Liquefied Natural Gas—A New Source of Energy: Part II, Peak Load Shaving and Other Uses

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IN THE previous issue* the development by Constock International Methane Ltd. of the liquefaction of natural gas and transportation by ship was traced. Although the principal use for liquefied natural gas (LNG) is in domestic heating and industrial use, there are several other outlets.

Peak Load Shaving

At least one promising use for LNG which does not involve the liquid transportation problem is known as peak-load shaving, or simply, peak shaving. This concept can be most easily described by referring to Figure 1, in which the variation in daily demand for gas by a local utility throughout the year is shown. It is obvious that the sinusoidal curve represents a highly idealized smoothing of the actual curve which has numerous peaks and crevices. The demand peaks on the coldest day in winter and bottoms on the hottest day in summer. The yearly average daily demand is represented by the horizontal broken line such that the shaded areas labeled deficit and surplus are equal. In order to obtain the best price and to be assured of a guaranteed supply, the local utility must contract to purchase from the gas pipeline company at a fixed rate the year round. If the purchases are made on the yearly average daily rate, customer demand in the winter months cannot be met. On the other hand, there will be a surplus of gas available in the summer months.[1] The obvious solution is to "save" the *surplus* in the summer time and draw on it to make up the deficit in the winter time. However, because huge volumes of gas would have to be stored, no man-made storage is practical.

In some regions of the country there are depleted gas and/or oil fields or aquifer[2] where large volumes of gas can be stored underground. In this case the solution is simple; the utility company stores surplus gas in

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* AMERICAN SCIENTIST, June 1965, page 260. "Liquefied Natural Gas—A New Source of Energy: Part I, Ship Transportation."

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[1] The treatment here is considerably simplified. Gas distribution and pricing is a complex matter [1].

[2] Aquifer here refers to a geologic anticline or trap having a stratum of permeable water-bearing sandstone or limestone which can be developed for storage of gas. In some cases, salt caverns or abandoned coal mines can be used for storing gas.

the natural, underground reservoir and draws on it during cold weather when consumer demands exceed pipeline capacity. The amount of such storage in the United States is increasing rapidly; in 1962, the capacity was 3.56 trillion cubic feet (about $^1/_2$ is usable) as compared to a total marketed gas production of 13.3 trillion cubic feet [2]. The big storage concentration, fortunately, is in the more populated areas in such states as Pennsylvania, Michigan, Ohio, West Virginia, California, and Illinois. Nevertheless, there are many areas, particularly New England, the East and South, where other measures have to be taken. For example, the surplus gas could be sold to local industry at a bargain (interruptible) rate, in which case synthetic gas would have to be used to supply the deficit. The synthetic gas is frequently manufactured by thermal cracking of residual oils, catalytic reforming of propane and butane, or blending propane and air with the pipeline gas.

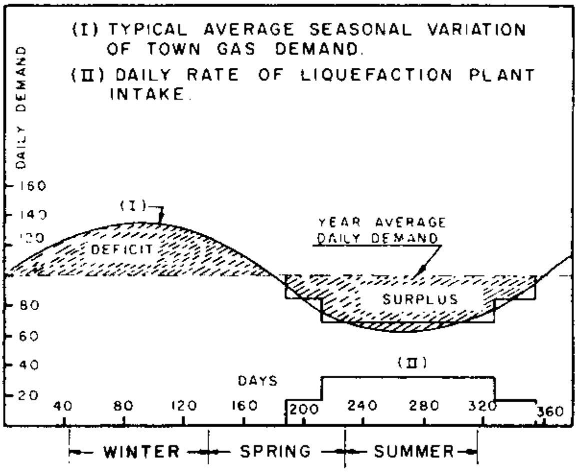

FIG. 1. Variation in daily gas demand with seasons of the year.

As an alternative to manufactured gas for peak loads, but not competitive with natural, underground gas storage, natural gas could be liquefied and stored during the summer months, and then vaporized during the winter months to augment the pipeline supply for meeting peak demands. The Cleveland plant was built for this purpose in the early 1940's. Within the last ten years, technological improvements in liquefaction equipment and cryogenic storage have tipped the economic balance in favor of LNG over manufactured gas for peak-shaving. Realizing this potential, Constock International Methane Ltd. and J. F. Pritchard Co. formed a new company, Constock-Pritchard, Inc., early in 1958, to develop and construct LNG peak-shaving plants.

