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Liquefied Natural Gas as a Marine Fuel

A Closer Look at TOTE's Containership Projects

Anna Lee Deal

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New rules by the International Maritime Organization and the U.S. EPA have created limitations on the sulfur emissions for the marine industry and changed the economics of LNG as a marine fuel. Compared to other emissions compliance options, LNG is an economically viable option for some vessels. Over time the lower operating costs (fuel and emissions compliance) can pay for the large capital investment in an LNG conversion project or new build LNG powered vessel. Tote Inc., an early adopter of LNG fuel in their marine operations has shared their insight into their decision to convert two large (Ro/Ro) containerships to LNG power for the Alaska trade and to invest in two new LNG powered containerships for the Puerto Rico trade. Key to TOTE's success are 1) the ability to have a long term outlook on their investment 2) building a partnership to provide LNG fuel at the right price, and 3) in the case of the retrofit - an EPA/Coast Guard exemption from 2012 sulfur limits during the time that they convert their vessels to LNG. Vessels that spend the majority of their voyage within Emission Compliance Areas (ECA's) and those with high utilization and high fuel use will maximize the fuel savings of LNG compared to other more expensive, low sulfur fuel blends that would otherwise be required to comply with emissions standards. These vessel operators will look seriously at LNG as a marine fuel as the most stringent ECA sulfur emissions limits approach in 2015. These early adopters will likely need to build partnerships in order to develop LNG supply and bunkering infrastructure for their vessels. With its high fuel use per vessel, the marine industry has a unique opportunity to act as a critical core customer for the development of new LNG infrastructure projects and, in the process, establish LNG supplies for other transportation industries in the region.

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Introduction:

The U.S. uses the equivalent of 21 billion gallons of diesel for transportation each year. Of this, approximately 4.7 billion gallons are used by heavy duty vehicles, including tractor trailers, and approximately 1.7 billion gallons are used by marine vessels while inside of U.S. waters (Figure 1).

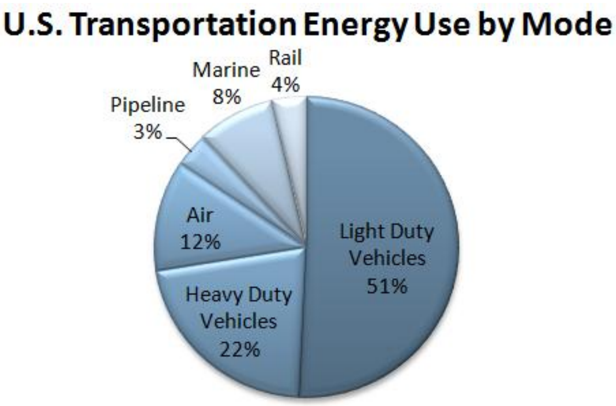

Figure 1. U.S. Transportation Energy Use by Mode in 2010. From EIA's Annual Energy Outlook 2012.

Natural gas has caught the attention of the trucking industry as a cost competitive alternative to diesel for high mileage fleets. This is because many of the inherent challenges of using natural gas as a truck fuel are overcome by the economics of low cost natural gas, at least where fuel consumption per truck is high enough. The availability of natural gas refueling infrastructure along U.S. highways is growing, but remains the largest barrier for high mileage truck fleets interested in using natural gas.

While the marine sector uses only 1/5th the amount of fuel used by heavy duty vehicles, a single cargo ship uses approximately the same amount of energy as 100 long-haul tractor-trailers. As of 2010, there were approximately 9,000 U.S. flagged self-propelled vessels (excluding fishing vessels, dredges and derricks used in offshore construction work) compared with an estimated 2 million tractor-trailers in operation on U.S. roads. With relatively few engine conversions and fueling infrastructure projects compared to those needed for on-highway trucks, the transition to LNG for the marine industry could look very different from that of the heavy truck industry.

TOTE Inc., an early adopter of LNG, has offered their insight into their decision to begin conversion of two roll-on/roll-off (Ro/Ro) cargo ships to operate on LNG as well as the construction of two new LNG container ships and has shared their experience with this process. This paper explores the challenges and opportunities of using liquefied natural gas (LNG) in the U.S. marine industry with a focus on TOTE's experience.

Marine Fuels and Emissions Regulations:

There are two types of fuel used by the marine industry: 1) Marine distillate, also called distillate fuel oil or marine diesel oil (MDO) and 2) Residual fuel oil, sometimes referred to as bunker fuel, heavy fuel oil (HFO), or marine fuel oil (MFO). Sometimes marine distillate and residual fuel oils are blended together in a fuel called intermediate fuel oil (IFO). Similarly, marine distillate and low sulfur diesel can be blended to achieve the desired balance between sulfur content and price; low sulfur marine gas oil (MGO) is an example of this kind of blend.

Marine distillate is essentially a diesel fuel, but until recently, was allowed to contain a much higher level of sulfur and remained less expensive than on-road diesel.

Residual fuel oil, as the name implies, is the fuel that is left over after the lighter components are removed from crude oil to produce gasoline and diesel. It is heavier and much more viscous than marine distillate - it is a solid at room temperature so must be heated before use - and contains much higher levels of sulfur and heavy metals (Figure 2). It is the least expensive of all liquid fuels.

New (2012) U.S. and global emissions standards targeted at limiting marine sulfur emissions will require ships to begin using lower sulfur fuels or use emission control devices to reduce sulfur content to allowable levels.

Globally, the International Maritime Organization controls marine pollution under the MARPOL (short for "marine pollution") treaty. Each of six Annexes (I-VI) is concerned with preventing a different form of pollution from ships (oil, noxious bulk liquids, harmful substances in package form, sewage, garbage, and air pollution). Annex VI relates to air pollution and establishes emissions standards for ocean going ships for sulfur, NO_X and particulate matter (PM) - with sulfur emissions, the most targeted pollutant. These standards set a limit on the sulfur content of diesel fuel as a way of controlling SO_X emissions and indirectly limiting PM emissions (Figure 3). Limits for NO_X emissions are achieved by requirements for engine-based controls.

