The cold facts about a hot commodity: LNG

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Photo courtesy of ConocoPhillips.
A tanker docked at the Nikiski, Alaska, LNG plant.

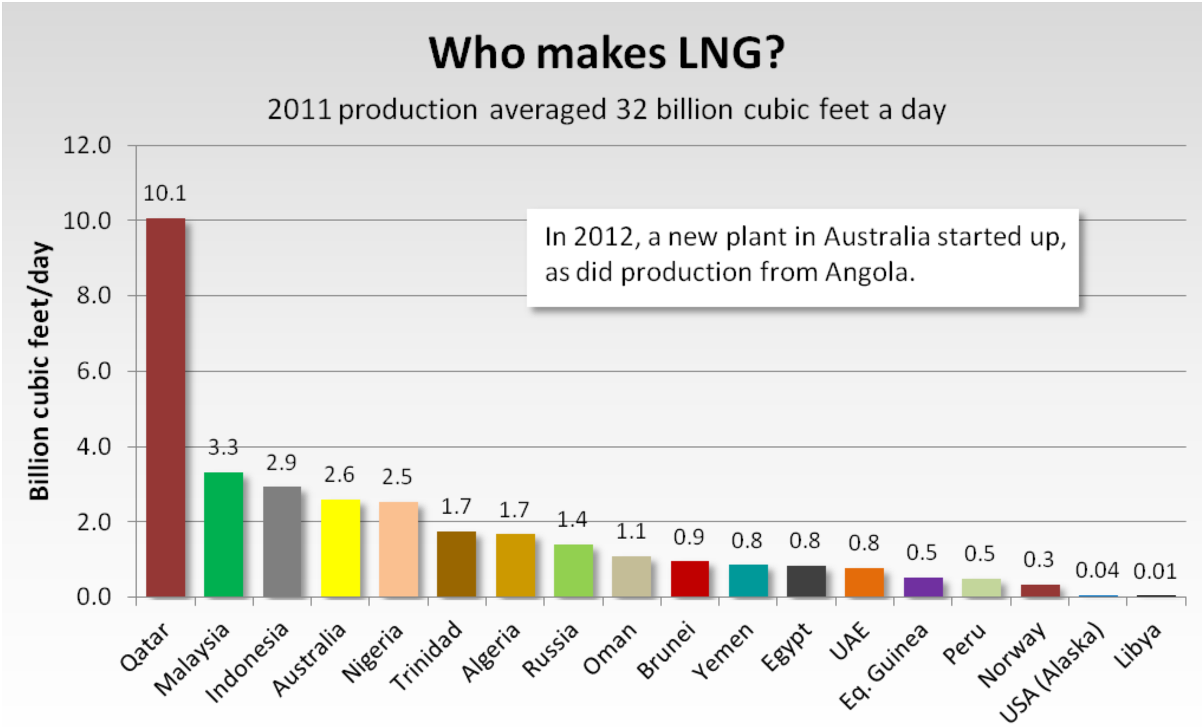
Liquefied natural gas is an odorless, colorless, non-toxic, non-corrosive and non-flammable form of methane. As fuels go, it's pretty cool.

Actually, LNG is colder than Antarctica on winter solstice. Methane is chilled to about minus 260 degrees — a temperature that transforms it from a vapor to a liquid, compressing its volume 600 times to make it more economical to store for later use or to ship long distances from countries endowed with natural gas to those starved for the fuel.

That's the broad story of LNG — a case of Adam Smith capitalism at work.

But in the details, the LNG story is a tale of brilliant physicists, savvy government engineers and entrepreneurial risk takers. LNG's back story includes a Nobel Prize, anxiety about U.S. air defense and a disaster that destroyed part of Cleveland.

LNG touches only a small portion of the world's gas supply, but it's the fastest-growing portion. Since 2000, global demand for LNG has grown 140 percent and now accounts for roughly 10 percent of the methane consumed worldwide. The rest moves to market by pipeline.



Source: International Gas Union

LNG is exported from 19 countries, including from one U.S. plant in Nikiski, Alaska.

