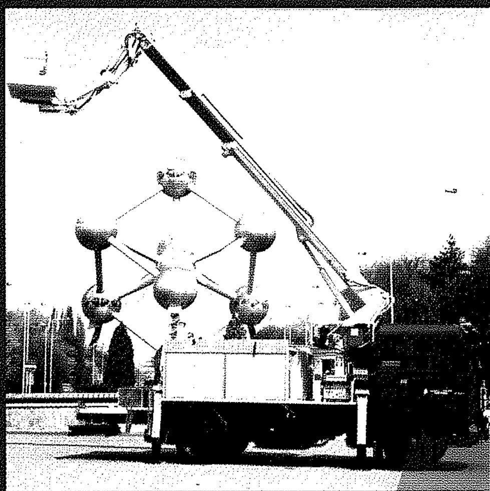
European Commission

New Solutions in Energy Utilisation

Task Force Natural Gas Vehicles

The Decision Makers' Guide to Natural Gas Vehicles



ENERGY

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This ENERGIE publication is one of a series highlighting the potential for innovative non-nuclear energy technologies to become widely applied and contribute superior services to the citizen. European Commission strategies aim at influencing the scientific and engineering communities, policy makers and key market actors to create, encourage, acquire and apply cleaner, more efficient and more sustainable energy solutions for their own benefit and that of our wider society.

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Delivery is organised principally around two Key Actions, *Cleaner Energy Systems, including Renewable Energies, and Economic and Efficient Energy fora Competitive Europe*, within the theme "Energy, Environment and Sustainable Development", supplemented by coordination and cooperative activities of a sectoral and cross-sectoral nature. With targets guided by the Kyoto Protocol and associated policies, ENERGIE's integrated activities are focussed on new solutions which yield direct economic and environmental benefits to the energy user, and strengthen European competitive advantage by helping to achieve a position of leadership in the energy technologies of tomorrow. The resulting balanced improvements in energy, environmental and economic performance will help to ensure a sustainable future for Europe's citizens.

In the present RTD Framework Programme, other key actions like the *City of Tomorrow* and *Sustainable Mobility and Intermodality* are supporting complementary activities.

Produced by

MVV InnoTec GmbH
c/o Mrs Renate Lemke
Kurfürstendamm 199
D-10719 Berlin
Germany
Phone:+49-30-8823432
Fax:+49-30-8854433
E-mail: lemke@euweb.de

City of Stockholm
c/o Ms Karin Johnson
Box 38024
S-10064 Stockholm
Sweden
Phone:+46-8-616900
Fax:+46-8-6169632

Stichting European Natural Gas Vehicles Association - ENGVA
c/o Dr. Jeffrey Seisler
Spaklerweg 28
NL-1096 BA Amsterdam
The Netherlands
Phone: +31-20-5973100
Fax: +31-20-5973000
E-mail: engva@euronet.nl

Stadt Köln
Amt für Europaangelegenheiten
c/o Dr. Barbara Möhlendick
Atherner Ring 4
D-50765 Köln
Germany
Phone: +49-221-2211479
Fax: +49-221-2211900

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Directorate-General Energy and Transport

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Stichting European Natural Gas Vehicles Association (ENGVA)

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The City of Stockholm

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Foreword

This *Decision Makers' Guide to Natural Gas Vehicles* is a European Commission-funded project that is a companion document to the *Natural Gas Vehicles Equipment Guide*. Used on its own, this Decision Makers' Guide provides basic but essential information required by public officials or commercial fleet owners considering using natural gas vehicles (NGVs) as part of their vehicle fleet mix.

The authors have attempted to present answers to some of the most basic questions asked about NGVs. But, with decision making in mind, there is fundamental, easy-to-read information that addresses issues about:

- Vehicle characteristics, including conversions and factory produced NGVs
- The best vehicle applications appropriate as NGVs
- Economics and availability of vehicles
- Fuelling approaches and technologies
- Special considerations for installing fuelling station equipment
- Safety for vehicles, fuelling, and operations (such as in underground parking situations)
- Assistance that may be available to provide detailed guidance and advice about their NGV choices and
- Specific and general sources of information that is readily available.

When it comes to selecting specific equipment – vehicles or fuelling stations – the companion *Natural Gas Vehicles Equipment Guide* will be useful to get a better understanding of what is available and from whom to purchase the equipment. Together these two documents should provide enough guidance for the users to know whether or not to continue to pursue the NGV option.

Once a decision is made to move further, the companies identified as sources of information or products should be contacted so that a detailed profile of your NGV programme can be created. This will enable your to determine the specific economics of your situation, the emissions reduction potential, and the many aspects about developing a fuelling station, if that will be required.

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For further information, requests or comments please contact:

MVV InnoTec

MVV InnoTec GmbH
Mrs Renate Lemke
Kurfürstendamm 199
D-10719 Berlin
Germany
Tel.: +49-30-8823432
Fax: +49-30-8854433
lemke@euweb.de

European Natural Gas Vehicle Association

Stichting ENGVA
Dr Jeffrey Seisler
Spaklerweg 28
NL-1096 BA Amsterdam
The Netherlands
Tel.: +31-20-5973100
Fax: +31-20-5973000
engva@euronet.nl

1 Vehicle fleet profile / Applications

Companies owning multiple vehicles – fleets – that return each night to one central depot have been a traditional form of vehicle profile that is economically attractive for natural gas. In most countries the NGV fuelling infrastructure is much less developed than for petrol/diesel, therefore, fleet operators are the best target for the early installation of a fuelling infrastructure. The more public access fuelling stations are installed, the more attractive natural gas will become to the full range of fleets and commuter vehicles. This has been the pattern in countries such as Italy, with 320,000 vehicles and 320 fuelling stations and Argentina, with over 420,000 vehicles and over 400 fuelling stations.

Many cities are also becoming interested in locally produced biogas as a vehicle fuel. Biogas is produced from organic waste as a by-product of sewage treatment, and has long been used as a domestic heating fuel. In purified form it can be used in any vehicle designed to run on methane gas.

1.1 Original equipment manufacturers and conversions

Original Equipment Manufacturers

More and more original equipment manufacturers (OEMs) are making factory-built NGVs of different kinds. In fact, today more than 40 manufacturers world-wide are producing NGVs. These vehicles are either dedicated (running on natural gas only) or are bi-fuel (running on natural gas or petrol). The dedicated vehicles are optimised for natural gas to take advantage of the high octane rating – about 130 – compared to petrol at 80-95. These vehicles are fully engineering by the manufacturer and, as such, typically perform to the best of the manufacturer's standards, similar to a petrol or diesel vehicle. These NGVs are fully warranted so that if a breakdown occurs, the vehicle can be returned to the manufacturer for servicing and maintenance.

Some OEMs have programmes with companies that do factory-quality conversions to natural gas, but that are sold as factory-built vehicles. These vehicles are treated as if they came off the factory assembly line, and are fully warranted as long as the service schedules of the manufacturer are followed.

Conversion to Natural Gas

Most NGVs on the road today are petrol vehicles converted to run on natural gas *or* petrol by a private company once the vehicle has left the manufacturer's factory. There are many national and international standards that must be met when converting a vehicle to run on natural gas (Please refer to section 7). This provides some assurance that if the regulations are followed by the conversion company, there should be few problems. This also offers some forms of consumer protection if something should go wrong due to actions by the conversion company.

Bi-fuel conversions of petrol vehicles: A bi-fuel conversion system and high-pressure fuel tank are added to an existing petrol vehicle. The vehicle can operate either on natural gas or on petrol. When the natural gas has been used up, the driver flips a switch (or with some systems it happens automatically) and the vehicle switches to petrol. This can be done while the vehicle is in operation or is idle. The natural gas equipment can also be removed from the vehicle at the time of resale and returned to its normal petrol operation if desired.

Dual-fuel conversions of diesel vehicles: Some diesel engines are converted using a *dual fuel* system; that is, they run on a combination of natural gas and diesel. When the engine is idle, it engine runs on 100% diesel. As soon as the vehicle starts driving, and as it builds up speed, increasingly more natural gas is injected into the engine, up to about 80% gas and 20% diesel. In a diesel engine, the fuel is ignited through the heat of combustion (instead of a spark plug) the diesel fuel acts as a 'pilot' fuel to ignite natural gas in the engine.

Dual fuel performance and emissions vary depending upon operating conditions and the sophistication of the control system. Systems developed in the 1980s tended to 'fumigate' the natural gas into the engine through the air intake manifold. Later developments used replacement diesel injectors that instead injected natural gas into the diesel cylinder, and thus improved performance and emissions. New developments in dual fuel systems that are computer controlled, so-called direct injection systems, have overcome some of the problems associated with previous generations of the technology. These systems are, however, limited to a small number of engines and manufacturers. Depending upon the technology, and the manufacturer, dual fuel diesel/natural gas engines can offer economical alternatives to purchasing a new vehicle and/or 'repowering' (replacing) an existing diesel engine.

Practical tips when considering converting a vehicle:

- **What kind of vehicles can be converted to run on natural gas?**

Almost any type of *petrol vehicle* can be converted, mostly to bi-fuel so that it runs on natural gas *or* petrol. These include: passenger cars, taxis, police cars, small buses, vans and delivery service vehicles. Off-road vehicles, including airport tugs, fork lifts, ice-cleaning machines, and even boats and trains are candidates for conversion to natural gas.

Many *diesel vehicles* can be converted but it is more complicated than converting a petrol engine. Most diesel conversions tend to be large vehicles such as garbage trucks or buses. (See above, *dual fuel* conversions)

- **It is better to convert newer vehicles rather than old ones.**

Depending upon the annual kilometres you travel and how much fuel you consume, the payback period may be 2-5 years (Please refer to 4). This favours converting newer vehicles. Sometimes complete overhauls of old vehicles would be recommended prior to conversion, to ensure the vehicles are in good working order. Remember, a car running poorly on petrol also will run poorly on natural gas.

