

Bay Engineering, Inc.

Naval Architects and Marine Engineers

S.S. BADGER CNG/LNG Conversion Study

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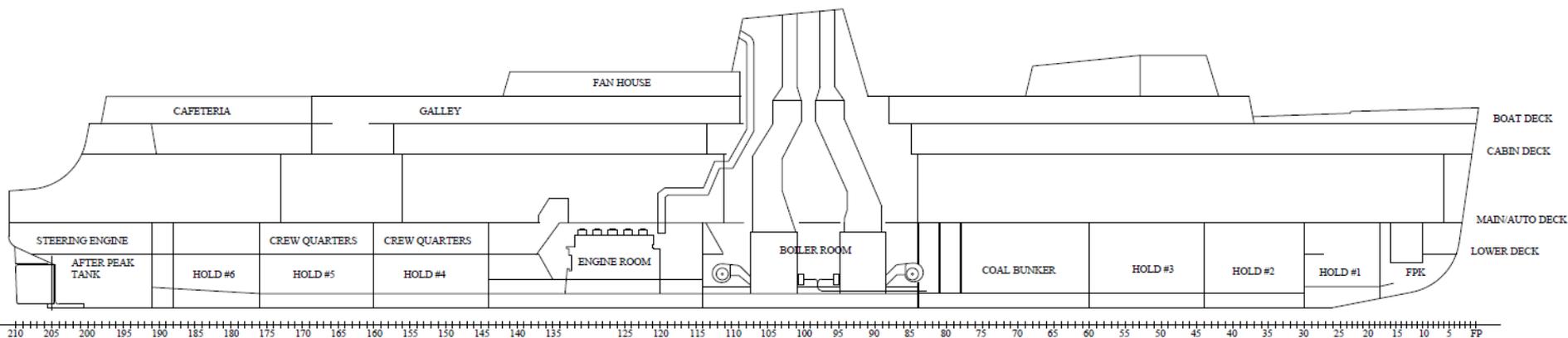
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Funded through Great Lakes Maritime Research Institute

SNAME Ann Arbor 10/5/2012

Purpose:

- S.S. BADGER (Car Ferry)
- Coal fired ship => natural gas fired ship
- Coal fired steam plant => natural gas fired steam plant
- Engineering feasibility analysis



The following aspects will be discussed in the presentation:

- The reason: why switch to natural gas as a ship fueling option against coal
- Storage options: LNG & CNG
- The possible natural gas source
- System layout & design details
- Regulatory compliance
- Value of this project as a pilot program for the Great Lakes vessels

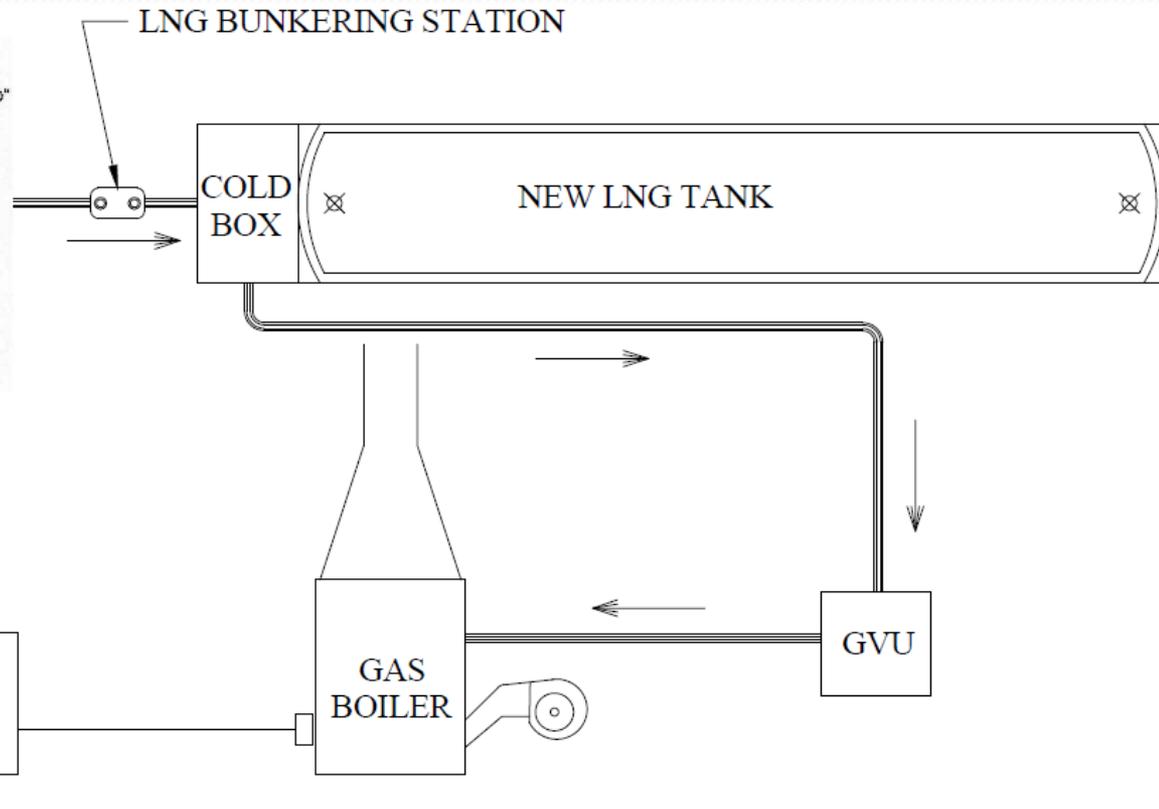
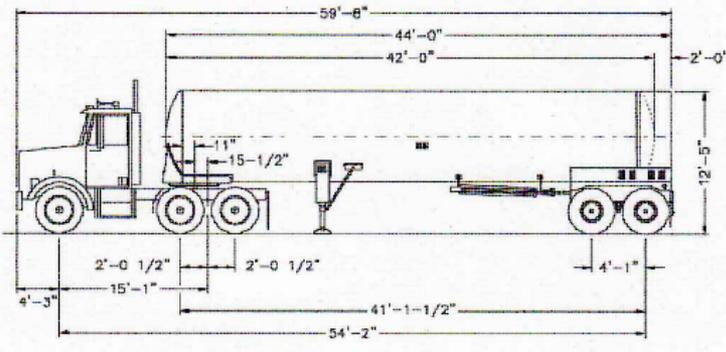
Efforts to Improve Environmental Impact

