? NAVC Conducted Testing:

Test matrix: HEBs with advanced aftertreatment vs. pre-2000 NG buses w/ oxy cats:

Bus OEM	Bus Chassis	Drive	Engine / Model Year	Fuel	Aftertreatment
NovaBUS	RTS	3 speed	DDC Series 50 / 1998	Diesel[A]	Oxidation Catalyst
Neoplan	AN440T	5 speed	Cummins L10 280G / 1998	CNG	Oxidation Catalyst
New Flyer	C40LF	5 speed	DDC Series 50G / 1999	CNG	Oxidation Catalyst
Orion	V	5 speed	DDC Series 50G / 1999	CNG	Oxidation Catalyst
Orion	VI Hybrid	LMCS Hybrid	DDC Series 30 / 1997 & 1998	Diesel-Electric[B]	NETT Particulate Filter Trap
NovaBUS	RTS Hybrid	Allison Hybrid	DDCVMM 642 DI / 1991 (1998 engine)	Diesel-Electric[C]	Johnson Matthey Regenerative Particulate Trap

A – The NovaBUS was tested on D1, and MossGas® diesel fuels.
B – The Orion-LMCS bus was tested on D1, low sulfur D1, and MossGas diesel fuels.
C – The Nova-Allison bus was tested on low sulfur D1 diesel fuel.

Findings:

- Diesel hybrids with advanced after-treatment (catalyzed PM filters and LSD) were significantly lower-emitting than conventional diesel buses
- Comparisons to **pre-2000 CNG buses w/ oxy cats** were also favorable

Northeast Advanced Vehicle Consortium study on emissions from hybrid buses (February 2000) can be found at: http://www.navc.org/Navc9837.pdf

NOTE: New rounds of testing on latest models and technologies are needed

Emissions Module: Summary and Conclusions

- The NG versions of the two major bus engines (C Gas Plus and DDC S50G) are still the lowest-emitting, mainstream transit bus engines available
- These engines nearly achieve 2007 NOx levels today (given NOx averaging to 1.2 g/bhp-hr)
- Oxidation catalysts have greatly enhanced their overall emissions benefits
- More "apples-to-apples" tests of in-use transit buses are needed and planned
- Diesel engines will meet 2007 using EGR, after-treatment and fleet averaging, but larger-sized engines (e.g., in 40 ft. transit buses) will face tough challenges
- Diesel buses will become more expensive, less fuel efficient and possibly less durable as they move ahead to meet 2007 and 2010 standards
  - Capital and maintenance costs: use of advanced EGR, SCR, lean-NOx adsorbers, particulate filters, oxidation catalysts, hybrid drivetrains
  - Fuel costs: ultra-low sulfur diesel **(note: hybrid efficiency may offset this)**
- Alternative fuel (AF) engines also need to incorporate advanced technologies, but **they don't have "as far to go"** to meet 2007 and 2010 standards
- AF engines will further benefit from transfer of advanced diesel technologies
- Hybridization (diesel/electric, NG/electric, LPG/electric) holds strong promise

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