NATURAL GAS FOR VEHICLES 1995

ASIA-PACIFIC ECONOMIC COOPERATION

REGIONAL ENERGY COOPERATION WORKING GROUP

RESEARCH, DEVELOPMENT AND TECHNOLOGY TRANSFER THEME

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REGIONAL ENERGY COOPERATION WORKING GROUP

NATURAL GAS FOR VEHICLES

1995

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FOREWORD

The energy sector involves a large number of complex issues which are intimately associated with our way of life. Major issues include economic development and the importance of energy as an input to the development process, quality of life considerations, such as personal mobility and the impacts of energy supply and use on the environment. Addressing all these issues is too large a task for any one economy alone, making it essential that we cooperate to find solutions.

Although the answers will not be the same for all economies, there will be many issues where there are common factors and, even when the answers are different, we can learn from one another about ways of approaching a problem.

The use of natural gas in vehicles is a good example of this. In one economy it may be seen as providing a benefit by diversifying sources of supply, in another as a means of reducing imports and, in yet another, as a means of improving urban air quality. Another economy might be interested because of a combination of these factors.

For these reasons different economies in the region have concentrated on different aspects of natural gas vehicles and have developed different expertise. This publication is an attempt to draw some of this pool of knowledge together and to indicate where more information can be found. I believe that a publication of this nature will be instrumental in fostering technology and commercial cooperation between economies in the Asia-Pacific region.

It is with pleasure that I acknowledge the work of members of the Expert Group on Technology Cooperation who have given their time and expertise in preparing this publication. I am confident that their effort will be rewarded through the benefits that will accrue to member economies.

P. Amranand

Dr Piyasvasti Amranand
Chairman

Expert Group on Technology Cooperation

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INTRODUCTION

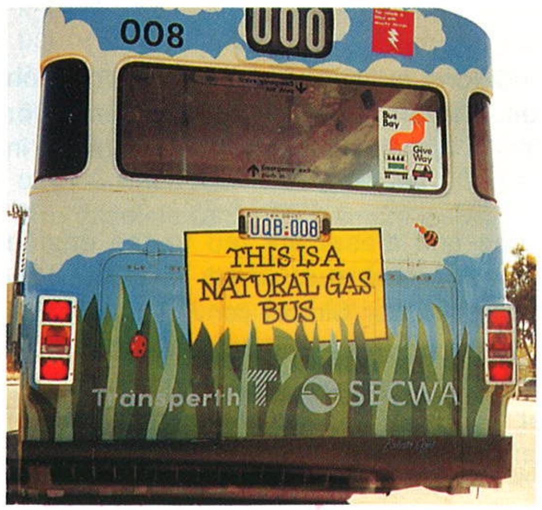
Energy demand in APEC member economies is growing at a rate unequalled anywhere else in the world. One of the major components of this growth is demand for liquid petroleum fuels for transport, which is growing as a result of increasing demand for transport.

While the rapid growth in energy use is underpinning increasing economic activity, it is also contributing towards some environmental and economic strains. These adverse effects include deterioration of air quality and increased traffic congestion in urban areas, and an adverse impact on the balance of payments from increased oil imports, or in the case of oil exporting economies, reducing the amount of oil available for export. These impacts will increase in the absence of effective measures, and will operate to constrain the levels of and benefits from further economic growth.

There are many options that can be used to help reduce some or all of these problems. For example, emission controls on new cars will help address the issue of urban air quality, while alternative transport fuels may help address balance of payments issues and possibly, depending on the fuel in question, the air quality issues.

One option which has the potential to contribute is the increased use of natural gas as a fuel for vehicles. Natural gas can substitute for conventional petroleum fuels derived from crude oil, enabling economies to diversify their sources of energy supply, and can also help address urban air quality.

Considerable development work on natural gas has taken place around the world, including New Zealand, the USA, Canada and Australia. Vehicles which use natural gas are known as Natural Gas Vehicles (NGVs).



A bus using natural gas, Perth, Australia

NATURAL GAS AS A VEHICLE FUEL (NGV)

Natural gas is a very good fuel for vehicles and can be used in almost all forms of transport. Its use, however does require modifications to the vehicle as well as the development of refuelling infrastructure.

Some vehicles can be modified to use natural gas quite readily and in these cases it is often practical to convert vehicles to use natural gas after sale. In other cases, more complex conversions are needed.

Engine conversions

Spark ignition engines in passenger cars and derivatives can be converted by a relatively simple process which involves the installation of a storage cylinder, valves, piping and a gas carburettor or micro-processor controlled fuel system. Such a conversion usually leaves the vehicle with the original gasoline fuel system intact so that the vehicle can switch from natural gas to gasoline use and back again. Selection of fuel simply requires operation of a switch. Vehicles converted in this way are known as bi-fuel vehicles and form the vast majority of natural gas vehicles in use in the world today.

This type of conversion costs around $US1000 to $US1500, slightly more than conversion to liquefied petroleum gas (LPG). The cost of the storage cylinder is a major part of the conversion cost.

One of the disadvantages of this type of conversion is that the engine is not optimised for the use of natural gas and is unable to take advantage of all its properties, including its high octane number and clean burning characteristics. As a result, retrofit vehicles usually suffer some degradation in performance compared with gasoline operation, especially a reduction in power output at wide open throttle, which may be as much as 15%. However purpose built cars which run solely on natural gas optimised to avoid this performance reduction, are becoming available in some economies.

