In December 2012, General Dynamics NASSCO signed a contract with TOTE, Inc. to design and construct the world’s first liquefied natural gas (LNG)-powered containerships. Consistent with its commercial business model, NASSCO teamed with DSEC, a Korean-based subsidiary of Daewoo Shipbuilding & Marine Engineering (DSME), the world’s second largest shipyard. The key element of this approach centered on DSEC’s access to DSME’s patented HiVAR fuel gas supply system, which was specifically designed for dual-fuel, low-speed, high-pressure, two-stroke diesel propulsion engines. As a result, DSEC designed one of the most environmentally friendly oceangoing ships in the world. At present, NASSCO is 75% complete with constructing the lead Marlin class containership, which is scheduled to deliver in fourth quarter 2015.

NASSCO had signed a memorandum of understanding in late 2005 with DSEC to support construction of five 49,000-DWT Jones Act product tankers, designated as the PC-1 program. This relationship was founded on NASSCO’s aim to secure a competitive advantage by developing a long-term strategic relationship with an international shipbuilder. DSEC, as a subsidiary of DSME, was specifically created to engage in international collaboration projects, but had the ability to leverage DSME’s vast design portfolio and extensive supply chain. NASSCO partnered with DSEC for several reasons:

- **Strategic fit.** DSME created DSEC specifically for international collaboration, which provides NASSCO a focused, dedicated partner.
- **Design portfolio.** DSEC possesses direct access to a range of proven designs and design standards, which creates options for NASSCO’s commercial customers.
- **Procurement advantage.** DSEC leverages DSME’s widespread purchasing network to minimize equipment and material costs, which reduces material costs and risk for NASSCO.
- **Technology compatibility.** DSEC uses the same design software as NASSCO, which enables smooth integration between design and planning systems.
- **LNG experience.** DSME is a leader in LNG-related technology for maritime applications. This positions NASSCO well in the U.S. Jones Act market, which demands environmentally friendly ships in a stringent regulatory environment.

The PC-1 program was successful both for NASSCO and DSEC. All five ships delivered ahead of schedule and are currently operating under American Petroleum Tankers, a subsidiary of Kinder Morgan. More importantly for
The TOTE containership under construction, with the vessel approximately 65% complete when this photo was taken in October 2014.
NASSCO, the success of the PC-1 program proved that international collaboration was not only achievable, but also vital for keeping the pulse of cutting edge design and construction techniques. Over the course of eight years, NASSCO and DSEC have partnered on fifteen commercial ships, including two LNG-powered containerships for TOTE, as well as several U.S. government ships, including the recently delivered mobile landing platform ships.

Opened in 1973 and located in Opko Bay, South Korea, DSME has been involved in the design and construction of leading ship and offshore programs for the past two decades, including containerships; 18,270 TEU Triple E class containerships for Maersk; and complex drill ships. The company has more than 100 LNG carriers in its portfolio and the capacity to build up to 14 LNG carriers annually.

New regulatory environment
Over the past five years, both international and national legal requirements regarding the exhaust emissions of large-bore diesel engines have become more stringent. For marine diesel engines, these requirements focus primarily on the reduction of nitric oxides (NOx) and sulfur oxides (SOx). Recently, requirements for reducing greenhouse gas carbon dioxide (CO2) also have played an important role in this arena.

For the past two decades, engine manufacturers, such as MAN Diesel & Turbo (MDT) and Wärtsilä have been working to reduce NOx emissions. Since the introduction of the International Maritime Organization (IMO) tier I, the first stage of the IMO MARPOL 73/78 Annex VI emissions regulations for marine diesel engines in 2000, these engine suppliers have expanded the range of NOx-optimized engines. The next stage of the IMO requirements, tier II, came into force in 2011 and requires an additional 20% reduction in NOx emissions compared to IMO tier I.

Moving forward, the third stage of the IMO emissions regulations, tier III, is planned for 2016 and will require completely new measures and technical solutions. Companies like MDT are on track to providing these solutions and are already developing numerous primary and secondary measures to enable compliance with these highly demanding requirements. Tier III provides a further reduction in NOx emissions in emission control areas (ECAs) to 80% lower than the tier I level. ECAs are special zones where separate restrictions apply for SOx and particle emissions, NOx emissions, or both. Existing ECAs are in the North Sea, Baltic Sea, and around the coastline of North America.

In ECAs, the proportion of sulfur in fuel must not be more than 1.0 percent since 2010. After January 2015, the proportion of sulfur...
will be limited to 0.1 percent. From January 2020, IMO stipulates a maximum of just 0.5 percent globally. IMO is considering an extension of this requirement to 2025. As an alternative to compliance with these fuel regulations, ship operators can also use appropriate exhaust gas after-treatment systems that reduce SO\textsubscript{x} emissions accordingly. (For more on this subject, see “No Simple Answer” beginning on page 64 in this issue.)

The exponential increase in emissions regulations has led shipowners to look at new solutions for ship propulsion. This is particularly true for Jones Act owners who operate in U.S. coastwise trade where significant portions of their voyages are within ECAs. More specifically, the new TOTE Marlin class ships will operate between Jacksonville, Florida and San Juan, Puerto Rico. Burning natural gas and distillate fuel provides TOTE a means to not only meet, but significantly beat existing emissions regulations.

Dual-fuel propulsion
For the Marlin class ships, the components of the LNG propulsion system were carefully selected and then integrated into the ship design by DSEC, with assistance from DSME. There are four primary components of this system:

- MDT dual-fuel main engine
- Cryos LNG tanks
- DSME HiVAR fuel gas supply (FGS) system
- MDT dual-fuel diesel generators (DFDGs).

