Great Lakes Maritime Research Institute

A University of Wisconsin - Superior and University of Minnesota Duluth Consortium

MICHIGAN

The Potential Conversion of the U.S. Great Lakes Steam Bulk Carriers to LNG Propulsion – Initial Report

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Disclaimer

This is the initial report on a conceptual and feasibility study and is, therefore, subject to revision and change as the study moves forward.

The opinions expressed here are those of the authors only and do not represent the opinions, conclusions, or plans of any of the companies that have provided assistance to this study.

Outline

- Vessels under consideration
- Emission Control Area (ECA) emissions
- Reasons to consider conversion to LNG
- Challenges in using LNG fuel
- Predicted future natural gas production and price
- Conceptual design for AAA LNG conversions
  - Engine availability
  - Fuel use and tank sizing
  - Arrangement feasibility
  - Thoughts about conversion
- Conclusions and future plans

U.S. Flag Great Lakes Steam Bulk Carriers

Name	Length	Year Built	normal SHP	Capacity (net tons)	Typical Cargoes	Fleet	Building Yard	Notes
Edward L. Ryerson	730'	1960	9,000	30,800	Iron ore	Central Marine Logistics	Manitowoc	straight decker
American Victory	730'	1943	7,000	29,120	Iron ore, coal, limestone	American	Bethlehem	AO71 *Neshamic*
American Valor	767'	1953	7,000	28,560	Iron ore, coal, limestone	American	AMSHIP Lorain	
John G. Munson	768'	1952	7,000	28,560	Iron ore, coal, limestone	Keylakes	Manitowoc	boom forward, bunker aft
***Arthur M. Anderson* ***	767'	1952	7,000	28,336	Iron ore, coal, limestone	Keylakes	AMSHIP Lorain	
***Cason J. Callaway* ***	767'	1952	7,000	28,336	Iron ore, coal, limestone	Keylakes	GLEW Detroit	
***Philip R. Clarke* ***	767'	1952	7,000	28,336	Iron ore, coal, limestone	Keylakes	AMSHIP Lorain	
Herbert C. Jackson	690'	1959	6,000	27,776	Iron ore, coal, limestone,	Interlake Steamship	GLEW Detroit	
American Fortitude	690'	1953	7,000	24,976	Iron ore, coal, limestone	American	AMSHIP Lorain	
Wilfred Sykes	671'	1949	7,000	24,080	Iron ore, coal, limestone	Central Marine Logistics	AMSHIP Lorain	parent hull for later ships
Kaye E. Barker	767'	1952	7,000	29,008	Iron ore, coal, limestone	Interlake Steamship	AMSHIP Lorain	to be converted to diesel
Alpena	519'	1942	4,000	15,568	Cement	Inland Lakes Management		layup- storage
St. Marys Challenger	552'	1906	3,000	12,656	Cement	Port City Steamship Services		layup- storage

* AAA class

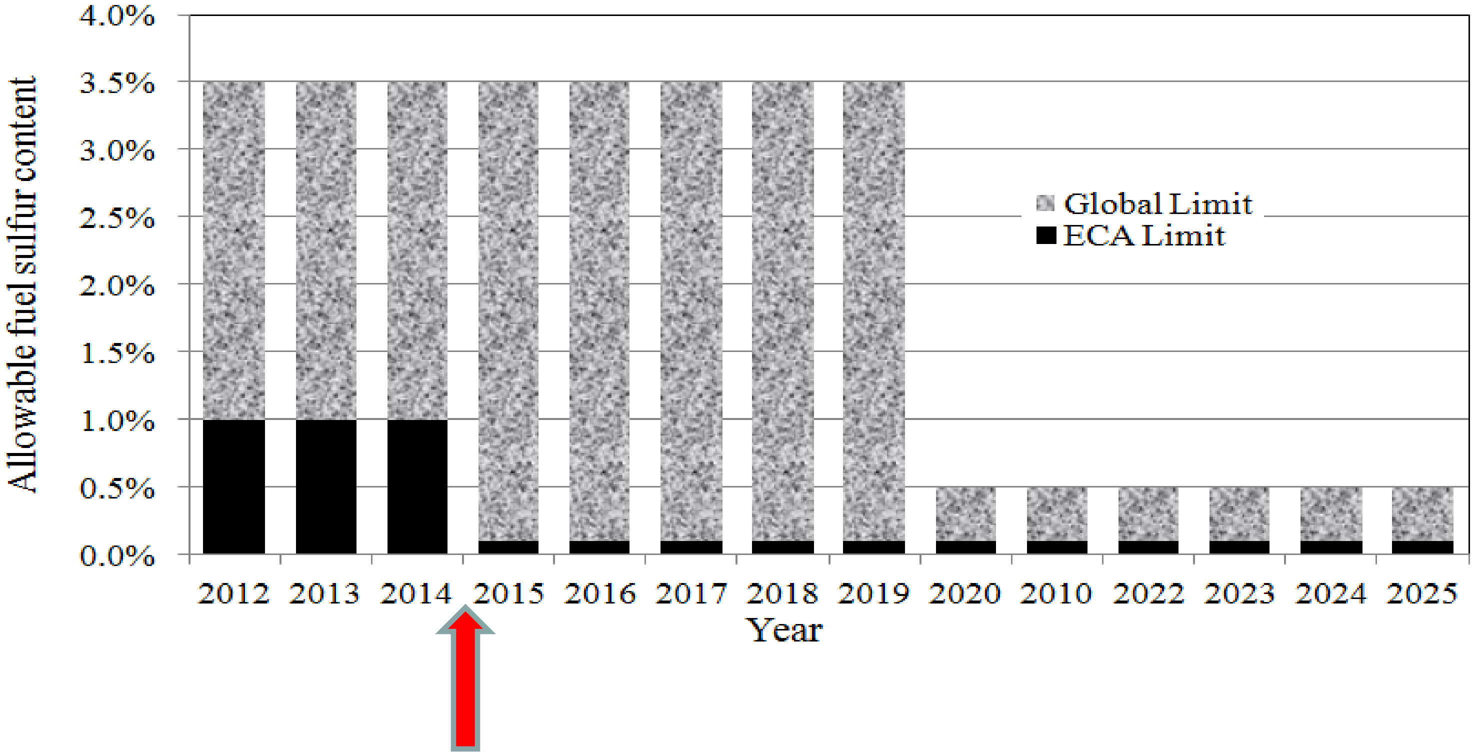
Ten remaining U.S. Flag steam bulk carriers