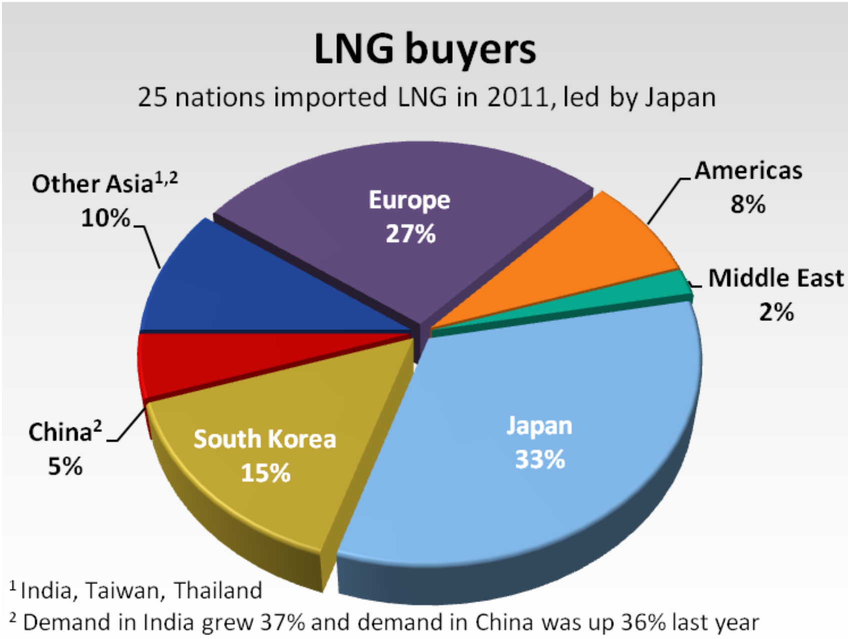
Since 2006, Norway, Russia, Yemen, Peru, Angola and Equatorial Guinea all have started making LNG, while Qatar, Nigeria, Australia, Oman and Indonesia have expanded production.

Qatar's expansion was an act of sheer audacity. Qatar tripled its LNG production capacity to over 80 million metric tons a year — about 11 billion cubic feet a day — leaping past Malaysia and Indonesia as the world's largest LNG maker. Last year Qatari plants exported almost one-third of the LNG traded across the globe. In the mid-2000s, with construction under way, Qatari officials thought they'd be selling much of their LNG to the United States. The Lower 48 shale-gas boom blew apart that plan. But last year, as Japan idled nuclear power production after the Fukushima disaster, Qatari exports to Japan soared 56 percent over their 2010 level, according to the BP Statistical Review of World Energy. That dulled Qatar's pain of losing the U.S. market.

Meanwhile, more countries are clamoring for LNG to quench their growing energy appetite.

Since 2006, China, Brazil, Chile, Dubai, Kuwait, the Netherlands and even Canada and Mexico all became first-time importers of LNG. They joined the mainstay LNG consumers of Japan, South Korea and Taiwan, according to the International Group of Liquefied Natural Gas Importers.

In all, 25 countries took LNG shipments last year, the gas importers group said.



Source: International Gas Union

As the world's demand for LNG grows, more locations are mulling entry into the production game. Export projects in Western Canada, Eastern Africa, Russia and the U.S. Gulf Coast are under consideration.

One other possible contender: Export of LNG made from Alaska North Slope gas. The main North Slope producers — ExxonMobil, ConocoPhillips and BP — jointly are at an early stage of considering such a project.

HOW IT WORKS

Chemical engineers have known for years how to liquefy vaporous methane.

And for decades LNG tankers — essentially massive thermos bottles that keep the gas cold and liquid — have sailed the oceans safely.

Like many great inventions, liquefied natural gas emerged as an industry via a progression of events over many years, responding to both commercial and geopolitical pressures.

A key development was learning methane's "boiling point," a temperature below which methane is a liquid and above which it's a vapor.

Most people likely are familiar with the boiling point of water: 212 degrees. Heat water above that temperature and the liquid becomes a vapor.