Natural gas will not ignite under the conditions experienced in a compression ignition (diesel) engine. Heavy vehicles, therefore, are either converted or reconfigured to use a spark ignition engine, or converted to dual fuel operation in order to be able to use natural gas.

In a dual fuelled engine, both natural gas and diesel are fed to the engine simultaneously, with the diesel acting as a pilot fuel which is ignited by compression and then in turn ignites the natural gas. Simple conversions of this type typically achieve 40-50% diesel substitution on a trip average basis, but more advanced conversion technologies involving electronic control of engine functions can achieve substitution levels of over 70%. An advantage of this type of conversion is that the engine can run on diesel alone when natural gas is not available. This can be an important factor in the absence of an extensive natural gas refuelling network. The disadvantage is that, because of partial substitution, potential cost savings from the use of natural gas are reduced.

Spark ignition engines for heavy vehicles may be supplied by original equipment manufacturers or may be the result of the conversion of a diesel engine. Engines designed for the use of natural gas and produced by original equipment manufacturers are usually dedicated to the use of natural gas, that is, they cannot use gasoline. As such they use high compression ratios and are thermodynamically highly efficient.

Engines in NGVs generally require less maintenance than conventional engines, although maintenance problems have been reported when NGVs are first introduced. This situation, however, is believed to be attributable to users and maintainers unfamiliarity with the technology and "teething" problems, rather than any inherent disadvantage.

The replacement of gasoline with natural gas greatly reduces cylinder wear and engine fouling. In some conversion programs in the early 1980s, the absence of lead in gasoline had an adverse impact on valve and bearing life. However modern cars designed for unleaded gasoline do not experience this problem when converted to run on natural gas.

In the case of heavy vehicles, operational experience is relatively limited. We are not aware of any fleets having reached the end of their operating lives. This makes it difficult to draw definitive conclusions on maintenance, although the trend to date is entirely favourable and laboratory tests confirm that lower wear can be expected.

On-board storage

Natural gas is usually stored on vehicles as compressed natural gas (CNG) in high pressure cylinders at pressures up to about 20 megapascals (approximately 3000 psi or 200 atmospheres). However, even at this pressure, the energy density of the natural gas is low compared with that of conventional liquid fuels, and the amount of natural gas that can be carried is limited. For example, a 70 litre cylinder for a car might weigh about 55 kg when empty, and contain about 15 kg of CNG when full. This provides the vehicle with a range equivalent to that of a 20 litre gasoline tank which would weigh little more than 20 kg when full.

The weight of cylinders and the space they occupy, therefore, is much more than the equivalent required for gasoline or distillate. As a result the range of vehicles operating on natural gas can be limited. The extra weight and space is usually less of a problem for trucks and buses than for cars.

Typically NGV passenger cars fitted with standard tanks can travel up to 150 to 200 km before refuelling. Dedicated natural gas cars developed in Japan and the

An NGV showing on board storage.

USA can travel up to 320 km before refuelling. The range of trucks and buses is typically 300-400 km.

The issue of range may not be critical for bi-fuel and dual fuel conversions because they can switch back to using gasoline or diesel. However, the limited range may mean that such vehicles have to operate a significant part of the time on conventional fuels, thus reducing some of the benefits that could accrue from the use of natural gas. Dedicated natural gas vehicles, on the other hand, may be restricted in the places they can travel to by the combination of range and lack of refuelling stations.

An NGV bus showing on board storage.

Research and development of light-weight cylinders and of other technologies, such as solid state adsorption of natural gas, is continuing in an effort to reduce further the space and weight required for CNG in vehicles.

There are a number of types of gas cylinders currently on the market.

- All steel seamless cylinders account for the majority of an estimated one million NGV cylinders in use all over the world (mainly in Italy, Argentina and New Zealand). Lightweight NGV cylinder design codes allow thinner and more highly stressed walls than pressure vessel and industrial gas cylinder codes. Fabrication generally involves deep drawing of sheet blanks or hot billet piercing. The open end is spun to close it before it is bored for the outlet fitting. The cylinder is heat treated to the desired hardness.

- Hoop wrapped cylinders consist of two structural parts: a metal liner which can be either steel or aluminium, and a resin impregnated fibre hoop wrapping applied to the cylindrical portion of the liner. A prestressing process lowers tensile stresses and fatigue levels in the liner. New techniques allow the prestressing to be done during the winding process.

- Fully wrapped cylinders are lighter in weight than others. Production begins with a thin seamless liner - either plastic or metal - which provides a gas tight barrier. Metal end fittings allow for valve connections. Reinforcing fibres are then wrapped over the cylinder in a matrix of resin. The fibres may be glass, Kevlar or graphite; the latter two provide the best performance, but at a higher cost.

An alternative to CNG is to cool natural gas to a temperature below minus 162 degrees Celsius at which point it becomes a liquid and is known as liquefied natural gas (LNG). At such a low temperature, LNG has to be contained in cryogenic tanks to prevent the liquid warming and boiling. Such tanks are like large vacuum flasks, built of steel to contain the LNG at moderate pressure. They can be built as fuel tanks for trucks. LNG has an energy density similar to that of gasoline or diesel and the driving range can approach that achieved with conventional fuels.