- **Convert the vehicles that tend to travel many kilometres per year.**

Payback of the natural gas system will depend upon the price differential between natural gas and petrol/diesel. Vehicles that travel high kilometres each year will achieve a quicker payback than vehicles that do not travel too much.

- **Consider the way a vehicle is used before converting it.**

Vehicles that travel more than about 160-175 km per day may require an additional fuel tank to increase the vehicle range. The vehicle should be sizeable enough to include a second fuel tank.

Petrol engines converted to natural gas tend to lose about 8-10% power. This is because natural gas is introduced into the cylinder as a vapour, which replaces about 8-10% of the oxygen in the cylinder head, thus reducing power. Larger engines (at least more than 1 litre) converted to natural gas tend to exhibit less of a power loss than smaller engines.

In the absence of a complete fuelling infrastructure, converting fleet vehicles that return to one base each night is a sound, economical approach.

1.1.1 Urban buses

Fig. 1-1: MAN natural gas bus in operation in Augsburg, Germany

The urban bus is a very popular candidate to run on natural gas (25% of new buses purchased in the U.S. and in France run on natural gas).

- The vehicle uses a lot of fuel and the more diesel fuel can be replaced by natural gas, the quicker the payback will be achieved.
- City buses travel in high density, congested (with people and buildings) areas of town. Particulates and other emissions will come into contact with more people living in the inner cities than will buses running in areas with reduced populations and more open space.
- The start-and-stop driving patterns of buses increase pollution potential, so natural gas can help reduce visible smoke, soot, and particulates.
- Large, high compression bus engines result in good driving performance due to the 130 octane rating of natural gas.

Many buses run 100% on natural gas. Most worldwide bus manufacturers make a version of their products running on natural gas, so it is relatively easy to

Fig. 1-2: Renault natural gas bus in operation in Poitiers, France

order a bus to everyone's specification. Buses (and other diesel-cycle engines) may also be converted to run on natural gas. Some of these tend to be *dual-fuel* conversions.

- **What special considerations are there when making a decision to use natural gas buses?**

– *The weight of natural gas fuel cylinders* - with enough on-board fuel storage capacity will take up about 17% of the vehicle's carriage weight. If the vehicle becomes too heavy it reduces the number of standing passengers.

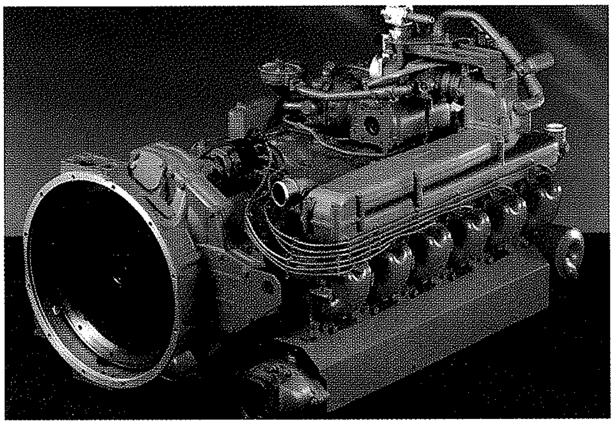


Fig. 1-3: CNG engine, MAN, capacities are available 170 kW and 228 kW (lean burn technology)

– *The fuel efficiency on natural gas buses is not as good as diesel engines.* Reports of 10-15% decreased fuel efficiency are common. When a vehicle shows much higher natural gas fuel consumption (25-40%) then drivers should be monitored and retrained so that they are not over-driving the vehicle and reducing fuel efficiency.

– *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 required.

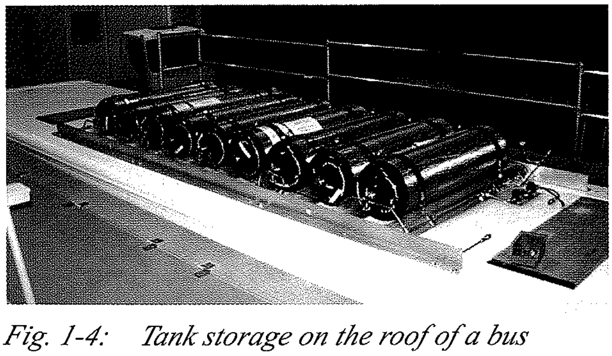


Fig. 1-4: Tank storage on the roof of a bus

– *Many bus operators demand quick filling as is the case with diesel.* Natural gas buses can be filled in the same time as diesel buses, but large compressors are required to ensure an adequate flow and capacity. Some bus companies use a combination of slow (overnight) filling as well as fast fill. This is possible depending upon the bus operator and his ability to be flexible when incorporating natural gas buses into his fleet (Please refer to section 2).

1.1.2 Minibuses

The minibus, typically, is used as a personal shuttle for small groups not requiring a large urban vehicle. Hotels and car rental companies typically use minibuses for short haul (but continual) service. They can be excellent candidates for driving on natural gas because of the large amount of fuel they tend to consume if they are in constant use. A wide variety of minibuses are available from the manufacturers, many of whom use other companies' standard natural gas engines and install them in their own chassis and minibus shells.

Fig. 1-5: Mercedes Benz minibus in operation in Roma, Italy

1.1.3 Garbage trucks

Garbage trucks are popular vehicles to drive on natural gas. They are high polluting, fuel consuming and noisy vehicles that are centrally fuelled. Natural gas octane rating results in a much quieter sound from the diesel engine. As many garbage trucks begin early in the morning, noise pollution is an important factor when considering the natural gas option.

The weight of storage cylinders on board the vehicle typically reduces the vehicle's carriage weight by about 17%, which is a cause of concern for the waste management industry. Experience has shown that the selection of suitable vehicles with regard to load and

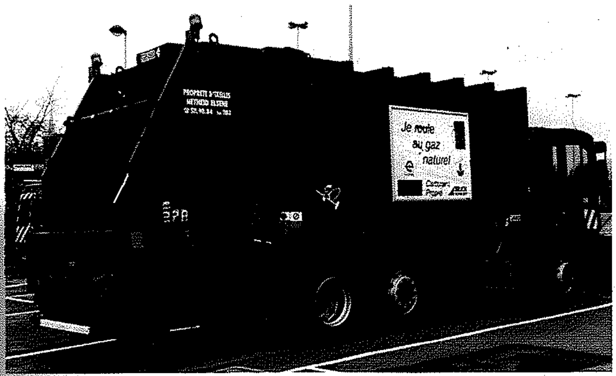


Fig. 1-6: ERF Garbage truck type EC 12.30 TMU 6x2, 26 metric tonnes, in operation in Ixelles, dedicated Perkins natural gas engine, type: Eagle 340 TxSi

axle width is difficult. Therefore, most of the natural gas garbage trucks are specially manufactured vehicles which leads to maintenance and repair problems. For example, the London Borough of Sutton has repair problems with frequent breakdowns coupled with unsatisfactory service support. Improved heavy duty vehicles are currently under development and the respective cities are awaiting results.

Some garbage trucks run on biogas made from waste materials (human, agricultural, urban waste, etc.). This offers an opportunity to have an 'environmentally closed loop' garbage truck whereby the 'fuel' (waste material) is processed into natural gas or biogas which, in turn, fuels the truck.

The biogas garbage trucks running in Stockholm are an example for such closed energy loops. Stockholm originally developed biogas facilities to reduce greenhouse gas emissions from rubbish dumps and sewage plants. Now, some biogas is purified for use as vehicle fuel, replacing about 360,000 litres of petrol annually. Biogas produced from Stockholm's sewage powers two Volvo biogas garbage trucks that collect 12-15 tonnes of waste daily.

Fig. 1-7: DAF Garbage truck in operation in Haarlem, The Netherlands, converted by Scania

The trucks not only produce fewer emissions, but are quieter than previously used vehicles, making them appropriate for use in Stockholm's dense but sensitive urban area Old Town. In the future, Stockholm's waste authority SKAFAB plans to build a facility where food waste collected from restaurants is converted to biogas and fertiliser, and has a goal of being 100% fuel self-sufficient.

1.1.4 Trucks

Commercial trucks come in many shapes and sizes. Most of them are ideal candidates for conversion to natural gas. Trucks that operate in and around the same city are well suited to using compressed natural gas. These vehicles tend to be well-travelled, high fuel consumers operating in downtown, congested urban centres. They have been identified as a source of urban pollution.

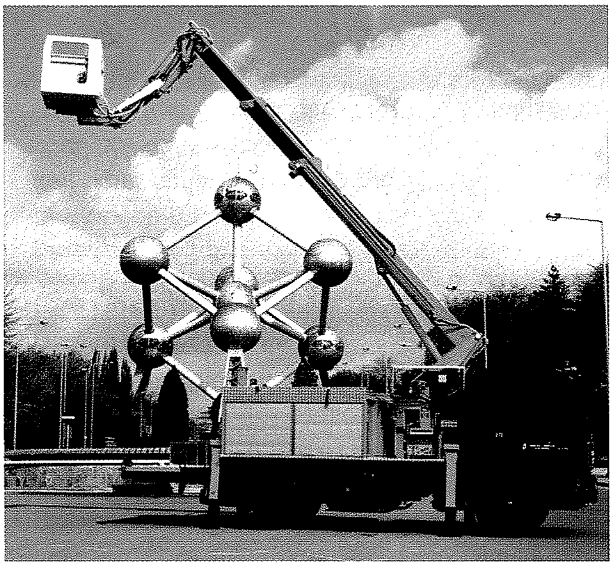


Fig. 1-8: MAN aerial platform truck in operation in Brussels, Belgium

Over-the-road *intra*-city trucks may not be as well suited for CNG because of the range they travel between two urban locations, unless there is a well established fuelling station network set up for this purpose. In Britain and the United States large intra-city trucks are being converted to run on liquefied natural gas (LNG). LNG, stored as a cryogenic fuel has about 60% more energy density than compressed natural gas and, therefore, provides greater range for large trucks operating between urban centres.