The U.S. Environmental Protection Agency began regulating sulfur emissions of on-road diesel fuel in 2005. To meet the standards for allowable sulfur levels, (15 parts per million, a 97% reduction from pre-2005 levels) on-road vehicles and non-road construction vehicles are now required to use Ultra Low Sulfur Diesel.

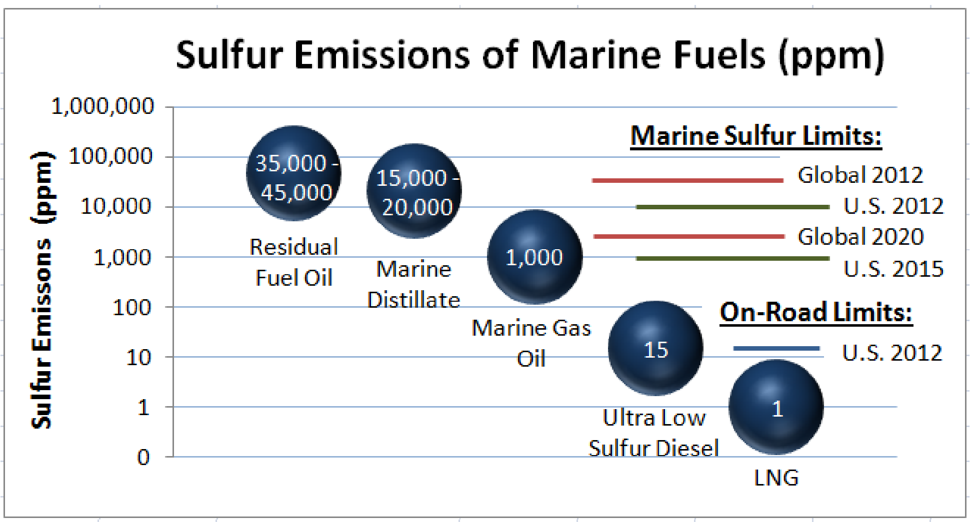

Figure 2. Sulfur Emissions of Marine Fuels (ppm) compared to the Sulfur Limits from Global (IMO), U.S. (North American and Caribbean ECA's), and U.S. On-Road Diesel Limits.

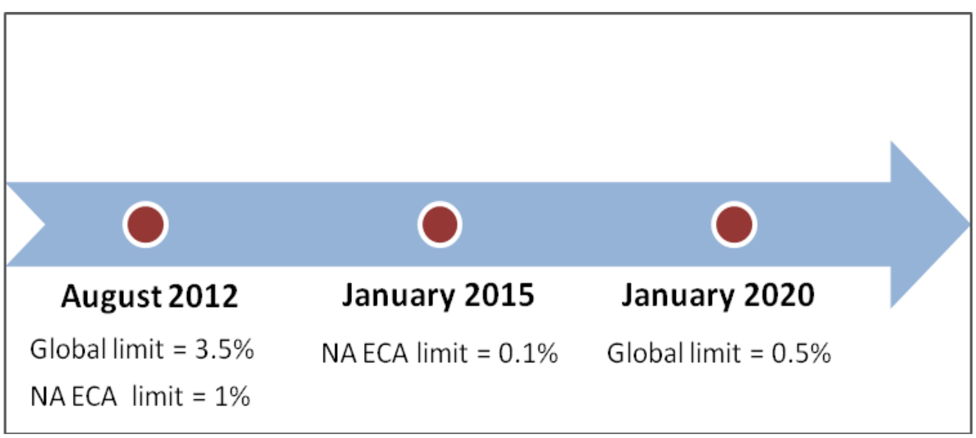

Figure 3. Timeline of Global (IMO) and North American ECA (Emission Control Area) Sulfur Limitations on Marine Fuels. The 2020 global standard is contingent on a fuel availability study in 2018 which could postpone these limits until 2025.

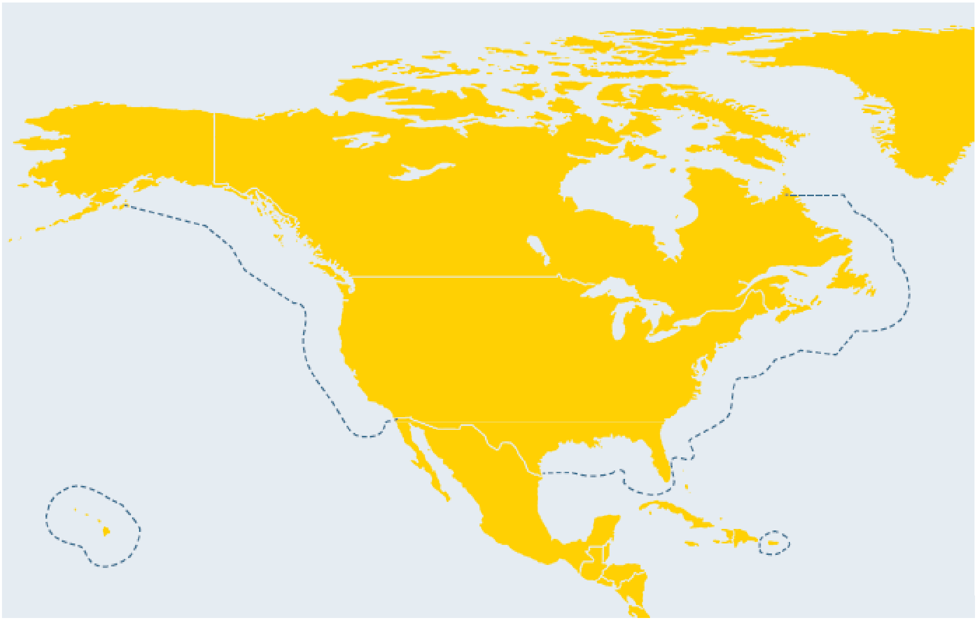

Figure 4. North American Emission Control Area (ECA) Boundaries extend up to 200 nautical miles from the coasts of the U.S., Canadian, and French territories. Western Alaska and smaller Hawaiian Islands are currently not included, but are under consideration.

The U.S. Caribbean ECA includes waters off the coasts of Puerto Rico and U.S. Virgin Islands.

Image courtesy of TOTE.

