Chapter 4
Natural Gas as a Vehicle Fuel

Although most attention has been directed to methanol produced from natural gas, natural gas itself, either compressed (CNG) or in liquid (low temperature) form (LNG), also can serve as an alternative fuel for vehicles, with the vehicles either equipped to use both gasoline and natural gas or optimized to serve in a single-fuel mode. There are currently nearly 700,000 CNG-powered vehicles worldwide, mostly in Italy (300,000), Australia (over 100,000), and New Zealand (130,000), with the United States (30,000) and Canada (15,000) having moderate numbers as well.[1] The primary attraction of these vehicles outside of the United States is their not using an oil-based fuel and, for New Zealand, their use of a domestic fuel that may otherwise have limited markets.

VEHICLES

Existing natural gas-powered vehicles generally are gasoline vehicles modified by after-market retrofitters and retain dual-fuel capability, i.e., they are able to use either gasoline or gas. Despite the low cost of the natural gas fuel, dual-fueled gasoline/gas-powered vehicles generally are not cost-competitive with gasoline-powered vehicles at current energy prices under most usage circumstances, and they will likely remain noncompetitive unless gasoline becomes heavily burdened with taxes or prices for oil rise sharply while gas prices remain low. Previous studies have shown that only heavily used vehicles (e.g., commercial fleet vehicles) can save enough money from lower fuel prices to compensate for higher vehicle costs and the costs for a compressor station (a natural gas retrofit costs $ 1,600/vehicle or more, and a factory built vehicle will cost $800 or more extra, to pay for the extra fuel tank, gas-air mixer, pressure regulators, and other components). In addition, most currently available dual-fueled vehicles have significantly less power and some driveability problems under heavy load when operated on natural gas (and slightly less power when operated on gasoline, because of the weight of the extra fuel tanks), and lose much of their storage space to fuel storage. Much of the power loss and probably all of the drivability problems are due to the design and/or installation of the retrofit packages; significant improvements in power and driveability can be realized with more-sophisticated retrofit kits, or in factory-built, dual-fueled vehicles.[3] Nevertheless, given the remaining problems, dual-fueled vehicles will have a difficult time competing with gasoline vehicles or vehicles fueled with other, higher-energy-density fuels except in high-mileage fleets or other specialized applications.

Single-fueled vehicles optimized for natural gas use are likely to be considerably more attractive in terms of performance, and somewhat more attractive in terms of cost—though firm conclusions must await considerable vehicle development and testing. The cost of pressurized storage will make the vehicles more expensive than a similar gasoline-powered vehicle, but probably by no more than $700 or $800,[4] not the $750 to $1,600+ differential posed by a dual-fuel vehicle. A natural gas-powered,

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[1]U.S. Department of Energy, *Assessment of Costs and Benefits of Flexible and Alternative Fuel Use in the U.S. Transportation Sector. Progress Report One: Context and Analytical Framework,* January 1988.

[2]U.S. Department of Energy, *Assessment of Costs and Benefits of Flexible and Alternative Fuel Use in the U.S. Transportation Sector. Technical Report Five. Vehicle and Fuel Distribution Requirements (Draft),* January, 1990.

[3]The improvements are obtained primarily from enriching the fuel mix during cold starts and during high power requirements, easing driveability problems, and advancing spark timing during operation with gas, to increase power. Most current retrofit kits aim for low cost and are not designed for specific vehicles, sacrificing power and driveability for cost. K.G. Duleep, Energy and Environmental Analysis, Inc., personal communication Mar. 15, 1990.

[4]That is the approximate cost of CNG cylinders storing about 0.8 mmBtu of gas. If the cylinders have a high salvage value (because they can last for several vehicle lifetimes), their net cost will be lower. If the vehicle does not need an NO_x reduction catalyst, its cost will be a few hundred dollars lower. M.A. DeLuchi, R.A. Johnston, and D. Sperling, "Methanol vs. Natural Gas Vehicles: A Comparison of Resource Supply, Performance, Emissions, Fuel Storage, Safety, Costs, and Transitions," Society of Automotive Engineers Technical Paper 881656, 1988.