Methane's boiling point is about minus 260 degrees. Above that frigid temperature it's a vapor. Below it and you have a liquid.

But liquefying natural gas involves more than superchilling it and maintaining the temperature.

That's because a natural gas stream rising out of the ground contains more than just methane, although methane usually is the main component. The ethane, propane, butane, pentane, carbon dioxide, water and other components each have separate boiling points.

Ethane liquefies at minus 127, propane at minus 44, butane at plus 31 degrees, and so on. Like water at 32 degrees, these gases also have "melting points," a temperature below which they become solid. (Dry ice is nothing more than solid carbon dioxide, whose melting point is minus 109.)

Boiling and melting points of gases

	Boiling point[1]	Melting point[2]
Methane	-260 F	-297 F
Ethane	-126 F	-278 F
Propane	-44 F	-306 F
n-Butane	+31 F	-217 F
n-Pentane	+97 F	-201 F
Water	+212 F	+32 F

[1] Approximate temperature at which liquid turns to vapor at atmospheric pressure

[2] Approximate temperature at which solid turns to liquid at atmospheric pressure

Source: National Center for Biotechnology Information

These gases have different boiling and melting points because although they're all hydrocarbons — composed of hydrogen and carbon atoms — the number of atoms differs. The more carbon atoms a molecule contains, the heavier it is. That weight determines the temperatures and pressures that make the gas a vapor or liquid.

Methane has the fewest carbon atoms — one — so it has the coldest boiling point of these gases. If the entire produced natural gas stream were liquefied, some components — such as butane with its four carbon atoms and pentane with its five — would freeze solid before the methane vapors got cold enough to become liquid.

Chilling the entire gas stream to minus 260 to liquefy methane thus could produce a slushy slurry of product that would muck up the machinery. This is why the heavier hydrocarbons mostly are stripped from the gas stream before liquefaction.

THE PROCESS

Here's a quick walk along the LNG value chain:

Step one: Clean the natural gas stream so that mostly methane is being processed. The residual ethane and other components left behind after processing are in quantities too small to matter.

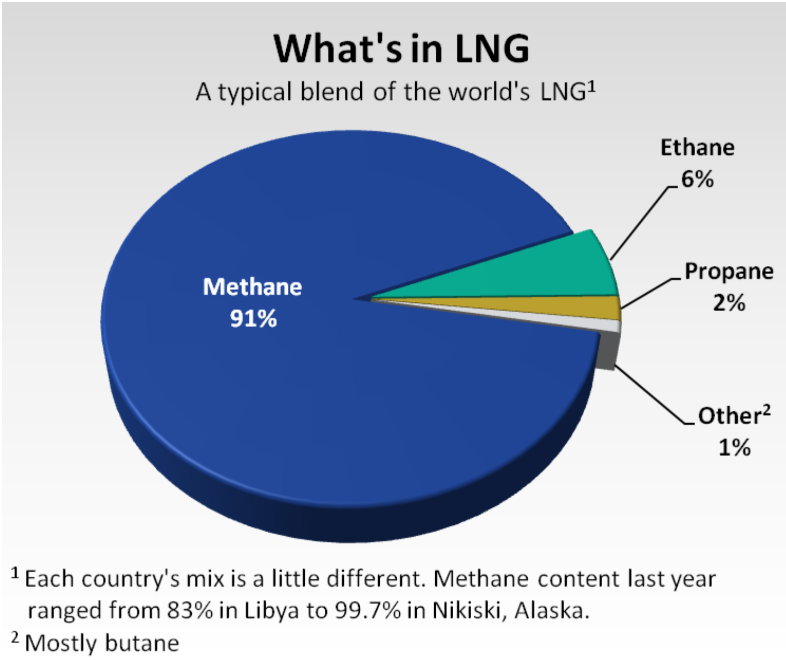
Sometimes this cleansing occurs before the gas reaches the liquefaction plant. More typically cleansing occurs at the plant.