Prior to 2012, U.S. EPA marine emissions regulations centered on engine-based controls and did not apply to marine distillate or residual fuel oil. But, in 2009 the U.S. and Canada jointly proposed the North American Emission Control Area (ECA) and it was approved by the IMO in 2010. The new rules took effect in August 2012 and now require marine vessels to comply with the new EPA sulfur limitations.

This applies to marine vessels that operate in U.S. domestic waters and to vessels that operate within 200 nautical miles of U.S. and Canadian coastlines. Waters off the coast of Puerto Rico and the U.S. Virgin Islands make up the U.S. Caribbean ECA. Waters surrounding Pacific U.S. territories, smaller Hawaiian islands, and western Alaska are currently not included, but are under consideration (Figure 4).

Special provisions have been developed for steamships and large ships that operate in the Great Lakes.

The North American ECA standard is more stringent than the global standard. In 2012, global sulfur emission standards drop from 4.5% to 3.5% (45,000 ppm to 35,000 ppm), tightening more substantially in 2020 to 0.05% (5,000 ppm). In contrast, North American ECA limits drop to 1% (10,000 ppm) beginning in 2012 and 0.01% (1,000 ppm) in 2015 (Figures 2 and 3). The U.S. Caribbean ECA will enter into force with the 1% limit beginning January 2014 and 0.01% limit in 2015.

***Options for Sulfur Emissions Compliance*:**

Marine vessels that operate within the North American ECA waters are no longer be able to use low cost residual fuel oil or marine distillate fuel; they are now required to use a low sulfur fuel or find other alternatives in order to comply with emission standards.

Operators of marine vessels have three options to comply with the low sulfur limits:

1. Use a blend of marine distillates and Ultra-Low Sulfur Diesel,

2. Continue to use Residual Fuel Oil or Marine Distillate and install an Exhaust Gas Treatment System, or

3. Convert existing ships or build new ships powered by LNG.

1. Use a blend of marine distillates and Ultra Low Sulfur Diesel to meet the 1% sulfur limit while operating inside of an Emission Control Area and marine distillates to meet the 3.5% limit while outside of the ECA. This option significantly increases fuel costs for vessels while operating within the ECA.

For TOTE, who operates 100% within the ECA on its voyages between Washington and Alaska, the additional cost is especially high. The current price of ECA compliant fuel blend is about 25%-30% more expensive than the marine distillate fuel that is currently used in TOTE ships. Fuel costs are expected to increase by about 60% for 2015 (0.1% sulfur) compliant fuel. TOTE estimates that using this lower sulfur fuel blend would have increased overall freight costs to its Alaskan customers by 7-8%.

There is also the question of low sulfur fuel availability. According to Lloyd's Register, there is currently not enough distillate fuel to meet global demand for the world's entire commercial fleet to switch from residual fuel oil to distillate fuel. Current refinery production would need to increase by 4 million barrels of distillates per day in order to meet the needs of a global marine fleet that is compliant with 2020 sulfur limitations.

TOTE currently uses marine distillate from Alaska crude oil, with an approximate 2% to 3% sulfur content, but would need to blend with ULSD in order to comply with the ECA limits. However, only two U.S. refiners indicated a potential willingness to develop and produce the custom fuel blend necessary for the TOTE ships. With few other ships able to use this particular blend "TOTE could essentially be held captive to whatever price the supplier set for fuels," says Phil Morrell, vice president of marine and terminal operations. "This is a daunting future for our company and domestic shipping as a whole."

Another downside of using low sulfur fuels is the additional maintenance costs associated with the lower viscosity, lubricity, acidity, flashpoints, and ignition quality of the fuel.

2. Continue to use traditional fuels and install scrubbers. Abatement technologies such as stack scrubbers can be installed that capture engine exhaust and "scrub" it of pollutants before releasing it into the atmosphere. The technology allows a vessel to meet the Sulfur (SO_X) and Particulate Matter (PM) standards while continuing to use either residual fuel oil or marine distillate. But, they are expensive, bulky, require additional energy to run, and create permanent increases in vessel operating costs.

The capital cost of scrubbers is significant. TOTE ships would have required between two and four scrubbers per ship at $7-$8 million per scrubber not including associated piping.

In addition, scrubbers would create permanent additional operating costs. TOTE expected an 8% loss in efficiency of the engines and associated increase in fuel requirements and cost. They would also have required an additional full time engineer per vessel. And scrubbers do not eliminate pollutants, they simply concentrate them. The sludge that is filtered out still creates a waste stream that needs to be disposed of on shore.

Another concern stems from the knowledge that the technology is not capable of abating emissions beyond the new standards. Scrubbers are able to reduce sulfur levels of residual fuel oil to around 2% and marine distillates to 0.01-1% but cannot reduce them further because the technology is at its limit. Ships that choose to use scrubbers to comply with the new sulfur limitations will not be able to meet any future standards that may become more stringent.

In order to address NO_x emissions, scrubbers would need to be used in conjunction with engine based controls such as Exhaust Gas Recirculation, Selective Catalytic Reactors, or Water Injection Humid Air Motors. While each is effective at reducing NO_x emissions to varying degrees, the technologies are still being refined for marine engine applications.

3. Convert existing ships or build new ships powered by LNG: The cleanest of all options, LNG virtually eliminates SO_x (1ppm) and PM emissions. It also reduces NO_x emissions ~90% and CO_2 emissions by ~20% (Figures 5 and 6). On their own neither low sulfur fuels nor scrubbers do anything to address NO_X or CO_2.

Pipeline natural gas is currently at least 70% less expensive on an energy equivalent basis than marine residual fuel and 85% less expensive than marine distillate fuel. This relative price advantage is thought to continue, and even increase, through 2035, according to the Energy Information Administration projections. However, the cost of liquefying natural gas approximately doubles this price, making LNG more expensive than traditional distillate and residual fuel oils, but less expensive than the low sulfur fuel blends required to comply with ECA emission limits.

While attractive environmentally and economically, conversion to LNG requires that a ship be retrofitted or replaced - both of which are very expensive propositions. Adding to the capital cost, LNG fueling infrastructure is virtually non-existent, so development of the infrastructure to fuel the ships is likely to be required.