Three, the AAA Class, are to the same design – initial focus

Emission Control Area (ECA)

- Now in place for the Baltic Sea and North Sea
- Requested by U.S., Canada, and France
- Approved by IMO – enforceable beginning August 2012
- ECA will include non-Arctic coastal and inland waters of the U.S. and Canada
- Lower marine fuel sulfur and NO_x requirements

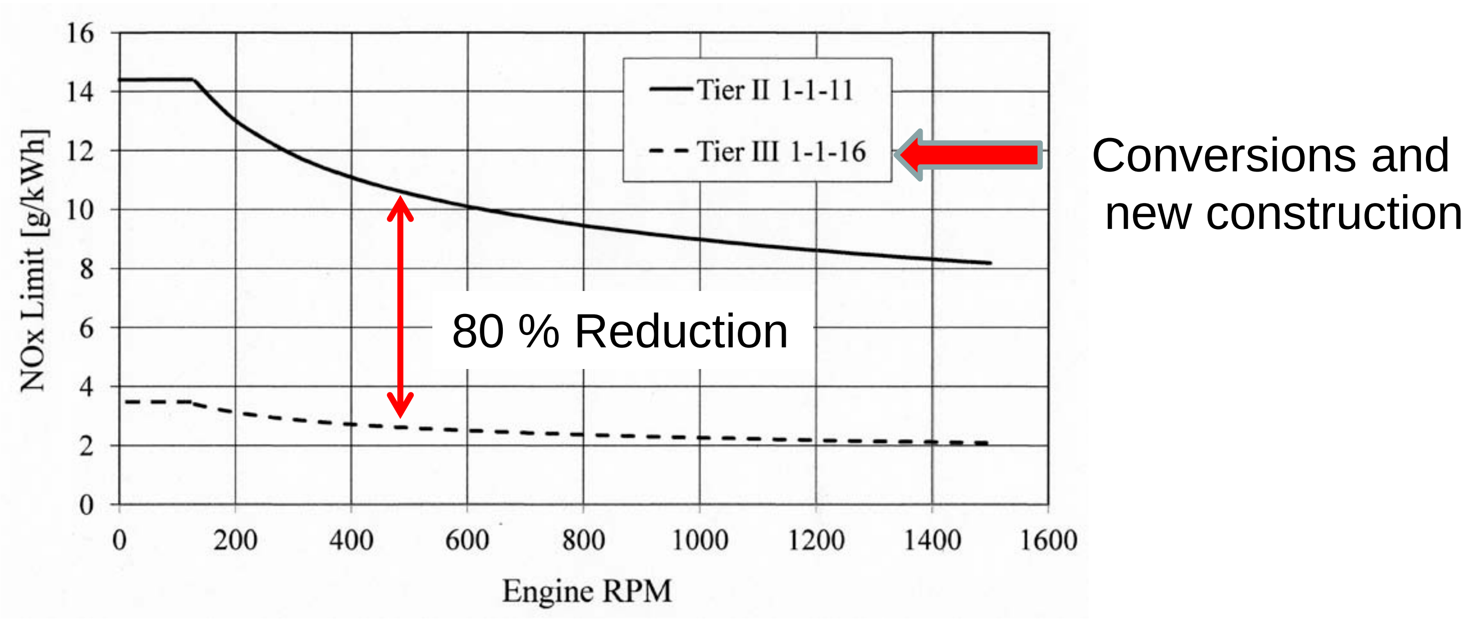
MARPOL (EPA) Marine Fuel Sulfur Limits



Alternative: use exhaust gas scrubbers (NaOH, weight, space, labor, cost)

1% S differential for IF now about $30-50/t in Rotterdam

MARPOL (EPA) ECA NOx Emissions Limits



Diesels will require Selective Catalytic Conversion (SCR) for Tier III with aqueous urea, weight, space, labor, cost penalty