Photo credit: Ford Motor Co.

The Ford compressed natural gas Ranger has a driving range of 225 miles with four compressed natural gas (CNG) tanks. Major component changes from a gasoline-powered Ranger include modifications to the exhaust valve seats, pistons, and piston rings and addition of a fuel mixer, pressure regulator, and CNG tanks.

single-fuel vehicle should be capable of similar power,[5] similar or higher efficiency, and substantially lower emissions (except for nitrogen oxides (NO_x)) than an equivalent gasoline-powered vehicle. Such a vehicle would have a much shorter driving range-due to the lower energy density of CNG versus gasoline[6]--unless the fuel tanks are made quite large, which would then entail a further penalty in weight, space, performance, and cost, and which could increase greenhouse emissions as well. Advanced storage containers made of fiber-reinforced steel and aluminum, and of composites, have been developed. These containers are lighter in weight than existing steel containers and, because of their greater strength, could reduce storage volume somewhat because they allow increased storage pressures. Fiberglass-wrapped aluminum is the most affordable option among the newer materials; a tank

[5]Designing the engine specifically for natural gas allows increasing the compression ratio and advancing the spark timing, which will approximately compensate for the power-depressing effect of the greater displacement and lower flame speed of gas versus gasoline and the vehicle's greater weight, though at some cost in higher NO_x emissions. Source: DeLuchi et al., op. cit., footnote 4. Because some further optimization of *gasoline* engines will likely occur during the period in which natural gas engines could be perfected, speculation over the precise final outcome of any gas vs. gasoline power competition seems fruitless.

[6]CNG at 3,000 psi occupies about 4 times more volume than gasoline of equal energy content,

of this material would add about 150 pounds to the vehicle (over a gasoline system), assuming 3,000 psi tanks and 300-mile range.[7] Another, longer term option for storage may be the use of absorbents that allow high density storage at lower pressure.

CNG vehicles' range limitations would be eased considerably if LNG were substituted as the fuel. Rather than CNG's 4:1 volume disadvantage (at 3,000 psi) with gasoline, LNG has only a 1.3:1 disadvantage.[8] Even with their required insulation, and the added bulk it causes, advanced LNG fuel tanks should be only about twice as bulky as gasoline tanks holding the same energy,[9] and possibly less than twice as bulky to achieve the same range if the vehicle can attain an efficiency gain over gasoline vehicles. Further, unlike CNG vehicles, the added weight of the storage tanks should be modest. And the extremely low temperature of the fuel can add an additional power boost to that obtainable with compression ratio and spark timing,[10] so the LNG vehicle will have a power advantage over a CNG vehicle.

LNG storage tanks have been demonstrated that allow vehicles to remain idle for a week without the need to vent gas.[11] Retrofit costs to convert a gasoline vehicle to LNG have been estimated at $2,780 per vehicle;[12] a factory-built dedicated vehicle would presumably have a considerably smaller cost penalty.

EFFECTS ON AIR QUALITY

The magnitude and character of emissions from natural gas vehicles, like emissions from methanol vehicles, will vary depending on trade-offs made between performance, fuel efficiency, emissions, and other factors. However, the physical makeup of natural gas tends to make it a basically low emission fuel. Natural gas contains virtually no nitrogen or sulfur and does not mix with oil; thus, it will not foul engine combustion chambers, engine oils, and spark plugs as readily as gasoline, and may help to avoid the deterioration of emissions control performance common in gasoline-powered automobiles. Fuel losses due to leaks will not add appreciably to ozone formation because methane-natural gas' key component—is not (photochemically) very reactive (however, as discussed later, methane is a powerful greenhouse gas, so leaks, as well as high concentrations of methane in vehicle exhausts, would be harmful from the standpoint of global warming). And because it is gaseous and does not require vaporization before combustion, its use will lessen the cold start problems—with the need to run 'rich' (air/fuel ratio lower than normal) before warmup is achieved—responsible for much of the hydrocarbon and carbon monoxide emissions of today's gasoline engines. With these advantages, natural gas is likely to be considered at least as good as methanol as a clean fuel so long as NO_x, emissions can be held down. In fact, as far as ozone effects are concerned, there is a general consensus that natural gas use will provide a strongly beneficial effect, in contrast to the controversy about methanol's impact (see ch. 3).

