KEY ELEMENTS

WHAT'S NEEDED FOR A SUCCESSFUL LNG TOWBOAT CONVERSION

BY NICK HUNTER

It's hard to think of the Mississippi River and not conjure images of Mark Twain piloting a plodding paddle wheeler from St. Louis to New Orleans, or to picture hulking ironclad monitors clashing at the Battle of Vicksburg. But in today's age of 10,000 HP towboats pushing impressive barge trains, one wonders what Mark Twain would include in a revised edition of *Life on the Mississippi*. Maybe he'd talk about the impact of United States Coast Guard (USCG) Subchapter M requirements or the advent of the automatic identification system and e-navigation? It's unlikely, but one topic that would be addressed, in one form or another, is propulsion. Mark Twain would likely note the lack of paddlewheels and steam boilers driving them; very dangerous pieces of machinery in the 19th century, boilers were fueled first by wood and then by coal. The river industry has moved away from wood and coal fuel, into diesel and gas fuels, and now, potentially, liquefied natural gas (LNG).

In order for an inland river towboat to be converted realistically to run off of LNG as a fuel, though, a number of key factors must be present in the concept and design. At my company, NETSCo., Inc., we've put our 36 years of naval architecture and marine engineering

A single screw towboat exits the McAlpine Lock and Dam upbound with a mixed train of 12 loaded open-top hopper barges. A deck extension would likely be required to secure containers.

experience to work in developing a conceptual LNG towboat conversion. In this design study, we look at which elements of a towboat's design impacts the conversion feasibility most significantly, with the goal of presenting our conceptual towboat conversion that addresses the identified challenges.

LNG as a fuel

LNG has long been a preferred alternative fuel for vessel owners who need to reduce their SO_x emissions or are looking for a cheaper, or more cost-stable, alternative to traditional diesel fuels. There are more than 200 vessels relying on LNG as a fuel globally and this number is expected to grow up to 50% in the next 5 years. Here in the U.S., however, we have seen the LNG-powered fleet expand at a much slower pace. There are a number of factors that have contributed to this lag, but the biggest is arguably the lack of available LNG fuel infrastructure. For towboats that run barges up and down the Mississippi, they need options for fueling locations from New Orleans to St. Louis and beyond. Establishing an LNG fuel infrastructure becomes paradoxical: it is difficult to build LNG-powered vessels when there isn't an established LNG infrastructure, but there is no reason for LNG infrastructure to be built when there are no vessels demanding it.

An LNG-powered river towboat with a more focused area of operation, however, would be more feasible in today's environment, as long as their operating range is reasonably close to a single LNG source. Smaller LNG bunkering barges could provide a solution to the fuel availability problem along the rivers, but these types of bunkering barges would also require a close LNG fuel source and would be limited by the time that they can store cold LNG. Bunkering barges would also require a consistent market of towboats requiring LNG fuel, taking us back to the infrastructure dilemma.

In lieu of bunkering barges, the LNG supply chain could be addressed with a different approach to the fuel storage onboard the towboat. Over the past five years, there has been a revolution in the LNG shipping industry with the development of LNG International Standard for Organization (ISO) containers. Today, we see ISO containers being used to ship LNG over the road and across some bodies of water to enable the transport of LNG to smaller communities that otherwise wouldn't be able to receive the import. The possibility of using ISO containers

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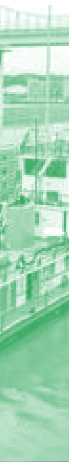
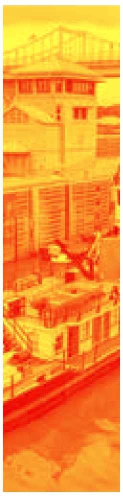
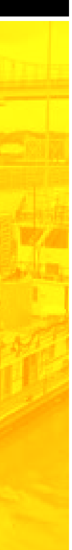