- Dumping coal ash from its boilers into the waters of Lake Michigan.
- Attracted attention from Environmental Protection Agency (EPA) and environmental groups, in late 2008.
- Find a way to capture and safely offload ash, change the fueling configuration of the ship, or cease operations by 2012.
- Plan to convert to natural gas as fuel option
- This would allow the historical steam system to be maintained and making the *SS Badger* the first "green" ship on the Great Lakes

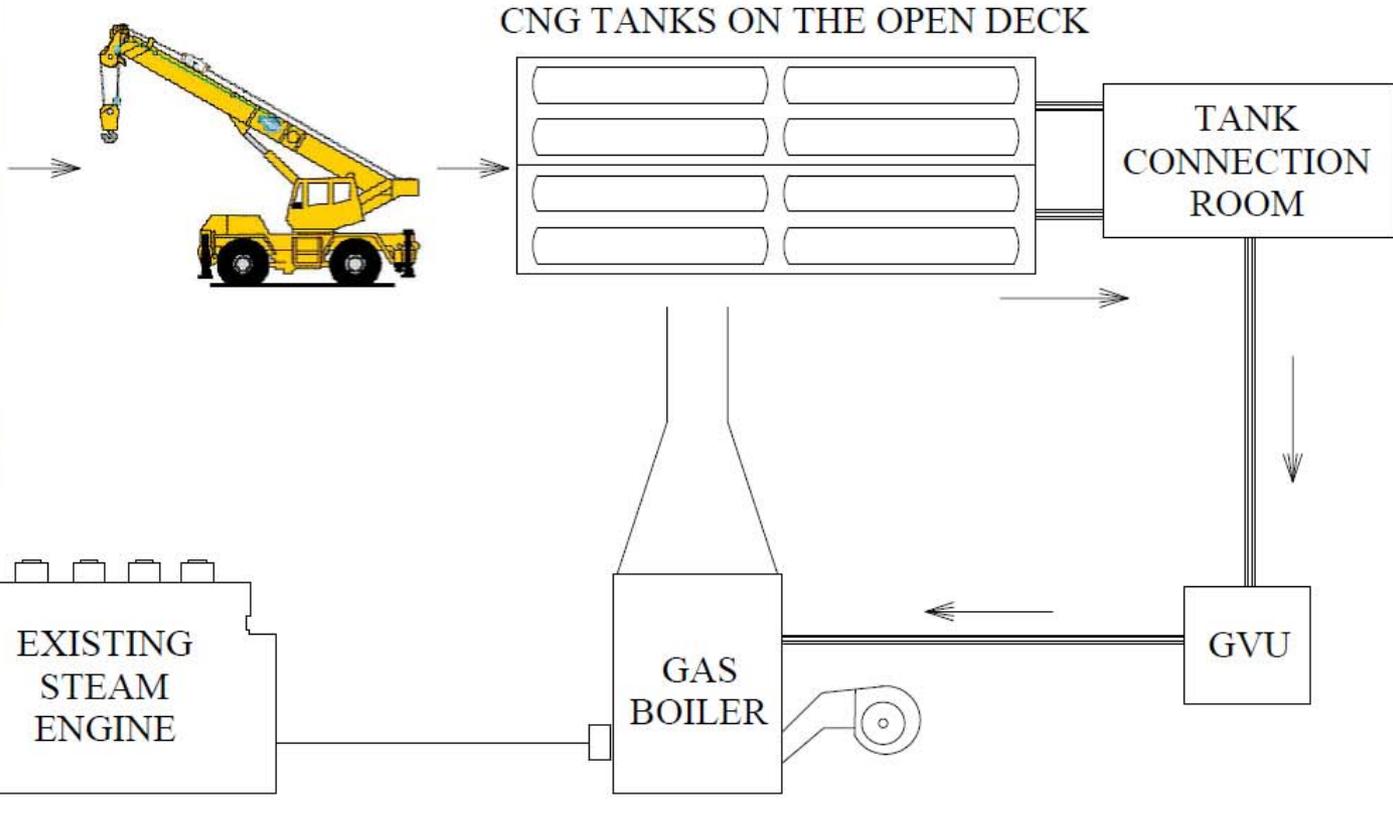
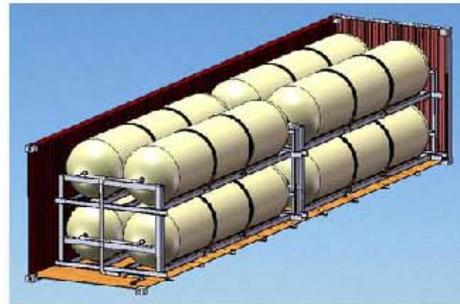
Storage Options: LNG & CNG

- LNG: Liquefied Natural Gas
- Natural gas is liquefied when it's cooled down to approximately $-162\text{ }^{\circ}\text{C}$ ($-260\text{ }^{\circ}\text{F}$) with a working pressure at about 5 to 7 bars.
- Cryogenic Independent 'Type C' tanks (thermos bottle)
- CNG: Compressed Natural Gas
- Compress natural gas to a pressure of 200-248 bar (2900-3600 psi).
- Stored in high pressure cylinders.
- Stacked vertically or horizontally in bundles.

