International Association for Natural Gas Vehicles (Inc.)

REVIEW PAPER

Natural Gas Vehicle Transit Bus Fleets:

The Current International Experience

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ABSTRACT:

This paper focuses on the worldwide experience of Natural Gas Vehicle (NGV) transit bus fleets. It has been produced for the use of the International Association of Natural Gas Vehicles (IANGV) as a snapshot of the existing experience with NGV transit bus fleets from information gathered from the USA, Canada, Europe, Asia, Japan and Australia.

Besides a general overview for each country, the paper identifies transit bus fleets with 10 or more similar NGV buses and documents the following data:

- Description of fleet and buses
- Operational information (route duty, distance traveled, terrain, passengers, environment, etc)
- Fuel economy including comparison with diesel buses
- Emissions, including where available the variation with age and a comparison with diesel
- Maintenance - requirements and reliability
- Refuelling - type, description including fill pressure, time to refuel, logistics of refuelling
- Economics - fuel cost, savings, capital cost, additional maintenance cost; all in comparison to diesel
- Views of fleet managers
- Issues, opportunities, problems and challenges

The paper summarises and reviews the information available on real, operational experience with transit buses, attempting wherever possible to do this on a comparative basis. The aim is to clarify the experience in terms of the fleets' age and technology and detail the facts provided by fleet operators. The paper provides a critical analysis of information collected and draws general conclusions on the world-wide NGV transit bus experience.

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1. OVERVIEW

World-wide, urban air pollution is a serious health and environment concern in our major cities. Road transport, particularly that using diesel vehicles, is generally the major contributor to the declining air quality in urban areas. This has provoked increasingly stringent vehicle emission standards worldwide and stimulated research into alternative fuels and technologies that promise cleaner and lower emissions. Transit bus fleets operate in most large cities throughout the world and have a major impact on the local air quality, both by being a more efficient transport means than private vehicles and by their direct pollution from the bus emissions.

This paper focuses on the experience of Natural Gas Vehicle (NGV) transit bus fleets world-wide, using information from the USA, Canada, Europe, Asia, Japan, Australia, New Zealand and South America.

Why Do Bus Fleets Choose Natural Gas for Transit Buses?

The reasons for using NGV buses are variously cited by bus fleet operators and those promoting NGV as:

- ***Air Quality*** - NGV buses have superior emissions to all commercially available alternatives. In some countries the use of cleaner fuels such as natural gas is mandated by governments.
  - *Reduced Particulate Matter* - the emission of particulate matter in the latest generation of NGV bus engines is almost below detection levels
  - *Reduced Ozone* - because NGV bus engines have nitrogen oxide (NOx) performance that is many times superior to diesel, and NOx is the precursor that when mixed with hydrocarbon in the presence of sunlight produces ozone and smog,
  - *Reduced Air Toxins* - natural gas does not contain toxins to any significant degree thus does not produce the air toxins that threaten health and the environment.
- ***Economics*** - in many countries, natural gas is significantly cheaper than diesel, even after all costs associated with compression or liquefaction are taken into account, so even allowing for its lower fuel efficiency as compared to diesel there are major economic advantages in using natural gas.
  - *Domestic Resource* - in many countries that lack domestic oil resources, natural gas is a significant fossil fuel resource, hence its use gives these countries certain security against shortages and crude oil price variations
  - *Less Expensive* - for many bus fleets, when full life cycle costs are taken into account, natural gas buses provide a lower cost alternative to equivalent diesel buses
- ***Climate Change and Reduced Greenhouse Gas Emissions*** - analysis in many parts of the world generally confirms that from production, distribution to end-use, the use of natural gas results in lower overall emission of greenhouse gases, savings being cited typically as about 10%.

What is Required for Successful Market Development?

The successful development of the market for NGV buses has generally been driven by environmental imperatives to clean up air pollution. To be a success, the NGV bus has had to perform effectively in the real-world situation. This paper however, cites a number of examples where this has not been the case. While generalisations are dangerous, it is reasonable to argue that only those operations that have committed to a large enough number of NGV buses to develop and support the necessary infrastructure, both in maintenance and refuelling, have had the greatest success. Usually this success has been achieved through the combination of a long-term commitment and motivation by the whole organisation (especially to maintenance and training), fuel cost savings and the need to meet strict environmental performance.

What Special Considerations are Required to Purchase, Use and Operate NGV Buses?

The decision by bus fleet operators to use natural gas vehicles involves a long-term commitment. Organisations must recognise this and be prepared to make the effort required to extract the benefits for all stakeholders. Without commitment from the top and throughout the organisation, NGV buses will suffer in terms of performance and acceptance, running the risk of being orphaned inside the organisation. Key personnel and groups that champion the cause of NGV buses are a common feature of successful fleets. Some of the specific issues are:

- *NGV Buses Cost More* - NGV buses typically cost between 10% and 25% more than their diesel equivalents. This extra cost must be allowed for in any economic assessment and is an important factor.
- *Fleet Size Needs to Achieve Economies of Scale* - generally the fleets that have been the most successful with NGV buses have had a third or more of their fleet converted to natural gas. From an examination of USA and French case studies and reports, a fleet size of 50 or more buses appears to lead to significantly better results than smaller fleets, particularly if they are all located at the one depot.
- *The Weight of Natural Gas Fuel Cylinders* - on-board fuel storage capacity will add about 17% to the vehicle's carriage weight, depending what type of cylinders are used. If the vehicle becomes too heavy, it typically involves a reduction of 10 standing passengers.
- *The Range of an NGV Bus is Less than Diesel* - typically NGV buses have a range of about 400 kilometres (250 miles) compared to 700 kilometres (440 miles) for diesels. The storage capacity involves a trade-off between the weight of the cylinders and the desired range and payload of the buses, reflecting the relative energy density differences of the fuel as stored. Routes and distances travelled during a day need to be carefully considered to ensure there are no operational difficulties or additional costs
- *The Fuel Efficiency of Natural Gas Buses is Not as Good as Diesel Buses* - reports of 10-15% decreased fuel efficiency are common. When a vehicle shows much higher natural gas fuel consumption (25-40%) drivers should be monitored and retrained. Rarely are such levels due to the gas engine unless they involve an old conversion technology.
- *Maintenance Garages* - normally have been set up to handle diesel fuel and vehicles. Since natural gas is lighter than air and dissipates upward, adequate ventilation is required at the ceiling-level in workshops. Sometimes explosion-proof lights may be prescribed by regulation.
- *Maintenance of NGV Buses May be More Expensive* - it has been consistently reported that, at best, maintenance costs of NGV buses are equal to diesel equivalents. Some operators, particularly in the USA and Canada, report maintenance costs up to 40% more than diesel buses, although others, notably Sunline and Sacromento RT, report lower costs (see section 2.1.2.1, page 16). It should be noted however that this comparison has been made on buses that were designed in the early 1990s and do not reflect the latest NGV or diesel technologies. It is acknowledged by both supporters and critics that:
    - NGV parts are generally more expensive due to lower volumes
    - NGV engines are in the early stage of their product development cycle and will continue to improve and
    - latest technology diesel engines will be more expensive to maintain.

- *Reliability of NGV Buses May Not Equal Equivalent Diesels* - it has been often reported that the NGV buses introduced in the early to mid-1990s did not have the reliability of diesels. In some cases the reliability of NGV buses was only half that of diesel equivalents. Many difficulties were experienced with spark plugs, coils and ignition leads both in terms of life and other difficulties. Backfiring was often reported as a concern, although generally these problems in the latest generation of buses have been reduced to much more tolerable levels. Electronic, closed-loop controls also had significant teething problems, but these appear to have been overcome in later NGV buses. CNG fuel pressure regulation and engine overheating were also reported as a common problem for US buses. Recent reviews however all report improvements in NGV engine reliability.
- *Refuelling Infrastructure Costs are Significant* - Natural gas buses can be filled in the same time as diesel buses, but large compressors and storage volumes are required to ensure an adequate flow and capacity and this means increased capital costs. Some bus companies (generally in Europe) use a combination of slow (overnight) filling as well as fast-fill. Whatever the choice, it will have implications on the refuelling infrastructure costs and operational costs. Careful consideration of the refuelling patterns and time for the NGV buses is essential, as is sizing the compressor and dispensing units to match the immediate demand and making allowance for planned future expansion. CNG infrastructure costs are five to eight times that for diesel. A number of transit fleet operators are using build/own/operate/transfer or lease/buy agreements with infrastructure suppliers to reduce capital expenditure.
- *Training of Maintenance Staff and Drivers* - it is considered essential that all staff involved in NGV buses receive adequate training for their roles as part of the introduction of the NGV buses.
- *Ensure that there are No Significant Regulatory Barriers to Be Overcome* - before committing to NGV buses it is essential to ensure all regulatory issues have been resolved with all government authorities - country, state and local. Many projects around the world have had to face considerable obstacles, costs and delays as authorities come to terms with natural gas as transport fuel.

What has Been the Experience of Bus Fleet Operators?

In the country section an overview of major NGV bus activities is given as well as many actual experiences of bus fleet operators.

This experience covers:

- Description of fleet
- Technical description of buses
- Operational information (route duty, distance traveled, terrain, passengers, environmental conditions)
- Fuel economy including comparison with diesel buses
- Emissions from reliable testing, including variations with age and comparisons with diesel
- Maintenance - regular and unplanned including incidents
- Refuelling - type, description including fill pressure, time to refuel, logistics
- Economics - fuel cost, savings, additional capital cost, additional maintenance cost; all in comparison to diesel
- Views of fleet managers
- Issues, opportunities, problems and challenges

The experience of NGV bus fleets has generally been a success where it has coincided with a long-term commitment by the organisation, strong environmental and/or economic benefits, sufficient NGV fleet size, OEM buses, good support from the fuel supplier and adequate staff training.

Conclusion

The major conclusions are:

- Diesel buses are a mature and reliable technology but suffer from severe environmental emission problems
- NGV buses provide the only commercial alternative fuel to diesel
- NGV bus emission performance is far superior to diesel buses
- NGV buses often offer significant fuel cost savings as a result of lower resource cost and differential taxes
- NGV buses have range and payload restrictions in comparison to diesel buses, but the importance of this depends on the duty of the buses
- NGV bus engines are still rapidly developing, with the latest fuel injection technologies offering great promise in combustion efficiency, emissions and reliability
- Initial capital costs of setting up an NGV bus fleet are more than 20% higher than for diesel fleet costs, but innovative financing of refuelling infrastructure can reduce the capital requirements of establishing an NGV bus fleet
- The 1990s OEM NGV buses suffered reliability, maintenance and fuel economy problems but by the late 1990s, OEM buses had largely overcome these problems

2. COUNTRY DATA

A range of countries is summarised, written in the context of each country with no comparisons made between countries. Actual reports of transit bus operators on their NGV fleet operations are included to allow evaluation directly of the experience with NGV buses. Development continues at a fast pace world-wide so it is important to allow for this when drawing any conclusions.

2.1 USA

The USA has been, and is, the world leader with NGV transit bus experience. Developments continue, with large numbers of NGV transit buses coming into service, particularly in California and Los Angeles where 86% of buses will be NGV in three years.

As of 1 January 2000 there were estimated to be 44,300 buses in the USA (APTA and ANGVC figures - see Appendix 2) giving an NGV bus market penetration of **8%** for the reported 3535 NGV buses in service. This figure excludes DRVs.

The table below is for all buses in urban use excluding DRVs. This figure is not strictly only transit buses so was not used in the calculation of market penetration. Even so the market penetration was still 7%. More importantly it shows that NGV buses account for 18% of current new bus orders and 28% for potential orders, indicating an increasing market share for NGV buses over time.

Year 2000	Existing	On Order	Potential Orders
All Buses	53,464	7,824	14,153
Alternative Fuel Buses*	3,992	1,448	3,954
Undecided			442
Natural Gas Buses			
CNG	2,986	1,207	3,487
CNG & E-Battery	2	41	20
CNG & Diesel	55		-
CNG & Gasoline	31		
LNG	505	129	336
LNG & Diesel	267		
LNG & E-Battery	3		
Total	**3,849**	**1,377**	**3,843**
NGVs % / AFVs / AFVs	96%	95%	97%
NGVs% / Buses	**7%**	**18%**	**28%**

These natural gas buses, because of their low emissions, are most in demand in cities where air quality is a prime issue. They also have lower overall greenhouse emissions. When NGV buses are put into operation, the public and commuters notice the lack of smoke and smell as well as the reduced noise, and mechanics find them cleaner to work on.

Natural gas buses provide a proven technology. All full-size transit bus manufacturers in the U.S. now offer natural gas buses. Buses are available from 16 vehicle manufacturers and four engine manufacturers, with buses supplied in 25, 29, 30, 32, 35, 40, 45, and 60 foot lengths (7.5, 8.8, 9, 10, 10.5, 12, 13.75 and 18.25 metre lengths).

Natural gas is used in two ways in buses in the USA:

- Compressed Natural Gas (CNG)
    - Now used most frequently
    - Gas is stored at 21 to 25 MPa (3000 to 3600 psi)
    - Fuel system volume about 5 times that of diesel fuel
- Liquefied Natural Gas (LNG)
    - Natural gas is stored as a liquid at around -160°C (-260°F)
    - Fuel system volume is about twice that of diesel fuel

There are over 1,200 CNG and almost 50 LNG Natural Gas Refuelling Stations throughout the USA, with over 70 stations serving transit bus fleets.

The USA Federal Government supports NGV buses since they are seen as a cost-effective means of improving air quality that is supported by an abundant domestic fuel resource. Even though NGV buses have a higher first cost, they are seen as a good long-term investment, their use promotes economic development and provides some insulation from crude oil price spikes and shortages. The USA Federal Government supports NGVs through the following incentives:

- Lower Highway Tax
    - CNG, 5.9 US cents per US gasoline-equivalent gallon (1.5USc/l)
    - LNG, 11.9 US cents per US gallon (3USc/l)
    - Gasoline (Petrol), 18.4 US cents per US gallon (4.7USc/l)
    - Diesel, 24.4 US cents per US gallon (6.3USc/l)
- Energy Policy Act Vehicle and Refuelling Tax Deductions
- Grants of up to $US50,000 per heavy-duty vehicle; up to $US100,000 per refuelling station

Some 32 USA State governments support NGVs through State incentives such as:

- Arizona: $US1,000 tax credit per vehicle for NGV
- Georgia: $US1,500 tax credit per vehicle for NGV
- Illinois: 80% of incremental NGV cost per vehicle, up to $US4,000

The lessons learnt about NGV bus operation in the USA have been that:

- Commitment is needed from bus fleet operators and must be from throughout the bus organisation
- A significant part of the fleet must be changed over to NGV, ideally at least a whole depot
- No extreme regulatory hurdles should need to be overcome if NGV buses are to be a success
- Financial capability must be in place since:
    - The capital cost of NGV buses is 10% to 20% more than their diesel equivalents
    - Refuelling, maintenance and bus storage infrastructure is expensive, but relatively simple, and long-lived
        - Typical refuelling capital costs to serve 200 buses is quoted as:
            - CNG $US2,700,000
            - LNG to CNG $US1,800,000
            - LNG $US 950,000
            - Diesel Fuel $US 350,000
    - Long-term commitment by the bus organisation is needed to justify additional costs

- Training of drivers and mechanics needs to be comprehensive and supported by the bus organisation to allay safety concerns and ensure competent support of the NGV technology on the buses
- Government Mandates/Regulation alone are insufficient, incentives are needed to encourage NGV
- There is a need for the active involvement of a fuel supplier
- There is a need to recognise and accept some additional costs and inconvenience during transition
- Passengers and the public need to be informed
- Fuel costs are generally reduced
- Life-cycle costs are generally lower, even without accounting for public health benefits

The US Department of Energy has produced a brochure titled “Clean Cities Fact Sheet Natural Gas Buses: Separating Myth from Fact” to clarify the true situation in respect to NGV buses compared to their diesel equivalents. In the brochure 15 areas of concern (myths) are dealt with:

MYTH	FACT
• NGV buses emit the same amount of particulates as diesels:	• tests show a 97% reduction, with most of the balance attributal to crankcase oil
• NGV emit more ultra fine paticulates:	• initial results are contradictory
• NGV buses create more greenhouse gases:	• assessments show GHG are slightly less
• NGV buses are more expensive than diesel buses:	• true ($US 25,000 to 50,000 per bus), but paid back by fuel savings (and diesel hybrids are twice as expensive)
• Advanced diesels make NGV unnecessary:	• NGV engines are cleaner under truly comparable conditions
• Hybrid diesel using ultra low sulphur negate NGV emission benefits:	• they are very close to NGV emissions but the fuel and technology is still not commercially available and is expensive
• NGV tanks prone to explode:	• untrue
• NGV buses are unsafe:	• untrue
• NGV maintenance garages and refuelling facilities are more dangerous:	• untrue
• Natural gas is toxic to breathe:	• untrue but natural gas is an asphyxiant
• Hybrid technology makes NGV buses obsolete:	• NGV better and cheaper
• NGV engines too expensive for use in hybrids:	• likely to be similar costs
• Diesels easier to maintain:	• it is a matter of training
• NGV bus maintenance cost higher:	• true (some costs higher, some lower)
• NGV buses heavier and therefore wear out tyres, brakes, etc more quickly:	• they are, but evidence indicates that drivers and routes are more the cause

The conclusion of the brochure is to seek the **current** facts with respect to NGV buses and not look to the past or forklore.

There have been setbacks for NGV buses. In the late 1990s there was a flattening of the trend to use NGV buses that was attributed directly to the cost and reliability of the the early generations of buses and was reflected in the decision by a number of transit agencies to review ordering additional NGV buses:

- Bi State Regional Transit Authority of St Louis reversed plans to purchase 300 NGV buses because of range and reliability concerns as well as increased purchase costs. The past experience had affected service quality and reliability (refer St Louis Dispatch archives,1998)

- Cleveland Regional Transit Authority was very disappointed in the 166 NGV buses it purchased in the early 1990s. A report on new NGV buses estimated their additional cost over diesel as $8 million over 12 years, however after Cleveland RTA reviewed costings as well as environmental and social values it was decided to purchase further NGV buses (refer to Cleveland RTA Alternate Fuels Analysis, June 2000 and section 2.1.6.)
- Capital Metropolitan Transportation Authority (Austin, Texas) purchased a fleet of 43 NGV buses in 1993 and the significantly higher capital and operating cost has led them to purchase diesel buses (refer Capital Metro Alternate Fuels Performance Report 1998).

There are now consistent reports that the early 1990s generation of NGV buses had a higher capital cost than their diesel equivalents, were about 30% to 40% more expensive to maintain and had considerably reduced reliability (mean time between failure, up to half that of the diesels). These are issues that new NGV buses are overcoming.

The American Public Transit Association (APTA) submitted comments to the Department of Energy on 16 July 1998 stating that the key issues for transit operators operating NGV buses were:

- Capital and Start Up Costs: higher bus costs ($US50,000), fuelling station costs, training costs for maintenance and operators, garage retrofit costs
- Operating Costs: fuel station maintenance, bus maintenance, fuel costs, reduced range (230 versus 400 miles, 370 km vs 640 km), engine reliability, increased weight, reduced brake life.

The APTA stated these were issues for future NGV buses to overcome if they were to increase their presence in the market.

In a recently released report by INFORM titled ‘Bus Futures New Technologies for Cleaner Cities’ there were five major findings regarding bus and fuel options:

1. Natural gas buses are commercial and road-ready and are an option for conventional diesel buses.
2. The evidence was overwhelming that NGV buses emit significantly fewer pollutants than diesels.
3. NGV buses are more expensive to buy and, for most transit fleets, to operate than conventional diesel buses, but an accurate picture requires assessment of societal and infrustructure costs.
4. The two major technologies to control diesel bus emissions, particulate trap technologies and low sulphur diesel fuel, are not available commercially nationwide.
5. Hybrid electric and fuel cell buses are very promising technologies but they are not yet commercial.

The study goes on to recommend that:

- transit operators should purchase NGV buses as the best choice for emission reduction,
- diesel technologies that are not yet commercial should not be part of an emission reduction strategy by transit operators,
- only proven technologies such as NGV should be used in large scale inservice fleets,
- investment in NGV buses and their infrastructure will result in progress towards cleaner buses and cleaner air.

The report highlights the fact that buses are a major contributor to urban air pollution. Particulate matter counts for 71% of the transportation sources of cancer risk in Los Angeles, with 1,3 butadiene and benzene accounting for a further 15%. It is believed that as natural gas is virtually free of the toxic chemicals that diesel contains, it will produce inherently cleaner emissions. Similarly for NOx, the report suggests diesels account for one-third of all vehicle emissions. Again, the performance of NGV engines on NOx is significantly better than diesels.

A list of transit bus fleet operators with natural gas buses in service in the USA and the size of the fleets, including the number of NGV buses on order, and potentially on order is given in Appendix 1. It is based on the year 2000 information from APTA, ANGVC, DOE and Calstart.

In the state-by-state sections below, information and the actual experience of NGV bus fleet operators as reported by them and other sources is covered. It generally confirms significant emissions improvement and fuel costs savings, while reinforcing that NGV buses are more expensive and their maintenance costs generally higher, reflecting the developing nature of the NGV engine technology. It also confirms there have been operational problems in introducing the NGV buses, but that the extent of the operator commitment and the size of the NGV fleet has had a significant effect on the impact of these problems.

2.1.1 Arizona

2.1.1.1 Phoenix Transit

- Description of fleet

411 buses including 157 NGV buses using LNG

- Technical description of buses

1998 & 1999 North American Bus Industries (NABI) 40 foot (12.2 m) & 35 foot (10.7 m) low floor, liquefied natural gas (LNG) powered buses with the Cummins series "C" 275 hp (205 kW) engine with World Allison transmission and ThermoKing Model R3-M5 (116,000 BTU/hr (39.97 kW)) air conditioning.
1998, 1999 & 2000 model El Dorado/National EZ Rider 30 foot (9.1 m) Low Floor, LNG powered bus with the Cummins series "C" 250 hp (186.4 kW) engine with World Allison transmission and ThermoKing Model R3-M5

- Operational information:

Transit duty with 40% idle; distance traveled - 50,000 miles/yr. (80,500 km/yr.); terrain - primarily flat; passengers - 150,000 per day; environmental conditions - dry, hot and hotter.

- Fuel economy including comparison with diesel buses:

LNG Cummins "C" 275hp (205 kW) - Average 1.9 mile/US gal (0.8 km/l) diesel equivalent gallons.
Detroit Diesel Series 50 diesel engines 275hp (205 kW) - Average 3.1 mile/USgal. (1.3 km/l)

- Emissions

The emission tests Phoenix Transit have done show the carbon monoxide (CO), hydrocarbon (HC) are at or a little lower than for a diesel engine of the same age. However, the nitrogen oxides (NOx) at idle is significantly higher for the NGV engine, whereas under load, the NOx is considerably lower than diesel. To get the cleanest emission possible, Phoenix Transit require a catalytic converter to be fitted even though the NGV engine meets EPA standards without it.

- Maintenance

Phoenix Transit records the road calls for all buses. They have been tracking the LNG buses against diesels of approximately the same age and found no significant differences in road call incidents.

- Refuelling

The LNG/LCNG station consists of two 30,000 US gallon (115,000 litres) vertical LNG tanks with electronically controlled pneumatic valves. The fuel is off-loaded from the tanker truck through a station-mounted cryogenic off-loading pump at a rate of approximately 8,000 gallons/hour (8.6 l/s). There are two LNG dispensers on the main fuel island along with one LNG dispenser and one LCNG on a separate detached island. LNG is converted to LCNG by being pressurized, vapourised (expanded), odourised, and stored in a 10,000 scf (28,000 litres) (pressure vessel at approximately 5,000 psig (35 MPa). LNG is dispensed at approximately 50 gallons/minute (3 l/s) at 170 psig (1.2 MPa) (100 psi / 700 kPa above bulk saturation pressure). Total fueling time from connect to disconnect is approximately five minutes per vehicle which will vary on vehicle fuel capacity. LCNG is dispensed at approximately 4.2 gasoline equivalent gallons/minute (0.25 l/s) at 5000 psig (35 MPa). The station is currently operated by internal employees while being maintained by an outside contractor.

- Economics

LNG fuel (98% methane) is provided at a contract cost of $US0.48/gal ($US0.127/liter), until June 30, 2002, which is equivalent to approximately $US0.80/gal ($US0.211/liter) for diesel.
The other costs are as follows:

1. The bus costs $US25,500 more than the same bus fueled with diesel (both LNG and diesel include a fire suppression system).
2. The fuel station cost, including design, was $US2,709,000 for a 60,000 US gallon (227,000 litre) L/CNG fuel station (3 LNG fueling nozzles and 1 CNG fueling nozzle).
3. A two year contract with the fuel provider to provide routine inspections of the maintenance facilities and L/CNG station which includes semi-annual methane detection and fire suppression system inspections and repair and L/CNG station maintenance services and station reports excluding parts (Phoenix City maintains a $US89,000 parts inventory for same-day turnaround repairs) for an annual cost of $US82,000.
4. Buses are still under warranty

- Views of fleet managers

Although LNG was not really a new fuel, it was considered new to Phoenix Transit. With the influx of new buses that were being powered by a "new" fuel type came some worries and concerns that are always present when you introduce something new into an atmosphere where the old has been the standard for many years. After the initial fear factor was overcome by the employees, Phoenix Transit progressed rapidly to the point that they are almost back to a state of business-as-usual. In the opinion of Earl Zwagerman, Manager of Phoenix Transit, aside from specific venting and piston problems not within the control of the transit bus fleet, you can make LNG or CNG work in a transit bus fleet environment.