Typical Towboat Categories and Their General Characteristics

	UTILITY	RIVER	LINEHAUL
LENGTH	20 ft. to 85 ft.	80 ft. to 150 ft.	100 ft. to 200 ft.
BEAM	15 ft. to 25 ft.	19 ft. to 30 ft.	20 ft. to 50 ft.
DEPTH	6 ft. to 10 ft.	10 ft. to 12 ft.	10 ft. to 12 ft.
PROPULSION ENGINES	One or two	Two or three	Two or three
INSTALLED HP	200 to 1,200 HP	800 to 6,200 HP	4,500 to 10,000 HP
RANGE	Less than 15 days	5 to 30 days	15 to 40 days
OPERATIONS	Barge fleeting or harboring services	Mid-range transits between locks	Long-range runs between major ports

as a local fuel source on a vessel, however, has been a largely untapped possibility. In theory, if a ship were to be carrying LNG fuel within containers, it could "refuel" wherever a semi-truck and crane could reach the vessel. In terms of Mississippi River transit, this means that a vessel owner could theoretically order a container replacement to refuel their towboat at any one of the many shipyards or major ports of call along the river system.

Fueled by the drive to reduce environmental impacts and operating costs, and using the emerging technology of LNG ISO containers with cutting edge equipment modifications, existing long-haul towboats could be retrofitted to run off of LNG fuel.

Typically, LNG-powered vessels use type C LNG tanks permanently mounted onboard for fuel containment. LNG ISO containers are essentially modularized type C tanks, just removable and portable units. The containers are self-contained and would not require any additional structural support for the tank apart from supporting the container corner castings. Onboard the container are all of the fittings and valves required to safely fill, vent, and discharge the LNG tanks, but transfer equipment and vapor recovery systems would be provided separately. Compared to fixed type C tanks, a modularized fuel solution has a major advantage in its simplified refueling requirement. Using containers, no LNG bunkering procedures would need to be followed and the connections involved are at the container supply and return. With permanent tanks, the vessel and shoreside crew would both need to be trained to handle ship to shore LNG transfer, or, if bunkering barges become popular on the rivers, ship to ship LNG transferring procedures. Onboard a vessel with fuel containers, the only LNG being transferred is within the vessel's fuel system. Crews still will need training to properly operate and maintain LNG fueling equipment, but this is substantially less training than what LNG bunkering operations would require.

If we consider our conceptual towboat conversion, selecting and sizing the containers depends on the vessel's current fuel profile. There are two sizes of LNG container; typically they are only offered in 40 and 20 ft. units. A 40 ft. LNG ISO container generally holds approximately 43,500 liters of LNG for 53 to 65 days depending on the tank's pressure rating, while a 20 ft. LNG ISO container can hold approximately 20,000 liters for 52 to 75 days. In an effort to fit as much LNG onboard as possible, two 40 ft. containers were selected, with 90,000 liters of LNG providing approximately 565,000 horsepower hours. Onboard a 3,800 HP towboat, therefore, two 40 ft. containers would power the engines for more than six days at full load while a 10,000 HP towboat would have about two days' worth of fuel at full load. Based on this estimated operating range, an owner would likely require some diesel to be maintained onboard as a backup fuel source.

Owner's requirements

Designing around the use of LNG ISO containers, our conceptual towboat conversion requires clear guidelines and requirements for the vessel modification from the "owner." The overarching requirement that we set forth for ourselves was straightforward: the LNG conversion should impact the vessel's operation and performance as minimally as possible. Looking more specifically at the current operating requirements and performance, we developed the following requirements. One, there is to be no negative impact on vessel operating speed, stability, or range. Two, the LNG handling equipment should be modular to enable quick servicing and/or replacement. Three, as much of the existing vessel's machinery is to remain to minimize crew re-training. Four, sightlines from the pilothouse are to be maintained. And last, air draft should not be increased in order to avoid affecting overhead clearances.

With these factors in mind, we can look at how various vessel characteristics impact the conversion, and whether any specific attributes would make the conversion infeasible. The most influential vessel characteristics for this type

A typical 40 ft. LNG ISO container.

of project are the vessel's principal dimensions, its stability, and its machinery and overall layout.