1.1.5 Delivery service

Delivery trucks operating in urban centres are a prime target to be NGVs. Some companies, such as the United Parcel Service (UPS) and the United States Postal Service operate these trucks to deliver mail and packages. They are highly visible in downtown areas and make up a significant part of the polluting vehicle population in metropolitan centres. Also, they have plenty of room for CNG tanks either on-board (usually mounted behind the driver) or within a normally ample frame. Many cities also use CNG delivery vans in urban service, such as senior transport vans in Sutton, United Kingdom.

Fig. 1-9: Ford Transit operating as delivery vehicle for pharmacies in the greater Koblenz area at CityCargo, Germany

1.1.6 Fork lifts

Vehicles operating indoors, where air pollution is a serious issue, are a constant cause for concern. Due to worries about indoor air pollution, the fork lift market has been moving relatively rapidly toward natural gas in a number of countries. Forklifts can be purchased directly from certain manufacturers or they can be easily and relatively inexpensively converted. These vehicles can consume an entire tank of fuel in one day and never leave the premises (they are categorised as off-road vehicles). CNG fuel tanks are conveniently located behind the driver or, depending upon the lift-truck design, can be mounted in a specially built rack above the vehicle.

Fuelling forklifts can be much easier than for road vehicles, because they use less fuel and, therefore, require smaller compressors to support their operation. One popular fuelling option has been the use of a small-fleet/home compressor that fills about four litres per hour. Alternatively, they can be fuelled in a couple of minutes from a small CNG storage tank, either indoors or outdoors. Compared to electric forklifts, which require many hours to recharge their bulky batteries, natural gas forklifts are a major improvement.

Fig. 1-10: Fork lift in operation in Amstelveen, The Netherlands

1.1.7 Taxis and shared cars

Some of the OEMs have designed vehicles specifically for their applications as taxicabs. Compared to their diesel counterparts (which are popular in cities world-wide) natural gas offers major competitive advantages in terms of fuel price and pollution. In Buenos Aires, for example, diesel taxis were banned in 1986 and replaced by NGVs within a relatively short period of time. Today Argentina boasts more than 400,000 NGVs, many of which are taxis in Buenos Aires.

The city of Göteborg in Sweden, the hometown of Volvo, has introduced a special line in front of the city's central station, giving clean driven taxis a privileged waiting position. This measure has had a very good impact on the introduction of natural gas driven taxis in Göteborg.

Fig. 1-11: Biogas driven taxi, Volvo, in Eslöv, Sweden

CNG can also be used in car sharing clubs, which has similarly intense energy use patterns. Bremen is using several CNG cars, both as taxis and as car sharing vehicles.

Other major cities in North America, Europe, China, Japan, Egypt and elsewhere are turning to natural gas taxis as a major contributor to improved air quality.

Taxi drivers are concerned about trunk/boot space and refuelling availability. They drive eight and sometimes many more hours per day so time spent finding fuel and at a fuelling station must be minimised. Bi-fuel vehicles help alleviate this problem due to the petrol back-up. In retrofit vehicles, fuelling tanks are often in the boot, and drivers typically are concerned about passengers with luggage not having enough space. Unless a taxicab is specifically assigned to airport duty, however, a vast majority of pickups have little or no luggage, so trunk space should not be a major issue.

For airport taxis there are other options: factory built cabs with the fuelling tanks installed in the chassis, or using small vans where generally there is space enough for a volume of CNG tanks, usually mounted underneath.

1.1.8 Cars

Many of the major automobile manufacturers in Europe, North America and Japan make a variety of natural gas passenger cars. (Many of these same vehicles are also used as police cars and taxis.) Some of these OEM vehicles have passed the most stringent California emissions standards far in advance of their petrol counterparts. The OEMs have gone to great lengths to improve the driving range of these vehicles and a number of them have installed the natural gas storage tanks inside the frame of the vehicle, so trunk/boot space is not compromised.

OEM vehicles are just beginning to enter the market, such as the Fiat Multipla Blupower. Most passenger cars are converted. The newest computer controlled, fuel injected vehicles can be converted using sophisticated conversion systems that are linked to the vehicle's computer, making it difficult to tell if the car is operating on petrol or natural gas.

Local governments, energy companies, police departments and taxi companies use passenger cars as the bulk of their fleet operations. Their concentration in urban centres makes them ideal candidates as NGVs.

Some of the newest factory-built petrol vehicles have made excellent advances in improving their emissions. They are, therefore, beginning to become competitive with bi-fuel NGVs in terms of emissions. That is because the bi-fuel vehicles cannot be optimised to one fuel or the other. As such, some people today are critical of natural gas passenger cars because they are no longer 50-80% cleaner than in the days when carburetted vehicles were in use. If the car is a dedicated NGV, however, there are few if *any* petrol or diesel cars that can compare from an emissions standpoint. Some of these natural gas vehicles are lower polluting than an electric car if the electricity is generated using coal or oil!

Fig. 1-12: Multipla Fiat Blupower, 1.6 l, 4 cylinders, 4 valves engine

1.2 Leasing options

Some dealers of OEM NGVs will be able to lease an NGV as easily as they can a petrol or diesel version. As long as the vehicle has been certified for operation in that country, there should be no special problems leasing a new NGV.

Some short-term leasing companies now offer NGVs in limited locations. Most companies leasing a large number of commercial vehicles to corporate customers are not yet attuned to providing NGVs. However, since natural gas conversion systems can be removed from a vehicle and returned to ordinary petrol service (and sometimes the gas systems reinstalled on another vehicle), there should not be a major problem for a company to lease NGVs if they are requested to do so by the customer! As the fuelling infrastructure is expanded, leasing companies undoubtedly will increasingly offer an NGV option.

1.3 Second-hand market

Finding a buyer for a used NGV can be a problem at the moment, without an established sophisticated fuelling station network. A typical fleet vehicle has a life span of 3-5 years and is taken out of service (usually because of high mileage) and scrapped or resold. Corporate users of these vehicles typically have standard intervals for service and maintenance. As such, they can be resold as a decent used vehicle.

There are some creative solutions that can be pursued.

- Local governments can be candidates to purchase used NGVs from, say, energy companies. The higher first cost of conversion to natural gas can be absorbed by the energy company so that the local government has access to a decent vehicle, running on a cheaper fuel, and whose first cost is competitive with a used petrol vehicle.
- Companies with NGV passenger/van fleets can sell their cars to their employees. When employees come to work they can use the corporate fuelling facilities, either fast fill or, during their working hours, at a slow fill station.
- The NGV associations can become a source of advertising for used NGVs. Their websites are beginning to expand, and many people are visiting them for increasingly more information (Please refer to section 9).

2 Fuelling of natural gas vehicles

The lack of filling stations is one of the crucial points for the wider market implementation of natural gas vehicles. However, during the last years the number of filling stations has grown in all European countries, e.g. Italy 300, Germany 130. The location of the filling stations can be obtained from the national gas associations and are often published on the homepages of these organisations (Please refer to section 9).

A CNG filling station consists of the incoming natural gas pipeline providing a pressure of 1-30 bar. The main parts of the filling station are the compressor, gas dryer, a high pressure system (200-250 bar) with a storage system (fast fill option), electric instruments for measuring and control, gas pump and a cover (encasement, building). Two types of fuelling systems are available on the market: fast fill and slow fill systems.

Slow fill or fast fill

Slow fill is a possibility if the fleet is used during the day with parking at the depot at night (or vice versa). During standstill the vehicles are filled directly by the compressor. Fast fill is used if filling has to be completed within a few minutes, e.g. for supply to external customers and large natural gas demand justifies the higher investment costs.

How to find the right system?

The capacity of the filling station has to be designed according to the CNG demand per time unit. Primarily the following parameters have to be taken into consideration:

Fleet parameters

- Number of vehicles
- Mileage per vehicle
- Consumption per kilometre
- Volume of fuel storage on-board
- Number of refills per time unit (fast fill)
- Duration of the filling period (slow fill)

Location parameters

- Locality, driveway
- Vehicle characteristics (weight, steering radius)
- Gas connection (location, design, intake overpressure)
- Electric connection (location, design)

Pre-feasibility

- Module sizes
- Capacity of the filling station
- Necessary storage volume
- Number of dispensers
- Design of other facilities
- Elaboration of filling cycles
- Design of modular extendable system
- Investigation of alternatives
- Economic analysis
- Discussion of safety of supply

Estimation of investment volume

- Rough framework of quantities
- Determination of standard purchase prices for all components, work and engineering
- Evaluation of different alternatives

2.1.1 *Fast filling*

Fast filling with CNG requires no more time than filling with conventional fuels such as petrol or diesel. This is usually needed when vehicles must be refuelled in a time period similar to that of gasoline, say three to seven minutes for automobiles and light-duty trucks.

