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International Experience with CNG Vehicles

South Asia Urban Air Quality Management Briefing Note No. 2

Natural gas (NG) is a clean-burning alternative fuel with a significant potential for reducing harmful emissions, especially those of fine particles, from vehicles. Vehicular particulate emissions in turn are a concern, because they are small (small particles are especially harmful to health) and numerous, and occur near ground level where people live and work. In response, some have argued for mandating NG as an automotive fuel, most notably in Delhi. This note discusses where NG vehicle[1] programs have been successful, where have they failed and why.

Users of Natural Gas Vehicles (NGVs)

According to the information collected by the International Association for Natural Gas Vehicles (IANGV) between August 2000 and August 2001, over 1.5 million vehicles run on NG worldwide fueling at more than 4,000 refueling stations (Table 1), with 14 countries having 10,000 or more NGVs. By far the majority of NGVs are gasoline vehicles converted to CNG.

Table 1: Top 5 NGV Markets [1]

Country	*Vehicles*	*Refuelling stations*
Argentina	686,496	896
Italy	370,000	355
Pakistan	200,000	200
Brazil	120,000	131
United States	102,430	1,250
World total	1,724,463	4,392

Types of Natural Gas Vehicles

In terms of fuel supply, there are three types of NGVs:

- *Bi-fuel*, where the vehicle can run on either natural gas or gasoline.
- *Dual-fuel*, where the vehicle runs either on diesel only or diesel and natural gas with the combustion of diesel used to ignite the natural gas. The stop-and-start nature of urban bus cycles limits the substitution of diesel by NG, and makes dual-fuel unsuitable if the objective is to reduce emissions.
- *Dedicated*, which runs entirely on natural gas.

All the three types can be

- manufactured from the start to use natural gas by original equipment manufacturers (OEM), or
- converted from vehicles that were originally manufactured to run on gasoline or diesel only.

Conversion of vehicles in poor condition, as well as poor conversions, are two of the most serious potential problems in developing country cities, and could even defeat the purpose of switching to natural gas.

Either way, there is an incremental cost relative to vehicles using conventional liquid fuels, and this additional cost has to be recovered from savings in operating costs, typically lower fuel costs. For minimizing emissions, OEM vehicles are considered superior to converted ones, but they are more expensive. In 1998, there were 43 OEMs around the world producing NGVs. Conversion of vehicles in poor condition, as well as poor conversions, are two of the most serious potential problems in developing country cities, and could even defeat the purpose of switching to natural gas. According to one estimate, 50 to 70 percent of vehicles being converted in developing countries may fail a good pre-conversion inspection [2], with many requiring rebuilt engines and other repairs for an effective NGV program.

Two Reasons for Switching to Natural Gas

1. *Diversification of energy sources* has been the historical reason for selecting natural gas as a motor fuel. In 2000, the ratio of proven reserves to production of natural gas was estimated to be 62 years, 63 percent higher than and that of oil at 38 years [3].
2. *Much lower emissions*, especially compared to conventional diesel vehicles. This is the primary reason for switching from diesel to NG today. However,

replacing diesel with natural gas makes sense only if diesel emissions have been confirmed to contribute substantially to ambient fine particulate concentrations—the pollutant that represents the greatest health hazard in urban air in the majority of developing country cities. How to evaluate different policy options for vehicular air pollution is described in an earlier briefing note [4].

Advantages and Disadvantages of NGVs

The advantages of NGVs include

- very low particulate emissions
- low emissions of airborne toxins
- negligible emissions of oxides of sulfur (SO_x)
- more quiet operation, having less vibrations and less odor than the equivalent diesel engines.

Their disadvantages are

- much more expensive distribution and storage
- higher vehicle cost
- shorter driving range
- much heavier fuel tank
- potential performance and operational problems compared to liquid fuels [5].

With respect to emissions, it is worth noting that advanced technology gasoline vehicles with three-way catalysts are so clean that the fuel itself (that is, whether liquid or gas) plays a relatively minor role, especially for the regulated emissions. Under these circumstances, converting an advanced gasoline vehicle to gaseous fuel could even increase, rather than decrease, emissions.