- Issues, opportunities, problems and challenges.

In this respect Phoenix Transit has the following views:
Issues: How do you implement a new engine, fuel, and fueling system effectively and efficiently with a new fleet of 196 buses and three different service and maintenance contractors?
Opportunities: Become less dependent on oil based fuels; Learn alternate fuels from the ground up. To work with engine and alternate fuel systems to develop a better and more efficient engine, fuel and refuelling system.
Problems: Phoenix Transit uses the saying here that "There are no problems only CHALLENGES": With any new technology, or in fact any new bus order, there are challenges. The main challenge is to have trained operators and maintenance staff that can observe and report changes in the buses while in operation and during preventive maintenance. The next challenge is to have bus manufacturers and component manufacturers working in partnership with the service and maintenance contractors. The bus, bus fueling system, refuelling system, transmission and engine have all been a challenge but the problem/s have not kept the buses out of service and each problem as it occurs is being resolved to make the bus better.

The bottom line is TRAINING, TRAINING, AND MORE TRAINING. Phoenix Transit initially met resistance from the operators, mechanics, fuelers, and subsequently the union. They trained everyone from top management to bus washers. A little "LNG 101" goes a long way, provided you have the answers to conciliate the resistance. One continuing challenge for Phoenix Transit as well as the manufacturer, has been the plugging of fuel flow check valves with debris. Phoenix Transit is working with the vendor to identify the root cause and provide a solution. This problem manifests itself as showing higher than normal tank pressures which causes difficulties refuelling. The tanks have to be manually vented down to a pressure so that the dispenser can overcome the internal tank pressure to allow fueling to begin. This has caused a significant time increase to refuel affected buses. It also takes a significant amount of time to properly diagnose the problem and make repairs.

2.1.1.2 City of Tucson Mass Transit System

- Description of Fleet:

Forty Foot (12.2 metre) buses, 42 seated passengers, supplied by the following manufacturers:

RTS	84 Each
Neoplan	68 Each
New Flyer	49 Each

- Technical Description:

RTS: Diesel Fuel Only (84 each), 6V92 Detroit, 731 Allison Transmissions
Neoplan: Diesel Fuel Only (22 each), 6V92 Detroit, 731 Allison Transmissions
Neoplan: Dual Fuel CNG/Diesel (46 each), 6V92 Detroit Diesel (Ping engine), 731 Allison Transmissions
New Flyer CNG Fuel Only (49 ea), Series 50 CNG Detroit, New World Transmission 400R

- Operational Information:

Passengers Yearly	15,334,428
Route Duty:	33 Fixed Routes
Distance travelled	8,021,791 Miles per year (12,900,000 km)
Number of Buses Used Daily	162
Terrain	2704 Feet Above Sea Level (824 metres)

Environment: Dry Desert Average Temperature 82 F (28C), Highest Temperature 117 F (47C), Lowest Temperature 6 F (-14C), Yearly Average Rain Fall 12 inches (300 mm)

- Fuel Economy:

Diesel Fuel for 106 Buses	Diesel Fuel Purchased for 51.17 % of Buses
US Gallons 1,644,776 (6.4 million litres)	Cost $US1,562,871.81 (95USc/US gal, 24.4USc/l)
Compressed Natural Gas for 95 Buses	CNG Fuel Purchased for 48.83 % of Buses
US Gallons 978,881 (3.8 million litres)	Cost $US422,128.33 (43USc/US gal, 11USc/l)

Average Mile Per US Gallon for Diesel	2.5 MPG (1.04 km/l)
Average Mile Per US Gallon for CNG	4.01 MPG (1.66 km/l)

- Maintenance:

Scheduled PMI at 6000-mile (10,000 km) interval.

- Refuelling:
  Type Description Including fill pressures:
  Diesel approx 5 minutes
  CNG Fast fill to 3000-PSI (21MPa)Approximate 10 minutes
  CNG Slow Fill to 3200 PSI (22MPa) approximate 30 minutes

The City of Tucson has made a commitment to alternate fuels choosing compressed natural gas (CNG). With the smog problem in Tucson they have found that CNG is making a difference, improving local air quality.

2.1.2 California

The NGVC reported that with the strong support of a diverse coalition of environmental, health, community and alternative fuel advocates, on 16 June 2000, California's South Coast Air Quality Management District (SCAQMD) unanimously approved the first three of a six-part series of regulations that will have a huge impact on the growth of the NGV market in California and, ultimately, the bus fleets in Los Angeles, Orange, Riverside and San Bernadino counties. It is estimated that up to 120,000 vehicles will be affected by the three rules.

Under Rule 1192, effective immediately, all new buses purchased by large transit fleets (100 or more buses) must be powered by non-petroleum alternative fuels (articulated buses are exempted). Transit agencies with fleets between 15 and 99 have until July 1, 2001 before being subject to the new rule. Transit fleets of less than 15 buses are not covered. There are about 4900 transit buses that operate in the four SCAQMD counties.

In the opinion of environmentalists and NGV advocates, this new ruling confirms NGVs superior emission and environmental performance and gives NGV buses a further strong boost.

2.1.2.1 Sunline Transit Agency and Sacramento Regional Transit

- Description of fleet

The Sunline Transit Agency, located in Thousand Palms in the Coachella Valley, undertook a three year comparison of natural gas and diesel transit buses. In conjunction with the Sacramento Regional Transit (SRT), Sunline compared its combined fleet of 170 natural gas buses (136 for Sacramento and 34 for Sunline) with 73 older diesel buses, all with SRT.

- Technical description of buses

Sunline Transit and Sacramento Regional Transit operate mainly Orion chassis buses with Cummins L10G/240 NGV engines and are air conditioned. The diesel buses were Gillig chassis with Detroit Diesel 6V92TA or 6V92TB engines.

Operational information

The Orion buses operate about 43,500 miles (70,000 km) per year, carrying 28 million passengers in areas described by the EPA as “severe non-attainment areas” and have air conditioning due to the extreme summer temperatures.

- Fuel economy

Sunline did not operate diesel buses but SRT did. SRT’s diesel buses averaged 3.51 miles per US gallon (1.41 km/l) whereas the most recent mileage per US gallon of the NGV buses was 3.07 (1.24) for SRT and 3.09 (1.24) for Sunline.

- Emissions - none reported

- Maintenance

The data from the study indicated that labour for the diesel vehicles was almost twice that of the NGV buses and parts were 25% more.

- Refuelling

Sunline spent $US1.5 million on CNG (2 compressors) and maintenance infrastructure, and Sacramento $US3.5 million; both use fast fill. The Sunline CNG facility has public access.

- Economics

The incremental capital costs of the NGV buses was between $US35,000 and $US50,000 per unit. This gave a payback period of approximately seven years or 300,000 miles (500,000 kilometres) per bus. It is important to note that the study acknowledged that newer buses have lower maintenance costs than older buses regardless of fuels. Sunline however stated that even so data showed the margin of cost reductions continued to grow over diesels. The diesel buses of SRT showed fuel costs nearly double that of the NGV buses (in 1997 the diesel cost was about $US500/1000 miles or 1600 km, versus $US300/1000 miles or 1600 km for CNG).

- Views of fleet managers

The view of Sunline is that the move to NGV buses was worthwhile and that it was the total committment that made the difference. This focussed staff and resources, rather than creating NGV buses as a special project (“orphan”) situation within a fleet which is dominated by diesel. The environmental and societal values of NGV buses was an important consideration and remains so.

- Issues, opportunities, problems and challenges

This study by Sunline, which was published in 1999, has since been criticised by other agencies and transit fleet operators as not comparing like-for-like. Subsequent studies by other transit operators who have NGV buses and diesel buses of the same make and vintage claim that NGV buses are significantly more expensive to maintain and are less reliable. However it is clear that NGV buses performed well for Sunline and SRT, so the argument would seem to revolve around the extent and degree of commitment. Sunline has expressed the view that it has found, for the most part, if it followed the training and the manufacturers guidelines they had very good results.

2.1.2.2 Los Angeles County Metropolitan Transportation Authority

- Description of fleet

NGVC reported in May 2000 that the Los Angeles County MTA proposed for FY 2001 to buy 502 more natural gas buses. Los Angeles already operates the nation's largest fleet of natural gas buses; including the buses it already owns, those about to be delivered and next year's purchases, the LACMTA bus fleet will be about 50 percent natural gas. Los Angeles currently has more than 2,600 buses in its fleets, currently operating about 900 NGV buses with 670 more on order over the next two years. With the new order by June 2002, the LACMTA will have 1,940 NGV buses in its fleet.

- Technical description of buses

LACMTA NGV buses are Neoplan buses with Cummins L10G engines.s

- Fuel economy

The fuel economy is 3.33 miles per US gallon for diesel (1.34 km/l) compared to 2.17 miles per US gallon for NGV (0.87 km/l). The fuel cost for NGV buses was 27% higher than diesel when compression costs were taken into account. The fuel cost for NGV buses was $US0.2 per mile while diesel was $US 0.16 per mile (12.4 and 10 USc/km).

- Emissions

The primary benefit of operating NGV buses was emissions reduction. The LACMTA quotes the Cummins L10G engine as having 1.4 g/bhp-hr (1.88 g/kWh) NOx and 0.02 g/bhp-hr (0.027 g/kWh) of particulates and the Detroit Diesel Series 50G as having 2.2 g/bhp-hr (2.95 g/kWh) NOx and 0.01 g/bhp-hr (0.013 g/kWh) particulates. In comparison diesels have yet to reach these levels. Current diesels meet the California 1998 standards of 4 g/bhp-hr (5.4 g/kWh) NOx and 0.05 g/bhp-hr (0.07 g/kWh) particulates.

- Maintenance

Due to chronic problems with engine and fuel system components, NGV buses have had a significantly greater defect rate. Problems have been experienced with the electronic systems, ignition coils, fuel mixers and catalytic mufflers. This caused a 96% higher parts costs for NGV buses over diesel. Labour costs were 3% less than diesel. Road calls for NGV buses related to engine and fuel systems were 48% of their total road calls versus 34% for diesel. The current mean time between failures of NGV buses and diesel was about the same.

- Refuelling

LACMTA uses fast fill systems. NGV buses typically have a midday fill as well as overnight. The initial facilities were purchased by LACMTA but a recent contract with Trillium to build, own, operate and transfer new compressor stations will result in savings of $US1 million in costs and will not require LACMTA to expend capital of some $US10 million.

- Economics

LACMTA found that the operating costs of 1995 NGV buses were approximately 40% higher than 1988 diesel buses. Engine and fuel system road calls on the 1995 NGV buses were also 40% higher. The purchase costs of NGV buses over diesel buses was approximately $US36,000 extra ($US 320,000 versus $US 284,000)

- Views of Fleet Managers

LACMTA acknowledged its choice for future bus purchases was between NGV buses using CNG and diesel. LNG was ruled out as a fuel due to the additional cost of infrastructure. Other alternative fuel buses were ruled out as being non-commercial at this stage. It also expected the performance of NGV buses to improve as technology matures. It also believes current costs for operating NGV buses are significantly higher than diesel, although it should be noted that this data was based on 1999 information and costs.

- Issues, opportunities, problems and challenges

In a report prepared by their transit operations department in 1999 LACMTA re-evalauated the agency's fuel strategy, completing an exhaustive analysis of the reliability and operating costs of several agencies, including Sacramento Regional Transit District, the New York City Metropolitan Transportation Authority and its own fleet.

LACMTA was concerned about conclusions drawn by comparing new buses with older buses and that the effect of warranties may not have been appropriately taken into account. Using the data from the above fleets, LACMTA developed a life cycle cost analysis for a fleet of 200 NGV buses compared to the same fleet of diesel buses. This revealed an increase in annual operating costs of between $US1.4 and 2.7 million for the NGV fleet. This analysis was criticised as the report relied on NYCMTA data comparing Cummins L10G gas engines to Detroit Diesel series 50 diesel engines. The most recent deliveries of low-floor NGV buses to NYCMTA resulted in 30 day acceptance tests without incurring mechanical failure, indicating an improved performance of current NGV buses.

LACMTA also found that a number of transit authorities had reversed their decisions to purchase additional NGV buses after being unable to resolve problems with vehicle range reliability and significantly increased operating costs. Transit authorities cited were:

Bi State Regional Transit Authority (St Louis)
The Cleveland Regional Transit Authority,
The Capital Metropolitan Transportation Authority (Austin, Texas), and
The City of Mississauga (Ontario, Canada).

However, closer examination of these authorities reveals specific special reasons for their decision. In the case of The Cleveland Regional Transit Authority it was found that the original figures upon which the study was based were incorrect to the detriment of NGV buses. When the Cleveland RTA Board was informed of the error and considered all other factors, they voted to purchase another 45 NGV buses in addition to the 166 already in service. The City of Mississauga had a requirement to replace all its buses and decided to stay with diesel to reduce costs as provincial support for alternative fuel vehicles had been discontinued (see section 2.2, page 31).

LACMTA also pointed out that the major funding for buses comes from federal sources and as both NGV and diesel buses comply with their requirements there is no financial incentive for NGV buses and therefore LACMTA must rely on state and local funding to offset increased costs of NGV buses. Whilst this has been provided it has not covered CNG fueling and maintenance infrastructure or NGV bus increased operating costs.

LACMTA held meetings with many stakeholders all of whom expressed significant concern over the agency's review and opposed any movement away from the existing policy to purchase NGV vehicles.

A number of criticisms were made of LACMTA evaluation of CNG buses versus diesel by these stakeholders. It was pointed out that the impact of new diesel engine standards and diesel capital and operating costs were not considered. Recent price rises in diesel compared to natural gas were also not considered. It was also assumed that the teething problems with the CNG fleet would continue, if not get worse in the future. This was disputed by many stakeholders.

2.1.2.3 Humboldt Transit Authority

The Humboldt Transit Authority has voted to switch its current transit buses from diesel to natural gas. It plans to establish a shared refuelling station that will also be used by the participating cities' NGV vehicles. The rising cost of diesel and concern about diesel emissions, especially particulates, were the two main drivers for the decision.

2.1.2.4 Metropolitan Transit Development Board, San Diego

- Description of fleet

MTDB operates 128 NGV buses which comprises 26% of the active fleet of 506 buses. It is planned to purchase another 42 NGV buses.

- Operational information

Since being placed in service in 1995 each of the buses have some 100,000 miles (160,000 km) of service. The service territory is in a coastal desert and in parts is quite hilly.

- Fuel economy

Fuel economy is lower for NGV buses compared to diesel.

- Maintenance

Maintenance costs today appear to be about the same for NGV and diesel buses. There are some fears that the hotter running NGV engines would fail earlier they appear to be in good condition after 100,000 miles (160,000 km).

- Refuelling

MTDB has two fast fill CNG fueling stations built and operated by San Diego Gas and Electric. The two compressors at each station are rated at a total of 1,400 scfm (40 m3/min). They are suitable for about 60 to 70 NGV buses at each station site. Each bus has a fuel capacity of 16,400 ft3 (460 m3) at 3,600 psi (25 MPa), taking about 4 to 10 minutes to fill.

- Economics

Diesel fuel cost has varied between 55 US cents to $US1 per US gallon (14 to 25 US cents per litre) and gas is about 85 US cents a therm (29 US cents per litre equivalent). Fuel pricing has been difficult with CNG prices rising and diesel prices varying erratically but currently CNG is cheaper than diesel.

- Views of fleet managers

MTDB has now had two years of extensive NGV bus operations. Its experience has generally been positive with the buses performing well. The buses' range proved to be excellent with minimal emissions, no safety problems and good public acceptance.

- Issues, opportunities, problems and challenges

Several issues remain to be addressed including fuel pricing, defueling facilities, and engine longevity. The buses originally received in 1995 had significant problems with the valves that supply fuel to the engine. While not totally solved the valve has been much improved.

One of the issues that has proved to be a problem has been the defueling of buses to work on fuel valves. At present the only way to do this is to vent the gas to atmosphere which is wasteful and expensive. MTDB intends to install equipment to allow the gas to be passed back into the gas utility system.

2.1.3 Illinois

2.1.3.1 Springfield Mass Transit District

- Description of fleet

Springfield Mass Transit District in Springfield, Illinois has a fleet of eighteen (18) New Flyer compressed natural gas fuelled buses.

- Technical description of buses

Seven (7) are 1996 models and (11) eleven are 2000 models. All are 35 foot (10.7 m) low floor transit buses, model C35'LF. The engines are Detroit Diesel Series 50 and the transmissions are Allison B400R. Springfield also operates thirty (30) older model buses with diesel engines. These buses are 35-foot high-floor buses.

- Operational information

All these buses operate in route service on very flat terrain. They travel approximately 25,000 miles (40,000 km) per bus per year, with 1,400,000 passenger trips per year system wide. Weather conditions range from -15 F (-26C) to 100 F (38C).

- Fuel economy including comparison with diesel buses

Average fuel mileage is 3.04-mpUSg (1.26 km/l) for diesel buses and 2.54-mpUSg equivalent (1.05 km/l) for the CNG buses.

- Emissions testing

So far no emissions tests on the CNG buses have been made to compare them with the diesel buses

- Maintenance

No comparisons have been performed on maintenance costs.

- Refuelling

The Springfield Mass Transit District has its own CNG fuelling station on the property. The cost of this station was $US400,000 when it was installed in 1996.

- Economics

The CNG buses cost the district approximately $US30,000 more than a diesel bus. Current cost for fuel is $US0.95 per US gallon ($US0.24 /l) for diesel fuel and $US0.82 per US gallon equivalent ($US0.21 /l)for CNG including costs for compression.

- Issues, opportunities, problems and challenges

Springfield has had some engine fuel delivery problems with its buses but Detroit Diesel Corporation seems to have resolved most. The 1996 model buses have done just over 100,000 miles (160,000 km), the 2000 model buses were put in service in May 2000.

2.1.4 Maryland

2.1.4.1 Montgomery County Transit

Montgomery County is just north of Washington D.C. in Rockville, Maryland. Montgomery County runs the transit bus service and is a non-attainment area of ambient ozone and carbon monoxide standards.

- Description of fleet

The County plans to purchase additional CNG powered buses in the near future as funds become available, increasing the fleet of CNG transit buses to 35 by 2002.

- Refuelling

A slow-fill site at the main repair facility is currently fuelling five CNG transit buses. Washington Gas Co. supplied and installed the fuelling installations. Fleet Management installed a methane detection system in the shop at a cost of $US10,123.

- Economics

In Maryland, state tax credits are also available for vehicle purchases. The fuel costs for CNG buses ($US0.126/mile or $US0.078/ km were lower than the diesel buses $US0.177/mile or $US0.11/km) as expected. The CNG buses use approximately 1100 US gallon equivalents per bus per month. The cost of diesel fuel is $US0.87 per US gallon ($US0.22 /l) and the cost for CNG is $US0.72 per US gallon equivalent ($US0.185 /l). The fuel savings cost over the life of the bus are expected to offset the higher acquisition cost of approximately $US70,000.00 per bus.

- Views of fleet managers

The major benefit of CNG vehicles is the lower operating cost over the life of the vehicle due to lower fuel costs. The life-cycle costs, combined with the environmental benefits and visibility within the county, contributed to Montgomery County's support of clean fuel NGV buses.

- Issues, opportunities, problems and challenges

The shorter operating range of the CNG buses meant the CNG buses were put on runs that did not exceed their range and also put on split runs so midday fuelling could be accomplished. After training was provided to the users on the properties of CNG, most of the operator's fears were removed and the mechanic training was carried out by the bus manufacturer.

2.1.5 Massachusetts

The **Massachusetts Bay Transportation Authority** did a prototype evaluation of new technology buses. The MBTA compared over six months (September 1999 to February 2000) two NGV buses, two hybrid diesel buses, two new 2000 diesel RTS buses and two 1995 diesel RTS buses as a baseline.

The evaluation was on reliability, maintainability, air quality, emissions, cost and passenger and driver opinions. Of the alternate fuels, natural gas was the most reliable,and both hybrid and NGV buses demonstrated lower NOx and particulates but more carbon dioxide than diesel. NGV buses were more costly to purchase than diesels (24%), their fuel costs were twice that of diesel and fuel consumption was also twice that of diesel buses.

The MBTA plans to purchase and operate 40ft (12 m) NGV buses, and an outdoor compressed natural gas refuelling facility.

2.1.6 New York

2.1.6.1 New York City Metropolitan Transportation Authority

- Description of fleet

The NYC MTA operates a fleet of over 4000 buses including a fleet of 221 NGV buses as of 1999. Recently NYC MTA announced it would be buying an additional 300 natural gas buses.

- Technical description of buses

The NYC MTA operates Orion V NGV buses using Cummins L10G engines. Its diesel buses are Orion V and TMC RTSII buses using Detroit Diesel Series 50 engines.

- Operational information

The NYCMTA operates throughout New York City. NGV buses operate out of the Jackie Gleeson depot.

- Maintenance

There have been considerable problems with road calls on NGV buses with stalling and engine/fuel system problems accounting for half the road calls. It has been reported that some of these problems have been due to some of the NGV buses having fuel cylinders removed, but the resulting range decrease not being allowed for in the scheduling.

- Economics

The NYC MTA has reported that when it compared the performance of its 1995 Orion V NGV buses with their Orion V diesel equivalents it found a 34% higher operating cost for NGV buses, with a mean time between failures of 1154 miles (1850 km) for NGV and 2142 miles (3420 km) for diesel. The cost of the NGV buses was $US1.64 per mile ($US1/km) compared to $US 1.22 per mile for diesel ($US0.76/km). A major cost was the labour which was twice that for diesel, $US0.31 per mile versus $US0.17 for diesel ($US0.2/km vs $US0.1/km)

- Issues, opportunities, problems and challenges

In a recent article in the New York Times the New York City Transit was cited as preferring to move faster into hybrid technology rather than natural gas. The NYC MTA cited “huge” costs of NGV buses and dangers associated with compressed natural gas as also contributing to their view. The NYC MTA is the only fleet in the USA to date to put a significant amount into hybrid diesel technology. The major reason for this is the very high cost to convert city bus depots to be able to fuel and service NGV buses, with figures of $US25 to $US40 million being claimed. The NYC MTA has been pleased with the results of its six hybrid buses and has ordered 125 more along with 135 NGV buses. Only Tempe in Arizona and Boston have shown an interest in hybrid buses. Hybrid buses currently cost about $US60,000 more than an NGV bus which costs $US325,000.

It should be noted that the hybrid buses were equipped with particulate traps and used special low sulphur diesel, neither of which are commercially available. Even so they still produced more NOx and particulates than NGV buses, although the latter produced more carbon dioxide.

2.1.7 Ohio

2.1.7.1 Greater Cleveland Regional Transit Authority

- Description of fleet

The RTA has 166 NGV buses - 22% of its fleet.

- Fuel economy

The average fuel economy of RTA NGV buses was 2.3 miles per US gallon equivalent (0.65 km/l) compared to diesel with 3.6 (1.5 km/l).

- Maintenance

NGV buses suffered fuel leaks and out-of-fuel problems. They also suffered “slow coach” defects which are expected to be resolved during the warranty period.

- Refuelling

The RTA has three garages equipped with NGV fuelling facilities. It has decided not to proceed with equiping the fourth garage at this time. The stations are fast fill and operate at 25 MPa (3,600 psi).

- Economics

In its determinations and findings it highlighted that NGV buses are priced 24-31% higher than current comparable diesel buses($US330,000 vs $US255,000). NGV buses have been determined to have higher acquisition, maintenance and operating costs with the incremental difference over the 12 year life of the bus being approximately $US56,000. The operating costs were $US 0.26 / mile ($US0.16/km)for NGV buses and $US 0.17/mile ($US0.11/km) for diesel, based on early 2000 diesel and gas prices. The RTA experienced about 16% higher costs for maintenance of NGV bus engines versus diesels.

- Issues, opportunities, problems and challenges

The Greater Cleveland Regional Transit Authority in an extensive analysis of alternative fuels confirmed it would continue to use NGV buses. It noted that emission standards for urban transit buses have been tightened by the EPA and although it was expected that NGV engines would be certified to these higher standards, it is still uncertain if diesel will meet the standards by 2004. New bus technologies, both hybrid and fuel cell, were considered to be still in development. NGV engines are still in the early stages of product life cycle development and engine component failures are disappointing but not unexpected. These failures were likened to those for diesel engines in the early 1980s. In its conclusion, the RTA has decided to continue purchase NGV buses after weighing carefully the likely higher costs against the environmental and social benefits. The RTA determined that it should continue working with the East Ohio Gas Company to keep pace with the latest advances of NGV technology. The RTA concluded that it should continue operating NGV buses on routes which would have the most impact on improving air quality.