A towboat is a unique style of workboat that is designed to push barges within the inland river system. Towboats are slightly different than their tugboat cousins in that they are typically designed with very little freeboard, intended for very shallow draft environments, and are subjected to extreme grounding, bumping, and scraping conditions. Towboats are generally viewed in two or three different categories: linehaul towboats and river, or utility, towboats. Linehaul towboats can see voyage requirements that span long runs of the river system south of St. Louis, while river towboats usually service the river system between locks and dams. Utility towboats are generally tethered to one specific area, supporting barge fleeting, shipyard services, or barge management at a lock and dam. For the purposes of our study, linehaul towboats were the targeted platform in order to focus on the problem of insufficient LNG fuel sources along greater lengths of the Mississippi River. An additional benefit to linehaul towboats is that they offer more space to arrange the LNG equipment atop the deckhouse and within the engine room.

When we look at the typical linehaul towboat, they are arranged with an elevated pilothouse and a flat, low deckhouse. The flat deckhouse top will act as a suitable platform where the LNG containers can be mounted. A typical linehaul towboat is generally 115 ft. to 180 ft. long, and the flat deckhouse top is generally between 30-40% of the towboat's overall length. At these lengths, the deckhouse top will allow sufficient space for the containers to fit oriented longitudinally with available maintenance space at either end. The deckhouse top also will have enough width to fit two containers side-by-side. A towboat's beam typically ranges from 35 ft. to 54 ft., and considering an ISO container is 8 ft. wide, the remaining deckhouse width would be used for walking space and maintenance.

Some modifications will be made to the deckhouse, though, in the form of exhaust stack relocations. Typically, a towboat's exhaust funnels are directly above the engines on top of the deckhouse. Each main engine will have a dedicated funnel structure, and towboats will generally either have two or three engines. Onboard a towboat with two engines, there is some space between the port and starboard stack to land the containers with minor modifications to the funnel structure; however, making space on top of the deckhouse for the containers becomes complicated onboard a towboat with three engines. If there is a centerline engine, the exhaust will need to be relocated outboard to avoid the LNG containers on top of the deckhouse. In most cases, this modification is straightforward, but in some cases, the deck height in the engine room may complicate the new exhaust pipe routing.

A towboat pushes a barge train down the Mississippi River. Note the loaded hopper barge being towed "on the hip." The Z drives on this barge force the exhaust funnels further aft. An LNG conversion would require relocating these structures.

During our study, we determined that the available length of the deckhouse is the constraining dimension and not the deckhouse width or exhaust funnel locations. Our selected 120 ft. long twin-engine towboat could physically fit two containers side-by-side on top of the deckhouse after minor exhaust stack modifications. The existing exhaust stacks would need to be relocated about 4 ft. outboard to fit the containers side-by-side, but the final longitudinal placement of the LNG containers is driven by the vessel's stability assessment. The residual stability of the typical linehaul towboat is limited. Towboats operate with very little freeboard and they continually combat trim issues. Using a longer

A conceptualized LNG-powered towboat rendering. Note the LNG fuel containers on the aft deckhouse roof.

towboat would enable the LNG containers to be shifted further forward, in relation to the vessel's longitudinal center of gravity, to avoid exacerbating the towboat's existing stern trim.

Sufficient stability

A towboat is generally subject to USCG Subchapter S requirements, and needs to comply with standard weather criteria and special rules pertaining to towboats. Allowable trim, however, typically is mandated by operating conditions. The stern trim of a towboat is induced by the high machinery weight in the aft engine room; a condition that is even worse for Z-drive boats where the engine is 10 ft. to 20 ft. further aft than on a traditionally shafted towboat. Often, the trim of a towboat can drive the owner to install tons of permanent ballast in the forepeak or within the push knees. One foot of aft trim is usually acceptable, and vessel operators manage this with careful fuel tank manipulation.

