ALASKA NATURAL GAS TRANSPORTATION PROJECTS
OFFICE OF THE FEDERAL COORDINATOR

LNG carriers called 'floating pipelines'

The story of LNG shipping is a tale of massive investment, sophisticated technology, engineering wizardry and repeated efforts to tame the ocean's mayhem. All in the pursuit of moving trillions of cubic feet of natural gas worth tens of billions of dollars a year across the seas.

It's a fast-growing industry that connects a mix of sellers, buyers, middlemen, financiers and engineers. The fleet ranges from a pair of aging carriers whose maiden voyages saw them set sail from the shores of Alaska's Cook Inlet 45 years ago to ultra-modern behemoths partly powered by the very gas they carry.

Worldwide, ships carried more than 11.5 trillion cubic feet of natural gas as LNG in 2013.

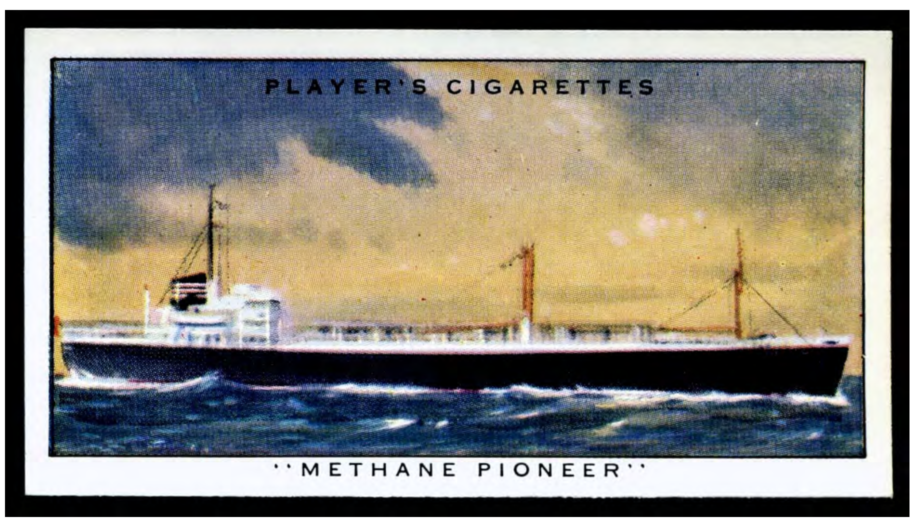
That may sound like a lot — it's enough to supply the entire United States for nearly half a year — but it was only about one-tenth of all natural gas used around the world. Most gas moves by pipeline, which, as in the case of oil, generally is far cheaper than hauling it in expensive tankers.

But for island-bound customers, such as Japan, or for others too far away to reach by pipeline, seagoing LNG deliveries are the only option, despite costing more than delivery by pipeline.

It actually started 10 years before that Cook Inlet cargo when the world's first LNG delivery left the U.S. Gulf Coast aboard the Methane Pioneer, destined for England.

Looking ahead to the proposed Alaska North Slope LNG project, an entire day's production from its plant at Nikiski would fit easily into a single oceangoing tanker after the natural gas was supercooled into a liquid 1/600th the volume of its gaseous state.

The job then: Keep it cold, keep it safe and keep it moving to customers.



When the Methane Pioneer began hauling LNG from Louisiana to England in 1959, it was such big news that it was featured among notable ships in a set of cards produced about a year later by Player's Cigarettes. The U.K.-based tobacco company produced more than 200 different sets of collectible cards over the years including athletes, cars and aircraft.

The expense isn't so much running the ships as making the LNG. It generally costs far more to convert the gas into a liquid than to haul it across the ocean.

It required several thousand voyages to deliver all that gas last year, using several hundred ships, with new ones costing about $200 million each to build. And with global demand expected to grow a lot over the next decade or two, it will take a lot more ships and a lot more voyages to deliver all that LNG.

A GROWTH INDUSTRY

Compared with where the industry stands today, the beginnings of LNG shipping can only be described as modest. The first vessel was like souping up a '57 Chevy in your garage: Let's convert an old World War II freighter into an oceangoing LNG tanker. In fact, the term "oceangoing LNG tanker" didn't even exist until this made-over vessel — aptly named the Methane Pioneer — hauled its first test load from Louisiana to England in 1959, the same year Alaska joined the union.

This was the fledgling industry's Gemini orbital space launch — a totally new thing. Although the builders and operators of the Pioneer thought and hoped they knew what they were doing, they were at or beyond the edge of what was known about LNG and how to move it safely across the sea.

Workers installed aluminum tanks in the ship, using balsa word supports and plywood and urethane insulation. A press release issued the week the ship left Louisiana said it was a "historic voyage," carrying the fuel to "gas-deficient England." It added, "The maiden voyage climaxes five years of research and development."

The test worked, the market grew and it looks to keep growing.

And though eight or ten oil tankers still move across the seas for every one LNG carrier — as they are known in the industry — liquefied natural gas is nonetheless the hot ticket these days for shippers and shipbuilders.

During 2013, about 360 LNG tankers were in service. They averaged 150,000 cubic meters in capacity, which is enough gas to supply some 42,000 U.S. homes for a year. An additional 108 vessels were on order, according to an end-of-year report by the International Gas Union.

The going rate for building a typical LNG carrier these days is around $200 million, with orders normally placed two to three years before delivery.

Source: National Maritime Museum, Greenwich, London

The Methane Pioneer (foreground) was the world's first LNG tanker, starting service between Louisiana and Tilbury, England, in 1959. The Tilbury docks (above) are on the River Thames, about halfway between London and the sea.