Experience with the use of LNG in vehicles is still limited, although a number of experiments have been carried out around the world.

Refuelling

Both slow and fast refuelling systems are in use. Fast refuelling systems consist of a cascade of high pressure cylinders continuously refilled by a compressor. Such systems can refill the CNG cylinders of a car, truck or bus with little more time and effort than that required for gasoline or diesel. Even the dispensers look similar.

Refuelling of an NGV bus.

Slow refill systems involve the direct connection of the vehicle to a compressor with minimal storage. This option may be the most cost-effective when vehicles spend significant periods out of service (for example, overnight) and can be particularly appropriate for private cars or for urban bus fleets (provided that on-board storage is sufficient for a complete day of operation).

The installation and operation of compressors and storage cylinders is expensive compared with the underground tanks used for gasoline and diesel. On the other hand, natural gas is transported to the refuelling station by the normal pipelines and hence road tankers are not required to deliver the fuel.

One of the difficulties relating to the introduction of a network of refuelling stations is the lack of commercial incentives for establishing stations in the absence of a large number of vehicles using natural gas. However, at the same time, the lack of refuelling infrastructure poses a significant disincentive to consumers to switch to natural gas.

An alternative is the use of small compressors known as home refuelling appliances for vehicles that can be used to slowly refuel vehicles which stand idle for long periods, for example, overnight. The use of such devices can allow the use of CNG fuelled vehicles in the absence of a refuelling network.

Refuelling an NGV from home.

The lack of an established refuelling infrastructure is, of course, a transient problem which disappears as the use of NGVs matures in a region. Government incentives for the introduction of refuelling stations, etc, such as those that applied in the past in New Zealand, are one means of addressing this issue.

Many city vehicles, such as fleets of buses, are refuelled at central depots rather than service stations. The refuelling plant at those depots can be built specifically for the fleet, so that the operator can chose the most cost-effective refuelling mode.

Although a number of experiments and trials have been undertaken, worldwide experience with LNG refuelling remains relatively limited.

Environmental factors

As a general statement, the use of natural gas reduces adverse environmental impacts compared with conventional fuels. Transport related emissions are the major sources of nitrogen oxides (NOx), hydrocarbons (HC), carbon monoxide (CO) and lead in urban air in most economies. NOx and some types of HC react in the presence of sunlight to produce photochemical smog. Ozone levels are used as a measure of the severity of smog.

The primary environmental benefit from the large scale substitution of conventional fuels by natural gas in vehicles will be reductions in vehicle related ozone levels in urban areas, through both lower HC emissions and the lower photochemical reactivity of these emissions.

In addition, fuel substitution by natural gas leads to a reduction in emissions of NOx and SOx. It also eliminates emissions of lead resulting from the use of leaded gasoline. When used as a substitute for diesel, natural gas greatly reduces (in the case of dual fuel engines) or eliminates particulate emissions.

Natural gas also offers the potential to greatly reduce CO emissions as a result of better fuel/air mixing, lean operation and no need for enrichment for cold starting.

In the greenhouse gas context, the lower carbon content of natural gas relative to petrol and diesel results in less CO_2 being produced per unit of useful energy, and thus reduced emissions of this greenhouse gas. The reduction for petrol engines is about 20%, but rather less for diesel. Although this reduction may seem modest, given the difficulty in identifying viable options to reduce emissions of greenhouse gases in the transport sector, it is a benefit which should be taken into account. The overall viability of using NGVs, of course, still needs to be evaluated on a cost/benefit basis.

Safety

Natural gas is not toxic and the major safety issue relates to fire and explosion. However its properties are such that natural gas as a vehicle fuel has a very good safety record worldwide.

Natural gas is lighter than air and moves rapidly upwards and outwards from a leakage source. Hence it does not have the "puddling" characteristic of gasoline or LPG and is therefore far less likely to form an accumulation which can ignite should any leakage take place. Natural gas installations must be designed to take advantage of this property by providing a natural upward escape path.

Natural gas has narrower ignition limits in air (that is the range of natural gas/air mixtures which can be ignited) than LPG or gasoline which reduces the chances of ignition of any leakage. The high self-ignition temperature (that is the temperature required to start combustion) further lessens the likelihood of combustion.

If natural gas is allowed to accumulate in an enclosed space, it can effectively exclude air, thus depriving people of oxygen they need for breathing. This possibility can be prevented with good ventilation.

The high-pressure cylinders for CNG need to be

- fitted with safety-relief and shut-off valves
- built to strict safety standards that require, for example, an ability to withstand more than twice the normal maximum pressure, and being re-filled and discharged up to 40,000 times in a lifetime of 30 years (see below)
- registered, inspected and certified regularly (for example, every five years)
- strongly anchored in vehicles to prevent them being thrown out in an accident.

Pipe connections should be contained in vented enclosures to prevent leakage of gas into vehicles. Care should taken to eliminate any risk of vehicles moving off while refuelling hoses are connected. Refuelling dispensers should be designed to prevent flailing hoses and 'freezing' burns (by rapid expansion of gas) if something breaks.