SYSTEM DIAGRAM (LNG)

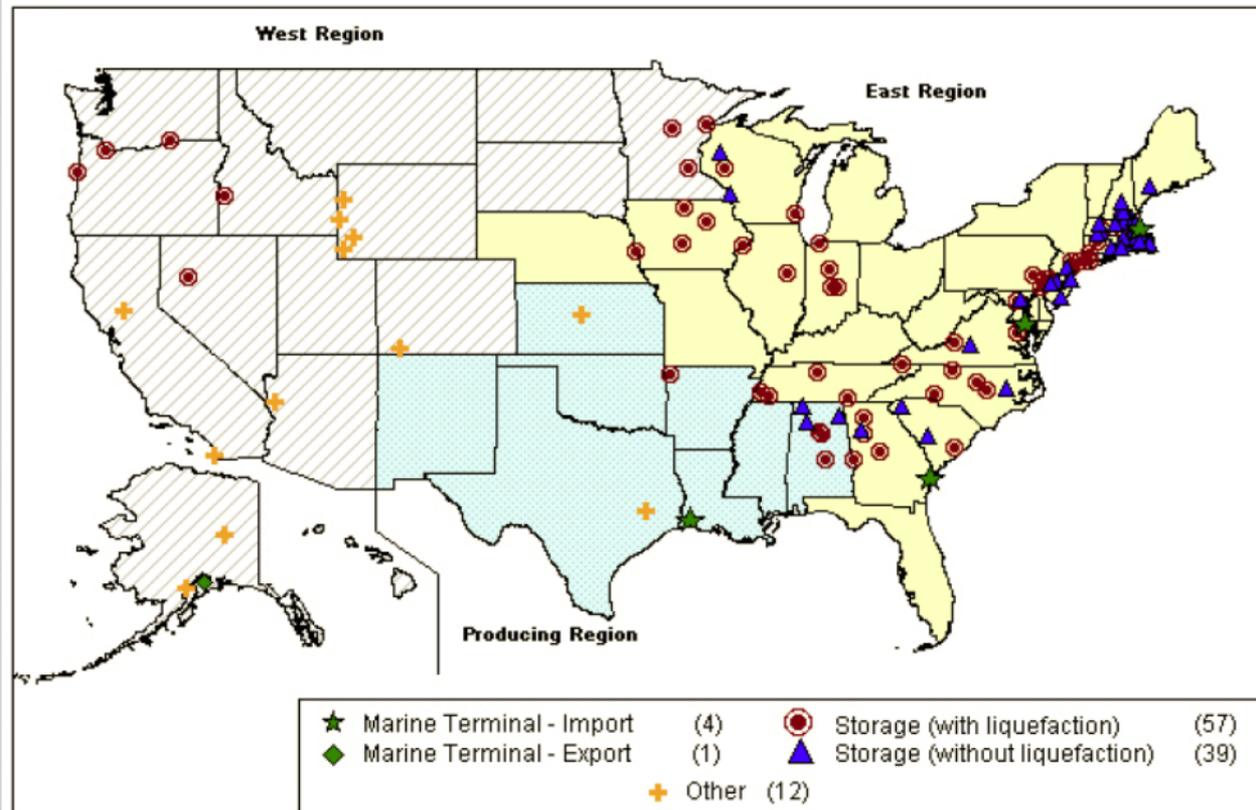


SYSTEM DIAGRAM (CNG)



Source of LNG /CNG

Figure 1. U.S. Liquefied Natural Gas Facilities as of June 2004



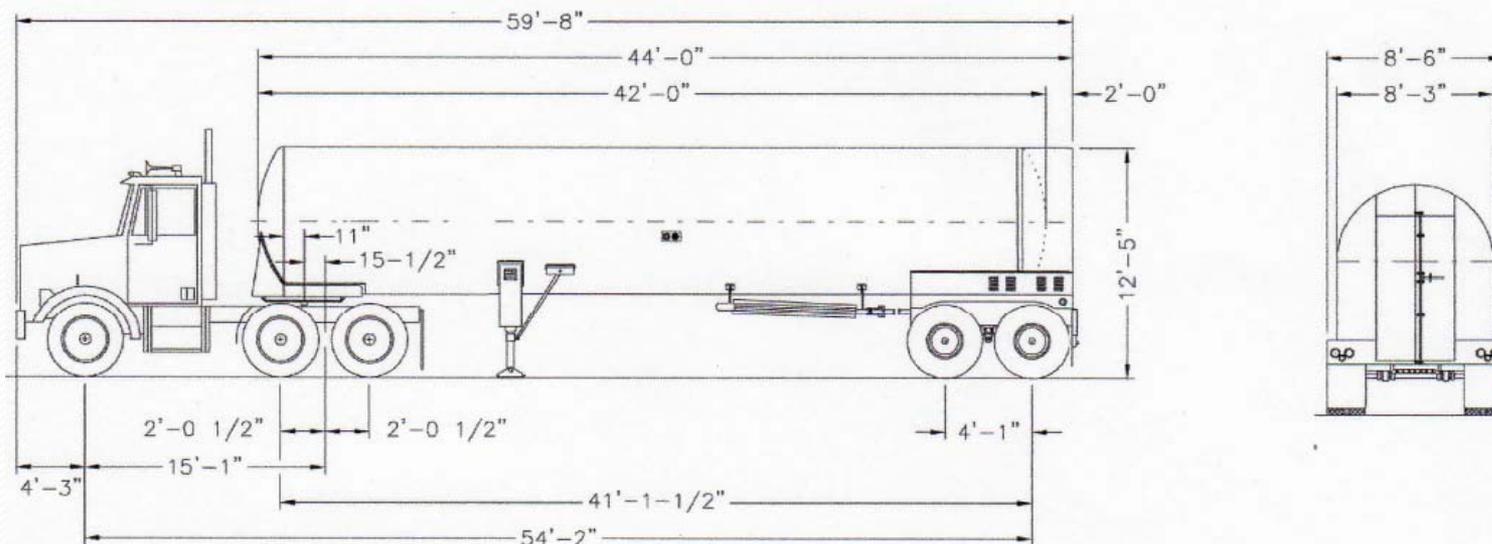
Notes: Map excludes the import facility in Puerto Rico. Other includes: stranded utilities, vehicular fuel facilities, nitrogen rejection units and other special processing plants.
Sources: Energy Information Administration, Office of Oil and Gas, and industry sources.