As a further boon to LNG peak shaving, the concept of in-ground storage for LNG was developed in the early 1960's. Working independently, Conch [3, 4, 5], the American Gas Association [6, 7, 8], and Phillips Petroleum Co. [9] each developed their own version. A schematic of the in-ground storage, piloted by Conch at Lake Charles in 1961, is shown in Figure 2. The construction of the cavity-in-ground (CIG) is as follows:

(1) Freeze pipes for circulating refrigerant are sunk to the required depth along the periphery of a circle whose diameter is 20 to 40% greater than the diameter of the intended cavity.
(2) The ground is prefrozen by circulating an external refrigerant, such as propane, to form a frozen ring.

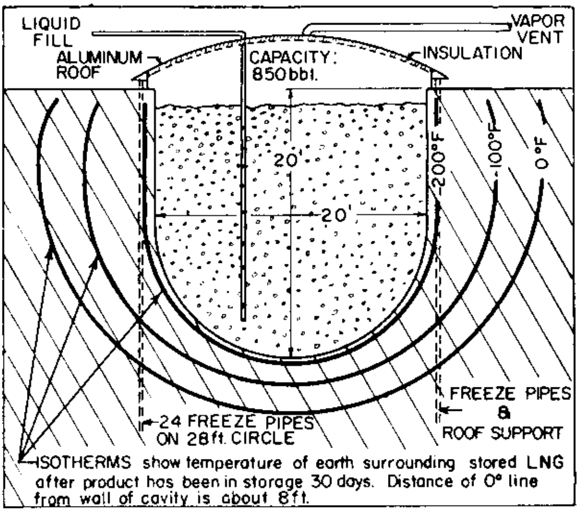

FIG. 2. How liquid methane is stored in frozen ground by Conch.

(3) When the inner diameter of the frozen ring reaches the diameter of the cavity, the unfrozen ground, bounded by the frozen ring is excavated.
(4) On completion of excavation, an insulated roof is installed.
(5) The cavity is now ready for filling with LNG.

The prefreezing operation eliminates the need for costly shoring during excavation since the frozen ground has structural strength comparable to concrete. It also prevents moisture penetration during excavation. The frozen ground acts as an impermeable barrier to any penetration or loss of LNG into the surrounding ground and also provides adequate insulation to prevent excessive boil-off during storage.

The temperature distribution measured during the Lake Charles tests is also shown on Figure 2. The problem of theoretically predicting these isotherms and the rate of heat leakage into the cavity is not easy [8, 10, 11, 12]. It is necessary to know the heat leak quite accurately in order to establish the size of the refrigeration equipment needed.

Equally important is a knowledge of the properties of frozen ground, concrete, and other construction materials at these low temperatures in order to be able to predict the structural integrity of the cavity with time [13, 14, 15, 16]. Review of the design problems involved in cavity-in-ground storage is given by Sharp [17] and by Khan, *et al.* [18].

A number of articles on the economics of peak shaving with LNG have been published [18, 19, 20, 21]. The basic differences between LNG transportation and LNG peak-shaving plants are:

(1) Peak-shaving plants tend to be of much smaller liquefaction capacity, but their vaporization capacity is larger since they must be able to deliver gas at a very high rate for the few (5–15) coldest days in the year.

(2) The liquefaction section of peak-shaving plants lies idle $^1/_3$ to $^1/_2$ of the year, whereas, in LNG transportation, it operates around the clock.

(3) Peak-shaving plants require relatively more storage than LNG transportation plants. The cost of storage in the former runs over 25% of the total investment, whereas, in the latter, it is usually below 10%.

(4) Even though the peak-shaving plants require no investment in tanker, loading and unloading docks, reforming facilities, etc., the total investment per unit of liquefaction capacity tends to run 10–20% higher than LNG transportation plants. Oddly, both of them run pretty close to $1 of total investment per cubic foot of gas liquefied.

(5) The unit selling price of gas delivered to the pipeline will run about 30–50% higher in a peak-shaving plant than an LNG transportation plant, depending on whether reforming costs are included in the latter. Round figures for the LNG transportation plant are $1.10 per 1000 cu ft as compared to $1.50 per 1000 cu ft for peak shaving.

It is to be understood that the above figures are used for illustrative purposes only, in an attempt to typify and compare a peak-shaving plant having a liquefaction capacity of around 10 million cu ft of gas per day with a transportation plant of 100 million cu ft of gas per day. Depending on the location of the site, these figures can vary drastically.