On-board storage cylinder standards

The International Standards Organisation (ISO) formed a working group, TC58/SC3/WG17, to prepare a standard for NGV cylinders. A draft standard was considered by the ISO in September 1994. It has been decided by the ISO that further work in preparing the standards should be undertaken.

The draft standard allows for the possibility of different types of cylinders, including metal, metal liner reinforced with resin impregnated continuous filament ("hoop wrapped"), metal liner reinforced with resin impregnated continuous filament ("fully wrapped"), resin impregnated continuous filament with a non-metallic liner ("all composite").

The reasons for requiring a separate standard covering only CNG cylinders are related to the special conditions under which they operate. Industrial gases are homogeneous, and the cylinders used are subject to a low fill frequency, with no special weight criterion. CNG cylinders may have fill frequencies as high as 1,000/year and are subject to a wide range of operating conditions. However, CNG cylinders are fixed in the vehicle and unlike industrial cylinders, they are not subject to heavy or rough user handling. Finally, there is a strong incentive to reduce cylinder costs to enable NGVs to be competitive with conventional fuelled vehicles.

The draft standard was developed from the Australian draft standard and R&D and expertise from many economies was incorporated.

Development of the standard made it apparent that a major requirement would be a minimum specification for the natural gas to be used in vehicles. Gas surveys in several economies helped establish limits for the various components encountered.

EXPERIENCE WITH NGVs

Rapid development of the NGV industry, in terms of numbers of vehicles converted per capita, has so far only occurred in economies where there is a large differential between the price of CNG and conventional liquid fuels. Within APEC member economies, New Zealand, the USA, Canada and Australia have had considerable experience with the development and use of NGVs.

Australia

The use of natural gas as a vehicle fuel in Australia is encouraged through fuel pricing policies. Natural gas is exempt from the petroleum products excise of nearly 34.1 cents (Australian) per litre and State charges of up to 10.6 cents per litre which apply to gasoline and diesel fuel. As a result, natural gas is available at costs around half that of conventional fuels. The Government has announced that alternative fuels, including natural gas, will remain excise free for at least five years.

A taxi using natural gas, Brisbane, Australia.

The major focus of development has been the use of natural gas as a substitute for diesel in heavy vehicles, rather than as a substitute for gasoline. This situation has arisen for several reasons:

- while natural gas is well suited for high mileage urban vehicles such as taxis, this market is already well served by LPG which is available in Australia at prices similar to those of natural gas. Hence it is difficult for natural gas to make major inroads into this market
- the disadvantage of the size and weight of cylinders is less critical in heavy vehicles than in passenger cars
- many heavy vehicles, including buses, operate in fleets from depots, removing the need to develop a widespread refuelling infrastructure.

The Australian Government, in conjunction with industry, has undertaken a major research, development and demonstration program on natural gas vehicles. As a result, the technology for using natural gas in some applications (for example, urban buses) has now reached the stage where it can be adopted on a normal commercial basis. Technology in other areas (for example, heavy trucks) is maturing rapidly.

Natural gas fuelled buses, both dual fuel and dedicated engine, have been evaluated by a number of fleet operators. Experience has been that dedicated natural gas operation is usually the preferred option, offering a cost-effective alternative that is reliable, quieter and less polluting than conventional diesel.

In Australia, the urban bus segment of the market is regarded as technically mature and decisions to use natural gas are being made on a normal commercial basis. Significant further purchases are expected. Several large orders have been placed with manufacturers. The South Australian State Transport Authority has ordered 100 new buses which will use a fast-fill refuelling station at one of the Authority's depots. The New South Wales State Transit Authority is intending to purchase up to 250 new gas powered buses by 1998. In Perth, Western Australia there are 44 buses running on natural gas, with plans to bring an additional 100 buses using natural gas into service. In Victoria several bus companies are using natural gas with about 40 buses.

Development work on the use of natural gas in trucks is continuing and a number of dual fuel and dedicated natural gas trucks are being evaluated.

One particular development relates to engine conversion and management systems for heavy-duty engines. The electronic engine management system, known by the trademark, Lambda 2, has been developed for both spark-ignition and dual-fuel heavy duty engines. The system is the culmination of five years of R&D by NGV Australia, Robert Bosch Australia Pty Ltd, and VDO Instruments Australia Pty Ltd, with support from the Australian Government. Already proved in 1 500 000 km of service, the system is now being fitted to NGVs both in Australia and abroad.

Although numerous truck conversion projects have been undertaken over the past 6 years, development is moving towards commercialisation with the increasing involvement of truck manufacturers. Ford Australia installed a 400 hp natural gas Cummins engine equipped with a Lambda 2 system to one of a fleet of Ford Louisville trucks being used by the company. The truck is in regular service, and fuel costs have been reduced by around 40%.

Transcom Gas Technologies Pty Ltd, in Perth, has developed a system for the use of natural gas in heavy-duty engines for buses and trucks. The system uses electronic measurement and control and can be applied to all kinds of such engines. It is particularly suitable for the turbo-charged, fuel-injected engines that are being increasingly used in new vehicles. The system is the product of six years of R&D by Transcom, and is undergoing in-service testing.