The design concept of the LNG main propulsion system is quite simple. Low-pressure LNG is pumped out of the LNG tanks using submerged cryogenic booster pumps. From here, the low-pressure LNG runs through a high-pressure LNG pump that increases the pressure to approximately 300 bars. The high-pressure LNG is then isobarically converted to gas as it goes through the vaporizer (special heat exchanger). From there, high-pressure gas is delivered to the main engine for combustion.

MDT dual-fuel main engine. MDT first began testing on an ME-GI, or gas injection, engine back in the early 1990s in Tokyo, Japan due to the high price of fuel oil at that time. This 12K80MC-GI engine operated at a peak load for more than 20,000 hours on high-pressure gas. At the same time, MDT received approval of concept for a gas injection engine from all major classification societies.

On the TOTE project, the Marlin class ships use a MDT 8L70ME-GI main engine that has been built by DOOSAN Engine, a Korean licensee of MDT. The engine weighs 642 metric tons and delivers approximately 25 MW of power. This will be the first ME-GI engine newbuild project in the world. Since the orders for the TOTE program, MDT has sold more than 80 ME-GI engines worldwide.

MDT’s approach to its ME-GI, dual-fuel engines uses existing proven parent model engines as the base design. For example, MDT has sold several L70ME engines that operate in fuel oil mode only. The primary physical difference between an ME and ME-GI engine is the cylinder cover. On an ME-GI engine, the cylinder cover has both fuel injection valves and gas injection valves. As

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One of the two Cryos 900 m\textsuperscript{3} LNG tanks that will be onboard each of the two Marlin class containerships.
such, the gas system includes a gas supply line design with ventilated double wall piping. Gas injection control is added to the proven MDT electronic control system. An inert gas system, sealing oil system, and control and safety system are all included to ensure the safe operation of the powerplant.

Fuel flexibility is a significant advantage of an ME-GI engine. A two-stroke, high-pressure gas injection engine can easily burn different types of fuels without much loss of thermal efficiency. The ME-GI engine can also shift from fuel oil-only mode to gas mode in just minutes without observing fluctuations in the engine load. In gas mode, pilot oil is as low as 1.5% as the engine approaches 20% load. This enables maximum usage of gas, which reduces emissions.

Cryos LNG tanks. Several different LNG tank concepts exist in the marketplace today. For LNG fuel tanks, most concepts include type C cylindrical tanks that offer “plug and play” installation and operation. On the Marlin class vessels, DSEC employed the Cryos type C double-wall tank concept. For these two 900 cubic meter tanks, the inner tank is comprised of stainless steel and the outer tank is regular mild steel. The annular space in between these two tanks is insulated with evacuated perlite, which offers superior insulation qualities leading to low LNG boil-off rates.

On the TOTE Marlin class ships, the LNG tanks can be seen above the main deck just aft of the accommodation space. This is conveniently located immediately adjacent to the LNG bunkering stations in addition to being directly above the propulsion plant.

DSME HiVAR fuel gas supply (FGS) system. DSME started development of its LNG FGS system approximately ten years ago. To date, this system includes more than 30 approved patents. DSME received its first patents as early as 2007 in Korea. In 2010, DSME completed its development of the HiVAR FGS system skid. This skid was shipped to Copenhagen, Denmark to be part of the first ME-GI demonstration in 2011. Several tests have been performed since 2011, including the factory acceptance tests performed on the ME-GI engines used for TOTE’s Marlin class ships.

The biggest benefit of DSME’s FGS system is the ability to convert LNG to natural gas in a highly efficient and economical way. On some LNG carriers, gas is converted to high pressure via the use of a large gas compressor. This method uses approximately 15 times more power than DSME’s HiVAR system. The combination of a high-pressure pump and vaporizer is highly efficient and requires a relatively small amount of space. It also provides other benefits such as low noise, low vibration, and easy maintenance.

TOTE’s Marlin class FGS system includes two skids. One skid contains the ACD cryogenic high-pressure pumps and associated components, while the other skid contains the remaining components such as the high-pressure vaporizer and intermediate heating medium pumps that circulate glycol-water in a closed loop system to the vaporizer. The FGS system is located directly between the two LNG fuel tanks, which minimizes the length of LNG piping connections.

One of the biggest early design hurdles was to ensure the DSME FGS system was in accordance with all American Bureau
of Shipping (ABS) and United States Coast Guard (USCG) regulations. “NASSCO and DSEC spent significant effort early in the design process meeting with both ABS and USCG to ensure regulatory compliance,” says Eric Icke, NASSCO’s program manager for the TOTE Marlin class containerships. “For example, hazardous zone definition required close collaboration between all parties. In the end, we set the benchmark for high-pressure LNG propulsion system design.”

**MDT dual-fuel diesel generators (DFDGs).** While sometimes overlooked, the DFDGs on the TOTE Marlin class vessels serve an important purpose within the LNG propulsion system. Unlike the large, two-stroke ME-GI engine, the three DFDGs operate as low-pressure, four-stroke, medium-speed engines. As a result, there are two ways to deliver gas to these engines. First, low-pressure LNG coming from the LNG tanks passes through a low-pressure vaporizer and is delivered for combustion. Second, if boil-off gas pressure in the LNG tanks reaches a pre-defined setpoint, natural gas is directed to a DFDG engine for consumption. This serves as a safety feature of the LNG propulsion system.

**Leading the way**

Significant progress has been made to date on this program. From the major equipment to the integrated design, this LNG propulsion system leads the way into an era of new green ship technology. With the lead ship scheduled to deliver ahead of schedule in fourth quarter 2015, these vessels will be the world’s first LNG-powered containerships.

These Marlin class vessels will replace the existing Ponce class vessels operating in the Puerto Rican market with drastically reduced vessel emissions per container nautical mile. **MT**

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