2.1.8 Texas

2.1.8.1 Dallas Area Rapid Transit (DART)

- Description of fleet
  - 141 natural gas large transit buses (two CNG 1990 & 139 LNG 1998) in a fleet of 1000 buses, rail cars and vans.
  - 1st ULEV Certified heavy-duty natural gas engines in the USA
  - 20 compressed natural gas fuelled trolleys
  - 200 compressed natural gas fuelled paratransit vans
  - 148 compressed natural gas fuelled automobiles & trucks
  - 41% of DART's total motor vehicle fleet is natural gas
  - Upcoming solicitation for 160 DART buses will include LNG fuel option

- Fuel economy including comparison with diesel buses

Range issues resulted in 36% less utilisation of LNG buses compared to diesel buses.

- Emissions

LNG emissions 31% cleaner than current technology diesel

- Maintenance

LNG fuel & oil costs are 39% greater than current technology diesel. Current technology diesel engines are 2.5 times more reliable than LNG engines. It should be noted that this is an "apples to apples" comparison with the Cummins L10 NGV engine being compared with the Cummins M11 280 diesel engine.

- Refuelling

  Two LNG fueling facilities are used (at Northwest and at South Oak Cliff)

- Economics

  Summary of incremental capital dollars spent over last five years are:
  - $US 6,059,620 transit buses
  - $US 2,833,200 paratransit vans
  - $US 7,500,000 fueling facilities
  - $US 1,000,000 facility modifications
  - $US 619,084 automobiles & trucks
  - $US16,011,904 five year total

As utilisation increases, cost differential is expected to decrease. Overall the cost of LNG buses is 13% higher than the diesel equivalents. The reliability issues (which are expected to improve substantially) are believed to have impacted significantly on these costs.

- Issues, opportunities, problems and challenges
  - Engine manufacturer modifications will markedly increase reliability of LNG engines
  - DART will continue to participate in the DOE/NREL Alternate Fuel Transit Bus Evaluation Project comparing NGV with diesel
  - DART will explore advanced alternative technologies, including hybrids
  - National task force will continue attempts to optimise LNG vehicle and facility systems
  - DART will continue to provide leadership for Clean Fuels Formula Grant Program Coalition

What Has Been Learned

- CNG works reasonably well in a gasoline type engine (paratransit, automobile & truck)
- CNG has serious range issues in a large transit bus application
- LNG has less of a range problem in a large transit bus application, due to fuel density. With the addition of a fourth LNG tank a range of 380 miles (600 km) was achieved
- Natural gas reliability comparable to gasoline performance in light duty applications
- Natural gas reliability in the current fleet is five times worse than diesel in heavy duty applications
- Further development of natural gas engines not being pursued by engine manufacturers because of truck markets lack of acceptance, however Cummins is still working on resolving problems with the L10 engines even though they are discontinued. It is felt the resolutions of the problems will be applicable to the C8.3G which is the current Cummins heavy duty NGV engine for the transit market. Cummins is working on spark plugs, cylinder head design, coils, turbo activators and waste gate. The early failure of these components have nearly all been resolved
- Engine manufacturers R&D dollars are going into advanced diesel technologies
- Comparative data for LNG vs. Diesel. Total operating costs of LNG buses was only 13% higher but maintenance costs for the engines and fuel systems were 33% higher and fuel costs were 32% higher. Mileage between road calls for LNG buses was 50% lower

Where is DART Going in Near Term

- Continue with CNG initiative in light-duty application (Demand Response Vehicles and Paratransit)
- Recommend Board establish moratorium on further expansion of heavy duty natural gas buses
- Work with industry representatives to try to resolve issues with natural gas in heavy duty application
    - Reliability
    - Range
    - Economics
- Stay abreast of further development of emerging technologies such as fuel cells

2.1.8.2 Metro Houston

- Description of fleet

The fleet consists of 5 LNG and 5 CNG New Flyer 40ft Low-Floor Buses.

- Technical description of buses

Length 40.7 ft. (12.4m) , Seating capacity 39, Weight LNG 29,180 lbs (13,240 kg). CNG 30,700 lbs (13,930 kg), Engine Series 50G Detroit Diesel 270 HP, 890 ft. lb. torque, Transmission Allison World B400R, Fuel Storage LNG 187 US Gallons equivalent(= 15,450 SCF or 725 l), CNG 146 US Gallons equivalent (= 18,125 SCF or 570 l), Tanks are roof mounted, Safety systems- Amerex fire suppression and gas detection system, Fuel system- both CNG and LNG use DDC's low pressure engine fuel system which can operate as low as 60 psig (540 kPa) gas pressure.

- Operational Information

These buses are treated the same as diesel buses and are scheduled on routes with distances up to 300 miles (480 km). They are used on local routes and express routes and operate in an environment with temperatures ranging from 40°F to 103°F (4°C to 40°C).

- Fuel Economy

CNG 2.93 mpg diesel equiv.(1.2 km/l), LNG 2.30 mpg diesel equiv. (0.96 km/l), Diesel 3.52 mpg (1.46 km/l).

- Emissions

Series 50G: HC- 0.8, CO- 2.2, NOx- 1.5, PM- 0.01,
Series 50 Diesel: HC- 0.1, CO- 1.0, NOx- 4.0, PM- 0.04.

- Maintenance

6,000 mile (9,700 km) inspections take the same amount of time for gas or diesel. Detroit Diesel Series 50G requires engine tune-up at 36,000 miles (58,000 km) while the Series 50 Diesel requires only one tune-up at 60,000 miles (97,000 km).

- Refuelling

LNG buses use a low pressure which requires a minimum of 100 PSI (700 kPa) and it takes an average of 6-10 minutes to fill a bus. CNG buses use a slow fill system which requires pressures in the range of 3,000 - 3,600 PSI (21 to 25 MPa) and takes an average of 45 minutes to fill a bus.

- Economics Operating Cost Per Mile

	Diesel	**CNG**	**LNG**
Fuel -	$US0.104	$US0.211	$US0.318
Parts -	$US0.176	$US0.184	$US0.265
Labour -	$US0.133	$US0.572	$US0.792.

- Views Of Fleet Managers

Too much down time, constant learning curve, requires to much attention, parts availability a concern.

- Issues

Alternate Fuels must be mandated before one would choose them over diesel fuel. CNG engines contribute to 30% more road calls that a diesel bus.

2.1.8.3 Sun Metro, El Paso

- Description of fleet

For Sun Metro, the public transportation authority of El Paso, Texas, 53% of the fleet of 240 vehicles – buses, paratransit vehicles and support vehicles – runs on natural gas (128 are CNG and LNG vehicles: 62 buses, 42 paratransit vehicles, 24 support vehicles).

- Fuel economy

It takes about 1.5 gallons of LNG to equal the energy in 1 gallon of diesel fuel. Buses average 3.5 miles per diesel-US gallon-equivalent (DGE) of CNG (1.45 km/l) and 3.5 miles per US gallon (1.45 km/l) when operating on diesel fuel. Paratransit and support vehicles average 7.5 miles per DGE of CNG (3.1 km/l). The CNG buses achieve a driving range of about 300 miles (480 km). In contrast, LNG buses have a driving range of a little less than 400 miles (640 km), and diesel buses a little more than 400 miles. LNG paratransit vehicles have a driving range of 250 miles (400 km). On the basis of their respective mileage accumulation and driving ranges, CNG, LNG, and diesel buses fuel once a day, LNG paratransit vehicles twice a day.

- Refuelling

Sun Metro is reported to have the world's largest LNG/CNG fuelling facility. It is served by three cryogenically insulated bulk LNG tanks that each hold 20,000 US gallons of LNG (75,000 litres) at -50°F (-156C) and 10 psi (70 kPa). The CNG flash-evaporated from LNG creates enough pressure to transfer the low-pressure LNG from the tanks to the vehicles. The facility can fuel six vehicles simultaneously from individual fuelling positions, with LNG and CNG supplied from separate dispensers. It takes 20 minutes to fuel a 40ft (12 m) bus with CNG and 4 minutes for small vehicles. In contrast, LNG fuelling takes 4-7 minutes. The reason Sun Metro went to LNG was a concern about two drawbacks of using pipeline CNG:
(1) it is not consistently 98% methane and
(2) it can be contaminated by dirty pipeline gas, oil from compressors, and trace gases in the pipeline.
LNG supplied in bulk tanks alleviates these drawbacks.

- Economics

A combination of state legislation, federal grant funds, and cost savings motivated Sun Metro to make the move to alternative fuel.
Diesel buses cost about $US216,000 each, LNG buses about $US256,000 each, and CNG buses about $US275,000 each. Sun Metro will realise a cost saving of about $US8,000 per bus per year.
When comparing LNG with diesel on an energy-equivalent basis, the actual cost of LNG rises to $US0.54 per DGE ($US0.13/l), about 60% less than the price for a US gallon of diesel fuel – $US1.30 at the time the case study was written. Diesel prices are now reported to be about $US2 a US gallon ($US0.52/l). Sun Metro's fleet uses 150,000 diesel gallons equivalent (dge) of LNG (585,000 l) and 24,500 dge (95,000 l) of CNG per month, for a total of 174,500 dge (680,000 l) of LNG per month, compared with 120,000 gallons (467,000 l) of diesel fuel. Over the course of a year, Sun Metro saves about $US1.6 million by using LNG instead of diesel.
A recent analysis of operating costs showed no significant difference between the NGV vehicles and diesels.
According to Sun Metro the pay back period for the NGV fleet is:
Before Grant Funds
(Total Costs $US7,187,000) / (Net Savings $US1,599,426/yr) = 4.49 yr
After Grant Funds
(Total Costs $US1,437,000) ¸ (Net Savings $US1,599,426/yr) = 0.90 yr

- Issues, opportunities, problems and challenges

Drivers of CNG and LNG buses have found that vehicle performance depends on the engine installed. The 18 CNG buses delivered in 1993 had Cummins L10G natural-gas engines. Drivers had to adjust their driving techniques to the slower acceleration of these buses: In contrast, the 35 LNG buses supplied in 1995 use the Detroit Diesel Series 50 natural gas engines and have excellent performance.

2.1.9 Washington State

2.1.9.1 Pierce Transit

In 1986, the Pierce County Transportation Benefit Area Authority (Pierce Transit), based in Tacoma, Washington, made a commitment to the environment by deciding to put buses powered by compressed natural gas (CNG) into everyday service. Pierce Transit is a Clean Cities National Partner Award Winner.

- Description of fleet

Currently Pierce Transit has 117 NGV buses (of total fleet of 176 buses) in operation, Plans are for the for fleet to be completely natural gas fuelled by 2003.

- Technical description of buses

Pierce uses Orion V buses powered by Cummins L10-240G, 260G and 280G engines depending on the route and when they were ordered and 45 New Flyer of America low-floor NGV buses.

- Operational information

Formed in 1979, Pierce Transit operates in a 450-square-mile (1150 sq km) area with a population of about 600,000. The agency provides both rural and urban route service, including express lines to Seattle and Olympia. Its 56 fixed routes cover more than 900 miles (1450 km). In 1995, Pierce's vehicles travelled more than 7 million miles (11 million km) and carried more than 10 million passengers.

- Fuel economy

Pierce Transit's CNG engines are about 20% less fuel efficient than their diesel counterparts. This disparity can be attributed to the lower compression ratios and throttling losses of the CNG engines, slight differences in duty cycles between the two kinds of buses, and the additional weight of the CNG tanks. The CNG tanks on the Orion buses are made of carbon fibre, a light-weight composite material that reduces the total weight of the tanks and mounting hardware from nearly 3,900 pounds to about 2,500 pounds (1775 kg to 1140 kg). This weight reduction, along with new electronic engine controls, should have a positive effect on fuel efficiency.

- Emissions

West Virginia University measured the CNG fleet for emissions data by using a chassis dynamometer. The university tested these vehicles with the standard Central Business District test cycle. Dynamometer test results for NGV buses show that particulate matter was below detectable limits of the instrumentation. Average emissions of nitrogen oxides from the NGV buses with Cummins L10-260G engines were 54% lower than those from comparable diesel buses with L10 engines. Average carbon monoxide emissions were 94% lower. Hydrocarbon (HC) levels from the NGV buses were significantly higher than those for diesel. However, 90% to 95% of the total HC count may be attributable to methane, which is considered non-reactive in the formation of atmospheric ozone and, therefore, is not used by the EPA as a basis for emissions regulations.

- Maintenance

There are still problems with the ignition system, specifically spark plugs and wires. The electronics are making the engines more reliable, which translates to lower maintenance costs. On average, the CNG buses travel 4,500 miles (7,250 km) per month compared with 5,000 miles (8,000 km) per month for the diesel fleet. The average distance between road calls for Pierce Transit's CNG and diesel fleets are identical, even if only engine-and fuel-system-related road calls – the types of road calls that may be caused by the use of an alternative fuel – are examined.

- Economics

The Pierce buses each cost $US30,000 to $US50,000 more than their diesel counterparts. Most of this additional expense is attributable to the higher cost of CNG engines and natural gas storage cylinders. Necessary changes to facilities present additional capital costs. Pierce Transit's CNG fuelling facility, completed in 1992, cost $US847,000. The agency also had to add natural gas detectors to its maintenance facilities and modify its ventilation systems at a cost of more than $US500,000. Maintenance costs for the agency's diesel and CNG fleets are nearly equal.
Natural gas prices are more stable than diesel prices, which protects Pierce Transit when the price of petroleum products increases. Pierce Transit is now buying CNG as a commodity from natural gas suppliers rather than from Washington Natural Gas, a state-regulated utility. This arrangement cuts the cost of CNG from $US0.52 to $US0.30 per diesel equivalent gallon (129,000 Btu) ($US 0.13 to 0.08 /l).

	Diesel Bus	CNG Bus
Fuel Cost (d e gal)	$US0.65 (0.17/l)	$US0.30 (0.08/l)
MPEG (d e gal)	5.8 mpg (2.4 km/l)	4.5 mpeg (1.9 km/l)
Fuel Cost per Mile	$US0.11/mile ($US0.07/km)	$US0.07/mile ($US0.04/km)

The DOE/NREL data indicate that after 10 years of experience with CNG, Pierce Transit has reached the point where CNG operating costs are almost the same as those for diesel. The evaluation program collected and analysed operating costs for vehicle maintenance (repairs, inspections, cleaning, and rebuilding), fuels, and lubricants. An additional $US0.06 was added to the cost of a diesel equivalent gallon of CNG to account for the cost of maintenance labor and parts for the natural gas compression station used in fuelling

- Views of fleet managers

Pierce Transit believes it has made the right choice on environmental, security and economic grounds and have been cited as the standard that can be achieved by NGV bus fleets.

2.1.10 Washington, DC

The Washington Post reported on the 5 September 2000 that Washington Metro plans to order 100 NGV buses using compressed natural gas; the major reason for the order was to improve the environment by reducing emissions. This is despite compressed natural gas buses costing about 15% to 25% more than a standard diesel bus ($US50,000) and requiring special refuelling stations that cost an average of $US1.7 million, according to a report by the US General Accounting Office. The environmentalists lobbied key political figures effectively to apply pressure in favour of the cleaner NGV buses, despite the initially higher capital cost. The new NGV buses are anticipated to be on the road as early as November 2001. The Diesel Technology Forum, which represents manufacturers and suppliers of diesel engines, was surprised by the change to NGV buses, saying that diesel is cheaper and more reliable than the newer alternative fuel vehicles. Metro already has purchased 230 diesel buses to replace part of the transit agency's 1,300-bus fleet, the nation's fifth-largest, and has the option to order an additional 100 buses later in autumn.

2.2 Canada

The use of NGV buses in Canada has been primarily driven by environmental emission improvement desires, but also with the belief that overall life cycle costs of NGV buses will be superior to diesel. In a recent meeting of the Canadian Transit Users Technical Support Group the sharp contrast in implementing the use of natural gas buses in Canada and the USA was highlighted. While Canada led the development and utilisation of natural gas buses in the early 1990s, the purchase rate slowed considerably in 1998 and basically appears to have stopped. This is generally attributed to the lack of equivalent Canadian Government and provincial policies regarding air quality compared to the USA. Two major operators are currently showing disquiet in respect to the operational problems and maintenance costs of NGV buses. Both Coast Mountain Bus Company (formally BC Transit) and the Toronto Transit Commission have been reported as being inclined to pursue other alternative fuel options to improve vehicle emission performance. This is attributed to the disappointing performance in terms of reliability and maintenance costs of the gas engines in the buses purchased in the early 1990s.

The City of Mississauga reversed plans to purchase an additional 75 NGV buses due to the loss of government subsidies and a 39% higher operating cost for the NGV buses than for diesel buses. Due to the reliability problems, the required replacement of the CNG tanks and the requirement to add 124 buses to the fleet in 1997/98 they decided to convert their eleven NGV Cummins L10 powered buses back to diesel in early 1997 and move to the latest diesel technology (refer to 1996 Mississauga Corporate Report)..

The current fleets operating NGV transit buses are believed to be:

Transit District	City	Province	NGV Buses	Total Buses
Toronto Transit Commission	Toronto	Ontario	125	1500
Hamilton Street Railway Company	Hamilton	Ontario	91	180
Kitchener Transit	Kitchener	Ontario	23	114
London Transit	London	Ontario	48	160
Burlington Transit	Burlington	Ontario	15	47
Cornwall Transit	Cornwall	Ontario	12	35
Chatham Transit	Chatham	Ontario	*2	
Coast Mountain Bus Company (BC Transit)	Vancouver	British Columbia	51	1006
TOTAL			367	3042

* service being contracted out and contractor will sell natural gas buses

2.2.1 British Columbia

2.2.1.1 Coast Mountain Bus Company

Coast Mountain Bus Company (formally BC Transit) provides a fully integrated transit service in the Vancouver lower mainland area using diesel buses, NGV buses, trolley buses, Sea Bus, Sky Train and commuter rail in an 1,800 square kilometre area. In surveys of transit passengers, Coast Mountain was noted for being one of the cleanest in North America with the majority of passengers. The performance of the NGV buses was monitored against a diesel control fleet for a three-year period, commencing April 1, 1996, with a report every six months.

- Technical description of buses

Coast Mountain Bus Company ordered 25 high-floor lift-equipped natural gas buses from New Flyer Industries in 1994. The natural gas buses were commissioned and placed into between November 1995 and April 1996.
An additional 25 NGV buses were ordered from New Flyer Industries Ltd in 1998. These buses were commissioned and placed into service from October to December 1998. An operating lease for 15 of these buses was entered into with Westcoast Energy. The trend in the transit industry in North America is to low-floor buses (no interior steps in the entrance area). This bus offers floor heights of about 14 inches (350 mm), which is just slightly higher than kerb height. With the kneeling feature on these buses, customers can walk directly onto the bus without having to step up. Each coach is 40ft (12 m) long and 8.5ft (2.6 m) wide.
This bus is now offered in both natural gas or diesel configurations. Compressed natural gas is stored at pressures up to 3,000 psi (20 MPa), in seven medium size cylinders mounted on the roof of the bus. The bus has two wheelchair positions and seats 38 passengers. The diesel version has a carrying capacity of 77, and the CNG version has a carrying capacity of 61. The 16 fewer passengers in the NGV bus is due to the extra weight of the CNG tanks.
Both gas and diesel Detroit Diesel Series 50 engines are inline four cylinder, four stroke engines. The block and internal components are all similar. The major difference is the diesel engine is equipped with electronic fuel injectors while the gas engine is equipped with an air and fuel mixing chamber and spark plugs. Both are controlled electronically by Detroit Diesel Corporation's DDEC electronic control module. Expected range is 600 km (375 miles) for the gas and 700 km (435 miles) for the diesel.

- Operational information

The annual ridership in the Vancouver area is approximately 120 million and its revenue kilometres are approximately 86 million (54 million miles).

- Fuel economy

Fuel costs for the diesel fleet are $C0.237 per km ($US0.252/m) compared to the natural gas fleet at $C0.125 per km ($US0.133/m) - a savings of $C0.112 per km ($US0.12/m) for the natural gas fleet. The current cost of diesel is $C0.418/ltr ($US1.07/US gal) and natural gas is $C0.227/ltr ($US0.58/d e US gal).

- Emissions

The sixth monitoring report notes that the certified factory emission levels from both the new clean diesels and natural gas buses are similar and both engines are very clean (the natural gas engine emissions. These new diesel engines produce five times less particulate matter than a 1995 two cycle diesel engine.

Current Engine Emission Certification (g/Bhp.hr)

	HC/NMHC	CO	No_x	PM	Notes
1997 DDC Series 50 Diesel Bus with catalyst.	0.1	1.1	4.7	0.04	Meets 1996 standards. Plan to meet 1998 standards.
1997 DDC Series 50G NG No Catalyst	0.08	2.6	1.19	0.03	CARB Urban Bus certified. Meets 1998 standards.
1997 DDC Series 50G NG Estimated with catalyst	0.2	0.9	2.0	0.02	Would meet 2004 standards.

- Maintenance

Bad orders which prevent the use of a bus and road calls are 4.5 times higher for NGV buses than the diesel buses. Major cost items contributing to these are turbocharger failures and subsequent fires, air compressor failures, and oxygen sensor problems. The natural gas fleet has generally operated fewer kilometres than the diesel fleet due to the increased downtime and repair incidents, although the difference between the two fleets has been decreasing.

- Refuelling

The gas supply and compression contracts were renegotiated with BC Gas. To fuel the buses, BC Gas supplied a fuelling station capable of filling a bus in an average fuelling time of 3 - 7 minutes as long as there was sufficient time between fillings to partially refill the vessels. The station has two IMW 585 cfm (275 l/s, 16.5 m3/min) compressors and a maximum working pressure of 3600 psi (25 MPa). The storage cascade has three banks consisting of six ASME cylinders with a total capacity of 60,000 cubic feet (2,000m3). The first bank comprises three cylinders, the second two and the third one.

- Economics

In the sixth report prepared by CMBC's Eric O. Holmberg, Maintenance Engineer and Gary J. Strachan, Manager, Vehicle Engineering covering the 1999 year, it was stated that the cost of operating the high floor natural gas buses is 49% higher. This amounts to an additional $(C)21,700 ($US14,300) annually for each natural gas bus. Parts and labour costs for high floor natural gas are 103% higher than the diesel buses. The fuel cost savings of 47% do not offset the increased maintenance costs.

- Issues, opportunities, problems and challenges

The report states there are still several significant operating and technical issues with natural gas to be overcome, as reflected by the increased costs and number of maintenance incidents. The new low-floor natural gas buses have additional technical and operational issues to overcome before this technology can match the lower costs and productivity of the diesel low-floor bus. Long-term component reliability and "life to overhaul" times cannot be determined at this time. Labour and material costs for the natural gas fleet have been rising, whereas the diesel fleet costs have remained steady. Major fleet-wide repair campaigns are underway or have been completed on the high floor natural gas fleet including a complete engine and fuel delivery system upgrade, revised power system for the gas detection and fire suppression system, and extremely premature turbocharger failure. CMBC personnel along with factory representatives have expended significant resources to study, test, and resolve many CNG related problems, however as the buses age new issues require attention. Reliability is slowly improving, but the lower passenger capacity and higher downtime of the natural gas buses actually cause an increase in use of older diesel buses, which emit up to 10 times the amount of particulate matter.

2.2.2 Ontario

2.2.2.1 Toronto Transit Commission:

The Toronto Transit Commission (TTC) aimed to improve its environmental performance by using natural gas to power buses and reduce air pollution. Compressed natural gas buses were considered the best option.

- Description of fleet

A fleet of 1500 buses serving the city of Toronto.

- Technical description of buses

The TTC has 125 low-emission NGV buses and has built a garage and fuelling station to accommodate them at the Wilson Garage. The types of buses used are 75 Orion V standard and 50 Orion VI low floor 40ft (12 m) buses delivered between 1991 and 1998. They are powered by Cummins L10G engines of 240 and 280 bhp (180 to 210 kW) respectively and have a range of approximately 640 kilometres (400 miles).

- Emissions

For Ontario Province the diesel bus emission requirements are:

EMISSION	**2000**	**2002**	**NGV Certification**	**EPA 2007-2010**
NOx	4.0 (5.3)	2.4 (3.1)	1.4 (1.9)	0.2 (0.027)
Particulate Matter	0.05 (0.07)	0.05 (0.07)	0.02 (0.027)	0.01 (0.013)
Hydrocarbons	1.3 (0.18)	NA	0.14 (0.19)	NA
Carbon Monoxide	15.5 (20.8)	15.5 (20.8)	4.1 (5.5)	Approx 0

All figures are in grams per horsepower-hour. Those in brackets are grams per kilowatt-hour.