LNG is also being trialled as a truck fuel. Methane from a coal mine in New South Wales is being used as input to a small LNG plant. The LNG is then being used in a coal haulage truck. The 400 hp Volvo engined truck has been converted to dual fuel operation and is now in operation 24 hours a day, 6 days a week. The truck has now completed about 60,000 km on LNG.

Most work on passenger cars has involved market conversions after the vehicle is manufactured. However one project is underway to produce locally manufactured Ford taxis which have been optimised to use natural gas. Such taxis are expected to be competitive with LPG-fuelled taxis in centres where LPG costs are relatively high.

The future of natural gas as a fuel for vehicles in Australia, especially as a substitute for diesel in heavy vehicles, appears to be positive.

Canada

The Government of Canada has encouraged the development of alternative transport fuel markets by helping develop technology (such as a natural gas refuelling appliance and a gaseous fuel injection technology), helping establish a market where opportunities appear, and then offering broad support for market growth, mainly by distributing information to the public.

Additionally, for natural gas, the Federal Government has managed, under agreements with Canada's principal natural gas producing province that date back to 1983, a grant program for vehicle conversions and refuelling stations. Recently, this was extended to cover residential refuelling appliances.

Natural gas costs significantly less per kilometre travelled than gasoline and some Federal and Provincial grants are available for vehicle conversions and cylinders. The Federal Government exempts all alternative transport fuels from Federal excise tax. Natural gas further benefits from a full exemption of the Provincial road tax in every province where it is available.

With the help of Government programs, there now are about 30,000 natural gas vehicles in operation in Canada, supported by 117 public and 67 private refuelling stations. There also are 50 natural gas transit buses in operation in Canada and 100 have been exported to the United States. Natural gas for vehicles is supplied by long-established companies and utilities, and is sold through the motor fuel distribution network. About 80 conversion shops serve the NGV network.

While there remains significant potential for further fleet conversions, the future of alternative transport fuels is seen to lie with factory produced vehicles. Canadian motor vehicle manufacturers presently offer a limited number of natural gas pick-up trucks, vans, mini-vans and cars.

There are 16 Canadian companies supplying products to the natural gas transport fuel market. Most are involved in manufacturing and distributing conversion kits. However, the largest are involved in manufacturing natural gas fuelled transit buses, home fuelling devices and full composite cylinders. Information on these companies can be found in the Canadian Directory of Efficiency and Alternative Energy Technologies.

Currently, propane (LPG), natural gas and ethanol account for about 2% of transport energy demand in Canada. It is expected that this will grow slowly over the rest of the decade and, although propane will remain the principal alternative transport fuel, the market share held by natural gas should almost double in that time.

Indonesia

Natural gas has been selected as one of the alternative fuels for inclusion in the Government's development program.

The use of natural gas began in 1987 with a trial of natural gas as a fuel for taxis and it is now planned that all taxis should be converted. By 1992 there were five compressed natural gas refuelling stations in Jakarta, with plans to install another 24 stations in 1993 and 1994 to raise the total refuelling capacity to 9600 cars a day. Research and development underway includes engine and road tests.

The major obstacles to the increased use of gas as a transport fuel relate to pricing and the difficulty in finding space for refuelling stations in an already overcrowded city.

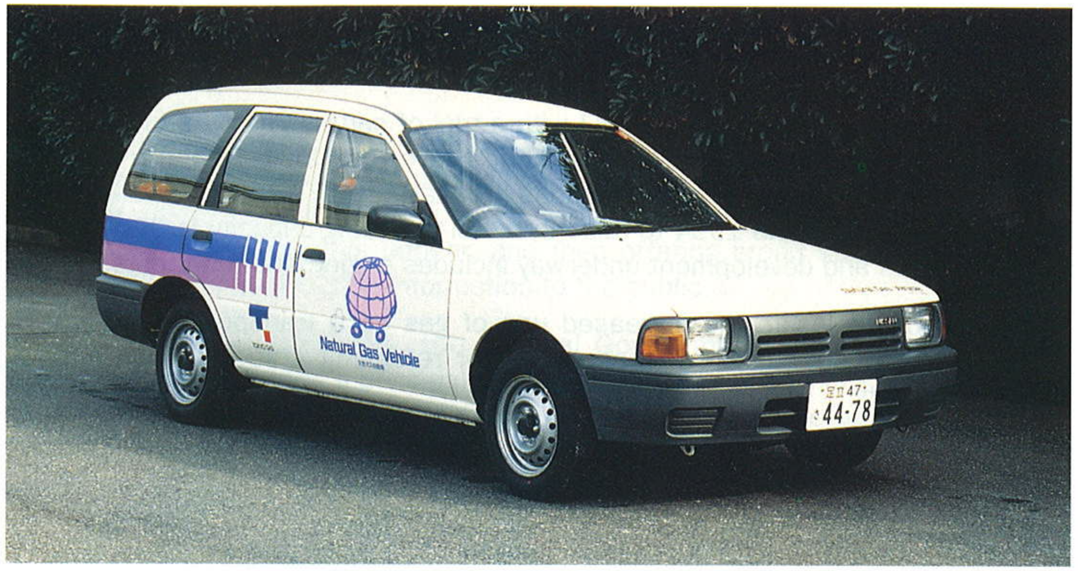
A taxi refuelling with natural gas, Indonesia.

