

The Transit Bus Niche Market For Alternative Fuels:

Module 4:
Overview of Liquefied Natural Gas as a Transit Bus Fuel

Clean Cities Coordinator Toolkit

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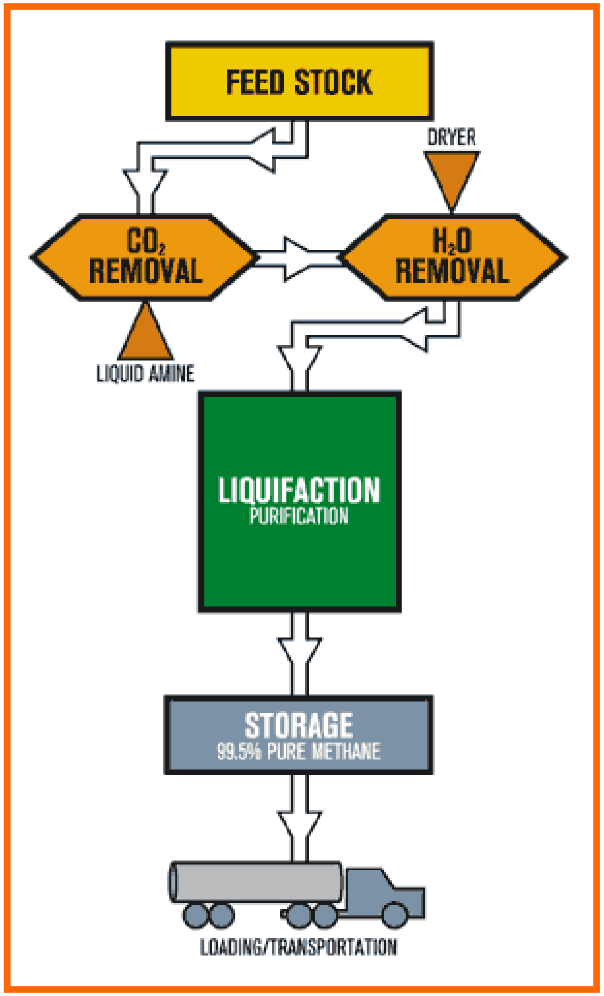
Overview of LNG as a Motor Vehicle Fuel

- LNG is a cryogenic liquid fuel, stored at very low temperatures (from -120 to -260°F) and relatively low pressure (less than 100 psi)
- LNG has a high purity (up to 99%) of methane **(CH_4)** compared to CNG
- LNG is vaporized into a combustible gaseous fuel on-board the vehicle
- LNG is not odorized like CNG (but it's being worked on)
- As an automotive fuel, LNG is almost exclusively used in heavy-duty vehicle applications (e.g., transit) -- it therefore displaces **DIESEL** fuel
- A gallon of LNG contains less energy than a gallon of diesel:
  - **LNG:** (on average) **73,500** British Thermal Units (BTUs) per gallon
  - **Diesel:** (on average) **122,700** BTU per gallon
- About 1.7 gallons of LNG contains the same energy as one diesel gallon
- LNG generally costs slightly less than diesel on an equivalent energy basis
  - Recent price range for LNG: $0.53 to $0.65 per LNG gallon
  - Equivalent to diesel at $0.89 to $1.10 per gallon

Overview of the LNG Production and Distribution Process (Willis, Texas)

- Feedstock gas brought in via pipeline
  - > 450 psi, up to 12 million cubic feet per day
  - Contains 85% methane / 15% CO_2, H_20, and "higher" hydrocarbons (e.g., ethane, propane)
- Inlet Metering and Cleanup
  - Continuous monitoring allows compensation for temperature and pressure changes
  - On-line analysis for Btu value and composition
  - CO_2 and H_20 removal
- Liquefaction - hydrocarbons are cooled and condensed, then compressed (5,000 horsepower)
- LNG Storage - double-walled insulated vessels with an inner tank and a carbon steel outer vessel
- Trailer Loading - two pumps, total capacity of 700 gallons/min.
- Trailer load of 10,500 gallons filled in ~ 45 min.



The LNG production and transportation process used by ALT USA (Source: ALT USA website)