A key determinant of emissions will be the decision to run the vehicle either "lean" (with excess air) or stoichiometric (with just enough air to theoretically achieve complete combustion). However, no optimized, dedicated, natural gas vehicles running stoichiometric, and very few running lean, have ever been built or tested,[13] so any discussion of emissions effects must be based largely on theory and extrapolation.

Running the engine lean will optimize efficiency and lead to low engine-out levels of CO and

[7] DeLuchi et al., op. cit., footnote 4.

[8] LNG's lower heating value is about 87,600 Btu/gallon versus gasoline's 115,400. S.C. Davis et al., *Transportation Energy Data Book: Edition 10, Oak* Ridge National Laboratory report ORNL-6565, September 1989, table B.1.

[9] DeLuchi et al., op. cit., footnote 4.

[10] DeLuchi et al., op. Cit., footnote 4.

[11] F.L. Fischer, "Introduction of a Commercial System for Liquid Methane Vehicles," *Nonpetroleum VehicularFuelsIII, Symposium Papers*, Institute of Gas Technology, Chicago, 1983, and R.J. Nichols, "Ford's CNG Vehicle Research," 10th Energy Technology Conference, Washington DC, Mar. 1, 1983, both cited in M.A. DeLuchi, op. cit., footnote 4.

[12] R.E. Adkins, "An Alternative Transportation Fuel—"The Lng Option," paper presented for American Gas Association September 1989, Adkins is the president of a firm that is marketing LNG systems.

[13] C.S. Weaver, "Natural Gas Vehicles-A Review of the State of the Art," Society of Automotive Engineers paper 892133, presented Sept. 25-28, 1989, SAE International Fuels and Lubricants Meeting and Exposition, Baltimore, MD.

nonmethane hydrocarbons.[14] Major drawbacks of running lean include drivability problems and low power, both of which would adversely affect consumer acceptance. Also, an NO_x reduction catalyst will be ineffective under excess air (lean) conditions, and NO_x tailpipe emissions may increase over gasoline-based emissions with catalytic control. Because NO_x formation is dependent on the duration of the fuel combustion process, some analysts hope that so-called "fast burn" designs, probably coupled with high levels of exhaust gas recirculation, will be capable of keeping NO_x emissions down to or below the levels of the best current gasoline engines.[15]

CO emissions under lean burn conditions should be considerably lower than those of a competing gasoline engine equipped with similar controls; running the engine in a lean burn mode *with* an oxidation catalyst could virtually eliminate CO emissions.[16] Because manufacturers may be able to satisfy Federal CO standards without a catalyst, however, theoretically they might choose to forego catalytic control to reduce vehicle cost. In this event, CO emissions would be comparable to those from gasoline-fueled vehicles.

If gas engines are run stoichiometric (at significant loss in efficiency), the emissions result will be somewhat different. CO emissions during most of the driving cycle will generally be similar to emissions from gasoline engines. However, the reduction in cold start fuel enrichment allowed by natural gas should reduce sharply the relative emissions during the vehicle warmup period which, for newer cars, is when the bulk of CO emissions are produced. During the winter, when CO air quality problems tend to occur, the warmup period is longer and the emissions benefit more pronounced. Nonmethane hydrocarbon emissions will be higher than with lean burn, but probably still lower than gasoline-fueled engines, again because of gas' low cold-start emissions. Also, as with all gas-fueled vehicles, much of the total exhaust hydrocarbons will be methane, which is essentially nonreactive and will not contribute to ozone formation (though methane *is* a powerful greenhouse gas). Consequently, the overall ozone-producing impact of the hydrocarbon emissions should remain very low even without running the engine lean.

