



# FINAL REPORT

## Evaluation of Inland Maritime Use of LNG in UTC Region 3

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<b>16. Abstract</b> This work assesses the characteristics of the market for natural gas and alternative vehicles within Region 3 and explores applications to inland maritime within the region. This work includes a summary of existing research outlining the market conditions necessary for supporting the proliferation of alternative fuel vehicles; describes the economic characteristics of the region; and provides a scan of existing infrastructure considerations for supplying LNG as a fuel for inland maritime activities along the Ohio River system. While the supply of natural gas is abundant within the region due to the Marcellus shale activities, existing LNG supplies may be insufficient to support long term growth. In addition to competing uses for natural gas, which serves chemical manufacturing and energy industries, a critical condition for the use of LNG as an alternative fuel is complementary refueling infrastructure, which is largely absent at current.  Additionally, this paper investigates end use and life-cycle contexts for the introduction of alternative fuels in an inland maritime commercial navigation fleet. This paper characterizes fleet technology and informs longer term technology-policy decisions regarding regional transportation innovation. We focus on the Mid-Atlantic Transportation Sustainability University Transportation Center (MATS UTC) Region 3, but include adjacent waterborne freight corridors that connect with other regions. We investigate domestic fuel infrastructure and shallow water navigation		

technologies in the region and assess the emissions reductions associated with a transition to natural gas propulsion for the inland river fleet. The study focus mainly addresses natural gas in liquefied (LNG) contexts, but the infrastructure and vessel activity analysis can be applied to compressed natural gas (CNG) by the region's vessels. Discussion of a fleet switch over to natural gas products is currently focused on LNG and motivated by the high volume of natural gas being produced from Marcellus Shale deposits within UTC region 3. This study characterizes the inland river fleet in UTC region 3 (henceforth referred to as Region 3), primarily on the Ohio, Allegheny, Monongahela, Kanawha, and Big Sandy Rivers. Based on the existing fleet composition, we consider technology performance comparisons for vessels to switch from traditional marine bunker fuels (marine gas oil/MGO) to natural gas fuels (LNG).

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The contents of this report reflect the views of the authors, who are responsible for the accuracy of the data presented herein. The views expressed in this report are those of the authors and do not reflect the official policy or position of Marshall University or its governing bodies. The use of trade names, if applicable, does not signify endorsement by the authors.

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## Introduction

### A. Inland Maritime Freight Volumes and Characteristics

A key characteristic of the inland waterways is the ability to efficiently move large volumes of bulk commodities long distances for a lower price. A 15-barge tow is common on larger rivers such as the Ohio and can move approximately 22,500 tons of cargo as a single unit. This is the equivalent of 200 rail cars or 870 tractor-trailer trucks. It would require an estimated 5.6 million additional rail cars or 25.2 million trucks to carry the loads if the inland waterway did not exist.<sup>1</sup> A comparison of cargo capacity by mode is presented in **Table 1**.

**Table 1: Comparison of Cargo Capacity by Mode**

Mode	Capacity		
	Tons	Bushels	Gallons
Barge	1,500	52,500	453,600
15-Barge Tow	22,500	787,500	6,804,000
Jumbo Hopper Car	112	4,000	33,870
100 Car Unit Train	11,200	400,000	3,387,000
Large Semi	26	910	7,865

Source: <http://www.iowadot.gov/compare.pdf>

#### Values

Barges are ideal for the movement of large quantities of bulk commodities such as coal, petroleum, grain and raw materials. In 2006, 627 million tons of goods were transported via inland waterways. Coal is the largest commodity by volume and represented approximately 29 percent of the total tonnage. Petroleum and petroleum products accounted for 25 percent and crude materials 18 percent. More than 60 percent of farm exports move on inland waterways and nearly 80 million tons of grain move by barge annually. In 2006, Ohio River Basin commercial navigation users saved \$3.1 billion by using the Ohio River System waterway to ship commodities by barge. For the entire U.S. inland river system and using an estimated \$10 to \$12 per ton shipper savings, national transportation shipper savings were estimated at \$7.0 billion.<sup>2</sup>

#### Overall Traffic

As of October 2014, there were over 8,980 vessels registered under the United States flag with the largest percentage of these vessels being tugboats and push boats. These vessels are responsible for the transport of unpowered barges along the inland waterway system. The next

<sup>1</sup> <http://www.iowadot.gov/compare.pdf>

<sup>2</sup> Texas Transportation Institute Center for Ports and Waterways. "America's Locks & Dams: A Ticking Time Bomb for Agriculture?". December 2011. <http://d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/TTI-2011-9.pdf>



largest sector is composed of cargo and passenger vessels. These are primarily shipping vessels located in the Gulf of Mexico and delivering cargo and personnel to the drilling platforms.

### *Locks, Dams, Terminals*

A key feature of the inland waterway system, is the use of locks and dams to move larger and heavier vessels through shallow sections of the rivers. Maintained by the United States Army Corps of Engineers, these locks and dams allow vessels to “stair-step” their way through the system. The locks can generally be categorized by three different sizes, as expressed by length. About 15 percent of the lock chambers are 1,000 to 1,200 feet long, 60 percent are 600-999 feet long, and 25 percent are less than 600 feet long. Lock widths are mostly 110 feet. The 1200-foot locks can accommodate a tow of 17 barges plus the towboat, while the 600-foot locks can accommodate at most eight barges plus the towboat. The lock size and tow size are critical factors in the amount of cargo that can pass through a lock in a given period of time. The nearly 12,000 miles of U.S. inland and intracoastal waterways include 192 commercially active lock sites with 238 lock chambers.<sup>3</sup>

### B. Existing Research

Natural gas as it is used for the transportation industry exists in two forms: compressed natural gas (CNG) and liquefied natural gas (LNG). CNG is natural gas stored at the high pressure of 3,600 psi. This type of fueling is relatively easy to produce and store compared to LNG. LNG is a cryogenically cooled fuel that becomes a liquid at -260 degrees Fahrenheit. This type of natural gas requires very specialized production facilities and handling to maintain its liquid state.

The physical and cost profile of LNG makes it a very capital-intensive fuel to produce. CNG is less expensive to produce and distribute, and has an unlimited hold time in vehicle fuel tanks. LNG is more energy dense and will vent if it remains unused in fuel tanks.<sup>4</sup>

In evaluating the potential market for natural gas powered vehicles for inland maritime along the Ohio River, the essential question is one of creating a market for an infrastructure-dependent transportation technology.<sup>5</sup> While thus far much of the focus on alternative vehicles has been on passenger cars and trucks<sup>6</sup>, some findings are relevant to inland maritime usage.

Research on alternative fuel vehicle (AFV) markets indicates that refueling infrastructure is among the most important considerations for technology adoption and development of the market.<sup>7</sup> As AFVs still represent a relatively new technology, particularly for inland maritime, there are costs for retrofitting or converting current fueling technologies.<sup>8</sup> While there may be

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<sup>3</sup> <http://www.sas.usace.army.mil/Portals/61/docs/lakes/thurmond/navigate.pdf>

<sup>4</sup> <http://www.agilityfuelsystems.com/lng-vs-cng.html>

<sup>5</sup> Alkemade et al (2009); van der Vooren et al (2012)

<sup>6</sup> Werpy et al (2010)

<sup>7</sup> Johnson and Hettlinger (2014); Knittel (2012); Melaina and Bremson (2008); Meyer and Winebrake (2008); Yeh (2007)

<sup>8</sup> Verbeek et al (2011)

environmental benefits or other savings that can be captured over time, explicit costs for acquiring new technology are often incurred upfront. Additionally, new technology adoption may be considered risky, particularly in the absence of complementary, necessary infrastructure.<sup>9</sup>

Another main motivator of AFV adoption is relative fuel prices.<sup>10</sup> Incumbent technologies, such as diesel-fueled vehicles, often become entrenched due to cost advantages that arise on the supply side in terms of production but also on the demand side from things such as familiarity.<sup>11</sup> As the price of diesel rises relative to natural gas, for example, the relative attractiveness of AFVs increases as costs savings from fuel consumption may begin to outweigh perceived costs of switching technologies. If market conditions are insufficient to generate a relative price that motivates adoption, financial incentives may be required, as have been used on the consumer side of the AFV market.<sup>12</sup>

Using six market indicators, Johnson and Hettinger (2014) evaluate the potential market for various alternative fuels in each state. The six market indicators considered were (in order of priority weighting): existing fueling stations, vehicle density (by zip code), gasoline and diesel prices, state incentives (including tax credits, carpool lanes for AFVs), resource proximity (as measured by refineries and gas processing plants), and environmental benefit. With regards to states within Region 3 and along the Ohio River, their findings (presented in **Table 2**) indicate the following market potentials.

**Table 2: State Level Market Indicators for Alternative Fuels**

State	Electricity	Biodiesel	Ethanol	CNG	Propane
Delaware	Strongest	Healthy	Weak	Weak	Healthy
Indiana	Healthy	Strongest	Strongest	Strongest	Strongest
Kentucky	Weak	Healthy	Healthy	Patchy	Patchy
Maryland	Strongest	Healthy	Patchy	Weak	Patchy
Ohio	Healthy	Strongest	Strongest	Strongest	Healthy
Pennsylvania	Strongest	Strongest	Healthy	Strongest	Strongest
Virginia	Healthy	Strongest	Patchy	Healthy	Patchy
West Virginia	Healthy	Patchy	Weak	Strongest	Strongest

Source: Johnson, C and D. Hettinger. (2014). "Geography of Existing and Potential Alternative Fuel Markets in the United States." National Renewable Energy Laboratory Technical Report NREL/TP-54000-60891.

Based upon Johnson and Hettinger’s (2014) analysis, West Virginia, Pennsylvania and Ohio have strong potential for a CNG market, largely due to proximity to Marcellus Shale gas production. In contrast, Delaware, Maryland and Kentucky had the weakest potentials for CNG vehicle

<sup>9</sup> Melaina and Bremson (2008); Meyer and Winebrake (2008); van der Vooren et al (2012)

<sup>10</sup> Johnson and Hettinger (2014); Knittel (2012); van der Vooren et al (2012); Yeh (2007)

<sup>11</sup> van der Vooren et al (2012)

<sup>12</sup> Johnson and Hettinger (2014); Melaina and Bremson (2008); Meyer and Winebrake (2008); Werpy et al (2010); Yeh (2007)

markets. Their analysis of a variety of alternative fuels highlights another potential issue in creating a market for natural gas – the presence of many competitors in the AFV market. van der Vooren et al. (2012) find that too many alternatives can weaken the effectiveness of policies to promote any particular technology.

With regards to the inland maritime market, a few studies have considered the potential for liquefied natural gas (LNG).<sup>13</sup> As with passenger vehicles, these studies indicate that relative fuel prices will be a primary motivator in technology adoption. A favorable price for natural gas is critical for offsetting the costs of technology conversion.<sup>14</sup> Additionally, environmental regulations will also be key for motivating adoption.<sup>15</sup> Such regulations will likely increase the implicit price of diesel. Refueling infrastructure is also a crucial consideration. Similar to Melaina and Bremson (2008) who consider the locations of existing fuel stations for evaluating the necessary urban coverage for passenger vehicles, the DNV GL (2014) study notes that LNG bunkering for inland maritime will depend heavily on specific ports. The needs of each port will vary, depending on technical, geographic and physical considerations.

DNV GL (2014) considers four aspects of creating the necessary refueling capacity – physical infrastructure, safety, regulations, and training requirements. They note four primary methods of bunkering - Truck to Ship (TTS) (most common); Shore/Pipeline to ship (PTS), with scalable on-site facilities; Ship-to-Ship (STS), offering considerable locational flexibility; and portable tanks. The preferred bunkering option will vary depending on the specific characteristics of the port.

While capital costs are a barrier to creating infrastructure, DNV GL (2014) note that co-locating bunkering for multi-modal use is one way to potentially address this barrier. Another important barrier is public perceptions and discomfort in having a nearby facility, particularly concerns over safety and risks from fire events.

In terms of demand potential, GNA (2014) examines the Great Lakes, Mississippi River System and Gulf Coast. The study echoes similar themes from passenger vehicle studies such as “availability of emerging technologies, regulatory uncertainty, end-user familiarity, and fuel supply and distribution questions.” Proximity to fuel source is a key consideration, with 250 miles being the identified distance to a fuel source beyond which it becomes cost prohibitive to transport LNG by truck to refueling sites.

Additionally, the type of refueling infrastructure required varies by region as vessel traffic varies. For the inland waterways, the predominant vessels are pushboats. Refueling largely takes place via barge as opposed to specific ports or other typical bunkering locations.<sup>16</sup> GNA (2014) also notes that “[e]ach pushboat company will have its own specific fueling approaches,

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<sup>13</sup> DNV GL (2014); GNA (2014); Verbeek et al (2011)

<sup>14</sup> Verbeek et al (2011)

<sup>15</sup> DNV GL (2014)

<sup>16</sup> GNA (2014)

regional hubs and specific barge-fueled locations and not all companies operate on all the rivers.”

While Cincinnati, Pittsburgh, and Huntington Tri-State all appear in the second largest category for annual fuel usage, the study determines inland waterways to be only of moderate market potential, much of which would initially derive from vehicle conversions, as opposed to new builds. GNA (2014) notes that “potential LNG demand centers do not necessarily correlate with actual current fueling locations along the waterways.” The nature of inland navigation, lacking standard locational bases, suggests that refueling infrastructure would need to be present along several points. Further, while there is demand inland, much of the LNG supply infrastructure for Region 3 is located in coastal areas and produced by gas distribution utilities for peak shaving supply.<sup>17</sup> Additional information related to peak shaving is presented in **Chapter 3, Section C.**

The cost of a CNG fueling station is quoted to have a price tag up to \$1.8 million for a large, fast-fuel facility. A CNG station receives natural gas via a local utility line at a pressure lower than that used for vehicle fueling and compresses it to the pressure needed for a vehicle.<sup>18</sup> Although an LNG fueling site may have a similar cost, said to be somewhere between \$1 and \$4 million,<sup>19</sup> this cost does not include the cost of producing the LNG. Currently, to get LNG to a fueling station near the Ohio River, it must be trucked from a production facility, just as diesel and gasoline are.

The cost of an LNG plant of an unspecified size is said to be between \$40 and \$100 million,<sup>20</sup> making the construction of this type of facility a large capital investment. According to a report written by KBR in 2007, “the primary drivers for the capital cost of an LNG liquefaction facility are site-specific, and are a function of site related conditions, project development and project execution efforts.”<sup>21</sup> In terms of costs that would be specific to a LNG facility constructed to serve vessels on the Ohio River “the cost of marine facilities is largely independent of plant capacity and configuration and totally depends on the location of the plant.”<sup>22</sup>

According to KBR, project risk inherent in potential LNG projects is also very site-specific. Two risk factors perhaps most applicable to an inland maritime market are the nature of potential LNG sales agreements and customer diversity. A proposed facility with access to long-term purchasing contracts rather than short-term contracts can reduce market risk and potentially makes the project more attractive to investment. Financiers will also prefer a facility to have

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<sup>17</sup> Ibid.

<sup>18</sup> USDOE (2014). “Costs Associated With Compressed Natural Gas Vehicle Fueling Infrastructure.”

<sup>19</sup> [http://www.afdc.energy.gov/fuels/natural\\_gas\\_infrastructure.html](http://www.afdc.energy.gov/fuels/natural_gas_infrastructure.html).

<sup>20</sup> FC Gas Intelligence (12/17/13). “Where will LNG grow?”

<sup>21</sup> KBR (2007). “LNG Liquefaction: Not All Plants Are Created Equal,” Paper PS4-1.

<sup>22</sup> Ibid.

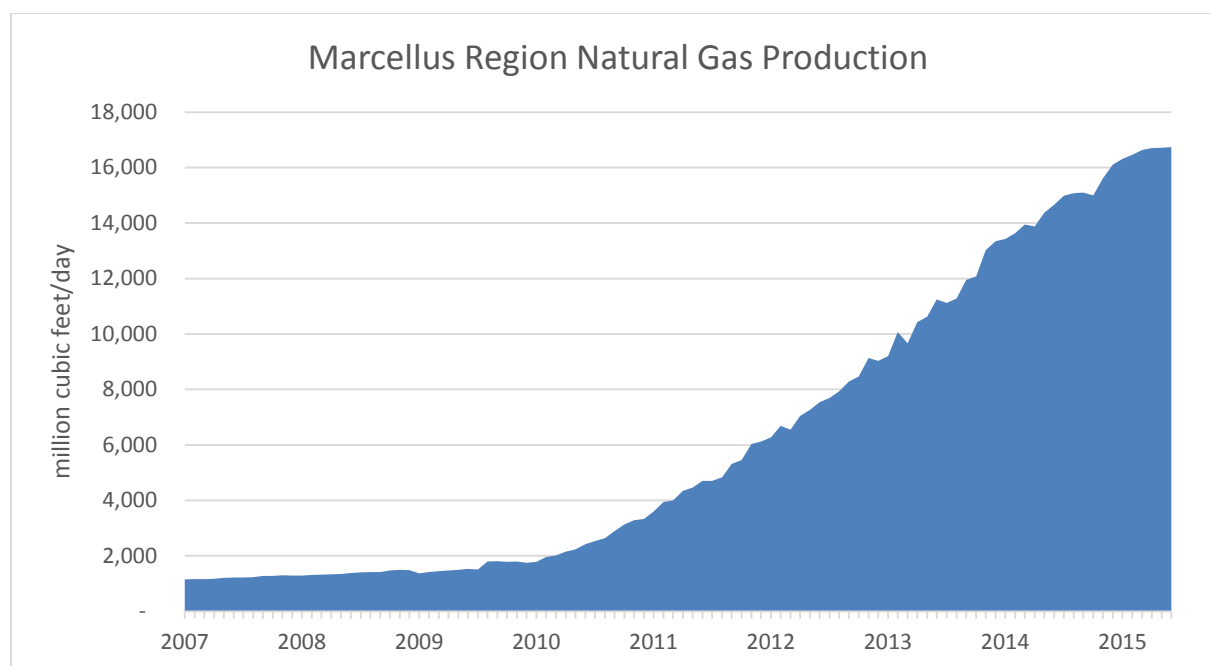
customers representing diverse markets rather than limited markets to protect against future price fluctuation.<sup>23</sup>

### Overview of LNG/CNG Market

#### A. Marcellus Shale Production

The Marcellus Shale gas play, located primarily in Pennsylvania, West Virginia, Ohio, and New York, is the largest producing shale gas basin in the United States. Almost 40% of total U.S. shale gas comes from the Marcellus region alone.<sup>24</sup> As illustrated by **Figure 1**, production from the region increased by a factor of eight between 2010 and early 2015.<sup>25</sup>

**Figure 1: Marcellus Region Natural Gas Production**



Source: Drilling Productivity Report, May 2015, EIA (<http://www.eia.gov/petroleum/drilling/>)

The natural gas present in the Marcellus play can be of the dry or wet type. Dry gas is nearly pure methane while wet gas includes other natural gas liquids (NGLs) such as ethane, butane, propane, and pentane. Wet gas is located in the western Marcellus region including the northern panhandle of West Virginia, eastern Ohio, and western Pennsylvania, as shown in **Figure 2**.<sup>26</sup>

<sup>23</sup> KBR (2007). "LNG Liquefaction: Not All Plants Are Created Equal," Paper PS4-1.