Gas Fuel Transportation Method

- LNG Tanker truck (for example: Charter AT-506)

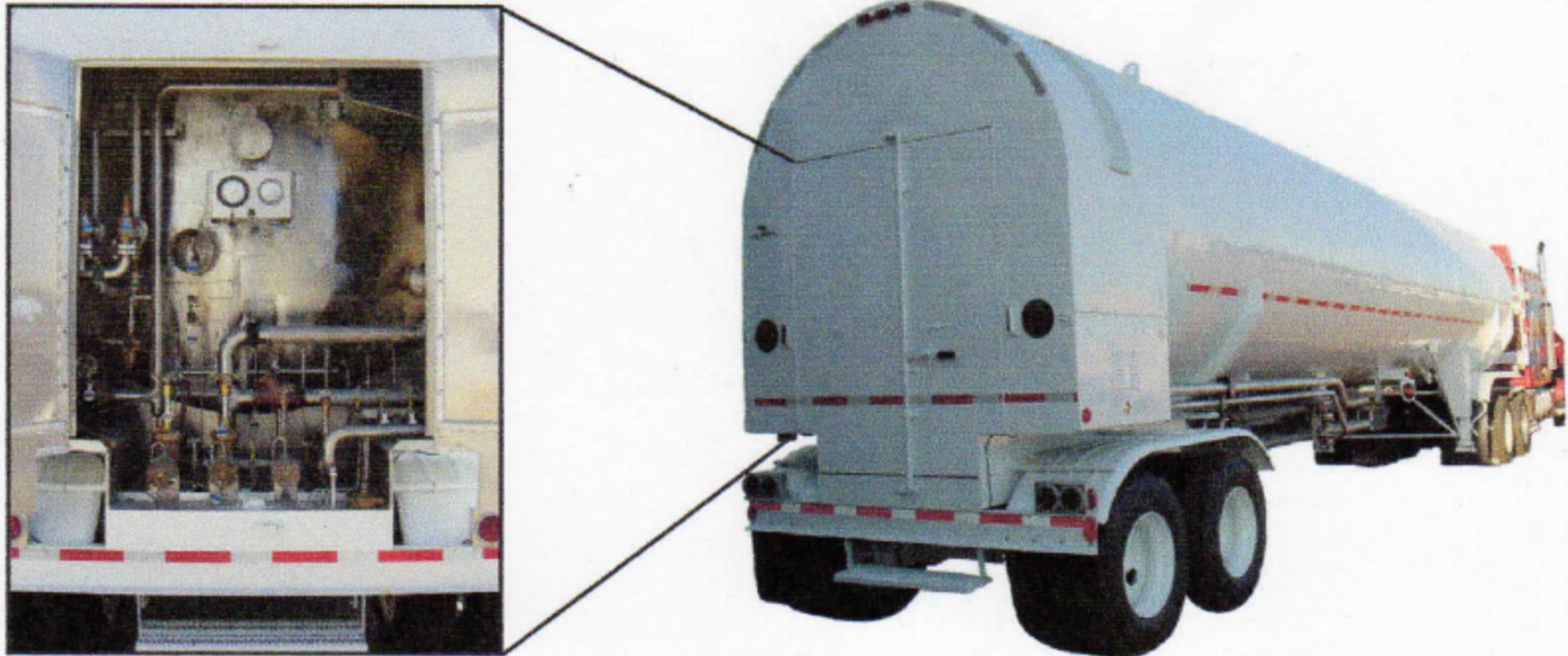
SPECIFICATIONS	
LNG Capacity (at 15 psig)	43,360 lbs / 19,668 kg*
Maximum Allowable Working Pressure	70 psig / 4.83 bar
Length (overall)	44 ft / 13.4 m
Width (overall)	8 ft 6 in / 2.6 m
Height (overall)	12 ft 5 in / 3.8 m
Weight (tare)	24,700 lbs / 11,204 kg
Design Codes	ASME Section VIII Division 1 USDOT MC-338

* Based on US DOT fill density limits; 43,360# of LNG = 12,250 gal @ 3.54 #/gal; 15 psig relief device setting.



Gas Fuel Transportation Method

- Control Piping and instruments are located in the rear piping cabinet.

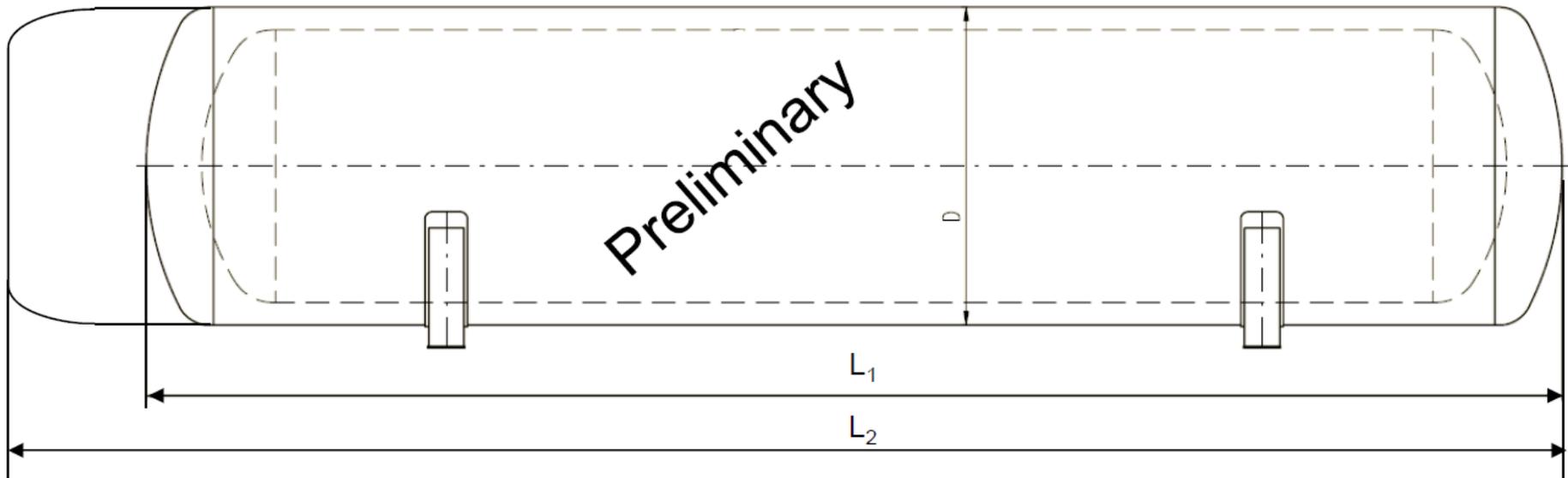


Gas Fuel Transportation Method

- CNG (CNG tube trailers)