The ability to use a reduction catalyst under stoichiometric conditions should allow NO_x emissions to be kept low—to the level of the best gasoline vehicles—for these engines,[17] though perhaps not as low as with similar methanol engines.[18] Such emissions probably could be made still lower by using fast burn technology with exhaust gas recirculation, as with the lean burning engines.[19] Unfortunately, this type of emission control strategy may have driveability and low power/weight problems.

All natural gas vehicles will emit aldehydes, primarily in the form of formaldehyde. Relatively high formaldehyde emissions (compared to gasoline engines) from methanol vehicles are considered a key uncertainty in determining methanol's net effect on ozone formation. Limited testing of natural gas vehicles indicates that uncontrolled aldehyde emissions may be considerably lower than those from methanol vehicles, approximately comparable to uncontrolled emissions from gasoline engines,[20] and should be of less concern than emissions from methanol vehicles.

Natural gas vehicles are expected to produce moderately lower net emissions (including all fuel cycle emissions) of greenhouse gases than gasoline-fueled vehicles, though the use of different but plausible assumptions yields a range spanning about a *25* percent decrease in greenhouse emissions to an 11 percent increase for domestic natural gas,[21] and lower benefits for overseas gas.[22] The overall effect

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[14] Methane often is not counted as part of hydrocarbon emissions because its atmospheric reactivity is so low that it plays little role in ozone formation. Its low reactivity also means that it is not efficiently controlled by catalytic *converters,* however, so that exhaust levels of methane maybe fairly high, depending on engine operating conditions. DeLuchi et al., op. cit., footnote 4.

[15] C.S. Weaver, op. cit., footnote 13.

[16] DeLuchi et al., op. Cit., footnote 4.

[17] C.S. Weaver, op. cit., footnote 13.

[18] DeLuchi et al., op. Cit., footnote 4.

[19] Ibid.

[20] DeLuchi et al., op. cit., footnote 4.

[21] D. Sperling and M.A. DeLuchi, *Alternative Fuels and Air Pollution,* draft report prepared for Environment Directorate, OECD, March, 1990.

[22] Overseas shipment as LNG extracts a significant energy penalty.

is complicated by several factors, including methane's potency as a greenhouse gas—it is many times as effective as CO_2, pound for pound, though the precise effect is in some dispute[23]—and the role that CO plays in destroying hydroxyl radicals in the atmosphere and possibly preventing these radicals from scavenging methane out of the atmosphere.[24] Of special concern is the amount of additional methane that might leak into the atmosphere if a significant shift to natural gas vehicles were to occur; measurements of current leakage in the natural gas production and distribution systems are highly variable and of suspect accuracy. The greenhouse estimate is also sensitive to assumptions about gas engine efficiency, methane emissions from the tailpipe, and vehicle range. Sperling and DeLuchi's "base case," which assumes the use of domestic CNG with a 10 percent efficiency gain and an assumed range equal to that of a gasoline vehicle, estimates the greenhouse benefit to be 3 to 17 percent depending on methane's assumed potency as a greenhouse gas.[25]

SAFETY

Natural gas should be a safer fuel than gasoline. It is neither toxic, carcinogenic, nor caustic, whereas gasoline is all three. A gas leak into an enclosed area can be an extreme explosion hazard, implying the need for strict control of refueling operations (particularly if home refueling becomes popular). However, a leak into open air will not detonate because gas disperses quickly and the concentration in air required for detonation is high, 5.3 percent (versus 1.1 percent for gasoline vapors, which can represent a strong detonation hazard[26]). Also, the temperature required for natural gas ignition is higher than gasoline's, about 1,000 'F versus 440 to 880'F.[27]

An important safety concern associated with natural gas vehicles has been the integrity of the pressurized or cryogenic storage tanks carried on-board the vehicles. Because they are designed to withstand high pressure, CNG pressurized tanks are extremely strong and have no record of problems in collisions despite extensive use on vehicles.[28] LNG tanks, while not as strong, do not carry material under high pressure, and thus represent a situation somewhat similar to gasoline tanks, though with less fire and explosion hazard but with some danger of frostbite were the tanks to rupture and the fuel contact vehicle occupants or passersby.