Status of Emission Control Area (ECA) Air Emissions Requirements

Status

- Fuels must be available
- Congressionally mandated steamship exemption
- EPA offer for streamlined conversion to diesel, but S waiver only to 2026

Premise for study:

Not coming up to EPA ECA emissions standards is not socially and politically sustainable in the long run

Reasons to Consider LNG Conversions

- LNG cargo carriers use cargo burn-off for fuel (steam, then diesel) approaching 200 vessels; over 40 years experience
  (classification by ABS, DNV, others)
- Beginning in 2000 with the ferry *Glutra*, non-LNG cargo & C.G. vessels in Norway (DNV) – approaching 25
- Recent conversion of a 5 year old 25,000 DWT product tanker *Bit Viking* from HFO to LNG in a two month conversion (DNV)
- Harvey Gulf International contracted for 4 LNG powered offshore supply vessels
  (ABS, U.S. Coast Guard)

Advantages: Improved Fuel Efficiency

- Steam plants (7000 normal shp, 450-470 psig/750 deg. F steam, 1 ½" Hg vacuum, 3 stages of feed heating)

$$\eta_{th} \times \eta_{B} = 0.30 \times 0.865 = 0.26$$

- Current diesel or gas internal combustion engines

$$\eta_{th} \times \eta_{M} = 0.46 - 0.48$$

- Conversion is almost 85% better on thermal efficiency

Improved Specific Air Emissions

		up to 1-1-2015	after 1-1-2016	
	steam turbine	diesel engine	diesel engine	gas engine
EPA		Cat 3, Tier 2	Cat 3, Tier 3	
fuel	Bunker C	MDO	MDO	LNG
% sulfur	2% S	1.0% S	0.1% S	0.0% S
SOx [g/kWh]	11.90	4.11	0.41	0.00
PM [g/kWh]	1.16	0.58	0.28	0.00
NOx [g/kWh]	low	9.5-10.5	2.3-2.6	2.00
CO2 [g/kWh]	580-630	580-630	580-630	430-480
CO [g/kWh]	0.20	1.10	1.10	n.a.

sources: Harkins 2007, Boylston 2011, EPA 500-900 RPM for NOx

Tier 3 diesel NO_x assumes SCR addition

Reduced Fuel Cost

- Recent Washington State ferries tradeoff of LNG or Ultra Low Sulfur Diesel (ULSD = 15 ppm S highway diesel with biofuel % but no state tax)

144 Car Ferry

- Comparison ULSD $4.10/gallon versus
  energy equivalent LNG $2.12/gallon in 2014

- Houston (1/26/12) IF380 $2.41/gal. - LNG equiv. $2.31/gal.
  MDO $3.08/gal. - LNG equiv. $2.12/gal.

Reduced Manning

- Norwegian experience: manning same for diesel and LNG
- Requires central engine control room rated for unmanned engine room, ACCU
- Conversion could save one licensed and three unlicensed
- Save about $600,000 to $700,000 per year

Challenges in Using LNG Fuel

- Fuel availability
- Volume for fuel storage
- Protecting hull structure from spills
- Increased capital and maintenance cost
- Training and increased safety culture
- Methane slip

The Availability Question

- Ship owners:
  "show me the gas station"
- Suppliers:
  "show me a long-term fuel contract and we can build a liquefaction plant"

Or could this actually become a "Field of Dreams" question?

Aggregate Demand with Conversions

Name	Normal steam power (shp/kW)	Annual requirement (gallons)	2014 Operating Season	2015 Operating Season	2016 Operating Season	2017 Operating Season
Edward L. Ryerson	9000/6711	3,941,000				3,941,000
American Victory	7000/5220	3,065,000			2,043,000	3,065,000
American Valor	7000/5220	3,065,000		2,043,000	3,065,000	3,065,000
John G. Munson	7000/5220	3,065,000				2,043,000
Arthur M. Anderson	7000/5220	3,065,000		3,065,000	3,065,000	3,065,000
Cason J. Callaway	7000/5220	3,065,000	3,065,000	3,065,000	3,065,000	3,065,000
Philip R. Clarke	7000/5220	3,065,000			3,065,000	3,065,000
Herbert C. Jackson	6000/4474	2,627,000		2,627,000	2,627,000	2,627,000
American Fortitude	7000/5220	3,065,000				3,065,000
Wilfred Sykes	7000/5220	3,065,000			3,065,000	3,065,000
total fleet requirement	gallons/yr	31,088,000	3,065,000	10,800,000	19,995,000	30,066,000
over a 10 mo. season	tonnes/yr	53,657	5,290	18,640	34,511	51,893
	ave. t/day	179	18	62	115	173
	ave. visits/day	1.77	0.18	0.71	1.24	1.77
	ave. t/visit	128	100	100	100	128

Assumptions:

PHASE I – design, regulatory, planning, long lead equipment

One lead ship in lead yard first winter

Then two phased in lead yard, one in follow yard

Volume for Fuel Storage

- Energy equivalence requires:

  ~2.0 x as much LNG as IF   ~1.7 x compared to MDO

- Storage is a -162 deg. C at up to 10 barg (145 psig)
- Storage is in cylindrical double-walled insulated tanks
- Cold requires tanks to be independent of ship structure
- Net effect:

  LNG storage requires 3-4 x the ship volume as

  IF/MDO tanks integrated into the ship structure above the IB

Protecting the Hull Structure

- Ship structure nil ductility temperatures well above -162C
- LNG spills on ship structure can cause brittle cracking
- Tanks and piping must use cryogenic materials;
  e.g. 304L stainless steel
- Tanks and piping must be thermally isolated
- Potential spill locations must have stainless steel drip trays

Training and Increased Safety Culture

- LNG cargo carrier safety requires greater training and formalization of safety procedures
- Some concern expressed that broader use in marine industry will require a more focused safety culture
- Norwegian Fjord1 has 2-5 days extra training and about 1 week extra training onboard ferries
- Experienced training companies available in the U.S.