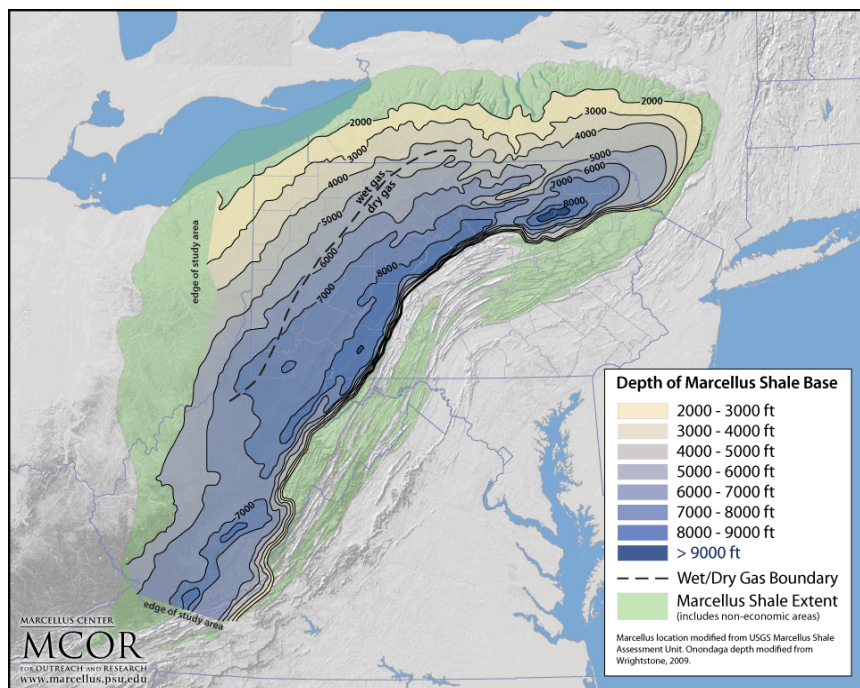
<sup>24</sup> <http://www.eia.gov/todayinenergy/detail.cfm?id=17411>

<sup>25</sup> Drilling Productivity Report, May 2015, EIA (<http://www.eia.gov/petroleum/drilling/>)

<sup>26</sup> <http://www.marcellus.psu.edu/resources/maps.php>

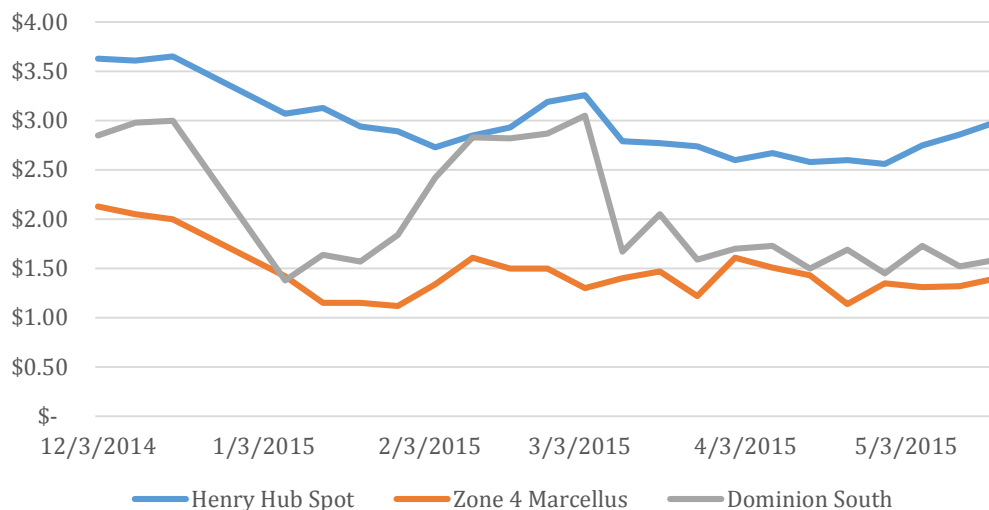
NGLs have applications in the chemical manufacturing (e.g. ethane as a feedstock for ethylene-based plastics), transportation (e.g. propane), residential (e.g. propane), and other industries. The presence of these co-products allows producers of wet gas additional revenue, provided they have access to relevant markets.

**Figure 2: Map of Marcellus Shale Wet/Dry Gas Boundary**



Abundant natural gas production from the Marcellus play since 2010 has resulted in decreased prices throughout the country but particularly in the Marcellus area. Marcellus-area prices frequently trade at a discount to the Henry Hub price, the national benchmark for natural gas. **Figure 3** shows some recent prices for Zone 4 Marcellus gas, a hub in northeast Pennsylvania, and Dominion South, a hub in southwest Pennsylvania. Both regions have recently been trading at one-half of the Henry Hub price.

**Figure 3: Recent Marcellus Area vs. Henry Hub Gas Prices (\$/mmBtu)**



Source: Energy Information Administration, Natural Gas Weekly, 2014 and 2015.

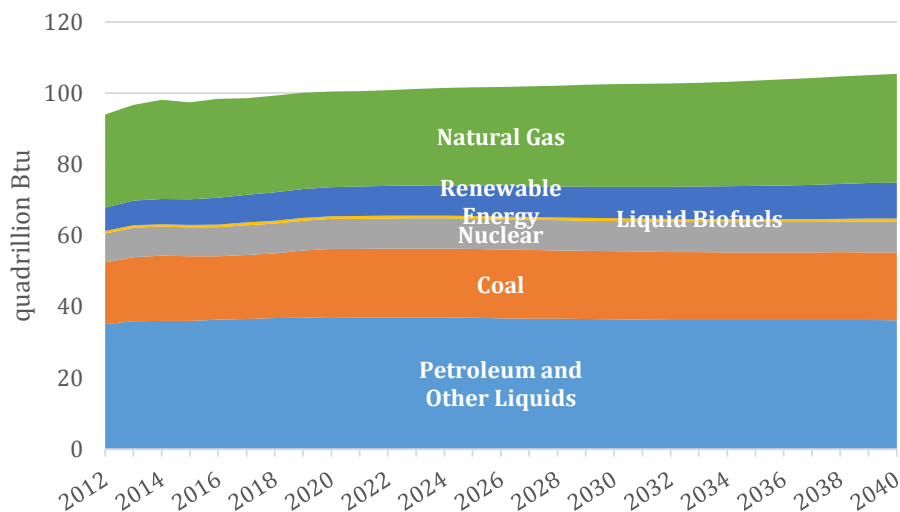
In spite of these low commodity prices, increased U.S. natural gas production is projected through 2040 by the U.S. Energy Information Administration (EIA) in all of its Annual Energy Outlook (AEO) 2015 cases.<sup>27</sup> Natural gas production is highest in the High Oil and Gas Resource case (26% higher than in the Reference case), and with this production level is large enough to meet the increasing domestic consumption and projected exports of pipeline gas and LNG.

#### B. Natural Gas Industry and Users

The Annual Energy Outlook (AEO) is a document produced by the EIA that forecasts demand and supply figures for several fuel types. In the AEO 2015 Reference Case, the EIA projects that U.S. natural gas consumption will increase from 26.2 Tcf to 29.7 Tcf in 2040. Thus, demand is expected to increase commensurate with increasing supply. Several sectors account for this increasing demand. Projected energy consumption by fuel type is presented in **Figure 4**.

<sup>27</sup> [http://www.eia.gov/forecasts/aeo/pdf/0383\(2015\).pdf](http://www.eia.gov/forecasts/aeo/pdf/0383(2015).pdf)

Figure 4: Energy Consumption by Fuel in the AEO2015 Reference Case, 2012-2040



Source: [http://www.eia.gov/forecasts/aeo/pdf/0383\(2015\).pdf](http://www.eia.gov/forecasts/aeo/pdf/0383(2015).pdf)

Table 3 shows U.S. natural gas consumption by end-use sector as published by the EIA. Natural gas consumed for vehicle fuel accounts for less than one percent of total U.S. natural gas consumption in 2014.<sup>28</sup>

Table 3: U.S. Natural Gas Consumption by End-Use (MMcf)

Year	Lease Fuel	Plant Fuel Consumption	Pipeline & Distribution	Delivered to Consumers					Total Consumption
				Residential	Commercial	Industrial	Vehicle Fuel	Electric Power	
1997	776,306	426,873	751,470	4,983,772	3,214,912	8,510,879	8,328	4,064,803	22,737,342
1998	771,366	401,314	635,477	4,520,276	2,999,491	8,320,407	9,341	4,588,284	22,245,956
1999	679,480	399,509	645,319	4,725,672	3,044,658	8,079,359	11,622	4,819,531	22,405,151
2000	746,889	404,059	642,210	4,996,179	3,182,469	8,142,240	12,752	5,206,324	23,333,121
2001	747,411	371,141	624,964	4,771,340	3,022,712	7,344,219	14,536	5,342,301	22,238,624
2002	730,579	382,503	666,920	4,888,818	3,144,170	7,527,184	14,950	5,671,897	23,027,021
2003	758,380	363,903	591,492	5,079,351	3,179,493	7,150,396	18,271	5,135,215	22,276,502
2004	731,563	366,341	566,187	4,868,797	3,128,972	7,256,408	20,514	5,463,763	22,402,546
2005	756,324	355,193	584,026	4,826,775	2,998,920	6,601,168	22,884	5,869,145	22,014,434
2006	782,992	358,985	584,213	4,368,466	2,832,030	6,526,546	23,739	6,222,100	21,699,071
2007	861,063	365,323	621,364	4,722,358	3,012,904	6,654,716	24,655	6,841,408	23,103,793
2008	864,113	355,590	647,956	4,892,277	3,152,529	6,670,182	25,982	6,668,379	23,277,008
2009	913,229	362,009	670,174	4,778,907	3,118,592	6,167,371	27,262	6,872,533	22,910,078
2010	916,797	368,830	674,124	4,782,412	3,102,593	6,826,192	28,664	7,387,184	24,086,797
2011	938,340	384,248	687,784	4,713,777	3,155,319	6,994,120	29,974	7,573,863	24,477,425
2012	987,957	408,316	730,790	4,149,519	2,894,926	7,226,215	29,970	9,110,793	25,538,487
2013	1,068,289	406,782	861,583	4,914,327	3,278,856	7,413,918	33,624	8,153,285	26,130,666
2014			884,257	5,072,030	3,459,061	7,655,209	32,850	8,149,111	26,818,334

Source: [http://www.eia.gov/dnav/ng/ng\\_cons\\_sum\\_dcunus\\_a.htm](http://www.eia.gov/dnav/ng/ng_cons_sum_dcunus_a.htm)

<sup>28</sup> [http://www.eia.gov/dnav/ng/ng\\_cons\\_sum\\_dcunus\\_a.htm](http://www.eia.gov/dnav/ng/ng_cons_sum_dcunus_a.htm)



i. Energy

The largest source of the projected increase in natural gas consumption is electricity generation. The EIA projects electricity consumption will rise at an average annual rate of 0.8% from 2013 to 2040. This figure aligns with expected national population growth. In 2013, natural gas provided 27% of electricity generation; by 2040, EIA projects it will be 31% of total electricity. The only other fuel type expected to increase its share of electricity generation in the time period is renewables.

ii. Chemical Manufacturing

Consumption of natural gas is also expected to increase in the industrial sector, in the form of methane and NGLs. Projected increases result from abundant shale gas production slowing the growth of natural gas prices. Consumption is projected to increase most rapidly through 2016 and maintain a slower growth through 2040.<sup>29</sup>

The chemical industries using natural gas as a feedstock will constitute the largest change for the industrial sector. Natural gas use as a feedstock is forecasted to increase 0.4 quadrillion Btu between 2013 and 2040. Consumption of the NGLs ethane and propane (including ethylene and propylene) will grow by about one quadrillion Btu. These NGLs are extracted in processing plants from wet gas found in the northwest Marcellus region.

iii. Transportation

The following data are the most recent available describing use of CNG and LNG for transportation in the U.S.<sup>30, 31</sup> CNG is more commonly used, with applications for transit buses, garbage disposal trucks, and light-duty vehicles. LNG has limited use, only for long-haul trucking. Consumption data (illustrated in **Table 4**) is reported in gasoline equivalent gallons (geg).

**Table 4: U.S. Natural Gas Vehicles – Fuel Consumption and Number of Vehicles (2005-2011)**

Year	CNG and LNG Consumption (thousand geg)		Number of Vehicles in Use	
	CNG	LNG	CNG	LNG
2005	166,878	22,409	117,699	2,748
2006	172,011	23,474	116,131	2,798
2007	178,585	24,594	114,391	2,781
2008	189,358	25,554	113,973	3,101
2009	199,513	25,652	114,270	3,176
2010	210,007	26,072	115,863	3,354
2011	220,247	26,242	118,214	3,436

Source: <http://cta.ornl.gov/data/index.shtml>

<sup>29</sup> [http://www.eia.gov/forecasts/aeo/pdf/0383\(2015\).pdf](http://www.eia.gov/forecasts/aeo/pdf/0383(2015).pdf)

<sup>30</sup> <http://cta.ornl.gov/data/index.shtml>

<sup>31</sup> As of May 2015 EIA had not yet released its 2012 alternative fuel vehicle data.

The AEO 2015 Reference Case projects consumption of LNG and CNG in the transportation sector to increase at an average annual rate of 10.3%. As heavy-duty vehicle (HDV) fuels, LNG and CNG are predicted to increase from an insignificant share of total energy in 2013 to 7% of HDV energy by 2040. This increase is likely due to the competitive natural gas prices expected, as evidenced by increased interest in LNG and CNG fuel technology.<sup>32</sup> Many Marcellus-area prices, e.g. Dominion South and Marcellus Zone 4, have recently been even lower than the Henry Hub prices used in the EIA projections, as shown earlier in **Figure 3**.

It has been estimated that a plant needs to produce at least 100,000 gallons of LNG a day with average utilization of at least 80% to be viable. In the inland maritime market, that would equate to about seven Great Lakes bulk carriers, 24 ferries or 38 tugs in order to be viable.<sup>33</sup>

#### iv. Exports

In addition to domestic demand for natural gas for energy, manufacturing, and transportation, there is a large market for the export of both pipeline gas and LNG. Pipeline exports of natural gas have grown over the last five years and are projected to continue that trend. The EIA links this increased export of pipeline gas to increased demand from Mexico for natural gas for electricity generation. Overall, the EIA projects the U.S. net imports of natural gas to go to zero within the next couple of years.<sup>34</sup>

EIA predicts the U.S. to become a net exporter of LNG through 2040 in its reference case and all other forecasted scenarios.<sup>35</sup> The export of LNG from the United States is driven by a strong price differential between U.S. domestic natural gas and LNG supplied to international markets. This differential is expected to remain, at least in the near term. This same price difference also discourages imports of LNG. The lowest level of exports are projected in the AEO 2015 Low Oil Price case. Since the price of LNG supplied to the international market reflects world oil prices, the Low Oil Price case would indicate a weak price differential between domestic natural gas and LNG exports.<sup>36</sup>

## Transportation Applications for LNG/CNG in UTC Region 3

### A. Overview of the Region

UTC Region 3 consists of Delaware, the District of Columbia, Maryland, Pennsylvania, Virginia and West Virginia, containing both coastal and inland waterways. The region contains almost

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<sup>32</sup> U.S. EIA Annual Energy Outlook 2015 ([http://www.eia.gov/forecasts/aeo/pdf/0383\(2015\).pdf](http://www.eia.gov/forecasts/aeo/pdf/0383(2015).pdf))

<sup>33</sup> FC Gas Intelligence. "LNG for Marine Transportation – The USA," <http://fc-gi.com>, Posted by Stephen Morris on Nov 24, 2014.

<sup>34</sup> Ibid.

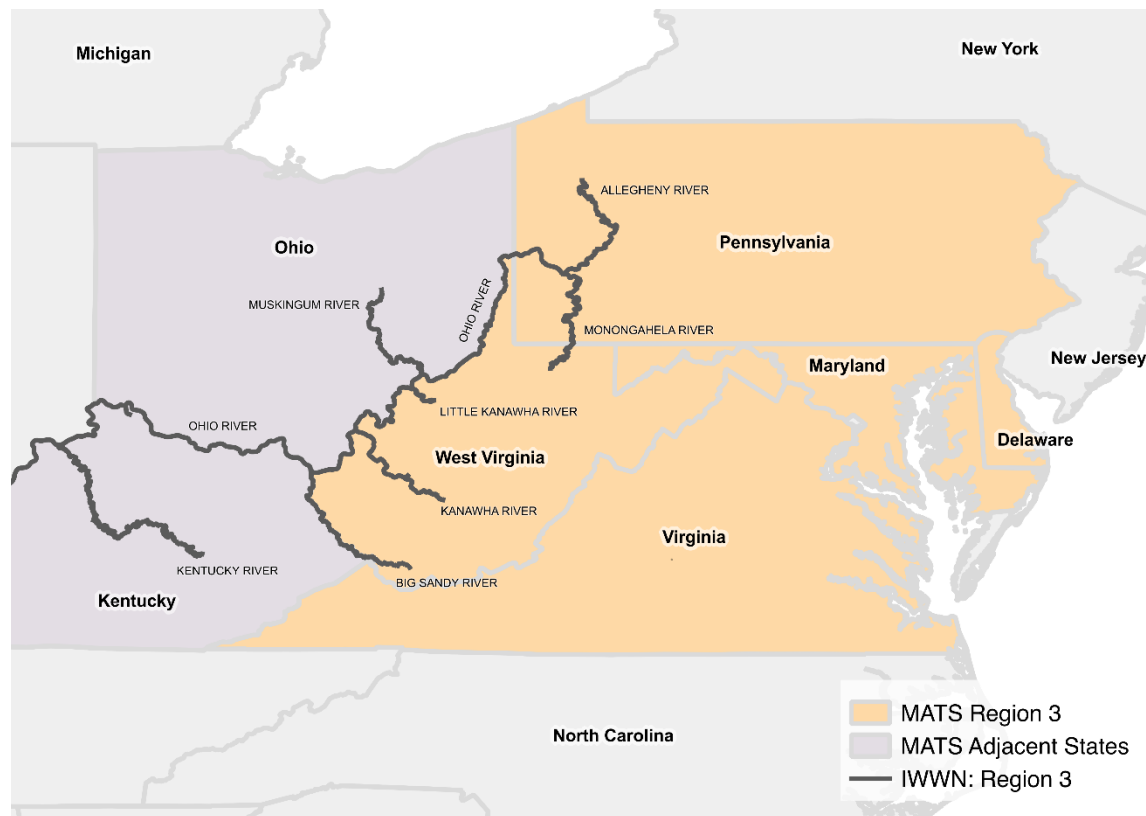
<sup>35</sup> EIA presents six primary forecast scenarios in the Annual Energy Outlook 2015: a Reference Case, a High Economic Growth Case, a Low Economic Growth Case, a High Oil Price Case, a Low Oil Price Case, and a High Oil and Gas Resource Case.

<sup>36</sup> Ibid.

## Evaluation of Inland Maritime Use of LNG in UTC Region 3

10 percent of the US population, with Pennsylvania and Virginia accounting for nearly two-thirds of the region’s population, as noted in **Table 5**. A map of Region 3 is provided in **Figure 5**.

**Figure 5: MATS UTC Region and Adjacent States**



Source: Assessment of Potential Emissions from LNG as a Marine Fuel in MATS UTC Region 3 – July 2015

**Table 5: Regional Population Estimates**

Geography	Population 2014	Percent Change Since 2010
Delaware	935,614	4.2%
District of Columbia	658,893	9.5%
Maryland	5,976,407	3.5%
Pennsylvania	12,787,209	0.7%
Virginia	8,326,289	4.1%
West Virginia	1,850,326	-0.1%
Region 3 Total	30,534,738	2.4%
United States	318,857,056	3.3%
Share of US	9.6%	

Source: US Census Bureau, Population Division

As with population, the region also constitutes about 10 percent of national wages and salaries, with utilities and transportation and warehousing comprising the largest sectors along with

## Evaluation of Inland Maritime Use of LNG in UTC Region 3

construction and retail trade. The region accounts for only 7.5 percent of national manufacturing wages and salaries. Table 6 displays the wages and salaries by industry.

**Table 6: Wages and Salaries by Industry, 2014**

Description	US	DC	DE	MD	PA	VA	WV	Region 3 Total	Region 3 Share of US	
	Millions\$	(\$1000s)								
Wages and salaries by place of work	\$7,431	\$64,076	\$23,604	\$154,460	\$295,632	\$214,388	\$30,007	\$782,168	10.5%	
Farm wages and salaries	\$28	\$ -	\$44	\$181	\$698	\$347	\$39	\$1,309	4.7%	
Nonfarm wages and salaries	\$7,403	\$64,076	\$23,560	\$154,279	\$294,935	\$214,041	\$29,968	\$780,859	10.5%	
Private nonfarm wages and salaries	\$6,200	\$40,363	\$19,972	\$117,298	\$257,622	\$165,591	\$23,578	\$624,424	10.1%	
Forestry, fishing, and related activities	\$17	\$ -	*	\$59	\$236	\$197	\$36	\$528	3.1%	
Mining	\$86	\$ -	*	\$79	\$3,010	\$521	\$2,386	\$5,996	7.0%	
Utilities	\$54	\$196	\$211	\$1,103	\$2,361	\$1,092	\$433	\$5,396	9.9%	
Construction	\$353	\$968	\$1,149	\$9,250	\$14,075	\$9,459	\$1,864	\$36,765	10.4%	
Manufacturing	\$776	\$100	\$1,521	\$7,456	\$33,099	\$13,425	\$2,622	\$58,223	7.5%	
Wholesale trade	\$420	\$595	\$1,007	\$6,569	\$17,232	\$8,384	\$1,233	\$35,020	8.3%	
Retail trade	\$457	\$725	\$1,436	\$8,736	\$16,767	\$11,740	\$2,167	\$41,571	9.1%	
Transportation and warehousing	\$240	\$348	\$611	\$3,757	\$10,237	\$5,702	\$1,050	\$21,706	9.0%	
Information	\$252	\$2,138	\$305	\$3,342	\$6,007	\$6,597	\$462	\$18,852	7.5%	

\*data not disclosed

Source: US Bureau of Economic Analysis

Industry employment within the region displays a similar pattern to wages and salaries, as noted in **Table 7**. Thus, regional employment is relatively representative of the nation, containing neither disproportionately higher nor lower wage jobs across industries.