Fig. 2-1: Fast-filling at Ruhrgas in Dorsten [Ruhrgas AG]

At a fast fill fuelling station, natural gas is compressed by the compressor and stored in the high pressure storage system, e.g. in gas storage cylinder "cascades". When vehicles are being refuelled and the pressure of the fuel supply in the storage system begins to drop, the compressor is automatically activated, causing it to replenish the supply of natural gas in the storage cylinders. Other systems are working with a hydraulic piston system which keeps the pressure in the storage system always at the same level. A dispenser then delivers and meters the natural gas into the fuel storage cylinder(s) onboard the vehicle. In detail the following equipment is needed:

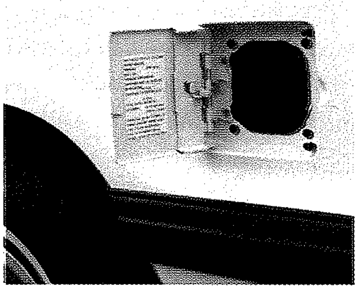


Fig. 2-2: Tank opening at the vehicle [Ruhrgas AG]

Compressor

In a fast fill application high stationary storage pressure and capacity present good working conditions. Compressors serving fast fill stations are capable of providing at least 250 bar. Compressors are available with flow capacities from 0.8 litre/sec to hundreds of litres/sec. Compressor controls guarantee safe operation. Critical pressures and temperatures are monitored by shutdown devices.

Fig. 2-3: High-pressure hose with plug coupling [Ruhrgas AG]

Visual indicators are usually provided to indicate the operating or shutdown condition.

Controls

The controls required depend on the type of station specified. Basic controls determine the flow of gas to and from the compressor, the gas recovery system and to the dispenser. Most compressors have their own control system for start/stop, monitoring and safe operation. When high pressure cascade storage is installed, a higher level of controls must be installed to determine to and from which tank or bank of cylinders the gas will flow.

A pneumatically or electrically operating valve system, so-called priority system, directs the natural gas coming from the compressor into either high, mid or low pressure storage banks. The controls switch from bank to bank until all have been filled to maximum storage pressure. The compressor is then switched off automatically.

The sequence system of valves controls the flow from the storage system to the vehicle. Only a portion of each bank's capacity can be used due to pressure equalisation between the vehicle and the storage system. As the pressure difference between the vehicle and storage system is reduced during the refuelling process, the flow rate decreases. In order to achieve maximum filling efficiency, the sequence valve system switches to the next bank. The usable portion of the storage varies from system to system with manufacturers in the range of 25% to 60%. An average can be estimated to be 30%. As storage pressure increases these percentages will change. This is important as it affects the total amount of storage needed and may also affect the compressor size.

Storage system

For the storage system a variety of synonyms exists. They are often referred to as bottles, receivers, tanks, banks, cascades, pressure vessels and cylinders The most common cascade systems divide the storage into high, mid and low tanks or banks. Whereas each bank is filled to the same working pressure, the terms high, mid, and low refer to the level the pressure will be reduced to once fuelling begins. Some systems use only two different pressure levels.

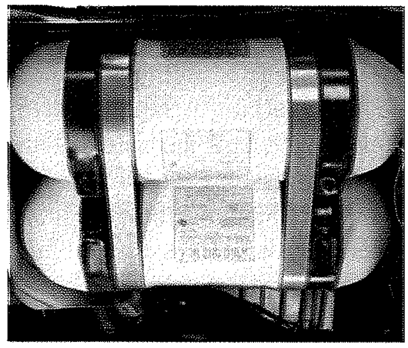


Fig. 2-4: Tanks are installed under the rear [Ruhrgas AG]

Fig. 2-5: Side view: High-pressure tanks under the vehicle [Ruhrgas AG]

As an example, assume a system has all banks in a three bank storage system which are filled to 300 bar. Once vehicle filling begins, the stored natural gas will flow into the vehicle until the pressure in the low tank is reduced to 70 bar, then the controls will switch to the mid tank where the flow will continue until the pressure between the vehicle and tank equalises at 140 bar. Finally, the high bank will top off the vehicle storage at 250 bar. The controls will initiate refilling the storage as soon as the pressure in any bank drops below the compressor cut-in pressure setting and stop when all storage is at maximum pressure again.

Dispenser system / Metering

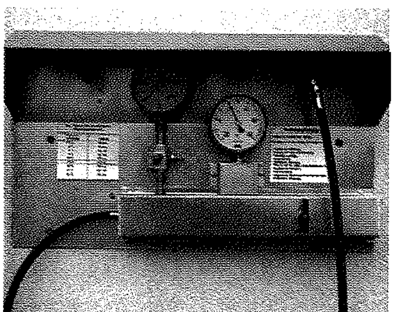


Fig. 2-6: Metering pressure and fuelling quantity [Ruhrgas AG]

All stations must have a dispenser in order to fill vehicles. This may be as simple as a fill post with hose and nozzle or it may consist of a programmable double hose metering dispenser with display and card lock system similar to a gasoline pump. A break away device is usually required to stop the gas flow in drive away situations.

The two types of metering devices currently used are mass flow and sonic nozzle. Both are built into dispensers in order to account for, bill, or calculate natural gas usage. Specifications should be read carefully in order to determine if a metering device is required.

Temperature compensation at the dispenser is also commonly specified. This can be electronically calculated or controlled through the use of pressure sensing valves and reference cylinders. It is important because over-pressurising vehicle storage can occur. Conversely, underfilling is a nuisance that can be minimised through the use of temperature compensation. [Naturalgas home page]

Another aspect of fast filling is the slightly reduced fuel storage capacity on the vehicle in comparison with a slow filled tank of the same type and the same pressure. The reason is, that as the gas rapidly builds up and compresses the gas that is already there the temperature in the tank will rise, which in turn lowers the density of the gas. With the slow-fill approach this effect will not be encountered because of the significantly lower temperature rise during refilling.

2.1.2 Slow filling

The fuelling of vehicles with slow fill stations occurs directly from the compressor through special slow fill dispensers. This eliminates the need for a costly high pressure storage system but lengthens the fuelling process to several hours for every vehicle. A slow fill compressor only needs to develop a pressure slightly higher than the vehicle storage pressure. Slow fill is usually recommended for fleets where

Fig. 2-7: Slow-filling station in Poitiers, France

vehicles return to a central location for 6 to 8 hours or private cars which can be refilled overnight at home.

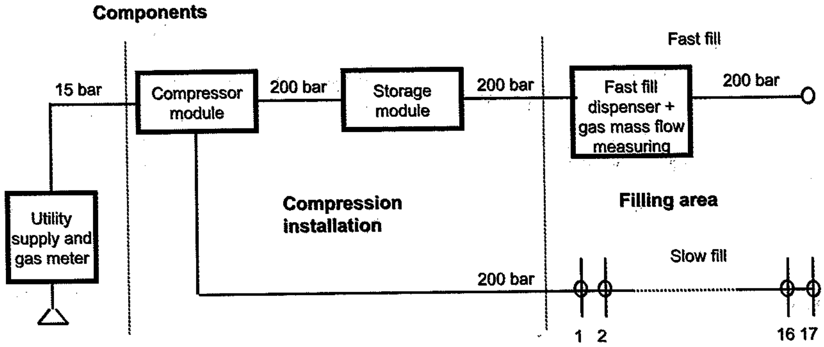
Components of a slow-fill station are:

- Access to natural gas piping system
- Compressor
- Slow fill dispenser

2.1.3 Combination of slow and fast filling options

Also, a combination of both fast fill and slow fill is possible and can be an interesting solution for big fleet operation when just a part of the fleet needs fast fill thus reducing the requested onsite storage capacity and saving investment costs. [Natural Gas Vehicle Coalition, 1995]

Combination of slow and fast filling options is also advisable if it is impossible at the beginning of an NGV project to predict how fast the demand will grow. A filling station can be expanded any time. Building a filling station that can be expanded as an NGV fleet grows minimises the investment risk. Combination of fast and slow fill can also be used to serve different user groups, e.g. external customers are served in fast fill operation and the company vehicles can be filled in slow fill operation during the night.



General description

1 Compressor module with 2 compressors :

nominal inlet pressure :	15 bar gauge
minimal inlet pressure :	10 bar gauge
nominal outlet pressure :	200 bar gauge
flow rate :	2 x 150 m³(n)/h
compressor type :	Hydraulic Twin
number of compression stages :	2
nominal motor power :	70 kW
power factor (cos phi) :	> 0,9
capacitor package :	to improve power factor
rated power :	80 kVA

1 Storage module containing :

2 storage units, each with 2 x 12 cylinders of 50 litres water capacity
= 2400 litres water capacity, corresponding to 540 m³(n)
of natural gas available

1 Fast fill dispenser equipped with :

Fuel Scout (card reader and admittance control)
1 delivery hose with NGV profile fill connector
1 mass flow metering unit
rest gas of delivery hose evacuated via recovery vent

17 Slow fill dispensers :

Each dispenser equipped with 2 delivery hoses with NGV profile fill connector

Fig. 2-8: Combined slow & fast fill NGV filling station for filling 34 refuse collection vehicles [NGVeurope, 1999]

2.2 Economics

Depending upon the design of the service station, its fuel storage requirements and the vehicles to be refuelled, investment costs for the filling stations range from 3,500 Euro to 10,000 Euro for slow fill systems that can serve only a few vehicles to several hundred thousand Euro for large stations capable of fast filling and fuelling over a hundred vehicles. For normal fleet vehicles, however, as a general rule you can expect to spend 1,000 – 2,000 Euro per vehicle to install a fuelling station. [IANGV homepage]

The revenue of the filling station has to cover at least the investment and operation costs as well as giving a market interest rate for the capital employed. The revenue depends on fuel sales volume and fuel price. To reach payback point the price at the "petrol pump" has to be:

	Costs for natural gas purchase (Refer to section 4.1)
+	Mineral oil tax (Refer to section 4.1)
+	Cost of capital
+	Energy costs
+	Operation costs
	Minimum price at petrol pump

2.2.1 Investment / Capital costs

The costs for the filling station include the costs for the compressor, the cascades for intermediate storage, the dispensers and construction costs. To the best extent possible, the compressor should be selected to reach an optimum utilisation of up to fifteen hours per day. The intermediate storage should have the capacity to refill approximately 50% of all vehicles per day. In the following, all costs represent average values. The investment costs are converted to yearly capital costs using a capital recovery factor taking into consideration an operating life of 10 years for technical equipment and 40 years for buildings, with an interest rate of 7%.

