Advantages - Natural Gas for Vehicles:

Major *Commercial*, *Environmental*, *Security* and *Technical* benefits over petrol and diesel:

Abundant local supplies – vast reserves, without relying on imports

Cheap – a fraction of the cost of petrol and diesel

Readily available – excellent 24-hour infra-structure – fuel already piped to (or near) most fleets

Safe
Extremely strong storage tanks
Gaseous fuel – disperses and diffuses quickly
Lighter than air – any leaks quickly rise
High ignition temperature – 650 ^{0}C compared with 300 – 400 ^{0}C for petrol
High lower-flammability-limit – 5% volume in air, compared with 0.6% for petrol
Non-toxic (anaesthetic only)

Clean-burning
Much less CO (carbon monoxide) harmful emissions -
Much less HC (hydrocarbon) harmful emissions -
Much less NOx (oxides of nitrogen) harmful emissions -
No fine particulates (dangerous respiratory) emissions -
Much less emissions during cold starts – no choke (enrichment) required
Simple fuel molecules - less *Greenhouse Gas* emissions – carbon dioxide
The few hydrocarbons formed are not "*radical*" – do not form "smog"
Power/economy-robbing emission controls not required

High-octane rating
Prevents detonation – less susceptible to pre-ignition
Permits higher compression ratios – more power for the same fuel flow
Permits turbo-charging – more power, without engine modifications
Slow-burning – smoother power and quieter combustion – less NOx

Gaseous fuel
Does not wash lubricating oil off the cylinder bores – much less wear
Does not get trapped in piston rings to form high hydrocarbons
Does not dilute the lubricating oil
Does not form carbon – no abrasive carbon in lubricating oil
Does not form smoke – even if the mixture is very rich
Cannot foul spark-plugs – vital for emergency-service vehicles
No fuel line freeze-up in cold weather – no water in fuel system
Mixes evenly and quickly with the induction air – even air/fuel ratios
More tolerant to very lean mixtures – will not melt pistons

No losses
No evaporative losses – completely sealed system
No pilferage

Less maintenance
Longer oil and filter life
Longer engine life – no abrasives in oil, no dilution of oil
Longer spark-plug life – no fouling
Simple fuel system – reliable and very easy to diagnose and service
Less break-downs due to engine problems

Natural Gas:

NGV - Natural Gas [for] Vehicles has been receiving much attention around the world in recent years, as being *the* automotive fuel of the future. There are many sound reasons for this.

Natural gas, which consists normally primarily of methane and a small amount of ethane, is the "simplest" fuel in the hydro-carbon family, and as such, has many significant advantages over other fuels, especially petrol blends which are a long way down the family tree, and have highly complex chemicals in them. A major advantage of methane - which has the formula of CH_4, meaning that each molecule consists of just one carbon atom and four hydrogen atoms - is that it forms very few harmful pollutants. In fact, the hydrocarbon emissions from a natural-gas powered engine are not "*radical*"... in other words, they do not react with sun-light and oxides of nitrogen to form photo-chemical smog.

Fuel	Chemical Name	Formula	Boiling Point ^{0}C	Octane	Energy	Density
Natural Gas	Methane	CH_4	-160	130	50.0 MJ/kg	0.55
Natural Gas	Ethane	C_2H_6	-90	115	47.5	1.05
LP Gas	Propane	C_3H_8	-40	110	46.3	1.5 & 0.5
LP Gas	Butane	C_4H_{10}	0	105	45.6	2.1 & 0.6
Petrol	Hexane, etc.	(2n + 2)..	25 – 215	91 - 96	42.7-43.5	0.71-0.78
Diesel			180 – 360	Cetane	42.5	0.81-0.85
Bitumen, etc.						

Stoichiometric: Methane 10:1 Ethane 15:1 Propane 24:1 Butane 32:1

% by weight: Methane 75 C; 25 H Propane 82 C; 18 H Petrol 86 C; 14 H Diesel 87 C; 13 H

$CH_4 + 2O_2 = 2H_2O + CO_2$

$C_5H_{12} + 8O_2 = 6H_2O + 5CO_2$

$2C_5H_{12} + 15O_2 = 20H_2O + 4CO_2 + 4HC + 2CO$

Natural gas is always a gas (except as discussed later under LNG), both in the storage cylinder, and when it is metered into the engine. LP Gas, on the other hand, is stored (under pressure) as a liquid. This is the biggest draw-back to NGV... because it can only be (conventionally) stored as a gas, it creates two disadvantages: (1) The storage pressure has to be quite high - typically 20.6 MPa [3,000 psi] - hence the cylinders and fittings have to be very strong and reliable, and (2) The driving range is significantly reduced, compared to liquid fuels. The fuel is dispensed as a gas, but is measured and priced in terms of "*equivalent* litres of petrol"; a ball-park comparison is that 0.75 standard cubic metres of natural gas will drive a vehicle the same distance as one litre of petrol. [Imperial: 120 standard cubic feet of natural gas will drive a vehicle the same distance as one gallon of petrol].