Thus far, four LNG peak shaving plants in this country are scheduled to begin operations in 1965. The first one will go on stream early in 1965. It is being built by Constock-Pritchard Inc. for Transcontinental Gas Pipeline Corp. (Transco) on 420 acres in the Jersey Meadows near South Hackensack, N.J., at a reported cost of $12 million. It will have a liquefaction capacity of 5 million cu ft per day into 1 billion cu ft of equivalent gas storage with a maximum vaporization capacity of 200 million cu ft of gas. Transco will initially sell the gas to eight utility companies from Georgia to New Jersey for winter peak shaving at a cost (reported to be $2.20 per 1000 cu ft) about $^1/_2$ to $^3/_4$ the cost a utility would pay to manufacture its own peak-shaving gas. Because of the marshy nature of the ground, which rendered above-ground storage impractical, Transco will use in-ground storage consisting of a cavity 115 ft in diameter and 165 ft deep [22], with a capacity of 12 million gal of liquid or a billion cubic feet of gas.

The second LNG peak-shaving facility is under construction at a cost of $3 million near Birmingham, Ala.; it will be jointly owned by Air Products and Chemicals Co. and Alabama Gas Co. This plant is slightly smaller than Transco's. It has a daily liquefaction capacity of about 4 million cu ft of gas and a vaporization capacity of 85 million cu ft. The storage consists of a conventional, above-ground, double-walled tank having an inner liner of 9% nickel steel and insulated with 5 ft of perlite. The storage capacity is 7.2 million gal or 600 million cu ft of gas [23]. In proximity to this plant, Air Products is involved in a cryogenic complex which includes a gas reforming plant to produce hydrogen from natural gas. The hydrogen is used for manufacturing ammonia and as feed to a 30 ton per day hydrogen liquefaction plant which will supply NASA's Pearl River test site near New Orleans. In addition, some of the LNG from the peak-shaving plant might find outlet as a rocket fuel. A multiplicity of cryogenic products from a single complex offers intriguing economic returns and could set the stage for a healthy growth in cryogenic processing, which, to date, has been monopolized by the production of liquid nitrogen and oxygen.

A third LNG peak-shaving plant should be in operation late in 1965 at Chula Vista, Calif. It is being built by American Messer Corp. for San Diego Gas and Electric Co. The liquefaction plant will use pipeline pressure drop to liquefy natural gas in an expander cycle at a capacity of 2 million cu ft of gas per day. The storage tank is identical to the one at Birmingham except that it uses 3 ft of perlite insulation instead of 5 ft. The vaporization capacity is 60 million cu ft of gas per day. The cost is $2.7 million [24].

A fourth peak-shaving plant is being built for Wisconsin Natural Gas Co. at Oak Creek, Wis., between Racine and Milwaukee. The plant will have an above-ground metal, double-wall tank providing the equivalent of 250 million cu ft of gas storage, a vaporization capacity of 50 million cu ft of gas per day and a net liquefaction rate of 750,000 cu ft of gas per day. Chicago Bridge and Iron Co. are the designers and builders of the plant, scheduled to go on-stream in the Fall of 1965 [25].

Other Uses for LNG

As LNG peak-shaving plants become more widespread across the

United States, a number of other uses for LNG will develop because of its increased general availability at reduced costs. Two promising possibilities are as a rocket propellant and as a fuel for supersonic aircraft.

Prior to 1959, LNG was considered a possible candidate as a rocket fuel. However, it seemed to drop out of the picture when NASA took over the space program and proceeded to concentrate on such fuels as RP-1,[3] hydrazine, and liquid hydrogen. Within the last two years, NASA has had to modify its thinking somewhat. Although liquid hydrogen, in combination with liquid oxygen, provided the high performance characteristics needed, there were some applications, such as space storability, recoverable vehicles, etc., for which the hydrogen–oxygen system—as well as other fuels—was unsuited. In this respect, LNG offers the most attractive alternative. When LNG is used in combination with the oxidizer, FLOX (a liquid mixture of fluorine and oxygen), its performance is commensurate to the hydrogen–oxygen system.[4] Compared to RP-1, hydrazine, and hydrogen it is the safest material to handle [26] and its cost is substantially lower than hydrazine and hydrogen, being only slightly higher than RP-1. In addition, its properties are such that it can be adapted to existing rocket hardware, or it can lead to simplification in new hardware.

The enormous heat dissipation problem presented by supersonic jets will require the development of more thermally stable fuels which can serve as a heat sink for cooling the engine and the leading edges of the air frame, in addition to maintaining the required temperature in the cabin for both the payload and electronic instrumentation. Some of the thermally stable fuels which have been considered cost 20- to 50-times as much as jet fuel. Whether or not supersonic jets will ever become a reality hinges on fuel economy. LNG, with its superior performance and cooling capabilities, added to the fact that its cost is comparable to jet fuel, offers the most promising solution.