- Maintenance

Mean time between failure for NGV buses at 3,000 miles (5,000km) is half that for diesel The NGV fleet reliability is impacted by recurring major engine problems currently under investigation by Cummins. The major problems with the Phase III Cummins L10G engine relate to the failure of head gaskets and torching of exhaust valves.

- Refuelling

To fuel the buses, the Commission commissioned to have a compressor station capable of filling the buses in approximately four minutes on a continuous basis. This requirement was similar to the fuelling rate of diesel buses in the diesel service lane. The station has four Knox Western dry lubricated 550 cfm (15.5 m3/min) four stage compressors, is equipped with regenerative driers and has a maximum working pressure of 3600psi (25 MPa). The buffer consists of three10,000 scf (285 m3) ASME cylinders that minimise the unloading of the compressors while buses are moved through the filling lane. Also, they reduce pressure pulsations and provide for some gas cooling. It was completed in the spring of 1991 and was thought to be the largest in the world at that time.

- Economics

NGV buses are far cheaper to fuel than their diesel counterparts - natural gas costs an average of 16.3 cents (C) per kilometre ($US0.174 per mile) compared with 29.7 cents(C) ($US0.316) for the standard diesel buses. This is more than offset by purchase prices an average $(C)60,000 ($US 39,500) more than standard diesel vehicles, the expense of creating new, specially equipped garages to house them and their propensity to break down more often. The conclusion is that natural gas buses offer almost no cost advantage (or disadvantage) for the system.

- Views of fleet managers

Bill Brown, the TTC's manager of vehicle engineering is quoted in the Toronto Star on 31 July 2000 as saying that there are now other technologies to be considered because of the higher initial costs of the NGV buses and increased maintenance costs. He is quoted as urging the Commission to look at two clean-emission options that should be well into development by the time the TTC must upgrade its fleet: hydrogen fuel systems and hybrid diesel-electric engines.

- Issues, opportunities, problems and challenges

The Star states that with a combined 16 million kilometres (10 million miles) under their belt, the TTC's natural gas buses have given system managers ample opportunity to assess their cost efficiency and performance and TTC staff have come to the conclusion that they can do better. The TTC is quoted as saying natural gas buses are high maintenance, high cost and offer no environmental advantage over some of the clean-emission technologies that are rapidly emerging.

2.2.2.2 London Transit

London Transit is based in Ontario and is a medium size transit system serving a population of 300,000 and has a yearly ridership of approximately 12,000,000. It operates 160 buses, 48 powered by natural gas and 112 by diesel, out of a central transit facility. London Transit operates two types of natural gas powered buses built by Orion Bus Industries. One , the Orion VI, is a full-size low-floor transit bus with the natural gas cylinders integrated into the roof structure and powered by a Cummins L10G engine. The other, the Orion II, is a 25ft (7.6 m) low floor bus powered by a GM 427G used in both special and community service routes.

The operator wanted to use natural gas because it was clean and could reduce operating costs. The first natural gas buses began arriving in London in September 1997 and service started in November 1997.

To fuel the buses, the compressor station is capable of filling a bus in approximately four minutes and has three Ariel 850 cfm compressors driven by Caterpillar 3306G natural gas engines and a maximum working pressure of 3600 psi (25 MPa). The cascade consists of 8 ASME cylinders with a total capacity of 30,000 cu ft. (845 m3). The cascade has three stages. The first stage comprises four cylinders, with the remaining two stages using two cylinders each.

2.2.2.3 Kitchener Transit

Kitchener Transit is a medium-size transit system that operates a modified radial network to the urbanised area of Kitchener and Waterloo. It operates 114 buses, 23 powered by natural gas and 91 by diesel, out of a central transit facility.

In 1994, Kitchener Transit began evaluating the use of natural gas. Since the municipality owns the natural gas utility, Kitchener Gas Utility, which supplies both natural gas and water, Kitchener transit thought that natural gas could provide some cost savings. The use of natural gas buses on its routes also complemented the municipality’s plans for transit friendly neighbourhoods.

The first natural gas buses began arriving in Kitchener in 1996. They were built by New Flyer Industries and are powered by Series 50G Detroit Diesel natural gas engines. They have a range of approximately 650 kilometres (400 miles).

To fuel the buses, the compressor station would fill a bus in approximately five to seven minutes with the buffer full. The indoor station has three Gemini 570 cfm (16 m3/min) compressors driven by Caterpillar 3306G gas engines and has a maximum working pressure of 3600 psi (25 MPa). The storage cascade consists of three 10000 scf (285 m3) ASME cylinders.

Natural gas bus operations began in mid 1997. Since the Ontario Ministry of Transportation has stopped its transit capital subsidy program, Kitchener Transit has curtailed all bus purchases for the next six years. However, future purchases will continue to be natural gas.

2.2.2.4 Burlington Transit

Burlington Transit serves an urban area with a population of approximately 137,000 and has an annual ridership of approximately 1,321,000. It operates 45 conventional and two special transit buses from a central transit facility. Fourteen are powered by natural gas and 33 by diesel. Burlington Transit recently introduced 13 low floor Orion II natural gas buses into community routes that service residential areas and the downtown. Since these are smaller buses, they are used on lower density routes and are less intrusive to the neighbourhood.

In the mid-nineties, the Burlington Council made a decision to purchase natural gas buses based its interest in reducing emissions from its buses and lowering the operating costs.

In 1996, Burlington Transit purchased one low floor Orion II for evaluation. In 1998 they placed an order for an additional 13 vehicles; the first entered service in May 1998. The buses are powered by Cummins B5.9G natural gas engines.

To fuel the buses, Burlington Transit use an outdoor compressor station using two Atlas Copco 200 cfm (5.7 m3/min)compressors operating at 3600 psi (25 MPa) which fill a bus in approximately four to five minutes with the buffer full. The storage cascade has three banks consisting of five ASME cylinders with a total capacity of 50,000 cubic feet (2,000 m3). The first bank has two cylinders, the second two and the third one.

2.2.2.5 Cornwall Transit

Cornwall Transit is a medium-size transit system that serves the cities of Cornwall and St. Andrews in Ontario serving 50,000 with ridership about 1,400,000. CT operates 35 buses, 12 powered by natural gas and 23 by diesel, out of a central transit facility. After undertaking a short study, CT decided to change an order for five diesel buses to natural gas for environmental and economic reasons.

The five Orion V natural gas buses were delivered to Cornwall in 1994 are powered by Cummins L10G natural gas engines and were followed by 5 low floor Orion II buses using the Cummins B5.9G in 1997 and two bus using converted Ford 427 engines.

To fuel the buses for CT, Union Gas found that a slow fill operation was the most cost effective solution. The station has one compressor and a maximum working pressure of 3600 psi (25 MPa).

2.2.2.6 Hamilton Street Railway

The Hamilton Street Railway (HSR) is a medium-sized transit system that serves Hamilton, Stoney Creek, Ancaster, Dundas, Flamborough and Glanbrook in Ontario. It has an annual ridership of around 20,000,000 and the population within its service area is approximately 400,000. HSR was the first transit system in North America to introduce natural gas buses and the current fleet comprises a total of 174 standard buses and six articulated buses.

By mid-1999, the HSR natural gas buses comprised approximately 40% of the total fleet, made up of 30 Cummins L10G powered Orion Vs and 35 low-floor Detroit DDC Series 50G powered New Flyers. HSR was given permission to pursue a demonstration project using natural gas in transit buses in June 1984, setting out to evaluate the economics, performance and durability of natural gas powered buses. In addition, HSR expected to realise environmental benefits from the low emission natural gas buses operating in the high density urban core.

Compressed natural gas is supplied to the outdoor fuelling lane by four IMW electrically driven compressors designed for rapid filling of the buses. Their current total capacity is 2140 cfm (61 m3/min). It is designed to fill a bus in approximately four to five minutes on a continuous basis. A buffer is also available to supplement the fuelling process when two buses are being filled. With two buses being filled, the fuelling time increases by a couple of minutes.

2.3 Europe

The overall objective of the European Union's Energy Policy is to help ensure security of energy supplies for Europe at competitive prices and in an environmental compatible way.

The Joule-Thermie program was launched in 1995 and the Thermie demonstration component of the program is focused on the "cost-effective, environmentally-friendly and targeted demonstration and promotion of clean and efficient energy technologies", including transport. Thermie supports proving both the technology and economics in market applications. It aims to highlight the benefits and assist in wider market penetration in EU and globally.

The major NGV part of Thermie is called "Natural Gas Vehicles for European Cities and their Integration with Urban Transport Management" or NGVeurope. It is a co-operative partnership between public and private urban interests.

NGVeurope combines innovative NGV technologies with scientific advancement aimed at improved urban air quality by putting 323 vehicles on the road in 15 cities in 7 European countries. NGVeurope includes never before demonstrated technological advancements such as the renewable fuel, biogas, to enhance vehicle range, particularly for heavy duty urban vehicles. The project aims to include the most advanced NGV technologies built by European manufacturers.

The innovative aspects of the NGVeurope project are:

- All vehicles, representing most of the OEMs, are state-of-the-art NGV technologies now at the market entry or early adoption phase;
- First European demonstration of biogas use in light *and* heavy duty OEM vehicles;
- Use of latest lean-burn heavy-duty engine technology and self-adaptive light duty systems, designed to accommodate a wide range of European natural gas compositions;
- Empirical emissions testing to demonstrate life-time emissions and deterioration and
- The first conclusive study on NGV operation and maintenance benefits.

The results of this project are expected to be:

- Reliable quantification of emission benefits using modern engine control technologies for a complete range of urban light, medium and heavy duty vehicles
- Quantification of operation and maintenance aspects of NGVs
- Determination of economic viability of NGVs; particularly for future NGV projects

- Determination of the feasibility of biogas in urban NGVs and in refuelling processes
- Strengthening of NGV fuel infrastructure in urban areas
- Enhanced public awareness of applications and benefits of NGVs through information dissemination and
- Attaining economic, employment and export benefits by involving 25 manufacturers and gas suppliers.

Information and data gathered for this project can also play an important role in identifying the cost-benefits of pollution reduction, particularly for the inner city regions throughout Europe. An essential part is emission testing of the vehicles and the evaluation of the economical and environmental aspects of the project.

The major projects in NGVeurope that involve NGV buses are:

Project Location	Project Description
City of Augsburg, Germany	Introduction of 13 low floor articulated MAN NG303 buses (228kW/310 hp) for operation in the centre of the first Natural Gas Model City – the city of Augsburg. Conversion of the public transport fleet of approximately 140 buses to the use of natural gas by the year 2005.
Société des Transports Urbains de Colmar et Environs, France	Implementation of 6 CNG buses, 4 slow filling dispensers and one fast fill dispenser with two compressors each one with a capacity of 350 Nm^3 (12,500scf). Installation of an emergency compressor. Following success, substitution of the whole fleet of 36 buses by CNG vehicles during the next 9 years.
District de Poitiers, France	The operation of over 1.3 million kilometres (800,000 miles) since January 1998 of 22 CNG buses (five Heuliez, fourteen RVI Agora and three Iris). on two inner city lines. Installation of slow fill and semi-fast filling station. Establishment and standardisation of methodologies, criteria and measurement / testing procedures. Analysis of the total operating costs. Evaluation of legal, fiscal, and technical-economic parameters.
ATAC, Rome, Italy,	Implementation of at least 40 NGV buses and the installation of a fast filling station and bus depot at A.T.A.C. "Magliana". Monitoring of effects of pollution in the centre city.

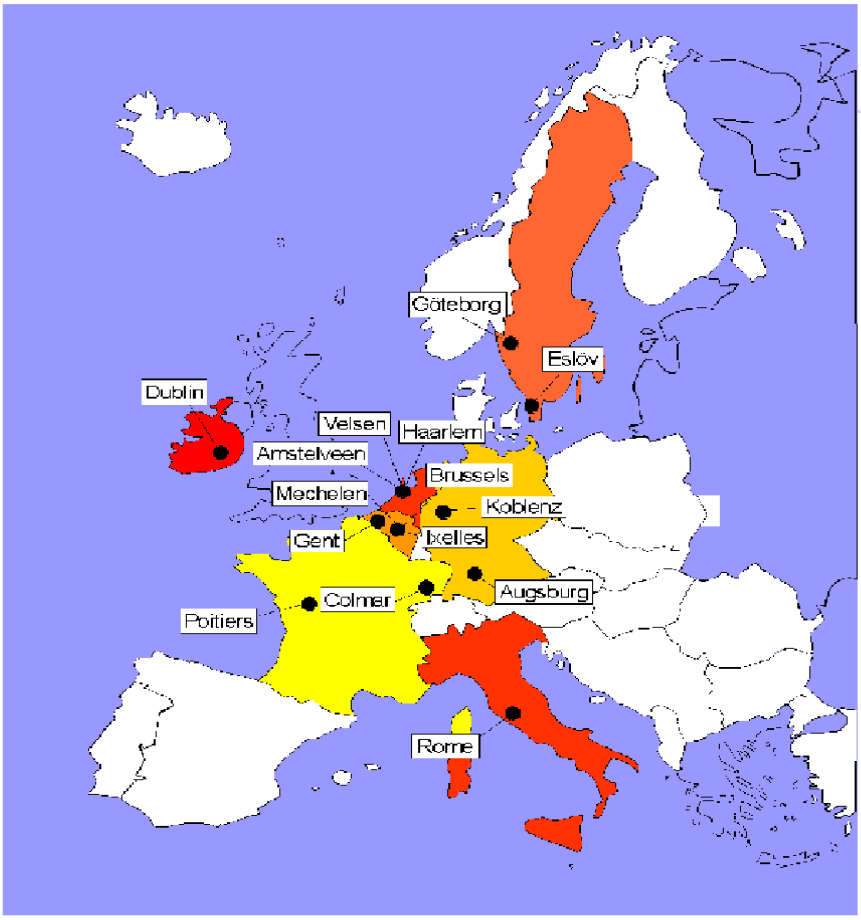

Fig. 2.3 Cities participating in the NGVeurope project

JUPITER-2 (Joint Urban Project In Transport Energy Reduction-2) is a major transport and energy initiative involving large scale demonstration projects promoted by a consortium of nine organisations including local authorities and transport companies in cities of the European Union, Aalborg, Bilbao, Florence, Gent, Heidelberg, Nantes, the conurbation of Merseyside, and Riga as a follower city, and funded by the European Commission's, Joule-Thermie Programme. The overall aim of the JUPITER consortium is to promote the concept of the energy efficient city from the perspective of the transport sector. JUPITER-2 started in 1996 and finished in 1999 and is currently being evaluated.

Jupiter-2 is designed to reduce energy consumption and harmful emissions through three types of measures:

- *Integrated transportation policies* aimed at increasing the use of public transport and reducing the use of private transport;
- The introduction of new, *fuel-efficient public transport vehicles*; and
- The use of *alternative fuel technologies* in bus fleets.

Each project has a range of new vehicles and clean fuels integrated with innovative transport management measures to optimise the use of the infrastructure. Each city project took place within the context of strategies to increase the use of environmentally-friendly transport modes at the expense of private motorised transport.

During the course of the project, the consortium has invested in a minimum of 100 new buses and 20 vehicles of other types, powered by a range of alternative fuels. This investment has been accompanied by measures designed to influence the modal split in favour of public transport, walking and cycling, including telematics technologies, traffic regulation schemes, integration of residential/commercial/business functions and promotion of intermodality. JUPITER-2 is predicted to reduce energy consumption by 20% and emissions of CO2 and other pollutants by between 16% and 25%.

Another Joule - Thermie transportation program is the demonstration project ZEUS (Zero and low Emission vehicles in Urban Society) The ZEUS program, a collaborative effort of eight northern and southern European cities, will procure and put into use more than 1000 zero and low emission vehicles. The program includes cars, vans, buses and trucks and a wide range of alternative fuels. Its objective is to demonstrate the role that municipalities of European cities and transport industry actors play in the future success of more environmentally sustainable transportation. The ZEUS partners are: Stockholm (coordinator), Helsinki, Palermo, Athens/ Amaroussion, Bremen, London/Coventry, Copenhagen, and Luxembourg. This program focuses on removing market obstacles which currently hinder a mass market for zero and low emission vehicles. Helsinki is trialing NGV buses under the ZEUS project. Athens also evaluated the optimum effect of introducing NGV buses.

2.4 United Kingdom

As a result of lobbying by the UK NGV Association there has been:

- progressive reductions in fuel duty for gas fuels with annual increases in conventional fuels duty, current retail prices for diesel being 83p / litre ($US4.74/US gal) and natural gas 43p / litre equivalent ($US2.46 /US gal),
- grant schemes to help with the additional cost of vehicles of 25, 50 or 75% based on the percentage emission improvement from current legislation and
- agreement in 1996 for NGV buses in public transit to receive the full public transit fuel rebate of the fuel duty available , equivalent to 36p / litre ($US2.06 / US gal) of the 50 p/l ($US2.86/US gal) duty

The economics however are still not sufficient to encourage fleet operators to switch to natural gas, as the government has frozen the public transit rebate and not proceeded with the proposal to rebate alternative fuels to receive a progressively higher graduated rebate compared to conventional fuels. This problem has been compounded with all the fleet operators now privately controlled and focussed on profitable returns. Currently NGV buses are operating in Southampton City (20), Northampton (6), Merton (6) and West Midlands (14). Operating costs remain the major concern and unless the government is prepared to provide the appropriate structure to operating NGV buses more economic further fleets are unlikely. Reports have suggested a 25% increase in fuel consumption over diesel in dense urban bus route use.

For **Northampton**, the local FirstBus subsidiary, Northampton Transport, has invested £900,000 in six new Volvo fully accessible low floor NGV buses. The compressed natural gas is supplied by British Gas from a purpose-built gas station supplied by British Gas NGV, at Northampton Transport's depot in St. James' Road, which will also be available for other natural gas vehicle users in the Northampton area.

Travel West Midlands' £2 million ($US3 million) fleet of fourteen low-floor Volvo NGV buses fitted with low emission engines, the largest NGV bus fleet in the UK, is to run between **Walsall and Wolverhampton** on the 529 route, a high frequency service which operates 18 hours a day, seven days a week and carries 62,000 passengers per week. The buses will refuel at a gas station at TWM's Walsall Garage. The project is a private investment partnership between TWM, British Gas and Volvo with support from the Energy Saving Trust's Powershift program.

Currently it is felt by NGV observers that unless Cummins and others are prepared to invest to meet new European standards they are likely to lose out to the new generation of natural gas bus engines to be introduced by bus builders such as Iveco (see Italy).

2.5 The Netherlands

There has been some work in the Netherlands. The companies which were involved with NGV buses were GCN, the local gas distribution company and the bus company MidNet. A total of 11 buses were operated in the Utrecht (city) region. Since beginning the project, both companies have been taken over by larger companies and the responsible people have retired. The project has stopped as the buses were already 14 years old when they were converted, and the investment costs are reported as too high to replace them. At the moment there is an NGV fuelling station, quick and slow fill facilities at the bus companies premises, but only one bus is still operating.

2.6 Germany

In 1996 it was estimated by SRI International that there were 58,700 urban buses in Germany. In 1996 Germany had 220 NGV buses. This gives NGV buses a market penetration of 0.4%.

The main driver is environment concerns of local authorities who are determined to improve local air quality in city centres. The lowering of taxes on gas in 1996 has boosted the market. Currently the major fleets operating NGV buses are:

City	NGV Buses	Total Buses
Augsburg	30	140
Berlin	10	1700
Hanover	15	180
Mainz	4	150
Saarbrucken	64	140

2.6.1 Saartal Line of the City of Saarbrucken

- Description of fleet

Saartal Lines has half its buses running on natural gas and plans to have the remainder of its 140 strong fleet converted by 2004.

- Technical description of buses

Currently it has 40 MAN NL 232 NGV buses and 24 of the latest MAN NG 313 NGV buses in its fleet.

- Refuelling

In April, 1999 the line opened what is believed to be Europe’s largest NGV filling station for the operation of its expanded fleet of NGV buses. The station fills a bus in three minutes. The compressors, supplied by Sulzer, have a capacity of 2730 m3/h (1600 ft3/min)with an outlet pressure of 25 MPa (3,600 psi). The storage cascade has a capacity of 7,200 m3 (250,000 ft3). There are six dispensers, four of them being high capacity. The main reason natural gas has been chosen is to improve vehicle emissions.

- Fuel Economy and Economics

The comparison with its diesel buses at Saartal Lines is as follows:
Diesel: Fuel Consumption 39.7 l/100 km (6 miles/US gal), Cost 0.9 DM / litre ($US1.55/US gal)
CNG Fuel Consumption 41.2 kg / 100 km (4.4 miles/US gal), Cost 0.75 DM / litre ($US1.29/US gal)

Specific Bus Costs per Kilometre: Diesel 0.357 DM($US0.253/mile), CNG 0.301 DM($US0.214/mile)

2.6.2 Berlin

Results from the CNG Bus Project in Berlin show an 80% reduction of environmental impairment as against that of a similar sized diesel fleet. The project is supported and co-financed within the EU Thermie program. Berlin has a fleet of 1700 buses of which, for the past eighteen months, ten have been operating on CNG. The Swiss environmental bureau BUWAL has monitored emissions of hydrocarbons, particulates, nitrogen oxides and noise from the NGV buses. It reports that the 80% improvement confirms results obtained in other cities such as Basel.

2.6.3 Augsburg

- Description of fleet

The city of Augsburg has 13 articulated lean burn natural gas buses and 17 other low floor NGV buses as part of a fleet of 100 buses. The details of the NGV low floor articulated buses of the Augsburg public transport company are:

No of buses	Bus type	In operation since	Average distance per bus (km)
8	Low floor articulated MAN NG232 CNG (lambda 1)	Jan. 1996	140,000 (87,000 miles)
9	Low floor standard MAN NL 232 CNG (lambda 1)	June 1996	115,000 (71,000 miles)
13	Low floor articulated MAN NG 313 CNG (lean bum engine)	Aug. 1998	15,000 (10,000 miles)

- Technical description and performance of buses

The Augsburg buses are MAN and the first buses with the new designed 228 kW (306 hp) natural gas engine. The Stadtwerke Augsburg - public utilities and public traffic company of Augsburg - is the "outsourced development department" of MAN Nutzfahrzeuge AG in Munich. MAN is doing a large field test because the buses are operating in normal line service.

MAN NG 313 CNG Low Floor Articulated Bus:
Engine type: 228kW MAN E 2866 LUH 01 catalytic conversion (lean burn) 12.0 litres
Fuel system: cylinders on the roof: 8 + 4, capacity: 1,680 litres (60 ft3)

Practical experience with the 1996 MAN articulated natural gas bus:

1.) Vehicle manufacturer, vehicle type:	MAN NG 232 CNG (with natural gas heating system)
2.) Engine:	E 2866 UH (monofuel) catalytic conversion (lambda 1)
- cubic capacity:	12.0 l
- power:	170 kW, 230 hp
3.) Average mileage:	140,000 km, 90,000 miles
4.) Consumption (including. heating):	65.0 m^3 /100 km
- diesel equivalent:	65.0 l/100 km or 3.72 miles per US gal
- theoretical value (MAN):	70.0 m^3/100 km
- additional consumption versus diesel EURO 1	ca. 20 %
5.) Additional weight by natural gas equipment:	2,100 kg, 4,600 lbs
6.) Fuel system	
- cylinders on the roof:	8
- volume:	1,120 litres, 40 ft3
7.) Range (remaining pressure in the fuel cylinders 40 bar):	ca. 280 km, 175 miles

Practical experience with the 1996 MAN standard natural gas bus:

1.) Vehicle manufacturer, vehicle type:	MAN NL 232 CNG (with natural gas heating system)
2.) Engine:	E 2866 UH (monofuel) catalytic conversion (lambda 1)
- cubic capacity:	12.0 l
- power:	170 kW, 230 hp
3.) Average mileage:	100,000 km, 62,000 miles
4.) Consumption (including heating):	51.0 m^3/100 km
- diesel equivalent	51.0 l / 100 km or 4.74 miles per US gal
- theoretical value (MAN):	55.0 m^3/100 km
- additional consumption versus EURO 1:	ca. 42 %
5.) Additional weight by natural gas equipment:	2,100 kg, 4,600 lbs
6.) Fuel system	
- cylinders on the roof:	6
- volume:	840 litres, 30 ft3
7.) Range (remaining pressure in the fuel cylinders 40 bar):	ca. 270 km, 170 miles

- Emissions

Low pollution diesel technology as catalytic reduction technology (CRT) can only drop soot and particulate matters. It costs 12,000 DM ($US5,300) and leads to an additional consumption of about 10%. To lower the nitrous oxide pollution diesel buses need the selective catalytic reduction technology (SCRT) system which is not in practical operation. Additional costs and fuel consumption resulting from this technology are unknown, however the expectation is that a diesel bus which is as clean as a natural gas bus will cost the same but with a higher carbon dioxide output.