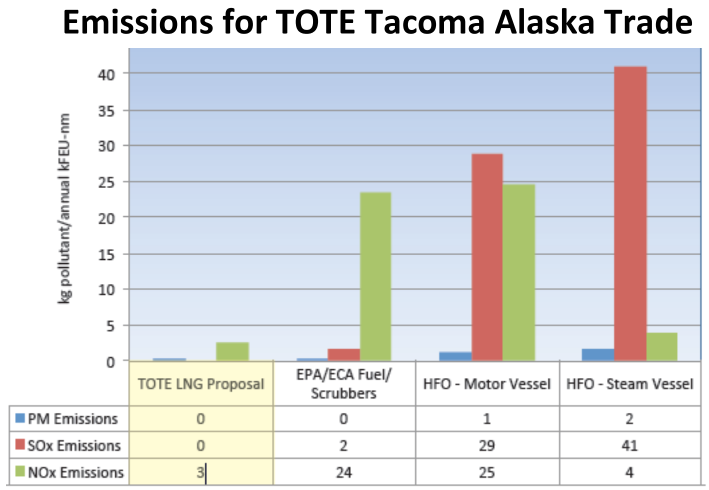

Figure 5. Emissions profile of LNG, Stack Scrubbers, and Heavy Fuel Oil for both motor and steam vessels. Image courtesy of TOTE.

Fuel Type	SO_x (g/kWh)	NO_x (g/kWh)	PM (g/kWh)	CO_2 (g/kWh)
Residual Oil 3.5% sulfur	13	9-12	1.5	580-630
Marine Distillate 0.5% S	2	8-11	0.25-0.5	580-630
Gasoil 0.1% S	0.4	8-11	0.15-0.25	580-630
LNG	0	2	~0	430-480

Figure 6. Indicated air emissions from LNG and other marine fuels. Emissions are related to engine output in kWh. Source: Marintek

Figure 7 summarizes the advantages and disadvantages of the three main options for marine vessels to comply with sulfur limits.

	Use a Low Sulfur Fuel Blend	**Install Exhaust Gas Treatment System (EGTS) or "scrubbers"**	**Convert Ship to Run on LNG (Liquefied Natural Gas)**
PRO's	- Low capital cost - Established technology	- Capital cost is roughly 30% of the cost to convert to LNG - Established technology	- Fuel cost is lower - Domestic fuel reduces price volatility - Low emissions: SO_X 100% reduction; 95% lower than ECA limits NO_x 80-90% reduction PM 98-100% reduction CO_2 10-20% reduction
CON's	- Higher fuel costs - Higher maintenance costs - Limited fuel availability & corresponding price vulnerability	- Additional operating costs - Not able to meet further reductions in SO_X or NO_X limits - Produces toxic solid waste	- High cost of vessel conversion - New build 15-20% more expensive - Lack of LNG infrastructure - Possible decrease in cargo space

Figure 7. Pro's and Con's of 3 Options for Complying with Emission Control Area Emission Standards

TOTE's Conversion to LNG:

Totem Ocean Trailer Express (TOTE), a TOTE Inc. company, operates twice weekly Roll-On Roll-Off (Ro/Ro) containership service between Anchorage, Alaska and Tacoma, WA - a route entirely within the North American Emission Control Area. Tote, Inc. also operates regular marine service between Jacksonville, FL and Puerto Rico, the U.S. Virgin Islands, and Tortola. This service operates 40% of the time within North American and U.S. Caribbean ECA's.

When faced with the question of how to comply with the North American ECA limits, TOTE initially included the option to convert to LNG more as a wild outlier, but it soon became apparent that the downsides of other options made LNG appear more and more attractive. It is “no small undertaking,” TOTE says, but “is the most attractive long-term solution.”

In August, 2012 TOTE was granted a limited waiver from the North American ECA during conversion of their ships to LNG under a joint partnership between the U.S. EPA, U.S. Coast Guard, and TOTE. TOTE would be allowed to operate using current distillate fuels while they converted their two ships to run on LNG, with required project completion by 2016.

In December, 2012 Tote Inc. announced their intent to build 2 new LNG powered containerships for the Puerto Rico trade, with options for three more vessels for additional domestic service. The first two vessels will be delivered and enter into service between Jacksonville, FL and San Juan, PR in 2015 and 2016.

While LNG has been used in the European short sea shipping market for some time, TOTE Inc.'s Alaska trade conversion will be the first large ocean-going vessels (Figure 8) and its Puerto Rico trade ships (Figure9) are expected to be the largest of any kind to operate primarily on natural gas.

TOTE's announcement to convert its two Alaska service ships came as a surprise to many, because the Orca vessels, built in 2003, are only nine years into the typical 30-year life span of a ship and are already among some of the most environmentally friendly in the world. The ships were designed and built to exceed the expected environmental requirements at the time, but the new ECA requirements far exceed anything that was anticipated.

Environmental leadership is not new for TOTE. In addition to the high emissions standards of the engines onboard the Orca vessels, TOTE was the first company in the Northwest to equip their ships with cold-ironing capabilities to allow the ships to plug-in to the shore-side electrical grid rather than run the diesel engines while docked. And they were the first in the Puget Sound to demonstrate the effectiveness of "rain gardens" using landscape elements to filter contaminants from water runoff in an industrial setting.

Figure 8. TOTE's dual-fuel LNG containership retrofit for Alaska Service. Image courtesy of TOTE.

Figure 9. TOTE Shipholdings new LNG containership for Puerto Rico service. Image courtesy of TOTE.

<u>TOTE's Conversion of Alaska Trade Vessels to Dual Fuel LNG Power:</u>

Conversion of TOTE's Midnight Sun and North Star Alaska trade vessels to LNG power requires an investment of approximately $90 million and major modifications to the engines and fuel system. While each component of the system is proven technology that has been used somewhere before, the entire assembly has never before been used on a marine vessel.

The engines...

The Orca vessels currently each have four MAN 9L 58/64 diesel engines and two auxiliary 9L 28/32 diesel engines, two or three of which run at a given time. TOTE plans to convert the four main diesel engines to run on "dual-fuel" (diesel-LNG) and replace the auxiliary diesel engines with new dual-fuel 9L 35/44s.

The duel-fuel engines will use an approximate 4% diesel blend to ensure clean combustion. Lower blends lead to what is called "methane slip" where unburned gas escapes into the atmosphere. They also allow the engines to run on 100% oil if needed, creating redundancy in the system.