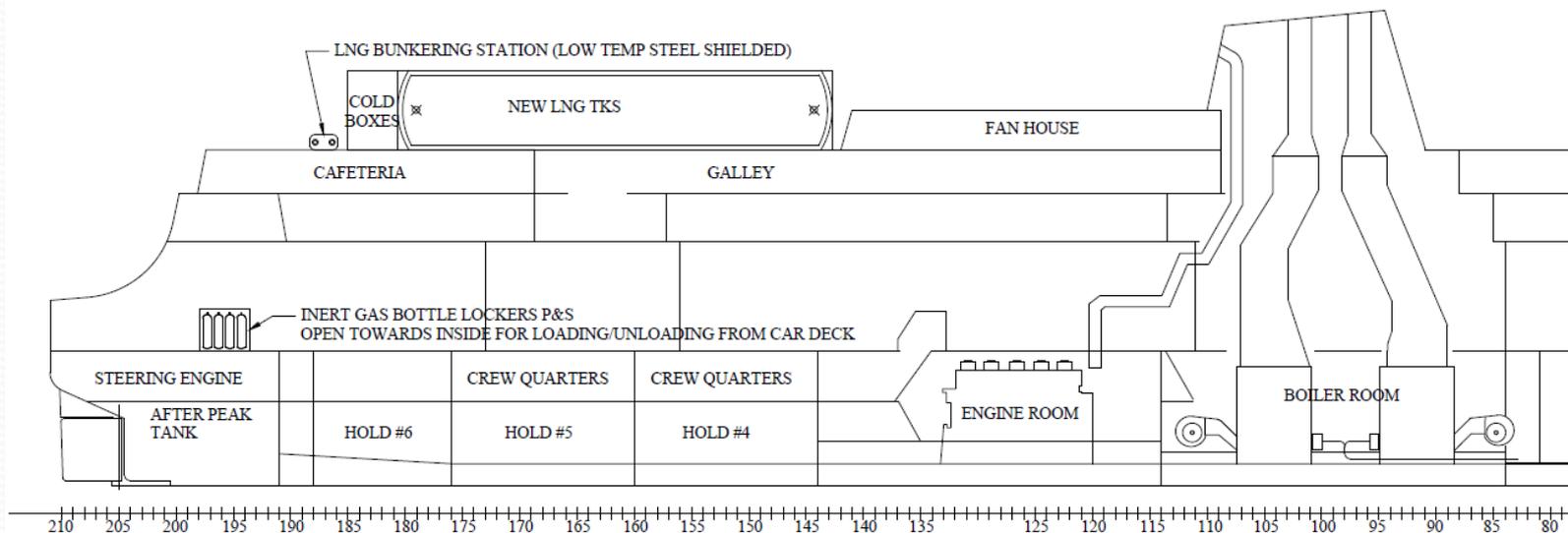
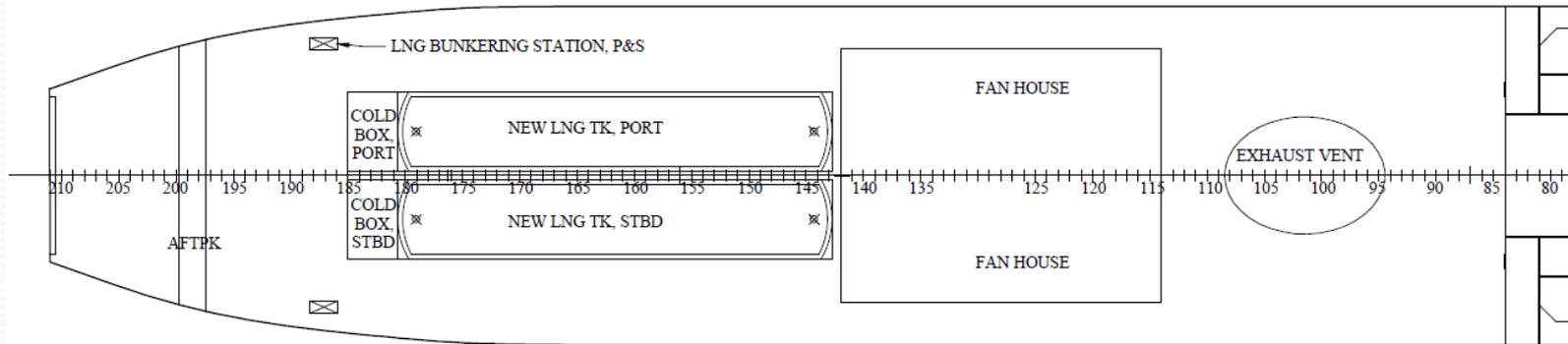
On Board LNG Type C Tanks



Type		LNGPac 105	LNGPac 145	LNGPac 194	LNGPac 239	LNGPac 284	LNGPac 280	LNGPac 308	LNGPac 339	LNGPac 402
Geometric volume	[m ³]	105	145	194	239	284	280	308	339	402
Net volume 90%	[m ³]	100	130	175	215	256	252	277	305	362
Diameter	[m]	3,5	4,0	4,3	4,3	4,3	4,8	4,8	5,0	5,0
Tank length	[m]	16,7	16,9	19,1	23,1	27,1	21,3	23,4	23,5	27,5
Cold box	[m]	2,5	2,5	2,7	2,7	3,0	3,0	3,0	3,0	3,0
Total length	[m]	19,2	19,4	21,8	25,8	30,1	24,3	26,4	26,5	30,5
Empty weight	[ton]	46,6	62	76,6	90	103,6	105,1	112,9	118,8	135,2
Tank full weight	[ton]	92	125	161	195	228	229	248	375	440
Max operating weight	[ton]	94	127	163,5	197,5	231	232,5	251,5	379	444