South Korea has long been the dominant player in building LNG carriers; 56 percent of the current fleet was built there, according to an August 2013 presentation for the Alaska Legislature by the consulting firm PFC Energy. And the global investment banking firm Jefferies reported in June 2013 that Korean shipyards had nailed down 86 percent of orders for new tankers currently under construction, with Japan and China splitting the rest.

The price that really defines the market is not the cost to build a tanker, but the daily cost of chartering it. That rate comes in two flavors: long-term and spot.

CHARTER RATES VARY

The dominant flavor is long-term. From 2009 to 2012, long-term charter rates ranged from $61,000 a day to $109,000 a day, according to PFC.

Benjamin Gage, a PFC analyst, estimated early this year that 85 percent of tankers were operating under long-term charters. But, he said in an email, he expects that share to erode as new vessels being built on speculation come into service and older tankers come out of long-term charters.

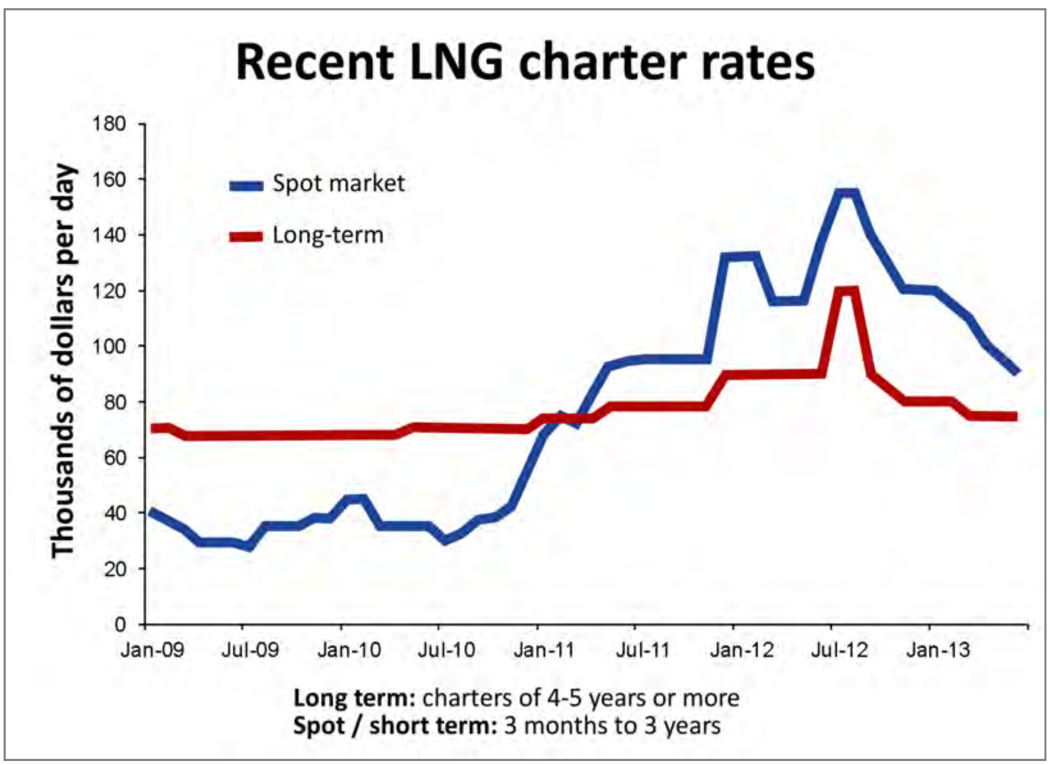
Eero Vanaale, an analyst with the British ship brokers and consulting firm Clarksons LNG, projected early this year that 73 percent of newly built tankers between 2014 and 2017 would be committed to charters on delivery, with the remainder open for the spot market.

Most often, tankers under long-term contracts are tied to a specific project, a business model often called "the floating pipeline."

The floating pipeline has developed because most LNG is sold under long-term contracts, so the sellers have certainty of sales revenues before undertaking multibillion-dollar investments to build liquefaction plants, and the buyers have certainty that the gas will be delivered when they need it. Both parties have enormous incentives to nail down shipping costs for the duration of the contract, even if that can mean having to forgo surprise opportunities on the spot charter market.