NGVs have a marked advantage over conventional diesels. Example data taken from the United States comparing compressed natural gas (CNG) with diesel, shown in Table 2, amply illustrate this point.

Table 2: Emissions Benefits of Replacing Conventional Diesel with CNG in Buses [6]

Fuel	*CO*	*NO_x*	*PM*
Diesel	2.4 g/km	21 g/km	0.38 g/km
CNG	0.4 g/km	8.9 g/km	0.012 g/km
% reduction	84	58	97

Note: Medium-duty diesel buses, central business district test cycle. CO carbon monoxide; NO_x oxides of nitrogen; PM particulate matter; g/km grams per kilometer.

At the same time, the emergence of the so-called "clean diesel," pilot tested in North America and Europe and slated for mandatory deployment by the latter half of this decade, may pose a challenge to the long-term future of NGVs. Clean diesel technology relies on dramatic reductions in the level of sulfur in diesel fuel (sulfur content of below 0.005% and preferably even below 0.001%) to enable the use of such after-exhaust treatment devices as continuously regenerating particulate traps for reducing fine particles and lean deNOx catalysts for reducing oxides of nitrogen (NO_x). Limited available data indicate that CNG may not have measurable advantages over state-of-the-art clean diesel technology for particulate emissions (Table 3).

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Table 3: Comparison of CNG and "Clean Diesel" Buses in New York, g/km [7]

Driving cycle	*Central business district cycle*		*New York bus cycle*	
Pollutant	*CNG*	*Clean Diesel*	*CNG*	*Clean Diesel*
Particulate matter	0.011	0.015	0.044	0.023
NO_x	15	16	32	45
Total hydrocarbons	10	0.01	42	0.038

Note: Heavy-duty diesel buses (1999 model year) using diesel containing 30 parts per million (ppm) sulfur and Johnson Matthey's continuously regenerating particulate filter system (but not lean deNOx catalysts); CNG buses (1996, 1998 and 1999 model year) equipped with oxidation catalysts.

Many technical breakthroughs have been announced for the deployment of clean diesel, including refining processes to produce ultra-low sulfur diesel at a fraction of the cost employing conventional technologies. But clean diesel is likely to be many years away for widespread application in developing countries. Today, natural gas remains the only commercially proven clean fuel alternative for heavy-duty engine applications, with considerable implications for investment in infrastructure.

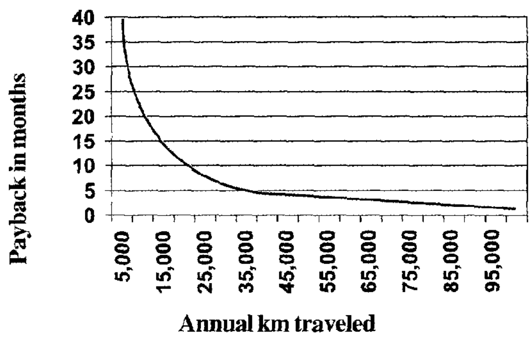
Two Contrasting Country Cases: Argentina and New Zealand

Argentina and New Zealand were once two world leaders in the NGV market. Today, Argentina's market remains the largest in the world, while New Zealand's NGV market has declined precipitously beginning in the late 1980s.

Argentina [8]

Argentina launched its CNG vehicle program in 1984. By then, there was an extensive network of natural gas pipelines reaching most cities. The government offered no subsidies, and instead the incentive for fuel switching stemmed entirely from the high tax on gasoline. The fuel prices in December 1999 were US$1.04 per liter of premium gasoline, US$0.50 per liter of diesel, and US$0.33 per cubic meter ($m^3$) of NG (or about US$0. 41 per kilogram). At these prices, the payback period for those vehicle owners converting from gasoline to CNG could be a matter of months depending on the total number of kilometers (km) traveled a year (Figure 1). Most CNG vehicles are those converted from gasoline vehicles.

Figure 1: Payback for Conversion from Premium Gasoline to CNG in Argentina, 1999 Fuel Prices



In contrast, there has been little conversion from diesel to CNG because the price difference between diesel and CNG is not sufficient to recover the incremental cost of NGVs within a reasonable period. As a result, there are no CNG buses in regular operation today, and in fact diesel is actively competing with CNG to capture the taxi market away from CNG.