Overview of LNG in U.S. Transit

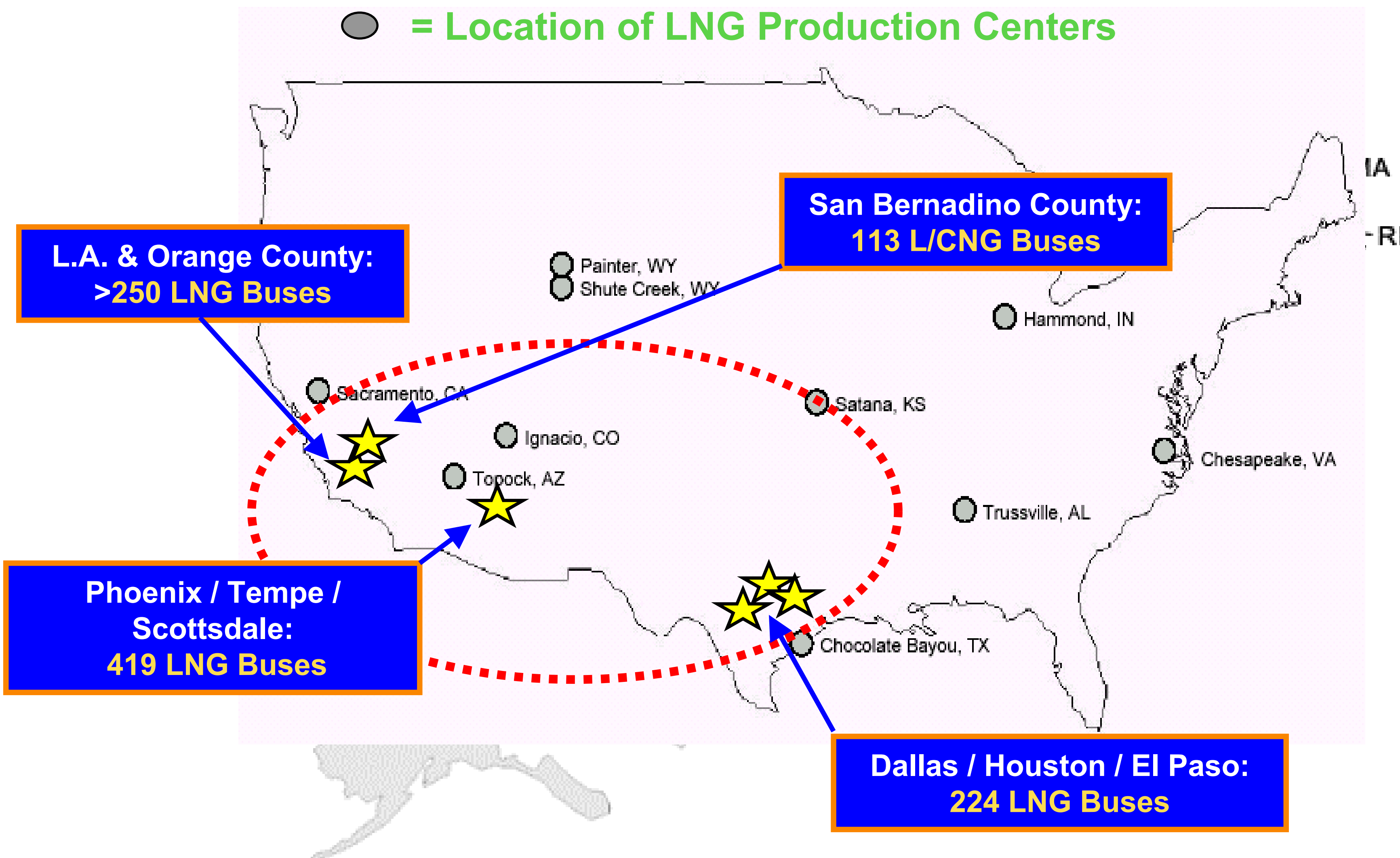
- Today there are nearly 1,000 operational LNG transit buses
  - 1.6% of all active transit buses in APTA's 2003 survey
  - 12.3% of all active **alternative fuel** transit buses
  - The same engines used for CNG buses (e.g., DDC S50G, Cummins C Gas Plus) are used for LNG buses
- In addition, some CNG transit vehicles fuel at LNG stations (LCNG)
- Most districts purchase LNG directly from the producer through a long-term contract
- Transportation of the LNG is contracted separately from a cryogenic liquid trucking company (e.g., JB Kelley)
- Truckloads of 10,000 LNG gallons are typically delivered
  - 2 to 5 times per week (depending upon fuel usage)
  - Transportation is a significant portion of the cost of LNG
  - Generally, it's not economical to transport >500 miles from plant

U.S. Transit Agencies That Currently Operate LNG Buses (per APTA '03)

Transit Authority	Area Served	# of Existing LNG Buses	Primary Make / Model	Primary Engine Make / Model
Orange County Trans. Authority	Orange County, CA	232	NABI 40LFW-09 (40 ft. low-floor)	DDC S50G
Dallas Area Rapid Transit	Dallas, TX	184	NOVA Bus WFD (40 ft. high-floor)	Mix of DDC Series 50G and Cummins L-10G
City of Tempe Trans. Division	Tempe, AZ	96	NABI and El Dorado National (30, 35 and 40 ft. low floor)	Cummins C Gas and B Gas Plus
Regional Public Trans Authority	Phoenix, AZ	42	NABI and El Dorado National (30, 35 and 40 ft. low-floor)	Cummins L-10G and Cummins C Gas Plus
El Paso Mass Transit	El Paso, TX	35	New Flyer G40HF (40 ft. high floor)	DDC Series 50G
City of Scottsdale Transit	Scottsdale, AZ	25	El Dorado National EZ Rider (30, 35 and 40 ft. low-floor)	Cummins C Gas and B Gas Plus
Metro Transit of Harris County	Houston, TX	5	New Flyer L40LF (40 ft. low floor)	DDC Series 50G