The investment for the compressor includes costs for natural gas dryer, noise and weather protection, natural gas control system, spare parts, freight and packaging, montage, and putting into operation (Please refer to Fig. 2-9).

Refills per day (cars)*	Suction volume flow [m³/h]	Suction pressure [bar]	Investment [Euro]	Compr. operation time**
4	3	1.013	5,000	20
10	10	1.013	50,000	15
20	20	1.013	60,000	15
40	45	1.013	80,000	13.3
100	114	1.013	185,000	13.1
150	160	1.013	200,000	14.1
200	240	1.013	210,000	12.5
150	170	16	165,000	13.2
200	350	16	200,000	8.6

Fig. 2-9: Average investment for compressor station

The approximate investment costs for the intermediate storage cascades are given in Fig. 2-10. For the refilling of 200 cars/day a storage of 960 litres is sufficient, because the suction volume flow of the compressor is large enough to fill vehicles also directly in only a few minutes.

The investment costs for the dispenser with one hose – sufficient for 40 vehicles per day – are 25,000 Euro

Storage volume	Costs [Euro]	Capacity
640 l (8x80 l)	8,000	4 cars
800 l (10x80 l)	9,000	10 cars
960 l (12x80 l)	10,000	20 cars
2,000 l (25x80 l)	15,000	40 cars
2 x 3,200 l (40x80 l)	2 x 70,000	100 cars
8,400 l (4x2,100 l)	120,000	150 cars
+ storage control	5,000	
+ emergency lock	5,000	

Fig. 2-10: Investment costs for intermediate storage bench

or with two hoses 40,000 Euro, including data collection system and protocol printer.

The construction costs including collision protection, roofing of the dispenser and connection to the electrical and gas network can be estimated as follows:

- 25,000 Euro (4 cars per day)
- 50,000 Euro (10 cars per day)
- 100,000 Euro (from 20 cars per day)

The operation costs are the maintenance costs for the filling stations which can be estimated to be 5% of the investment costs of the compressor.

The energy costs are mainly caused by the operation of the electrical engine of the compressor. These costs can be obtained from the performance data given by the manufacturer. Average costs are given in Fig. 2-11.

Roughly, for the economic analysis energy costs of 5 respective 2.5 Euro/MWh(H_o) for suction pressure of 1 or 16 bar can be used.

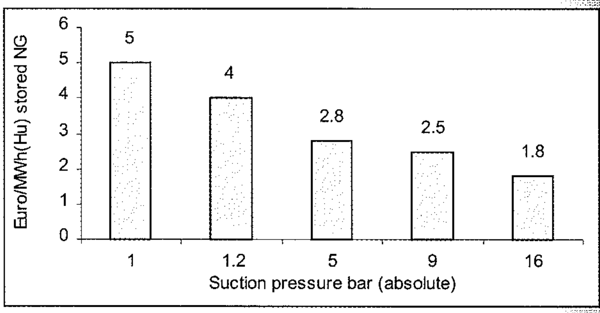


Fig. 2-11: Specific energy costs for NG filling station

With the increasing size of the compressor and the assumption of the optimum utilisation of the filling station the share of the debt service and operation costs decrease over proportionally. The costs are between six and three Euro/MWh(H_o), with increasing size of the filling station this costs share can be decreased down to 0.7 Euro/MWh(H_o). Plus NG sup-

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* For refilling of one car (fuel storage of 80 litres) fifteen cubic metres natural gas are necessary. A van counts for two cars. A bus or a truck counts for 10 to 15 cars.

** For maximum number of refills per day [h] ply and energy costs fuel costs at the station amount to between 8.1 and 2.5 Euro/MWh(H_0).

At smaller filling stations the investment costs have the crucial influence on the fuel price, that means a reduction of the investment costs results in lower fuel prices. For large filling stations the situation is the exact opposite. Gas supply and energy costs have a decisive influence on the fuel price. The energy costs could be decreased by connecting the filling station to a high pressure network. For example, the increase of the suction pressure to 16 bar reduces the fuel price from 3.3 to 2.9 Euro/MWh(H_0) for a filling station with a capacity for 150 cars/day.

Within the ZEUS project (please refer to Section 8.3), in almost all cases municipalities using CNG have covered at least some of the cost for infrastructure provision, service, and maintenance. This is especially true when the local energy or fuel provider is a municipally-owned company. However, in many cases fuel providers have been willing to cover the cost of infrastructure provision if the municipality ensures a volume purchase.

Refills per day (cars)	Suction volume flow [m³/h]	Storage volume [l]	NG consumption, 100% utilisation [MWh (H_0)/a]	Total costs for 100/50% utilisation	Energy costs [Euro/MWh (H_0)]	Necessary fuel price for 100/50% utilisation
4	3	640	153	6.1/12.2	5	8.1/14.2
10	10	800	382	5.3/10.5	5	7.3/12.6
20	20	960	764	3.7/7.4	5	5.7/9.4
40	45	2,000	1,530	2.1/4.3	5	4.2/6.3
100	114	6,400	3,820	1.6/3.2	5	3.6/5.2
150	160	8,400	5,730	1.2/2.5	5	3.3/4.5
200	240	960	7,640	0.8/1.5	5	2.8/3.6
150	170	8,400	5,730	1.1/2.2	2.5	2.9/4.0
200	350	960	7,640	0.7/1.3	2.5	2.5/3.1

*Fig. 2-12: Total costs for the filling station operator (*incl. natural gas supply costs of approximately 15 Euro/MWh(H_0))*

2.3 Financing of infrastructure

Investment in the infrastructure most often is borne by the natural gas industry. The integration in the filling station network of the traditional oil industry is essential to reach smaller fleets and private customers.

Fleet operators interested in natural gas vehicles should contact their local gas supplier to receive information about the location of filling stations. Depending on the gas demand of the fleet, the gas supplier could be interested in investing in the filling station. Natural gas filling stations have an advantage in that they have a demand for natural gas which does not depend on the season, such as the heat NG market.

Typically the gas company and the fleet operator agree on a minimum amount of natural gas supply and a fixed price for the natural gas which may be scaled according to the amount of natural gas sales.

- **CNG refuelling in Athens**: The municipality bought the compressor, but the gas supplier DEPA provided a standard cabinet, regulator, and meter. DEPA also supervised all construction work for the connection of the compressor to the pipe network.
- **CNG in Bremen**: Two public refuelling facilities have been implemented by Shell and Esso, a third private facility was financed by the gas provider Enordia and is used for its own fleet.
- **CNG fast fill in Merton and Sutton**: Stations built by British Gas on the basis of ten-year fuelling agreements.
- **Biogas refuelling in Stockholm:** Stockholm produced four refuelling sites for biogas in co-operation with the fuel providers OK, Q8, Statoil, and Shell. The fuel is locally produced at the local sewage facility.

2.4 Land use planning for refuelling stations

Before any infrastructure is ordered, review land use regulation for any possible restrictions that may affect infrastructure siting. In most cases, these regulations have been written with petrol or diesel infrastructure in mind, and obtaining variances or permits can take considerable time and effort. Safety is of particular concern in planning infrastructure, especially when tanks or other equipment are housed underground or have special ventilation requirements.

Land use planning can also be a tool for the optimal siting of infrastructure. For example, Geographic Information System (GIS) analysis can help determine which available site best serves a certain fleet, or calculate the municipal "coverage" of several vehicles.

3 Emissions of natural gas vehicles

NGVs are known for their overall contribution to cleaner air and lower emissions than either petrol or diesel vehicles.

Emissions compared to petrol vehicles

Natural gas has low carbon monoxide (CO) emissions, emits virtually no particulate matter and has reduced volatile organic compounds (VOC). Per unit of energy, natural gas contains less carbon than any other fossil fuel, leading to lower carbon dioxide (CO_2) emissions per vehicle kilometres travelled. Cold-start emissions from NGVs are also low, since cold-start enrichment is not required, and this reduces both non-methane hydrocarbons (NMHC) and CO emissions. Specific emission reduction levels for NGVs compared to petrol are:

- CO, 60-80%
- Non-methane organic gas (NMOG), 87%
- NO_x, 50-80%
- CO_2, by about 20%
- Ozone-producing reactivity, 80-90%

(These numbers will vary depending upon the comparative vehicles used, however, they can be considered representative of the average vehicle populations.)

Evaporative & refuelling emissions

Another emission benefit is achieved when fuelling NGVs. Petrol vehicles have evaporative emissions during both fuelling and use. These emissions account for approximately 50% of a vehicle's total hydrocarbon emissions. Natural gas, because the vehicle system is a closed, pressurised system, has no evaporative emissions.

Emissions compared to diesel vehicles

There is a wide range of diesel engines of different sizes, used for various applications. When running on diesel fuel, these engines function on the 'heat of compression'. The diesel fuel is pressurised in the cylinder head and then 'auto-ignites' when put under pressure. One hundred percent natural gas used in a diesel engine functions only if a spark plug is introduced, since natural gas ignites at more than double the temperature of diesel. Thus, the diesel engine retains the heavy duty long life characteristics of its original design but is transformed into an Otto cycle engine (like gasoline). The best emissions results typically come from dedicated natural gas engines although there have been some breakthroughs in dual-fuel technology.