A towboat pushes two empty tank barges along a calm stretch of the Ohio River in Cincinnati, OH.

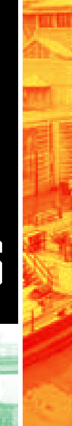
A typical linehaul towboat can carry as much as 100,000 gallons of diesel fuel onboard, and it is almost always contained in fuel tanks located toward the bow, beneath the main deck. With fuel tanks located toward the bow, the vessel has the ability to control its stern trim by careful fuel tank burn sequencing. After two LNG containers are loaded on top of the aft deckhouse, however, we expect some of the diesel tanks to be eliminated or converted to carry enough ballast to even out the trim. Subchapter S criteria are still satisfied with the LNG tanks onboard, but operational restrictions will drive the loading scenarios in order to limit trim.

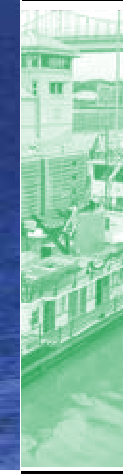
Onboard our 120 ft. towboat concept, limiting trim was the biggest challenge. With the LNG containers located aft of midship, our stability analysis suggested larger than usually accepted trim by the stern if there is no diesel fuel or ballast carried onboard. Converting half of this vessel's diesel tanks to permanent ballast, however, enabled the towboat to maintain acceptable trim levels in all operating conditions. We further improved the vessel's trim characteristics by lengthening it. Lengthening by four frame spaces would improve the trim by 20-25% and less ballast would be required. Additionally, lengthening the vessel would allow the permanent ballast to be replaced with temporary ballast. Lengthening the vessel within the parallel midbody would have the smallest additional cost and would provide the largest trim improvement. The vessel's list is largely unaffected by the symmetrical addition of LNG containers; however, the ability to transfer LNG between containers will be required. Having the ability to transfer LNG from one container to the other will enable more efficient fuel burn and replenishment sequences and enable more control over the vessel's heel.

The equipment

In addition to a careful consideration of the vessel's arrangement and stability, the machinery and vessel's propulsion system must be suitable for the conversion to LNG fuel. The

A conceptualized LNG-powered towboat rendering. Locating the LNG containers on the aft deckhouse requires relocating the exhaust funnels further outboard.





standard approach for LNG conversions is to replace the vessel's engines with a medium speed dual-fuel package. While this approach has a proven track record for retrofitting other vessel types, on certain linehaul towboats this will not be a feasible retrofit.

There are two common configurations of linehaul towboat propulsion systems. Medium speed (750-950 rpm) diesels coupled with directly driven independent propellers, or high-speed (up to 1800 rpm) diesels directly coupled to Z-drives. While Z-drives are not as common as the traditional straight shaft, in either arrangement, the diesel engine is directly coupled to the propeller shaft, which means that all propeller speed adjustment happens at the engine. In lieu of installing new engines to replace the tried-and-true engines, the owner would likely prefer to modify the existing engines, if possible, to LNG-only or dual-fuel machines. Further, modifying the existing engines would minimize the capital expense. Purchasing new engines could increase the overall conversion cost by up to 50%.

There are a number of ways to retrofit an existing diesel propulsion plant to run off of LNG fuel, but it is largely determined by the propulsion engine manufacturer. In the U.S. inland river industry, there are a small number of engine manufacturers who share the majority of the market share. EMD, Cummins, and Caterpillar are all common names to find onboard a linehaul towboat, but only EMD has an advertised conversion solution to convert their diesel engine package to LNG. EMD offers either a duel fuel or LNG-only conversion kit, but both kits focus on their more modern EMD-710 product line. A conversion of the older GE-645 product line would be considered a special project. For other engine manufacturers who might not have conversion kits prepared, third party solutions can be pursued from engine accessory manufacturers. In order to convert a diesel engine to use LNG, traditionally the engine needs to be disassembled and the pistons and cylinder heads need to be modified. Using LNG, the pistons require a lower compression ratio and spark plugs need to be introduced in order to combust the gas in the cylinder. A new ignition system would be added, and some of the timing sensors and mechanisms will need fine tuning after the engine is reassembled. While there are some third party options that advertise external packages not requiring engine rebuilding, the candidacy of the engines for fuel conversion are evaluated on a case-by-case basis and can make or break the project's feasibility.