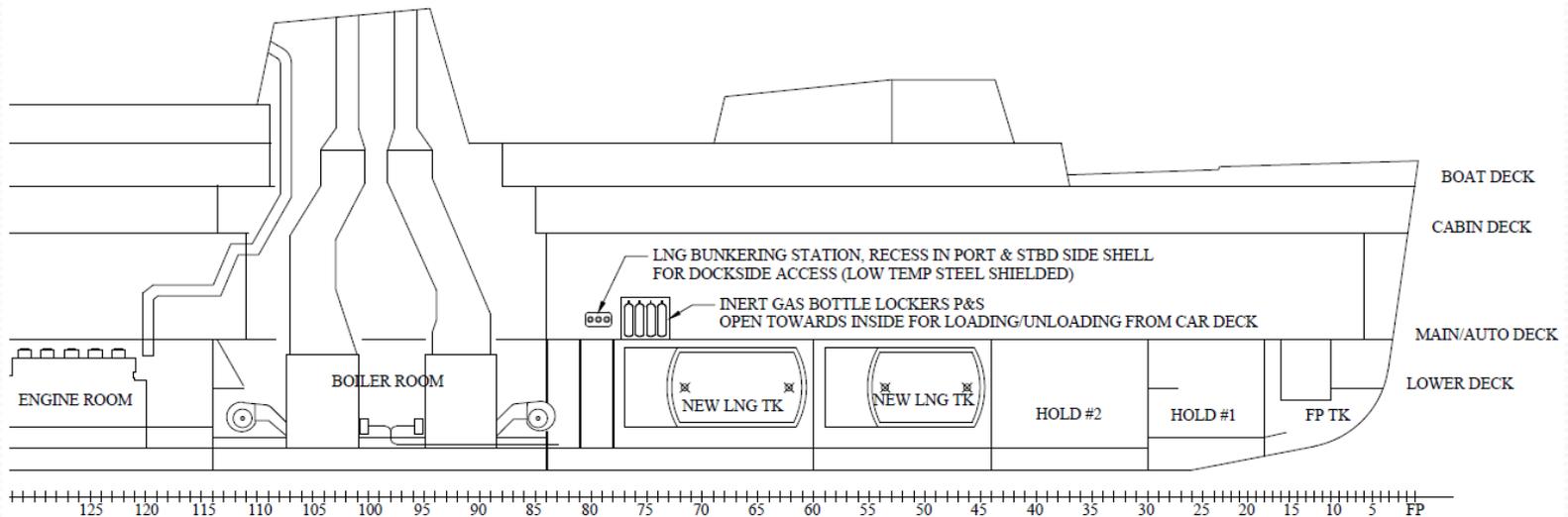
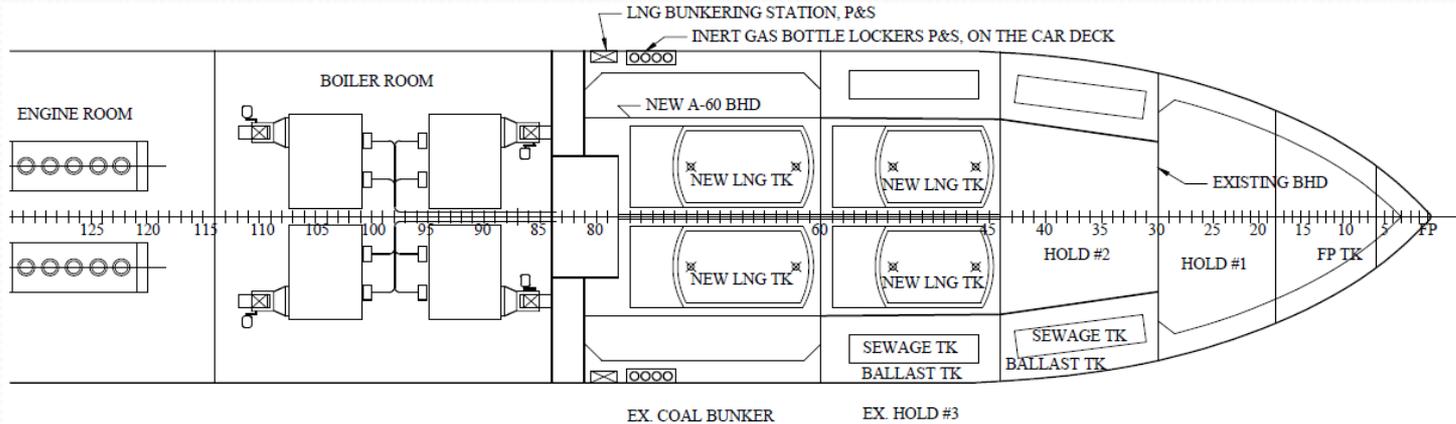
Gas Fuel Storage