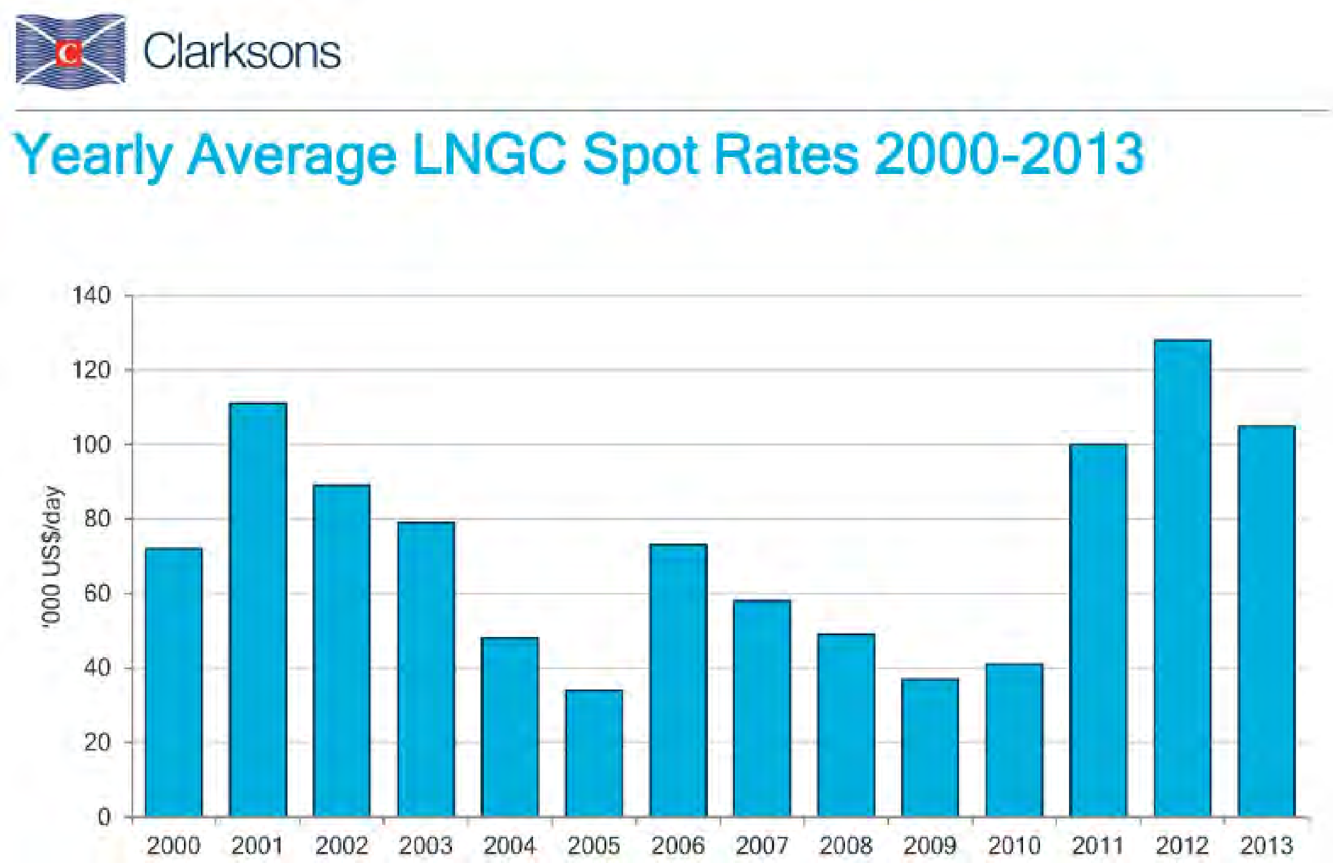
While the floating pipeline may not pare final transportation costs to the bone, it does remove some uncertainty and risk from the complicated and unpredictable energy business.

The other flavor of tanker rates is the highly variable spot-charter rate, meaning what a tanker will cost if



Source: PFC Energy

Long-term LNG tanker charter rates have been a lot less volatile than spot- or short-term rates in recent years.



Source: Clarksons

Yearly average spot-charter rates for LNG tankers since 2000 have ranged from less than $40,000 a day in 2005 to more than $120,000 in 2012.

you need it only for a relatively short time. The usual definition is 3 months to 5 years. Recent rates ranged from about $24,000 a day in the summer of 2009 to $141,000 a day in the summer of 2012, according to PFC.

Over the past year, the short-term rate has sagged to around $70,000 a day, which industry players and observers say is somewhere near the break-even point for operators in the spot market.

This is putting retirement pressure on a category of aging tankers known in the business as "Old Ladies" due to higher costs for maintenance, upkeep and fuel. The oldest of them are the 45-year-old SCF Arctic and SCF Polar, operated by Russia's Sovcomflot Group. They're due to be sold for scrap this year.

And, with them, a notable chunk of Alaska history will be scrapped. The two vessels started life as the Arctic Tokyo and the Polar Alaska and were built to service the small LNG export facility at Nikiski that opened in 1969.

SHIP OWNERS VARY, TOO

Who owns and operates the ships? Ownership structures are as varied as the worldwide LNG market and the players in it.

Some LNG tankers are owned and operated by shipping companies such as Vancouver-based Teekay, Greece's Dynagas, and Japan's NYK Line and Mitsui O.S.K. Lines.

Others are owned and operated by international hydrocarbon producers like the Netherlands-based Shell and Britain's BG Group and BP.

Still others are owned and operated by the companies that buy LNG, such as Japan's Tokyo Electric Power and Tokyo Gas (a major supplier of gas and electricity) and the French electric utility and global gas supplier GDF Suez.

Finally, some are owned and operated by the LNG projects themselves such as North West Shelf Australia, which started operations in 1989, and Angola LNG, which is a partnership of the Angolan national oil company with four international oil companies.

In many cases, LNG projects, sellers and buyers that run their own tankers also charter additional vessels from shipping companies.

HOW BIG ARE LNG TANKERS?