The gas is compressed 200-fold, from 103.3 kPa to 20.6 MPa (at a reference of 20 ^{o}C.), hence 3.40 SCM of gas would require a cylinder of 0.017 cubic metres internal volume. [Imperial: from 15 psi to 3,000 psi (at a reference of 68 ^{o}F.), hence 120 SCF of gas would require a cylinder of 0.6 cubic feet internal volume.] A large oxygen-bottle sized cylinder would provide the equivalent driving range of around 4 gallons of petrol. For most applications of city vehicles, this is quite sufficient. Depending on the vehicle and the pay-load, multiple cylinders can be used. A fleet of school buses, each of which had 32 cylinders under the floor, gave a driving range of around 320 km, which was fine for a full day's operation; that fleet had something like an overall 68% savings in fuel and maintenance costs.

For trucks, it is usual to use steel oxygen-type cylinders. For cars and vans, it is preferable to use composite aluminium/fibreglass cylinders; while these cost around 60% more than a comparable steel cylinder, they are around 40% lighter, and will not upset the handling the vehicle nearly as much.

Whereas propane (LP Gas) gas is 1.5 times heavier than air, methane is only *half* the weight of air. This is a major safety benefit, in that any leakage will rise, and *not* settle in low spots (such as garage pits, and the floors of car boots).

Natural gas also has a very high ignition temperature - even higher than that of LP Gas - hence it adds even more safety benefits in any accident situation. Of course, there always has to be a down-side to any benefit, and in this case it means that a much hotter (higher energy) spark will be required in the combustion chamber, in order to ensure that it ignites every time you want it to!

NGV is technically a superb automotive fuel, from a combustion point of view... it has a very high octane number (up to 130 RON), and very low susceptibility to pre-ignition. This means that the fuel can withstand a much higher compression pressure, without detonating. One can actually get “something for nothing” - extra power and fuel economy in this case - by increasing the compression ratio, or turbo-charging or super-charging the engine.

Because methane is at the top of the hydro-carbon tree, its boiling point is the lowest of all the hydro-carbon fuels, and its static flame speed is the slowest. This means that for the best get-up-and-go power and economy, you need plenty of low-down ignition advance (even more than for LP Gas); however, like LP gas, you do not get any internal cooling with natural gas, hence you need to limit the top-end advance.

An alternative to conventional on-board storage of NGV is Liquefied Natural Gas (LNG), where the fuel is stored as a (*very* cold) liquid, at low pressure (typically only 34 - 68 kPa, in a thermos-flask type of cylinder, consisting of a double-skin cylinder, with a vacuum between the skins to minimize heat transfer. The fuel is stored at around –160 ^{o}C; it is vaporized to atmospheric temperature before entering the mixer. The big advantage to this concept is that the driving range is increased by a factor of about 3, for the same size storage tanks. The disadvantage is that the cylinders are a quite expensive, and there are not many cryogenic refuelling stations around at the present time.

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Natural Gas Engines:

Natural gas is an *excellent* fuel for:

- Petrol (spark-ignition) engines, and
- Diesel (compression-ignition) engines.

For ***spark-ignition*** engines, natural gas can be used:

- Single-fuel, or
- Bi-fuel, where natural gas is used as the main fuel, but LPG (or petrol) is used as a “limp home” back-up fuel, or to extend the driving range; in this case, only *one* fuel is used at any time.

For ***compression-ignition*** engines, natural gas can be used:

- Converting the engine to spark-ignition, using natural gas as the *only* fuel, or
- Dual-fuel operation, where diesel and natural gas are used *concurrently*, that is, diesel is used to *commence* the combustion, and natural gas is induced into the induction air to *supplement* the fuel supply to the engine.

For ***compression-ignition dual-fuel*** engines, two alternatives are available:

- Leave the diesel fuel system completely standard, and simply add a small amount of natural gas - typically around 15% of the total fuel flow - to the induction air. This is an easy but important environmental and “good citizen” first-step introduction to alternative fuels, and provides a modest power increase and fuel cost saving, and appreciably reduces the:
    - smoke,
    - smell, &
    - noise, or

- De-rate the fuel delivery system, and add a much larger amount of natural gas - typically up to around 80% - to the induction air. This also increases the engine power, and provides a substantial reduction in fuel costs.

Note: It is important that everyone precisely understands what is meant by “bi-fuel” and “dual-fuel”. There is much confusion. Originally, and in many overseas countries, the above meanings were, and are, reversed. “Dual-fuel” LPG/petrol systems are, by the new definition, actually “bi-fuel” systems, where only one fuel is used at any time.