Both of these applications are being investigated by the Research Division of Continental Oil Co. For their studies, and to supply test quantities for others, they have erected a liquefaction and purification unit at Ponca City which can produce up to 600 gal per day of liquid methane having a purity of 99.9+%.

The fact that LNG is currently not generally available should not serve as a deterrent to its ultimate use as a rocket or supersonic jet fuel.

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[3] Similar to jet fuel.

[4] Another interesting comparison of performance is afforded by the 3-stage, Saturn V rocket. If the present RP-1/LOX booster stage were replaced by LNG/FLOX, the payload for solar system escape could be increased from 3500 to 10,300 lb. This performance even exceeds the payload of 7000 lb which could be put into solar system escape by replacing the third stage, LH_2/LOX, in the present Saturn V, with a nuclear engine.

Even if LNG were not being developed for heating purposes, it would merit development for rocket and aircraft fuels. Although the total consumption of LNG by the rocket industry would represent an insignificant fraction of the total natural gas currently produced, it can be readily liquefied at any site near a pipeline or imported as LNG at a cost substantially lower than the other rocket fuels, with the exception of RP-1 (and ammonia if it enters the picture). On the other hand, supersonic jets, with their voracious appetites for fuel, could eventually consume up to 10% of the total natural gas production in the United States. In this case, the demand is sufficient to realize the savings in manufacturing costs in large-scale plants; consequently, the LNG could be produced competitively solely for the purpose of replacing present-day fuels. On the other hand, the day is rapidly approaching when LNG will be available in practically every major population center in the world to satisfy either a peak-shaving or a base-load demand. Since supersonic jets will largely confine their operations to such centers, the general availability of LNG may well exceed the current, general availability of jet fuel. Even today, certain preferred jet fuels are difficult to obtain abroad.

Summary

The next decade will probably reveal an unprecedented growth of a single commodity, LNG, as a major factor in supplying the world's demands for energy. Although the pioneering efforts of Constock were primarily directed toward the foreign markets, the demand for LNG in the United States, both as peak shaving and base load, could even surpass many of the foreign markets. Both the East and West Coasts are feeling the pinch for more gas. Although the nation's 1500 gas transmission and distribution companies are laying pipelines at the rate of about 30,000 miles per year and a cost of about $1.7 billion per year to an already established piping network of over 700,000 miles [27], it is questionable whether they can keep pace with the growth in demand, notwithstanding predictions to the contrary [28]. The cost of constructing pipelines in this country varies from $10,000 to $280,000 per mile depending on the terrain and pipe size. An average cost for good pipelining country is around $100,000 for a 30-inch pipe, or roughly an average of from $2000 to $3000 per mile per inch diameter of pipe. These costs include right-of-way, surveying, communications for remote operation, maintenance, meter stations, miscellaneous materials, and compressor stations [29]. The cost of transporting natural gas by pipeline is about 1.7 cents per 1000 cu ft per 100 miles, which is about double the corresponding cost for transporting it by LNG tanker. When one adds to the LNG figure the costs of liquefaction and regasification, the pipeline and LNG begin to approach an even trade-off for the same distance between the source and the market. In fact, Venezuelan gas for the East Coast and Alaskan gas for the West Coast, or possibly Mexican gas for either coast, could put the squeeze on pipeline gas, which is experiencing a steady rise in cost, year after year. If LNG does not dent the pipeline market, it certainly will establish a ceiling for the "city-gate" price. Furthermore, if gas prices at the producing fields continue to rise at present rates, coal shipped from the North by barge or tanker could displace gas for power generation in the Southwest.[5]

In the last analysis the total energy picture will depend greatly on the continued development of atomic energy and direct conversion devices such as the fuel cell, the thermionic converter, the thermoelectric generator, and the magnetohydrodynamic (MHD) converter. Of these, the fuel cell and the MHD generator will probably have the greatest effect on the increasing use of natural gas for generating power.

The use of LNG as a starting raw material for petrochemical processing represents a good, profitable usage even though the quantity, as compared to fuel consumption, is only a matter of a few per cent.

Lastly, political factors, such as import regulations and nationalization of privately-owned plants in foreign countries, could be the tail that wags the donkey.

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[5] A tragic, but not inconceivable, turn of events would be a flow reversal in which coal slurries are pipelined from the Northeast to the Southwest.

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