**Table 7: Regional Employment by Industry (thousands), 2013**

Description	US	DC	DE	MD	PA	VA	WV	Region 3 Total	Region 3 Share of US
Wage and salary employment by place of work (number of jobs)	142,173	758	443	2,709	5,946	3,953	745	14,553	10.2%
Nonfarm wage and salary employment	141,383	758	441	2,704	5,923	3,941	743	14,510	10.3%
Private nonfarm wage and salary employment	117,338	507	367	2,135	5,135	3,072	585	11,802	10.1%
Forestry, fishing, and related activities	559	-	0	2	8	6	1	17	3.1%
Mining	808	-	4	1	35	8	31	80	9.8%
Utilities	549	2	2	10	22	11	5	51	9.4%
Construction	6,054	15	20	151	234	184	36	640	10.6%
Manufacturing	12,030	1	25	106	564	231	48	977	8.1%
Wholesale trade	5,779	5	12	86	227	112	23	465	8.0%
Retail trade	15,248	20	52	287	639	415	89	1,502	9.8%

### Evaluation of Inland Maritime Use of LNG in UTC Region 3

Transportation and warehousing	4,506	4	12	69	224	106	20	435	9.7%
Information	2,722	17	5	40	89	71	10	231	8.5%

Source: US Bureau of Economic Analysis

As illustrated in **Table 8**, the region accounts for 11 percent of the value of national freight flows and 10 percent of the volume, with approximately 6 percent of the nation's waterways. While transportation is an important sector in the region, and important for national freight movements, the regional transportation sector is a slightly lower user of energy compared to commercial and industrial sectors. When compared to the nation, the percentage of energy consumption accruing to transportation is slightly less within the region, about 85 percent of the national share for the sector. Both transportation energy use and emissions have decreased in the region. While energy use in the region has maintained its share relative to the nation, emissions in Region 3 have decreased proportionally more than nationally, lowering the region's relative share between 2002 and 2012.

**Table 8: Regional Transportation Statistics**

Item/State	US	DC	DE	MD	PA	VA	WV	Region 3 Total	Region 3 Share of US
Number of Major Ports									
<i>Major Airports</i>	528	-	1	3	16	9	7	36	6.8%
<i>Border Ports of Entry</i>	111	-	2	1	5	3	1	12	10.8%
Miles of Transportation Infrastructure									
<i>Public Road</i>	4,092,730	1,502	6,377	32,372	119,846	74,592	38,684	273,373	6.7%
<i>Freight Railroad</i>	138,524	20	250	758	5,151	3,215	2,226	11,620	8.4%
<i>Waterway</i>	25,000	10	100	530	260	-	680	1,580	6.3%
Freight Flow									
<i>Value (Billion USD)</i>	17,000	28	92	92	1,000	540	113	1,864	11.0%
<i>Tons (Millions)</i>	19,700	26	102	102	936	544	297	2,009	10.2%
<i>Ton-miles (Billions)</i>	6,200	5	22	22	286	163	119	617	10.0%
Energy Use by Sector (Percentage of BTUs Consumed)									
<i>Transportation</i>	28	12	24	24	26	32	25	24	83.6%
<i>Residential</i>	21	21	23	23	24	25	22	23	108.5%
<i>Commercial</i>	18	66	21	21	17	25	15	27	149.9%
<i>Industrial</i>	33	2	33	33	34	19	38	26	80.7%
Transportation Energy Use (Trillion BTUs)									
<i>2002</i>	26,844	25	69	69	1,001	689	182	2,034	7.6%
<i>2012</i>	26,700	20	64	64	940	747	179	2,014	7.5%
Transportation Energy Use per capita (Million BTU)									
<i>Petroleum</i>	82	22	69	69	70	90	78	66	80.5%
<i>All</i>	85	31	70	70	74	91	96	72	84.7%
Transportation Emissions (Million metric CO <sub>2</sub> )									
<i>2001</i>	1,852	2	5	5	70	48	12	141	7.6%
<i>2011</i>	1,855	1	4	4	61	46	11	127	6.9%

Source: US Bureau of Transportation Statistics, State Transportation by the Numbers 2014

The Ohio River system constitutes the most significant inland waterway for freight transportation within the region. More than half of the domestic shipping traffic along the internal Mississippi River system occurs in the Ohio River region, with coal and crude oil constituting the major bulk commodities shipped.<sup>37</sup> **Table 9** contains the tonnages for major commodities shipped through Region 3 in 2012.<sup>38</sup> Similar to the Ohio River System as a whole, coal products constitute the largest commodity shipped from the region by volume, as well as the largest import. Crude, petroleum products and aggregates (sand, gravel, shells, clay, salt and slag) are also significant imports to the region via inland waterway.

<sup>37</sup> Grossardt et al. (2014)

<sup>38</sup> <http://www.navigationdatacenter.us/data/datawvus.htm>

**Table 9: Regional Waterborne Commodity Shipments (Tons)**

Commodity	Exported from Region	Imported to Region
Coal, Lignite, and Coal Coke	117,993,094	38,078,525
Crude Petroleum	-	22,002,180
Petroleum Products	17,421,269	15,032,036
Chemical Fertilizers	816,760	1,080,352
Chemicals excl. Fertilizers	2,778,234	4,573,838
Lumber, Logs, Wood Chips	3,197,628	1,248,620
Sand, Gravel, Shells, Clay, Salt and Slag	4,219,097	15,529,349
Iron Ore, Iron, & Steel Scrap	1,318,090	1,754,383
Non-Ferrous Ores and Scrap	162,925	915,115
Primary Non-Metal Products	1,133,324	2,426,619
Primary Metal Products	1,478,182	4,404,383
Food and Food Products	6,137,283	8,110,265
Manufactured Goods	3,258,783	5,762,851
Unknown & Not Elsewhere Classified	11,112,292	9,023,342
Total	171,026,961	129,941,858

Source: USACE U.S. Waterway data

### B. Natural Gas Vehicles in Region 3

The U.S. market for LNG for transportation is largely confined to the State of California. In 2011, California had 40 of 54 vehicle-grade LNG dispensing sites in the U.S. and one of six production facilities for off-site use. According to the USDOE’s Alternative Fuels Data Center there is currently one LNG dispensing facility in Region 3, located in Carlisle, Pennsylvania. CNG stations are dispersed more broadly, with the Center listing 833 stations nationwide in 2015. In Region 3 there is one in Delaware, three in Maryland, 33 in Pennsylvania, five in Virginia, and three in West Virginia.<sup>39</sup>

With regards to natural gas as a transportation fuel, consumption in Region 3 is 12 percent of the nation, as noted in **Table 10**. Petroleum constitutes the largest energy source, both nationally and within the region.

<sup>39</sup> USDOE, Alternative Fuels Data Center, updated March 2015.

**Table 10: Transportation Energy Consumption by Source in Region 3, 2012 (Trillion BTU)**

Fuel	US	DE	DC	MD	PA	VA	WV	Region 3 Total	Region 3 Share of US
Natural gas	779	1.08	2.01	7.91	39.12	10.05	34.51	94.67	12%
Total petroleum	25,847	63.32	14.18	420.23	891.64	735.28	143.94	2,268.58	9%
Ethanol	1,046	3.35	0.63	19.71	32.56	32.54	6.35	95.14	9%
Electricity	25	-	1.11	1.80	2.99	0.64	0.01	6.55	26%
Net energy	26,651	64.39	17.29	429.94	933.75	745.97	178.46	2,369.80	9%
System Energy Losses	49	-	2.44	4.10	6.05	1.38	0.03	14.00	29%
Total	26,700	64.39	19.73	434.03	939.80	747.35	178.49	2,383.79	9%

SOURCE: U.S. Department of Energy, Energy Information Administration, State Energy Data System, Consumption Estimates.

With regards to alternative fuel vehicles (AFV), Region 3 contains about 9 percent of the vehicle registrations in the US, as noted in **Table 11**. AFVs comprise about 0.5 percent of vehicle registrations nationally and in the region. Among these fuels, ethanol has the greatest representation regionally constituting nearly 90 percent of all AFVs.

**Table 11: Alternative Fuel Vehicles in Use in Region 3, 2011 (Trillion BTU)**

State	US	DE	DC	MD	PA	VA	WV	Region 3 Total	Region 3 Share of US
Total Vehicle Registrations (1000s)	2,532,157	929	3,162	3,906	10,303	6,998	1,458	23,911	9.4%
Alternative Fuel Vehicles									
<i>Liquefied petroleum gases</i>	136,970	52	0	265	812	1,632	223	2,984	2.2%
<i>Natural gas</i>	121,254	21	1,531	2,046	1,598	1,695	9	6,900	5.7%
<i>Ethanol</i>	862,679	5,204	15,157	24,538	22,484	32,057	2,659	102,099	11.8%
<i>Electricity</i>	66,614	0	354	1,261	121	790	62	2,588	3.9%
<i>Hydrogen</i>	408	0	0	0	0	0	0	0	0.0%
<i>Total</i>	1,187,925	5,277	17,042	28,110	25,015	36,174	2,953	114,571	9.6%
Percentage of Total Vehicle Registrations	0.46%	0.57%	5.38%	0.72%	0.24%	0.52%	0.20%	0.48%	

See *State Transportation Statistics 2014, Table 7-5*

SOURCE: Alternative fuel vehicles: U.S. Department of Energy, Energy Information Administration, Renewable & Alternative Fuels, Alternative Vehicle Fuel Data, available at [www.eia.gov/renewable/afv](http://www.eia.gov/renewable/afv) as of May 2014. Vehicle registrations: U.S. Department of Transportation, Federal Highway Administration, Highway Statistics, VM-1, available at [www.fhwa.dot.gov/policyinformation/statistics.cfm](http://www.fhwa.dot.gov/policyinformation/statistics.cfm) as of May 2014.

As reported by the U.S. EIA data on alternative fuel vehicles, from 2004 to 2011 Region 3 saw a decrease of more than 3,000 total vehicles fueled by natural gas (please refer to **Table 11** for more information). While the number of both CNG and LNG vehicles in service may be higher today, data more recent than 2011 is not available.<sup>40</sup> All states within the region have

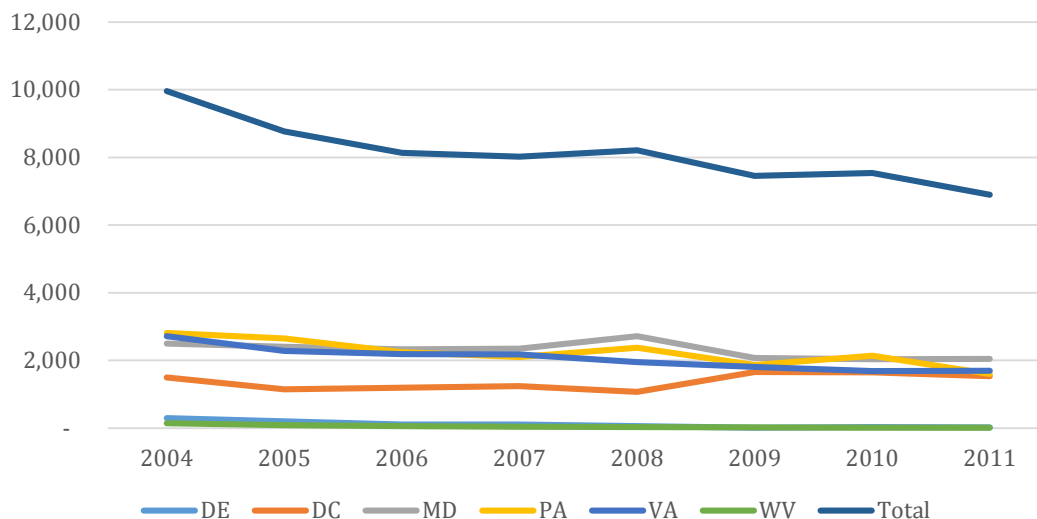
<sup>40</sup> As of May 2015 EIA had not yet released its 2012 alternative fuel vehicle data.



## Evaluation of Inland Maritime Use of LNG in UTC Region 3

experienced a similar trend with the notable exception of the District of Columbia. The District had 37 more natural gas vehicles in operation in 2011 than in 2004 after recovering from a drop in natural gas vehicle use in 2005. Please see **Figure 6** for an illustration of CNG/LNG vehicles by state.

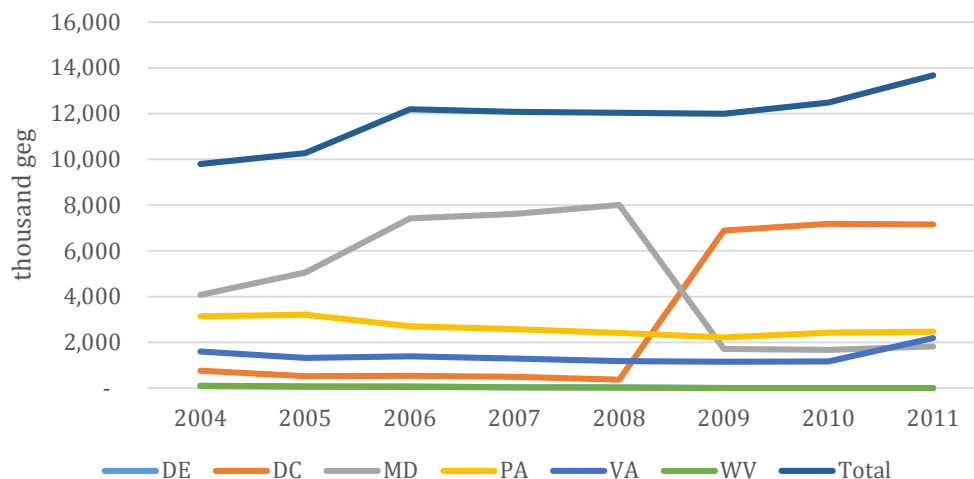
**Figure 6: Number of CNG/LNG Vehicles in Region 3, 2004 - 2011**



Source: EIA Alternative Fuel Vehicle Data, <http://www.eia.gov/renewable/afv/index.cfm>

Despite the substantial decrease in the number of natural gas vehicles in Region 3, CNG and LNG fuel consumption has increased over the same time period as presented in **Figure 7**. The region saw an increase of nearly four million gasoline equivalent gallons (geg) from 2004 to 2011.

**Figure 7: CNG/LNG Fuel Consumed in Region 3, 2004-2011**



Source: EIA Alternative Fuel Vehicle Data, <http://www.eia.gov/renewable/afv/index.cfm>

### C. Infrastructure Considerations

LNG demand in the North American transportation market is supplied by two primary types of LNG facilities: merchant LNG facilities and utility peak shaving storage facilities. Merchant LNG facilities are designed to produce LNG for commercial sale while utility peak shaving storage facilities are plants designed to provide pipeline supply of natural gas to regulated natural gas utilities during peak demand periods. Merchant plants are the dominant source of LNG for the U.S. transportation market due to the fact that peak shavers often have limited excess capacity or fall under strict state utility regulatory constraints.

There are no merchant LNG plants in the region. In Region 3 almost all production of LNG is by local gas distribution companies for the purpose of maintaining a reliable supply of gas for direct use customers during winter peak demand. Gas is stored as LNG and re-gasified as needed. In 2014, the US DOT Pipeline and Hazardous Materials Safety Administration noted the existence of one peak-shaving plant in Delaware, three in Maryland, four in Pennsylvania and three in Virginia.<sup>41</sup> There are no peak shaving LNG plants in West Virginia or the District of Columbia.<sup>42</sup> LNG will soon be produced by the Cove Point facility for export, but this facility is presently not designed to supply the domestic transportation market. The Cove Point LNG import terminal in Maryland is the only facility of its type in the study region. The facility is currently under construction to convert it to an export facility, which when complete will produce LNG from domestic natural gas received at the plant via pipeline. Cove Point was an import facility for nearly 40 years.<sup>43</sup>

The location of LNG plants is critical. As noted previously, if LNG plants are farther than 250 miles from an end user, the costs associated with transporting the LNG may be prohibitive.<sup>44</sup>

#### i. Pipelines

The natural gas infrastructure in Region 3 is extensive. Three major interstate gas pipelines - Transcontinental, Tennessee Gas, and Texas Eastern - transverse the region, in addition to multiple smaller interstate and intrastate pipelines. There is also ubiquitous gas distribution in the region's cities, which are the location of several existing, older LNG plants. The gas pipeline infrastructure in the region is still under expansion to catch up with growth in production from Marcellus Shale. All three of these above pipeline systems have announced expansions that are planned to come online by 2017 or 2018. In total, when including all the announced or proposed new and expanded regional pipeline projects that may be developed by 2018, there are 2,700 miles of new pipeline.<sup>45</sup> Siting a new LNG production plant is thus likely less a matter of finding access to natural gas, but finding the best place to build such a facility to optimize proximity to potential marine fueling facilities.

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<sup>41</sup> US DOT Pipeline and Hazardous Materials Safety Administration.

<sup>42</sup> Expansion Energy (2011). "NYS Liquefied Natural Gas (LNG) 6 NYCRR Part 570 Promulgation Support Study."

<sup>43</sup> <https://www.dom.com/covepoint>

<sup>44</sup> <http://www.gladstein.org/pdfs/GNA-LNGOpportunitiesforMarineandRail.pdf>

<sup>45</sup> USDOE, EIA, "Completed and Planned Pipeline Projects," 2015.

The price of gas is another variable that is likely to influence optimal proximity. The regional transmission system is about to undergo a major change in the nature of supply as several major pipelines, including portions of the three listed above, will or may soon reverse their primary direction of flow.<sup>46</sup> The reversal of flows from Zone 3 of the Rockies Express Pipeline is planned for August of 2015, which will allow Marcellus and Utica gas to be shipped west, and “will reconfigure continental gas flows and price relationships across multiple regions as it comes online.”<sup>47</sup> The low prices currently experienced at some Marcellus area price hubs, may not continue after this transmission capacity is made available.

### ii. Storage & Fueling

As LNG cannot be transmitted over long distances via pipeline, it must either be produced on-site or delivered by truck to a bunkering facility or by ship to the vessel. A transition to LNG fuel for inland maritime will incorporate the method of bunkering determined to be a best fit for the specific characteristics of the port(s) selected. As outlined in the study introduction, these options are Truck to Ship (TTS); Shore/Pipeline to ship (PTS); Ship-to-Ship (STS); and portable tanks. If the LNG is produced on-site a short PTS option can be used. The other options offer more flexibility on location of fueling and small-scale infrastructure that may be more appropriate for pilot or early stage LNG adoption.

To provide LNG at a marine port, suppliers could transport LNG to the port via barge or tanker truck or new production facilities could be created. While building a shore-side production facility would be the ideal course of action, there must be sufficient demand for the LNG and the location could limit the use of LNG for other purposes. Pros and cons of each supply option are discussed in the following table, as summarized by the American Clean Skies Foundation and presented here in **Table 12**.<sup>48</sup>

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<sup>46</sup> Ibid.

<sup>47</sup> RBN Energy. “Big Deal! REX to Open the Floodgates: 5.2 Bcf/d of Marcellus/Utica Natural Gas Receipt Capacity,” June 28, 2015.

<sup>48</sup> American Clean Skies Foundation, 2012.

**Table 12: Supply Options for Marine Vessels**

Option	Pros	Cons
Shore-side LNG production facility	Secure, local fuel source; scales to potential demand.	Requires economies of scale and sufficient demand. Location could limit use of LNG for other purposes.
Transport (via barge) LNG from new LNG production facility	Facility could be strategically located to serve both marine and road transport markets. Could be located near existing natural gas pipelines to reduce infrastructure needs.	Fuel not produced on site. No dedicated source of LNG.
Transport (via barge) LNG from existing LNG import terminal	Interim solution that takes advantage of existing infrastructure.	Fuel not produced on site. No dedicated source of LNG.
Transport LNG (via barge or tanker truck) from existing LNG peak storage location.	Interim solution that takes advantage of existing infrastructure.	Fuel not produced on site. No dedicated source of LNG. Opportunities may be limited passed on proximity of storage locations to ports. Volumes of LNG may be limited. Tanker truck transport is expensive due to volume of LNG required.