COST COMPETITIVENESS

A fleet of natural gas-powered vehicles might be competitive economically with gasoline-powered vehicles, but there are significant uncertainties. Most important are the uncertain future prices of natural gas and gasoline, and the uncertain cost penalty of the gas-powered vehicles. The latter uncertainty is due to the relative lack of interest of auto manufacturers in this fuel, and thus the limited research and development effort that has been devoted to single-fueled natural gas vehicles. A recent analysis assumed that mass-produced, dedicated, optimized CNG-powered vehicles would cost $700 to $8OO/vehicle more than comparable gasoline vehicles, with most of the cost difference attributed to the high pressure storage, and would be 10 to 25 percent more thermally efficient[29] (the higher end of this efficiency range appears overly optimistic). Assuming $7.50 to $9.00/mmBtu gas delivered to the compression station, the analysis concluded that a single-fueled CNG vehicle would break even with a gasoline-fueled vehicle when gasoline cost between $0.75 to $2.14/gallon. A parallel analysis for LNG-fueled vehicles arrived at a virtually identical gasoline breakeven cost range, $0.75 to $2.23/gallon.[30] Uncertainties in costs, performance, engine lifetimes, etc. will widen this range, but from a cost standpoint-as well as an environmental standpoint-natural gas-powered vehicles appear to deserve further attention for at least a portion of the vehicle fleet.

23 Sperling and DeLuchi, ibid., define the range as 10 to 40 times more effective than CO_2, pound for pound.

24 C.S. Weaver, op. cit., footnote 13.

25 D. Sperling and M.A. DeLuchi, Op. Cit., footnote 21.

26 DeLuchi et al., op. Cit., footnote 4.

27 Ibid.

28 Ibid.

29 Deluchi et al., op. cit., footnote 4.

30 Ibid.

SOURCES OF SUPPLY AND STRATEGIC CONSIDERATIONS

As with methanol-powered vehicles, natural gas vehicles have been promoted as a measure to enhance national security by shifting to supposedly more-secure natural gas. Unlike methanol, however, natural gas needs no expensive processing to become a viable vehicle fuel, so that higher priced gas can be a viable feedstock if transportation costs are not too high. Consequently, although relatively high-priced U.S. gas is not an economic feedstock for methanol, it might be a viable feedstock for a U.S. natural gas vehicle fleet if supplies hold out. U.S. natural gas supply currently is in surplus, and the United States has a substantial gas resource base, which has caused some analysts to predict that domestic gas production could fuel a major transportation shift to gas.[31]

This projection is correct for the short term-the next few years-but probably incorrect for the longer term. Although there is room for argument about the size of the current surplus, it probably is in excess of 1 trillion cubic feet (TCF) per year, which is enough gas to power about 25 million automobiles.[32] However, gas demand is likely to be increasing over the coming decade, while domestic gas production is unlikely to keep pace. Much of the new generating capacity expected to be added to the U.S. electricity supply system during this time is expected to be natural gas-fueled, and current acid rain control strategies appear likely to increase gas use in existing generating capacity as well. Essentially all major U.S. gas supply forecasts project growing gas imports during the 1990s and beyond *without* any movement of gas to vehicular use. And although none of these forecasts fully incorporate the potential increases in recoverable resources that might be available with advanced technology, OTA does not believe that such advances are likely to provide enough increased supply to simultaneously displace imports, power a growing segment of the electric utility sector, *and* fuel a substantial portion of the fleet.[33] Thus, *the natural gas necessary to power a large U.S. fleet of gas-fueled vehicles is likely to come from gas imports.*

A second potential source of natural gas for U.S. transportation needs is pipeline imports from Canada and Mexico. Although gas from these sources also will not be cheap at the wellhead and thus, like U.S. gas, is unlikely to be used to produce methanol, pipeline access for the gas is relatively inexpensive, except from the Canadian Arctic. Thus, a key to the magnitude of potential national security advantages from a shift to natural gas as a transportation fuel may be the magnitude of gas imports that the United States can obtain via pipeline from Canada and Mexico. Current projections generally include steady or rising imports from Canada, but little or no imports from Mexico. There is potential for increased gas imports from both sources, but little assurance that such imports can be obtained.