Increased Capital and Maintenance Cost

- Norwegian *Bergensfjord* ferry experience:

  Capital cost 15-20% greater than diesel

  Maintenance cost 10% greater than diesel

  Engine rebuild intervals expected to be longer

- Washington State 144 car ferry study

  Diesel option $2.5M for machinery

  Duel-fuel LNG option $9.3M for machinery

  Single-fuel LNG option $10.7M for machinery

  but single-fuel LNG option 30 year life-cycle (3% discount)

  $29.9M cheaper than diesel option (on ULSD)

  $9.3M cheaper than duel-fuel LNG option

Methane Slip

- Methane is currently an unregulated Green House Gas
- Methane is 21x more damaging to the atmosphere than CO_2
- A small fraction is not burned in gas engines – slip
- It can easily cancel the 20-25% reduced CO_2 of LNG
- Losses in bunkering, etc. would also contribute
- U.S. may eventually have a carbon tax like in Europe

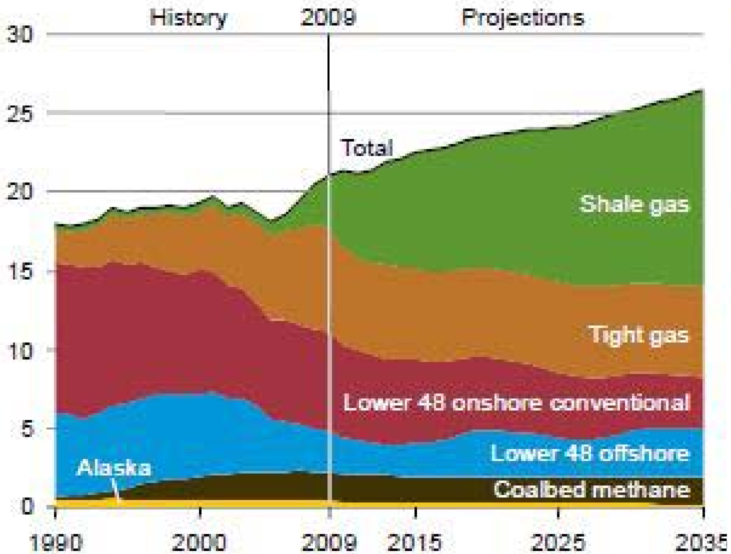
Projections of LNG Production and Price

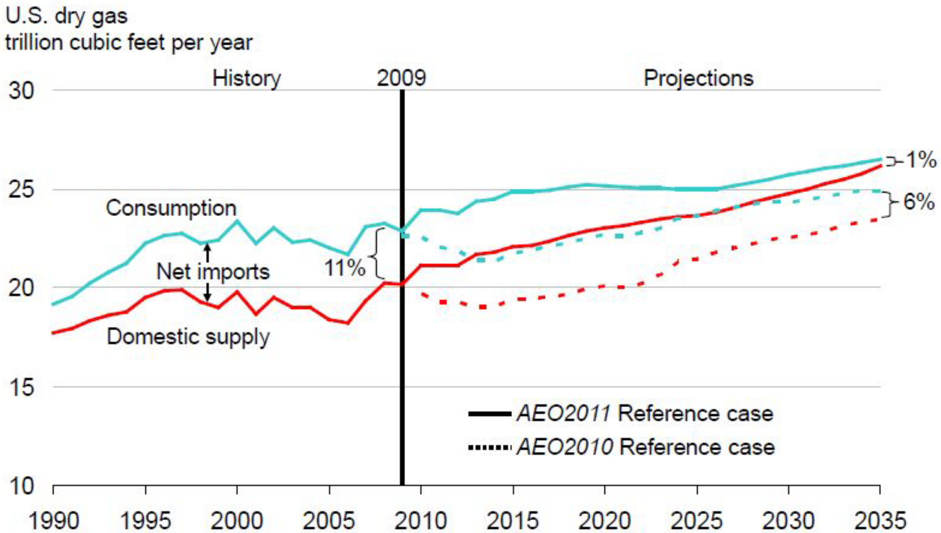
- North America has a regional LNG market
- Henry Hub is a location in the Sabine Pipeline near Erath, LA
- Henry Hub spot price is basis for trading and pricing LNG in N.A.
- Prices have been relatively less affected by international issues

2009 $/million Btu

from: DOE EIA
"Annual Energy Outlook 2011 with Projections to 2035"