- Option 1: LNG on the open deck



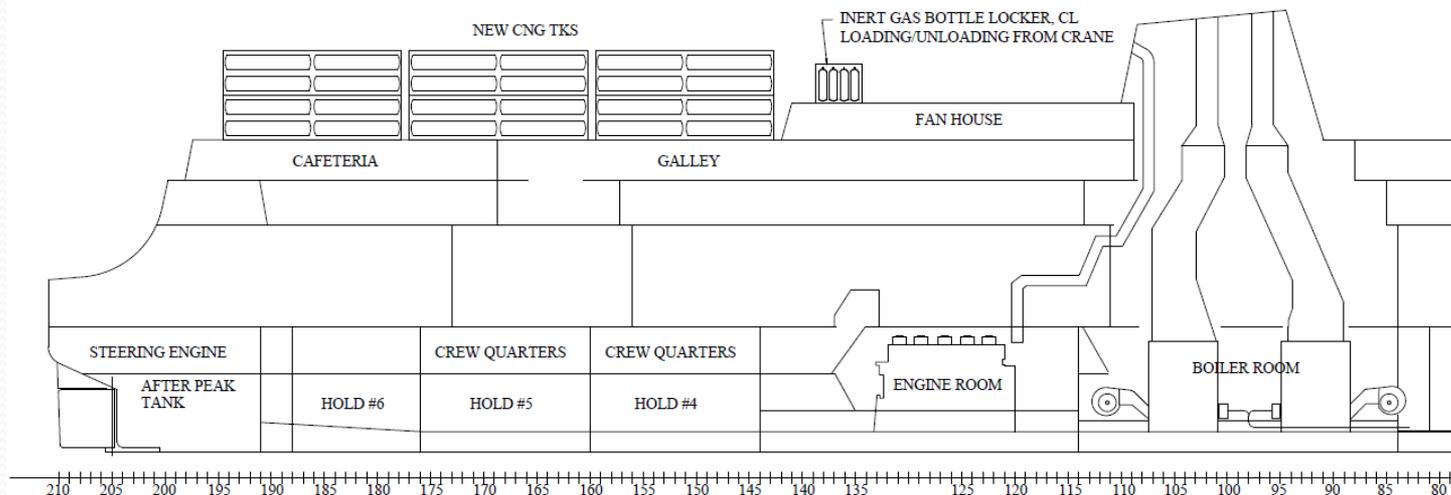
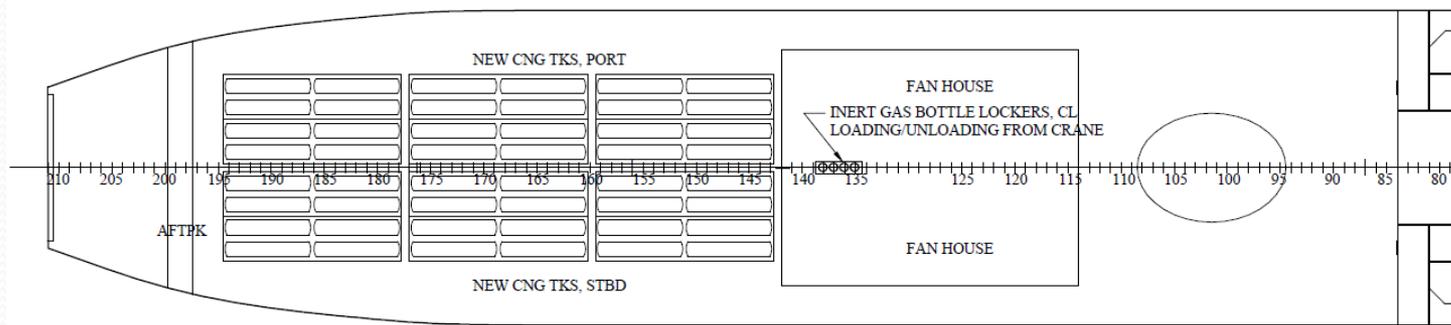
Gas Fuel Storage

- Option 2: LNG under the car deck



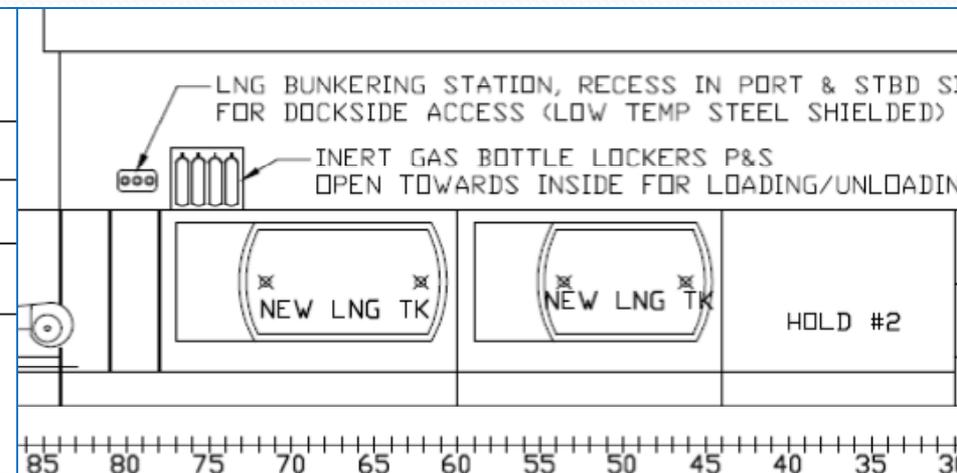
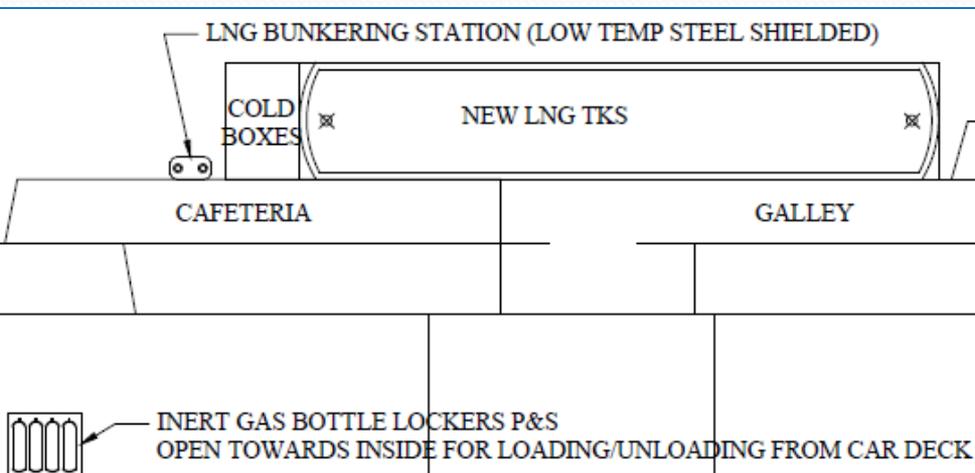
Gas Fuel Storage

- Option 3: CNG on the aft open deck
 - The concept of removable CNG container modules



Onboard Fuel Bunkering Station

- Bunkering stations located on the open deck or both sides of the vessel (the recessed area on either side of the ship)
- Each station will have provision for two bunkering lines and two return lines (LNG vapor return lines) together with nitrogen purging facility, associated relief/safety valves and control station.
- Purging gas bunkering lines and supply lines with nitrogen
- During vessel operation, the bunkering pipes will remain gas free.