In 1988, the United States imported more than a TCF of natural gas from Canada, with existing pipelines close to maximurn capacity at peak gas demand periods.[34] Additional pipeline capacity, 1.2 TCF/yr if all proposed projects are built, could be ready by the 1990s.[35] Most U.S. supply projections foresee steady or gradual growing Canadian gas imports to the lower 48 during the next few decades, and there is little doubt that Canada has the resources to provide such imports-Canadian resources are comparatively undeveloped, with recent National Energy Board of Canada estimates of total recoverable resources at slightly above 400 TCF,[36] with 100 TCF in proved reserves, but with total production below 3 TCF/yr.

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31 Ibid.

32 Assumptions: Average vehicle driven 10,000 miles/year, efficiency equivalent to 35 miles per gallon of gasoline.

33 Several hundred additional TCF of gas are available in the United States in tight sands, Devonian Shales, and coal seams. Commercial production of these resources is possible with significant improvement in production technology, for example, with improved capability of fracturing tight (low permeability) reservoirs. The potential for such improvements is high but uncertain. Research efforts are maintained by the Gas Research Institute, but previous efforts by the Federal Government have been dropped or reduced, and current low prices are stifling private initiatives. The potential of developing the United States' unconventional resources is discussed in a previous OTA report, *U.S. Natural Gas Availability: Gas Supply Through the Year 2000*, OTA-E-245 (Washington DC: U.S. Government Printing Office, February 1985).

34 The pipeline capacity exists t. sustain a theoretical flow of over 1.8 TCF/yr if sales could be sustained at peak levels, but seasonal changes in gas demand prevents this. Source: Arthur Andersen & Co. and Cambridge Energy Research Associates, *Natural Gas Trends, 1988 to 1989 Edition.*

35 Energy Information Administration, *Annual Outlook for Oil and Gas 1989*, DOE/EIA-0517 (89), June, 1989.

36 Reported in Energy Modeling Fore, Stanford University, *North American Natural Gas Markets*, EMF Report 9, vol. 2, February 1989.

In the past, the magnitude of Canadian exports to the United States was strongly constrained by the Canadian Government. Although export policies have been liberalized, future imports will still be constrained by Canadian perception of the adequacy of their resource base and their capacity to serve growing domestic needs, as well as by the price offered.

There also is little doubt that Mexico has the physical resources to provide large quantities of export gas for the U.S. market, but its recent energy policies have focused on expanding domestic use of gas and stressing oil development in its capital spending plans. With a resource base of at least 200 TCF, reserves of 60 TCF, and annual production of less than 1.0 TCF, Mexico could export substantial quantities of gas, especially if it began to develop its nonassociated resources.[37] However, it is highly uncertain whether it will do so without a substantial rise in U.S. gas prices. Aside from the Mexican Government's desire to boost internal use of gas, there is concern about public reaction to "cheap" gas sales-that is, sales at price levels below the $/Btu level of oil.

If imported LNG is the marginal supply source for a gas-powered fleet, the national security advantages of building a gas-fueled vehicle fleet probably will resemble somewhat the security advantages of a methanol fleet: probably still positive, but much less clear than the advantages of domestic and North American supplies. If a large worldwide gas trade has placed the Middle East and Eastern Bloc into the role of swing suppliers of LNG, the national security advantage of a gasoline-to-natural-gas shift will be reduced. However, because of the very large capital requirements for both suppliers (liquefaction plants) and buyers (expensive port and regasification facilities) in the LNG trade, LNG markets are more likely than oil markets to be based on long-term contracts, and the stability of the specific suppliers is likely to be a more important factor in overall security concerns in the LNG supply system than it is in the oil supply system. According to the Department of Energy, likely LNG suppliers for the United States are Algeria, Norway, Nigeria, and Indonesia,[38] which may be viewed as a group as reliable suppliers. LNG shipments from these countries earmarked for use as a transportation fuel thus may provide to U.S. policymakers a welcome offset to oil imports from the Persian Gulf.