Source: American Clean Skies Foundation, 2012.

Overall LNG infrastructure is limited in Region 3, as shown in **Table 13**, although LNG is produced and sold in the region for transportation. There are no existing large-scale liquefaction facilities within the region that can support marine vessels transitioning to LNG but there are several intermodal hubs that have access to LNG. Peak shaving LNG plants are available in the eastern metropolitan areas of the region, and possibly in the Pittsburgh area<sup>49</sup>, and are able to supply limited amounts of LNG but may not be able to provide enough long-term supply to support marine market growth.<sup>50</sup> These plants may be able to provide LNG for a pilot project, using portable or TTS or STS bunkering, where ground transport of LNG does not exceed the recommended maximum 250 mile distance.

**Table 13: LNG Facilities in Region 3 (2014)**

State	Peak Shaving LNG Plants	LNG Tanks
Delaware	1	1
District of Columbia	0	0
Maryland	3	12
Pennsylvania	4	6
Virginia	3	3
West Virginia	0	0
Region 3 Total	11	22
Region 3 Share of US	9.4%	10.7%

Source: US DOT Pipeline and Hazardous Materials Safety Administration

<sup>49</sup> The GNA report refers to “existing LNG supplies in Memphis and Pittsburgh” but no specific plants are listed.

<sup>50</sup> GNA (2014).

Refueling infrastructure is critical to developing a market for alternative fuels. Region 3 currently contains 5.7 percent of the CNG facilities in the US and no LNG fuel stations, as noted in **Table 14**. Thus, a market for LNG vehicles would be difficult to establish in Region 3 due to the lack of complementary infrastructure.

**Table 14: Region 3 Alternative Fuel Stations by Fuel Type (2015)**

State	CNG	LNG
Delaware	1	0
District of Columbia	2	0
Maryland	9	0
Pennsylvania	40	1
Virginia	16	0
West Virginia	0	0
Region 3 Total	68	0
Region 3 Share of US	5.7%	0%

Source: U.S. Department of Energy, Alternative Fuels Data Center, updated March 2015.

iii. Truck vs. Barge

LNG trucks cost significantly more than diesel trucks and the costs vary depending on the model. The primary cost components are the engine, which can be either compression ignition (CI) or spark ignition (SI) and the natural gas onboard storage system. Cost components are broken down in **Table 15**, as reported by the American Clean Skies Foundation.<sup>51</sup>

**Table 15: Range, Fuel Economy and Cost Differentials of Trucks**

Vehicle	Range (Miles)	Fuel Economy (mpgde) <sup>52, 53</sup>	Engine Cost	Storage Cost	Incremental Manufacturer Cost	Incremental Consumer Cost
Diesel	900	5.6	\$9,000	\$1,000	\$0	\$0
LNG CI	700	5.4	\$20,000	\$35,200	\$45,200	\$67,800
LNG SI	570	4.4	\$10,000	\$35,000	\$35,500	\$38,200

Source: [http://www.cleanskies.org/wp-content/uploads/2012/04/Marine\\_Vessels\\_Final\\_forweb.pdf](http://www.cleanskies.org/wp-content/uploads/2012/04/Marine_Vessels_Final_forweb.pdf)

Barges powered by LNG require additional costs, measures and logistics compared to trucks powered by the same. These LNG-powered ships will require additional investments compared to a standard ship. This includes a new or retrofitted engine, LNG tanks, control rooms, additional piping and insulation, and additional safety measures. What the ship gains in equipment and infrastructure, it also loses in cargo space and storage. These ships will require crew training as well as higher costs to man the ship.<sup>54</sup> There are currently three natural gas engine technologies used for large marine vessels:

<sup>51</sup> [http://www.cleanskies.org/wp-content/uploads/2012/04/Marine\\_Vessels\\_Final\\_forweb.pdf](http://www.cleanskies.org/wp-content/uploads/2012/04/Marine_Vessels_Final_forweb.pdf)

<sup>52</sup> Mile per gallon diesel equivalent (mpgde).

<sup>53</sup> UC Davis Institute of Transportation Studies, “Exploring the Role of Natural Gas in U.S. Trucking”. February 18, 2015.

<sup>54</sup> Semolinos, Pablo et al.

1. spark-ignited lean-burn
2. dual-fuel diesel pilot ignition with low-pressure gas injection
3. dual-fuel diesel pilot ignition with high-pressure gas injection.

Spark-ignited engines operate exclusively on natural gas, while diesel pilot ignition engines can operate on a range of fuels, including natural gas, marine distillate, and marine residual fuels. Besides fuel flexibility there are other trade-offs between the various technologies, including NOx and GHG emissions, efficiency, and sensitivity to natural gas quality. Estimated costs to convert typical marine vessels to LNG operation are shown in **Table 16**.<sup>55</sup>

**Table 16: Costs to Convert Typical Marine Vessels to LNG Operation**

Type	Size (Tons)	Engine	Engine Cost	Fuel System Cost	Total Conversion Cost
Tug	150	2 x 1500 HP	\$1.2 million	\$6.0 million	\$7.2 million
Ferry	1000	2 x 3000 HP	\$1.8 million	\$9.0 million	\$10.8 million
Great Lakes Bulk Carrier	19000	2 x 5000 HP	\$4.0 million	\$20 million	\$24 million

Source: [http://www.cleanskies.org/wp-content/uploads/2012/04/Marine\\_Vessels\\_Final\\_forweb.pdf](http://www.cleanskies.org/wp-content/uploads/2012/04/Marine_Vessels_Final_forweb.pdf)

#### D. Supply-Side Industry Players in Region 3

The ubiquitous presence of supply-side gas industry players in Region 3 is an indicator of the potential success of developing natural gas for future transportation initiatives. Players include gas producers, mid-stream service providers, transmission firms, and gas distributors. Historically, gas distributors have been the most active in expanding CNG and LNG infrastructure in the region. Several Region 3 companies involved in production and delivery of natural gas-based transportation fuels are described in the following sections.

##### i. Gas Producers

Regional gas producers are motivated to expand demand for natural gas and in recent years have been champions of natural gas as a transportation fuel. Several regional producers have supported installation of CNG fueling stations for use in their own fleets and for the public. Some producers also use LNG in place of diesel fuel in drilling operations.

**EQT Corporation** is involved in gas production, gathering and compression, transmission, and NGL mix transportation. EQT operates a CNG fueling station in Pittsburgh, PA for retail sales and to fuel its own NGV fleet.<sup>56</sup>

**Chesapeake** and **Antero Resources** are both regional natural gas producers that have partnered with IGS Energy to supply CNG stations in Region 3. (See more on ISG Energy under “Gas Distributors.”) Antero also uses LNG at its drilling operations.

<sup>55</sup> [http://www.cleanskies.org/wp-content/uploads/2012/04/Marine\\_Vessels\\_Final\\_forweb.pdf](http://www.cleanskies.org/wp-content/uploads/2012/04/Marine_Vessels_Final_forweb.pdf)

<sup>56</sup> <https://www.eqt.com/ourbusiness/natural-gas-fueling-station.aspx>

### ii. Mid-Stream Service Providers

Mid-stream gas services providers operate gas gathering, processing, fractionation and sometimes storage facilities that allow producers to get gas and NGLs (particularly propane and ethane) to market. Mid-stream firms do business with gas producers, rather than end-use customers, which may be one reason why these firms are not in the CNG or LNG supply business. However, these entities may have synergies with CNG or LNG supply in the future due to established roles in similar markets where they link producers and wholesale consumers.

### iii. Transmission Operators

Gas transmission providers operate the gas pipelines that deliver high-volume gas to utilities and industrial consumers. These firms also operate storage facilities to help manage seasonal demand swings.

**Dominion Resources** owns natural gas transmission and delivery assets as well as electricity generation and delivery assets, including the Cove Point LNG terminal in Maryland, the only LNG import-export terminal in the region. Construction is currently underway to convert the facility from an LNG import to an LNG export facility, with operations projected to begin in late 2017. The capacity of the plant is fully subscribed with 20-year service agreements with Sumitomo Corporation, Tokyo Gas Co., Ltd., and GAIL Global (USA) LNG, an Indian gas distribution firm.<sup>57</sup>

**Columbia Gas Transmission Company** operates the Chesapeake LNG facility in Virginia. This plant is located at the end of the Columbia Gas pipeline on the south side of the Virginia Natural Gas service territory. Access to this facility provides AGL Resources subsidiary Virginia Natural Gas with a send-out capability of up to 52,090 Dth/day and a storage capacity of 778,500 Dth.<sup>58</sup>

### iv. Gas Distribution Utilities

Gas distribution utilities have a long history of investing in both CNG and LNG facilities. Many gas utilities built LNG production facilities to provide peak-shaving supplies of natural gas for their direct-use customers to ensure adequate winter supply. Due to recent expansion of natural gas transmission capacity serving the densely populated urban areas, these peak shaving plants may be faced with excess capacity and, particularly in the summer months, looking for demand.

Experience with natural gas supply and proximity to customers provides a natural link to invest in CNG stations. To date, most stations provide only CNG to retail customers.

**Philadelphia Gas Works** (PGW) is a municipal gas utility that operates a peak shaving LNG plant for direct use customers. PGW currently sells some LNG to off-site customers, but has not engaged in larger export activities. When asked about the possibility of converting a portion of

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<sup>57</sup> <https://www.dom.com/corporate/news/news-releases/136996>

<sup>58</sup> <http://www.aglresources.com/about/LNG.aspx>

the facility to function as an export terminal, a PGW spokesperson said it “may be feasible.”<sup>59</sup> PGW is considering an expansion of its liquefaction capacity to fully use its new LNG storage capacity. According to its website, the company is “taking non-binding requests to purchase LNG from potential buyers to determine potential LNG demand in the region.”<sup>60</sup>

**UGI LNG, Inc.** operates an LNG peak shaving facility in Reading, PA called Temple LNG. This plant offers 1.25 Bcf of LNG storage, associated peak shaving services, and an LNG tanker truck-loading terminal. Temple LNG has a liquefaction capacity of 60,000 gallons per day. UGI LNG is a subsidiary of the larger UGI Corporation which distributes natural gas to more than 550,000 customers through approximately 12,000 miles of gas mains.<sup>61</sup>

Other utilities, including **Baltimore Gas & Electric (BG&E)**, have also operated LNG peak-shaving plants. BG&E had at least one such plant in the 1970s that was the subject of expansion studies and impacts to the Baltimore Harbor.<sup>62</sup> Reportedly, “the smallest “commercially viable” LNG plant in the U.S. is the 20,000 GPD peak-shaving plant in Delaware.”<sup>63 64</sup>

**Virginia Natural Gas** is a Virginia Beach-based natural gas distribution company that is part of the AGL Resources Company. As of March 2014, Virginia Natural Gas operated 3 of the 4 public CNG refueling stations in Virginia.<sup>65</sup>

**Chesapeake Utilities** is a natural gas distributor serving approximately 56,000 customers in Delaware and Maryland. As of June 2014, Sharp Energy, a subsidiary of the Chesapeake Utilities Corporation, had opened one public fueling station for propane auto gas in Delaware.<sup>66</sup>

**IGS Energy** is an independent distributor of natural gas and electricity based in Dublin, Ohio. A subsidiary company is IGS CNG Services. IGS CNG is building fast-fill CNG stations open for retail sales. The company operates more than ten regional stations with three stations located along the I-79 corridor in West Virginia.<sup>67</sup> IGS has partnered with several regional groups to supply its CNG stations, including Antero Resources, Chesapeake Energy, EQT Corporation, and the West Virginia Department of Highways.<sup>68</sup>

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<sup>59</sup> [http://articles.philly.com/2013-08-24/business/41441109\\_1\\_hess-lng-pgw-spokesman-philadelphia-gas-commission](http://articles.philly.com/2013-08-24/business/41441109_1_hess-lng-pgw-spokesman-philadelphia-gas-commission)

<sup>60</sup> <http://www.pgworks.com/index.php/business/fueling-the-future/advanceLNG-project/>

<sup>61</sup> <http://www.ugilng.com/>

<sup>62</sup> National Oceanic and Atmospheric Administration (1980). Coastal Energy Impact Program, “Baltimore Harbor energy facility study.”

<sup>63</sup> [http://www.dec.ny.gov/docs/remediation\\_hudson\\_pdf/lngnyserdareport1.pdf](http://www.dec.ny.gov/docs/remediation_hudson_pdf/lngnyserdareport1.pdf)

<sup>64</sup> It is assumed that this facility is part of the former Delmarva Power & Light, now Calpine, group of plants.

<sup>65</sup> [https://www.virginianaturalgas.com/-/media/Files/VNG/10739\\_VNG\\_Handout.pdf](https://www.virginianaturalgas.com/-/media/Files/VNG/10739_VNG_Handout.pdf)

<sup>66</sup> <http://www.chpk.com/news-2014/sharp-energy-teams-with-autoport-inc-to-provide-new-castle-countys-first-24-hour-propane-autogas-fueling-station/>

<sup>67</sup> <http://www.igscngservices.com/public-stations/>

<sup>68</sup> <http://www.igscngservices.com/partners/>



### v. Retail Gasoline Stations

Retail suppliers of gasoline have also shown interest in expanding their product lines to include CNG and LNG. Several of the major brand names in fueling stations have announced plans to incorporate these fuels.

**Shell** and **TravelCenters of America (TCA)** announced in 2013 that they plan to create a nationwide network of LNG fueling stations. Plans include adding two LNG fueling lanes and storage at 100 existing TCA or Petro Stopping Centers. These additions are targeted at centers along the interstate highway system. Shell also plans to invest in LNG liquefaction technology with two plants to be built in the Gulf Coast Corridor and the Great Lakes Corridor.<sup>69</sup>

**Clean Energy Fuels** owns more than 500 fueling stations in 43 states and is largely involved in building and supplying natural gas fueling stations. The company has placed a bid to build CNG stations for Pennsylvania DOT. In addition to its owned stations, the company partners with truck stop operator **Pilot/Flying J**. Its subsidiaries include IMW and Northstar, which manufacture and construct gas fueling equipment. Clean Energy was originally Pickens Fuel Corp., and grew by buying SoCal Gas Company's 33 gas fueling stations in 1997.<sup>70</sup>

**Giant Eagle** operates CNG fueling stations at some of its grocery and fuel retail locations in Pennsylvania. The stations were made possible through a private-public partnership with Allegheny County and the Pennsylvania Department of Environmental Protection.<sup>71</sup>

### E. Case Studies

#### *Rhine-Main-Danube Europe*

The LNG Masterplan for Rhine-Main-Danube is an ongoing initiative in its early stages. The Action is coordinated by Pro Danube Management, a service company of Pro Danube International Association. Pro Danube is a non-profit organization dedicated to improved waterway infrastructure and better services on the Danube. The group unites transport users, logistics service providers, barge/terminal operators, and related industry officials. The LNG Masterplan combines the expertise of 34 EU-owned companies with relevant authorities from 12 countries. In addition to these funded companies, almost 70 other groups are involved in the LNG Masterplan as Industry Reference Group and Advisory Group members.<sup>72 73</sup>

The LNG Masterplan is structured to perform 6 primary activities: framework and market analysis, technologies and operational concepts, vessels and terminal solutions, regulatory framework and masterplan, pilot deployment, and project management. The goal of the project is to make the waterway an LNG artery for Europe that connects the Netherlands and Romania,

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<sup>69</sup> <http://www.etenv.com/wp-content/uploads/2014/03/NGV-Whitepaper-web.pdf>

<sup>70</sup> <https://www.cleanenergyfuels.com/about-us/history/>

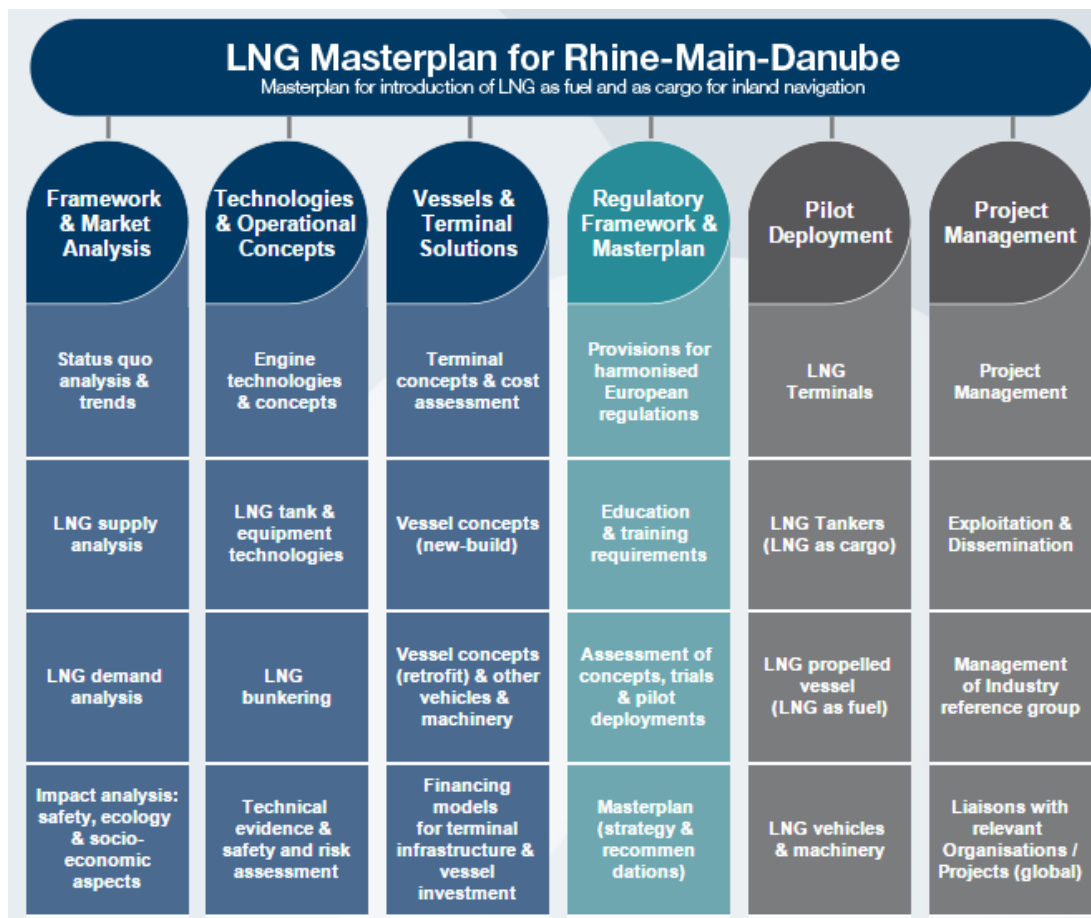
<sup>71</sup> <http://www.gianteagle.com/About/News-Releases/Giant-Eagle-Delivers-A-Cleaner-Future-with-Opening-of-First-Two-Compressed-Natural-Gas-CNG-Fueling-Stations/>

<sup>72</sup> <http://www.lngmasterplan.eu>

<sup>73</sup> Schrauer and Putz 2014.

providing LNG transport and fueling. **Figure 8** graphically illustrates the Rhine-Main-Danube LNG Masterplan.

*Figure 8: Case Study: LNG Masterplan for Rhine-Main-Danube*



Source: LNG Masterplan for Rhine-Main-Danube, <http://www.lngmasterplan.eu/masterplan/activities>

The LNG Masterplan addresses the inland transportation of LNG to expand the supply chain as well as the use of LNG as a vessel fuel. Current and upcoming activities of the Masterplan include pilot deployments that cover parts of an entire supply chain. Vessels to be included in the pilot study are LNG tankers, container vessels, LNG-propelled pushers, and LNG-propelled chemical tanker. Infrastructure upgrades as part of the pilot program will occur at the bunker station in Port of Antwerp and the LNG terminal in Bulmarket. Combined LNG/CNG fueling stations for land vehicles will be built at Bulmarket as well.<sup>74</sup>

Several barriers to LNG transport on the Danube have been identified. Schauer and Putz (2014) acknowledge the lack of regulatory framework, the lack of infrastructure, and the lack of knowledge and experience as primary barriers. Interviews were conducted to determine what awareness and education level the workforce and industry have regarding LNG. The authors

<sup>74</sup> <http://www.lngmasterplan.eu>

found that “people outside the gas industry are hardly familiar with LNG.” A particular focus was to emphasize the importance of changes at the university level to better educate the future workforces in LNG as a transport fuel.<sup>75</sup>

### *The Great Lakes – U.S.*

LNG-fueled ships in the Great Lakes is a concept with support from the U.S. and Canadian governments, port operators, and local stakeholders. Increased discussion of the feasibility of LNG-fueled vessels in the Great Lakes began when Shell released plans to build a small LNG plant in Sarnia, Ontario. The plant was set to provide LNG for waterway, truck, and train fuel.<sup>76</sup> Shell has since announced that plants for the LNG facility are put on hold.<sup>77</sup> Stakeholders, including Interlake Steamship Co., are continuing to look for ways in which LNG may fuel its fleet.