Emissions reductions from using natural gas in heavy duty engines typically are in the following ranges:

- CO, 70-90%
- Non-methane organic gases, 40-60%
- NO_x, 80-90%
- Particulate Matter (PM_{10}), 90-95% (Note: Much of the particulates emitted tend to be from engine lubricating oil encroaching inside the piston head and is not a direct result of the natural gas fuel.) [Energy Information Administration, homepage]

NGVs global warming contribution

Many people are concerned about the global warming potential (GWP) of NGVs because these vehicles emit amounts of unburned methane (a non-ozone forming hydrocarbon) that typically is in excess of the existing total hydrocarbon (THC) standard for petrol vehicles. Methane is, in fact, a global warming gas, however, compared to petrol vehicles, considering CO_2 and methane, the GWP of an NGV is about 20% less than a petrol vehicle and about the same or slightly less than a diesel engine. Natural sources of methane emissions – livestock, rice fields, termites, etc. – produce far more methane than will be created by hundreds of thousands of NGVs on the road.

For example, the German Ministry of Environment estimates that, if 10% of the diesel fuel was replaced by natural gas, the contribution of the total methane emissions in Germany would be between 0.0004% and 0.0017%, depending upon the type of engines being used.

Noise emission

Noise emission from vehicles poses a serious pollution problem for human beings. Natural gas powered vehicles operate quieter than, in particular, diesel vehicles. This is important especially when the vehicle is operated in public transport. The Natural Gas Bus Project Berlin recorded the noise of different bus types running on both diesel and natural gas[1].

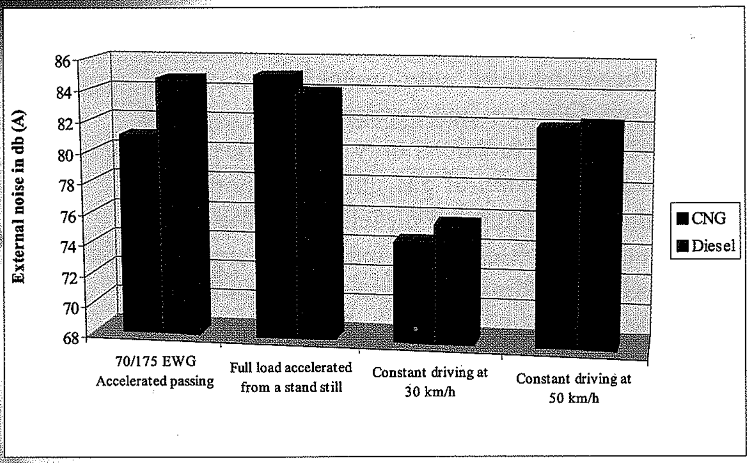

Fig. 3-1: Comparison of external noise in CNG and diesel bus

Fig. 3-1 shows the results of the external noise recordings. The values measured at a constant speed of 30 km/h and 50 km/h as well as from simulated acceleration away from a bus stop differed between diesel and CNG by approximately 1 dB(A). The accelerated overtaking showed a noticeable difference in favour of the natural gas vehicle by 3.3 dB(A). An increase of 3 dB is equal to a doubling of the noise effect. [The Natural Gas Bus Project Berlin, 1998]

A decision based upon emissions reduction

Many policy makers look to NGVs as one of the solutions to urban pollution, based upon how many *tonnes emissions reduced* can be achieved. This can be factored into a cost/benefit analysis and compared to the results using other alternative approaches to reduce pollution.

Most NGV users in the average corporate fleets, however, tend to look at the economic benefits and are less concerned about the emissions aspect, although it still is a factor in making a decision. Other NGV users who are concerned specifically about on-site pollution, such as at an airport, will put much higher priority on the emissions benefits of NGVs.

Supporters of petrol and diesel vehicles make claims that the newest technologies, coupled with the use of new 'clean' petrol and diesel, negate the need for alternative fuels such as natural gas. Consider these factors:

- The new generation of petrol vehicles are cleaner than ever before. Computer control technologies, new catalysts and low sulphur petrol can compete with some, but not all, light duty bi-fuel NGVs because the NGVs systems have to be balanced to fit different characteristics of two fuels. However, the emissions from a dedicated light duty NGV will be very hard to beat, even for some electric vehicles if the full fuel cycle emissions are taken into consideration.
- The new generation of diesel vehicles – particularly the heavy duty types – also are cleaner than previous generations of vehicles. Many of these new diesel catalysts and continuously regenerating traps (CRTs) will be destroyed if low sulphur fuel is not used and, furthermore, many of these systems have not been fully tested as to their durability and effectiveness over time[2].

4 Economy of natural gas vehicle operation

4.1 Cost of diesel, gasoline and natural gas

The differential in the price of natural gas versus the prices of diesel and petrol is the key factor in determining the overall economics of any conversion to NGVs. The other factor is the amount of fuel consumed by the various vehicles that will run on natural gas. Because natural gas generally is cheaper than the other fuels, the more fuel a vehicle consumes, the better the economic payback will be when factoring the NGV project economics.

As a general *rule of thumb*, if the price differential

[1] The noise measurement was carried out in accordance with 70/157 EWG of the European Union.

[2] Emission reduction figures are based upon data taken from the European Auto/Oil II programme and from U.S. Federal Government reports on Alternative Fuels

between natural gas and diesel/petrol is about 30% (natural gas being cheaper) then a *typical* fleet project can payback somewhere in the 3-5 year range, but possibly longer. When the price of diesel/petrol is 50% higher than natural gas, then payback periods fall more into a traditionally acceptable range for investments, in about 2-3 years. But this is a very broad generalisation since there are many factors that must be included in the calculation of each specific project's costs and benefits.

In some countries, natural gas has a clear price advantage against petrol and even diesel due to favourable tax reductions for natural gas. This benefit leads to a drastic shortening of the payback period for the investment in NGVs.

European fuel prices

Fuel prices vary widely country by country, mostly due to taxation. The tax rates on petrol across Europe range from about 64-81%; on diesel about 54-85%; and on natural gas from 0-65% [ENGVA,1996]

- The sale price of the three fuels *typically* shows that petrol is the highest cost fuel, varying by octane content; diesel is next highest priced and natural gas is the cheapest.
- Private, centrally fuelled fleets that purchase their own fuel in bulk directly from a wholesale company will find their fuel prices lower than the normal pump price at a public fuelling station.
- Public transport companies benefit often from special tax advantages on diesel.
- Over time, however, the prices of diesel fuel may change relative to petrol because some countries are beginning to change their fuel taxation policies because of suggested linkages between public health and diesel particulates.

Relative fuel prices – specifically tax rates – also are changing in different countries because of government environmental policies that are tending to favour the so-called 'clean' or 'environmental' fuels. For example (at the time of publication) in Switzerland, natural gas costs more than diesel or petrol unless it is from renewable resource *biogas*, in which case there is no tax on the fuel, making it cheaper than diesel/petrol. In Germany, tax on natural gas has been limited to 15% of the tax on petrol until the year 2009.

Natural gas prices

The price of natural gas as a vehicle fuel will vary widely, even within one country. This is due to a number of factors:

- Different natural gas companies charge different rates for their gas.
- Generally there are very few natural gas companies that have established a 'natural gas vehicle rate' for selling the fuel to the transportation sector.
- Traditionally natural gas companies sell gas on the basis of a 'declining block rate'. That is, the more gas a consumer uses (calculated in 'blocks' of consumption rates) the less the *unit price* will be for the gas. Thus, residential customers tend to pay the highest unit rate for natural gas and large industrial customers consuming vast quantities pay less per unit of gas supplied.

Many natural gas companies are offering, however, the preferred large customer rates for the natural gas sold as a vehicle fuel in order to be competitive against diesel and petrol and thus provide the best economics for the NGV customers. Also, natural gas companies, unlike diesel and petrol suppliers, often are willing to enter long term contracts (2-5 years) for the fuel. This can lead to improved, more stable gas prices for customers. For large fleets, such as city buses, this can provide a strong economic incentive against diesel prices that tend to fluctuate in different economic conditions.

For the vehicle customer, therefore, it is very important to be in close contact and negotiation with the local gas supplier in order to get the most favourable rate for natural gas relative to diesel and petrol.

4.2 Payback period of natural gas vehicles

Next to the fuel price the investment costs are the crucial factor for the determination of the payback period of NGVs. Today, due to the low number of NGVs produced, NGVs are suffering under a higher sales price than comparable diesel or petrol vehicles. The following Fig. 4-1 gives some examples of the additional costs for purchasing NGVs.

The payback period for investment in NGVs is calculated using the additional investment, maintenance and fuel costs.

The fuel costs depend on two factors, the fuel price and the fuel consumption, which results from the efficiency of the engine. For the comparison of the energy consumption of diesel, petrol and natural gas driven vehicles a common base is necessary which for the example below is the heating value of the fuels H_u, expressed in kWh. Fig. 4-2 shows the cal-

Manufacturer	Vehicle type b = bi-fuel m = monofuel	Additional net costs (Euro)
	Original Equipment Manufacturer	
BMW	316 g Compact (b)	3,000
Daimler Chrysler	Sprinter (m), different editions	5,000 – 7,500
FIAT	Marea (b), Multipla (b), Multipla (m)	1,500
Honda	Civic GX (m)	1,750
Iveco	Daily 35.11 CNG (m) Daily 49.11 CNG (m) Heavy duty truck MH 260 E CNG (m)	5,000
MAN	Low-floor articulated bus NG 232 CNG (m) Low-floor articulated bus NG 313 CNG (m) Low-floor standard bus NG 232 CNG (m) Heavy duty truck LT 38 K 06 CNG (m)	40,000 57,500 37,500 37,500
	Manufacturer Authorised Conversion	
Ford, GFI Mainz	Ford Ka Ford Fiesta Limousine, 60 l tank Ford Fiesta Limousine, 80 l tank Ford Mondeo Turnier Ford Galaxy Ford Fiesta Courier Ford Transit van, 80 l tank Ford Transit van, 2 x 80 l tank Ford Transit Pick-up	3,300 3,350 3,400 3,350 3,450 3,050 2,950 3,850 4,500
Volkswagen, IAV Berlin	VW Polo 1.4 VW Polo Variant 1.6 VW Caddy 1.4/1.6 VW Golf IV 1.4/1.6 VW Golf III Variant 1.6 VW Passat, VW Passat Variant 1.6 VW T4/2.0 VW LT II 2.3	4,400 4,450 4,250 4,500 4,300 4,850 4,650 5,700

Fig. 4-1: Additional costs for natural gas vehicles (list is incomplete) [Stadtwerke Augsburg, 2000]

culation of the payback period for the Fiat Multipla. As another example the same calculation is possible for natural gas powered buses using the following parameters.