Effect of Shale Gas Development





from: DOE EIA “Annual Energy Outlook 2011 with Projections to 2035”

LNG Fuel Price Projections

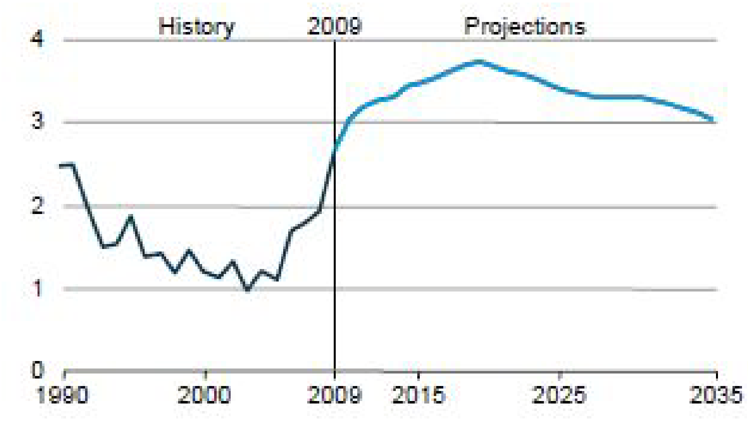
- Norwegian value chain

pipeline cost	50-60%
liquefaction	25-20%
distribution	25-20%

- Washington State ferries study

Henry Hub ±	$0.50/gal.
liquefaction	$0.43/gal.
trucking	$0.31/gal.

- Appears to be little basis for linking LNG price to diesel or oil in North America

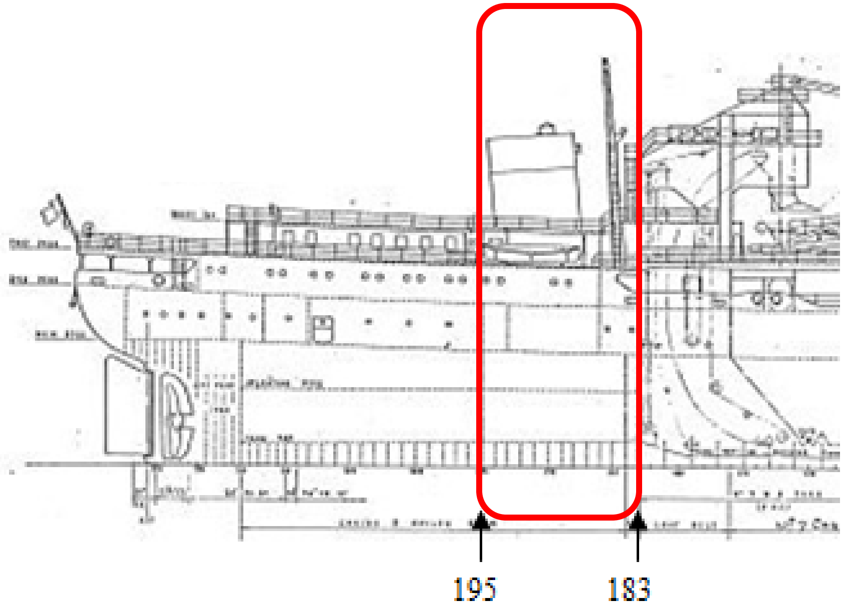


Ratio of Low Sulfur Crude Oil to price to Henry Hub natural gas price

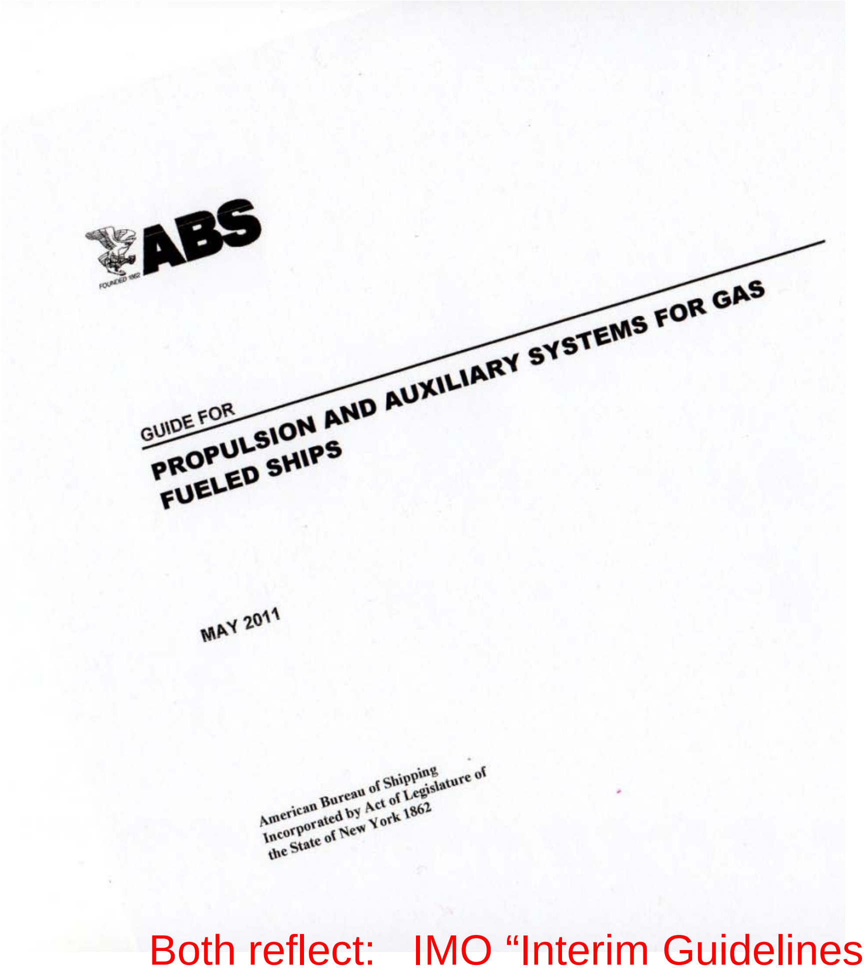
from: DOE EIA
"Annual Energy Outlook 2011 with Projections to 2035"