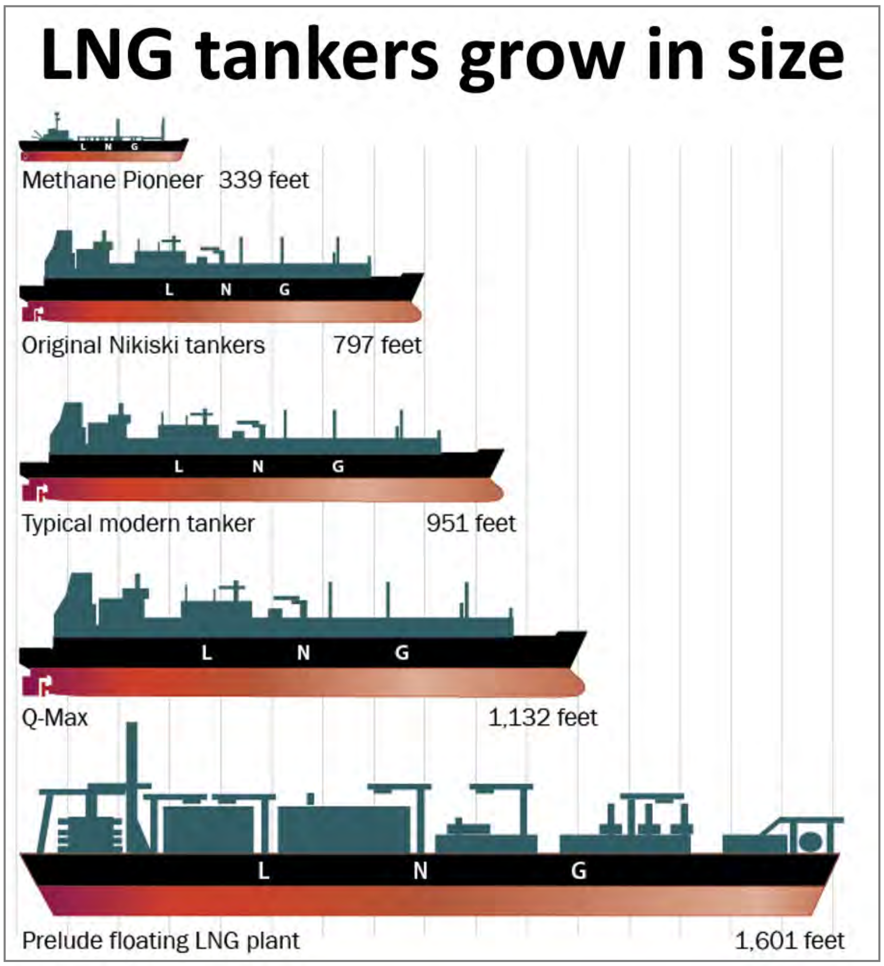
The world's largest LNG carriers are the Q-Max tankers, so-called because they are the maximum size that can be accommodated at liquefaction terminals in Qatar, the world's biggest exporter of LNG.

Q-Maxes are 1,132 feet long and 177 feet wide. They draw 39 feet of water. Qatar went for economies of scale with these ships — move the most gas in the biggest tanker possible — though only a limited number of customers can receive the big ships at their docks.

How big is a Q-Max? Pretty big, but not on the same scale as some of the world's true seagoing behemoths.

The biggest ship ever — more of a barge than a ship, actually — is Shell's gigantic Prelude floating LNG vessel. It was moved out of a South Korea dry dock in early December 2013 and is expected to enter service in an offshore Australia gas field in 2016. It's 1,601 feet long — longer than five football fields — and has no propulsion of its own. Instead, it'll be towed into position and anchored over the gas field. There, it will take gas piped from under the seabed, liquefy it and store it to be loaded on LNG tankers for shipment.

Probably the smallest oceangoing LNG tanker ever to sail was also the first: The Methane Pioneer, a mere 339 feet long. It left the U.S. Gulf Coast for England with the first load of LNG ever to cross an ocean in January 1959.



Credit: Ron Engstrom

About 360 LNG tankers were in service last year, most around 900-plus feet in length – larger than the ships that served the Nikiski, Alaska, export terminal when it opened in 1969, yet smaller than the world's largest Q-Max tankers. And all fall far short of measuring up to Prelude, the giant floating LNG factory ship being built for Shell. Prelude will make and store LNG, offloading it to tankers for delivery.

Source: Nakilat-Keppel Offshore & Marine

LNG tankers tied up, waiting for repairs at a Qatari shipyard at Ras Laffan Port in 2012. The shipyard, a partnership between Singapore and Qatar firms, is one of the world's leading yards for LNG carrier repairs.

After Prelude, the big-ship field drops away pretty fast. Next are a fleet of Maersk Line container vessels at just over 1,300 feet, followed by a number of oil tankers over 1,200 feet, then the Q-Max tankers and some bulk carriers and cruise ships over 1,100 feet.

But what matters about a ship is not how long it is. The question is, how much cargo can it handle?

A Q-Max tanker can carry about 266,000 cubic meters of LNG, equal to roughly 5.5 billion cubic feet of natural gas in the vapor form burned in furnaces, water heaters and kitchen ranges. That's enough to supply almost 75,000 U.S. households for a year. (The old Methane Pioneer carried 1/50th as much, about 5,000 cubic meters. The Polar Alaska and Arctic Tokyo, which launched the Alaska LNG trade, carried 71,500 cubic meters each.)

But most LNG carriers are not sized for the Qatar trade. They tend to be of a more utilitarian size — around 950 feet — so they can fit most LNG export and import terminals anywhere in the world. Their LNG capacity falls into the range from 125,000 to 175,000 cubic meters. Energy consultants IHS CERA reported that, as of late 2013, of the more than 100 new LNG tankers on order through 2017, only one had a capacity over 190,000 cubic meters.

The common mid-range tankers can move from 2.6 billion to 3.6 billion cubic feet of natural gas (when supercooled into LNG) per load, and the vessels envisioned for the proposed Alaska LNG project would fall within that range. The North Slope producer-led project would pipe natural gas from Prudhoe Bay and other North Slope fields to a liquefaction plant in Nikiski on the Kenai Peninsula. That project in full operation could fill several tankers per week.