NOTE: Santa Monica Big Blue Bus also uses LNG, and Long Beach Transit plans to purchase LNG buses

The Southwest Connection for Transit Bus Fleets Using LNG or LCNG . . .



. . . proximity to LNG plants & distribution centers is a determining factor

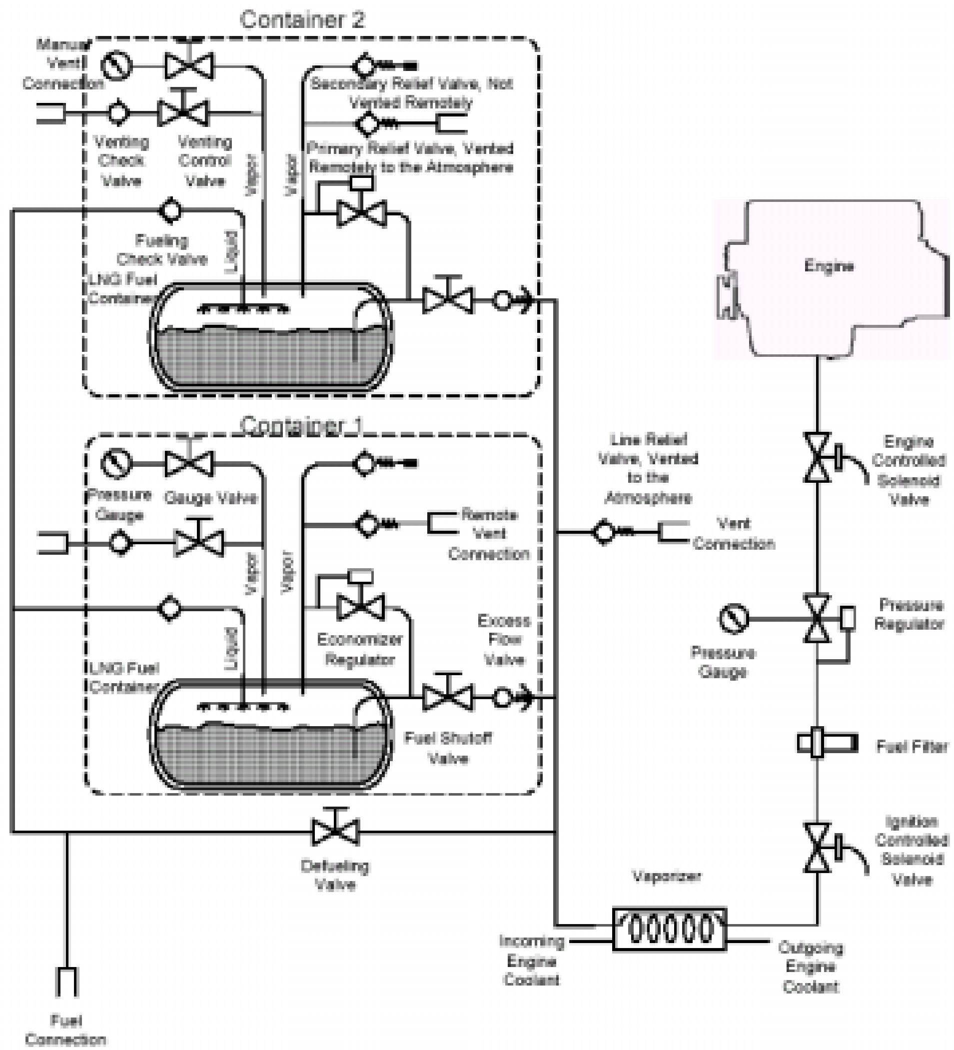
Source: 2003 APTA Database, Active LNG Transit Buses

LNG is Typically Delivered to Transit Users in 10,000 Gallon Tanker Trucks

Photo: from Applied LNG Technologies website (http://www.altlngusa.com/uses.htm

Typical LNG Fuel System for Transit Buses

- Low pressure system designed for normal operating pressure of 80psig
- Fuel lines are fully annealed high quality stainless steel hydraulic tubing
- Fuel tanks are constructed of 304 stainless steel, inner and outer vessel
- On-board LNG tanks hold about 100 usable gallons of LNG
- Two tanks typically used on a single 40 ft. transit bus
- Cost with installation: $15,000 to $20,000
- Price will come down with more volume and increased marketplace competition



