OVERVIEW

LNG: So Simple, So Mysterious

By Jim Lewis and Pat Outtrim

Liquefied natural gas (LNG), the sister fuel of CNG, is a few years behind maturitywise to her older counterpart. Like a toddler, the LNG industry has had a few slow, wobbly starts, and skinned knees. A *brief* overview of the history of LNG and its basic anatomy will help in the understanding of this technology and the emerging liquefied natural gas vehicle (NGV) industry.

The first internal combustion engines used gaseous fuels before they used liquid fuels. Similar to today, the difficulties associated with gas supply inconvenience, equipment size and lack of infrastructure created barriers for vehicle fuel. Furthermore, prior to the 1950s, most "gas" was manufactured rather than natural, and thus was expensive.

The roots of LNG lie in the cryogenic liquefaction and handling technology. Permanent "gas" liquefaction was first accomplished in the laboratory by Michael Faraday in 1845. In 1895, Carl von Linde developed commercial air separation. Initial LNG efforts were envisioned by Godfrey Cabot in 1920, to transport natural gas by barge. In 1940, the first LNG peakshaving plant was built in West Virginia. That first plant had a liquefaction capacity of 3,600 gallons per day, and a storage capacity of 345 barrels.

The first commercial-sized plant was not put into operation until 1942 in Cleveland, Ohio. Construction of a 100 MMcf storage tank began with the inner shell of the tank consisting of 3.5 percent nickel steel. In 1944, the tank failed, causing a disastrous fire. The accident investigation did not conclude exactly what caused the failure, but research confirmed that 3.5 percent nickel steel becomes brittle at cryogenic temperatures. The tank simply cracked. The inner tanks of today's vessels are constructed of ductile 9 percent steel, stainless, aluminum or other materials that have been thoroughly tested to withstand cryogenic temperatures.

A 20-year interval passed before LNG activities were again initiated. The Cleveland accident still haunts the LNG industry. Strict safety regulations and public opposition to projects reflect a disproportionate, perhaps irrational, concern over the hazards of natural gas, and LNG in particular, compared with other fuels. Fortunately, this concern and caution has contributed to an excellent safety record for the LNG industry.

The LNG industry recovered, however, and three peakshaving plants came online in 1965. Today there are approximately 100. A combination of the rebirth of the industry and the invention of vacuum-insulated containers in 1892 by Sir James Dewar led to the feasibility of onboard storage tanks for LNG. The military and space efforts of the 1950's and 1960's accelerated the technology. Industrial gas suppliers of oxygen, nitrogen and argon, etc., quickly adopted and expanded the commercial designs. It was now logical to look at LNG as a potential vehicle fuel, since most of the technical equipment was ready and waiting to be placed onboard LNG-fueled vehicles.

LNG plant owners were the initial advocates of LNG as a vehicle fuel. The first vehicle was run by San Diego Gas and Electric, and consisted of a standard vertical nitrogen dewar in the back of a pickup, with a vaporizer/regulator and off-the-shelf natural gas carburetor. Life was simple then, and all the basic elements were available. The modern NGV complexity results more from what comes out of the tailpipe, rather than what goes into the engine. Similar projects were undertaken by Southern California Gas (1967) and Boston Gas (1968). Interesting projects before 1970 included two open-pit mine trucks for U.S. Steel (1967), some 60 vehicles for the California Department of Transportation (1967), and 19 buses at the San Diego Zoo (1967). About two dozen other projects were initiated, mostly within the next five years, but none survived. What happened?

The promise of better economics drove these LNG projects. "Clean air" was a talking point but not a selling point, except at the San Diego Zoo. Interestingly, the zoo was the longest-lasting project. But who benefited from the economics? The gas companies, by law, could only pass the revenue back to the traditional ratepayers. Equipment suppliers were only selling ones and twos. And, except for the U.S. Steel mine trucks, none of the vehicles used enough fuel to realize an attractive payout. It didn't make much sense, since gasoline was cheap, abundantly available and easy. Each of these projects was a "technical success." The San Diego Zoo project ended after 20 years — it "just wasn't worth the trouble."

But the most successful of the LNG "NGV" projects are never mentioned. This fleet contains the only truly *big* LNG-fueled vehicles — the LNG ships. There are some 120 of them, running their 40,000 horsepower engines 24 hours a day. In their 30 years of service, under some of the roughest conditions, these vessels have had few minor incidents, and no serious accidents.

BUT WHAT *IS* THIS THING WE CALL LNG?

LNG is natural gas that has been cooled to -260 degrees F to its liquid state: liquefied natural gas. The predominant molecule in natural gas is methane, the most basic of the hydrocarbons. Other hydrocarbons found in pipeline gas are ethane, propane and butane. These constituents are heavier than methane and are sometimes called "heavies." Other components of pipeline gas are water, carbon dioxide and nitrogen, called "inerts." Because water and carbon dioxide are solid at -260 degrees F, these components are removed before liquefaction.