LNG tankers and oil tankers are in essentially the same business — moving liquid energy across oceans. But, as a general rule, LNG costs more to get to market.

This is partly a function of two cost factors tied to producing and moving LNG.

One factor is the expense of the huge and complex plant that turns vapor into LNG. Another factor is that LNG tankers are more complicated to build and operate than oil tankers. The tanks holding the LNG must be heavily insulated to keep it cold enough to stay liquid, and the ship has to have onboard systems for managing what is called boil-off — the LNG that evaporates because no insulation system is perfect.

But another key factor at work in the higher cost of transporting LNG has nothing to do with equipment or operations. Rather, it's basic physics: A given volume of LNG contains only about 64 percent as much energy as the same volume of crude oil.

For example, the crude oil on a fully loaded million-barrel tanker contains 5.6 trillion Btu of energy.

And LNG? A tanker of the same volume would carry 3.6 trillion Btu.

To put it another way, to move equal amounts of energy, you'd need either an LNG tanker about half again as big as your oil tanker, or 50 percent more tanker loads.

FLOATING THERMOS BOTTLES

Every LNG tanker on Earth has to do one thing: make sure that its cargo — methane gas chilled to about minus 260 degrees Fahrenheit to turn it into a liquid — doesn't warm up and turn back into a gas. This is why LNG tankers are often called "floating thermos bottles."

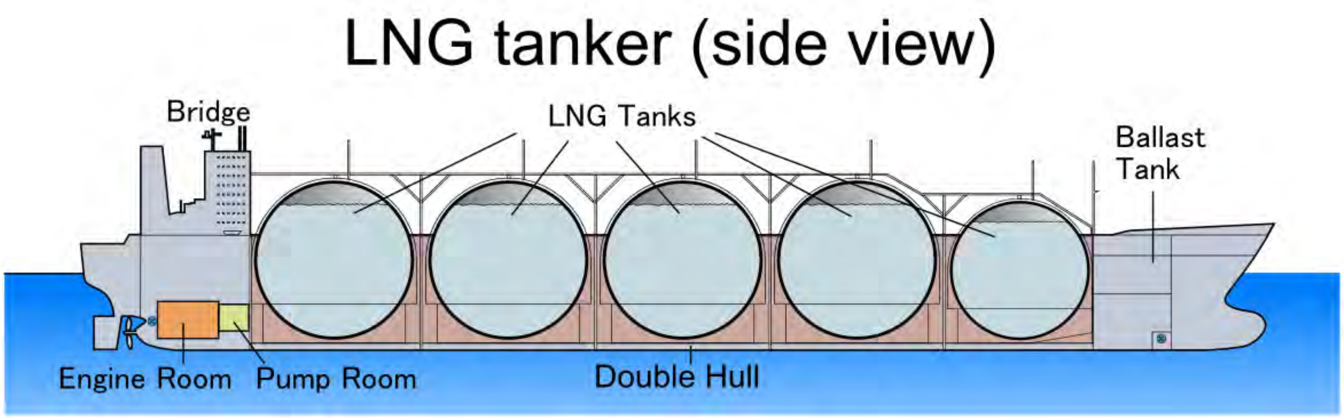
To keep the gas cold, LNG tankers come predominantly in two designs: Moss and membrane.

If there's such a thing as an instantly recognizable LNG tanker, it's one with the Moss design, developed by Norway's Moss Maritime. What makes it recognizable is a row of what look like giant golf balls running down the middle of the deck. Those golf balls — typically about 140 feet across, or as wide as eight Chevy Suburbans parked bumper to bumper — are actually a series of spherical tanks for the LNG.

Moss tankers may be the most recognizable, but they are not the most common.

Instead, membrane tankers dominate the market. These look about like any other ocean freighter that doesn't carry containerized cargo on deck. The bridge, several stories high, is at the back, and the deck is characterized by a complicated system of pipes and valves for getting LNG on and off the ship.

As of 2011, only about 30 percent of the world fleet relied on the Moss design and only about 6 percent of new orders were for Moss tankers, according to a report from the University of Texas Center for Energy Economics. The rest of the market belongs to membrane tankers.



Source: Wikimedia Commons

Moss-style LNG tankers use individual, spherical storage tanks built separately and set in place in the hull. They are faster to build than membrane-style carriers, where the storage tanks are built into the hull, but they carry less gas for a ship of the same hull dimensions.

Source: Woodside Petroleum

Woodside Petroleum's Northwest Seaeagle docked at the North West Shelf LNG project loading terminal at Karratha, Western Australia. The Seaeagle uses the Moss design with the distinctive spherical tanks built separately, then set into its hull.

PROS AND CONS

Each design has its advantages and disadvantages.

Moss tankers can be faster to build, because the spherical tanks are constructed separately from the ship, then lowered into position and installed when the vessel is ready. Also, Moss tankers don't suffer from the problem of cargo sloshing described below.

On the other hand, those big tanks are heavy — typically around 900 tons each — meaning they can be built and installed in only a relative handful of shipyards.

Also on the downside, the shape of Moss tanks makes them a poor fit with a ship's hull — they've been described as "balls in a box." A membrane tanker, by contrast, has built-in tanks. They can be fitted to the shape of the hull and do not project far above the deck — a much more efficient use of space. As a result, it takes a bigger ship to haul the same amount of LNG in Moss tanks than in membrane tanks.

Since tolls and other ship fees are based on something called net tonnage — derived solely from ship's dimensions without reference to its cargo capacity or the actual load aboard — Moss tankers pay more per cubic meter of LNG in tolls and fees. For example, a 2005 calculation by Lloyd's Register determined that a Moss tanker able to carry 135,000 cubic meters of LNG would pay 30 percent more in net-tonnage-based fees to use the Suez Canal than a membrane tanker of the same capacity.