Japan

Most Japanese automotive manufacturers have been involved in the development of prototype vehicles in cooperation with gas utilities. These prototypes include passenger cars, station wagons, small trucks and a motor bike.

To date around 120 vehicles have been built. However, natural gas vehicles will not be available for general commercial use in Japan for at least two years because of the need for more testing relating to issues such as safety, fuel efficiency, emissions, etc, to allow development of standards for vehicle licensing.

In the long term, replacement of diesel powered vehicles is seen as the most prospective market in the light of increasing stringency of emission standards for NOx and soot after 1996.



An NGV, Japan.

New Zealand

In New Zealand, the major emphasis has been on the use of CNG as a substitute for gasoline in passenger cars and derivatives, although considerable development work on heavy vehicles has also been undertaken and a number of these vehicles are in operation using CNG.

Interest in NGVs commenced in the latter half of the 1970s and in 1979 the Government announced a national CNG program which included incentives for establishing refuelling stations and converting vehicles, together with the conversion of Government vehicles, publicity and support for research and development. Work was also commenced on the preparation of relevant standards and safety regulations for vehicles and refuelling stations were established.

After initial high rates of growth, the rate of conversion slowed down, particularly because of a bottleneck in refuelling capacity. In 1980, in response to this situation, the Government announced further incentives, especially for refuelling stations and guaranteed that the price of CNG would not be more than about half the price of gasoline.

Over the period to 1985, further incentives were introduced and the number of CNG vehicles rose rapidly to reach 110,000 with conversions being undertaken at the rate of 5000 a month. The CNG refuelling network grew to over 400 facilities, mostly at existing service stations, which also provided petrol, diesel, in some cases LPG, and other services.

However, in 1985/86, the Government decided to withdraw all financial incentives for CNG. The consequences of this, combined with the sharp fall in oil prices in 1986, was a precipitous drop in vehicle conversions followed by steeply declining CNG sales.

There was, however, some recovery in the rate of conversion in 1991/92 because of concerns about supply arising from the Persian Gulf crisis and the introduction of higher fuel taxes which were not applied to CNG. Currently, there are about 60,000 CNG fuelled vehicles in New Zealand, which is about 4% of the total car fleet.

An NGV, New Zealand.

Thailand

Thailand has introduced natural gas as a fuel for buses in the Bangkok metropolitan region. The main objective is to reduce air pollution levels, but it also forms part of a program aimed at improving mass transit systems to reduce the number of cars in metropolitan Bangkok. In addition, the lower cost of locally produced natural gas will reduce fuel costs by about 25%.

Refuelling buses with natural gas, Bangkok, Thailand.

As a result of these considerations, the Bangkok Mass Transit Authority commenced operating natural gas fuelled buses in October 1993. There are now 82 natural gas fuelled buses in operation in Bangkok. To support this project, the Petroleum Authority of Thailand has established a compressed natural gas refuelling station together with a pipeline. The number of CNG fuelled vehicles is expected to increase rapidly and the Petroleum Authority of Thailand plans to establish more service stations to service this demand.

United States of America

About 30,000 vehicles (mostly cars) run on natural gas in the United States, about 80% of which are owned by gas utilities. These numbers have been relatively static for about ten years, because of the low price of gasoline and a primary interest in methanol as an alternative fuel.

However, the potential of NGVs to contribute to improving urban air quality is now being recognised, which is stimulating manufacturers to build engines and vehicles specifically for natural gas. Thousands of new NGVs are expected to be sold in the next few years and many new refuelling stations are being built.

A number of manufacturers have, or are planning to introduce dedicated natural gas vehicles, including passenger cars, light commercial vehicles, trucks and buses.

Sanitation trucks using natural gas, New York, USA.

The Gas Research Institute and a consortium of gas utilities is collaborating with a number of vehicle and equipment manufacturers in an R&D program to ensure the technical viability of natural gas as a vehicle fuel. The total program being managed by the Institute exceeds $30-35 million annually. One of the major projects being undertaken involves the development of medium duty Hercules natural gas engines which will be emissions certified. These engines are particularly applicable to the route delivery vehicle market. The 6 cylinder GTA5.6L engine has met the 1994 Californian Air Resources Board emissions standards by a large margin without exhaust after-treatment. 1998 Ultra Low Emission Vehicle standards were met by modifying the fuel system calibration and using a new oxidising catalyst.

Other projects include a demonstration of CNG in heavy duty trucks by the Californian Energy Commission and a major demonstration/trial by the New York Department of Sanitation. This latter project involves 9 CNG trucks using Caterpillar and Cummins engines. Other projects cover emissions certification testing, evaluation of conversion equipment and an assessment of the market potential for CNG for use in fleet vehicles.

Developments in non-APEC economies

NGVs have been used in Italy for about 60 years. There are now about 250,000 such vehicles, supported by about 250 public service stations. The use of NGVs has grown largely because of a much lower price for natural gas, compared with that for gasoline. Equipment for engine conversions, storage cylinders, and refuelling plant is manufactured in Italy and exported worldwide.

Argentina's NGV program began in the mid 1980s and some 250,000 NGVs are now in use, with many more being added each week. They are supported by 260 refuelling stations, with 280 more under construction. Since late 1990, all newly registered buses and taxis in Buenos Aires have been required to run on natural gas. Equipment for engine conversions, storage cylinders, and gas compressors is both imported and locally made. Some manufacturers are now selling vehicles dedicated to natural gas.