- MAN standard bus: diesel consumption: 40 l/100 km, natural gas consumption (H_u 10 kWh/Nm³): 55 Nm³/100 km
- MAN articulated bus: diesel consumption: 52 l/100 km, natural gas consumption (H_u 10 kWh/Nm³): 72 Nm³/100 km.

As a result, the NGV Multipla reaches the payback after less than 35,000 km. For other cars similar val-

	Multipla natural gas	Multipla petrol super	Multipla diesel
Additional vehicle costs, incl. VAT	1,750 Euro	-	1,750 Euro
Fuel price, incl. VAT	0.58 Euro/kg	0.97 Euro/l	0.76 Euro/l
Consumption	5.6 kg/100 km	8.60 l/100 km	7.90 l/100 km
Fuel costs	3.25 Euro/100 km	8.34 Euro/100 km	6.00 Euro/100 km
Fuel cost savings • against diesel • against petrol	 2.75 Euro/100 km 5.09 Euro/100 km		
Payback • against diesel • against petrol	 0 km 34,381 km		

Fig. 4-2: Determination of the payback period for natural gas vehicles, German example

ues are achievable, depending on the amount of the additional investment costs, e.g. Honda Civic 53,000 km.

Initial maintenance costs of natural gas vehicles can be expected to be slightly higher than the costs for conventional vehicles due to a "learning curve" effect caused by higher technical efforts for the natural gas engine and the fuel tanks. After the initial period, maintenance costs can be even lower than for conventional vehicles because the use of natural gas results in less wear and tear on cylinders, rings and spark plugs. However, the intervals between oil changes can increase by a factor of two, three or more and due to the greater weight of the natural gas vehicles a higher tire rub-down can be expected, especially for buses.

For cars and light-duty vehicles, maintenance costs can be estimated to be 5% of the conversion costs (excluding the costs for the storage bottles). For the yearly inspection of the high pressure tanks a lump sum of 50 Euro can be calculated. [BGW, 1997]

Vehicle taxes will also affect the pay-back. Some countries reduce taxes for "clean" vehicles, e.g. in Germany, vehicles which conform to Euro 3 standards are exempt from taxes. On the other hand, when taxes are based on vehicle weight (i.e. The Netherlands) NGVs are at a financial disadvantage.

In addition, with regard to the national economy the reduced external costs as a result of lower emissions have to be taken into consideration.

5 Guidelines on usage

5.1 Indoor parking

Can a natural gas vehicle be parked safely in an indoor parking garage? What happens if there is a gas leak? Will an explosive situation occur?

Since natural gas is lighter than air, if a leak occurs the gas disperses upwards. The relatively low flammability range of natural gas – 5-15% natural gas to air – makes it difficult to ignite when adequate ventilation is available. Ventilation systems have to be integrated into the garage roof to allow dissipating gas to be removed safely.

Two types of garages

While there is a wide range of parking garage designs and different building codes regulating them, they all tend to have two common features: open space for parking and the need for ventilation to mitigate the results of carbon monoxide (CO) released by vehicle exhausts. Two types of ventilation systems are typically used: natural circulation with open building sides and forced circulation for enclosed structures. These features mitigate the effects of natural gas leaks.

A definitive study shows CNG is no problem

A landmark and definitive study on this topic was done in New York City, and was used in a number of major metropolitan areas to help encourage urban regulators to treat NGVs as they do petrol and diesel vehicles. The study, which used sophisticated modelling and empirical testing found:

"If a small leak occurs it resulted in no hazard beyond a few centimetres from the leak, and there was no build-up of gas anywhere in the garage. In the worst case, a full discharge (of a natural gas cylinder), did result in a flammable mixture of gas in the garage, but this situation was quickly mitigated by the dispersion of gas into the open space and its removal by the ventilation system. Only a small fraction of the natural gas released was in the flammable region at any one time, and there was no permanent build-up of gas in the garage. Maximum concentrations were reached in a few seconds to a few minutes and declined rapidly thereafter.

A CNG vehicle poses no extraordinary risk in a typical parking garage; that is, the risk of the CNG vehicle is equal to or less than the risk posed by a gasoline fuelled vehicle. This conclusion is valid for both forced and natural circulation type garage designs, and should cover every type of public parking garage normally encountered. Certain unusual situations might not be covered and this includes garages with no ventilation, a garage with no ceiling vents or a garage with a low flow carbon monoxide sensor. Overall, parking in public garages is not a major CNG safety concern." [Ebasco Services Incorporated, 1991]

5.2 CNG vehicle safety in case of an accident

Vehicles running on natural gas, carrying high pressure cylinders, often are perceived as having greater concerns about the safety in case of an accident. Based on various accident statistics it is clear that vehicles running on compressed natural gas are as safe or safer than vehicles operating on traditional fuels such as gasoline or diesel [DNV Technical Report, Annex 9, 1992].

Safety regulations for all fuels – whether liquid or gaseous – will generally ensure that the risk of a fire under normal operating conditions is very small. So it is generally in the event of a crash or equipment failure that a hazardous situation occurs.

A US survey of more than 8,000 vehicles that cumulatively travelled approximately 278 million miles from 1987-1990 found that the injury rate for NGVs per vehicle mile travelled (VMT) was 37% lower than the rate for gasoline-powered fleet vehicles and 34% lower than the entire population of registered gasoline vehicles. In addition to the lower injury rate, no deaths were recorded for the NGVs in the survey. In contrast the deaths associated with the gasoline fleet vehicles surveyed came to 1.28 deaths per 100 million VMT. The US national average was 2.2 deaths per 100 million VMT for all U.S. gasoline vehicles. [IANGV homepage]

There are two fundamental reasons for this excellent NGV safety record: the structural integrity of the NGV fuel system and the physical qualities of natural gas as a fuel.

The fuel storage cylinders used in NGVs are much stronger than gasoline fuel tanks. For example, in the US the design of NGV cylinders are subjected to a number of required "severe abuse" tests, such as heat and pressure extremes, gunfire, collisions and fires.

Thick-walled reinforced aluminium cylinders, steel cylinders or 100% composite materials are used to store compressed natural gas as a vehicle fuel. These cylinders are manufactured and tested in compliance with strict regulations, and have withstood severe abuse testing under conditions far more stringent than gasoline fuel tanks. Natural gas vehicles submitted to test crashes up to 52 miles per hour, which have been totally destroyed, show little or no damage to the compressed gas cylinders. Bonfire and dynamite tests push cylinders to temperature and pressures exceeding specified limits showing that compressed natural gas cylinders are durable and safe. Further, the fuel system components may be physically protected or located so that the likelihood of damage upon a crash is minimised. Of course, as with all fuel systems, these cylinders are not indestructible and should be inspected periodically to ensure that no surface damage has occurred.

Gas cylinders are equipped with pressure relief devices and shut off valves which automatically shut off the gas supply in the event of tube rupture or when the motor is turned off (e.g. in an accident). To avoid the danger of explosion in a fire, a burst-disc and a melt fuse ensure the controlled release and burning of the pressurised gas before a rupture through overheating may occur [DNV Technical, Annex 10, 1992].

While fuel storage cylinders are stronger than gasoline fuel tanks, the composite material used to encase the tanks are fundamentally more susceptible to physical damage than metals under abusive conditions. For this reason, composite materials on NGV cylinders must be properly handled. After several incidents involving natural gas cylinder ruptures due to some form of chemical attack or physical damage to the composite overwrap on the cylinder, new materials have been developed that reduce the risk of damage and thus increase safety.

Additionally, NGV fuel systems are "sealed," which prevents any spills or evaporative losses. Even if a leak occurs in an NGV fuel system, the natural gas dissipates into the atmosphere because it is lighter than air and, unlike liquid fuels does not pool on the ground. Natural gas has also an oderant added so that any leakage can be detected.

Natural gas is not toxic or corrosive and will not contaminate ground water. Natural gas combustion produces no significant aldehydes or other toxins and volatile organic compounds, which are a concern with many fuels.

5.3 Fuelling safety aspects

Natural gas is dispensed into vehicles through sealed systems designed to allow natural gas into the vehicle without any leakage into the atmosphere. In dispensers utilising ANSI-NGV1 nozzles, unless the nozzle is connected to a receptacle on a vehicle, natural gas will not flow.

In case the car drives away with the nozzle still connected, an in-line break-away device positioned in the refuelling hose will disconnect. The flow from the compressor is stopped instantaneously by a check valve and prevents damage to the filling station. Also the check valve on the vehicle will close automatically and stop further flow from the tank [Stäubli, 1998].

6 Support for implementation

6.1 Gas company support

Every gas company approaches the NGV market and its customers slightly differently. Some will be extremely enthusiastic and helpful. Others may not have an NGV marketing programme and be less helpful. If the company is not particularly enthusiastic about the vehicle market, your reception at the gas company when you go looking for assistance may be disappointing. Ask if any of the company's natural gas transmission companies might be able to help. Alternatively, inquire about assistance from a national natural gas or NGV association.

What are you looking for?