As of 2014, there are 415 registered, U.S.-flagged vessels operating on the Great Lakes. Due to the freshwater present in the Great Lakes, these vessels have a longevity of up to 100 years; this longevity provides little opportunity to build a LNG-fueled fleet with new purchases. In its analysis, America’s Natural Gas Alliance (ANGA) identified 37 U.S.-flagged lakers that would be the most likely prospects for LNG conversion: ships built since 1950 with at least 20 years of remaining use. ANGA projects 4 new builds and 10 conversion vessels by 2029 demanding 19,585,524 gallons of LNG annually.<sup>78</sup>

Several barriers to the introduction of LNG in the Great Lakes have been identified. According to Great Lakes Maritime Research, there is insufficient planned LNG bunkering to support a Great Lakes fleet. BLU LNG is one company looking to rectify this situation; two permits are under review for bunkering in Duluth and South Lake Michigan. There is still a concern over regulatory requirements for LNG transfers. Given the international aspect of the Great Lakes, local, state, and national authorities need to complete the work to identify how LNG tankers and bunkering will be handled in U.S. and U.S.-adjacent waters. Financial feasibility has not yet been determined and will depend on the availability of LNG bunkering and the price of LNG supplied to the area.<sup>79</sup>

### *Norway*

Fifty-six of the world’s 79 confirmed LNG-fueled ships operated in Norway in 2013.<sup>80</sup> This was an abrupt change from 2012, when all the world’s 29 LNG fueled ships were operating in

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<sup>75</sup> Schauer, Olivia and Lisa-Marie Putz (2014). “Educational Aspects on Promoting Liquefied Natural Gas as a Fuel and Cargo on the Danube: the European LNG Masterplan.” *Proceedings of Informing Science & IT Education Conference 2014*, pp.405-429.

<sup>76</sup> VanderKlippe, Nathan (March 2013). “Shell aims to fuel Great Lakes freighters with liquefied natural gas.”

<sup>77</sup> <http://gcaptain.com/will-great-lakes-lng-bunkering/>

<sup>78</sup> ANGA (October 2014). “LNG Opportunities for Marine and Rail.”

<sup>79</sup> Holden, Danielle, Aaron Brown, and Cheryl Stahl (January 2015). “When Will the Great Lakes Have LNG Bunkering?”

<sup>80</sup> Einang, Per Magne (November 2013). “Gas fuelled ships: Norwegian experience.”

Norway.<sup>81</sup> Considerations for LNG-fueled vessels in Norway includes small-scale sourcing, distribution, and terminals along the coast. LNG production of 10,000 to 300,000 tons per year; distribution by coastal tankers, road trailers, and local pipeline; and around 40 receiving terminals are included.

The Environmental NOx Agreement 2008-2017 by the Norwegian NOx Fund is an initiative between 15 Norwegian businesses and the Ministry of the Environment. There are 725 affiliated groups who receive a tax exemption and lower shipping rates for their participation. The Fund has approximately 600 million NOK available for the NOx-reducing activities annually of which 30% is tagged for LNG support. This support is to cover up to 80% of the additional costs incurred in purchasing and/or converting vessels to be fueled by LNG and provide a discount per kilo NOx reduced.<sup>82</sup>

### *Applicability to Region 3*

Of the case studies examined here, the Rhine-Main-Danube River area has the most similarity to the Ohio River Basin area as those rivers are also inland water bodies with traversing vessels that have historically not used LNG. The Ohio River area also lacks experience in the LNG industry. However, a major incentive for development of the EU LNG Masterplan is to support the EU's transport, energy, and environmental policy goals and actions. Such a framework does not exist for application to inland navigation in the U.S. The structural organization of the initiative could prove useful for a future endeavor should the region decide to pursue inland maritime use of LNG.

Due to proximity, the Great Lakes initiative is also worth tracking. Some of the businesses involved, e.g. Shell, also have investments in the Ohio Valley area. However, the geography and depth of the Great Lakes are substantively different than the Ohio River, as are the type of vessels using those water bodies.

The Norwegian example is less of a model for the Ohio River as the target vessels are largely oceangoing freighters. However, the tax incentives offered by the Norwegian government for NOx reductions may be worthy of further study.

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<sup>81</sup> [http://www.norway.cn/News\\_and\\_events/Business/Oil-and-gas](http://www.norway.cn/News_and_events/Business/Oil-and-gas) - "Norway's Experience with LNG as Shipping Fuel"

<sup>82</sup> Einang, Per Magne (November 2013). "Gas fuelled ships: Norwegian experience."

### Conclusions

This evaluation of use of alternative fuels in the Region 3 inland marine industry has focused on LNG rather than CNG as that fuel is perceived to be a better fit for engines and vessels used by the industry. In spite of its extensive gas reserves the region has yet to develop a significant market for on-road CNG or LNG, but particularly for LNG, with only 45 CNG stations and one LNG station available as of 2015.

Region 3 has very well-developed natural gas infrastructure, particularly the inland portion of the region. Both West Virginia and Pennsylvania are net producers of gas and are the location of several major interstate and intrastate gas pipeline systems. These two states are also the location of substantial underground gas storage capacity that link transmission networks with additional sources of supply.

Inland maritime use of LNG in Region 3 is regarded as a beneficial transportation fuel choice due both to environmental factors and cost factors. LNG is a very clean burning fuel and the price of the natural gas has become very competitive due to greatly increased supply from the Marcellus Shale. However unlike CNG, which can be relatively cheaply produced on-pipeline, LNG production facilities require a much larger capital investment.

If LNG is to be developed as a marine transportation fuel in the region, decisions must be made regarding sourcing the fuel from existing LNG supplies that were not originally designed for the transportation industry and transporting the fuel to end-users or constructing entirely new capacity. The refueling infrastructure that must be developed to support widespread use of LNG will take time to put in place. Well-established incumbent technologies and fuels are a barrier to such a transition.

Existing LNG supplies in Region 3 may not be enough to support long-term growth of an inland marine demand for the fuel, but may be of a sufficient capacity to enable near-term pilot projects for demonstration. LNG production capacity is largely on the eastern side of region. With the exception of the new LNG export terminal at Cove Point, which is fully subscribed, the existing capacity is older and perhaps inefficient, although some of these plants already supply LNG for transportation usage and some, e.g. Philadelphia Gas Works, are interested in expanding their off-system sales. A pilot project where LNG produced off-site is delivered and dispensed to vessels is very flexible and would allow the marine transportation industry to test fuel and engine performance. The fueling station could be located anywhere under this model. This would be a regional supply and demand scenario similar to the single existing LNG fueling station in the region, and the model of conventional gasoline and diesel supply, where trucks deliver refined products from petroleum refineries to regional fueling stations.

The nature of refueling on the Ohio and other inland rivers does not lend itself naturally to central bunkering. Refueling in the region largely takes place via barge as opposed to specific ports or other typical bunkering locations. In addition, different pushboat companies also have their own specific fueling approaches and preferred barge-fueled locations. It is thus likely that a transition to LNG would involve use of portable fueling equipment to distribute the fuel to vessels.

The Port of Pittsburgh has been identified as a prime inland location for a pilot project to take advantage of existing LNG capacity, as well as an eventual location for a LNG plant. An LNG corridor is in the planning stages, organized by Pittsburgh Clean Cities. At least one firm is already in the planning stages to build an LNG production plant in the Pittsburgh area near the Ohio River. The location has yet to be

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disclosed, but the plant would produce 600,000 gallons of LNG per day, which would be transported via barges on the Ohio, Allegheny and Monongahela Rivers.<sup>83</sup>

In the absence of supply of LNG in the Pittsburgh area, one of the potentially more feasible relationships may be transport of LNG produced from existing peak shaving capacity in Baltimore, Philadelphia or Reading to Pittsburgh. At a distance of approximately 250 miles, Baltimore may be the closest LNG plant to Pittsburgh. Any other two points in the region, from a peak shaving LNG plant to an inland river port, would be a greater distance.

The other primary inland port is the Port of Huntington. Both Huntington and Pittsburgh have access to high-volume gas pipelines, and both may eventually be a good sites for LNG production. On-pipeline production of LNG would take advantage of proximity to the Marcellus resource, and avoid the need to transport the LNG from the production facility to the customer. The eventual model could be an on-pipeline LNG production facility that served a fleet of vessels at that location.

It has also been stated that “technically viable, “small-scale” LNG production systems (capacity of 5,000 to 20,000 GPD), which have not yet been commercialized, are essential to the growth of LNG facilities based on local demand for LNG (or interstate LNG station “corridors”).<sup>84</sup> Although the market may have to start with regional demand served by the existing, centralized LNG production plants, smaller locally produced fuel may be a more feasible approach than building a large-scale plant.

In Region 3, due to location of LNG capacity, LNG use in Mid-Atlantic ports may be a more logical next step toward development of LNG for transportation. Vessel types may also be more similar to other areas that have adopted marine LNG, e.g. Norway, Antwerp, and others considering adoption, e.g. Great Lakes.

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<sup>83</sup> <http://shalegasreporter.com/news/lng-production-plant-planned-near-ohio-pa-river/47252.html>

<sup>84</sup> Expansion Energy (2011).

## References

- Agility Fuel Systems. "Natural Gas Fuels: CNG & LNG." <http://www.agilityfuelsystems.com/lng-vs-cng.html> (accessed April 2015).
- AGL Resources. "LNG and Propane," <http://www.aglresources.com/about/LNG.aspx> (accessed June 2015)
- Alkemade, F., Frenken, K., Hekkert, M. and M. Schwoon. (2009). "A complex systems methodology to transition management." *Journal of Evolutionary Economics*. 19: 527-543.
- Chesapeake Utilities, Corp. "Sharp Energy Teams with Autoport, Inc. to Provide New Castle County's First 24-Hour Propane Autogas Fueling Station." Chesapeake Utilities, June 26, 2014.
- Clean Energy Fuels. "Our Story." <https://www.cleanenergyfuels.com/about-us/history/> (accessed April 2015)
- Cornot-Gandolphe, Sylvie. et al. "The Challenges of Further Cost Reductions for New Supply Options (Pipeline, LNG, GTL)." 22nd World Gas Conference, 2003.
- DNV GL. "Liquefied Natural Gas (LNG) Bunkering Study". Report No. PP087423-4, Rev. 3. Prepared by DNV GL for the Maritime Administration. September 2014.
- Dominion Energy. "Dominion Cove Point." <https://www.dom.com/covepoint> (accessed May 2015)
- Dominion Energy. "Dominion, Business Partners Celebrate Construction of Cove Point Liquefaction Project." Dominion Energy, [March 25, 2015](#).
- Einang, Per Magne (November 2013). "Gas fueled ships: Norwegian experience."
- EQT. "EQT CNG Fueling Station." <https://www.eqt.com/ourbusiness/natural-gas-fueling-station.aspx> (accessed May 2015)
- Expansion Energy. "NYS Liquefied Natural Gas (LNG) 6 NYCRR Part 570 Promulgation Support Study." New York State Energy Research and Development Authority, 2011.
- FC Gas Intelligence. "Where will LNG grow?" FC Gas Intelligence, December 12, 2013.
- FC Gas Intelligence. "Natural Gas Vehicle Market Whitepaper USA 2013-2014." FC Gas Intelligence, n.d.
- Giant Eagle. "Giant Eagle Delivers A Cleaner Future with Opening of First Two Compressed Natural Gas (CNG) Fueling Stations." Giant Eagle, July 14, 2011.
- Gladstein, Neandross & Associates. "LNG Opportunities for Marine and Rail in the Great Lakes, Gulf of Mexico and Inland Waterways." America's Natural Gas Alliance, October 2014.
- Holden, Danielle, Aaron Brown, and Cheryl Stahl. "When Will the Great Lakes Have LNG Bunkering?" gCaptain, January 7, 2015.
- IGS CNG Services. "Public Stations." <http://www.igscngservices.com/public-stations/> (accessed April 2015)
- IGS CNG Services. "Our Partners." <http://www.igscngservices.com/partners/> (accessed April 2015)

## Evaluation of Inland Maritime Use of LNG in UTC Region 3

Johnson, C and D. Hettinger. (2014). "Geography of Existing and Potential Alternative Fuel Markets in the United States." National Renewable Energy Laboratory Technical Report NREL/TP-54000-60891.

KBR. "LNG Liquefaction: Not All Plants Are Created Equal," Paper PS4-1. KBR, 2007.

Knittel, C. (2012). "Leveling the Playing Field for Natural Gas in Transportation." The Hamilton Project. Discussion Paper 2012-03.

LNG Masterplan for Rhine-Main-Danube. <http://www.lngmasterplan.eu> (accessed May 2015)

Maykuth, Andrew. "Questions on potential of PGW plant to export gas." *Philadelphia Inquirer*, August 24, 2013.

Melaina, M. and J. Bremson. (2008). "Refueling Availability for Alternative Fuel Vehicle Markets: Sufficient Urban Station Coverage." *Energy Policy*, 36. Pp. 3223-3231.

Meyer, P., and J. Winebrake. (2008). "Modeling Technology Diffusion of complementary goods: The case of hydrogen vehicles and refueling infrastructure." *Technovation*.

M.J. Bradley & Associates, LLC. "Natural Gas for Marine Vessels: U.S. Market Opportunities." American Clean Skies Foundation, April 2012.

National Oceanic and Atmospheric Administration. Coastal Energy Impact Program, "Baltimore Harbor Energy Facility Study." National Oceanic and Atmospheric Administration, 1980.

Oak Ridge National Laboratory. *Transportation Energy Data Book*, Edition 33. U.S. Department of Energy, 2014.

Philadelphia Gas Works. AdvanceLNG Project. <http://www.pgworks.com/index.php/business/fueling-the-future/advancelng-project/> (accessed April 2015)

Royal Norwegian Embassy. "Norway's Experience with LNG as Shipping Fuel" [http://www.norway.cn/News\\_and\\_events/Business/Oil-and-gas/Norways-Experience-with-LNG-as-Shipping-Fuel/#.VYHgPU05AuU](http://www.norway.cn/News_and_events/Business/Oil-and-gas/Norways-Experience-with-LNG-as-Shipping-Fuel/#.VYHgPU05AuU) (accessed May 2015)

Schauer, Olivia and Lisa-Marie Putz (2014). "Educational Aspects on Promoting Liquefied Natural Gas as a Fuel and Cargo on the Danube: the European LNG Masterplan." *Proceedings of Informing Science & IT Education Conference 2014*, pp.405-429.

Semolinos, Pablo et al. "LNG as Marine Fuel: Challenges to be Overcome." *TOTAL Gas & Power*, 2013.

Texas Transportation Institute Center for Ports and Waterways. "America's Locks & Dams: A Ticking Time Bomb for Agriculture?" December 2011.

The Pennsylvania State University. Marcellus Center for Outreach & Research. <http://www.marcellus.psu.edu/resources/maps.php> (accessed April 2015).

UGI LNG. "Serving the High-Growth Mid-Atlantic Demand Market." <http://www.ugilng.com/> (accessed April 2015)

U.S. Army Corps of Engineers. "Inland Waterway Navigation: Value to the Nation." U.S. Army Corps of Engineers, n.d.



## Evaluation of Inland Maritime Use of LNG in UTC Region 3

U.S. Department of Energy. Alternative Fuels Data Center. "Natural Gas Fueling Infrastructure Development." [http://www.afdc.energy.gov/fuels/natural\\_gas\\_infrastructure.html](http://www.afdc.energy.gov/fuels/natural_gas_infrastructure.html) (accessed May 2015)

U.S. Department of Energy. Alternative Fuels Data Center. "Natural Gas Fueling Station Locations." [http://www.afdc.energy.gov/fuels/natural\\_gas\\_locations.html](http://www.afdc.energy.gov/fuels/natural_gas_locations.html) (accessed May 2015)

U.S. Department of Energy (2014). "Costs Associated With Compressed Natural Gas Vehicle Fueling Infrastructure."

U.S. Energy Information Administration. *Annual Energy Outlook 2015*. U.S. Department of Energy, 2015.

U.S. Energy Information Administration. *Drilling Productivity Report*. U.S. Department of Energy, May 2015.

U.S. Energy Information Administration. *Today in Energy*, "Marcellus Region production continues growth." U.S. Department of Energy, August 5, 2014.

U.S. Energy Information Administration. *Natural Gas Consumption by End Use*. U.S. Department of Energy, 2015.

van der Vooren, A., Alkemade, F. and M. Hekkert. (2012). "Effective Public Resource Allocation to Escape Lock-In: The case of infrastructure-dependent vehicle technologies." *Environmental Innovation and Societal Transitions*. (2). PP. 98-117.

VanderKlippe, Nathan. "Shell aims to fuel Great Lakes freighters with liquefied natural gas." *The Globe and Mail*, March 5, 2013

Verbeek, R., Kadicjk, G., van Mensch, P., Wulfers, C., van den Beemt, B., and F. Fraga. (2011). "Environmental and Economic Aspects of Using LNG as a Fuel for Shipping in The Netherlands." TN Report 2011-00166.

Virginia Natural Gas. "Natural Gas Vehicles (NGVs)." [https://www.virginianaturalgas.com/-/media/Files/VNG/10739\\_VNG\\_Handout.pdf](https://www.virginianaturalgas.com/-/media/Files/VNG/10739_VNG_Handout.pdf) (accessed April 2015)

Werpy, M., Santini, D., Burnham, A. and M. Mintz. (2010). "Natural Gas Vehicles: Status, Barriers, and Opportunities." Center for Transportation Research, Energy Systems Division, Argonne National Laboratory.

Yeh, Sonia (2007). "An empirical analysis on the adoption of alternative fuel vehicles: the case of natural gas." *Energy Policy*. 35. Pp. 5865-5875.



## Region 3



## FINAL REPORT

# Assessment of Potential Emissions from LNG as a Marine Fuel in MATS UTC Region 3

Date: July 2015

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<b>16. Abstract</b> This work investigates end use and life-cycle contexts for the introduction of alternative fuels in an inland maritime commercial navigation fleet. This paper characterizes fleet technology and informs longer term technology-policy decisions regarding regional transportation innovation. We focus on the Mid-Atlantic Transportation Sustainability University Transportation Center (MATS UTC) Region 3, but include adjacent waterborne freight corridors that connect with other regions. We investigate domestic fuel infrastructure and shallow water navigation technologies in the region and assess the emissions reductions associated with a transition to natural gas propulsion for the inland river fleet. The study focus mainly addresses natural gas in liquefied (LNG) contexts, but the infrastructure and vessel activity analysis can be applied to compressed natural gas (CNG) by the region's vessels. Discussion of a fleet switch over to natural gas products is currently focused on LNG and motivated by the high volume of natural gas being produced from Marcellus Shale deposits within UTC region 3. This study characterizes the inland river fleet in UTC region 3 (henceforth referred to as Region 3), primarily on the Ohio, Allegheny, Monongahela, Kanawha, and Big Sandy Rivers. Based on the existing fleet composition, we consider technology performance comparisons for vessels to switch from traditional marine bunker fuels (marine gas oil/MGO) to natural gas fuels (LNG).			
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## Introduction

### Scope and Purpose

This work investigates end use and life-cycle contexts for the introduction of alternative fuels in an inland maritime commercial navigation fleet. This paper characterizes fleet technology and informs longer term technology-policy decisions regarding regional transportation innovation. We focus on the Mid-Atlantic Transportation Sustainability University Transportation Center (MATS UTC) Region 3, but include adjacent waterborne freight corridors that connect with other regions.

UTC Region 3 covers a domain that includes domestic inland river shipping in West Virginia, Pennsylvania, Virginia, Maryland, and Delaware. We investigate domestic fuel infrastructure and shallow water navigation technologies in the region and assess the emissions reductions associated with a transition to natural gas propulsion for the inland river fleet.