- Maintenance

Measures	Diesel	Natural gas
Changing of engine oil	30,000 km 19,000 ml	Manufacturer's recommendation: 30,000 km; expected for the future: 45,000 km (28,000 miles). No special engine oil required
Valve adjustment	60,000 km 38,000 ml	Manufacturer's recommendation: 15,000 km (9,300 miles). Only necessary for the first engine generation. The new designed lean burn engine operates with lower temperatures so longer intervals are expected.
Changing of sparking plugs	n/a	Manufacturer's recommendation: 15,000 km.

Repairs: No considerable differences between diesel and natural gas buses.
Additional brake consumption:

Articulated buses:

- front axle: no difference between NGV and diesel
- middle axle: changing interval: NGV 50,000 km (30,000 miles), diesel 80,000 km (50,000 miles)
- back axle: no difference between NGV and diesel

Standard buses:

- no difference between NGV and diesel

Additional tire consumption:

Articulated buses:

- Tires were destroyed before used to the end.

Standard buses:

- 20% especially front right.

- Refuelling

The existing station was enlarged by firstly increasing fuelling capacity by setting both existing piston compressors by hand into parallel operation directly connected to the natural gas network with 36 bar (3.6 MPa, 500 psig) suction pressure (realised). Second step was to install two further compressors in the next four months which can operate in direct connection with the natural gas network or as boosters in connection to the gas storage with a suction pressure of 100 to 250 bar (10 to 25 MPa, 1500 psig to 3700 psig). The fuelling then will be handled by a one-bank-system with a constant pressure of some 220 bar (22 MPa, 3,200 psig) and be integrated in the normal work flow.
The enlarged filling station consists of

- one fuelling station with two fuelling nozzles (outdoor)
- one fuelling station with 1 fuelling nozzle (indoor)
- two piston compressors (LMF)
- two hydraulic compressors (Mannesmann/Hydromecanica)

Fuelling capacity after enlargement:
Fuelling station 1 (outdoor), 3-bank-system

- nozzle 1: normal cars, vans, minivans; 25 kg/min (9 US gal/min);
- nozzle 2: buses; 90 kg/min (33 US gal/min);

Fuelling station 2 (indoor), 1-bank-system

- nozzle 1: buses; 90 kg/min;

Two piston compressors (LMF):

- 1,140 m^3/h (700 scfm): when operating parallel in direct connection with the natural gas net;

Two hydraulic compressors (Mannesmann/Idromeccanica):

- 500 m^3 /h (300 scfm): when operating parallel in direct connection with the natural gas net;
- 1,500 to 3,500 m^3/h (900 to 2,100 scfm) when operating parallel as boosters in connection with the high pressure storage.

Fuelling time:

- at present: 10 min/bus (additional time for service and cleaning: 1.5 min/bus)
- after enlargement: 6 min/bus (including. time for service and cleaning)

- Economics -

The additional purchasing costs for the natural gas equipment - standard buses 70,000 DM ($US31,000), articulated buses 80,000 DM ($US35,000) including gas heating - are too high. Co-operation when ordering the buses is absolutely essential as standardisation of the gas equipment could decrease the additional costs. Fuel cylinders - especially composite cylinders - are expensive.

- Views of fleet managers

Natural gas technology remains expensive. Buses need to be designed for the actual duty, hilly and flat geography, to optimise fuel consumption. Light composite fuel cylinders are needed to lower the additional consumption. The fuel capacity in the buses should be sufficient for one day and exactly calculated. Fuel cylinders with a life time that corresponds with the lifetime of the buses are required. Until such cylinders are available, a testing method after 4 or 5 years which allows to test the cylinders on the roof and without dismounting them is required.
A clear decision for a conversion of the complete bus fleet makes planning the fuelling station easier and cheaper: there are then no expensive intermediate solutions necessary. The capacity of the filling station should be high enough to guarantee a fast fill: at most five minutes per bus. The fuelling station should be integrated into the bus hall and into the normal work flow enabling the buses to be cleaned and watered while being fuelled.
There should be financial support to the cities which have passed such progressive resolutions to convert their fleets to NGV and which have to order more natural gas buses in future years. The other cities need a secure financial base for planning a conversion of their fleets and to start their planning in the right direction.
Fuel tax must be kept at the minimum level over ten years or longer to encourage alternative engine development and give investors safety and security for their investment.

- Issues, opportunities, problems and challenges

Although it is only a short time since the buses began operation it can be said:

1. The power of the new engine is remarkably higher than of the first generation engine - there is no comparable diesel engine for articulated city buses so comparisons will be difficult. The new bus generation is the first which was designed with disk brakes, again making comparison difficult.
2. The NGV buses are part of the Augsburg traffic and well accepted by the Augsburg citizens.
3. *Positive:* Lower exhaust temperatures than the first engine generation.
4. *Positive:* Service is easier than with the first generation engine. This is due to the fact that more parts of the diesel engine could be used. That should lead to lower engine costs in the future.
5. *Positive:* The engine noise is lower
6. *Positive:* The engine was designed with a better engine management.
7. *Positive:* Gas inlet valve by HERION allows a final “empty” remaining pressure of 20 bar (300 psig), increasing range by about 10 %.
8. *Negative:* Problems with the lambda-sensor (sensitive against humidity).

2.7 France

- Description of fleet

In France 730 NGV buses are on order and 350 are in service in transit fleets. Currently one new bus out of three is running with natural gas. Twenty five per cent of all new buses ordered are NGV buses. Environmental concern is the key reason for the choice. About 30 cities in France have made the choice of NGV buses, the major fleets are :

City	**NGV Buses* (on the road + ordered)**	**Total Number of Buses in the Fleet****
Paris	53	~ 4 000 (including 57 LPG buses)
Nice	90	240
Montpellier	71	187
Poitiers	45	113
Nancy	45	162
Le Mans	50	149
Dunkerque	52	94
Nantes	80	278
Bordeaux	115	514
Besançon	60	129
Strasbourg	50	290
Les Ulis	27	93
Montbéliard	25	79
Valence	20	75
Lille	100	311
Colmar	30	33
Meaux	13	45
Chambéry	5	60

- Technical description of buses

The NGV buses are built by either Renault or Heuliez, the engines being either Renault or Volvo. The NGV buses are "low floor" with the CNG tanks located in the roof in a compartment separate from the passenger space. Most tanks are made of composite materials.

- Operational information

The buses have a life span of 12-15 years and travel about 40,000 km / year (25,000 miles) on urban routes.

- Emissions

The environmental emissions from the NGV buses when compared to diesel are:

- half the nitrogen oxides (NOx)
- less hydrocarbons
- less carbon monoxide
- virtually no particles
- neither black fumes nor unpleasant odours

- Refuelling

Most of the filling stations use the "filling at the parking location" method, where each bus is linked to a refuelling hose which fills it in several hours when it is parked (at night). This technology is handled by GNVert, a Gaz de France subsidiary.

- Economics

In simple terms the economics for NGV buses are:

- purchasing cost premium: $US28,000 to 35,000 per bus (213,000 to 266,000 Francs)
- refuelling installations: $US138 000 to 415 000 (1,050,000 to 3,150,000 Francs)
- fuel price: competitive price compared to diesel (ie cheaper)

The financial break-even compared to diesel is generally assured for fleets of 20 buses and over. For example, Nice, with a fleet of 43 buses, has a saving of $US1,000 (7,600 Francs) per bus per year. This saving includes the allowance for the bus purchase price premium, as well as operation, maintenance and fuel expenses.

- Views of fleet managers

Fleets managers have declared themselves satisfied with NGV buses.

- Issues, opportunities, problems and challenges

According to a recent study (May 2000), 96% of the passengers think that NGV buses are better than traditional diesel buses and 90% believe they truly improve air quality. The main strong points are cleanliness, silence, less vibrations and less fumes and odours.

2.7.1 Colmar, Alsace

- Description of fleet

Under the NGVeurope project, 12% of the buses in Colmar (in Alsace) are run on natural gas (three standard buses and one articulated bus) and the town intends to replace the entire fleet (36) with natural gas buses.

- Technical description of buses

The NGV low floor buses were manufactured in France by Renault Vehicules Industriels (RVI) in Annonay are the "AGORA" model. They were delivered during 1998. The engine is a 9.8 litre exhaust turbocharged 6 cylinder in-line 4 stroke Renault M6DR 06.20.45 A491 186 kW (253 hp) at 2100 rpm. The buses have 9 composite tanks : total capacity 125 litres (4.5 ft3), total capacity : 1,125 litres (40 ft3).

- Operational information

These NGV buses run on all public transport routes including those within the city centre. This project targets the evaluation of the environmental and commercial impact of the natural gas technology used.

- Fuel economy

Since the six standard buses have been put into service, each has covered between 30, 000 and 60, 000 km. (18,500 to 37,000 miles). The measurements of the consumption are high, on average 70.80 m^3 per 100 km (3.4 miles / US gal) since the beginning of 1999. The gas price is 1.40 francs excluding tax, but with the tax on petrol products (TIPP) of 0.556 F/m^3, the gas price for one cubic metre comes to 1.956 francs ($US1/US gal) excluding value added tax (1.377F/km). A diesel bus, of the same type, needs 42.50 litres to run 100 kilometres (5.7 miles/US gal). The diesel price amounts to 3.20 francs/litre ($US1.64/US gal)) excluding value added tax.

- Emissions

The comparison in emissions between diesel and the NGV bus engine is:

Emission (measured by RVI in g/kWh (g/hp-h))	**NOx**	**HC**	**CO**	**Particulates**
Diesel Engine Euro 1	9 (7)	1.23 (0.92)	4.90 (3.6)	0.40 (0.3)
Diesel Engine Euro 2	7 (5)	1.10 (0.82)	4 (3)	0.15 (0.12)
CNG Engine (Renault) with oxidising catalyst	4 (3)	>0.3 (>0.2)	>0.1 (>0.08)	<0.08 (<0.06)

- Maintenance

No significant problems in the operation or in the maintenance of the buses have been experienced. Some problems have been experienced with the electric cables and the spark plugs due to the high temperature of the engine. Just after starting the engine at very cold temperatures (-8 ° C, 18F) it was necessary to wait 15 or 20 minutes before the engine functioned correctly.

- Refuelling

The compression station uses two compressors with a capacity of 350 m3/h (21 cfm). The storage system has a capacity of 40 m^3 (1400 ft3) at 200 bars (20 MPa, 2,900 psig). The storage is only used for the fast fill, and a mass gas meter measures the consumption. Seven flexible hoses have been installed at the bus depot for slow filling. The buses are connected to these flexible tubes during the night. There is one fast fill dispenser for external fleets. During the day using the fast fill system, the refuelling time for a bus that comes with a residual pressure of 70 bars (7MPa, 1,000 psig) is 15 minutes.

- Economics

The total capital costs were approximately 7.3 million Francs ($US960,000):

  - One standard bus costs 1 564 000 F ($US206,000) (excluding tax), the specific additional cost for the gas amounts to 230 000 F ($US30,000) (excluding tax).
  - The articulated bus costs 2 152 000 F ($US283,000) (excluding tax), the specific additional cost for the gas amounts to 300,000 F ($US39,500).
  - Garage and depot modification : 232 000 F ($US 30,500) (excluding tax)
  - The filling station with slow and fast nozzles : 2 266 000 F ($US300,000) (excluding tax)
  - Other costs : 120 000 F ($US15,800) (excluding tax)

2.7.2 Poitiers

The District of Poitiers has a population of 115,000 residents (a third of the population of the department of Vienne) and includes 10 cities: Biard, Buxerolles, Chasseneuil Du Poitou, Fountaine Le Comte, Mignaloux-Beauvoir, Migne-Auxances, Montamise, Saint-Benoit, Vouneuil-sous-Biard and Poitiers, the regional capital. The residential population is characterised by its youth: 40% of residents are under 25 (approximately 30,000 are students).

- Description of fleet

Poitiers operated 22 natural gas buses (17 RVI, 5 Heuliez Bus) on 31st December 1999. 1 276 029 km (792,000 miles) have been driven since the arrival of the first NGV bus in January 1998, an average of 4,691 km (2,910 miles) per bus per month. Five new buses were bought during the last period.

- Technical description of buses

Technical data	Heuliez bus GX 317	RVI Agora
Number of buses	5	17
Length/Width/Height	11,705 / 2,500 / 3,230 mm 38.5/8/10.5 ft	11,990 / 2,500 / 3,350 mm 39.4/8/11 ft
Floor height	340 mm 13.5 ins	320 mm 13 ins
Full/ empty weight	19,600 / 11,980 kg 43,000/26,300 lbs	19,600 / 12,476 kg 43,000/27,450 lbs
Seating/standing places	25 / 84	22 / 90
Engine	Natural gas engine GDR 06 20 45 A 491 water cooled - cylinders in lines with external ignition	
Output	186 kW - 253 CV at 2,100 RPM - Maximum torque 1000 Nm^3 at 1,100 RPM	
Displacement	9,840 cm^3	
Compression ratio	11 / 1	
Transmission	Gear box ZF 4 HP 500	
Gas tanks	7 x 126 litres = 882 litres (31 ft3)	9 x 125 =1,125 litres (40 ft3)
Tyres	11 R 225	

- Operational information

Poitiers has an exceptional architecture. The Notre-Dame-la Grande is the monument of the city and was entirely restored from 1992 to 1994. It was during this restoration that the city and the district decided to forbid all traffic in front of the church and to improve its environment. The bus network is 368 km (230 miles) long (including common sections), with 759 bus stops. The S.T.P. manages 22 regular lines, except the special and school bus lines (Handibus, Petíbus). In 1997, 11.3 million passengers were transported on the S.T.P. lines and 4,084,632 km (2,500,000 miles) were driven. The natural gas buses are operated in the inner city. Buses have been installed on two natural gas dedicated lines: a short one (4.5 km, 2.8 miles) and a second one which links the city centre to the university (9.2 km, 5.7 miles).

- Fuel economy

1. The average gas consumption is 56 m^3 / 100 km (4.3 miles/US gal).
2. Variations from 54.1 to 58 m^3/100km/month for the whole fleet are probably mainly due to gas quality variations
3. Diesel consumption also changes month by month: variations in the number of passengers, traffic density, outdoor temperature explain this variation.
4. The diesel consumption is similar to that of gas, so the gas /diesel ratio is almost constant (about 1.29 m^3 per litre).
5. The gas consumption is lower than expected (ie., 56 versus 65 m^3/h per 100 km).
6. The gas fuel consumption is not significantly different between summer and winter.

- Maintenance

No maintenance problem for the buses occurred but there have been many upgrades to reduce the number of breakdowns during cold periods. Many technical adjustments have been made by the bus manufacture to resolve idling problems. It is difficult to determine whether the reason for these problems is due to either the bus engine or the gas quality (water, oil, dust, variation of the proportion of normal components in the gas). Although the NGV buses have the same mileage as diesel buses, they are not as reliable. Data has been collected on oil consumption for the first months and the NGV bus oil consumption is lower than diesel buses consumption, but the difference is decreasing. The diesel buses are one year older than the NGV buses.

- Refuelling

The compressor station operates at 200 bars (20 MPa, 2,900 psig). The slow filling system is sequential (by groups of 5 buses). It is equipped for night operation which is controlled by a timer. The semi-rapid filling system is currently used for emergency filling (in case of complete breakdown during the slow filling) and for filling external users. The station is equipped with a mass meter which can be used to control the amount of gas that is supplied to each individual bus. This is not possible with sequential filling line.

Twelve filling points have been added to fill the new buses that arrived at the end of 1998. This made it possible to fill 16 buses at the beginning of 1999 and 22 by the end of 1999. Some aspects of the filling nozzle design have been improved in order to achieve better safety conditions.

Some problems have been detected with the volumetric gas meter. It has been necessary to install a new anti-pulsation tank between the external gas meter and the compressors to suppress variation in gas measurement.

Experiences of fast filling in other French networks (40 NGV buses in Nice) show that it is impossible to fill a bus in less than 3.3 minutes. The objective for Poitiers is to have very fast filling (express filling) in less than 1.3 minutes, the same time as for a diesel bus.

A disadvantage of fast filling is the gas temperature which limits complete filling of tanks. As the filling time of the buses is shorter, the gas temperature cannot decrease during the filling, so the gas pressure goes down to 160-170 bars (16-17 MPa, 2350-2,500 psig) four or five hours after the end of the filling and consequently the gas quantity is about 15 to 20% under the real tank capacity. In slow filling a second short filling can be done (very easily with the compressor timer) to complete the first filling.

- Economics

Comparison between fuel costs show that the NGV is today cheaper than diesel under Poitiers price conditions; the presented cost includes maintenance and electric cost of the compressors and cost of the compressors, but not civil engineering. The economic balance was reached when the monthly gas consumption reached 45,000 m3 (1.6 million ft3), ie 16 buses driving more than 4,700 km/month (3,000 miles/month).

This balance was reached earlier than expected (at about 20 buses) because of:

- diesel price increases during 1998-1999 because of the market and increased taxation on diesel fuel
- taxes on gas for NGV buses decreased between 1998 and 1999. This tax reduction has been done by a tax exemption for 24,000 m^3 (6,200 US gal equivalent) per year per bus (for an annual consumption of 30,000 m^3). This means a 0.11 F/m^3 ($US0.06/US gal equiv) lower price (3,300 F/m3 per bus per year – 500 Euro - $US430).

The actual benefits enable amortisation of the bus incremental costs without subsidies.

- Issues, opportunities, problems and challenges

Gas buses are much quieter than diesel buses.

2.7.3 Nice

- Description of fleet and buses

Nice has a fleet of 240 buses, 42 of which are NGV buses with a further 38 on order. The NGV buses are Heuliez-Volvo GX 217 three door buses. The Volvo engine is a direct injection lean burn engine.

- Operational information

Nice has 360,000 inhabitants and is densely populated. The bus routes cover 74 km2 (28.5 sq. miles) and serve the concentrated urban zones where population and traffic regularly peak.

- Fuel economy

The original contract specified that the consumption of the NGV buses in cubic metres of natural gas should not exceed 1.4 times the diesel equivalent in litres of diesel fuel. The actual result was a ratio of 1.34. The NGV buses used 75 m3/100km (3.2 miles/US gal).

- Maintenance

It is considered too early to make a definitive judgement regarding maintenance and technical issues.

- Refuelling

Gaz de France supplied a permanent filling station with fast fill facilities enabling a bus to be filled in three minutes.

- Economics

Purchase cost (tax free) of the 42 NGV buses	61 million Francs ($US8 million)
Extra cost (tax free) for each NGV bus	200,000 Francs ($US26,000)
Government subsidy	50,000 Francs ($US6,600) per bus
Reduction of Oil Tax on natural gas since 1998	59 centimes per m3

(This almost covers the amortisation of the residual bus cost)

- Views of fleet managers

The selection and introduction of NGV buses has been positive in the view of SEMIACS, the fleet operator because:

  - drivers found the buses comfortable and powerful to drive
  - the public was generally convinced pollution was less
  - passengers found the buses cleaner and with less odour
  - the politicians choice to use NGV buses was well received by voters

- Issues, opportunities, problems and challenges

The vehicles remain under a two year guarantee so the real cost of maintenance and engine life expectancy will not be revealed for some time to come.

2.8 Italy

The cities using or having on order NGV buses are:

City	NGV Buses	NGV Buses on Order
ACAP Padova	0	10
ACT Bolzano	12	20
ACTF Ferrara	0	13
ACTV Venezia	0	20
AGESP Busto Arsizio	0	4
AMAT Palermo	10	50
AMT Catania	0	30
APM Perugia	0	10
ASM Brescia	0	34
ASM Pavia	0	15
ATAF Firenze (Florence)	64	16
ATC Bologna	0	40
ATESINA Trento	2	0
ATM Alessandria	0	10
ATM Ravenna	30	18
ATM Torino	0	100
ATM Udine	40	7
COPIT Pistoia	5	15
CPT Pisa	1	0
CTP Napoli	0	50
TRA-IN Siena	0	2
ASPES Pesaro ATMA Ancona APM Macerata SAUC Ascoli Piceno	0	100
ATAC Rome	5	0
TOTALS	**169**	**564**

Italy is one of the few countries that has chosen NGV buses on economic grounds as well as environmental reasons. However the penetration of NGV buses is still lower than might be expected, with space limitations at key city bus depots appearing to be the major limiting factor. The major potential for NGV buses is believed to be in small to medium size cities where space is not such a concern. The environmental driver is the trend in Italy to close historic city centres to private transport, and require transit operators to use a clean fuel.

2.8.1 Florence

As in many other European cities, Florence, one of the most historical city in Italy, with 594,000 inhabitants in urban area, is affected by an heavy traffic congestion, noise and air pollution problems. The Florence Municipality Council approved an environment transport policy that required the reduction of pollution in the city centre and the Transit Company of Florence (ATAF) aims to introduce an ecological fleet based on CNG technology. This advanced fleet will be operated in the historical centre to reduce pollution levels. Florence was one of the cities in the Jupiter 2 program.

- Description of fleet

The latest NGV buses purchased by Florence are 31 IVECO City Class. The operational performances of these NGV buses are comparable with diesel buses which operate on the same routes, but with an added value of improved environmental performance. Before the end of 1999 the fleet will contain 64 CNG buses in addition to conventional buses.

- Technical description of buses

Details for both the NGV and diesel versions of the Iveco City Class buses are given in the following table:

Fuel	**Diesel**	**CNG**
Type	IVECO 491 City Class	IVECO City Class CNG
Total Weight (kg)	18370 (40,500 lbs)	18990 (41,850 lbs)
Length (m)	11.995 (39.4 ft)	11.995 (39.4ft)
Breadth (m)	2.500 (8.2 ft)	2.500 (8.2 ft)
Height (m)	2.795 (9.2 ft)	3.245 (10.7 ft)
Floor height (m)	0.340 (13.4 ins)	0.345 (13.6 ins)
Volume (m^3)	83.81 (2950 ft3)	97.3 (3430 ft3)
Mechanical		
Engine capacity (litres)	7.68 turbo	9.5
Power (kW)	162 (217hp)@2050rpm	161 (216 hp)@2100rpm
Max. torque (Nm)	950@1200	873@1100rpm
Max. speed (km/h)	80 (50mph)	80 (50 mph)
Max. slope (%)	25	26
Tank capacity (litres)	300 (77 US gal eq)	1120 lt@200bar (40 US gal equiv eq)
Range (km)	700 (435 miles)	450 (280 miles)
Load		
Passengers seating (n.)	22	32
Passengers standing (n.)	91	70
Maximum load (kg)	7700 (17,000 lbs)	7000 (15,500 lbs)
Doors boarding and alighting (n.)	3	3
Specific cross reference parameters		
Mass power (W/kg @full load)	8.82	8.47
Volumetric mass ratio (m^3/ton)	4.56	5.12
Max. mass speed (km/h * ton)	1469	1519
Passenger statistics		
Space for passenger (m^3/passenger)	0.74	0.95
Passengers vs. b & a doors	37.6	34
Power cross reference parameters		
Max. power capacity (kWh)	2971	2214
Max. power density (kWh/km)	4.24	4.92

Fuel	Diesel	CNG
Operational Issues		
Max. continuous daily service (km)	300 (190 miles)	450 (280 miles)
Daily refuelling rate	1	1
Refuelling time (min)	5	20
On line refuelling	No	No
Emissions		
Normative		CEE R49.02-13
NOx (g/kWh)	6.31 (4.71 g/hp-h)	0.11 (0,08 g/hp-h)
HC (g/kWh)	0.39 (0.29 g/hp-h)	0.02 (0.015 g/hp-h)
CO (g/kWh)	1.9 (1.41 g/hp-h)	0.28 (0.21 g/hp-h)
PM (g/kWh)	0.129 (0.1 g/hp-h)	0.009 (0.007 g/hp-h)
Noise		
Max external noise level (dB)	79	74.5
Financial Issues		
Purchasing cost (euros)	227241 ($US196,000)	256162 ($US221,000)
Running cost (euros/km)	0.42 ($US0.58/mile)	0.32 ($US0.44/mile)
Infrastructures cost (euros/year*vehicle)	310 ($US270)	310 ($US270)

The new injection Multipoint (MPI) system replaces the carburettor (Venturi mixer) to obtain fast response and reliability. Emissions are drastically reduced especially during the acceleration and deceleration phases of the urban cycle. The engine has 6 cylinders and is turbocharged, with electronic control to keep the air/fuel ratio near the stoichiometric value. The 3-way catalytic converter decreases the NOx, HC and CO emissions to below Euro 2 limits.

- Operational information

In Florence the routes within the city centre on which NGV buses operate are characterised by passenger volumes consistent with the passenger capacity of the NGV buses. The particular engine performance allows for effective utilisation of the buses. The environmental benefits for both the people and the heritage buildings are compatible with travel needs.

- Fuel economy

Some operational data and preliminary results from energy consumption testing of the Iveco City Class NGV bus are summarised in table below:

Fuel consumption	1.71 km/kg (4.54 miles/US gal)
Average speed	15.02 km/h (9.3 mph)
Total distance travelled	170,881 km (106,000 miles)

- Emissions

The emission of pollutants from the NGV bus are lower than diesel (about 10 times in most cases) but the level of particulate emission is much lower (0.009 vs. 0.129 /kWh). In other tests carried out by VITO Research Institute of Bruxelles on urban routes in Bruxelles, the Iveco Multipoint Injection engine was able to reduce the emission of pollutants more than other natural gas technologies or the Diesel Euro 2 engine.