Naturally, in addition to the modification of the prime movers, ancillary systems will need to be installed to support the LNG handling. Gas supply leak detection and venting systems, inerting systems, glycol cooling systems, and LNG control systems are all new, prepackaged systems that would be installed in the engine room. Additionally, gas handling units, gas storage and control systems, transfer pumps, and gas and flame detection systems would need to be installed in a new refrigerated fuel-handling space near the LNG containers. Currently envisioned, this "cold box" would be located just aft of the pilothouse and just forward of the containers atop the deckhouse, but could also be installed aft of the LNG containers.

Business case

Before any of the modification work can commence to convert a linehaul towboat to use LNG as a fuel, the business case should be evaluated and determined to be favorable. In terms of a typical LNG conversion, this business case has been well documented in previous articles, but generally depends on the low cost of LNG compared to diesel fuel.

For a typical tug or towboat operator, the business model is dependent on how much product you can move and how quickly and cost effectively you can move it. The primary factors that drive an operator's cost are labor rates, fuel costs, external services (cleaning, shifting, and so forth), river conditions, and equipment use levels. The more factors that an operator can control and minimize variability, the more profitable a contract becomes. Arguably, using LNG as a fuel affects each of these

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A towboat outside of Wheeling, WV. The open space atop the deckhouse can be used to locate LNG fuel containers.

variables in one way or another. Labor rates for crew and operators could likely increase as increased training would likely be required to handle LNG and the crew sizes onboard the vessel may inflate as well. External services and equipment use levels would only be minimally affected, but there is potential to decrease costs in these areas. With efficient planning and reliable LNG fuel sources along the towboat's standard operating routes, utilization levels of a specific boat could increase as the downtime to refuel decreases. Ancillary service costs also reduce as refueling becomes easier and is decoupled from traditional fueling docks or terminals.

While a number of factors affect the operating costs incurred by a towboat operator, fuel costs would be the most impacted by the switch to LNG. Fuel costs would dramatically decrease as the cost to burn LNG is far less than the cost to burn diesel oil. This fuel cost savings would be the largest component of an operating expense reduction, and would control the break-even point for the owner.

The operating costs of the towboat would clearly be affected by an LNG conversion, but the ultimate goal is to ensure that the cost savings over time are significant enough to warrant the upfront capital expense of the conversion. Considering the costs associated with the new machinery, the shipyard's modification effort, the technical design effort, and regulatory approvals, we estimate it would take less than 10 years to recoup the capital costs for our conceptual conversion. This time required to break even is largely dependent on operating hours per year, horsepower requirements, and difference in the fuel price between diesel and LNG. Many towboats see up to 60 years of service, though, so a ten-year payback would be viable. Regardless of usage and service life, however, a $2 million to $4 million dollar conversion expense is a large expenditure for a towboat operator, especially when the estimated cost to build a new linehaul towboat is typically $15 million to $30 million.

Lasting effects

Steel may not be cut for this project yet, but there are good towboat candidates in the inland river fleet for an LNG conversion. As the International Maritime Organization and the Environmental Protection Agency increase regulatory pressure on vessels to minimize their greenhouse gas emissions, owners will be looking for different ways to comply with new requirements. In some cases, building a new vessel or repowering a vessel with a different engine are cost-prohibitive solutions, and modifying an existing vessel to use a different fuel source would be the most cost-effective option. Exploiting the modularity of LNG ISO containers and leveraging the reliability of the tried-and-true towboat engines are two aspects of this conversion that would provide positive results for the vessel owner. It may not be a boat that Mark Twain would recognize, but there's no denying the towboat industry is steadily evolving from its coal and steam roots. **MT**

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