The NGV program in the former USSR began in earnest in 1981 as a government policy. Now 470,000 vehicles use gaseous fuels, LPG and CNG, supported by nearly 470 refuelling stations. The price of natural gas is half or less than that of gasoline. Most vehicles can operate on either gas or gasoline. It is planned to replace 20 million tonnes of gasoline a year with gaseous fuels by 1995.

More than 40 other economies in Europe, Asia, the Americas, and the Middle East also have NGV programs in place. Gas utility companies in all such economies are members of the International Association for Natural Gas Vehicles, to help communicate and coordinate their activity worldwide.

TECHNOLOGY TRANSFER

Technology transfer must play a major role in the further development of NGVs in the APEC region. Although all the knowledge required to implement successful NGV projects resides within the region, no one economy has a sufficiently developed NGV infrastructure to be able to cover all facets.

There are a number of existing organisations which are contributing to technology transfer. These include the International Association for Natural Gas Vehicles (IANGV), and the International Gas Union (IGU) through a task force on NGVs and its Committee K. Both of these organisations have published substantial position papers on natural gas vehicles and published a major joint report in 1994.

IANGV includes membership and participation from a wide range of governments, institutions and industry from around the world. Its mission includes collecting and disseminating information relating to the use of natural gas in vehicles, promoting uniform standards and codes of practice, identifying international R&D requirements and facilitating cooperative research.

In addition, the International Energy Agency (IEA), through its Centre for the Analysis and Dissemination of Demonstrated Energy Technologies (CADDET), has produced a detailed evaluation report on natural gas vehicles. Professional bodies, such as the Institute of Gas Engineers, also play an important role in the dissemination of information.

There is a need to ensure that relevant individuals and organisations in APEC member economies are aware of the availability of information from these bodies. This booklet is designed to help fulfil this need, and encourage co-operation between APEC economies to assist the development of the NGV industry in the region.

However, the further development of NGVs is very much in the hands of industry and much technology transfer will take place as part of normal commercial activity.

ISSUES

The availability, or potential availability of natural gas at competitive prices provides the opportunity to consider this generally more environmentally friendly fuel for use in vehicles. Such consideration raises a number of major issues which are discussed here.

Costs

In many economies, the additional costs of NGVs may be more than recouped through savings in energy costs, giving an attractive payback period, because the price of natural gas is sufficiently less than that of conventional fuels to offset these costs.

Also, conversion costs are declining with increased competition and larger numbers of conversions. In addition, the increased supply of purpose built vehicles by manufacturers will help to reduce costs. However, the cost of NGVs is likely to remain somewhat higher than that of a conventional vehicle because of higher cost of the storage cylinder relative to a petrol (or diesel) tank. Although major cost reductions appear unlikely, R&D should continue to be aimed at the development of more cost-effective cylinders and systems.

One of the major avenues for cost reductions internationally is to work together to ensure common standards and practices are adopted to obtain the maximum possible benefits from competition and economies of scale.

On-board storage

The weight and space of CNG storage cylinders can pose significant problems for some potential users. The issue is particularly important for conversions after vehicle manufacture, especially for passenger vehicles. In the case of original equipment vehicles, these problems should be greatly ameliorated.

The other issue associated with on-board storage is the restricted range imposed on most types of NGVs, resulting from fuel storage limitations. This is particularly a problem at the introductory stage of NGVs when the refuelling network will be limited. Solutions include extension of refuelling networks, and the use of dual and bi-fuelled vehicles. Centrally fuelled fleet vehicles will not have this problem.

Relatively low cost refuelling devices for vehicles which spend considerable periods stationary (for example overnight) can also be used. Such devices (referred to as trickle-fill) are available.

Research and development may also play a role, with improved CNG cylinders, LNG and adsorption technologies all having the potential to offer improvements.

Refuelling

Related to the issue of range and on-board storage is the lack of an established refuelling network in most economies and the high costs (relative, for example, to

petrol and diesel) involved with its establishment. Refuelling time can also be an issue, but fast-fill systems for all classes of vehicles can be supplied, although in the case of heavy duty vehicles, this may involve significant additional costs.

Retrofit vehicles

Ensuring quality of conversions, particularly in the early stages of a program when there is a lack of experienced personnel, can pose a problem. This is best addressed through training programs and the adoption of standards for equipment and accreditation schemes for installers and maintainers of systems. Experience in those economies with mature NGV programs, has shown this to be only a transient problem.

The use of original equipment manufactured (OEM) vehicles is a way of avoiding any perceived problems which may arise from the use of retrofitted vehicles. There is a consumer preference for OEM vehicles and engines, partly because they are provided with warrantees which are valued by NGV purchasers. OEM vehicles are also perceived as being more reliable in comparison to vehicles which have been converted to run on natural gas. The industry has been producing OEM vehicles and engines over a number of years to meet the market demand. At present, Japan, South Korea, the USA and a number of economies in Europe manufacture OEM vehicles in substantial quantities.

Safety

The problem here is more one of perception than reality. NGVs have an excellent safety record and concerns arise typically from lack of familiarity. The issue is best addressed through public information programs.