Source of schematic: Battelle, *LNG Resource Guide*

LNG Station Features Include:

- One or more highly insulated storage tanks that keep LNG in a cryogenic state with double-walled sides using vacuum “superinsulation”
- Must maintain the LNG below -117°F to remain a liquid, independent of pressure
- Dispensing LNG fuel requires proper procedures and safety gear to ensure safe transfer of the cryogenic liquid to the vehicle’s on-board tank
- Dispensers are typically placed side by side with diesel dispensers in the fueling lanes at a transit district
- Cost and complexity of station depends on the space available, speed of fueling required, need for defueling capability, and local building code requirements
- LNG fuel stations require preventative maintenance to ensure proper operation
- LNG stations must periodically vent vaporized methane - usually to the atmosphere unless a special system has been added to flare the gas or generate electricity through a gen-set (sell power back to grid)

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, and safe handling for cryogenic fuels must be addressed
- 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*

Orange County (California) Transit Authority Operates Two LNG Stations

- Garden Grove and Anaheim stations re-fuel 232 LNG buses
- Each station has two underground LNG storage tanks, @ 15,000 gallons / tank
- 3 fueling islands per station
- ~116 buses re-fueled at each station
- Total capital cost per station: $4.6 million

Early Challenges for OCTA's LNG Operations Are Being Addressed . . . .

- Bulk tank boil off and venting is excessive and wasteful
- Problems with on-board LNG tanks (e.g., loss of vacuum, rapid increase in pressure during fills)
- Plumbing contamination by Loctite sealant required costly fixes
- Hydraulic pumps at stations required trouble shooting
- Initially about 17% more labor hours to maintain LNG buses, but training has improved this gap
- OCTA is making improvements and expects to add new LNG fueling islands at both stations
- LCNG will also be considered in the future (transit buses and support vehicles)

OCTA's Garden Grove LNG Station Venting Methane

LNG Bus Technology

- Detroit Diesel Series 50G natural gas engine
- NOX+HC emissions certification for 2003: 1.2 g/bhp-hr
- PM emissions certification for 2003: 0.025 g/bhp-hr
- Onboard fuel storage: 2 X 150-gallon LNG tanks (Chart Industries)
- Real-world driving range: 280 to 340 miles (less than diesel)
- Maintenance: OCTA allocates ~17% more labor hours for LNG buses

Safety Systems Are Essential, e.g.:

Driver's fire safety panel

Protective gear for LNG

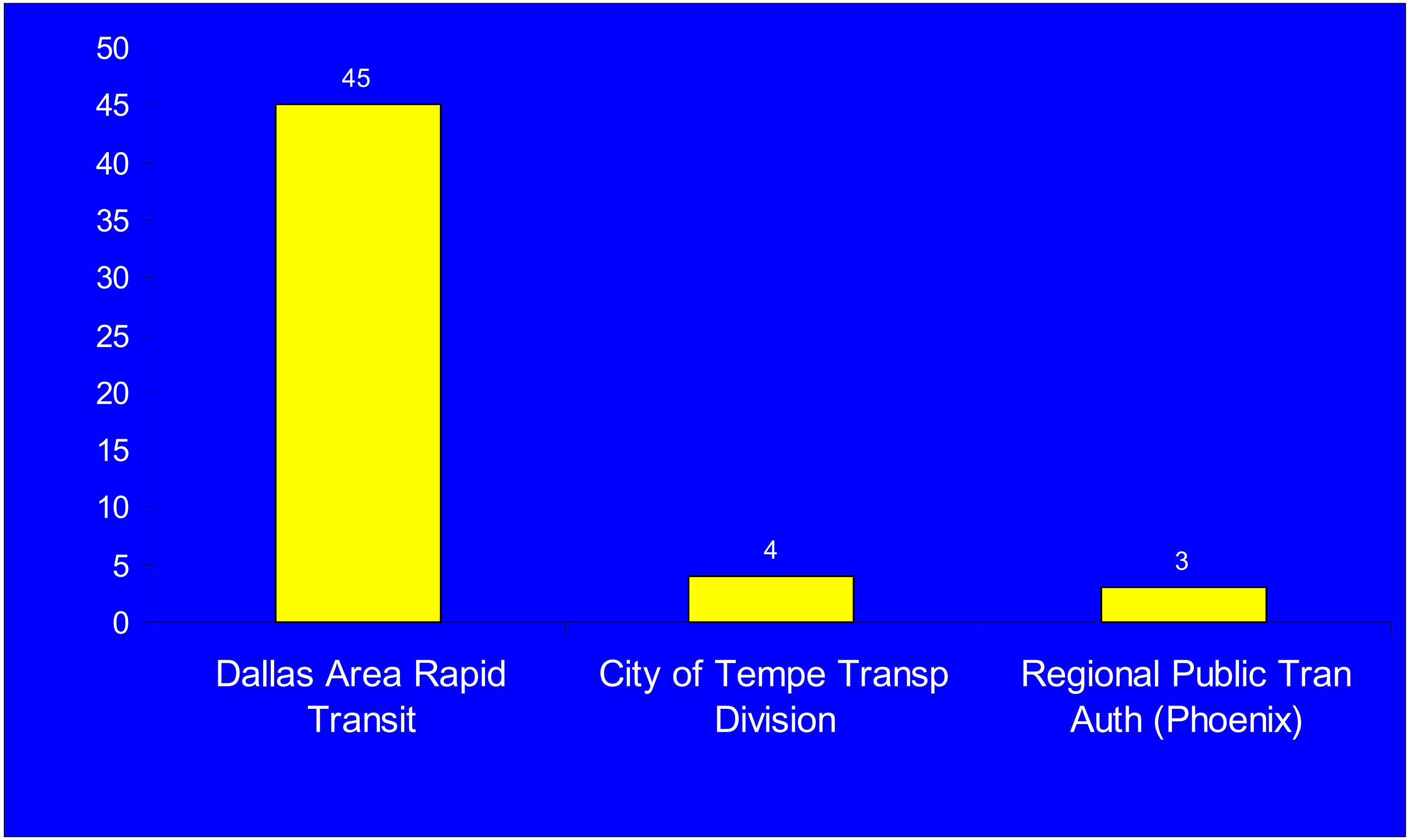
On-board methane detector inside bus

Station signage / warnings

Safety systems add capital and operating costs (e.g., training)

Which Transit Districts Ordered LNG Buses in 2002?

APTA Survey Data on Number of LNG 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.

Dallas Area Rapid Transit (DART) has been a Leader with LNG Buses

- 1998 Procurement of 10 Buses:
  - Nova Bus 40 ft. high floors
  - 280 hp Cummins L-10G engine
  - 1998 and 1999 chassis model
- Subsequent Procurements of 174 Buses:
  - 2002 Nova Bus 40 ft. high floors
  - 275 hp Detroit Diesel Series 50G engine
- More buses are on order
- DART's LNG bus program has provided invaluable data and "lessons learned" for other transit agencies

LNG Bus at Dallas Area Rapid Transit (DART)

DART's LNG Buses Compare Favorably on Operational Costs per Mile

DART Cost Summary				
Vehicle	Fuel Cost/ Mile ($)	Engine Oil Cost/ Mile ($)	Maintenance Cost/ Mile ($)	Total Cost/ Mile ($)
DART MY1998 Diesel Transit Bus Average	0.238	0.001	0.534	**0.773**
DART MY1998 LNG Transit Bus Average	0.314	0.002	0.484	**0.799**
DART MY1999 LNG Transit Bus Average	0.314	0.001	0.398	**0.713**
The LNG buses had an incremental cost of about $39,400 with LNG busses costing about $330,000 compared to $290,000 for comparable diesel buses				
Maintenance facilities modifications cost about $7.5 million for design, construction, and start-up. $3.6 million of these costs were attributed to the fueling stations. These fueling facilities service roughly 140 buses, but were designed to be capable of servicing at least 70 more buses.				

Operating Costs:

•LNG buses have higher fuel cost per mile, but lower maintenance cost per mile (especially newer versions of LNG buses)

•Newer LNG buses (1999 MY) in the fleet had lower total costs per mile compared to 1998 MY diesel buses

Capital Costs:

•DART paid approximately $7.5 million for the design, construction and start up of its LNG fueling stations and maintenance facility modifications

•Each LNG bus cost about $40,000 more than comparable diesel buses

Like Most Transit Bus Fleets Using Alternative Fuels, DART Had to Work Through Initial Problems and Issues

- Range and fuel economy optimization
  - Fuel economy was lower than expected -- additional LNG tank was added
  - Resulting range of 358 miles in service (380 miles in track tests) works well for DART
- LNG bus range was also increased through 1) modifications to the fuel gauges onboard the buses and 2) improved LNG station operating procedures
- LNG buses now operate on all routes (except a few of the longest) originating from the Northwest facility
- Other obstacles overcome included
  - Ensuring full fills of on-board LNG tanks at each fueling stop
  - Redesigning the LNG fueling nozzle to prevent leaking
  - Exploring the use of a breakaway hose to prevent damage from driveaways during fueling
  - By spring 2000, DART had resolved nearly all the problems with the LNG buses by applying the lessons learned from start-up and by cooperating with manufacturers and component suppliers