LNG will have two major roadblocks to serving as a supply source for gas-powered vehicles. First, for imports greater than about 750 bcf/yr,[39] new LNG terminals would have to be built, and there is substantial environmental opposition to such construction. Second, LNG is expensive. Liquefying the gas costs between $1 and $3/mcf plus about 10 percent of the incoming gas stream (for energy and losses)[40]; transportation can add up to $1 or so per mcf,[41] and regasifying can add still more. All in all, the delivered price of LNG to the United States needs to be *at least $2* or so per mcf *plus the* wellhead price to make the operation profitable to the exporting country.

REFUELING AND INFRASTRUCTURE

Whatever their relative advantages or disadvantages in cost, performance, and emissions, the outlook for any substantial shift to natural gas as a vehicle fuel--especially for the general fleet-may ultimately rest on consumer acceptance of a new and different refueling system. For CNG vehicles used only in low-mileage applications, refueling conceivably could occur at low compression systems that would fill storage tanks overnight-in essence, the fossil fuel equivalent of recharging the batteries of an electric vehicle. Home systems currently are quite expensive, however, costing upwards of $1,000.[42] Providing "filling station"-type service may be a more formidable barrier. Assuming dedicated CNG

[37]Nonassociated gas resources are gas resources that are separate from oil resources and whose production generally is not tied to oil production.

[38]Energy Information Administration, op. cit., footnote 35.

[39]This is the capacity of the United States' four existing LNG terminals, at Cove Point, MD; Elba Island, GA; Lake Charles, LA; and Everett, MA, reported by the American Gas Association. Other sources (Arthur Andersen, the Energy Information Administration) report capacity at about 900 bcf/yr.

[40]U.S. Department of Energy, Office of Policy, Planning, and Analysis, *Assessment of Costs and Benefits of Flexible and Alternative Fuel Use in the U.S. Transportation Sector. Technical Report Three: Methanol Production and Transportation Costs, DOE/PE-0093,* November 1989.

[41]Ibid. DOE estimates transport costs from Trinidad to San Francisco at $0.67/Mcf, from Bahrain to either Baltimore or San Francisco at more than $1.00/Mcf.

[42]DeLuchi et al., op. cit., footnote 4. Current systems cost $2,000 and up (personal communication, David Kulp, Ford Motor CO.), but mass production should lower costs.

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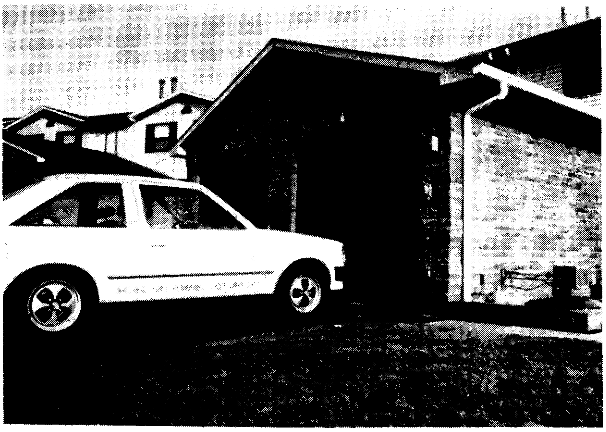

Photo credit: Natural Gas Vehicle Coalition

Natural gas commuter vehicle being filled by a home compressor.

vehicles, large numbers of such stations with rapid fill capability will be needed to maintain a practical system with large numbers of vehicles. Current rapid fill systems, with gas stored at high pressures, allow refilling times that are at least twice as long as refilling gasoline tanks[43]--an inconvenience but one that may be overcome by further equipment development. A further problem, however, is that the stations could share little else besides cashier and maintenance facilities with the gasoline distribution infrastructure. Otherwise they will need to be constructed essentially from scratch, an important hurdle in moving to a gas-based vehicle system. The Department of Energy projects the cost for a rapid-fill station designed to handle 300 vehicles/ day, with 8 minute fill time, peak capacity of 30 vehicles/hour, and four refilling stations, to be $320,000 plus land acquisition costs.[44] In the scenario constructed by DOE, the capital cost of sufficient public stations to displace 1 mmbd of gasoline would be $7.6 billion.[45]