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Natural Gas Vehicles: Refuelling Facilities

It is every bit important to have a professional natural gas refilling system, as it is to have professional vehicle conversions.

There have been many cases overseas where the "lowest bid" got the job, resulting in a disastrous thumbs-down for the entire NGV project. With a cheap system, one vehicle will be able to refuel quickly, and the next in line will be acceptable, but subsequent vehicles will take for ever to refuel... and then only receive half a tank of gas.

There are two types of natural gas refilling:

Slow-fill & **Fast-fill.**

If you have vehicles that do not cover many kilometres each day, and return to the same depot every night, you can simply connect all of them directly to the compressor, and allow all night for them to refuel while they are parked. When all of the tanks are filled to the correct (temperature-compensated) pressure, the compressor will automatically stop. This is usually quite adequate for small fleets appraising the viability of natural gas, on a trial basis, as it does not require the expense of fast-fill dispensers. It is important to remember that with natural gas bi-fuel vehicles, they can run on the second fuel when the natural gas is consumed.

However, if you have some vehicles that travel a large distance each day, and require frequent refilling, it is necessary to add a fast-fill installation, so that they can be refuelled in a matter of minutes. In this case, cascade storage cylinders must be added to the compressor system; the compressors deliver gas at 24.8 MPa, hence the storage cylinders are filled to this pressure (at 20 ^{o}C). The vehicle cylinders can then be refilled (to 20.6 MPa simply by connecting them, via a hose, to the storage cylinders.

In order to provide a constant mass of gas in the cylinders at all times, the actual pressure at which refilling stops is controlled by a **"Dome-load Valve"**. This valve is an automatic temperature-compensating device, that shuts off the refilling at a lower pressure in cold weather, and at a higher pressure in hot weather. If one vehicle is refilled at -10 ^{o}C., and another is refilled at 40 ^{o}C., and the vehicles are not driven, the pressure in each cylinder would be 20.6 MPa when the temperature changed to 20 ^{o}C.

The "quality" or composition of natural gas varies considerably, from the different wells. It is important that the gas is prepared correctly before it is compressed and used in engines. Obviously any dirt must be removed, along with any undesirable impurities such as corrosive sulphur compounds. Of major importance is the dryness of the gas; a large water content will cause problems, particularly the formation of hydrites in the pressure regulators (reducers). Most high-pressure regulators on NGV engines have - like LPG converters - a heating chamber, through which runs engine coolant, to help prevent the formation of these ice-like crystals. Often the injection of alcohol (methanol) is required to absorb water from the gas in order to obtain a sufficiently dry fuel.

The prime design aspect of a fast-fill system concerns the manner in which the compressor supplies gas to the storage cylinders, and the way in which gas is dispensed from the storage cylinders to the vehicle cylinders. The storage cylinders are normally arranged in three "banks", or cascades, called the low, medium, and high-pressure banks.

It is vital to ensure that the top priority is to always have some cylinders topped-up to 24.8 MPa, otherwise it will be physically impossible to fill any vehicle cylinders (within a reasonable time span) to their maximum capacity.

Remember, there is no pump between the storage cylinders and the vehicle cylinders, hence you are relying solely on the pressure difference between the two lots of cylinders to provide the fuel flow.

The greater the pressure difference, the faster the filling rate; there will always be frictional (fluid pressure) losses in the filling hoses and valves, so it is always necessary to have at least 4.13 MPa pressure difference in order to achieve an acceptable filling rate.

The **"Priority Panel"** is a valve system that does its best to always ensure that the high-pressure storage cylinders are filled completely (24.8 MPa. When they are, it then directs the gas from the compressor to the medium-pressure cylinders, and when they are filled (again to 24.8 MPa, it directs the gas to the remaining storage cylinders. When all cylinders are completely filled, it automatically stops the compressor.