AAA Conceptual Design

- Same delivered power
- Same range, if feasible
- All LNG, if feasible
- ABS/DNV require LNG tanks
  near centerline
  min(B/5 or 11.5 m) from side
  min(B/15 or 2 m) from bottom
- Room for two 17.5 ft OD x 54 ft
  tall tanks P/S



Requirements Exist but Not Official Yet in U.S.



ABS

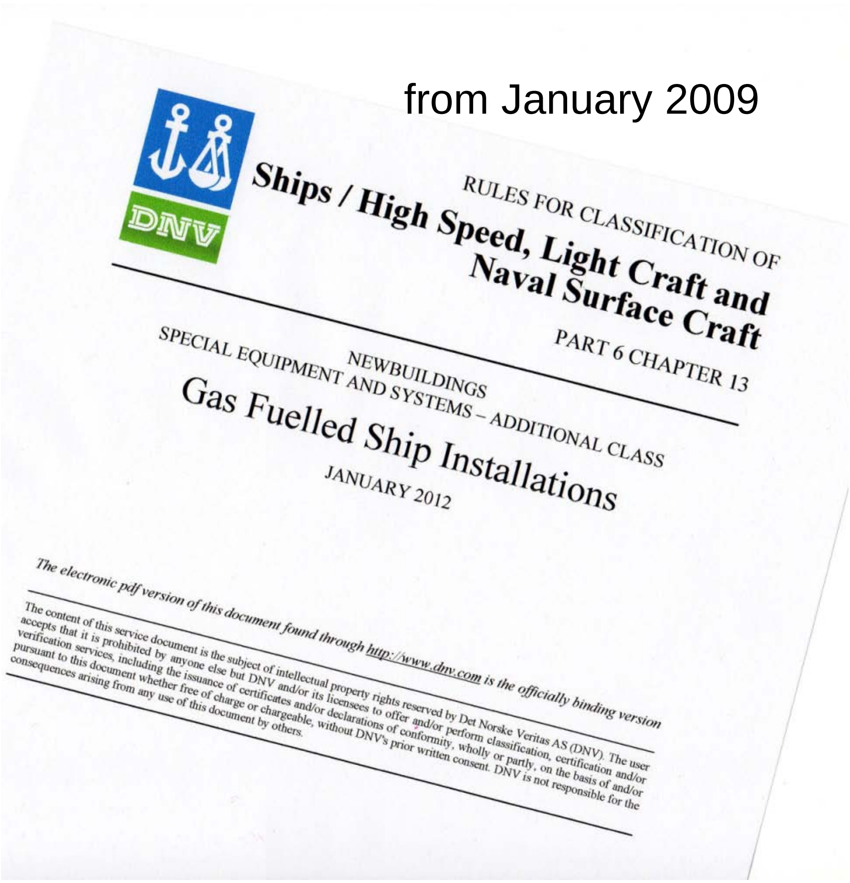
GUIDE FOR

PROPULSION AND AUXILIARY SYSTEMS FOR GAS FUELED SHIPS

MAY 2011

American Bureau of Shipping
Incorporated by Act of Legislature of
the State of New York 1862

from January 2009



DNV

RULES FOR CLASSIFICATION OF

Ships / High Speed, Light Craft and Naval Surface Craft

PART 6 CHAPTER 13

NEWBUILDINGS

SPECIAL EQUIPMENT AND SYSTEMS – ADDITIONAL CLASS

Gas Fuelled Ship Installations

JANUARY 2012

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Both reflect: IMO "Interim Guidelines on Safety for Natural Gas-Fuelled Engine Installations in Ships," Resolution MSC 285(86), June 2009

Candidate Gas Engines

vendor	Rolls-Royce Bergen	Wärtsilä	MaK (in 2014)
engine	B35:40V12PG	12V34DF	6M46C DF
operating principle	lean burn spark ignition	diesel pilot dual fuel	diesel pilot dual fuel
cylinders	12	12	6
bore (mm)	350	340	460
stroke (mm)	400	400	600
EPA Category	C3	C3	C3
rpm	750	750	514
MCR (kW)	5250	5400	5400
MCR (hp)	7040	7242	7242
gas heat rate (kJ/kWh)	7475	7700	7200
diesel pilot sfc (g/kWh)	none	1.8	2.0

Sources: Rolls-Royce 2011, Wärtsilä 2011, Westcar 2011

Plant Configuration

- Two P/S 250 cubic m useable volume LNG tanks
- Single fuel gas main engine

  Rolls-Royce Bergen B35:4012VG engine (5250 kW)

- CRP propeller driven through single reduction gear
- Three gas generator sets – under development

  Cat G3516 60 Hz 770 kWe @ 1200 rpm (available in 2014?)