TOTE is working with MAN to design the dual fuel retrofit for the Orca vessel's 58/64 engines. MAN has not built conversion kits for this engine yet, but in a rather unprecedented move, TOTE is forward funding the research and engineering for this project.

Conversion of the main diesel engines results in an 18% loss in power because the cylinders are not big enough to get the same power out of the less dense natural gas fuel. In order to compensate for the loss in power, the two auxiliary engines will be replaced with purpose built, more powerful engines: 9L 35/44s. This class of dual fuel engines has been used in power plants for years, but never before on a marine vessel.

Adding to the challenges is the need to convert the vessels while preserving the vessels' commercial schedules. TOTE currently overhauls its engines once a year while on voyage. Using this overhaul schedule will allow 35-40% of the retrofit work to be completed while at sea. The installation of major components, such as the LNG fuel tanks, will require a major yard period, much of which will be completed during regularly scheduled single-sailing weeks. Over the five years that the project is expected to take to complete, there will be limited impacts to the service schedule.

The fuel system...

The LNG fuel tanks are similar to the double-walled super insulated cylinders used to hold LNG on motor vehicles, but much larger. In order to get the 9 million DGE (diesel gallon equivalents) fuel capacity needed for each of the weekly Alaska voyages, two small and one large tank will be mounted above deck allowing fuel to move with gravity to the bottom mounted engines (Figure 8).

The insulated tanks are designed to hold the super-cooled fuel for 21 days before it begins to warm and vent to the atmosphere, much longer than their motor vehicle counterparts. This allows a large margin of error for the ten days spent annually at dry dock for maintenance or an unintended breakdown.

The current diesel tanks are vertical and internal to the ship, creating an additional layer of prevention of a spill in the event of an accident. These will be left in place for redundancy and to hold the Ultra Low Sulfur Diesel needed for combustion of LNG.

As an additional safety precaution, TOTE plans to use double-wall piping throughout the fuel system with a vacuum and sensor on the inner wall of the pipes.

The Fuel Supply...

TOTE initially looked to Alaska to supply its LNG fuel with the understanding that the development of new infrastructure and demand for gas would feed the economy of TOTE's Alaskan customers. But the high cost of electricity and questions over availability of natural gas in Cook Inlet has led them to pursue all possible options, including LNG sources in the Puget Sound area.

Despite abundant natural gas resources, Alaska does not enjoy the current abundance in supply of natural gas experienced by the rest of the country. A combination of the dwindling supply from aging gas wells and a lack of development of new wells in the Cook Inlet has led to projected shortages of natural gas for South-Central Alaskan's heating and electrical generation needs. In addition to raising electrical rates, Anchorage utilities may need to import LNG by 2014 or 2015 in order to meet demand. However, trucking LNG from the North Slope may be a possible alternative. In contrast, Washington State has inexpensive tidewater LNG and an abundant supply of natural gas from the Wilson pipeline which is connected to both Canadian and U.S. supplies of natural gas.

The delivered cost of LNG is approximately 50% gas and 50% production, so the cost of electricity is also important. The cost of electricity in the Puget Sound is 1/4 the cost of electricity in Cook Inlet.

Key to this process is the understanding that neither TOTE nor a potential fuel supplier can pursue this project alone. TOTE needs LNG at a reasonable price and an LNG supplier needs a base customer to justify the substantial investment that will be required. With TOTE as a base customer, LNG suppliers also gain the ability to enter into a new market of supplying LNG to the trucking, rail, and other marine industries.

The LNG ships may also require new infrastructure from the bunkering industry in order to deliver fuel onboard the ship. TOTE is working with various companies to make those options available for themselves and others in the industry who are interested in moving to natural gas.

Tote Shipholdings' Construction of New LNG Containerships for the Puerto Rico Trade:

TOTE Shipholdings has announced its $350 million commitment to the construction of two new LNG powered containerships for the Puerto Rico trade. They also have the option to build three more vessels for additional domestic service. Like their retrofit counterparts for the Alaska trade, these ships will have dual-fuel LNG engines that greatly surpass the emissions requirements of the Caribbean ECA. Engines will be MAN 8L70ME-C8.2-GI, based on the prototype ME-GI engine that was first used in a power plant near Tokyo, Japan in 1994.

The 3,100 TEU vessels are expected to enter service between 2015 and 2016. At 764-feet, they are expected to be the largest ships of any kind powered primarily by LNG. In order to minimize the amount of cargo space lost to the large LNG tanks, these ships (Figure 9) will have a platform for storing containers above the tanks.

The new containerships will replace two smaller steamships that are currently operating in the Puerto Rico trade. As steamships, the current vessels would be exempt from the ECA requirements until 2020, but at 35 years old, they are ready to retire.

The new dual-fuel ships will cost 15-20% more than a traditional diesel ship, but TOTE expects the 30 year asset to save money in the long term over other ECA compliance options.

Recipe for Success:

TOTE's recipe for success hinges on a combination of being a privately held company with a long-term outlook, its pursuit to find fuel at the right price, and a history of successful partnerships with the EPA.

Even though a ship has an expected 30-35 year life, with an estimated payback in the decades, this project would not meet the investment criteria for many publically held companies. "It helps to be a family-owned, privately-held company with a long-term outlook" says TOTE president John Parrot. "These broader benefits (economic and environmental) will continue to accrue and compound over the next thirty years or longer".

Also key to the success of this project is TOTE's developing partnerships with potential LNG fuel suppliers. "The fuel differential does pay, but we have to drive the delivered cost of LNG down... our goal is to get the delivered cost of LNG down to a point where the overall project cost is positive compared to the alternative compliance options", says JP.

The third important component is the EPA and Coast Guard support of the project. TOTE has a history of successful partnerships with the EPA and a reputation for exceeding environmental requirements. When TOTE initially approached the EPA and Coast Guard with the idea of converting their vessels to LNG, they were met with enthusiasm, asking "What can we do to help?" TOTE's response at the time was, "We don't know yet." This eventually transformed into an EPA/ Coast Guard waiver to continue to use distillate fuel for 5 years while TOTE converts its vessels to LNG. This waiver translates to cost savings during conversion which can go toward paying off the large capital investment in LNG vessel conversion and has reduced the financial impact to TOTE's customers in the AK trade.