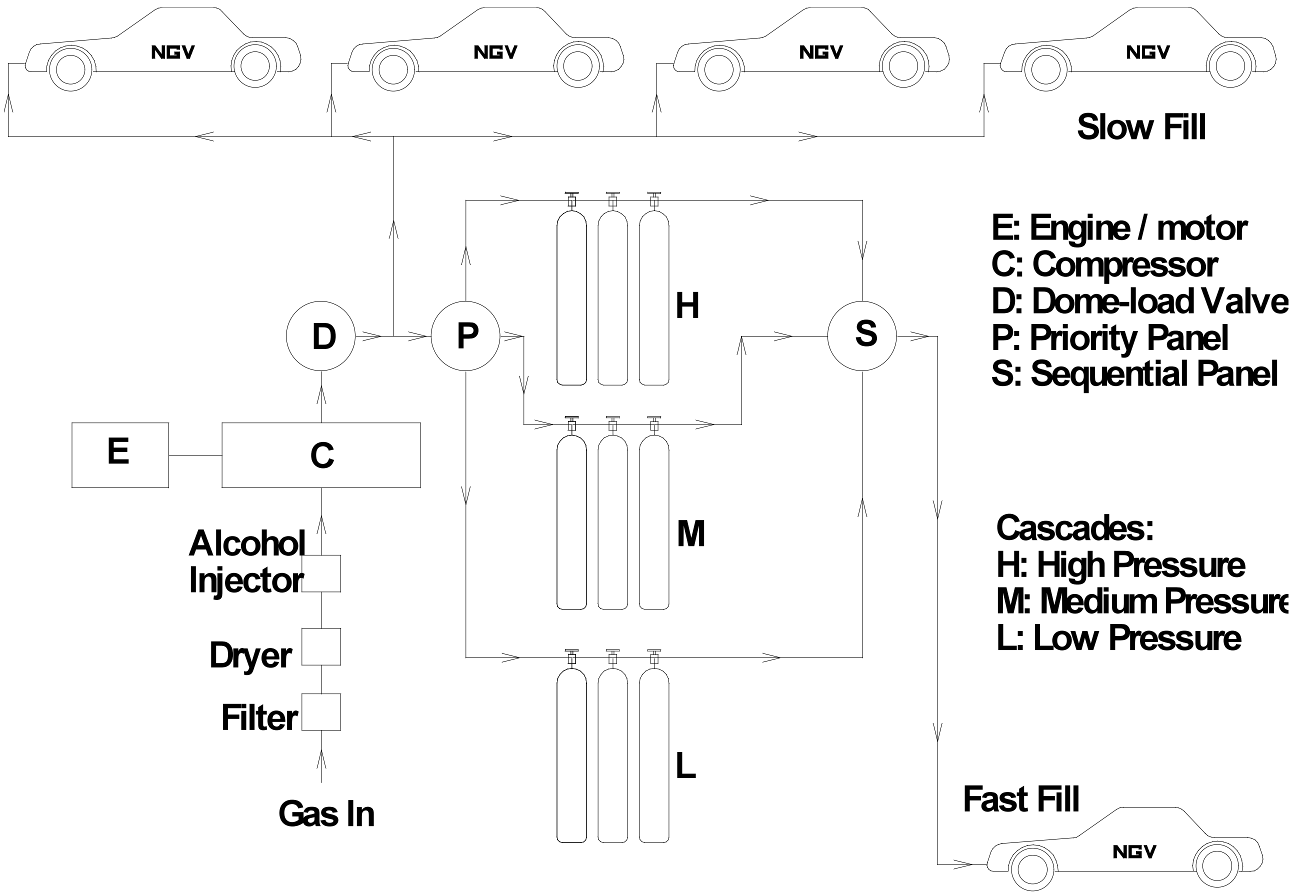
In reality, the size (cubic metres per minute) of the compressor, and the number of storage cylinders, must be determined accurately to provide a satisfactory facility, at the lowest possible cost. Needless to say, the cost of compressors rises roughly in line with their capacity, and storage cylinders are not cheap, hence it is important not to make an over-kill and buy a set-up that is way too big, or have a compressor that only needs to run 10 minutes a day. By the same token, compressors are not designed to run 24 hours a day, so it is important to make sure that they are not driven to destruction.

The **"Sequential Panel"** is a valve system that does its best to always ensure that vehicles are filled as quickly as possible, but more importantly, ensures that if several vehicles require refilling in quick succession, that the last in line will not have to sit there for hours. This is where "sizing" of the whole system is important, and where planning is advisable to ensure a roughly even rate of vehicle refilling during the day.

The panel will initially connect the low-pressure bank of storage cylinders to the vehicle cylinder; when the refilling rate - as determined by the pressure difference - drops below a pre-set value, it will then connect the medium-pressure cylinders to the vehicle cylinder, and when the refilling rate drops again, it will then connect the high-pressure cylinders to the vehicle cylinder, to ensure that the vehicle receives a "full tank".

To make it easier for those who, for safety reasons, prefer to still think in terms of imperial units - approximately 120 standard cubic feet of natural gas (methane) is equivalent, in driving range, to one gallon of petrol. If you want to travel as far on natural gas as you do on 4 gallons of petrol, you will need to carry 480 SCF of natural gas on board.

The gas is compressed 200-fold (from 15 psi to 3,000 psi) hence the actual internal volume of the cylinders will need to be 2.4 cubic feet. If you have 5 vehicles, and you wish to run a compressor for a conservative 10 hours a day, it would need to have a capacity of 4 CFM... 240 cubic feet per hour, times 10 hours, equals 2,400 cubic feet (which equals 5 times 480).



NGV Refuelling Facility

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