Buyers in Japan and Europe typically like their LNG to be spiked with a little ethane or other carbon-rich gases because their mainstream gas burns hotter than mainstream gas in North America. Ethane, propane, butane, etc., have higher Btu contents than methane and serve as the spiking agents.

Step two: Superchill the methane.

A variety of techniques will liquefy methane. A Pennsylvania company called Air Products licenses the technology that dominates the industry.

Air Products uses several variations on the same process. Essentially, it starts by using propane to precool the methane. Propane is compressed and condensed, then its pressure is eased in steps to provide refrigeration that cools the methane. (Gas warms as it is compressed and then cools as the compression eases. This principle is applied throughout a typical liquefaction process.)



Source: International Group of Liquefied Natural Gas Importers

Next, the cooled methane enters the main stage, a heat exchanger where the gas comes in contact with a blend of refrigerants that transforms the methane vapor into a liquid. Air conditioners work in a similar way: warm air passes over coiled tubing filled with a cold gas.

A new variation uses nitrogen as a final superchilling refrigerant. This allowed much bigger LNG plants to get built, and it partly explains how Qatar could construct so much capacity in recent years.

A technology that's a distant second in the market to Air Products' is licensed by ConocoPhillips. The company's Nikiski, Alaska, plant as well as plants in Trinidad and Tobago, Egypt, Angola, Equatorial Guinea and one site in Australia use it.

ConocoPhillips routes cleansed methane first into a propane heat exchanger to initially drop the temperature. Ethylene is used to drop the temperature more (you can make ethane colder than propane before it boils into a vapor). Then the gas enters a methane cold box connected to mighty compressors to cool the gas to near a liquid state. A final "flash blast" finishes the job.

Most LNG plants have on site more than one processing unit — called trains. The trains operate independent of each other, running in parallel to liquefy methane. Qatar hosts the world's largest trains — the biggest can handle about 1 billion cubic feet of natural gas per day. Qatar's most massive plant, at the Ras Laffan complex, features two such trains plus four smaller ones that together can process about 5 bcf a day. That's about twice the volume as has been discussed for an LNG plant that could process Alaska North Slope gas. Alaska's Nikiski plant is relatively small, with capacity to handle about 200 million cubic feet a day.

One final point about liquefying methane: About 10 to 15 percent of the gas gets consumed during the process. Much of it to run the plant's turbines, compressors and other machinery.

Step three: Store the LNG until it's shipped to market. Special insulated metal tanks keep the gas liquid. A small fraction will "boil off" — warm into a vapor — and this gas can be reliquefied or used to power the plant.

Storage tank dimensions vary widely, depending on whether the LNG is stored for truck fueling, peak shaving or import-export. The largest storage tanks stand as tall as a 14-story building (about 170 feet tall), are nearly as wide as a football-field length (280 feet in diameter) and can hold up to 200,000 cubic meters of LNG — the equivalent of roughly 4 billion cubic feet of vaporous methane, or about one-15th of daily U.S. gas production last year. In short: They can be big.

Step four: Ship the gas. Special tankers with insulated chambers keep the gas below minus 260. Again, a small volume of liquid methane vaporizes on the trip to market; this gas typically is used to power the ship or is reliquefied.

At the end of 2011, 360 ships comprised the global LNG fleet, according to the International Gas Union. Ships typically get built in tandem with LNG plants and get contracted to sail between the plant and its customers. Just as the capacity to make LNG has skyrocketed in recent years, so has the tanker capacity, growing 150 percent since 2006, the IGU said.

The average tanker capacity is about 3.1 bcf of gas (after the liquid gets converted back into a vapor). South Korea is the big builder of tankers. An average one can cost at least $150 million. The largest tankers were built for the Qatar expansion. They can carry about 5.5 bcf, but the tankers are too big for some LNG receiving ports.

Step five: Convert the liquid back into a vapor, called regasification.

This happens in the LNG destination port. LNG is offloaded into storage tanks. The LNG then is warmed into vapor as needed before entering the local gas pipeline system.

THE CRYOGENICS CRAZE

As an export product, LNG dates back less than 50 years, to 1964.