DART's Lessons Learned and Recommendations on LNG

- Transit agency employees should **learn all they can about potential problems** with alternative fuels in field operations
- Agencies should plan for **unexpected contingencies** and **exercise patience through the start-up process**
- Critical vehicle systems should undergo engineering design validation and/or performance tests before vehicles are put into service
- Transit agencies need to be **committed to success and to invest the personal energy, infrastructure, and financial resources** needed to make alternative fuel programs work
- The **LNG industry needs to improve** its own technology support infrastructure, and be able to respond to the needs of large fleets of LNG vehicles
- All critical systems need to be integrated through **strong communication and accurate information** within the transit agency

The "LCNG" Feature Enables CNG Vehicles to be Fueled from LNG

Components common to LNG stations and LCNG stations:

- Offload Connectors: enable LNG to be pumped from delivery truck
- Storage Vessel: stores LNG in "super-insulated" cryogenic tank (typically 15,000 gal.)
- Control Panel: (not shown) conditions the fuel, controls flows, enables remote monitoring, etc
- Dispenser: measures and dispenses natural gas to vehicles (as liquid or compressed gas)

Additional components needed for LCNG stations

- Cryogenic Pump: increases pressure of LNG from about 80 psi to ~4,500 psi
- High Pressure Vaporizor (heat exchanger): turns LNG into CNG
- Odorizer: adds ethyl mercaptan to CNG stream for safety
- CNG Storage and Cascade System: stores odorized CNG and enables pressure transfer to vehicles (in conjunction with the CNG sequencing panel in the Control Panel)