Challenges to the Adoption of LNG as a Marine Fuel:

The use of LNG as a marine fuel is very attractive from an emissions compliance perspective, but there are some significant challenges that must be addressed by a marine operator that chooses to convert its vessels to LNG.

1. LNG infrastructure is currently extremely limited and in most cases, the conversion of a marine vessel to LNG must also include development of an LNG fuel source at the marine port. Without a motivated partner to supply fuel, the development of fueling infrastructure adds to the overall cost of the marine LNG project.

The cost of production, including the cost of required infrastructure, approximately doubles the price of delivered LNG relative to the commodity price of natural gas. But, as demand for LNG increases, the incremental cost of infrastructure and overall price of delivered LNG should decline and add to the fuel savings of LNG conversion.

High fuel users in the marine industry have a unique opportunity to serve as an essential base customer for an emerging LNG infrastructure that can also serve other transportation sectors including truck, rail, and smaller marine operators.

2. Barging fuel to vessels is more expensive and presents regulatory hurdles. In many cases, first users of marine LNG must also develop the bunkering infrastructure to barge fuel to the vessel. This can be very capital intensive and as a relatively new industry, could pose a regulatory hurdle.

3. The high cost of vessel conversion or replacement presents a challenge to the long term return from fuel savings. LNG conversion can cost up to $7 million for a medium-sized tug, almost $11 million to convert a large car and passenger ferry, up to $24 million to convert a Great Lakes bulk carrier, and in TOTE's case, roughly $45 million per containership.

TOTE's new-build dual-fuel LNG-powered containerships are estimated to cost 15%-20% more than a traditional diesel ship.

The majority (over 80%) of the conversion or incremental cost of a new ship typically comes from the installation of LNG storage tanks and related safety systems, with the remainder related to the conversion of the vessel engines.

With payback on the conversion typically over 10 years, not all operators will be willing or able to take on such a long-term investment.

4. Percentage of time spent inside the Emission Control Area (ECA): Vessels that spend a significant amount of time outside of ECA boundaries are not likely to see high enough costs related to sulfur emissions compliance to justify the cost of conversion to LNG. Vessels such as international trade ships and cruise ships that operate seasonally outside of ECA's will likely continue to use traditional marine fuels for the majority of their voyage, then switch to a low sulfur distillate blend for the time that they are within the ECA boundaries.

In contrast, coastal operators who are required to comply with the ECA emissions standards during their entire voyage, will look more seriously at LNG as a viable option.

5. Loss of cargo space for larger LNG tanks. LNG fuel tanks take up about twice the amount of space as a diesel tank in order to get the same amount of energy as from a given volume of diesel. Adding to the space constraints, cylindrical shaped LNG tanks require more space than a typical rectangular diesel tank. In addition, some diesel tanks need to remain in place in order to supply the small amount of diesel required for the dual fuel engine. All of this may impact the available cargo space on board the vessel. However, this is not necessarily an issue for new-build LNG ships.

Implications for Other Marine Vessels:

TOTE's Perspective...

When asked about the likelihood of LNG use in other marine vessels, TOTE president John Parrot responded, "Let me put it this way, I don't think there will be another new ship ordered in the U.S. that is not dual-fuel."

"Key to success is finding LNG supply at a reasonable price" said Parrot. Noting that, there is substantial savings in eliminating sulfur emissions by using LNG. In addition, regulation of "NO_x is coming" (referring to 2016 tier NO_x limits for new ships). Other sulfur solutions can spike NO_x emissions, while natural gas has a massive reduction in SO_x, NO_x, and PM.

Marine LNG Projects Worldwide... As of July 2012, there were 30 LNG vessels in operation, mostly car and passenger ferries in Norway or the Baltic or North Sea. The number of LNG vessels currently on order will nearly double the world LNG fleet to around 60 vessels.

TOTE's LNG projects represent world firsts in terms of the type and size of vessels. The only other LNG powered containerships in the world are two substantially smaller (94 TEU vs. 3,100 TEU) Ro/Ro ships currently under construction for use in the North Sea.

In a Lloyd's Register survey of deep sea ship-owner's intentions for complying with new sulfur limitations, respondents saw low sulfur distillate as a short-term (next 5 year) solution, exhaust gas scrubbing as a medium term (next 5-10 year) solution, and LNG fuel as a viable option in the long term (10+ years).

Even so, they predict LNG will account for only 3% to 8% of global bunker fuel demand in 2025. According to their model, cruise ships show the highest uptake of LNG (11% of new ships) and dry bulk carriers make up the majority (43%) of the predicted 673 vessel global LNG fleet, primarily due to the volume of dry bulk carrier deliveries over the next decade.

A model by Det Norske Veritas (DNV), predicts 10-15% of new ships (1,000 of 10,000 new vessels) will be gas powered between now and 2020, assuming LNG prices are 30% lower than residual fuel oil (HFO). Under this scenario, an additional 600-700 ships could be retrofitted with dual-fuel engines. If LNG prices are higher than 110% of HFO, then this number drops to approximately 650 new builds and 100 retrofits. Conversely, if LNG prices are lower (70% less than HFO) they estimate 5,000 new builds and over 1,000 retrofits over the same period.

They also suggest that vessels which spend more than one third of their voyage within the ECA boundary, will see LNG as a cost-effective option for complying with sulfur limits.

In order for any vessel operator to consider using LNG, there must be plans in place for available fuel. LNG bunker fuel is currently limited to small scale projects in the North Sea, however several major deep sea ports have announced plans for LNG bunkering facilities to be available for ships by 2015. These include, Gothenberg and Nynäshamn, Sweden; Rotterdam, Netherlands; Zeebrugge and Antwerp Belgium; Warsaw, Poland, and Singapore.

Marine LNG Projects in the U.S.... Domestic LNG conversion will be more attractive to some vessels' operations than others. Key drivers will be: 1) the amount of time spent within an Emission Control Area (ECA) as discussed above 2) fuel use relative to vessel size and 3) LNG fuel availability.