The study focus mainly addresses natural gas in liquefied (LNG) contexts, but the infrastructure and vessel activity analysis can be applied to compressed natural gas (CNG) by the region's vessels. Discussion of a fleet switch over to natural gas products is currently focused on LNG and motivated by the high volume of natural gas being produced from Marcellus Shale deposits within UTC region 3.

This study characterizes the inland river fleet in UTC region 3 (henceforth referred to as Region 3), primarily on the Ohio, Allegheny, Monongahela, Kanawha, and Big Sandy Rivers. Based on the existing fleet composition, we consider technology performance comparisons for vessels to switch from traditional marine bunker fuels (marine gas oil/MGO) to natural gas fuels (LNG).

### Background and Literature

This analysis focuses on vessel activity on the Region 3 rivers shown in Figure 1 (DOT, 2014; MATS, 2015). We include Ohio and Kentucky, as these states share borders with important rivers, such as the Ohio and Big Sandy Rivers, and thus we can observe vessel traffic that crosses from Region 3 into these states. We use AIS data from the USCG Zone 17, which provides coverage for all river segments east of the Ohio/Indiana state border (NOAA, 2015).

### MATS UTC Region 3 Overview

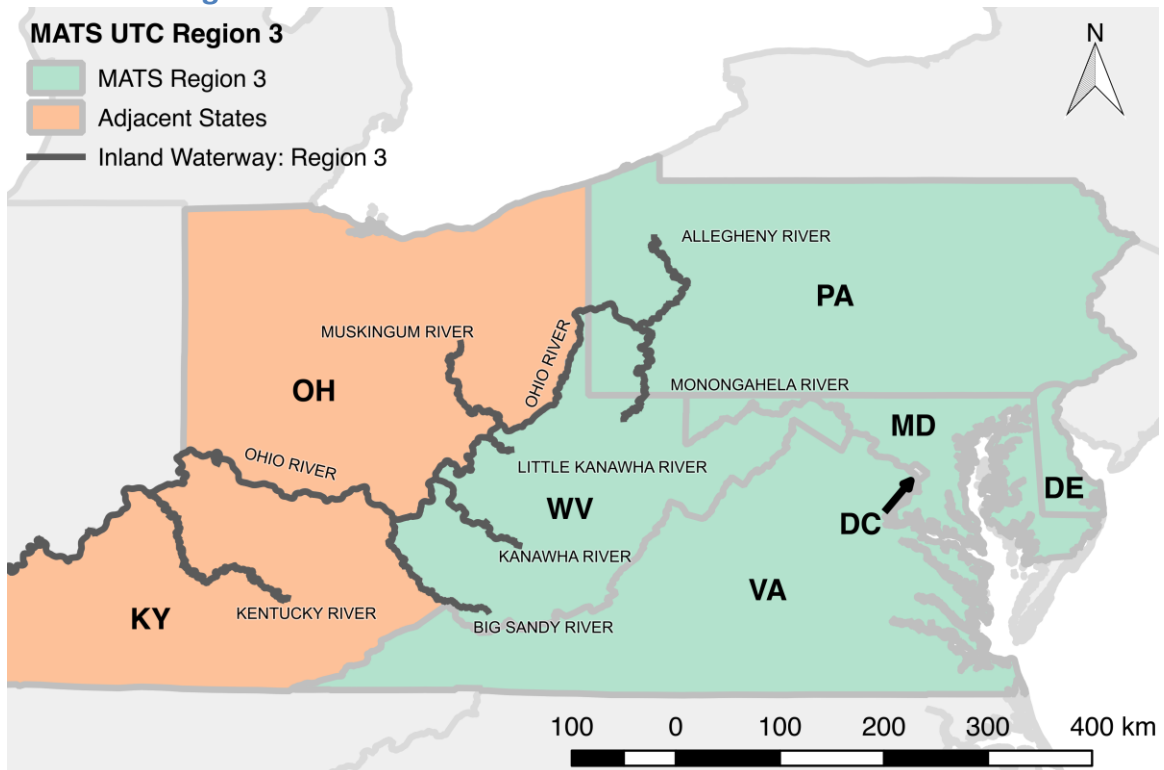


Figure 1: Overview of MATS UTC Region 3 rivers and adjacent states included in the analysis

The recent boom in natural gas extraction in the Marcellus Shale region, located primarily in West Virginia and Pennsylvania, has led to an abundance of natural gas. Production continues to grow, reaching 15 billion cubic feet per day through July 2015 and accounting for almost 40% of US shale gas production (EIA, 2015d). As production has increased, prices in the northeast region have fallen relative to the Henry Hub price. This source of relatively inexpensive fuel, coupled with tighter controls on vessel emissions has led the industry to investigate the use of natural gas products, such as liquefied natural gas (LNG) as marine fuels (Banawan, El Gohary, & Sadek, 2010; Pospiech, 2013; Wang & Notteboom, 2014).

LNG is a cryogenic liquid, formed by cooling natural gas (methane, CH<sub>4</sub>) down to -162°C at atmospheric pressure (Balon, Lowell, & Curry, 2012). Consequently, LNG can be distributed, stored, and dispensed like other liquid fuels, provided the temperature of the liquid remains below -162°C. If LNG rises above this temperature, a fraction of the liquid will be lost due to “boil-off”, i.e. change from the liquid phase to the gas phase. This boil-off is one potential source of greenhouse gases (GHGs), as methane has a warming potential 30 times greater than that of CO<sub>2</sub> (Myhre et al., 2013).

LNG fuels emit lower levels of criteria pollutants such as nitrogen oxides (NO<sub>x</sub>), sulphur oxides (SO<sub>x</sub>), and particulate matter (PM<sub>10</sub> and PM<sub>2.5</sub>) (Afon & Ervin, 2008; Bengtsson, Andersson, & Fridell, 2011; Corbett, Thomson, & Winebrake, 2014). LNG is not without its challenges as a fuel, however. Land-based studies of electricity



generation estimate that leakage during the upstream, liquefaction, and shipping stages of exported LNG are up to 37gCO<sub>2</sub>eq/MJ (Abrahams, Samaras, Griffin, & Matthews, 2015). The biggest technological challenge facing the adoption of LNG as a marine fuel is the requirement for larger fuel tanks and fuel systems, resulting in the entire system taking up three to four times as much space as conventional HFO/MGO engines and thus reducing available cargo space (Wang & Notteboom, 2014).

International Maritime Organisation (IMO) regulations state that vessels operating within the US exclusive economic zone (EEZ) must reduce the sulphur content of marine bunker fuels such that they do not exceed 0.1% sulphur as of January 1, 2015 (IMO, 2014). Prior to these rules going in to effect vessels were burning either heavy fuel oil (HFO) or marine gas oil (MGO), which have sulphur contents of 3.5% and 0.1% respectively. In response to these emission controls vessel operators are looking for avenues of compliance, with LNG fuel switching a potential alternative to exhaust gas scrubbers (Wang & Notteboom, 2014). Inland vessels in the US are within this sulphur control zone, but are unaffected by recent rule changes as inland vessels are already required to use low sulphur fuels (EPA, 2015b).

For the most part, LNG vessel interest has focused on oceangoing and coastal fleets. To date there are over 100 non-LNG carrier vessels operating on LNG fuels, operating primarily in Norwegian coastal waters (DNV GL, 2014). Estimates of LNG vessel build costs and retrofits are scarce due to the emerging nature of the technology and the relative paucity of LNG vessels in operation. Balon et al. (2012) provide a rough estimate of vessel conversion costs at \$7.2 million, with the fuel system accounting for \$6.0 million. Balon et al. (2012) further estimate that over a ten-year period a typical tug could save almost \$7 million in fuel costs after converting to LNG from HFO or MGO.

Modernization and infrastructure development may be needed on inland rivers in the United States. The Inland Waterway Network (IWWN) is aging. The average age of lock and dam infrastructure on the waterways is 61 years according to USACE statistics (USACE, 2014a) and the average age of towboats is 40.1 years (USACE, 2014b). The IWWN (Figure 1) is a network of rivers providing a water arterial for the movement of freight including coal and farm goods around the American mid-west and ultimately internationally via the Mississippi River.

While compressed natural gas may be a ready source of alternative marine fuel, better fuel storage densities favor liquefaction, and motivate study of the potential use of LNG as a marine fuel in inland waterway transport. Also motivating the study are local-scale studies conducted in Pittsburgh (Port of Pittsburgh Commission, 2015), the shifting marine fuels industry, and the abundance of relatively inexpensive LNG fuel. Coupled with a need for infrastructure upgrades on the IWWN and stricter marine emission regulations changing conditions on the IWWN present an opportunity for research into the modernization of the aging Region 3 fleet.

We identify and describe the fleet of tug and towboats operating on the IWWN in Region 3 using US Army Corps of Engineers (USACE) data and analyse Automatic Identification System (AIS) data provided by the US Coast Guard (USCG) to describe vessel activity. Based on AIS activity from 2013 we estimate total emissions of greenhouse gases (GHGs) and criteria pollutants (NO<sub>x</sub>, SO<sub>x</sub>, PM<sub>10</sub>, CO) in the region. Using the same vessel activity from 2013, we employ an LNG retrofit scenario whereby we assume that all vessels are retrofitted to run on LNG and natural gas liquefaction facilities are available. GHGs and criteria pollutants are estimated for an LNG fleet as well as estimates of fuel consumption for current and LNG technologies. We then briefly investigate the opportunity for LNG infrastructure development and capital costs.

## Methods and data

First, we characterize vessels operating in Region 3 based on operational characteristics such as age, vessel type, and installed horsepower. Second, we analyse vessel activity, including speed, number of voyages/trips, estimated emissions, and estimated fuel consumption.

### Vessel technology evaluation

We use data from the United States Army Corps of Engineers to describe the fleet characteristics, and AIS data from the National Oceanic and Atmospheric Administration (NOAA) and the United States Coast Guard (USCG) to characterize vessel activity in Region 3.

### Summary of age characterization

The USACE lists a total of 2,332 towboats as registered in the inland waterway network. Of these, 797 are registered to cities within states in, or directly adjacent to (Ohio and Kentucky), UTC Region 3.

### *Towboats*

The mean age of towboats in Region 3 and adjacent states of the inland river system is 40.1 years<sup>1</sup>, including retrofitted vessels (Figure 2). Vessels aged 40 and above comprise 48.9% of all towboats. As shown in Figure 2, the majority of vessels in Region 3 are more than 30 years old (80%), with 110 vessels (13.8%) less than 20 years old.

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<sup>1</sup> File "towb13.txt" available at <http://www.navigationdatacenter.us/db/wtlus/data/>, accessed April, 2015.

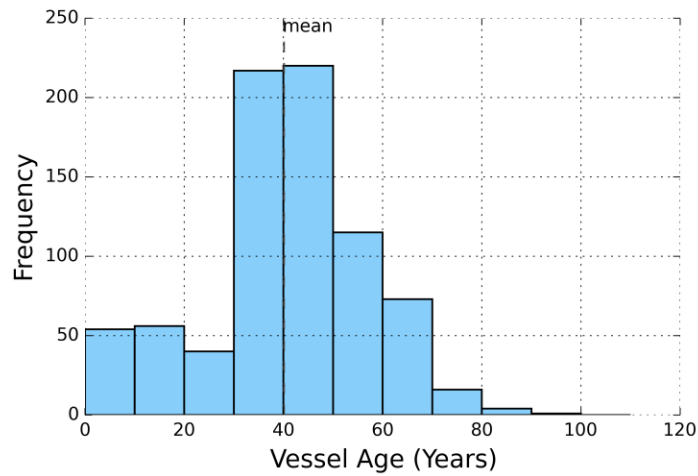


Figure 2: Age distribution of Inland Waterway towboats (Region 3) (2013)

### Horsepower

The distribution of vessel horsepower for towboats on the inland rivers is positively skewed, with 68.6% of all towboats registering horsepower below the mean value of 1,982 horsepower (hp<sup>2</sup>) (Figure 3). In general, Region 3 towboats are low powered and ageing. We geocoded the “Base1” variable in the USACE “towb13.txt” file, which describes the operation headquarters for each vessel in the USACE registry, in order to obtain the geospatial location for each tow boat. We then estimated the average horsepower by river segment based on vessels registered within that river segment. The mean horsepower of all Region 3 towboats was applied in cases where no towboats were registered in a river segment.

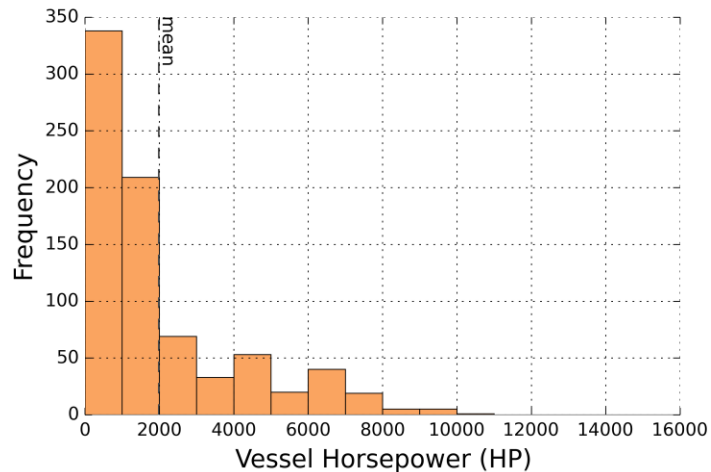


Figure 3: Horsepower distribution for towboats on the inland river system

### Self-Propelled Vessels

The USACE also maintains a database of self-propelled vessels operating on the inland rivers and associated coastwise shipping. The horsepower of self-propelled

<sup>2</sup> 1 hp = 746 watts (W) (EIA, 2015b)

vessels operating coastwise in Region 3 follows a similar distribution to the horsepower of inland vessels, as shown in Figure 4. The mean horsepower of coastal vessels is 12,795 hp compared to 669 hp for inland vessels. Of the self-propelled vessel operating in Region 3, 176 out of 203 (87%) operate in the coastal environment, with remaining vessel operating on the inland river system. Although both distributions are skewed heavily to the left, the maximum observed horsepower for a coastal vessel was 77,800 hp, compared with a maximum of only 3000 hp on the inland rivers.

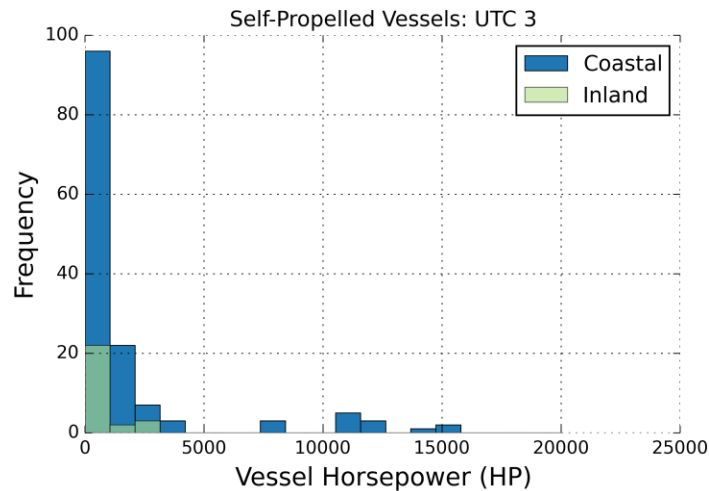


Figure 4: Installed horsepower for self propelled vessels operating coastwise and on the inland rivers in Region 3

### Analysis of Vessel Activity

We use AIS data provided by the United States Coast Guard (USCG)<sup>3</sup> to analyze vessel activity on the inland rivers in Region 3. AIS data are continuously collected and provide vessel information such as unique vessel identifier, location, ship type, speed, length, and course. Vessel identifiers are encrypted in the data provided by USCG and so it is not possible to directly link the USCG AIS data to the USACE list of registered vessels described in the previous section.

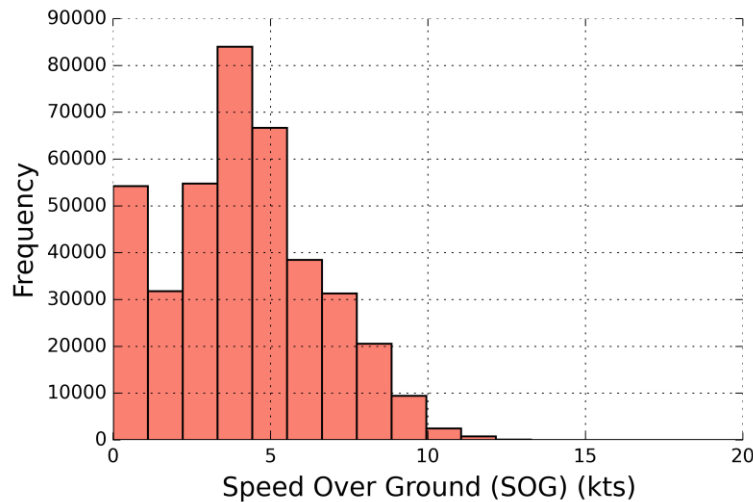
USCG AIS data are provided in ESRI file geodatabase point format, which provides geospatial information for each vessel observation point. We clipped the geodatabase to only include inland river data points, leaving 14.5 million AIS data points describing all of UTM Zone 17 for the year 2013. From these data we were then able to estimate vessel operation on the inland rivers in Region 3.

AIS data can be used in a number of ways to explain vessel movements in a given region. It is possible, yet computationally intensive, to link each data point in a vessel track using a common “VoyageID” identifier. In order to reduce computational overhead, we apply a modified technique, whereby we aggregate AIS data such as speed and number of voyages by river segment, thus providing mean transit statistics for each river segment in 2013.

<sup>3</sup> <http://marinecadastre.gov/ais/>, accessed May 2015

## Speed

Vessel speed is encoded in the AIS files as Speed Over Ground (SOG), given in knots (kt). We removed all SOG values below 0.2kts from the dataset, under the assumption that speeds from 0 - 0.2kts correspond with berthed/anchored vessels and observed fluctuations in the data for some vessels while at berth, but still includes most maneuvering vessels. The overall distribution of SOG values in Zone 17 is shown in Figure 5. The mean SOG was then calculated for each river segment in the USACE inland waterway network.



**Figure 5: Speed over ground (SOG) distribution for UTM Zone 17 in 2013. Note that SOG < 0.2kts were removed from the dataset to account for berthed and stopped vessels**

## Voyages

The USCG AIS data set links individual vessel observation points with specified voyages. Each point corresponding with a given vessel on a given voyage has a unique “VoyageID” identifier from which we estimated the number of vessels transiting a given river segment. For each unique “VoyageID” observed in a given river segment, it was assumed that the vessel transited the entirety of the river segment. A total of 1,813 voyages were observed in Region 3 rivers in 2013. Voyage counts per river segment are shown in (Figure 13).

## Vessels

Although identifying information is scrubbed from the AIS dataset, a unique, encrypted, Maritime Mobile Service Identity (MMSI) is provided for each vessel observed. Using the MMSI we were able to count the number of vessels operating in Region 3 rivers, as well as the vessel types. In total, 334 vessels completed 1,813 voyages in 2013. The number of voyages completed by each vessel type is shown in Figure 6. 86% of voyages were completed by towboats and tugs, with 11% of voyages performed by tows longer than 200m in length. WIG (Wing-in-Ground effect) vessels are high-speed, winged vessels that operate by skimming over the surface of the water on a cushion of air. The USCG has noted frequent misclassification of vessels in their AIS signal, resulting in a significant number of

vessels misclassifying as WIG vessels, when they are instead engaged in barge towing activities<sup>4</sup>.

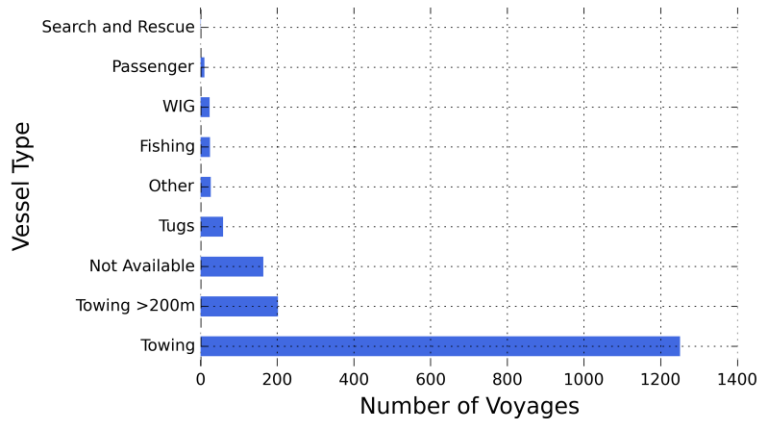


Figure 6: Number of voyages completed by each vessel type in Region 3 rivers in 2013

Figure 6 illustrates that over 85% of all voyages were by towboats. Therefore, we simplify our emissions estimates by assuming that all voyages are by tugs/towboats. Over 90% of tugs/towboats are category 1 vessels, and given the horsepower profile (> 1000kW) and aging nature of the fleet we assume that all vessels are Tier 0 vessels (EPA, 2009). There are four kinds of distillate fuels in marine service, DMX, DMA, DMB, and DMC. DMA, which contains no traces of residual fuel and is also referred to as MGO, is used primarily in Category 1 engines (EPA, 2008). The carbon content of these four distillate fuels is largely the same, thus CO<sub>2</sub> emissions assuming MGO provides a robust estimate, even if some vessels use other marine distillates. Based on information from EPA, we assume that all vessels in Region 3 are currently burning MGO/DMA.