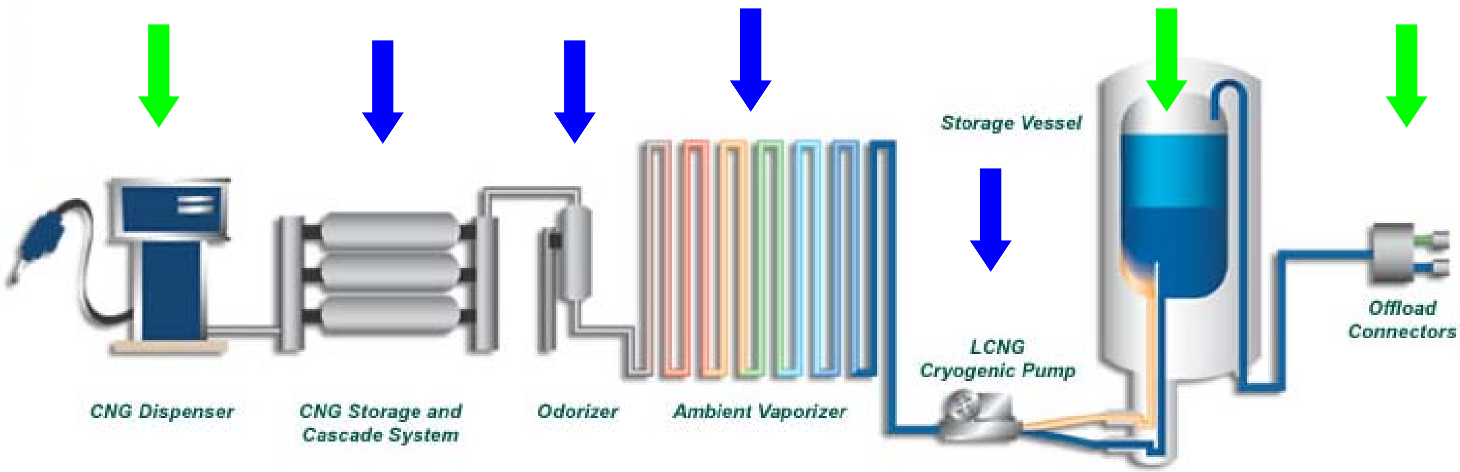


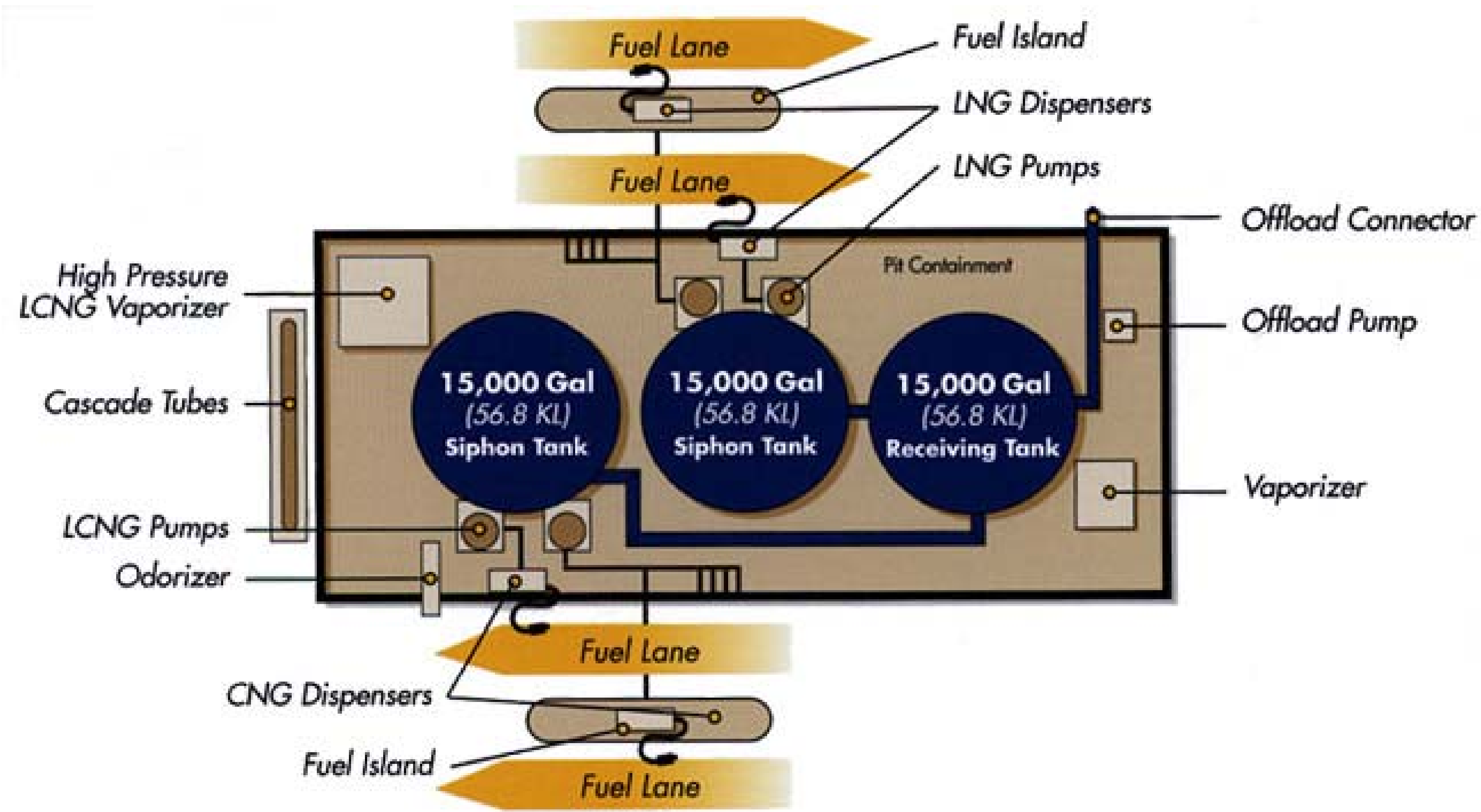
Diagram from Nexgen Fueling (http://www.nexgenfueling.com/t_howstationworks.html)

City of Tulare (California) LCNG Station

- Total cost of $2 million (about 65% from state and local grants)
- Fleet of 65 NGVs includes:
  - The CNG side (from LNG) is used to fuel transit buses, police cars and pickup trucks
  - The LNG side is used to fuel garbage trucks

Photo from: http://www.valleycleancities.org/tulare.htm

Layout of a Large-Scale LCNG Station for Transit Bus Operations



OmniTrans (San Bernardino, CA): Switch from CNG to LCNG

- Local residents complained that conventional CNG odors were excessive (leaks of odorized gas)
- Even though LCNG is usually now odorized -- less gas leakage was anticipated
- In addition, air quality permitting for engine-drive compressor stations had been problematic
- OmniTrans switched to LCNG in late 2002 / early 2003
- Station consists of:
  - A single 20,000-gallon horizontal LNG storage tank
  - Three 25 hp LNG boost pumps, and two 60 hp high-pressure LCNG pumps (16 gpm capacity)
  - A 7.5 hp vertical fan-assisted vaporizer converts the high pressure LNG to CNG
  - Two transit-style dispensers to fill buses with CNG
  - A 50KW diesel-powered generator for back-up power to the LCNG fuel station
- $2.5 million per station (fueling station only) -- grant funding from SEP (via CEC) and SCAQMD
- No changes needed for OmniTrans fleet of CNG buses (now up to about 125 transit buses)

Photo and source: OmniTrans website (http://www.omnitrans.org/about/fleet_cng-facts.shtml)

Sun Metro (El Paso) Operates a Mixed Fleet of LNG and LCNG Vehicles

Payback Analysis

Costs

Vehicle Type	Number	Incremental Cost per Vehicle ($)[a]	Total Investment ($)
CNG Buses	27	59,000	1,593,000
LNG Buses	35	40,000	1,400,000
Paratransit Vehicles	42	25,000	1,050,000
Support Vehicles[b]	24	6,000	144,000
Total	128	–	4,187,000

[a]Compared with similarly equipped, diesel vehicles.
[b]Costs are the same for CNG and LNG versions.