Composition has been a big issue in the LNG industry, and this seems like a good place to explain its fundamentals. Since natural gas is made up of methane and heavies, the composition of the liquid may vary. Most LNG is between 95 and 100 percent methane. However, when a multicomponent liquid is stored in a tank over time, the lightest components, i.e., the methane, evaporate. The heavier constituents remain in the tank and their percentage in the liquid phase will increase. This is called "weathering" or "aging" of the liquid. As any home mechanic knows, when an engine is tuned to run on a specific mix of fuel and that fuel mix changes, the engine can develop symptoms as mild as rough running, to severe problems such as burning up the valves. Large amounts of heavies in weathered LNG have caused engine failures in project vehicles. The methane has an octane equivalent, but the heavies have a serious octane-reduction effect. This problem has been addressed and the industry consensus is to use LNG composition and handling techniques to preclude the weathering problem.

The positive impact on the environment is one of the pluses of natural gas. There are several positives that are specific to LNG. The most obvious is that because LNG is a liquid, more volume can be stored in a smaller space. Many industries require as much room for payload and range as possible. Many are also weight sensitive. A recent comparative study showed that to store 55 gallons of diesel requires a 20-inch x 50-inch tank that weighs 551 pounds full. The equivalent of this for CNG would be 11, 13.5-inch x 72-inch cylinders that would weigh 2,535 pounds. LNG would require one 25-inch x 63-inch cylinder weighing 639 pounds. Clearly, for payload and range optimization, LNG is the way to go. Relative to the considerations of space and payload, LNG offers the fleet owner a longer-range vehicle than some alternate fuels such as CNG and electric vehicles.

Another advantage to LNG is that, like diesel, the fuel can be transferred rapidly to the vehicle. Usually, a large vehicle can be filled within four-to-six minutes. Also, as mentioned earlier, the composition of the fuel can be more accurately determined, since most LNG produced for vehicles is now in the 99+ percent range. This allows for more fine-tuning of the fuel system and engine to optimize engine performance, which leads to even greater fuel economy and further reduces emissions.

While LNG is more economical because it is less expensive than conventional fuels, it also reduces maintenance on the vehicles. Fleets have shown that because natural gas burns cleaner, the vehicles can go longer between oil changes. The oil simply does not get dirty or diluted as quickly. This in turn decreases the wear and tear on the internal parts of the engine. Natural gas engines can run significantly longer than conventionally fueled engines of the same model.

What are the drawbacks of LNG? Most obvious is the fact that it is a cryogenic liquid. Since the public is not used to dealing with liquids cooled to this low temperature, some education is necessary. Additional training and awareness are required in the handling of the fuel. These systems have been designed to the highest safety standards and are not as futuristic as one might imagine. The cryogenic drawbacks are problematic mainly in the design of the internal components, and a few problems have not yet found satisfactory solutions.

These issues are discussed in detail in the "issues" article of this publication, on p. 16.

Another disincentive is the lack of infrastructure to support LNG vehicles. Currently, most projects are centrally fueled fleets. These fleet owners provide their own refueling stations. No "public" fueling stations for LNG currently exist.

HOW IS AN LNG NGV SYSTEM DIFFERENT?

The heart of the vehicle, the engine, remains essentially the same, whether one uses LNG or CNG. This is because by the time the fuel reaches the engine, it is the same substance, natural *gas,* i.e., the LNG has been vaporized. Therefore, the main difference in vehicles is the fuel storage-and-delivery system. The following fuel system components are characteristic of LNG vehicles: refueling coupling, LNG tank(s), LNG liquid/vapor pressure-control system (possible fuel pump), heat exchanger, pressure regulator and natural gas mixer or fuel-injection system. The engine can also use higher compression ratios with LNG, consisting of nearly pure methane. This provides increased efficiency and power. The component that is the most different is the fuel tank. The LNG tank is considerably smaller and lighter than a CNG cylinder. All cryogenic fuel system piping is stainless steel.

WHERE ARE WE NOW?

LNG vehicle technology has come a long way since Houston METRO began converting buses to LNG in the early 1990s. When METRO first looked into converting its buses to LNG, there were no engines specifically designed to run on LNG, the fuel system was pieced together from various manufacturers, and costs for these parts and system development were extremely high. Since then, several engines have been designed specifically for LNG vehicles, conversion packages have been put together, and prices, due to competition, have dropped considerably.

Many pilot projects have been successfully completed across the country. These successful projects include the Roadway, UPS and WalMart truck projects; Houston METRO and Greater Austin Transportation Company bus systems; and a Burlington Northern Railroad locomotive. Promising projects include the Union Pacific and Santa Fe Railroad switch engine projects, the Tidewater Transit Authority ferry project and the Southern California Regional Rail Authority locomotive project.

We now see OEMs moving toward natural gas and, of special note, Navistar is preparing to offer LNG-fueled, heavy-duty vehicles from its assembly line. The demand for heavy-duty vehicles is now developing, as availability increases and diesel-emission requirements loom closer and closer.

It is also helpful to put the CNG and LNG markets in perspective. As a generalization, the CNG industry will find current gasoline-fueled vehicles as its market, while LNG is the more likely substitute for the current diesel market.

With the advent of the 21st Century on the horizon, the LNG vehicle industry has emerged from its infancy. It is now crawling fast and furiously toward a cleaner environment and reduced foreign energy dependence. Some in the industry are standing, taking their first cautious steps, and starting to walk confidently. Who will be the first to run?

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