Source: Shell

Shell's Granatina tanker is an example of the membrane design for LNG carriers, with the tanks built into the hull. The 918-foot-long ship can carry 145,500 cubic meters of LNG, within the capacity range envisioned for the Alaska LNG project.

Further complicating the picture for Moss tankers is the fact that they are more subject to wind forces than membrane tankers and thus may bear the added expense of more escort tugs and pilots.

The chief advantage of the membrane tanker is its lower operating cost, for the reasons discussed above.

SURF'S UP

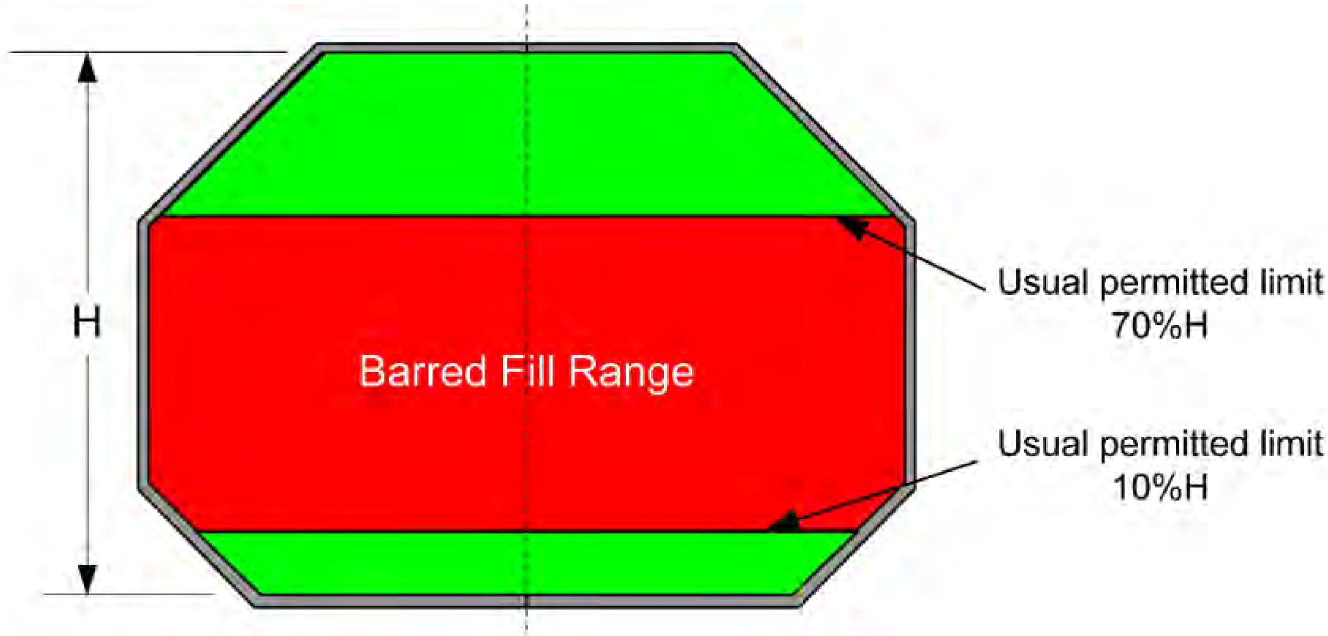
But membrane tankers come with their own disadvantages, perhaps most of important of which is susceptibility to sloshing.

Sloshing refers to waves being generated inside an LNG tank as the vessel rides the ocean.

Given the right combination of sea conditions, tank and vessel characteristics, and LNG volume in a tank, sloshing waves can become so big they damage the tank. This can include not only the walls or cap of the tank, but also the tall vertical pump mast used to move LNG in and out at the dock.

This is a fluid dynamics problem so complex that even the marvels of modern computer technology have yet to produce a complete answer to the challenge of designing a slosh-proof LNG membrane tanker. Nonetheless, some general rules have emerged that seem to work.

One tactic is to use smaller tanks — meaning more tanks are required for a given size vessel. Another is to limit loading levels. The basic rule is that a tank should always be either less than 10 percent full (too little liquid to hurt the tank) or more than



Source: Lloyd's Register

To avoid sloshing damage, tanker operators avoid loading within what's called the barred fill range. The permissible fill range is either less than 10 percent of the tank height or more than 70 percent, but not in between, where the wave action would be at its worst.

70 percent full (too little open space to allow damaging waves to build up inside the tank). However, operational considerations unrelated to sloshing often rule out running the tanks completely empty, as discussed below.

The forbidden zone between the numbers is known as the barred fill range, a result of both research and experience over the years.

"There's some science and some practice that comes into it," said Peter Noble, former chief naval architect for ConocoPhillips, in a December 2013 interview. Noble is now president of the Society of Naval Architects and Marine Engineers and principal adviser with Noble Associates.

The first recorded incident of sloshing damage to an LNG tanker came when the industry was barely a decade old. The vessel involved was the Polar Alaska, one of the two tankers built to export Cook Inlet LNG out of Nikiski. Damage to one of its tanks was discovered when it returned home to Alaska from its very first trip in 1969.

Nearly two years later, the Arctic Tokyo — sister ship to the Polar Alaska — also sustained damage to a single tank after surviving two typhoons in Tokyo Bay.

Neither incident resulted in a threat of sinking or release of any LNG cargo.