When you approach the company, you may be looking for information about:

- vehicles
- refuelling stations
- natural gas prices
- NGV programmes and subsidies available from your local or national government

The gas company should be able to help you 'size' the fleet; that is, determine the size compressor that you will need to fuel your vehicles. This will be determined by a number of factors, including: total fuel storage on board; daily driving distances; fuel consumption; and fuelling patterns, be they once a day or multiple times. Additionally, the gas company also may be able to help determine the best vehicles for conversion, if that is your choice. Or, many of them have contacts with original equipment manufacturers (OEMs) who would be ready to provide information about the availability of NGVs or companies that convert vehicles to NGVs.

When fuel dispensers fail

The experience of Helsinki, Finland

Early one Saturday morning in January 2000, the compressor for HKL Ruskeasuo CNG station broke down. Usually the station serves about 30 CNG buses, 22 of which belong to Helsinki's public transit company, HKL. After some attempts to fix it locally, it became evident that the station would be down for about two weeks, as the broken part had to be taken to Italy to be fixed.

CNG buses have been specified for use in the competitive bidding for particular routes. If the operator is unable to use the bus type specified for the route, it has to pay a penalty. Also, finding temporary replacement buses for 22 buses in a very short space of time is not easy. Thus, the aim was to get the CNG buses running as soon as possible.

To be able to avoid a stop in operations in the event of a CNG station failure at Ruskeasuo, plans were to use the smaller capacity station in Pirkkola (15 buses per day) which would be kept in operating condition for this purpose. However, some oil deposits had been detected in the CNG tanks of the first 11 HKL CNG buses refuelled at the Pirkkola station, so HKL had previously decided that the newer 11 buses should not be refuelled at Pirkkola. Thus, 11 CNG buses had no alternative but to be removed from service until the Ruskeasuo station could be fixed.

To make matters worse, the first attempts to refuel the remaining buses at Pirkkola failed. Suddenly, all 22 buses were out of service due to lack of fuel. After several hours of maintenance and a two-day CNG shortage, on Sunday evening it was finally possible to refuel at the Pirkkola station. To keep at least the 11 older CNG buses running, it was decided to refuel them overnight one after another, since the refuelling round-trip from the depot took about 45 minutes. This meant that one person had to work the night-shift to refuel the 11 buses for two weeks!

The episode finally ended happily when the Ruskeasuo station began to work again after new parts arrived from Italy. As the break-down happened during the warranty period, the repair costs were covered by the station manufacturer. The other costs incurred due to the time and expense of having buses out of service were covered by the CNG station's contractor as stipulated in the station's contract with HKL. Though the story had a happy ending, it does emphasise the importance of being prepared for almost anything, having a back-up system ready and well-maintained, and having a fuel supply contract that does not leave the bus operator in trouble should the fuel supply temporarily be cut off.

6.1.1 *Installation of a fuelling station*

Every gas company approaches this differently, and there are various financial (and financing) options that are available. Here are some examples of what you might find when discussing the installation of a fuelling station:

- **Installation on your own property.** If the fleet is centrally fuelled and you normally take charge of your own fuelling operations (such as in large bus fleets), then installation of a compressor station on your property is most likely.
- **Creative options** may also be possible if the gas company is highly motivated in the NGV sector. Some fleets actually allow vehicles of other companies onto their property for fuelling. (You should inquire whether this is possible for your fleet, too) Sometimes it may be possible to install a fuel dispenser outside the perimeter of your company so that other fleets can fuel. In this case, an arrangement with the gas company to install a computer card system would allow the gas company to bill any customers on a monthly basis, if need be.
- **Public fuelling**. Some countries are aggressive in building fuelling stations. So the idea of using public stations, as is done for diesel and petrol, is particularly attractive and costs nothing extra to you, the NGV customer.

If you wish to install a fuelling system on your own property, the gas company should be able to assist with codes, safety standards and all aspects of preparing and building the station. Alternatively, they may direct you to any number of private contractors who can help you as well. In this case, the gas company should be able to assist you in developing a bid specification to provide to different contractors to acquire competitive estimates for the work to be performed.

The complexity of installing a fuelling station will vary depending on its size, characteristics of your own site, and whether it is fast fill, slow fill, or both. Access to a natural gas pipeline required and electricity will have to be provided on site as well. Again, the local gas company and/or contractor will be able to provide you with assistance.

The type of garage can also affect project implementation and staff costs. In Helsinki, for example, diesel buses have automatic indoor refuelling, while CNG refuelling is outdoors and requires the presence of maintenance personnel. This means that the staff cannot use the refuelling time productively by cleaning the vehicles or checking oil, refilling other fluids etc. as they can with diesel. The gas buses must be first refuelled outside, then driven in for the other manoeuvres, and this takes extra time. In wet and cold climates this may also affect the acceptance of these vehicles by maintenance staff.

6.1.2 *Servicing*

Either the gas company or one of its local contractors should be available to service your station. Reliability of the station operation is critical in order to keep your vehicles on the road. It will be important to establish up front, with the gas company and/or its service company the terms and conditions of servicing. Everyone must realise that all mechanical devices either break down or need to be serviced. With critical facilities like fuelling stations, it is important that, whatever goes wrong, servicing can be done in a timely fashion. For very large fleets, redundant (backup) systems are critical. But here again, look to the gas companies for such technical advice and help.

6.2 Government support

There are a growing number of programmes in different countries that provide financial and other incentives to NGV customers. This ranges from tax incentives (credits, deductions, etc.) to other financial incentives such as grants for vehicle purchases or fuelling station installation. In some cases, clean fuel vehicles may be allowed to park free in certain locations, or to drive in traffic lanes normally accessible only to taxis and buses. The local gas company representative or the national gas (or NGV) association should be knowledgeable about incentive programmes in your area, and advise you where to go for more information (Please refer to section 9 for useful addresses where you can get further information).

7 Available standards

Standards are an important instrument for the systematic development of a new technology. Standards serve the harmonisation of NGV technology at an early stage, facilitate the exchange of goods, increase safety and/or protection of persons, goods and the environment as well as services in Europe and safeguard consumer interests (lower prices, more choice).

A well written standard gives planning security, defines the state-of-the-art and documents the due safety and reliability level.

In order to receive this for the Natural Gas Vehicles Technology standards are developed at European level in co-operation between the European standard institution CEN (Comité Européen du Normalisation) and ISO, the International Standardisation Organisation.

CEN Technical Committee 326 is the group responsible for developing NGV equipment standards in the European Union. It includes working groups (WG) developing European standards on gas safety requirements for filling station systems and vehicle fuel systems, including NGV conversion systems. WG 1 covers essential safety issues, design and construction requirements as well as the installation of a code of practice for outdoor and indoor refuelling.

WG 2 deals with safety issues, design and construction requirements for NGV fuel systems from the filling nozzle to the motor conversion system. This includes on-board fuel storage systems such as storage cylinders, pressure relief devices, cylinder valves and the installation code for cylinder mounting.

WG 3 concentrates on the operations conditions:

- Customer quality assurance in filling operation, especially safe fuelling condition and optimal filling charge
- Certification of NGV technicians for conversion, diagnosis and repair of NGVs
- Recommended requirements for NGV garages and workshops

For further and regularly up-dated information on NGV standards please refer to the home page of the IANGV: http://www.iangv.org/sources/standards.html.

In addition, the European Commission has developed several directives to regulate European type approval on vehicle homologation (Please refer to Fig. 7-1).

Approved international standards:

- ISO ISO/DIS 11439: High Pressure Cylinder for the On-Board Storage of Natural Gas as a Fuel for Vehicles

International standards in preparation:

- ISO TC22/SC25/WG1: Refuelling Connector (TC Technical Committee, SC Sub committee, WG Working Group)
- ISO TC22/SC25/WG2: Design Principles and Installation of Vehicle Fuel Systems
- ISO TC22/SC25/WG3: NGV Fuel System Components
- ISO TC58/SC3/WG11: Gas Cylinders of Composite Material
- ISO TC58/SC3/WG17: High Pressure Cylinders for On-Board Storage of NG
- ISO TC193: Natural Gas Composition Designation for Use as a Compressed Fuel for Vehicles
- CEN TC23/SC1: High Pressure Cylinders for On-Board Storage of NG
- CEN TC326/WG1: Safety Requirements for Refuelling Stations
- CEN TC326/WG2: NGV Fuel Systems
- CEN TC326/WG3: Safety in Natural Gas Filling Operations

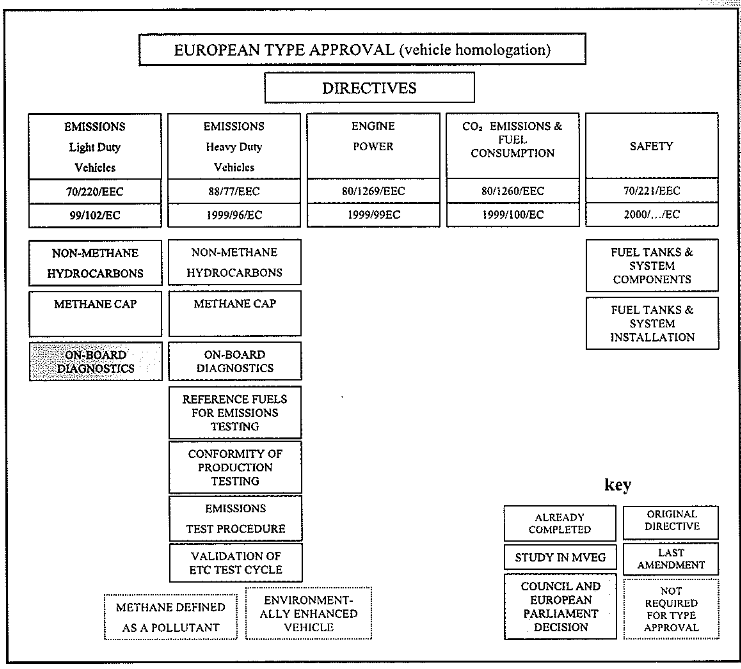

Fig. 7-1: European type approval on vehicle homologation