### Emissions

We can use river segment estimates of speed, horsepower, and voyages to estimate towboat emissions using Equation 1.

#### Equation 1: Emission estimation methodology

$$Emissions = Power \times Activity \times Load Factor \times Emission Factor \times nVoyages$$

Where emissions (g/kWh) are a function of the number of voyages and installed vessel power (kW), hours of vessel activity (h), load factor (the fraction of main engine load used for propulsion), and the emission factor (g/kWh). Emission factors for Marine Distillate Fuels (MGO) and liquefied natural gas (LNG) fuels are shown in Table 1.

Table 1: Emission Factors (g/kWh) for towboats using MGO and LNG fuels

Pollutant	MGO (g/kWh) <sup>5</sup>	LNG (g/kWh)
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<sup>4</sup> [http://www.navcen.uscg.gov/pdf/AIS/AIS\\_Special\\_Notice\\_and\\_AIS\\_Encoding\\_Guide\\_2012.pdf](http://www.navcen.uscg.gov/pdf/AIS/AIS_Special_Notice_and_AIS_Encoding_Guide_2012.pdf)

BSFC <sup>6</sup>	217	183
CO <sub>2</sub>	266	205.2
NO <sub>x</sub>	5.4	0.61
SO <sub>x</sub>	0.18	0
PM <sub>10</sub>	0.12	0.03
CO	0.47	1.01
N <sub>2</sub> O	0.014	-
CH <sub>4</sub>	0.0018	1.01

We estimate towboat emissions using a load factor of 69%, as suggested by Koerber et al. (2007) and employed by Comer et al (2011) to estimate emissions from marine vessels in the Great Lakes and portions of the inland waterway system.

### Fuel Consumption

Fuel consumption is estimated using the same formula as for emissions, shown in Equation 1, and using the MGO and LNG BSFC for the emissions factor for criteria or greenhouse gas pollutants.

## Results

We compare emissions under two scenarios. Our base case presents results for the existing MGO fleet. We also employ an LNG scenario, which estimates emissions and fuel use for a fleet-wide switch to LNG.

### Base Case: Existing fleet

#### Base Case: Fuel Consumption

Our results show that total fuel consumption in Region 3 and adjacent states was 35,434,000 gallons, or 113,000 metric tons, in 2013<sup>7</sup>. The results from our analysis using AIS data are validated using fuel tax data (Dager, 2014) collected for the inland waterways, as shown in Table 2. Our estimated fuel consumption results all undercount compared to fuel tax data. We anticipate that our results provide conservative estimates of fuel consumption as we do not account for fuel burned in auxiliary engines, and by main engines when weighed to at dams and shoals in the river. Note that the Ohio River segment in the fuel tax data describes the length of the Ohio River, from Pittsburgh to its confluence with the Mississippi, and thus our modeled estimates are notably lower as we only capture segments east of the Ohio-Indiana state line. The entire length of the Ohio River is listed as 864.7 miles in the USACE IWWN shapefile. We only estimate emissions over the 445.8 river miles downriver of Pittsburgh at the confluence of the Ohio, Monongahela, and Allegheny Rivers, equivalent to 51.6% of miles on the Ohio River. Assuming a uniform distribution of fuel consumption over the length of the Ohio River, applying this

<sup>5</sup> MGO and LNG emission factors taken from Bengtsson et al. (2011)

<sup>6</sup> Brake Specific Fuel Consumption (BSFC) describes the amount of fuel used to produce 1kWh

<sup>7</sup> 1 metric ton MGO = 7.64 barrels (EIA, 2015c); 1 barrel = 42 gallons

distance ratio to the fuel tax data yields expected fuel consumption of about 180,000 tons. Thus our estimate is on the same order of magnitude, and appears reasonable without additional processing of AIS data for the western reaches of the Ohio River (planned for future work).

Our estimates report fuel consumption on the Monongahela River to be 23% of the fuel use expected from the fuel tax data. This discrepancy might be explained by the fact that vessels may purchase fuel in one river segment, but then travel to adjacent segments. The AIS data show vessel traffic as constrained to the first 32 miles of the Monongahela from its confluence with the Allegheny and Ohio Rivers. It is conceivable that vessels operating in this region might purchase fuel at locations along the Monongahela, but spend much of their time operating along reaches of the Ohio River.

**Table 2: Comparison of modeled fuel consumption (gallons) with fuel tax data for the inland rivers in Region 3**

WTWY	Fuel Consumption (tons)		
	River Name	MGO Modeled	Fuel Tax Data
2027	Kanawha River, WV	5,800	11,956
2028	Elk River, WV	0	-
2077	Monongahela River, PA and WV	2,200	9,546
2078	Ohio River	104,400	345,054
2345	Big Sandy River, KY and WV	400	-
2346	Little Kanawha River, WV	0	-
2347	Muskingum River, OH	100	-
6529	Allegheny River PA	100	612
	<b>Sum</b>	<b>113,000</b>	

**Base Case: Emissions and GHG profiles**

We estimate that vessel activity on the inland rivers in Region 3 resulted in the regional emissions of 3,000 tons of NO<sub>x</sub>, 100 tons of SO<sub>x</sub>, 70 tons of PM<sub>10</sub>, and 260 tons of CO in 2013, as shown in Figure 7.



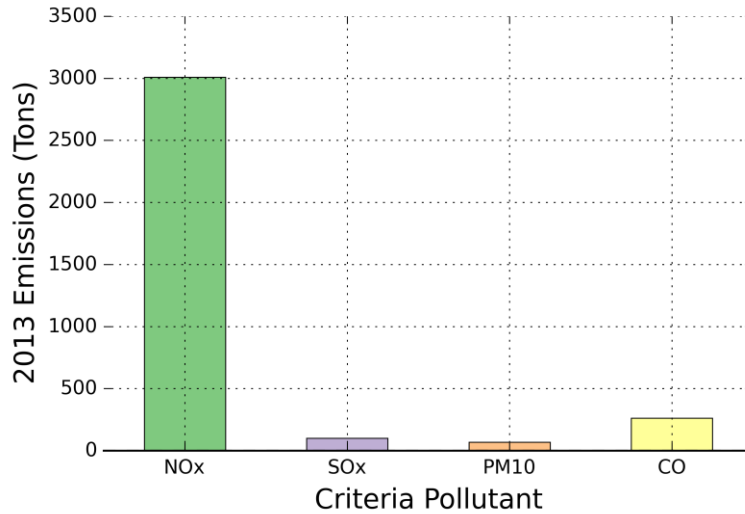


Figure 7: Total criteria pollutants released by inland river vessels burning MGO in Region 3 in 2013

Greenhouse gas emissions for our base case are shown in Figure 8. Inland river vessels in Region 3 emitted 148,400 tons of CO<sub>2</sub> in 2013, along with 1 ton of CH<sub>4</sub> and 8 tons of N<sub>2</sub>O, resulting in a total CO<sub>2</sub> equivalent of 150,600 metric tons.<sup>8</sup>

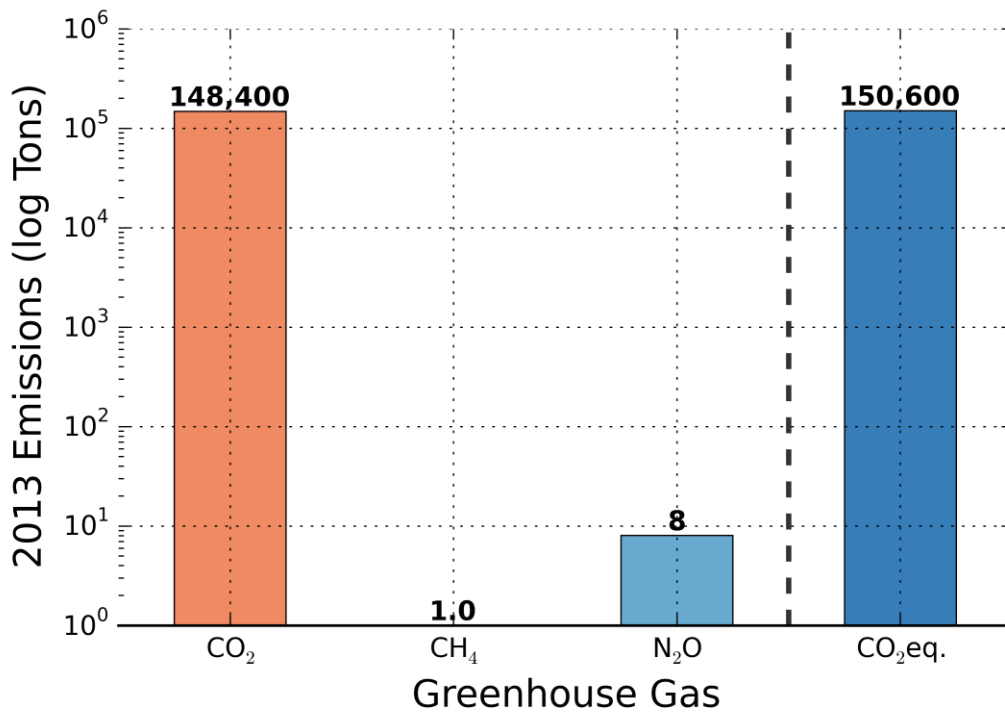


Figure 8: Greenhouse gas emissions by inland river vessels burning MGO in 2013 in Region 3 (rounded to nearest 100 tons)

<sup>8</sup> **Global Warming Potential**

We employ estimates from Myhre et al. (2013). EPA estimates are also included for reference. IPCC AR5 100-year Global Warming Potential (Myhre et al., 2013): CH<sub>4</sub> = 30, N<sub>2</sub>O = 265  
 EPA Greenhouse Gas Equivalencies Calculator (EPA, 2015a): CH<sub>4</sub> = 25, N<sub>2</sub>O = 298

## LNG Scenario: Fleet-wide switch to LNG

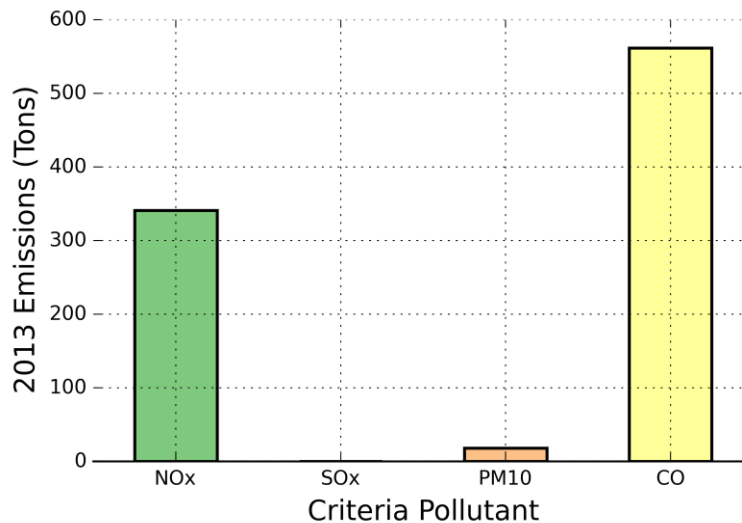
### LNG Scenario: Fuel Consumption

We estimate that fuel consumption would be 102,000 metric tons of LNG if all vessel operations for 2013 were switched to LNG fuel. The difference in fuel consumption is because the BSFC per kWh is lower for LNG than MGO, as described by Bengtsson et al (2011) (Table 1). This value represents the quantity of fuel used by vessel for propulsion, not accounting for boil off. Assuming a boil-off rate of 0.15% per day (Hasan, Zheng, & Karimi, 2009), the total annual LNG fuel required, including boil-off, would be 102,200 metric tons<sup>9</sup>.

**Table 3: Estimated LNG fuel consumption if all 2013 Region 3 vessel activity was converted to LNG power**

WTWY	River Name	LNG Fuel Consumption (tons)
2027	Kanawha River, WV	5,300
2028	Elk River, WV	0
2077	Monongahela River, PA and WV	2,000
2078	Ohio River	94,100
2345	Big Sandy River, KY and WV	400
2346	Little Kanawha River, WV	0
2347	Muskingum River, OH	100
6529	Allegheny River PA	100
Sum		102,000
+0.15% Boil-off		200
<b>Total</b>		<b>102,200</b>

### LNG Scenario: Fleet Emissions and GHG profiles

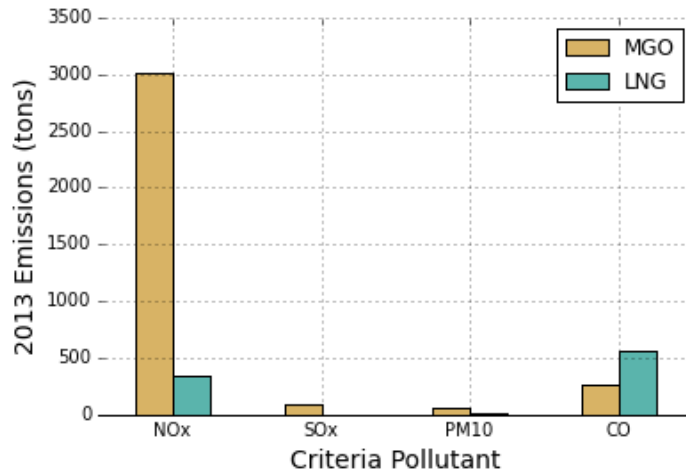


<sup>9</sup> 1 metric ton of LNG = 10.4 barrels (EIA, 2015c)

1 barrel = 42 gallons

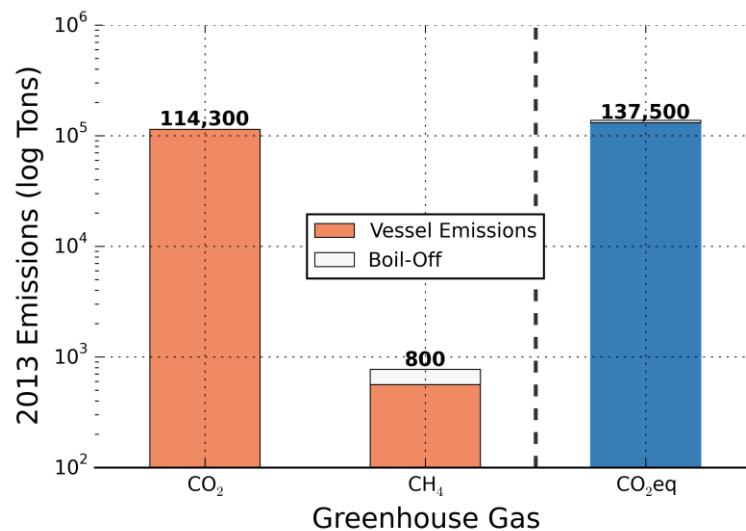
**Figure 9: Total criteria pollutants released if all Region 3 vessels used LNG in 2013**

We estimate that a Region 3 inland river fleet using LNG would emit 340 tons of NO<sub>x</sub>, near zero tons of SO<sub>x</sub>, 20 tons of PM<sub>10</sub>, and 560 tons of CO (Figure 9). Differences in emissions between MGO and LNG are shown in Figure 10. Switching to LNG results in a 90% reduction in NO<sub>x</sub>, a near complete reduction in SO<sub>x</sub>, a 97% reduction in PM<sub>10</sub>, and a 215% increase in CO.



**Figure 10: Emissions of criteria pollutants from current MGO vessels and LNG conversion scenario**

Fleet wide downstream CO<sub>2</sub> emissions from LNG vessels are estimated at 114,300 tons based on 2013 activity. We estimate that LNG vessels will emit an additional 780 tons of CH<sub>4</sub> through combustion, and 20 tons of CH<sub>4</sub> from boil-off, resulting in a total CO<sub>2</sub> equivalent of 137,500 metric tons, a 8.6% reduction in GHG emissions from fuel combustion compared with MGO during the in-use phase<sup>10</sup>.



**Figure 11: Greenhouse gas emissions from combustion if all Region 3 inland vessels switch to LNG fuel (rounded to nearest 100 tons)**

<sup>10</sup> See footnote 7 for description of global warming potential (GWP) conversion factors

## Life Cycle Emissions

As mentioned previously, upstream leakage of natural gas can occur during the extraction, liquefaction, transportation, and regasification phases. Total lifecycle analysis uses estimates of emissions at all stages of the fuel cycle, from the “well-to-hull,” thus providing a more accurate picture of the GHGs emitted compared to analysis GHGs from fuel combustion alone. A report for the US Maritime Administration (MARAD) estimates that for vessels burning MGO, for every 170g of CO<sub>2</sub>eq emitted during the downstream combustion phase, 45g are emitted during the upstream distribution and feedstock phases (Corbett et al., 2014). We estimate that MGO vessels emitted 150,600 tons CO<sub>2</sub>eq during the downstream phase, thus using the ratio of 170:45, we estimate that upstream MGO emissions result in an additional 40,000 tons of CO<sub>2</sub>eq, bringing the total GHG emissions from MGO vessels up to 190,400 tons CO<sub>2</sub>eq.

Corbett et al., (2014) estimate that for every 180g of CO<sub>2</sub>eq emitted by an inland river towboat during the downstream LNG combustion phase, 65g of CO<sub>2</sub>eq are released during the fuel transfer and feedstock stages. We use this ratio, 180:65, to estimate the additional upstream GHG emissions associated with LNG use. 137,500 tons CO<sub>2</sub>eq were emitted during the combustion phase of LNG operations, resulting in an estimated 50,000 tons CO<sub>2</sub>eq emitted during the upstream stages. Thus the total GHG emissions are estimated to be 187,200 tons CO<sub>2</sub>eq, or a 1.7% reduction compared with MGO (Figure 12).

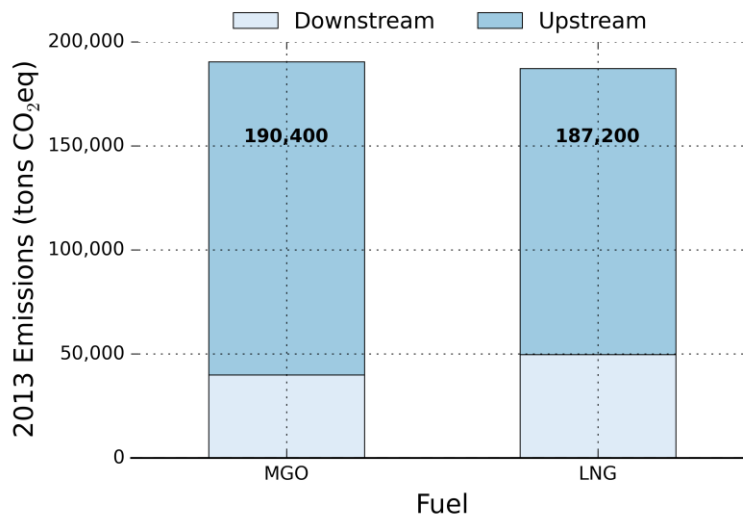


Figure 12: Total fuel cycle GHG emissions for MGO, and the LNG scenario emissions (CO<sub>2</sub>eq)

## Discussion

This section summarizes insights from our vessel technology assessment, emissions calculations of potential changes with 100% fleet-wide LNG conversion. We present initial assessments of potential benefits and consider available literature on fleet switchover costs and infrastructure opportunities to match regional supply with marine LNG fuel introduction.

### Potential benefits for GHGs and air quality

We estimate that a fleet-wide switch to LNG would result in a 1.7% reduction in GHGs from vessels operating in Region 3 when considering the total fuel life cycle. Given the inherent imprecision of inputs to activity estimates, which could vary by more than 2%, we interpret the small difference to represent GHG parity between LNG and MGO fuels for vessels in inland river service.