In both cases, the damaged tank had been 20 percent full as the ship returned home from delivering its load. That was before the industry figured out that 10 percent was the safest lower loading limit.

As is often the case, the Polar tankers had unloaded and kept some cargo aboard, known as heel. Heel serves two purposes. For one, the fact that some of the gas evaporates from the tanks — no matter how well insulated — helps keep them cold, which speeds up loading for the next cargo.

For another, many LNG tankers recover that evaporating gas, called boil-off, for engine fuel on the trip back to port for the next load.

The first response to the incidents on the Alaska and Tokyo was to reduce heel levels, though not to the specifications used today.

The Arctic Tokyo, shown here at the Nikiski dock, was one of two identical ships built for the startup of LNG exports from Alaska's Cook Inlet to Japan in 1969. They were the first LNG carriers known to suffer sloshing damage. The vessels were later replaced by larger models and sold off.

The second response was to study the problem in an attempt to determine what combination of tank design, loading levels and sea conditions would produce sloshing damage. This led to a recommendation that the shape of LNG tanks be altered by reducing the size of the bevels at the corners of the tanks, but no further advice on loading levels.

The problem, however, was far from solved. It cropped up again in 1978 on a 130,000-cubic-meter vessel that was the largest of its kind at the time. This time, all five of its tanks were damaged. Again, the ship was never in danger of sinking and no cargo was released.

THE SLOSHING CLUB CONVENES

The new evidence that sloshing still stalked the LNG shipping industry set off a fresh round of scrutiny and the formation of a group called the "Sloshing Club."

The club was led by Gaztransport — the French company that had designed the tanks damaged in the 1978 incident — with help from two Japanese shipyards, the American aeronautics and aerospace giant McDonnell Douglas, and a ship classification society (a non-governmental organization that establishes and maintains technical standards for building and operating ships).

The group's first recommendation was for more study, and a research program was launched. One finding was that changing the shape of LNG tanks, as recommended after the Polar Alaska and Arctic Tokyo incidents, had made the problem worse, not better. It turned out that the bigger bevels in the old design had served to clip the waves and reduce turbulence in the LNG.

Now things were back to about where they were right after the Alaska and Tokyo incidents: use the old tank shape, and keep heel levels low.

Time passed, and hopes grew that the sloshing monster had been driven permanently back into its cave. Wrong again.

"This," as a 2009 sloshing paper by Gaztransport and Technigaz (successor to Gaztransport as a result of a merger) put it, "is why the information from Navantia shipyard in El Ferrol, Spain, during spring 2006 came as such a shock."

The news from Navantia shipyard? An LNG tanker called the Cataluña Spirit had dry-docked and three tanks were found to have sloshing damage, apparently from side-to-side waves. The ensuing analysis triggered a re-thinking of how sloshing occurs inside a tank.

Until then, it had been assumed that the biggest waves caused the worst damage by producing the most violent motion of the LNG. Consequently, previous studies had focused on what happened in the stormiest seas.

Source: Lloyd's Register

Under the right conditions, LNG waves knocking around inside a membrane tanker can become large enough to damage the tank in a phenomenon called sloshing. The industry has worked for years to set standards to eliminate or at least minimize the problem.

In fact, the analysis showed, stormy seas were less of a threat than intermediate seas — not too big, not too small. That was because big sloshing waves, rather than slamming into the walls, tended to break in mid-tank, much like big surf breaks offshore rather than hitting the beach. And when the decaying wave finally did hit the wall, it was a mixture of LNG and gas rather than pure LNG.

How, then, could smaller sea waves damage a tank if big waves weren't the problem?

It turned out that one of the most crucial factors was the period of the ocean waves — the time between crests. If the timing was just right, the LNG wave could start at one wall of the tank, build up and up, then crash into the opposite wall of the steel tank at full power and inflict the kind of damage seen in the Cataluña Spirit.

Not surprisingly, yet more research ensued, resulting in indications that loading tanks just above the lower limit of the forbidden zone might have been the culprit.

The sloshing monster put in its last reported appearance in 2008, this time in a type of vessel with tanks of a design that had never experienced sloshing damage before. A total of three such tankers turned up with sloshing damage.

"Again," the 2009 paper said, "the LNG industry was strongly surprised."

Over the years, the practice of not loading below 70 percent had begun to emerge, and ship classification societies like Lloyd's Register endorsed it in 2009.

Nowadays, the operators of membrane tankers are getting a boost from high technology. At least one company markets a shipboard software product designed to help avoid sloshing in two major ways. One is to analyze weather forecasts and identify the route least likely to take the vessel through slosh-inducing seas. The other is to advise the captain if he starts to encounter such conditions on mitigation actions such as changing course or speed.

"Sloshing is not a major problem in the LNG trade today in ships that are well built, well maintained, and operated in a proper way," Noble said.

THE TRIP TO MARKET AND BACK

Once under way, the tanker crew faces the issue of boil-off, as discussed above. LNG tankers don't have refrigeration units on board to keep the LNG at minus 260, so they rely on the insulation around the tanks.

As no insulation system is perfect, the LNG starts to warm up and some of it evaporates — or boils off. (The current industry standard is to limit boil-off to a rate of 0.1 percent to 0.15 percent a day.) Boil-off cools the rest of the LNG and keeps it liquid, just as evaporating sweat keeps people cool on a hot day.

But how to manage boil-off?

Many LNG tankers use it for engine power. If there's not enough boil-off for the purpose, they can make more from the LNG cargo with their on-board vaporizers.