Fuel Use Relative to Vessel Size: In their 2012 analysis of LNG as a domestic marine fuel, the American Clean Skies Foundation (ACSF) suggests that given the high cost of vessel conversion, the best candidates for conversion to LNG are those vessels with very high utilization and annual fuel use relative to vessel size and engine power, so as to maximize annual fuel cost savings. These include large towing tugs and articulated tug-barges (ATB), medium-to-large car and passenger ferries, and Great Lakes bulk carriers. Ro/Ro containerships like TOTE's also fit into this category with some of the highest fuel use of any vessel.

Of the 9,100 U.S. flagged self-propelled vessels, there are currently almost 1,000 U.S.-flagged tugs larger than 100 tons, 65 ferries larger than 500 tons, and 43 Great Lakes bulk carriers that fit into the category of high fuel use and utilization as defined by ACSF.

According to ACSF, *"many of these vessels could potentially be candidates for conversion to LNG operation, but the economics will not work for every project. Despite low natural gas prices, some vessels will not generate high enough annual fuel cost savings to provide a reasonable payback period for the high vessel conversion costs. Each prospective conversion project... must start with a realistic assessment of likely delivered LNG costs given available infrastructure options".*

U.S. Fuel Availability: The majority of U.S. foreign and domestic marine cargo moves through relatively few marine ports. For example, 62% of total domestic and 52% of foreign marine cargo volume moves through 20 ports (Figure 10). The concentration of marine traffic is even greater for containerships. Of the 84 U.S. and Caribbean ports, approximately 90% of foreign and domestic container traffic moves through 20 ports and 80% moves through 10 ports (Figure 11).

U.S., U.S. Territory, & Caribbean Ports	Total Domestic Trade	Total Foreign Trade
South Lousiana, LA	11%	9%
Houston, TX	6%	12%
Huntinton - Tristate	5%	-
New York (NY, NJ)	5%	6%
New Orleans, LA	3%	1%
Plaquemines, LA	3%	1%
Baton Rouge, LA	3%	2%
Pittsburgh, PA	3%	-
Valdez, AK	3%	-
St. Louis, MO and IL	3%	-
Duluth-Superior (MN, WI)	2%	<1%
Mobile, AL	2%	1%
Beaumont, TX	2%	4%
Tampa, FL	2%	1%
Lake Charles, LA	2%	3%
Corpus Christi, TX	2%	4%
Texas City, TX	1%	3%
Chicago, IL	1%	-
Two Harbors, MN	1%	<1%
Long Beach, CA	1%	5%
% of TOTAL Trade	**62%**	**52%**

U.S., U.S. Territory, & Caribbean Ports	Domestic Container Trade	Foreign Container Trade
Honolulu, HA	20%	<1%
San Juan, PR	13%	1%
Jacksonville, FL	10%	1%
Long Beach, CA	7%	15%
Seattle, WA	7%	5%
Anchorage, AK	6%	-
Tacoma, WA	6%	3%
New York (NY and NJ)	5%	15%
Oakland, CA	5%	5%
Kahului, HI	2%	-
Kawaihae Harbor, HI	2%	-
Norfolk Harbor, VA	1%	5%
Apra Harbor, GU	1%	-
Ketchikan, AK	1%	-
Houston, TX	1%	5%
Port Everglades, FL	<1%	2%
Los Angeles, CA	-	21%
Savannah, GA	-	8%
Charleston, SC	-	4%
Miami, FL	-	2%
% of Container Traffic	**87%**	**90%**

Figure 10 (top) U.S. Port Ranking by Cargo Volume 2010 - in short tons. **Figure 11** (bottom) Top 20 Ports for U.S. Waterborne Container Traffic in 2011. Source: U.S. Army Corps of Engineers Waterborne Commerce Statistics Center.

Liquefaction and bunkering facilities are being planned for Cameron Parish, LA and Port Fourchon, LA; along the Mississippi River; and in the Great Lakes region.

Assuming LNG bunkering infrastructure is also developed in the Puget Sound or Anchorage and in Puerto Rico or Florida, then LNG bunkering will be at least regionally available to around 30% of domestic containerships and 25% of domestic cargo (by weight). However, that does not necessarily mean that the bunkering facilities for every operation will be available.

Every new LNG development and marine bunkering project makes it easier for successive vessel conversion projects, not only for marine transportation, but for trucking and rail as well.

Domestic Policy Implications:

LNG as a marine fuel has the potential to reduce oil imports, the national trade deficit, and air pollutants. New EPA and IMO sulfur emission standards have changed the economics of marine fuels, making LNG a viable option for some marine operators.

In TOTE's case, the ECA requirements and price differential of LNG set the stage to consider a switch to LNG. Their EPA/ Coast Guard waiver allows them operate using distillate fuels within the ECA during their conversion to LNG and provides additional savings that can be applied to the overall return of the expensive project. TOTE notes that the EPA and Coast Guard are open to working with other vessel owners on waiver proposals for LNG conversion projects.

However, only a small percentage of vessel operators have the willingness or ability to take the long-term investment view that is required for an LNG retrofit or new build ship, even with a waiver. In a 2012 survey of marine operators conducted by DNV, only 8% of respondents indicated a payback horizon of >5 years.

In the absence of the motivated vessel owner that we see in the TOTE project, the American Clean Skies Foundation suggests that "initial projects may require some government intervention to offset some of the cost of vessel conversion and/or LNG infrastructure development. After one or more vessel conversions within a geographic area [take place], further vessel conversions will become easier to justify on economic grounds."

Marine vessels with high fuel demands have the unique potential to serve as a vital core customer for new LNG developments that can then provide fuel to other marine vessels and transportation sectors in the region. In addition, because the majority of domestic and international marine trade travels through relatively few U.S. ports, there is greater potential for relatively few infrastructure projects to offset large amounts of high sulfur, crude oil based fuels. For these reasons, if government dollars are used to assist in a national LNG infrastructure, U.S. marine ports should not be ignored.

Similarly, government owned marine vessels such as ferries and military vessels with high fuel demands can also serve as base customers for regional development of LNG infrastructure. Government dollars spent converting publically owned marine vessels that meet the right financial criteria can reduce these vessels' cost of ECA compliance while at the same time driving local LNG infrastructure development.