That year, as Ford rolled out its new sports car, the Mustang, a British shipyard launched the Methane Princess, a tanker that carried the first commercial load of LNG, from a new plant in Algeria to a gas-hungry United Kingdom.

Within a few years, Algeria was sending LNG to France, too, and Libya was exporting it to Italy and Spain. In 1969, a new Phillips and Marathon plant in Nikiski, Alaska, started shipping LNG made of Cook Inlet natural gas to Japan, inaugurating LNG trade to Asia. Japan is the world's top LNG consumer today.

But the true history of LNG dates to 100 years earlier as scientists studied how very low temperatures changed matter, a specialty called cryogenics.

Credit: de.wikipedia.org
Carl von Linde)

In the 1870s, German engineer Carl von Linde's pioneering work in compressed refrigeration found a ready market among breweries and slaughterhouses. Von Linde's technique for chilling air to extract the oxygen, developed around the turn of the century, also was a transforming moment. Isolating oxygen led to development of a torch that revolutionized metal cutting as well as welding for skyscrapers.

Other scientists and engineers hopped aboard the cryogenics craze.

Ethane for plastics, chlorine for sanitizing sewage, oxygen for hospital patients, nitrogen for cryosurgery are among the thousands of products and uses that trace their origins to chilling gases to isolate their components.

THE GAS THAT WOULDN'T BURN

The birth of liquefied methane stemmed from work that used cryogenics to isolate helium.

Helium is a marvelous gas that has been adapted to many uses today, such as cooling superconducting magnets in medical MRI scanners.

If helium isolation has a Eureka! moment, it arguably is a 1903 event in a small flatland town called Dexter, Kan.

A driller hit a "howling gasser" of a well there. Nine million cubic feet of gas spit to the surface each day before the well could be capped. Dreams of riches infused the locals. Ore smelters. Brick and glass plants. Soon they would be wildly prosperous.

To celebrate, the town tossed a huge party, the climax of which was to be lighting the gas jet. After speeches, a bale of burning hay was nudged to the escaping gas to produce a promised "great pillar of flame." But the gas failed to ignite. To everyone's surprise, the burning bale got snuffed instead.

A geologist and a chemistry professor soon teamed to solve the mystery of the gas that wouldn't burn.

They discovered the gas was mostly nitrogen. The amount of methane present wasn't enough to combust given all the non-flammable nitrogen — just as trace quantities of methane in the Earth's air don't burst into flame every time someone lights a cigarette.

They also found "inert residue" present in the Dexter gas. After further analysis, they learned this residue included helium.

This discovery was astonishing. To that time, helium was considered a rare element. But now it seemed helium could be found in an ordinary natural gas stream. As for Dexter, it was located in the planet's great cradle of helium: The natural gas deposits of the U.S. plains.

Credit: en.wikipedia.org
Heike Kamerlingh Onnes

The scene then shifted to the lab of Dutch physicist Heike Kamerlingh Onnes. In 1908, he was the first to liquefy helium, chilling helium through a series of stages until getting it to minus 452 degrees, at which point the vaporous helium transformed into liquid helium, reaching its boiling point. It was the coldest temperature ever achieved on Earth. Onnes won the Nobel Prize in Physics five years later for his work.

World War I, with cryogenic isolation, became the great leap forward for helium and led eventually to the liquefaction of methane.

During the war, airships — dirigibles, zeppelins and the like — became a novel innovation of combat. Germans dropped bombs from them. The British hunted U-boats. A downside was hydrogen, the lighter-than-air gas used to float most airships. Hydrogen is spectacularly flammable, as the famous 1937 Hindenburg disaster demonstrated.

But helium isn't flammable. The U.S. launched a crash research program in 1917, as the country entered World War I, to find cheap ways to extract large volumes of helium from natural gas and stockpile it.

This research led the U.S. Bureau of Mines in 1924 to produce the first liquid methane as a byproduct of helium separation.

LNG'S EARLY YEARS

During the ensuing years, techniques for liquefying methane were refined and ideas for storing and transporting LNG were patented.