Standards

There are a wide range of standards which need to be applied to NGVs. These have to cover safety aspects as well as ensuring the optimum performance of NGVs. Standards are available in economies with mature NGV programs. These are providing the basis for the development of international standards which will help ensure compatibility of systems and reduced duplication of development effort. A great deal of effort is being devoted to this issue around the world and relevant international standards covering most aspects of NGVs and their associated infrastructure are expected to be available in the near future.

Regulatory environment

The absence of appropriate regulation can be a significant barrier to the effective introduction of NGVs. Economies which are considering implementing NGV programs should ensure that the regulatory environment in which they operate provides a framework which will facilitate the development of a technically and commercially viable NGV industry.

Training

The availability of appropriately trained personnel can be a limiting factor. There is a need to ensure that the appropriate training is undertaken at the beginning of and during any NGV program. Training should be backed up by accreditation schemes. Economies with mature NGV programs can provide help with training programs.

Articulated bus using natural gas, New Zealand.

CONCLUSIONS

The major potential benefits of using natural gas as a vehicle fuel are both economic and environmental. To achieve economic benefits from its use, the cost of the natural gas (in economic terms) must be sufficiently less than the cost of alternatives (that is, petrol and diesel) both to cover the extra costs involved in using the fuel (up-front vehicle costs, and the compression costs for producing the fuel, that is CNG), and to provide a worthwhile return to the user and the economy. The environmental advantages arise mainly from the cleaner burning properties of natural gas and the lower quantity of carbon dioxide emitted per unit of useful energy compared with petrol and diesel.

The technology for using natural gas as a vehicle fuel is now well established. Research, development and experience, particularly during the past decade, has produced safe and reliable vehicles which perform well under all service conditions. Refuelling technology for CNG is established. The availability of natural gas, or its potential availability, therefore provides the opportunity of using it as a vehicle fuel. It is suggested that the benefits of using CNG are likely to be achieved most readily through commercial NGVs particularly in fleet situations.

Using natural gas as a transport fuel, however, involves a number of trade-offs compared to the normal petroleum-based transport fuels which it can displace, namely petrol and diesel. These trade-offs are:

(1) The additional cost of converting an existing vehicle to CNG, or the higher cost of a purpose designed and built NGV. To offset this cost, and provide a reasonable return on the investment involved, the price of CNG needs to enjoy a favourable price margin over petrol or diesel. This may result from the lower cost of the fuel at the point of supply (including compression costs), and from favourable Government taxes or other incentives because of the economic and environmental advantages of the natural gas option to an economy as a whole.

(2) Unfamiliarity with the new fuel. This is a transitional problem which is addressed through education programs, ensuring high quality, safe conversions and performance of natural gas vehicles and emphasising their relative advantages.

(3) Loss of space because of the extra fuel storage required. This is mainly relevant for retro-fits, and particularly private passenger vehicles (the CNG cylinder or cylinders must usually be installed in the boot). It does not apply to dedicated, purpose built vehicles and it is not usually a major problem for commercial vehicles where it is suggested, initially at least, the emphasis on NGV development programs should be placed.

(4) Reduced range. Natural gas, even in the compressed form in which it is used as a vehicle fuel, has a considerably lower energy density than petrol or diesel.

Because of fuel storage restrictions, vehicle range is reduced and more frequent refuelling is required. The problem is greater where the refuelling network is limited, particularly in the early stages of the development of an NGV program. This difficulty should present few, if any, problems for fleet situations where refuelling can be planned ahead. This is not a problem for dual fuel or mixed fuel vehicles, although frequent running on the conventional fuel will reduce the benefits of using CNG. Although more frequent refuelling is still required, an extensive refuelling network also helps to overcome the difficulty.

(5) Extra weight. This arises from the high pressure cylinders required to store the compressed natural gas. For a passenger car, it is equivalent to having a small extra passenger permanently in the vehicle. For larger vehicles such as trucks and buses, which have several storage cylinders, it is a factor which may need to be taken into account in relation to the total tare weight of the vehicle.

Although improvements have been made in the above areas, and options are available for reducing their adverse effects, further R&D would also be helpful. Another area for R&D is the production of engines that can achieve and maintain "ultra low emissions" over their lifetime. Research in this area is well advanced but, while it has been shown that engines can attain these emission levels, considerable further work is required. Experience, again, in economies with mature NGV industries can be drawn on for these.

In conclusion, it is vital that appropriate attention is paid to technology transfer in this area, both to ensure commonality of approach and hence obtain maximum benefits from economies of scale, and to reduce duplication of effort.

APPENDIX

Suggested reading list

"Learning from Experiences with Compressed Natural Gas as a Vehicle Fuel". CADDET, Centre for the Analysis and Dissemination of Demonstrated Energy Technologies, Analysis Series Number 5, John Stephenson, May 1991. ISSN 0925-0085

"A Position Paper on Natural Gas Vehicles 1993", International Association for Natural Gas Vehicles, John Stephenson, 1993, ISBN 0-473-01938-8.

"Task Force Report 1994, International Gas Union and International Association of Natural Gas Vehicles". Presented at the World Gas Conference, June 1994, by Loek Mobers, Chairman of the International Gas Union - Natural Gas Vehicle Task Force.

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