- Maintenance

During the first testing phase no failure or relevant mechanical problems occurred.

- Economics

The low cost of natural gas in Italy significantly reduces the fuel costs. Purchasing cost is slightly higher for an NGV bus than a conventional diesel bus.

- Issues, opportunities, problems and challenges

The most evident operational problems that have caused concern are refuelling and maintenance. The driving of the NGV buses has not caused any problems but it should be stressed that the limited range (450 km (280 miles) for NGV versus 700 km (440 miles) for diesel) of the buses may, in adverse conditions, cause several problems.

2.8.2 Ravenna

- Description of fleet

Ravenna has been using NGV buses since the late 1980s. Today the fleet consists of 31 NGV buses, 31% of the fleet. Nine diesel buses were converted with government support in 1992 followed by an experimental run of five from an Italian vehicle manufacturer. Eight 10 metre (33 ft) buses plus 2 mini buses were purchased under the Thermie Joule program. The experience has been that the NGV buses have been and remain suitable for the task. As a result a further eight low floor NGV state-of-the-art buses were ordered. These buses have had excellent performance since their introduction in 1998.

- Fuel economy

The Thermie Joule and low floor NGV buses use about 1.8 km/m3 (4.35 miles/US gal) compared to 2.45km/litre (5.9 miles/US gal) for the diesel.

- Emissions

NGV bus emissions are still below Euro 3 standards and, in comparison to Euro 2:

    - NOx is reduced seven fold, down to 11.6 g/km (18.7 g/mile)
    - CO is reduced by 36 times, down to 9 g/km (13.2 g/mile)
    - non methane hydrocarbons are reduced by 46 times, down to 1.9 g/km (3 g/mile)
    - there are almost no particulates
    - there is less greenhouse gases produced than with diesel

The multipoint injection natural gas engine on the low-floor NGV bus shows further significant improvement again (NOx 0.6, HC 0.8 and CO 3 gram/kilometre; or 1.0, 1.3 and 4.8 g/mile).

- Maintenance

The main reliability weaknesses of the Thermie Joule NGV buses were that some components were not suitable for buses (since fixed), spark cables failed regularly (now improved), backfiring occurred when the vehicle was out of tune and electronic controls failed (now improved). Serious faults have dropped from 9 per year in 1993 to two per year in 1997.

- Refuelling

The filling station is capable of refuelling a bus in 11 minutes at 21.6 MPa (3,100 psig). The station uses two 110 kW (150 hp) compressors delivering 2000 m3/h (1200 cfm). Four dispensers are used to fill the buses.

- Economics

The major advantage has been in the fuel cost savings, with CNG being 0.18 Euros/m3 ($US0.60/USgal) (including compression costs) versus 0.60 Euros/litre ($US2/USgal) for diesel.

- Issues, opportunities, problems and challenges

Drivers and passengers appreciate the quieter buses and lack of smoke.

2.8.3 Rome

- Description of fleet

The A.T.A.C. (Azienda Tramvie ed Autobus del Comune di Roma - responsible for road public transport in Rome) project was part of NGVeurope. It was to investigate the use of the bio-methane-powered buses on specific routes. ATAC has selected 10 routes on its public transport network to convert from diesel-buses into bio-methane buses. The routes were all in the historical city centre, the use of the buses aimed to help improve the local air quality and so help protect the historical sites. The total number of bio-methane buses to be introduced under the project is 40.

The fleet vehicles in daily operation on the selected routes in the project are:

Type of vehicle	**Number**
11 m (36 ft)	30
12 m (39 ft)	5
8.5 m (28 ft)	4
Total	39

- Technical description of buses

A.T.A.C. has 5 bio-methane driven buses 8.5 m in length in operation. These are IBIS coaches on a Mercedes Benz 414 T40/46 chassis. The passenger capacity is 25. Four of these buses are in daily operation and one is in maintenance daily.

Technical data of buses:

- Number of vehicles 5
- Length/Width/Height 6,890/2,040/2,790 mm (22.5/6.7/9.2 ft)
- Full/Empty weight 7,100/4,600 kg (15,600/10,100 lbs)
- Seating/standing places 15/10
- Engine M111E, NGV (or gasoline), 4 water-cooled cylinders in line 4,000 RPM
- Displacement 2,295 cc (140 ins3)

- Operational information

A.T.A.C. covers 1,508 km² (580 sq mile) and about three million people, and operates 2,383 buses handling seven million passengers per year. A.T.A.C. is testing the bio-methane obtained by a process of purification of the biogas produced by the oxidation of Rome's urban rubbish. At present it is in use on two new bus lines (5 buses) for a total length of 50 km (30 miles). The demonstration project runs in an area on the west-side of the city, towards the biogas production plant to minimise unnecessary trips. The operation of the first group of buses started in April 1999 on the following routes:
088: Casaletto-Massimina
089: Via Portuense-Ponte Galeria railway station

Efforts are now being made to obtain a licence from Municipality and Lazio Region Administration to implement new routes running with NGV driven buses in the urban operating network. Currently only the two lines, 088 and 089, are in operation using NGV buses.

- Emissions

Bio-methane fuelled engines produce less particulates and unburnt hydrocarbons than diesel engines, with sulphur below detectable limits and noise lower by 3 decibels.

- Refuelling

The first filling station location is in Malagrotta, one of the major refuse disposal sites in Europe, the largest in Italy, with some two square kilometres (0.75 sq miles) of surface, with 530 bored pits for extracting biogas and a production of 150-200 m³ (500 - 700 ft3) per ton of waste during an estimated period of 30 years.

Technical characteristics of bio-methane installation:

Biogas capacity per bore	1.0 m3/h (1.1 kg/h) (35 ft3/h)
Methane production	400 m3/h (285 kg/h) (1400 ft3/h)
Operating pressure	8 barG (800 kPa, 120 psig)
Storage pressure	200 barG (20 MPa, 2,900 psig)

Compound concentration (% vol):

	Biogas	Bio-methane
Methane	50-58	97-99
CO2	35-45	1-3
H2S (ppm)	50-100	0.5
O2, N2, H2	0.5	0.5
H2O(ppm)	saturated	1.3

- Economics, Maintenance, Fuel Economy -

The short period of testing has not yet produced significant data from a statistical point of view about, performance, operating costs (maintenance and repair) or natural gas consumption.

2.9 Sweden

The decision to introduce NGV buses in Malmö was for environmental reasons, as the city wanted a cleaner transportation system within the city centre area. With deregulation and centralisation of public transport, tougher measures have been taken by the city, such as inner city environmental zones where only heavy vehicles with high emission standards (ie lowest emissions) are permitted. The city of Malmö has decided not to accept new diesel buses in the city traffic, only gas buses.

The total number of NGV buses in operation in Sweden about 320, including biogas buses.

- Description of fleet

In Malmö 125 city buses are running on natural gas. The total number of NGV buses in the region is 170.

- Operational information

The regional public transport (RPTC - “Skånetrafiken”) made a commitment to have 200 NGV buses in operation by the year 2000, a development that has been faster than expected. With funds from the

Swedish government the RPTC until recently covered the extra investment costs for purchasing NGV buses, but the subsidies have now ceased. In 1998, 80% of the total of 10,000,000 km were run by NGV buses.

- Fuel economy

In Malmö, the average fuel consumption figure for a modern diesel bus is 4.5 litres per 10 km, the corresponding figure for a NGV bus is 5 m^3 . This difference is considered reliable and the small difference may be attributable to the flat terrain of Malmö.

- Refuelling

The major refuelling station is located at Sydgas in Malmö. It is used for a public refuelling station and for supplying the slow fill facility to the 115 NGV buses at the adjacent bus depot. The compressors are three Nuovo Pignone Cubogas units each with a capacity of 850 m3/h (500 cfm). One Nuovo Pignone (NP BVTN/3) with a capacity of 400 m3/h (240 cfm), serves 14 intercity buses , another (NP BVTN/2) with a capacity of 850 m3/h (500 cfm), serves 15 city buses and in nearby city of Lund, a third compressor station serves 24 city buses. All facilities using a “slow” fill system for buses.

- Economics

Natural gas is the same price as diesel by an enactment of the Swedish government.

- Views of fleet managers

The conclusions for the operation of the Malmo NGV buses are quoted as:

Disadvantages	**Advantages:**
Hard to predict future maintenance costs.	Appreciated by drivers and passengers.
NGV requires training and information.	Significantly lower exhaust emissions.
Added risks for workshop routines (high pressure).	Reduced engine noise.
Periodical tank inspection.	Easy refuelling process.
Higher investment costs.	Lower production of carbon dioxide green house gases .
Added weight to the bus due to storage cylinders.	With a price tag on polluting, the buses pay off.
Involves new technical systems and care.	Excellent performance
Involves further bureaucracy and regulations	Fuel costs not affected (Sweden).
	No exhaust particulates.
	Eliminated idle engine vibrations.
	Refuelling when not in service.
	Existing vehicles and infrastructure market.
	Environmental-friendly public transport is good public relations.

- Issues, opportunities, problems and challenges

Bureaucracy and legislation have been major obstacles, the main reason is that there were no existing rules, especially for NGV tanks. Measurements show a decrease in the noise level of more than 10 dBA, which means a 50% decrease in engine noise. Another advantage is the reduced smell.

2.10 Spain

In 1996 the transit fleet in Barcelona (TMB) was reported as having two NGV buses in its fleet of 800 urban buses for trialing. Madrid (EMTM) had 15 in a fleet of 1000 and that of Bilboa has two NGV buses for trial purposes under the Thermie Program. Salamanca also has 5 NGV buses. NGV bus market penetration is minimal.

2.11 Greece

A Kathimerini English Edition newspaper article reported in July, 2000, that in an effort to improve the capital's atmospheric pollution and the image of public transport, the Greek authorities (OASA and the Transport Ministry) decided to buy a significant number of new vehicles for Athen's fleet of 1,500 buses, including 295 buses that are to run on compressed natural gas (CNG). The first 40 CNG buses will be delivered in September 2000 by Renault to OASA (the delivery will be completed in 2001), at a cost of approximately 28.1 billion drachmas ($US70 million)- the cost per bus being 90.7 million drachmas ($US225,000). The CNG buses with second-generation engines (together with second-generation catalysers) are considered to be among the least polluting buses in the world. The CNG buses are quoted as more expensive to buy, requiring costly refuelling stations, and having higher operation and maintenance costs than their diesel equivalents.

The article goes on to state that natural gas-fueled buses are more energy-consuming than those that run on diesel: they burn 15-20 percent more fuel, which means they have high emissions of carbon dioxide. But that they have much lower emissions of particulates, nitrogen oxide, carbon monoxide, sulfur dioxide and volatile organic combinations, except for methane. It highlights that all the latest studies show that the most dangerous pollutants are the particulates and ozone (the precursors of which are nitrogen oxide and the volatile organic compounds). It points out that despite the fact that the buses that run on natural gas have a lower energy performance than the others, they have important environmental and economic benefits, particularly in densely populated areas where the effects of local pollution are the greatest.

The article summarises a study on the environmental and economic benefits. The study included buses using four different technologies, diesel buses, diesel buses with catalysts, diesel buses using second-generation catalysts, and buses that run on natural gas. The hypothesis was made that all these types operate on the 300 routes. Then, the pollution that each of the four technologies causes was calculated, including - together with the type of vehicle, type of engine, type of fuel used, emissions control technology, engine power and age - other parameters, such as how the driver drives, how fast the bus goes, how many passengers it transports, etc. The data was cross-indexed with the population density of the area of each route and the environmental cost of each of the four types of buses on each specific route was calculated. The environmental cost per vehicle-kilometer was calculated, dividing the cost per route by the total length of the route. The results showed that there is a great variation in the environmental costs per vehicle-kilometer. The greatest costs occur on the old diesel buses - 68 eurocents (58 US cents) per vehicle-kilometer. Next came diesel buses with catalysts (55 eurocents, 47 US cents), diesel buses with second-generation catalysts (22 eurocents, 19 US cents) and natural gas-fueled buses (20 eurocents, 17 US cents).

It concludes that if the existing fleet has an annual environmental cost of about 57 million euros ($US49 million), the buses that run on natural gas amount to only 15 million euros ($US13 million). It also concluded that the maximum benefit occurs if natural gas-run buses are run on 50 inner city routes, which travel 65,000 kilometers a day and transport more than 12 passengers each time. The study showed the marginal benefits from the use of buses that run on natural gas fall significantly as their number increases beyond 295, as the replacement of old buses in the suburbs would not have significant environmental benefits.

2.12 Finland

At present there is no tax on natural gas in Finland. Uncertainty relating to a future possible tax and concerns about the costs and reliability of NGV buses and refuelling stations in Finland's very cold winters remain as significant deterrents to NGV bus market penetration.

Helsinki City Transport (HKL) is a municipal transport company which operates 370 buses and trams, and accounts for 55% of Helsinki's bus traffic. It has a policy to move to NGV buses gradually as a result on a Board of Public Transportation decision in the mid 1990s. The total bus operations for Helsinki are almost 35 million kilometres (22 million miles) and 200 million passenger trips.

HKL currently (August 2000) operates 22 Volvo Model B10L NGV buses, the first 11 being received in 1998. This is part of the Thermie project on transport. Due to the extensive use of HKL's NGV buses there has been a big impact on air quality in Helsinki. There are some 33 NGV transit buses operating in Helsinki with the total number expected to grow to 100 - 120 by 2005. Two fast fill refuelling stations have been built with a third under construction.

Tests by VTT Energy determined that the additional overall cost of NGV buses of 7% was more than balanced by the significant reductions in emissions.

2.13 Czech Republic

There are at least 57 NGV transit buses operating in four Czech cities. These buses are generally conversions from diesel buses. The choice of natural gas over diesel is due to its relative low price over diesel.

The Municipality of Havíøov, now has 43 natural gas buses (1 articulated and 42 standard buses), comprising about 60 % of their total urban bus transport fleet. Prague (DPMP) has five in its fleet of 1250.

2.14 New Zealand

2.14.1 Hamilton City Buses Ltd, Hamilton

- Description of fleet: 50 NGV buses

- Technical description of buses

The fleet is made up of MAN, SL202, MAN 11 series, Mercedes Benz 0305, HINO RK176/77 and eight Cummins powered Optare Metroriders. Generally all vehicles have been converted to run on CNG by the Hamilton Bus workshops.

- Operational information

Hamilton City Buses Ltd is a privately owned company operating approximately 50 NGV's under contract to the Waikato Regional Council located on the North Island.
All operate on daily route services and average around 40,000 kms (25,000 miles) per annum. Hamilton Bus do not operate a diesel equivalent fleet but from costings from the odd diesel vehicle still operating, indications are that running on gas is about the same or slightly cheaper than diesel when the price of diesel was around NZ$0.42c per litre ($US0.65/US gal). Current price is around NZ$0.73c per litre ($US1.13 per US gal) retail at the pumps.

- Fuel economy including comparison with diesel buses

At this time there is no economic advantage in respect to fuel, diesel versus natural gas

- Emissions: No reliable emission testing has been done.

- Maintenance

As the Hamilton Bus conversion process improves, the vehicles are starting to get considerably more reliable. They are currently in the process of extending service intervals to six monthly as all the components appear to be standing up to the workload. The Optare Metroriders appear to be very suitable for this type of service interval. With good regular maintenance, it is believed gas engines are as reliable as their diesel equivalent. Maintenance is generally greater than for the equivalent diesels and the NGV buses have had problems with backfiring. Other problems have occurred with the refuelling system, with hydrates forming a number of times causing delays.

- Refuelling

All vehicles are refuelled on a trickle fill facility. Taking advantage of the time brackets for the purchase of electricity, Hamilton Bus are currently filling between mid-day and 3pm daily while some of the vehicles are off the road prior to peak requirements and continuing to fill from 9pm through to 3am the following morning. As they trickle fill, the requirement for storage is somewhat minimised but they have facility to hold 4,000 water litre equivalent (142 ft3) of natural gas.

- Economics

As Hamilton Bus was unable to purchase OE engines that will run on the gas in New Zealand, all NGV's have had to be converted locally. The cost of a conversion is around NZ$5,000 ($US2,000) plus gas cylinders. Hamilton Bus vehicles require approximately 400 water litre (14 ft3, 100 US gal) equivalent per vehicle. Maintenance cost between a gas and a diesel fleet are believed to be very similar with the gas fleet requiring more regular but less expensive upkeep than a diesel. The gas installation and compressor has been operating for almost 10 years and is coming up to its second compressor overhaul. These cost approx. NZ$30,000 ($US12,000) each time it is overhauled.

- Views of fleet managers

The biggest problem or challenge for this company in regards to NGV's is the lack of OEM manufacturers that can supply a gas engine suitable for its requirements and that will run on the local natural gas.

- Issues, opportunities, problems and challenges

The current situation is that over recent months the price of petrol and diesel has significantly increased. This has encouraged car owners who have had a vehicle that was capable of running as an NGV or an LPG powered vehicle to re-certify their cylinders and continue operating on gas which they might not have done for some considerable number of years. There has been no large number of fleet conversions to NGV reported in New Zealand but the removal of refuelling facilities appears to have stopped at this stage.

2.14.2 Stage Coach New Zealand, Auckland

- Description of fleet: Stage Coach New Zealand operates 30 NGV buses.
- Technical description of buses: These buses were converted from diesel engines in the workshops of the company. The converted engines, using carburetion systems have less power than their diesel counterparts.
- Operational information: The buses operate in the city of Auckland on the North Island of New Zealand
- Fuel economy: Currently there is no advantage in fuel costs
- Maintenance: The maintenance on NGV buses is greater than their diesel equivalents. The company reports similar backfiring problems to the Hamilton buses. Fires have been caused by this backfiring but the causes have been due to faulty maintenance, including failing to reinstall flash arrestors.
- Views of fleet managers: Stage Coach do not plan to purchase or convert any more buses to NGV.
- Issues, opportunities, problems and challenges: Stage Coach see the major problem for NGV buses in New Zealand as the lack of OEM supply and support.

2.15 Australia

Australia at this time operates only natural gas buses using compressed natural gas (CNG). Based on present orders for new NGV buses and the retrofitting of existing diesel buses, the number of NGV buses in government owned urban transit fleets could rise from 478 in 2000 to 826 in 2002. There are 24 NGV buses operating in private fleets in Melbourne.

NGV Buses as a Percentage of Government Urban Bus Fleet, 2002

Metropolitan Area	Government NGV Buses in 2000	Government NGV Buses in 2002	Percent NGV Buses in Government Fleet in 2000	Percent NGV Buses in Government Fleet in 2002*	Total number of urban buses
Sydney/ Newcastle	254	402	14.9	23	3900
Adelaide	130	213	14.7	28	750
Brisbane/ SE Qld	12	132	2.0	22	1100
Perth	52	77	6.1	9	850
ACT	2	2	0.5	0.5	350
Melbourne[a]	0	0	0	0	1400
Darwin	0	0	0	0	65
Tasmania	0	0	0		222
Total	**478**	**826**	**10.6**	**18**	**8637**

[a] Private bus companies operate 24 NGV buses in Melbourne and Geelong.

It is estimated that currently about 6% of all urban buses (performing regular route duty) are fuelled by natural gas, excluding school buses. This percentage is likely to rise to 10% in 2004. Of the government owned buses, 826 or 18% are likely to be operating on natural gas by 2004.

Currently the bulk of Australia's NGV route bus fleet uses early generation, NGV engines which have higher fuel consumption, different maintenance requirements (particularly spark plugs, coils and ignition leads) and more stringent service schedules to produce similar reliability to diesel buses. The latest generation, multi point, EFI, NGV buses are only available from a few manufacturers. They are anticipated to reduce fuel consumption, have equivalent or lower maintenance costs to diesel buses and similar reliability to diesel buses when manufacturers maintenance schedules are followed.

Generally, while environmental considerations have been a factor in the decision to purchase NGV buses, the prime driver has been the economic advantage of the cheaper fuel price of natural gas compared to diesel.

2.15.1 Government Programs

With the introduction of Goods and Services Tax in Australia, the Federal Government has introduced a range of measures to support alternative fuels and protect them from the rural diesel rebate scheme introduced as part of the Goods and Services Tax package.

In early July, 2000 the Federal Government's Australian Greenhouse Office called for Requests for Proposals under the CNG Infrastructure Program. This effectively completed a package of Federal Government programs, allowing the NGV industry and end users to move forward with certainty. It is expected that the package will provide a strong stimulus for alternative fuels, especially NGVs. The programs include:

- **The CNG Infrastructure Program ($A7.6 million, $US4 million)—**funding up to 50% of the cost of installing in excess of 20 public refuelling facilities. This substantially reduces the fiscal risk for site providers and will establish a core public refuelling network. The first round of proposals closed on 5 October 2000, with tenders expected to be awarded in about three months;

- **The Alternative Fuels Conversion Program—**funding of up to 50% of the additional cost is available either for conversion to, or purchase of new NGV's over 3.5 tonnes GVM, thus reducing fiscal risk for the end user;

- **The Diesel and Alternative Fuels Grants Scheme**—ensures that the fuel price advantage of natural gas over diesel is maintained.

- **The Alternative Fuels Grants Scheme**—applies exclusively to urban buses and increases the CNG fuel price advantage over diesel.(see table below). This program explicitly targets urban buses and offers a grant of 12.1 cents(A)/m3 ($US0.25/US gal eq) of natural gas to the NGV bus operators but offers no such grant to diesel bus operators. As a result, the price advantage of natural gas over diesel for urban buses has improved by approximately 10%.

<table>
<tr><th colspan="2">Diesel and Alternative Fuels Rebate Scheme</th><th>CNG Rebate, c/m^3</th><th>Diesel Rebate, c/l</th></tr>
<tr><td rowspan="2">Buses between 4.5 and 20 tonnes GVM</td><td>Urban use</td><td>12.132
(25 USc/USgal)</td><td>0</td></tr>
<tr><td>Rural use</td><td>12.132
(25 USc/USgal)</td><td>17.798
(36.75 USc/USgal)</td></tr>
<tr><td colspan="4">Rebates are calculated after GST is removed from the pump price, e.g. if the pump price of CNG is 44 c/m^3 GST of 4c is deducted before subtracting the rebate of 12.132c . Thus the final price would be 27.868 c/m^3 (57.5 USc/USgal).
Rural and Urban Boundary maps can be found on the ATO website at http://www.taxreform.ato.gov.au/general/diesel/diesel.htm</td></tr>
</table>

2.15.2 Bell Street Buses, Melbourne Victoria

There are 40 private urban bus operators in the Melbourne metropolitan area using 1400 buses.

Bell Street Buses is a private bus fleet operating 28 buses on public transit routes in the north of Melbourne; 14 are NGV buses. It purchased nine Mercedes Benz Series 1 NGV buses in 1992. These buses have performed reliably although they are considered by drivers to be under powered. The limited range of 300 to 350 kilometres (220 miles) compared to 700 kilometres (440 miles) for the diesels is also an issue and requires the NGV buses to filled very day. In 1995 five Mercedes Benz Series 2 were purchased and while these have more power and excellent driveability, their reliability has not been as good as the Series 1. Backfiring has been a constant problem along with occasional fires. There have been other problems that occurred in high summer temperatures. A lot of the problems are considered to relate to the electronics and ignition system. Spark plug life is also a problem with lives of 18,000 kilometres (11,000 miles). Mercedes Benz has provided good support in working with Bell Street Buses to overcome the problems.

The buses were purchased purely on economic grounds of fuel savings of natural gas versus diesel. Even including all maintenance and down time, it is considered that the natural gas buses are more economic than their diesel counterparts.

The depot uses Norwalk compressors with a capacity of 400 m3/h (235 cfm) and with fast fill, taking 5 minutes per bus.

2.15.3 Benders Buses, Geelong, Victoria

Benders Buses were the pioneers in NGV buses in Australia, beginning their experiments with dual fuel buses in the late 1980s. In the early 1990s they purchased their first dedicated NGV buses from Mercedes Benz - a total of seven standard buses followed by two low floor buses in the late 1990s. The major problems experienced were backfiring and engine shut down during hot weather. The new low floor buses were reasonably trouble free except for premature valve wear. With a recent change in ownership, it is unlikely further NGV buses will be purchased in the near future. The depot uses compressors with a capacity of 400 m3/h (235 cfm) and with fast fill taking five minutes per bus.

2.15.4 Sydney Buses, Sydney, New South Wales

- Description of fleet

Sydney Buses is the largest division of the State Transit Authority and owns the largest bus fleet in Australia with 1600 buses carrying over 185 million passengers in 1998/99. Sydney Buses currently operates 104 Scania NGV buses from its Kingsgrove depot and is currently receiving 150 new Daimler Chrysler (Mercedes Benz) NGV buses. The Scania buses were delivered in 1994. The new NGV buses will operate from its Ryde and Port Botany depots (75 each). State Transit will have 254 CNG buses operating out of three depots in 2000 and, by 2002, will have a fleet of 404 NGV buses operating out of five or six different depots. State Transit has indicated that further fleet replacement is likely to be focused on CNG for both financial and environmental reasons.