Government incentives such as fuel excise tax credits could help make the financial case for some vessel operators to invest in LNG conversion by reducing the cost of LNG compared to other compliance options. However, tax credits that do not last for a significant period of time, such as those passed in January 2013 that expire at the end of the year, do little to promote investment in LNG infrastructure and vessel conversion. Unless there is certainty that the credit will last for a significantly longer period of time, it will not be considered a reliable part of the return on investment. Rather it will be a bonus for those who have already made the decision to use LNG on economic grounds without incentives.

Global Policy Implications:

The 2012 and 2015 ECA limitations have driven parts of the domestic marine industry to look seriously at LNG as a cost effective solution for complying with the new standards. But international trade vessels, which spend the majority of their time outside of ECA limits, are not likely to make major investments to reduce sulfur emissions unless emissions standards expand beyond the ECA's. Instead, they are more likely to use less expensive traditional marine fuels until they reach the ECA boundary, when they will switch to a low sulfur ECA compliant fuel.

According to DNV, of the 40% of the world fleet that enters North American or Northern European ECAs, only 7% spend more than 30% of their voyage within ECA boundaries.

In addition, only one third of ship owners pay for the fuel they use. For the majority of ship owners, the charterer pays all or part of the fuel bill. This diminishes the incentive to make large investments in a conversion that is justified by lower cost fuels, since at least some of the fuel savings will go to the customer. That being said, marine operators must keep fuel costs low in order to remain competitive.

If the IMO global sulfur limit (0.5%) goes into effect in 2020, then international trade vessels would be required to use low sulfur fuels continuously and would be much more likely to see LNG as a cost effective option. Based on their model of global economic trends, marine regulations, and technology, DNV predicts 1 in 10 new ships delivered will be gas powered between now and 2020. With a 0.5% worldwide sulfur limit, this number could increase to as many as half of new ships. However, the global limit is yet to be determined based on a fuel supply study in 2018, and could be deferred to 2025 or beyond.

Without implementation of the 2020 global sulfur limits, the majority of international trade vessels will likely continue to use Intermediate Fuel Oil blends to achieve the 3.5% sulfur limit for the majority of their voyage, then switch to distillates and/ or scrubbers once inside of the ECA boundaries to meet the 0.1% limit.

Beyond 2020, there are several policies being considered at the global level where LNG may play a role. Currently under consideration by the International Maritime Organization are regulations that address:

1. Black carbon emissions: these emissions from shipping have become a concern due to the disproportionately large impact on polar ice melt and global warming. LNG has significantly fewer black carbon emissions.

2. Underwater noise: its impact on sea mammals is also gaining global attention. Compared to diesel engines, natural gas engines are about 10 Db quieter, but it is not clear whether this is significant enough to have a noticeable impact.

3. Climate change: growing pressure on the marine industry to address greenhouse gas emissions may eventually lead to market based legislation where ships with lower greenhouse gas emissions will have a lower cost of compliance. Currently the IMO's Energy Efficiency Design Index (EEDI) requires new ships to be more energy efficient by 10% in 2015, 20% in 2020, and 30% after 2025.

LNG has the potential to reduce greenhouse gas emissions by 15-20%, so long as "methane slip" and other losses of unburned gas throughout the supply chain remains low. According to the Environmental Defense Fund, methane escape must be limited to less than 1% system-wide in order for the overall greenhouse gas impact of natural gas to remain lower than diesel.

LNG is not the only fuel of the future. According to DNV, bio-fuels, diesel-electric, marine fuel cells, batteries, solar panels, and retractable wind turbines may all have a place on ships beyond the next decade.

Conclusion:

The additional cost of complying with new sulfur emissions limitations has changed the economics of LNG as a marine fuel, making LNG a potentially cost effective option to meet the new emission standards.

Over the next decade, North American and Caribbean Emission Control Area (ECA) fuel sulfur limits will tighten from 1% to 0.1% in 2015 and the International Maritime Organization 's (IMO) global fuel sulfur limits may tighten from 3.5% to 0.5% in 2020. In order to comply with these limits, marine vessels will be required to switch to more expensive distillate fuel, install expensive emission controls, or convert to LNG power.

Domestic coastal operators like TOTE, who are required to comply with the ECA emissions standards during their entire voyage, will look seriously at LNG as a viable option in the near term to comply with 2015 emissions standards.

International trade ships, which operate the majority of their voyage outside of Emission Control Areas, will likely continue to burn traditional marine fuels in open waters, then switch to low sulfur fuels as they enter the ECA, at least in the near-term. LNG is seen as a long-term solution for meeting stricter 2020 global emissions requirements for these vessels.

LNG may not make sense for every situation, but promising projects will have access to LNG fuel at the right price, will be operations with high fuel use relative to engine size, and will spend the majority of their voyage within the ECA boundaries.

In TOTE's case, the fuel savings associated with the EPA/Coast Guard waiver during vessel retrofit and their ability to take a long-term view on the return on investment were also important factors.

LNG provides an opportunity to meet new ECA and global emission standards for SO_X while also addressing NO_X, PM, and CO_2 with a domestically produced, low cost, stable priced fuel.

However, the high cost of vessel conversion and lack of LNG supply and bunkering infrastructure pose serious challenges to vessel operators who are interested in using LNG as a marine fuel.

Generally, it is easier to justify an investment in a new-build LNG vessel than the conversion of an existing ship. With an average 30-35 year life span, the transition of the world's fleet of marine vessels to a different fuel will not happen quickly.

Global and ECA emissions limits have set the stage for the economic viability of LNG as a marine fuel for those vessel operators with the long-term outlook and boldness to develop the fueling infrastructure without government incentives. However, incentives or other forms of government leadership, support, and cooperation can help spur initial projects that, in turn could make subsequent projects more feasible. Government marine vessels such as ferries and military vessels that meet the right financial criteria for LNG conversion can reduce their long-term operating costs while also initiating the development of local LNG infrastructure.

A large marine LNG project like TOTE's can spur LNG infrastructure development for truck, rail, and smaller marine projects in the entire region. With its high volume of fuel use per vessel, the domestic marine sector provides a unique opportunity to act as a core customer base for LNG production and distribution, breaking supply barriers that have so far constrained the growth of LNG in other transportation industries.

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