However, we find substantial reductions in air pollutants. With the exception of CO which yields a 215% increase, a fleet-wide switch to LNG would result in an over 90% reduction in NO<sub>x</sub>, SO<sub>x</sub>, and PM<sub>10</sub>.

### Fleet Switchover

The rate of fleet modernization for inland river vessels is a complex business decision, including technology life, economic considerations related to cargoes and operating costs other than fuel, and infrastructure constraints. We consider briefly some of the costs directly related to LNG conversion.

### Costs

Vessel operating costs can be divided into capital costs and operating costs. Capital costs include the purchasing of new equipment and upgrading existing systems. Operating costs include purchasing fuel, maintenance, and payroll. We focus on vessel upgrade costs and fuel costs for the purpose of this analysis.

In general the cost of converting an MGO vessel to LNG is similar to the cost of purchasing a new engine altogether. Given the high cost of conversion, vessel operators rely on the potential for future cost savings due to the lower cost of LNG fuels.

The cost of converting a tug/tow vessel from MGO to LNG is estimated to be \$7.2 million (\$1.2 million for the engine, \$6.0 million for the fuel system) for a 3,000hp vessel (Balon et al., 2012). A feasibility analysis of using LNG in the Pittsburgh region supports these estimates, stating that the total conventional diesel to LNG conversion costs would be \$4 to \$6 million for a 3,000 to 4,000hp vessel (Port of Pittsburgh Commission, 2015). These estimates are for vessels that are slightly larger than the mean installed horsepower on the inland rivers; however, in the absence of better information we shall apply the \$4million rate to all 335 inland river vessels that completed voyages in 2013. Thus the total capital cost of retrofitting 335 vessels for LNG operation would be approximately \$1.34 billion, not including dock-side infrastructure upgrades to accommodate LNG bunkering and regional liquefaction facilities.

48% of the vessels operating on the IWWN in Region 3 are over 40 years old. Retrofits would be unlikely for such vessels as they near the end of their operational life, thus vessel operators may prefer to gradually phase in LNG vessels as they retire older vessels.

### Opportunities within Region 3

Figure 13 shows the density of natural gas processing facilities in Region 3 along with the number of voyages per river segment. The Ohio River and tributaries flow through a network of natural gas processing facilities, with a number of facilities in close proximity to the IWWN.

It is important to note that these facilities do not produce LNG through liquefaction or perform LNG peak shaving, and that there are currently not any liquefaction facilities in close proximity to Region 3 rivers (DOT, 2015). We include natural gas processing plants as a proxy for natural gas processing activity, with the potential for LNG facilities in the region. All natural gas processing facilities shown are well within the typical 250-mile drayage limit for trucks transporting natural gas products indicating the possibility for joint liquefaction/natural gas processing facilities.

The highest number of voyages per river segment occur along the Ohio River west of the Big Sandy River, and between the Little Kanawha and Big Sandy Rivers, meaning any LNG bunkering facilities installed along these reaches would be highly transited and accessible. Note that no data are shown for reaches of the Ohio River in western Ohio and Indiana as the AIS region changes from Zone 17 to Zone 16.

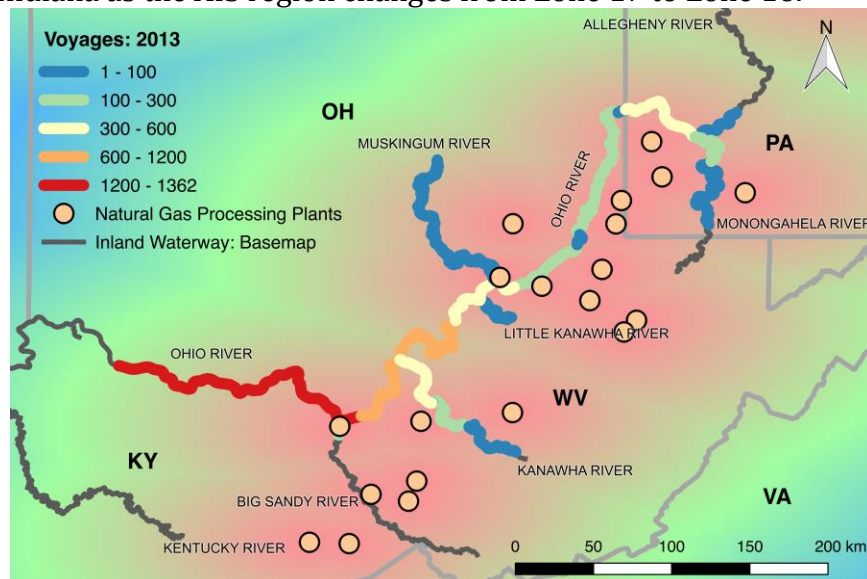


Figure 13: Number of voyages per river segment and density gradient showing clustering of LNG processing facilities in region 3 near parts of Region 3 waterways (EIA, 2015a)

Figure 14 shows fuel use by river segment along with ports listed as offering bunkering services in the USACE port and waterway facilities database (USACE, 2015). USACE lists a single facility, located on the Ohio River just west of the confluence with the Big Sandy River, as offering “gas” bunkering services. All fueling facilities listed in Region 3 offer either petroleum products or are listed generally as offering “fuel” bunkering services.

The highest MGO fuel consumption occurs along the Ohio River west of the confluence with the Big Sandy River, with fuel use declining slightly up to the confluence with the Little Kanawha River.

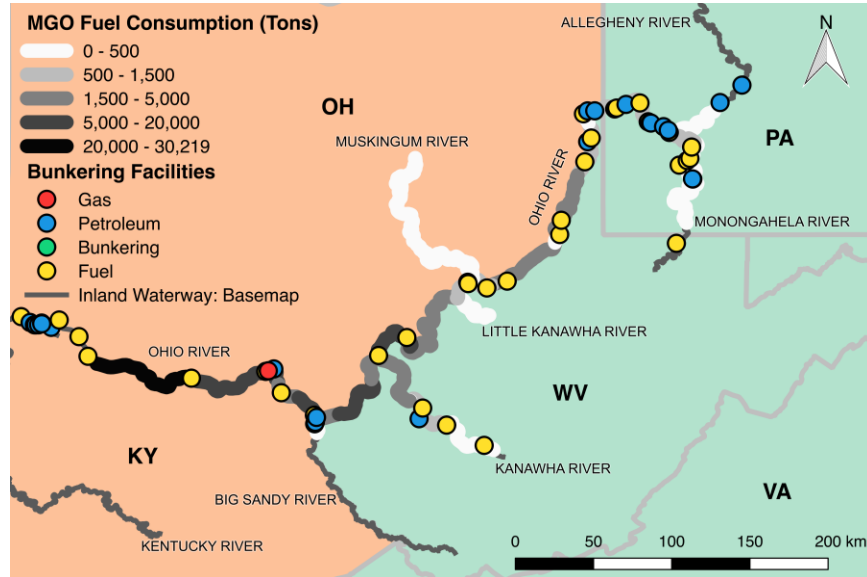


Figure 14: Fuel use by river segment and bunkering facilities by fuel type (USACE, 2015)

The mean vessel age is highest in the reaches around Pittsburgh, at the confluence of the Allegheny, Monongahela, and Ohio Rivers (Figure 15) with the average age in three reaches being above 50. The Kanawha and Big Sandy Rivers are home to vessels with a mean age greater than 39.5. Only in 7 reaches is the mean vessel age below 32, further demonstrating the aging nature of the IWWN fleet of tug and towboats.

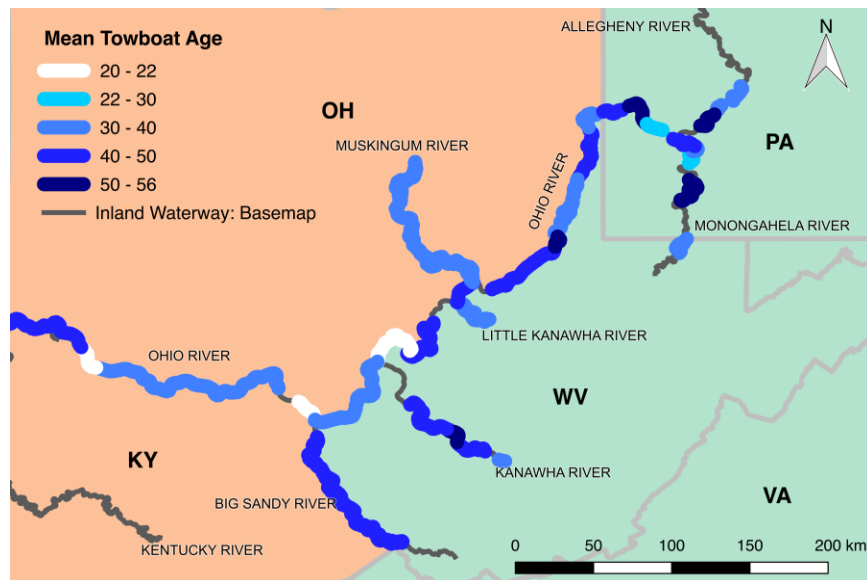


Figure 15: Mean age of vessels registered by river segment

CO<sub>2</sub> emissions are greatest along the Ohio River downstream of the Little Kanawha River (Figure 16). Driven by a high number of voyages along this river, CO<sub>2</sub>

emissions far exceed IWWN emissions in the eastern Ohio River corridor around Pittsburgh. CO<sub>2</sub> emissions also serve as a proxy for criteria pollutant emissions, which follow the same pattern of intensity and distribution as CO<sub>2</sub> emissions.

High fuel consumption, number of voyages, CO<sub>2</sub> and criteria pollutant emissions and average vessel ages along the Ohio River downstream of the Little Kanawha River, this area merits further study as a potential region for investment in LNG infrastructure.

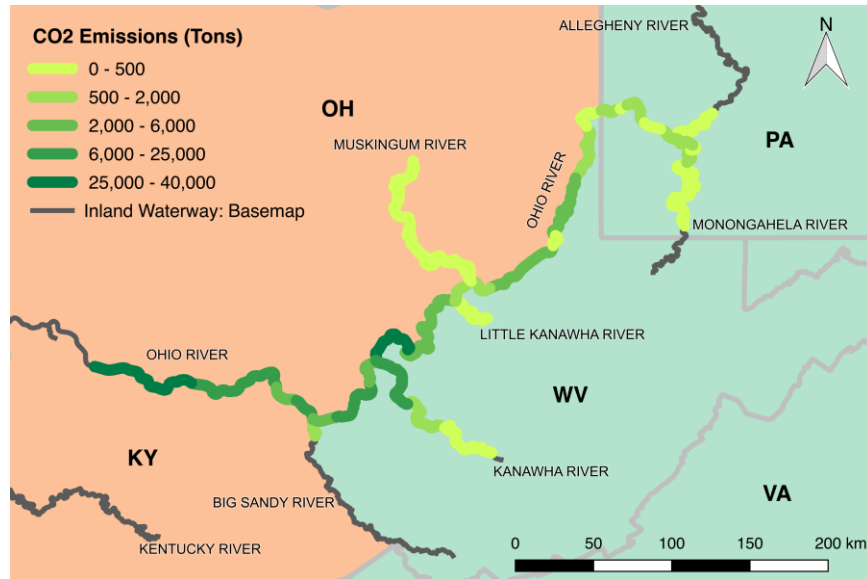


Figure 16: CO<sub>2</sub> emissions from IWWN vessel activity in 2013

## Conclusions

The average age of all towboats registered in Region 3 is 40.1 years. Vessels ages are above the regional average in the reaches around Pittsburgh as well as the Kanawha and Big Sandy Rivers in West Virginia. While likelihood of retrofitting vessels in such an old fleet may be low, vessel operators may have an opportunity to phase in new, LNG, vessels as they retire vessels at the end of their operational life.

In total, towboats in Region 3 consumed 113,000 metric tons (45,434,000 gallons) of marine distillate fuel in 2013. Of this total, 104,400 tons were consumed along the Ohio River. A switch to LNG would result in a drop in fuel consumption to 102,200 metric tons (9.5% change). Vessel activity is high in regions close to natural gas processing facilities, aiding connection with existing natural gas infrastructure by either truck or pipeline.

We estimate that LNG bunkers would reduce criteria pollutants by 90% for NO<sub>x</sub>, ~100% for SO<sub>x</sub>, and 97% for PM<sub>10</sub>. CO emissions would increase by 215%. Vessels operating on Region 3 waterways emitted GHGs totalling 190,400 tons CO<sub>2</sub>eq in 2013. If the entire fleet were to switch over to LNG and maintain similar operations,



factoring in upstream leakage, GHG emissions would be nearly on par with MGO use, reduced by 1.7% to 187,200 tons CO<sub>2</sub>eq. Emissions of CO<sub>2</sub>eq and criteria pollutants are greatest along the Ohio River from the Little Kanawha downstream into Kentucky, thus any reduction in criteria pollutants from an LNG fuel switch would have the greatest impact in these regions.

This fleet of inland vessels operates most voyages occurring along the Ohio and Kanawha Rivers in West Virginia. Vessels operating around Pittsburgh are older, with average age more than 50 years; however, relatively few voyages occur in this region. CO<sub>2</sub> and criteria pollutant emissions are greatest along the Ohio River in West Virginia and Kentucky.

West Virginia merits more study as an available option for investment in LNG infrastructure in Region 3 based on analysis of vessel activity and emissions. However, the fleet investment challenge in this region must be considered along with infrastructure. We assume LNG availability in the region; however, further work is required to study the LNG fuel supply market, as well as better characterization of the costs associated with a switch from MGO to LNG. Rivers in West Virginia are highly used, resulting in high fuel consumption and GHG and criteria pollutant emissions. Additionally towboats registered in the region are among the oldest, on average, in Region 3 and thus apparent opportunities for capital investment need to be studied further. Waterways in West Virginia are close to natural gas processing facilities and IWWN ports offering bunkering services, offering an opportunity for LNG facilities to link the two. Further studies are required to estimate the magnitude of the health benefits associated with a switch to LNG fuels. While all of Region 3 would benefit from air quality improvements associated with a switch to LNG, the magnitude of reductions, in terms of tons of pollutant abated, would be greatest in West Virginia.

## References

- Abrahams, L. S., Samaras, C., Griffin, W. M., & Matthews, H. S. (2015). Life Cycle Greenhouse Gas Emissions From US Liquefied Natural Gas Exports: Implications for End Uses. *Environmental Science & Technology*, 49(5), 3237–3245.
- Afon, Y., & Ervin, D. (2008). An Assessment of Air Emissions from Liquefied Natural Gas Ships Using Different Power Systems and Different Fuels. *Journal of the Air & Waste Management Association*, 58(3), 404–411.
- Balon, T., Lowell, D., & Curry, T. (2012). *Natural gas for marine vessels*. Technical Report, American Clean Skies Foundation, Washington, DC.
- Banawan, A. A., El Gohary, M. M., & Sadek, I. S. (2010). Environmental and economical benefits of changing from marine diesel oil to natural-gas fuel for short-voyage high-power passenger ships. *Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment*, 224(2), 103–113.
- Bengtsson, S., Andersson, K., & Fridell, E. (2011). A comparative life cycle assessment of marine fuels: liquefied natural gas and three other fossil fuels. *Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment*. doi:10.1177/1475090211402136
- Comer, B. ., Silberman, J. ., Corbett, J. J. ., & Stella, G. (2011). Commercial Marine Emissions in the LADCO Region Final Report. Retrieved July 22, 2015, from [http://www.ladco.org/reports/technical\\_support\\_document/references/commercial\\_marine\\_emissions\\_LADCO\\_final\\_report.pdf](http://www.ladco.org/reports/technical_support_document/references/commercial_marine_emissions_LADCO_final_report.pdf)
- Corbett, J. J., Thomson, H., & Winebrake, J. J. (2014). *Natural Gas for Waterborne Freight Transport: A Life Cycle Emissions Assessment with Case Studies*.
- Dager, C. (2014). *Fuel Tax Report 2013*. Center for Transportation Research, University of Tennessee, Knoxville, TN.
- DNV GL. (2014). We have reached 100 LNG fueled ships - DNV GL Blog. Retrieved July 25, 2015, from <http://blogs.dnvgl.com/lng/2014/03/reached-100-lng-fueled-ships/>
- DOT. (2014). University Transportation Centers. Retrieved July 25, 2015, from [http://www.rita.dot.gov/utc/about/grant\\_recipients/html/2013\\_grant\\_recipients.html](http://www.rita.dot.gov/utc/about/grant_recipients/html/2013_grant_recipients.html)

- DOT. (2015). LNG Plants Connected to Natural Gas Pipeline Systems. Retrieved July 31, 2015, from [https://primis.phmsa.dot.gov/comm/LNG\\_Map.htm?nocache=9347](https://primis.phmsa.dot.gov/comm/LNG_Map.htm?nocache=9347)
- EIA. (2015a). EIA Maps. Retrieved July 23, 2015, from [http://www.eia.gov/maps/layer\\_info-m.cfm](http://www.eia.gov/maps/layer_info-m.cfm)
- EIA. (2015b). Glossary - U.S. Energy Information Administration (EIA). Retrieved July 25, 2015, from <http://www.eia.gov/tools/glossary/index.cfm>
- EIA. (2015c). International Energy Statistics - Units. Retrieved July 25, 2015, from <http://www.eia.gov/cfapps/ipdbproject/docs/unitswithpetro.cfm>
- EIA. (2015d). Marcellus Region production continues growth. Retrieved July 23, 2015, from <http://www.eia.gov/todayinenergy/detail.cfm?id=17411>
- EPA. (2008). Control of Emissions of Air Pollution from Locomotive Engines and Marine Compression Ignition Engines Less than 30 Liters Per Cylinder. *EPA420-R-08-001*.
- EPA. (2009). Current methodologies in preparing mobile source port related emission inventories. (E. P. Agency, Ed.). US EPA.
- EPA. (2015a). Greenhouse Gas Equivalencies Calculator. Retrieved from <http://www.epa.gov/cleanenergy/energy-resources/calculator.html#results>
- EPA. Protection of the Environment, Pub. L. No. 40 C.F.R part 89 (2015).
- Hasan, M. M. F., Zheng, A. M., & Karimi, I. A. (2009). Minimizing Boil-Off Losses in Liquefied Natural Gas Transportation. *Industrial & Engineering Chemistry Research*, 48(21), 9571–9580. doi:10.1021/ie801975q
- IMO. (2014). ECA sulphur fuel requirements in effect from 1 January 2015. Retrieved July 23, 2015, from <http://www.imo.org/en/MediaCentre/PressBriefings/Pages/44-ECA-sulphur.aspx>
- Koerber, M., Lindhjem, C. E., & Browning, L. (2007). LADCO 2005 Commercial Marine Emissions. Retrieved from [http://www.ladco.org/reports/technical\\_support\\_document/references/commercial\\_marine\\_emissions\\_draft\\_03\\_02\\_07.pdf](http://www.ladco.org/reports/technical_support_document/references/commercial_marine_emissions_draft_03_02_07.pdf)
- MATS. (2015). MATS UTC. Retrieved July 25, 2015, from <http://www.matsutc.org/>
- Myhre, G., Shindell, D., Bréon, F.-M., Collins, W., Fuglestedt, J., Huang, J., ... Zhan, H. (2013). 2013: Anthropogenic and Natural Radiative Forcing. In *Climate Change*

2013: *The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 659–740). doi:10.1017/ CBO9781107415324.018

NOAA. (2015). Marine Cadastre - AIS. Retrieved from <http://www.marinecadastre.gov/ais>

Port of Pittsburgh Commission. (2015). *Pittsburgh Marine Corridor Natural Gas Conversion Feasibility Assessment*.

Pospiech, P. (2013). Full Speed Ahead with Gas. *Marine News*. Retrieved from <http://magazines.marinelink.com/Magazines/MarineNews/201309/content/speed-ahead-with-211303>

USACE. (2014a). NDC - U.S. Waterway Data - Lock Characteristics. Retrieved July 23, 2015, from <http://www.navigationdatacenter.us/data/datalck.htm>

USACE. (2014b). NDC - U.S. Waterway Data - Vessel Characteristics. Retrieved July 23, 2015, from <http://www.navigationdatacenter.us/data/datavess.htm>

USACE. (2015). NDC - Port and Waterway Facilities. Retrieved July 23, 2015, from <http://www.navigationdatacenter.us/ports/ports.htm>

Wang, S., & Notteboom, T. (2014). The Adoption of Liquefied Natural Gas as a Ship Fuel: A Systematic Review of Perspectives and Challenges. *Transport Reviews*, 34(6), 749–774.