An additional $1 to $2 billion would be needed to improve local gas distribution systems to accommodate the increased gas demand. DOE concluded that no additional long-range transmission expenditures would be required for the approximately 1.9 TCF/yr required to displace 1 mmbd of gasoline.[46]

To our knowledge, there are no studies of potential LNG distribution infrastructures similar to the DOE CNG analysis. An LNG filling station can be either purely a storage and dispensing facility, with LNG delivered to the station by truck from central liquefaction plants, or it can incorporate a small onsite prefabricated liquefaction plant.[47] Although there is some disagreement about whether or not LNG dispensers can be as safe and easy to use as gasoline pumps, firms marketing LNG dispensers claim that their products are comparable to gasoline pumps.[48] There is little reason to doubt that this type of performance is attainable, though presumably such dispensers would have to be maintained with considerable rigor.

NATURAL GAS OUTLOOK AND TIMING

A combination of factors will make natural gas a more difficult fuel than methanol to move into the automobile fleet. First, dual-fuel vehicles will not perform quite as well as competing gasoline vehicles, so that the first generation of vehicle buyers must be willing either to accept the limitations of these vehicles or to accept the risks-and travel limitations--of dedicated vehicles before an extensive infrastructure is built (Of course, operators of vehicle fleets with certain characteristics, e.g., central refueling, limited mileage/day/vehicle, will have an easier time accepting CNG vehicles). Second, range limitations or, conversely, the need for very bulky on-board fuel storage will continue to provide an unattractive comparison with gasoline vehicle characteristics. This is far more a problem with CNG than with LNG, however; the latter's range limitations are similar in scale to those of methanol. Third, the vehicle manufacturers have done comparatively little work on optimized light-duty natural gas

[43]Ibid.

[44]U.S. Department Of Energy, *Assessment of Costs and Benefits of Flexible and Alternative Fuel Use in the U.S. Transportation Sector. Technical Report Five. Vehicle and Fuel Distribution Requirements (Draft)*, Office of Policy, Planning, and Analysis, January 1990.

[45]The DOE scenario is not exclusively one of light-duty vehicles and public filling stations. Two-thirds of the oil displacement in the scenario is accomplished by light duty vehicles, one-third by heavy-duty vehicles. The capital costs were adjusted to represent a displacement of 1 mmbd by light-duty vehicles only.

[46]U.S. Department of Energy, Technical Report Five, Op.cit., footnote 44.

[47]Such plants are offered by Cryogas Engineering Ltd. and Cryopak, cited in DeLuchi et al., op. cit., footnote 4.

[48]Ibid.

engines (though appreciable work is presently being done on heavier duty engines), so that more time will be needed to develop a market-ready engine capable of competing with gasoline-fueled engines. And fourth, although the infrastructure for *long range* distribution of the fuel is in place, the infrastructure for retail distribution will be more expensive than a similar infrastructure for methanol fuels.

Despite these potential difficulties, natural gas is an attractive fuel that deserves careful consideration as an alternative to gasoline for the U.S. light-duty fleet. It appears likely to be a cleaner fuel than methanol, particularly so if M85 is the methanol fuel alternative. Although domestic supplies are limited, there is an excellent possibility that it can be obtained from our North American neighbors, or from quite secure sources as LNG (though building ports to handle the LNG could be an important hurdle) . . . in contrast to the possibility that a key methanol source would be the Middle East. It offers none of the toxicity and few of the explosion hazards of methanol (or gasoline),[49] and does not appear to offer a substantial engineering challenge to engine designers. And its short-term economics look good, though it is unlikely that gas prices from the likely sources could be uncoupled from oil prices the way methanol prices theoretically could be—if the methanol came from remote gas sources.

Given these characteristics, it seems likely that an effort to move natural gas into the light-duty fleet would lag behind a similar effort for methanol a few years, but could begin to play a significant role—especially in niche applications-well in advance of the other alternatives (aside from reformulated gasoline).

[49] Although indoor refueling could pose some hazards.