A public revulsion toward flaring natural gas as a waste product of oil production helped propel the industry. Better ways had to be found to move the gas from where it was produced and not needed to where it could be used. The solutions included long-distance pipelines for domestic transport and, much later, LNG for cross-ocean transport.

By 1941, science and capitalism converged to make commercial use of LNG.

That year the East Ohio Gas Co. built a plant in Cleveland that could process about 4 million cubic feet of gas per day into LNG. The company installed three insulated storage tanks to keep the LNG cold. The gas utility regasified LNG when customer demand peaked during winter.

This "peak shaving" concept is a key function of LNG today, the little publicized cousin of making large quantities of LNG for export. Small peak-shaving liquefaction plants and storage sites exist across the world.

The Cleveland operation ran smoothly for three years, until 1944 when the utility installed a fourth storage tank. It was larger and of a different design from the other three. This tank failed on Oct. 20, 1944.

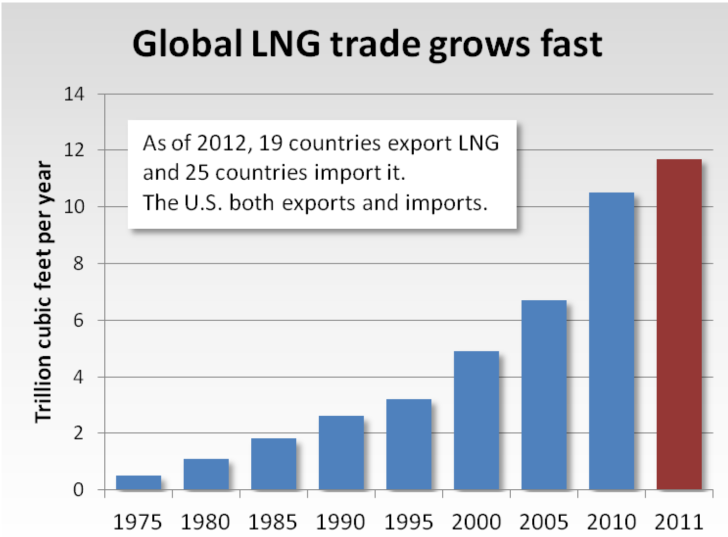
An estimated 1.2 million gallons of LNG spilled, so much that it flowed over the protective dike.

The liquid spread like batter on a griddle. Some dropped into the sewers, which filled with methane vapor as the LNG warmed above methane's boiling point. Gas seeped into basements. Houses blew apart as the gas contacted hot-water heater pilot lights.

The Cleveland catastrophe killed 128 people; 14,000 became homeless.

The LNG industry went dormant, except for a liquefaction plant Dresser Industries built for the Soviet Union in 1947.

HEADED TO SEA



Source: BP Statistical Review of World Energy

The idea of water-borne LNG deliveries started to get traction in the mid-1950s.

A joint venture of Continental Oil Co. (Conoco) and Union Stock and Transit Co., a Chicago stockyards operation, did pivotal work on how this idea could work. The venture's name was Constock, a blend of the partners' names.

Union originally wanted Gulf Coast methane barged as LNG to Chicago for refrigeration at its slaughterhouses. But in the late 1950s, with the United Kingdom, Japan and other countries expressing interest in LNG, the focus turned to trans-ocean shipments.

Constock worked on designing the entire system, from liquefaction to regasification. In 1959, a test shipment of LNG left a new plant near Lake Charles, La., and sailed to a new receiving terminal on Canvey Island, down river from London. The ship — and its LNG cargo — weathered the rough Atlantic well. More test shipments ensued, proving that international trade of LNG could work.

New gas discoveries in Algeria made that country the first mover in LNG exports. The Methane Princess, carrying the world's first commercial load to Canvey Island, was small by today's standards. It could carry up to about 500 million cubic feet of gas (after regasification). The average LNG tanker today is five times larger.

But the Methane Princess proved to be a workhorse through the early years of LNG export. The vessel was finally scrapped in India during the mid-1990s. Another tanker with the same name sails in the LNG trade today.