New Zealand [9]

In stark contrast to Argentina, the government of New Zealand was heavily involved in the NGV program from the outset. It provided generous financial incentives both for conversion and establishing refueling stations, so that the number of CNG vehicles doubled every year, seriously stretching the ability of the industry to cope. The industry was so preoccupied with meeting the demand for conversion that quality at times became a secondary priority, resulting in the perception of CNG as a second-rate fuel which was used only because it was much cheaper than gasoline.

When the new Labor Government began to deregulate the economy, withdrawing financial incentives for the CNG industry, the NGV market essentially died. The NGVs today number about 10,000, a decline of 100,000 from the peak of 110,000.

Observations from Around the World

Experience with natural gas vehicles

- *Poor conversions can lead to higher emissions, operational problems, and even accidents*, giving NGVs a bad name. When gasoline vehicles were converted to NG, one of the unpleasant surprises in industrial countries was that the converted NGVs were found to be more polluting when tested for emissions in the case of recent model year vehicles.
- *High-usage vehicle fleets which can exploit economies of scale*—in setting up refueling infrastructure, staff training, vehicle maintenance and fuel purchase—are especially suited for NGVs.
- *A champion coordinating activities among different stakeholders and publicizing the benefits of NGVs* are especially useful in the early days of a NGV program.
- *Consistent reports of poor performance of NG buses manufactured in the early 1990s* suggest that NG buses were not only more expensive to purchase but were also about 30 to 40 percent more expensive to maintain and had considerably reduced reliability. While many of these problems are being overcome, heavy-duty NG engine technology still needs some refinements.
- *Successful NG bus programs are based on dedicated OEM*, and not converted, buses. Conversion of existing diesel vehicles typically does not make happy customers.
- *Transit bus operators in many, if not most, developing countries are cash-strapped*, partly on

Box 1: Natural gas buses: Experience of Phoenix Transit, USA [5]

The bottom line is ***training, training, and more training***. Phoenix Transit initially met resistance from the operators, mechanics, fuelers and subsequently the union. They trained everyone from top management to bus washers. The main challenge is to have trained operators and maintenance staff that can observe and report changes in the buses while in operation and during preventive maintenance. The next challenge is to have bus manufacturers and component manufacturers working in partnership with the service and maintenance contractors.

account of fare controls. As a result, buses are not properly maintained, nor are the operators in a position to purchase more expensive NG buses, provide extensive training to all their staff on this new technology (see Box 1), and to accept the possibility of more repairs to deal with greater frequency of bus breakdowns. High emissions from diesel buses are not merely because of the choice of fuel, but are symptomatic of deeper problems, and the same problems may condemn NG bus programs to failure.

- *The number of refueling stations and NGVs must be balanced* so that there are no unacceptably long queues for refueling on one hand and under-utilization of filling stations on the other. During the early days of NGV programs, the government may consider giving incentives to provide a critical mass of both, as by granting permits where filling stations were not allowed earlier (Argentina) or by providing subsidies of limited duration.

Typical pre-conditions for success

- *A NG distribution pipeline* for other users of NG needs to be in place.
- *A proper regulatory framework* to create a fair and level playing field for all stakeholders should be established by the government.
- *Adequate safety and performance standards* that are monitored and enforced should be in place. This need has been underscored by recent cases of CNG vehicle fires in Delhi.
- *Inter-fuel taxation policy favorable to automotive natural gas over the fuel it is intended to replace* should be adopted, so that the retail price of natural gas is about half that of the liquid fuel. This makes NG substitution of diesel difficult because the tax on diesel is low in all South Asian countries. The alternative of mandating CNG in the face of unfavorable economics is unlikely to lead to a sustainable NGV program.

Note

[1] Natural gas vehicles (NGVs) can be fueled by compressed natural gas (CNG) or liquefied natural gas (LNG), with the majority of NGVs being CNG vehicles.

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More detailed information on this topic is available in *Breathing Clean: Considering the Switch to Natural Gas Buses*, World Bank Technical Paper No. 516.