Operation Schedule

- Ludington, MI - Manitowoc, WI
- Spring/Fall Schedule:
 - One Round Trip Per Day
- Summer Schedule:
 - Two Round Trip Per Day
- Average speed: 18 miles per hour (15.6 knots)
- 4 hours to cross the Lake Michigan



Gas Consumption Estimations

Daily Gas Consumption Summary

		Spring/Fall Schedule	Summer Schedule
LNG		One Round Trip Per Day	Two Round Trip Per Day
Energy Needed per Day	mmBTU	1,200	1,500
LNG Vol. Req'd per Day	m ³	50	63

Note: Energy Density (LNG): 23.87 mmBTU/m³

		One Round Trip Per Day	Two Round Trip Per Day
CNG		One Round Trip Per Day	Two Round Trip Per Day
Energy Needed per Day	mmBTU	1,200	1,500
CNG Vol. Req'd per Day	m ³	141	176

Note: Energy Density(CNG): 8.53 mmBTU/m³

Gas Consumption Estimations

Gas Storage Tank Volume Summary

LNG	Total Tank Vol	Usable Tank Vol
	m ³	m ³
Option 1 Aft Open Dk	477	420

CNG	Total Tank Vol
	m ³
Option 3 Aft Open Dk, Container Modules	576

Notes: * The ABS Guide in Ref [1] suggests remaining 10% LNG in the tank when emptied and filling to 98% full at maximum. Thus, tank usable volume is 88% of the LNG tank volume that can be filled or emptied.

Refueling Schedule

Refueling Frequency Summary

LNG	Usable Tank Volume	One Round Trip Per Day	Two Round Trips Per Day
	m ³	50.28 cu. m. LNG per Day	62.85 cu. m. LNG per Day
Option 1 Aft Open Dk	420	8.4 days	6.7 days

CNG	Total Tank Volume	One Round Trip Per Day	Two Round Trips Per Day
	m ³	140.67 cu. m. CNG per Day	175.84 cu. m. CNG per Day
Option 3 Aft Open Dk, Container Modules	576	4.1 days	3.3 days

Number of Truckloads Needed for Refueling and Ideal Bunkering Time

LNG	Usable Tank Volume	# of Truckloads per Fill *	Bunkering Time (Two Trucks to Two Hoses at a time) **	
			min	hr
Option 1 Aft Open Dk	420 m ³	9.1 #	204	3.4

Note:

* LNG Truck Tank Size = 12,250 Gal
 ** Truck LNG Transfer Rate = 300 GPM
 Bunkering Time for one truck of LNG = 40.83 min / per truck
 Ref: CHART LNG transport tank AT-506

CNG	Usable Tank Vol	# of Truckloads per Fill ***
Option 1 Aft Open Dk, Container Modules	576	24.0

Note:

*** CNG Total Volume per Truck = 24,000 L
 = 24 m³

Ref: The TOG Inc Multi-Element Gas Container (MEGC), Eight 3 m³ CNG Cylinders per Truck)

Operation Schedule (Spring/Fall)

One Round Trip Per Day:

SPRING & FALL 2012

58 days

May 24 — June 9 & September 4 — October 14

Departure	Arrival	Distance	Speed	Time
		Miles	MPH	Hrs.
Dockside				14.0
Ludington	Manitowoc	60.6	18.00	4.0
Dockside				2.0
Manitowoc	Ludington	60.6	18.00	4.0
Sum =				24.0

Operation Schedule (Summer)

Two Round Trip Per Day:

SUMMER 2012

86 days

June 10 — September 3

Departure	Arrival	Distance	Speed	Time
		Miles	MPH	Hrs.
Dockside				3.0
Ludington	Manitowoc	60.6	18.00	4.0
Dockside				2.0
Manitowoc	Ludington	60.6	18.00	4.0
Dockside				1.5
Ludington	Manitowoc	60.6	18.00	4.0
Dockside				1.5
Manitowoc	Ludington	60.6	18.00	4.0
Sum =		242.4		24.0

Safety Related Rules & Regulations

- ABS Guide for Propulsion and Auxiliary Systems for Gas Fueled Ships 2011 (ABS Guide)
- ABS Rules for Building and Classing Steel Vessels 2012
 - Part 5C Chapter 8 -Vessels Intended to Carry Liquefied Gases in Bulk
- CNG tanks: ABS Guide for Vessels Intended to Carry Compressed Natural Gases in Bulk (CNG Guide)

Safety Related Rules & Regulations

- USCG has no official rules for gas powered ships.
- The US Coast Guard has used the IMO interim guidelines as a baseline standard to evaluate the proposals and made equivalency determinations for gas-fueled ship designs.
- Interim Guidelines on Safety for Natural Gas-Fuelled Engine Installations in Ships, which were adopted by International Maritime Organization (IMO) Resolution MSC.285(86) on 1 June 2009.

VALUE AS A PILOT PROGRAM FOR THE GREAT LAKES VESSELS

- A demonstration project to consider engineering design implications of conversion this ship.
 - Relatively simple conversion
 - Convenient, small scale experimental subject
 - Low conversion cost compare to other Great Lakes Vessels
- Initiate Fuel supply chain (gas availability, transportation, route and frequency) around the Great Lakes area

Summary

- The following aspects have been discussed in the presentation:
 - The reason: why switch to natural gas as a ship fueling option against coal
 - Storage Options: LNG & CNG
 - The possible natural gas source
 - System Layout & Design Details
 - Regulatory Compliance
 - Value of this project as a pilot program for the Great Lakes Vessels

Special Thanks

Great Lakes Maritime Research Institute
Society of Naval Architects and Marine
Engineers

Questions?