- Technical description of buses

The new buses are Mercedes Benz 0405H ultra low floor air conditioned buses seating 43 with 25 standing. The engine is a Mercedes Benz 447HG. The engine has a closed loop technology and is fitted with a three way catalytic converter. The buses will have a range of 400 kilometres (250 miles), in contrast to the Scania buses which had a range of 250 km (155 miles). The on-board storage tanks are seven composite Mannesmann cylinders rated at 26 MPa (3,750 psig). The Scania NGV buses are 49 seat and 12.2 metre (40 ft) in length.

- Operational information

Sydney buses operate on routes within the Sydney metropolitan area. Routes vary from hilly to relatively flat.

- Fuel economy including comparison with diesel buses

It should also be noted the fuel cost for the NGV buses includes the operation of air conditioning whereas the diesel buses were non air conditioned. The additional fuel consumption can be as high as 25% on hot days as a result of the air conditioning. The fuel consumption of the Scania NGV buses has been estimated at 52 m^3/100km (4.6 miles/US gal) compared to an Australian average for diesel consumption by major cities urban buses of 43 l/100km (5.6 miles/US gal).

- Emissions

The reduction of particulates was also an important side benefit as air quality is an important issue in the greater Sydney area. Emissions are less than or equal to Euro 4 standard. The previous Scania NGV buses also perform at a level of emissions as good as or better than Euro 3.
State Transit contracted the Energy and Engines Research Group of the University of South Australia to test and optimise the Scania buses in 1993. The on-road trialling of the natural gas buses showed that oxides of nitrogen were significantly reduced when compared with diesel and that compared to the diesel equivalent, emissions of particulates were negligible.

- Maintenance

The delivery of the Scania buses began in 1994. The first two years of large scale operation saw major campaigns to replace spark plugs, coils and leads. Cable throttles have been replaced by electronic units and problems are still being experienced with the cooling system. Perception problems about poor driveable were put to rest with comparison trials with diesel buses. The conclusion was that the lack of noise from the NGV buses gave the drivers the impression of lack of acceleration!

- Refuelling

The Kingsgrove refilling system comprises two large three-stage Sulzer compressors, eight 250 bar (3,600 psig) storage cylinders and the associated dispensers and reclaiming units. The new compressor stations are supplied by Sulzer. Each depot will have three compressors operating at a rate of 3000 cubic metres per hour at 34 MPa (1750 cfm at 5,000 psig). The storage cascade has a total capacity of 3500 cubic metres. The buses will be able to be filled from empty to 20 MPa (2,900 psig) in three and a half minutes, with up to 40 buses being filled within two hours. The process is automatic with connection and disconnection of the coupling the only manual requirement.

- Economics

The financial results of the Scania NGV buses was a fuel saving of 11.08 cents(A) per kilometre (9.47 US cents/mile)while the additional maintenance and service costs were 3.74 cents(A) per kilometre kilometre (2.97 US cents/mile). With the 104 vehicles completing 7,231,670 km a year (4,490,000 miles/y), this was estimated to save Kingsgrove Depot around $A531,000 a year ($US330,000) compared to a diesel fleet. This level of savings gives a pay back period of seven years for the Scania NGV buses. What is still unknown is the life of the NGV engines and the tanks. The natural gas vehicles cost approximately $A36,000 ($US19,000) more than their diesel counterparts. Nevertheless the Scania NGV buses saved around $A4380 ($US2,750) (over 66,000 km/yr - 41,000 miles/y) a year compared to their diesel. Sydney Buses see a reduction costs of 30% inclusive of infrastructure costs.

2.15.5 TransAdelaide, Adelaide, South Australia

- Description of fleet

A further 100 NGV buses have been recently ordered and by mid-2001, 210 of the 750 buses of TransAdelaide will be NGV buses. The range of the buses was 11 hours. As the daily shifts were 15 hours, refuelling had to be organised. Diesels could complete the shift without refuelling.

- Technical description of buses

TransAdelaide trialed NGV buses by converting ten MAN SL200 diesel buses to natural gas in the late 1980s. The trial was supported by the local gas company, Origin Energy , MAN and the University of South Australia. The success of this trial led to an order for 100 MAN SL 202 NGV buses which were delivered from 1992 to 1996. The engine was a stoichiometric engine with Lambda 1 technology. The buses were airconditioned, unlike the trial buses. The latest MAN NL202 buses are low floor with cylinders in the roof.

- Operational information

Adelaide bus routes are generally flat.

- Emissions

The University of Adelaide was contracted to assess on-road emissions from these vehicles and produced a number of research reports on their findings. In particular, the research concluded that optimised natural gas bus engines produce much less carbon dioxide and particulates than the diesel equivalent. This is even achieved when the higher fuel consumption of natural gas over diesel is taken into account.

- Fuel economy

Fuel consumption was 61 m3 / 100km, compared to the diesel equivalents' 46 litres / 100 km (3.96 versus 5.25 miles/US gal). For the last eighteen months the SL 202 has been trailed with an AEC engine management system with a view to improving fuel economy.

- Maintenance

Operationally there were a few hitches but MAN helped with retrofitting and incorporating required changes. Accredited training of mechanics and electricians has been introduced. The buses were less noisy but did have less power due to the airconditioning, causing some driver concerns. Reliability has been an issue in respect to gas supply to the engine.

- Refuelling

TransAdelaide does not have temperature compensated fills so there have been problems with less than full filling operations. Fills are generally done in four minutes. Filling stations are at the Morphettville and Mile End depots. Morphettville has two Rix 2JJ 575 m3/h (340 cfm) compressors and one Sulzer C8U 650 m3/h (380 cfm) compressor. The storage cascade is 8,400 litres (300 ft3) and two quick fill dispensers are used. Mile End has two Sulzer C8U 650 m3/h (380 cfm) compressors, a storage cascade of 5,856 litres (210 ft3) and two quick fill dispensers.

- Economics

In terms of whole life analysis, TransAdelaide estimate that the NGV buses have a 14.2 cents(A) per kilometre (12.1 US cents/mile) advantage over their diesel counterparts. This has been helped as the price of CNG has been dropping in respect to diesel over the last eight years. NGV buses cost about $A40,000 ($US21,000) more than their diesel equivalents.

2.15.6 Brisbane Transit, Brisbane, Queensland

- Description of fleet

Brisbane Transport, a business division of the Brisbane City Council, is the main provider of bus and ferry services in the Brisbane region. It has a bus fleet of around 600 and operates 16 ferry boats. About 500 privately operated buses are dedicated to additional regular urban duties in the Brisbane region.

- Technical description

Brisbane Transit operates 12 NGV buses. Ten were converted and two were MAN SL202s delivered about 1990. They operate from the Carina Depot.

Fifty new Scania L94UB low floor NGV buses with the latest Euro 3 engine and roof mounted cylinders are to be delivered during 2000/2001. The buses are equipped with Scania's 260 hp (195 kW) 9-litre engine and a four-speed ZF automatic transmission. The engine is installed longitudinally and inclined at 60 degrees to keep the floor at the rear of the bus as low as possible. The new low-entry chassis from Scania uses a Volgren body has a body made entirely of aluminium. It has a low floor at the front, disc brakes and large passenger capacity. Further orders of another 70 over the coming three years depend on the performance of the first order of Scanias.

- Operational information

Around 41 million customers travelled on Brisbane Transport's buses in 1999. In the wider metropolitan area of south east Queensland, there are about 20 private bus operators running around 2500 buses on urban routes, school routes and charter activities.

- Emissions

Environmental considerations were a significant factor in the choice of natural gas.

- Maintenance

The existing NGV buses are heavy and lack the performance of their diesel equivalents according to drivers, but are reliable.

- Refuelling

A new refuelling station is to be built with 3.5 minute fuelling time. The local utility, Energex has a slow fill refuelling station (buses take about 20 minutes to fill) at the Carina Depot..

2.15.7 TransPerth, Perth, Western Australia

TransPerth operates some 848 diesel and NGV buses and has had varied experience with NGV buses, starting with the conversion of a Mercedes Benz bus in 1990. The selection of diesel buses over NGV buses has caused considerable controversy in Western Australia with two major inquiries into the selection process in recent years.

By August 2000, the NGV bus fleet had grown to 52, comprising 42 Mercedes-Benz buses fitted with early style CNG carburettor technology and ten Renault buses equipped with the latest computer managed sequential fuel injection systems. Of the 42 Mercedes-Benz buses, 27 are conversions with first generation technology and 15 are OEMs with second generation technology. Problems have been reported with reliability and maintenance of these buses.

The fuel consumption of the buses has been:

- 42 litres / 100 km (5.75 miles/US gal) for diesel low floor
- 55 litres / 100 km (4.4 miles/US gal) for new NGV buses
- 58 litres / 100 km (4.1 miles/US gal) for old NGV buses

Currently TransPerth has 5 NGV buses on order from Mercedes Benz. Recently Advanced Engine Components Pty Ltd has been awarded a $A2.5 million ($US1.3 million) contract to convert 25 more buses to NGV operation. The NGV buses operate out of Malaga and the fueling station is a slow fill unit.

2.16 Japan

At this time NGV buses are still in the development phase in Japan. The major driver is the reduction in emissions offered by NGV buses when compared to the alternatives. Local air pollution is severe in many of the large Japanese cities and there is a concerted effort to develop NGV bus transport technologies because of their potential over the alternatives to ameliorate this problem.

NGV Transit Bus Fleet operations in Japan are carried out by both private and government fleet operators and the number of NGV buses currently in operation is:

Government Sector	Private Sector
These fleets are primarily public transit buses:	These fleets are used for sightseeing buses on regular
	service routes:
Tokyo Metropolitan Government: 104	
Osaka Municipal Government: 68	Fuji Kyuko: 15
Yokohama Municipal Government: 33	Yamanashi Kotsu: 10
Kyoto Municipal Government: 16	Nihon Kotsu: 6
Nagoya Municipal Government: 7	

- *Specification of buses*

Nissan Diesel, Isuzu and Mitsubishi produce NGV transit buses with seating capacities varying from 64 for Nissan to 87 for Mitsubishi (which also makes a low floor version), depending and model and layout.

- *Range*

Operators use their buses in the range of 100 to 150 km (60 to 90 miles). Typically vehicle range is 200 to 250 kilometres (125 to 155 miles).

- *Filling station*

Generally owned owned by fleet operators. Typical time for refilling is several minutes (comparable to diesel vehicles).

- *Price of buses*

million yen (16 million for the vehicle, 8 million yen for modification for CNG), 50% higher than conventional buses, ie $US223,000 ($US149,000 for the vehicle, $US74,000 for CNG).

- *Fuel price*

Per unit fuel cost is comparable to conventional vehicles.

- *Maintenance costs*

Annual mandatory inspection for all buses (both conventional and NGV). Additional inspection costs (several thousand yen) to be incurred for both fuel containers (every other year) and fuel supply line.

- *Exhaust Emissions*

NGV buses are lower in NOx and carbon dioxide than electrics (taking into account power generation), hybrids, diesels and petrol equivalents according to tests.

2.17 Thailand

Bangkok Mass Transit Organisation

- Description of fleet

At present the Bangkok Mass Transit Organisation operates some 42 NGV MAN Model 16.230 HOCL/R 46 seat buses and 40 Mercedes Benz Model O 405, with plans to expand to 300 NGV buses.

- Technical description of buses

The NGV buses of the BMTA are of two types, the Mercedes Benz Model 0405 158 kW (210 HP) lean burn type and the MAN Model E2866 UH Lambda 1 technology type 170 kW (230 HP)

- Operational information

Each bus travels about 220 kilometres (140 miles) a day on two routes (Rungsit - Victory Monument - Silom (35 km, 22 miles) and Rungsit - Victory Monument - Sanum Luang (36 km, 22 miles)) so range is not a critical issue.

- Fuel economy including comparison with diesel buses

Engine Type	**Fuel**	**Consumption**		**Cost**	
	km/litre	miles/US gal	litre/km	Baht/km	$US/mile
NGV - MAN	1.32	3.19	0.76	4.27	0.16
NGV - M/Benz	1.96	4.74	0.51	2.88	0.11
Diesel - M/Benz	1.47	3.55	0.68	4.75	0.18

The fuel consumption of NGV buses is less than diesels when operating on urban routes.

- Emissions

Black smoke emissions are less for NGV buses than diesels.

- Maintenance

The Mercedes Benz maintenance costs are 1600 Baht ($US36.80) per day and the MAN 1400 Baht ($US32.18). The reliability of the MAN electronics is of concern.

- Refuelling

The filling station at the Rangsit depot has operated reliably. It uses IMW compressors from Canada, together with 9,000 litres (320 ft3) of high pressure storage with six quick fill pumps. The fill pressure is 20 MPa (2,900 psig). The refuelling rate is 1400 m3/h (825 cfm) which will fill eight buses. The only problem has been lubrication oil leaks due to the mismatch of the seal carrier and piston ring.

- Economics

The Mercedes Benz NGV bus cost 5.15 million Baht ($US118,000) and the MAN costs 4.625 million Baht ($US106,000).

- Issues, opportunities, problems and challenges

Driver and passenger acceptance of the buses is good. Gas quality problems have been a concern - the gas specification is - 65% methane and 17% carbon dioxide as well as moisture 3lbs/MMSCF. Refuelling cannot be done if there is a power failure. While the fill pressure is 20 MPa (2,900 psig) buses cannot operate with pressures below 5 MPa (725 psig).
The noise level of NGV buses is less than diesels.

2.18 South Korea

South Korea has undertaken a large and ambitious project with respect to city transit buses using CNG in conjunction with Daewoo and Hyundai Motor Co. The ambition of the Korean Government to increase the number of CNG buses and itss first target is 5,000 city transit buses in eight cities for the 2002 World Soccer Cup. Their second target is 20,000 city buses by 2007. Environmental and economic factors are contributing to this new market for buses fueled by natural gas.

The gas is stored inside the buses under the floor with storage at a maximum working pressure of 28 MPa (4000 psig). The engine is a lean burn, turbocharger-intercooled engine controlled by a full authority electronic control system. This system controls fuel metering, spark timing, boost pressure, throttle valve and governing. The control system features closed-loop adaptive learn fuel control with feed back provided by a universal exhaust gas oxygen sensor. Reliability was proven by both intensive bench tests and field operations. This R&D led to a final engine calibration which provides good efficiency and transient response while meeting Korea's proposed ULEV and USA LEV emissions levels.

2.19 Egypt

The Natural Gas Vehicles Co. (NGVC) recently opened the first two CNG public transit fueling stations at the Kattamaya Road Greater Cairo Bus Co. (GCBC) garage to fuel the 50 dedicated Thomas built buses provided from the $US60 million USAID Cairo Air Improvement Project (CAIP). Twenty five of these will move to the Nasr City Cairo Transportation Authority bus garage when its construction is completed. These were shipped as rolling chassis with final body and interior assembly completed by Egypt's NASCO company. Presently 14 of these buses are complete with the remaining 36 to be in service shortly.

About five years ago IVECO supplied seven dedicated CNG buses which were the first CNG buses in Egypt. Today Egypt's total new dedicated CNG public transit bus count is 57 buses.

Sherif Hashem of the Cairo Transportation Authority (CTA) reports that the CTA is now testing and modifying for diesel/natural gas dual fuel a limited number of diesel buses belonging to the Petroleum Sector in three of the Egyptian governorates (Cairo, Alexandria and Suez). The CTA is still in the modification and testing phase and once final conclusions about the performance, consumption and economy of the CTA buses are determined, the results will be published for the IANGV.

The CTA Bus Station Fleet and Buses:

1- The CTA fleet will be operated through four phases to reach 200 buses by the end of 2002, starting with 32 buses in October 2000 and adding around 55 buses each 6 months.
2- The buses are 50 passenger capacity, with air conditioning, dedicated to servicing greater Cairo.
3- The engine is Cummins of around 250 HP (186 kW).
4- Bus working time is around 17 hours per day.
5- The terrain in general does not comprise high grades since Egypt in general and especially Cairo is on a plain, but Cairo has, on the other hand, very heavy traffic
6- Comprehensive efforts are taking place to train drivers and maintenance crews.

- Refuelling

1. One fill per day starting after midnight.
2. The expected refuelling quantity of gas per bus is about 200m3/day (7000 cfm) up to 200 bars (20MPa, 2,900 psig).
3. Ten percent of the fleet will be stand-by.
4. The refuelling time of each bus is six minutes.
5. The station in its final stage will comprise six fueling dispensers of the fast fill type.
6. The bus will be equipped with two fueling nozzles one of 3/8 inch (10 mm) and the other is 5/8 ins (16 mm).
7. The consumption of gas in average is around 0.7 m3/km (3.5 miles/US gal)
8. The gas consumption is almost the same as diesel based on the calorific value. The cost of diesel is 0.4 Egyptian pounds per litre ($US0.41/US gal) but this price is subsidised. Meanwhile the cost of one cubic metre of natural gas is 0.45 Egyptian pounds, about 10% more expensive ($US 0.46/US gal eq).

- Environment & Emissions

1. The environment is in general hot in summer and cool in winter, temperature ranges 5 ° - 40° C (40°F - 104°F).
2. Emission tests are now taking place.

2.20 Argentina

There are no regular NGV bus fleet operating in Argentina. Only a few demonstration vehicles have been introduced in the last year and further demonstration buses are scheduled, based on local assembled bus chassis with a Cummins CNG engine. General situation and firm interest in NGV buses indicates that there is a good chance for NGV buses in the near future.

2.21 India

The Delhi Transport Corporation aims to convert all its 7,500 buses to run on compressed natural gas rather than diesel. The ambitious plan to have this completed by March 2001 was announced by the Delhi State Government recently. The state is also planning to allow 2,500 new NGV buses to be brought on to the roads by privately owned operators.

This action is a considered response to a Supreme Court ruling on a public interest petition which has directed the Delhi Government to ensure public transport vehicles do not spread air pollution.

There has been concern expressed in some quarters that the target date is far too ambitious and the initial conversions of the DTC buses is below standard.

2.22 China

For the two major cities of Beijing and Shanghai, it is estimated that the total population of transit buses is around 100,000 units. However only Beijing, Shanghai and Xian are currently using or working on NGV. Given the infrastructure investment and availability of good quality gas, the demand will be one of steady growth in the coming years, especially in these three cities.

Beijing Public Transit purchased 300 NGV engines (Cummins B5.9G 195) from Cummins in 1999 and all are in service. They ordered 1000 units for the year 2000 and the new buses powered by these CNG engines are already in route service in the streets of Beijing. Recently Beijing ordered additional 300 units of B5.9G 195. It is estimated there are 1300 NGV powered transit buses are running in Beijing and another 300 buses expected to be added. In total there will be 1600 units.

2.23 Other Countries

It has been reported there are NGV buses operating in Russia and a number of other countries but unfortunately no details are available.

In Chile a pilot program with two dedicated CNG buses (one Volvo, one Scania) has started with the support of the largest municipalities of Santiago. The NGV buses cost $US153,000, (87.5 million Pesos) each compared to a diesel bus at $US115,000, (65 million Pesos). All buses in the trial met EPA 94 standards for emissions. Fuel consumption was 57.2 l/100km (4.2 miles/US gal) for diesel versus 69.8 m3/100km (3.5 miles/US gal) for natural gas. Typical costs are 170 Pesos per litre ($US1.16/US gal) for diesel and 140 Pesos/m3 ($US0.95/US gal) for natural gas. The total annual running cost (including depreciation of bus cost) for the diesel versus the NGV buses was 20 million Pesos ($US35,000) versus 22.7 million Pesos ($US39,600) respectively. It has been proposed to the Chilean Government to implement an NGV bus program in a larger scale, but there is reported resistance among the bus operators to any expansion of the program due to concerns regarding NGV bus operation and cost.

Sao Paulo, Brazil is believed to be operating a bus fleet of about 200 Mercedes Benz buses on compressed natural gas.

3.0 CONCLUSIONS

The major conclusions of this review are:

- Diesel buses are a mature and reliable technology but suffer from severe environmental emission problems
- NGV buses are the only commercial alternative to diesel buses
- NGV bus emission performance is far superior to all current diesel technologies
- In many regions of the world NGV buses offer significant fuel savings over diesel equivalents
- NGV buses have range and payload reductions compared to diesel equivalents that may cause some bus fleet operators difficulties
- NGV bus engines are still developing, the latest fuel injection technologies offering great promise in terms of emissions, fuel economy, maintenance and reliability
- Initial capital costs of NGV bus fleet set-up and operations are at least 20% higher than an equivalent diesel fleet (bus, maintenance facilities and refuelling infrastructure)
- The 1990s OEM NGV buses were developmental and suffered reliability, maintenance and fuel economy problems and costs but were, and are, continuously improving

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Appendices

APPENDIX 1: USA Transit Bus Fleets Operating NGV Buses, January, 2000

Transit District	City	State
Birmingham - Jefferson Country Transit Authority	Birmingham	Alabama
Glendale Transit	Glendale	Arizona
City of Phoenix Public Transit Department	Phoenix	Arizona
Regional Public Transportation Authority	Phoenix	Arizona
City of Tucson Mass Transit System	Tucson	Arizona
Golden Empire Transit District	Bakerfield	California
Unitrans	Davis	California
Long Beach Transit	Long Beach	California
Los Angeles County Metropolitan Transportation Authority	Los Angeles	California
City of Los Angeles Department of Transportation	Los Angeles	California
South Coast Area Transit	Oxnard	California
Monterey-Salinas Transit	Monterey	California
Sacramento Regional Transit District	Sacramento	California
Omnitrans	San Bernadino	California
San Diego Transit Corporation	San Diego	California
San Diego Metropolitan Development Board	San Diego	California
San Luis Transit	San Luis	California
Riverside Transit Agency	Riverside	California
Sunline Transit Agency	Thousand Palms	California
Yolobus	Yolo County	California
Regional Transportation District	Denver	Colorado
Springs Transit	Colorado Springs	Colorado
Norwalk Transit District	Norwalk	Connecticut
Washington Metropolitan Area Transit Authority	Washington	Washington, DC
Delaware Transit Corporation	Dover	Delaware
Central Florida Regional Transportation Authority	Orlando	Florida
Hillsborough Area Regional Transit Authority	Tampa	Florida
Metro-Dade Transit Agency	Miami	Florida
Metropolitan Atlanta Rapid Transit Authority	Atlanta	Georgia
Boise Urban Stages	Boise City	Idaho
Rock Island County Metropolitan Mass Transit District	Rock Island	Illinois
Springfield Mass Transit District	Springfield	Illinois
Gary Public Transportation Corporation	Gary	Indiana
Brockton Area Transit Authority	Brockton	Massachusetts
Pioneer Valley Transit Authority	Springfield	Massachusetts
Worcester Regional Transit Authority	Worcester	Massachusetts
Mass Transit Administration of Maryland	Baltimore	Maryland
Prince George's County Department of Public Works & Transportation	Landover	Maryland
Montgomery County Transit Services	Rockville	Maryland
Blue Water Area Transportation Commission	Port Huron	Minnesota
Saint Cloud Metropolitan Transit Commission	Saint Cloud	Maine

Transit District	**City**	**State**
Bi-State Development Agency	Saint Louis	Missouri
New Jersey Transit Corporation	Newark	New Jersey
Regional Transportation Commission of Clark County	Las Vegas	Nevada
Regional Transportation Commission	Reno	Nevada
Niagara Frontier Transportation Authority	Buffalo	New York
MTA Long Island Bus	Garden City	New York
New York City Department of Transportation	New York	New York
MTA New York City Transit	New York	New York
Rochester-Genessee Regional Transportation Authority	Rochester	New York
New York Centreo	Syracuse	New York
Metro Regional Transit Authority	Akron	Ohio
Greater Cleveland Regional Transit Authority	Cleveland	Ohio
Laketran	Grand River	Ohio
Western Reserve Transit Authority	Youngstown	Ohio
Central Okalahoma Transportation and Parking Authority	Okalahoma City	Okalahoma
Metropolitan Tulsa Transit Authority	Tulsa	Okalahoma
Tri-County Metropolitan Transportation District of Oregon	Portland	Oregon
Salem Area Mass Transit District	Salem	Oregon
Southeastern Pennsylvania Transportation Authority	Philadelphia	Pennsylvania
Port Authority of Allegbeny County	Pittsburgh	Pennsylvania
Berks Area Reading Transportation Authority	Reading	Pennsylvania
Centre Area Transportation Authority	State College	Pennsylvania
Rhode Island Public Transit Authority	Providence	Rhode Island
York County Transportation Authority	York	Pennsylvania
Capital Metropolitan Transportation Authority	Austin	Texas
Brazos Transit Systems	Bryan	Texas
Dallas Area Rapid Transit	Dallas	Texas
El Paso Mass Transit Department	El Paso	Texas
Fort Worth Transportation Authority	Fort Worth	Texas
Metropolitan Transit Authority of Harris County	Houston	Texas
Utah Transit Authority	Salt Lake City	Utah
Tidewater Transportation District Commission	Norfolk	Virginia
Pierce County Public Transportation Benefit Area Authority	Tacoma	Washington
Kenosha Transit	Kenosha	Wisconsin

Source of Information: American Public Transit Association (APTA), US NGVC, DOE Clean Cities and Calstart

APPENDIX 2: USA Bus Fleet Composition, Current Orders and Potential Orders, January, 2000

The data presented below is from the American Public Transit Association (APTA) and the American Natural Gas Vehicle Council (ANGVC). While the APTA's data does not represent all transit agencies it is the most authoritative source that has been found at this time. APTA believes that its transit data represents about 70 percent of all buses and about 20 percent of all demand response vehicles (DRVs) for the USA.