But boil-off management is changing. Builders of LNG tankers are switching to fuel-efficient low-speed diesels for power, permitting more of the valuable cargo to reach market. Small onboard liquefaction plants return the boil-off to the tanks as LNG.

Some new tanker engines can even burn a mixture of diesel and LNG, in any ratio.

In the destination port, the tanker unloads using pumps immersed in the tanks, then starts the trip home.

BUT ARE THEY SAFE?

Given the complexity of building and sailing these huge tankers filled with a liquid cargo awaiting the chance to boil off into a flammable gas, what about their safety record?

The LNG tanker industry has essentially no history of such problems. As of 2011, more than 135,000 LNG tanker trips had taken place without a major accident in port or at sea.

Source: Hyundai Heavy Industries

The Hyundai Heavy Industries shipyard stretches almost 2.5 miles along the coast in Ulsan, South Korea. Most of the world’s LNG tankers were built in South Korea, though Chinese and Japanese shipyards are working to expand their share of the specialized market.

While there have been minor LNG spills in loading and unloading operations while in port, none involved fatalities or more than minor damage to the ship.

And, in some cases where disaster might have been expected, none occurred.

In 1979, for example, the El Paso Paul Kayser was heading out of the Mediterranean at 19 knots (22 mph) when it hit a submerged rock outcropping in the Strait of Gibraltar. The result was a 750-foot scar in the hull. While damage to the ship was substantial, none of the LNG was lost.

Experts and the industry alike attribute this safety record to a number of factors. One is that LNG tankers, like oil tankers, have double hulls to reduce the chances that a collision or grounding will breach the cargo space. In the case of LNG tankers, each hull is made of inch-thick steel and they are about 10 feet apart — space that is used for ballast water when needed.

Another factor is the elaborate precautions taken to prevent the LNG from mixing with air to create an explosive combination, as described above. LNG itself is not explosive or flammable.

The layer of insulation that separates the ship's inner hull from the LNG tanks is filled with nitrogen, so that any leak from the tank will enter an inert atmosphere. Additionally, the insulation is monitored for any intrusion of gas so that immediate action can be taken.

In port, federal rules require safety zones around LNG tankers, as well as around the facilities where they dock.

"LNG has been handled safely for many years and the industry has maintained an enviable safety record," wrote Michelle Michot Foss, chief energy economist at the University of Texas's Center for Energy Economics, in a 2012 briefing paper. "Engineering and design and increasing security measures are constantly improved to ensure the safety and security of LNG facilities and ships."

CAUTION — LOADING ZONE

Building an LNG tanker is complicated enough. Getting one safely loaded, across the ocean, and back again can be even more exacting.

Take loading. In some cases, the vessel returns home with heel or methane vapor in the tanks and the tanks still cold, ready to receive its next load and sail away.

In other cases, all of the LNG is taken off in the delivery port, and the ship starts for home with nothing but residual methane vapors in the tanks. As these will warm up during the passage home, the tanks are likely to need gradual re-cooling, as described below, before they can take on a new load of LNG at minus 260 degrees Fahrenheit.

In still other cases, the LNG tanks will need inspection or maintenance once in port, so the tanker is expected to arrive in a methane-free state with warm tanks full of air so workers can safely enter them. This requires a multi-stage process during the voyage.

First, the tanks are warmed up by using equipment on the ship to heat and circulate the gas they contain.

Next, the tanks are purged of that methane using carbon dioxide produced by burning diesel on the ship. This is called inerting the tanks; otherwise, introducing air (containing oxygen) would create a dangerous explosive mixture with the residual methane.

Finally, the tanks are filled with air and the at-sea part of the process is complete.

Once in port, any necessary maintenance and inspections are performed, then actual loading begins. The process can take almost three days if the tanks have been warmed and filled with air.

The first step in loading is to force out the air so it won't mix with LNG. Carbon dioxide is again used to purge and inert the tanks, a process that takes about 20 hours for a standard-size tanker.

Next, the tanks have to be purged of carbon dioxide and cooled to about minus 220 degrees Fahrenheit before they can take LNG at minus 260 degrees. Otherwise, the incoming LNG could freeze the carbon dioxide solid — into dry ice — possibly damaging pumps and equipment in the tanks.

Warm natural gas in its vapor form is used to force out the carbon dioxide. To achieve that, LNG is brought onto the ship from the terminal on shore, vaporized, heated to about 70 degrees, and pumped into the tanks.

At first, the carbon dioxide coming out of the tanks is vented to the atmosphere (at least in foreign terminals; at present, there are no LNG export terminals operating in the United States), with the methane level of the emerging mixture carefully monitored. Once the methane level reaches 5 percent, the threshold of flammability, the mixture is redirected to the terminal on shore and burned to prevent creating an explosive mixture around the ship.

This part of the loading process takes another 20 hours or so.

Now the tanks are full of natural gas, with all traces of air and carbon dioxide removed. But it's warm natural gas, still at 70 degrees or so.

Now the cooling process begins. (This phase is also necessary if the vessel docked with warm methane, but no air, in its tanks.) LNG is sprayed into the tanks, where it vaporizes and cools them. This forces the warm natural gas out of the tanks; it's pumped ashore to be reliquefied or burned off in a flare stack.

This phase takes about 10 hours.

Finally, the tanks are at about minus 220 degrees Fahrenheit — cold enough to take the LNG cargo. It's pumped in from the terminal until the tanks are full, with the expelled methane vapors continuing to be pumped ashore. This step takes about 15 hours. When it's done, the ship is ready to sail.

— Stan Jones

For more information, please visit our website: www.arcticgas.gov

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