Vehicles	$ 4,187,000
LNG/CNG Fueling Facility	$ 3,000,000
Total Cost	***$7,187,000***
80% Matching Grant Funds	$ 5,749,600
Net Cost	***$1,437,400***

Payback Time

Before Grant Funds
($7,187,000) ÷ ($1,599,426/yr) = 4.49 yr

After Grant Funds
($1,437,000) ÷ ($1,599,426/yr) = 0.90 yr

Savings

Fuel
(174,500 gallons/month) ($1.30 – $0.54/DGE) (12 months) = $1,591,440/yr

Oil Changes
(64,000 mi/yr) (62 buses) (oil change/12,000 mi) (7 gallons oil/change) ($3.45/gallon of oil) = $7,986/yr

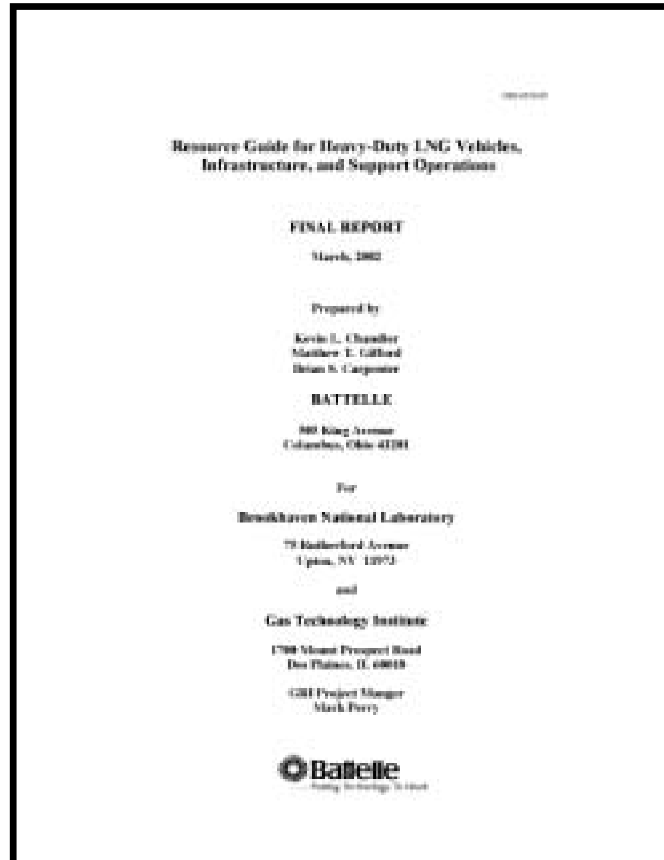
Total Savings ***$1,599,426/yr***

Source: U.S. DOE, "Sun Metro - 6.2 Million Miles on Natural Gas," online at http://www.ott.doe.gov/pdfs/sunmetro.pdf

Examples of Available Resources on LNG in Transit Applications:

(Also Provided in Module 11)

- Resource Guide for Heavy-Duty LNG Vehicles, 2002 (Battelle, available on CD-ROM)
- Final Report on DART's LNG Bus Fleet, 2002 (http://www.nrel.gov/docs/fy01osti/28739.pdf)
- Heavy Vehicle and Engine Resource Guide, DOE (http://www.afdc.doe.gov/pdfs/heavy_rg98.pdf)
- APTA web-based resource guide to transit buses, (http://wwwapta.com/research/info/briefings)
- DOE's list of commercially available alternative fuel transit bus models, (http://www.ccities.doe.gov/vbg/fleets/progs/hsearch_class.cgi?|n|Transit_Bus_Chassis*)
- Alternative Fuels in Public Transit: A Match Made on the Road, DOE 2002, (http://www.afdc.doe.gov/pdfs/public_transit.pdf)
- Sun Metro - 6.2 Million Miles on Natural Gas, DOE, (http://www.ott.doe.gov/pdfs/sunmetro.pdf)


Resource Guide for Heavy-Duty LNG Vehicles, Infrastructure, and Support Operations

FINAL REPORT

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Brookhaven National Laboratory

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NREL's Resource Guide for Heavy-Duty LNG Vehicles

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

- LNG has a small (less than 2%) but expanding share of the transit market
- LNG transit buses are now successfully displacing about 12 million gallons of diesel per year -- mostly in Southern California, Arizona and Texas
- Some transit agencies are moving towards 100% LNG fleets
- AQ benefits are strong and well documented (Module 10), but diminishing
- High capital and operational costs make grant funding essential
- Use of "turnkey" LNG 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 LNG 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)
- LNG is "bridge technology" to hydrogen fuel cells (20+ years; see Module 8)