The American Natural Gas Vehicle Council (ANGVC) adds information on transit authorities or other entities that operate natural gas buses and that are not listed in this table as it is reported to them.

The existing figures above only include vehicles in the fleet as of Jan. 1, 2000. Orders include buses for which there is a contract but delivery has not yet occurred. The table only includes data on transit authorities that currently own or plan to acquire natural gas vehicles.

Compressed natural gas (CNG) and liquefied natural gas (LNG) columns of the table include some buses that are hybrid electric/natural and also some bi-fuel vehicles (e.g., petrol or diesel with natural gas).

Demand Response Vehicles (DRVs) are transit vehicles that do not operate on fix routes; these vehicles often are vans or small buses.

Table 1 Bus Numbers for Existing Transit Bus Fleets Operating Natural Gas Buses

City	Transit Authority	All Buses	CNG Buses	LNG Buses	All DRVs	CNG DRVs	LNG DRVs
Akron, OH	Metro Regional Transit Authority	152	58	0	68	1	0
Arlington, VA	Arlington County Dept. Public Works	4	2	0	0	0	0
Atlanta, GA	Metro Atlanta RTA	698	118	0	77	0	0
Austin, TX	Capital Metropolitan TA	433	31	0	107	4	0
Bakersfield, CA	Golden Empire Transit District	106	41	0	18	17	0
Birmingham, AL	Birmingham-Jefferson County TA	75	0	0	18	0	0
Boise City, ID	Boise Urban Stages	60	45	0	6	5	0
Boston, MA	Massachusetts Bay Transport Authority	983	2	0	265	0	0
Buffalo, NY	Niagara Frontier TA	330	5	0	26	0	0
Burnsville, MN	Minnesota Valley TA	39	5	0	1	0	0
Chicago, IL	Chicago Transit Authority	1878	0	0	0	0	0
Clearwater, FL	Pinellas Suncoast Transit Authority	164	8	0	0	0	0
Cleveland, OH	Greater Cleveland Regional TA	751	166	0	92	0	0
Culver City, CA	Culver City Municipal Bus Lines	43	20	0	0	0	0

City	Transit Authority	All Buses	CNG Buses	LNG Buses	All DRVs	CNG DRVs	LNG DRVs
Dallas, TX	Dallas Area Rapid Transit	810	22	139	92	88	0
Davis, CA	University Transport System	43	16	0	0	0	0
Denver, CO	Regional Transportation District	994	10	0	222	0	0
Detroit, MI	City of Detroit DOT	540	14	0	0	0	0
Dover, DE	Delaware Transit Corp	195	2	0	141	0	0
El Paso, TX	El Paso Mass Transit Dept	159	45	35	54	0	54
Evansville, IA	Metropolitan Evansville TS	26	0	0	13	4	0
Fort Worth, TX	Fort Worth TA	141	88	0	33	18	0
Garden City, NY	MTA Long Island Bus	323	173	0	71	0	0
Gary, IN	Gary Public Transportation Corporation	51	0	8	0	0	0
Glendale, CA	City of Glendale Beeline	24	13	0	0	0	0
Grand River, OH	LAKETRAN	37	12	0	56	1	0
Hampton, VA	Trasportation District Comm Hampton Rd	356	1	0	121	0	0
Houston, TX	Metro TR Authority of Harris Co	1289	5	5	116	0	0
Indiana, PA	Indiana County Transit Authority	19	5	0	15	0	0
Kenosha, WI	Kenosha Transit	52	13	0	0	0	0
Landover, MD	Prince George's Co DPW&T	78	5	0	29	0	0
Laredo, TX	Laredo Municipal Transit System	46	23	0	23	20	0
Las Vegas, NV	Regional Transportation Commission	321	0	0	127	124	0
Long Beach, CA	Long Beach Transit	218	5	0	0	0	0
Los Angeles, CA	Los Angeles Co MTA	2638	795	0	0	0	0
Miami, FL	Miami-Dade Transit Agency	741	0	0	0	0	0
Monterey, CA	Monterey-Salinas Transit	72	17	0	26	0	0
Nashville, TN	Metropolitan Transit Authority	145	0	0	36	1	0
New York, NY	MTA New York City Transit	4371	4	0	598	0	0
New York, NY	New York City DOT	1304	354	0	0	0	0
Newark, NJ	New Jersey TC	3094	55	0	0	0	0
North Muskegon, MI	Muskegon Area Transit System	18	3	0	5	0	0
Norwalk, CT	Norwalk Transit District	43	16	0	17	0	0
Oceanside, CA	North County Transit District	163	6	0	0	0	0
Oklahoma City, OK	Central Oklahoma T&P Authority	112	5	0	30	2	0

City	Transit Authority	All Buses	CNG Buses	LNG Buses	All DRVs	CNG DRVs	LNG DRVs
Orange, CA	Orange County Transportation Authority	519	0	0	283	0	0
Orlando, FL	Central Florida Reg Trp Authority	223	16	0	0	0	0
Oxnard, CA	South Coast Area Transit	43	35	0	0	0	0
Pittsburgh, PA	Port Authority of Allegheny County	1027	5	0	0	0	0
Phoenix, AZ	City of Phoenix PTD	436	0	192	89	0	15
Providence, RI	Rhode Island Public Tr Authority	244	17	0	52	0	0
Reading, PA	Berks Area Reading TA	60	12	0	31	2	0
Reno, NV	Regional Transportation Commission	69	0	0	38	35	0
Riverside, CA	Riverside Transit Agency	108	28	0	57	0	0
Rock Island, IL	Rock Island County Metro MTD	57	0	0	10	0	0
Rockville, MD	Montgomery Co Transportation Services	237	19	0	0	0	0
Sacramento, CA	Sacramento Regional Transit District	213	136	0	10	0	0
Saint Louis, MO	Bi-State Development Agency	619	38	0	63	0	0
Salem, OR	Salem Area Mass Transit District	64	10	0	0	0	0
Salt Lake City, UT	Utah Transit Authority	557	5	0	135	0	0
San Bernardino, CA	OmniTrans	153	31	0	109	48	0
San Diego, CA	San Diego Metro Transportation Dev Bd	83	70	0	73	0	0
San Diego, CA	San Diego Transit Corporation	294	60	0	0	0	0
San Luis Obispo, CA	San Luis Transit	16	2	0	0	0	0
Scottsdale, AZ	Scottsdale Connection	8	1	0	0	0	0
Seattle, WA	Central Puget Sound RTA	95	0	0	0	0	0
Springfield, IL	Springfield Mass Transit District	48	7	0	15	0	0
Springfield, MA	Pioneer Valley Transit Authority	187	0	0	107	0	0
State College, PA	Centre Area Transportation Authority	52	34	0	4	0	0
Syracuse, NY	CNY Centro	203	56	0	28	0	0
Tacoma, WA	Pierce County PTBA Authority Corp	200	90	0	91	1	0

City	Transit Authority	All Buses	CNG Buses	LNG Buses	All DRVs	CNG DRVs	LNG DRVs
Tampa, FL	Hillsborough Area Regional TA	204	7	0	20	0	0
Tempe, AZ	City of Tempe Transportation Division	95	0	95	0	0	0
Thousand Palms, CA	Sunline Transit Agency	64	56	0	18	14	0
Tulsa, OK	Metro Tulsa Transit Authority	84	0	7	32	2	0
Tucson, AZ	City of Tuscon Mass Transit System	203	97	0	64	0	0
West Covina, CA	Foothill Transit	266	0	0	0	0	0
Worcester, MA	Worcester Regional Transit Authority	54	0	0	37	4	0
York, PA	York County TA	23	2	0	28	0	0
Youngstown, OH	Western Reserve Transit Authority	55	12	0	6	5	0
Totals		**31002**	**3054**	**481**	**3903**	**396**	**69**

Table 2: New Natural Gas Bus Orders for USA Transit Bus Fleets

		New Orders					
City	**Transit Authority**	**All Buses**	**CNG Buses**	**LNG Buses**	**All DRVs**	**CNG DRVs**	**LNG DRVs**
Akron, OH	Metro Regional Transit Authority	3	0	0	0	0	0
Arlington, VA	Arlington County Dept. Public Works	0	0	0	0	0	0
Atlanta, GA	Metro Atlanta RTA	206	206	0	0	0	0
Austin, TX	Capital Metropolitan TA	132	0	0	0	0	0
Bakersfield, CA	Golden Empire Transit District	0	0	0	0	0	0
Birmingham, AL	Birmingham-Jefferson Co TA	10	10	0	0	0	0
Boise City, ID	Boise Urban Stages	0	0	0	0	0	0
Boston, MA	Massachusetts Bay Trp Authority	0	0	0	0	0	0
Buffalo, NY	Niagara Frontier TA	21	0	0	0	0	0
Burnsville, MN	Minnesota Valley TA	6	6	0	0	0	0
Chicago, IL	Chicago Transit Authority	150	0	0	0	0	0
Clearwater, FL	Pinellas Suncoast Transit Authority	0	0	0	0	0	0
Cleveland, OH	Greater Cleveland Reg TA	29	0	0	4	0	0
Culver City, CA	Culver City Municipal Bus Lines	0	0	0	0	0	0
Dallas, TX	Dallas Area Rapid Transit	245	0	0	0	0	0
Davis, CA	University Transport System	0	0	0	0	0	0
Denver, CO	Regional Transportation District	506	34	0	0	0	0
Detroit, MI	City of Detroit DOT	100	0	0	0	0	0
Dover, DE	Delaware Transit Corp	27	0	0	31	0	0
El Paso, TX	El Paso Mass Transit Dept	0	0	0	0	0	0
Evansville, IA	Metropolitan Evansville TS	0	0	0	0	0	0
Fort Worth, TX	Fort Worth TA	26	26	0	10	10	0
Garden City, NY	MTA Long Island Bus	67	67	0	10	0	0
Gary, IN	Gary Public Transportation Corporation	0	0	0	0	0	0
Glendale, CA	City of Glendale Beeline	8	8	0	0	0	0
Grand River, OH	LAKETRAN	0	0	0	15	0	0
Hampton, VA	Trasportation District Comm Hampton Rd	37	0	0	30	0	0
Houston, TX	Metro TR Authority of Harris Co	486	0	0	136	0	0
Indiana, PA	Indiana County Transit Authority	0	0	0	0	0	0
Kenosha, WI	Kenosha Transit	0	0	0	0	0	0
Landover, MD	Prince George's Co DPW&T	0	0	0	0	0	0
Laredo, TX	Laredo Municipal Transit System	0	0	0	0	0	0
Las Vegas, NV	Regional Transportation Commission	0	0	0	19	19	0
Long Beach, CA	Long Beach Transit	0	0	0	0	0	0
Los Angeles, CA	Los Angeles Co MTA	342	342	0	0	0	0

		New Orders					
City	**Transit Authority**	**All Buses**	**CNG Buses**	**LNG Buses**	**All DRVs**	**CNG DRVs**	**LNG DRVs**
Miami, FL	Miami-Dade Transit Agency	20	0	0	0	0	0
Monterey, CA	Monterey-Salinas Transit	21	0	0	0	0	0
Nashville, TN	Metropolitan Transit Authority	20	0	0	0	0	0
New York, NY	MTA New York City Transit	1002	315	0	0	0	0
New York, NY	New York City DOT	0	0	0	0	0	0
Newark, NJ	New Jersey TC	272	27	0	0	0	0
North Muskegon, MI	Muskegon Area Transit System	0	0	0	0	0	0
Norwalk, CT	Norwalk Transit District	0	0	0	0	0	0
Oceanside, CA	North County Transit District	53	0	0	0	0	0
Oklahoma City, OK	Central Oklahoma T&P Authority	0	0	0	0	0	0
Orange, CA	Orange County Transportation Authority	61	0	61	0	0	0
Orlando, FL	Central Florida Reg Trp Authority	0	0	0	0	0	0
Oxnard, CA	South Coast Area Transit	0	0	0	0	0	0
Pittsburgh, PA	Port Authority of Allegheny County	40	0	0	0	0	0
Phoenix, AZ	City of Phoenix PTD	50	0	50	14	0	0
Providence, RI	Rhode Island Public Tr Authority	5	5	0	0	0	0
Reading, PA	Berks Area Reading TA	0	0	0	0	0	0
Reno, NV	Regional Transportation Commission	10	0	0	0	0	0
Riverside, CA	Riverside Transit Agency	0	0	0	0	0	0
Rock Island, IL	Rock Island County Metro MTD	0	0	0	0	0	0
Rockville, MD	Montgomery Co Transportation Services	18	0	0	0	0	0
Sacramento, CA	Sacramento Regional Transit District	0	0	0	0	0	0
Saint Louis, MO	Bi-State Development Agency	437	0	0	27	0	0
Salem, OR	Salem Area Mass Transit District	0	0	0	0	0	0
Salt Lake City, UT	Utah Transit Authority	113	0	0	0	0	0

		New Orders					
City	**Transit Authority**	**All Buses**	**CNG Buses**	**LNG Buses**	**All DRVs**	**CNG DRVs**	**LNG DRVs**
San Bernardino, CA	OmniTrans	64	64	0	54	0	0
San Diego, CA	San Diego Metro Transportation Dev Bd	30	30	0	79	0	0
San Diego, CA	San Diego Transit Corportation	31	31	0	0	0	0
San Luis Obispo, CA	San Luis Transit	0	0	0	0	0	0
Scottsdale, AZ	Scottsdale Connection	9	0	9	0	0	0
Seattle, WA	Central Puget Sound RTA	0	0	0	0	0	0
Springfield, IL	Springfield Mass Transit District	11	11	0	0	0	0
Springfield, MA	Pioneer Valley Transit Authority	0	0	0	0	0	0
State College, PA	Centre Area Transportation Authority	10	10	0	0	0	0
Syracuse, NY	CNY Centro	52	52	0	0	0	0
Tacoma, WA	Pierce County PTBA Authority Corp	0	0	0	0	0	0
Tampa, FL	Hillsborough Area Regional TA	0	0	0	0	0	0
Tempe, AZ	City of Tempe Transportation Division	18	0	18	0	0	0
Thousand Palms, CA	Sunline Transit Agency	0	0	0	0	0	0
Tulsa, OK	Metro Tulsa Transit Authority	0	0	0	0	0	0
Tucson, AZ	City of Tuscon Mass Transit System	0	0	0	0	0	0
West Covina, CA	Foothill Transit	88	4	0	0	0	0
Worcester, MA	Worcester Regional Transit Authority	0	0	0	0	0	0
York, PA	York County TA	21	0	0	10	0	0
Youngstown, OH	Western Reserve Transit Authority	28	0	0	0	0	0
Totals		**4885**	**1248**	**138**	**439**	**29**	**0**

Table 3 Potential Orders for Natural Gas Buses to USA Transit Fleets

		Potential Orders					
City	**Transit Authority**	**All Buses**	**CNG Buses**	**LNG Buses**	**All DRVs**	**CNG DRVs**	**LNG DRVs**
Akron, OH	Metro Regional Transit Authority	5	0	0	4	0	0
Arlington, VA	Arlington County Dept. Public Works	0	0	0	0	0	0
Atlanta, GA	Metro Atlanta RTA	140	140	0	107	0	0
Austin, TX	Capital Metropolitan TA	0	0	0	0	0	0
Bakersfield, CA	Golden Empire Transit Dist	0	0	0	0	0	0
Birmingham, AL	Birmingham-Jefferson Co TA	0	0	0	0	0	0
Boise City, ID	Boise Urban Stages	10	10	0	0	0	0
Boston, MA	Massachusetts Bay Trp Authority	44	44	0	0	0	0
Buffalo, NY	Niagara Frontier TA	0	0	0	23	0	0
Burnsville, MN	Minnesota Valley TA	43	32	0	0	0	0
Chicago, IL	Chicago Transit Authority	816	0	0	0	0	0
Clearwater, FL	Pinellas Suncoast Transit Authority	15	0	0	0	0	0
Cleveland, OH	Greater Cleveland Reg TA	507	468	0	97	0	0
Culver City, CA	Culver City Municipal Bus Lines	0	0	0	0	0	0
Dallas, TX	Dallas Area Rapid Transit	251	0	70	0	0	0
Davis, CA	University Transport System	4	4	0	0	0	0
Denver, CO	Regional Transportation District	428	0	0	116	0	0
Detroit, MI	City of Detroit DOT	256	0	0	0	0	0
Dover, DE	Delaware Transit Corp	88	0	0	179	0	0
El Paso, TX	El Paso Mass Transit Dept	79	0	0	64	0	0
Evansville, IA	Metropolitan Evansville TS	0	0	0	0	0	0
Fort Worth, TX	Fort Worth TA	38	38	0	25	25	0
Garden City, NY	MTA Long Island Bus	98	98	0	13	0	0
Gary, IN	Gary Public Transportation Corporation	1	0	0	0	0	0
Glendale, CA	City of Glendale Beeline	6	6	0	0	0	0
Grand River, OH	LAKETRAN	0	0	0	44	0	0
Hampton, VA	Trasportation District Comm Hampton Rd	128	0	0	25	0	0
Houston, TX	Metro TR Authority of Harris Co	204	0	0	0	0	0
Indiana, PA	Indiana County Transit Authority	0	0	0	0	0	0
Kenosha, WI	Kenosha Transit	5	0	0	0	0	0
Landover, MD	Prince George's Co DPW&T	16	0	0	12	0	0
Laredo, TX	Laredo Municipal Transit System	16	16	0	13	13	0
Las Vegas, NV	Regional Transportation Commission	0	0	0	0	0	0
Long Beach, CA	Long Beach Transit	134	0	0	0	0	0
Los Angeles, CA	Los Angeles Co MTA	1223	1223	0	0	0	0
Miami, FL	Miami-Dade Transit Agency	243	0	0	0	0	0
Monterey, CA	Monterey-Salinas Transit	9	0	0	4	0	0
Nashville, TN	Metropolitan Transit Authority	6	0	0	0	0	0
New York, NY	MTA New York City Transit	1056	300	0	438	0	0
New York, NY	New York City DOT	500	500	0	0	0	0

City	Transit Authority	Potential Orders					
		All Buses	**CNG Buses**	**LNG Buses**	**All DRVs**	**CNG DRVs**	**LNG DRVs**
Newark, NJ	New Jersey TC	1302	0	0	0	0	0
North Muskegon, MI	Muskegon Area Transit System	1	1	0	4	3	0
Norwalk, CT	Norwalk Transit District	38	19	0	15	0	0
Oceanside, CA	North County Transit District	0	0	0	0	0	0
Oklahoma City, OK	Central Oklahoma T&P Authority	63	4	0	12	0	0
Orange, CA	Orange County Transportation Authority	191	0	171	0	0	0
Orlando, FL	Central Florida Reg Trp Authority	140	0	0	0	0	0
Oxnard, CA	South Coast Area Transit	2	2	0	19	0	0
Pittsburgh, PA	Port Authority of Allegheny County	460	10	0	0	0	0
Phoenix, AZ	City of Phoenix PTD	95	0	95	56	0	0
Providence, RI	Rhode Island Public Tr Authority	92	0	0	38	0	0
Reading, PA	Berks Area Reading TA	43	0	0	9	0	0
Reno, NV	Regional Transportation Commission	0	0	0	3	3	0
Riverside, CA	Riverside Transit Agency	0	0	0	0	0	0
Rock Island, IL	Rock Island County Metro MTD	44	12	0	18	0	0
Rockville, MD	Montgomery Co Transportation Services	0	0	0	0	0	0
Sacramento, CA	Sacramento Regional Transit District	75	75	0	74	0	0
Saint Louis, MO	Bi-State Development Agency	0	0	0	21	0	0
Salem, OR	Salem Area Mass Transit District	25	25	0	0	0	0
Salt Lake City, UT	Utah Transit Authority	16	0	0	0	0	0
San Bernardino, CA	OmniTrans	87	87	0	115	0	0
San Diego, CA	San Diego Metro Transportation Dev Bd	0	0	0	0	0	0
San Diego, CA	San Diego Transit Corportation	75	75	0	0	0	0
San Luis Obispo, CA	San Luis Transit	0	0	0	0	0	0
Scottsdale, AZ	Scottsdale Connection	0	0	0	0	0	0
Seattle, WA	Central Puget Sound RTA	70	20	0	0	0	0
Springfield, IL	Springfield Mass Transit District	0	0	0	4	0	0
Springfield, MA	Pioneer Valley Transit Authority	0	0	0	0	0	0
State College, PA	Centre Area Transportation Authority	16	12	0	3	0	0
Syracuse, NY	CNY Centro	46	39	0	0	0	0
Tacoma, WA	Pierce County PTBA Authority Corp	121	121	0	0	0	0
Tampa, FL	Hillsborough Area Regional TA	17	0	0	71	0	0
Tempe, AZ	City of Tempe Transportation Division	0	0	0	0	0	0
Thousand Palms, CA	Sunline Transit Agency	15	15	0	16	16	0
Tulsa, OK	Metro Tulsa Transit Authority	13	0	0	0	0	0
Tucson, AZ	City of Tuscon Mass Transit System	101	101	0	26	0	0

		Potential Orders					
City	**Transit Authority**	**All Buses**	**CNG Buses**	**LNG Buses**	**All DRVs**	**CNG DRVs**	**LNG DRVs**
West Covina, CA	Foothill Transit	0	0	0	0	0	0
Worcester, MA	Worcester Regional Transit Authority	5	0	0	29	0	0
York, PA	York County TA	0	0	0	0	0	0
Youngstown, OH	Western Reserve Transit Authority	0	0	0	0	0	0
Totals		**9522**	**3497**	**336**	**1697**	**60**	**0**

The source for this information is the American Natural Gas Vehicle Coalition. If you have information on transit authorities or other entities that operate natural gas buses and that are not listed in this chart and you would like it added to this table, please contact:

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Appendix 3: Currency Rates

Currency	Value =$US1	Date	Currency	Value =$US1	Date
Australian Dollar	1.8836	13Oct00	Indian Rupee	46.19	13Oct00
Austrian Schilling	15.9410	13Oct00	Italian Lira	2243.13	13Oct00
Belgian Franc	46.733	13Oct00	Japanese Yen	107.69	13Oct00
British Pound	0.6802	13Oct00	Korean Won	1120.0	13Oct00
Canadian Dollar	1.5149	13Oct00	Malaysian Ringgit	3.7999	12Oct00
Chilean Peso	572.1	15Nov00	New Zealand Dollar	2.5125	13Oct00
Chinese Renminbi	8.2786	11Oct00	Norwegian Krone	9.3099	13Oct00
Czech Crown	41.39	30Oct00	Polish Zloty	4.7100	13Oct00
Deutschemark	2.2658	13Oct00	Russian Rouble	27.9150	13Oct00
Egyptian Pound	3.78	30Oct00	Spanish Peseta	192.75	13Oct00
Euro	1.1598	13Oct00	Swedish Krona	9.9521	13Oct00
Finnish Markka	6.8880	13Oct00	Swiss Franc	1.7420	13Oct00
French Franc	7.5991	13Oct00	Taiwanese Dollar	31.210	13Oct00
Greek Drachma	403.54	30Oct00	Thai Baht	43.490	13Oct00

Appendix 4: Unit Conversions

Pressure	one MegaPascal (1 MPa)	10 Bar	145 lbsf/in2
Distance	one kilometre (1 km)	1094 yds	0.6214 miles
	one metre (1 m)	39.37 inches	3.281 ft
	one millimetre (1mm)	0.0397 inches	
Volume	one cubic metre (1 m3)	220 gallons	264 US gallons
	one litre (1 l)	0.22 gallons	0.264 US gallons
	one litre	0.035312 ft3	61.02 ins3
Weight	one kilogam (1 kg)	2.205 lbs	984.2×10^{-6} ton
Power	one kilowatt	1.341 hp	3412 Btu/h
Flow Rate	one litre/second	0.1271 ft3/h	0.00212 ft3/min

Fuel Consumption of Transit Buses: Throughout the paper one cubic metre of natural gas is taken as equivalent to one litre of diesel unless the specific source has used an exact conversion. Typically natural gas is about 38.8 Megajoules per cubic metre and a litre of automotive diesel is 38.4 Megajoules per litre.