- Two new gas auxiliary boilers
- Stern thruster electric; bow thruster local diesel or electric

Assumed Round Trip Voyage Duluth to Gary

mode of operation	percent propulsion power	auxiliaries in use	hours per voyage	percent of voyage
loading	0.00%	ship service, ballast pumps	6	4.40%
maneuvering	30.00%	ship service	6	4.40%
reduced speed	50.00%	ship service	8	5.90%
open lake	85.00%	ship service	103	76.30%
locking/docking	10.00%	ship service, thrusters	2	1.50%
unloading	0.00%	ship service, ballast pumps, conveyors	10	7.40%
total			135	100.00%

Re: Parsons, M. G., Singer, D. J. and Denomy, S. J. 2011 Integrated electric plants in future Great Lakes self-unloaders, *Journal of Ship Production and Design*, **27**, 4, 169-185.

LNG Use in One Summer Round Trip

mode	hours	prop. kW	% load	kJ/kWh	LNG cubic m	ship service	ballast pumps	stern thruster	unload. conv.	total kWe	% e load	kJ/kWeh	LNGe cubic m	total kW
open lake	103	4572.2	87%	7550	172.1	476.4	0.0	0.0	0.0	476.4	61.9%	8800	20.9	5068.5
reduced speed	8	2700.0	50%	7600	7.9	476.4	0.0	0.0	0.0	476.4	61.9%	8800	1.6	3196.3
maneuvering	6	1620.0	30%	7750	3.6	476.4	0.0	0.0	0.0	476.4	61.9%	8800	1.2	2116.3
locking/docking	2	540.0	10%	8280	0.4	519.8	0.0	745.7	0.0	1265.5	82.2%	8550	1.0	1858.2
loading	6	0.0	0%	0	0.0	392.5	226.0	0.0	0.0	618.5	80.3%	8600	1.5	644.3
unloading	10	0.0	0%	0	0.0	488.9	226.0	0.0	1107.2	1822.1	78.9%	8650	7.6	1898.0
total	135	hours			184.1	cubic m						ship service	34.0	cubic m
	5.625	days		assumptions:								propulsion engine	184.1	cubic m
				LHV	45,300	kJ/kg						auxiliary boiler	0.8	cubic m
				density	0.465	t/cubic m						Total	218.9	cubic m

Tank margins:

head space 10%

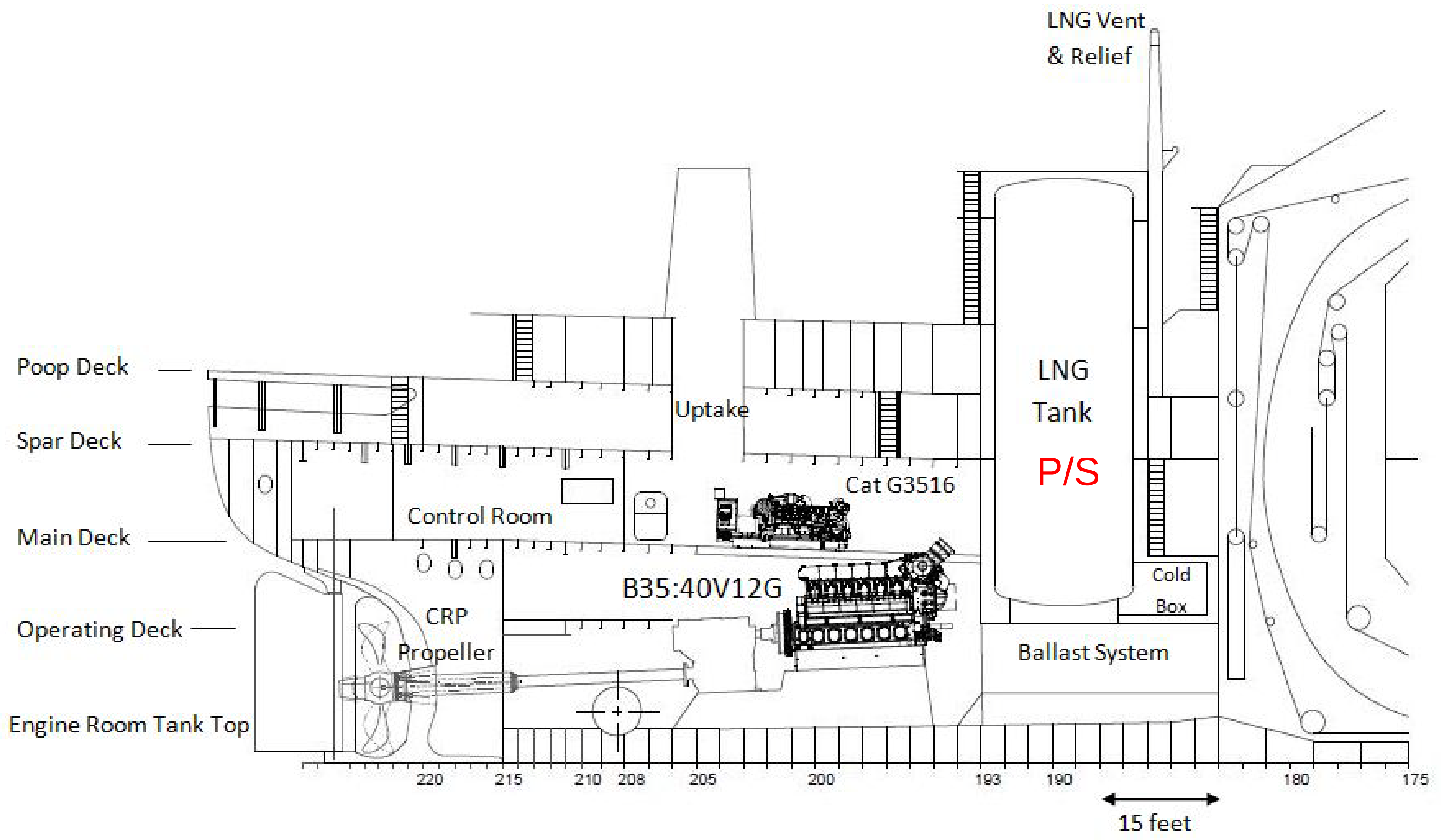
cooling margin 5%

Operational fuel margin with two 250 cubic m useable volume tanks:

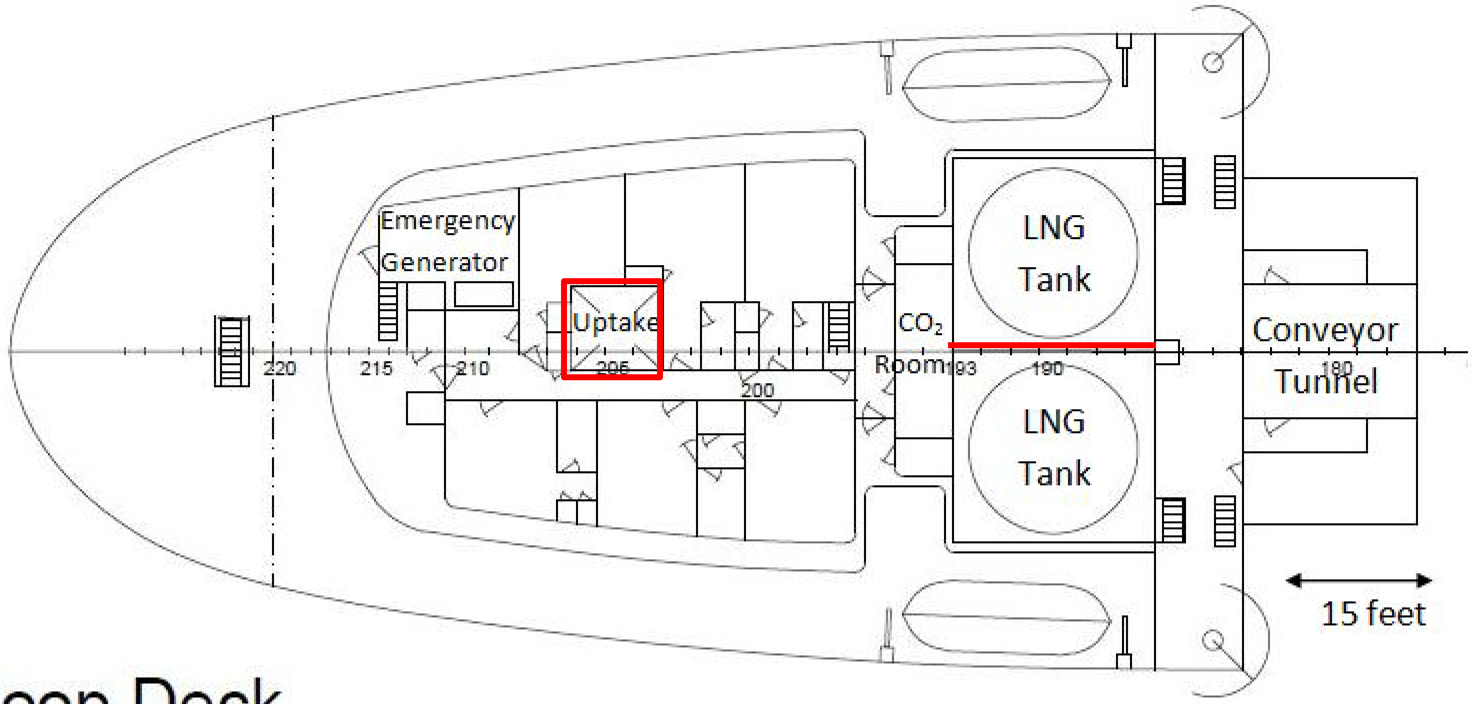
12.4% when refueling every second round trip

45.5% when refueling once per week

AAA Conversion Inboard Profile

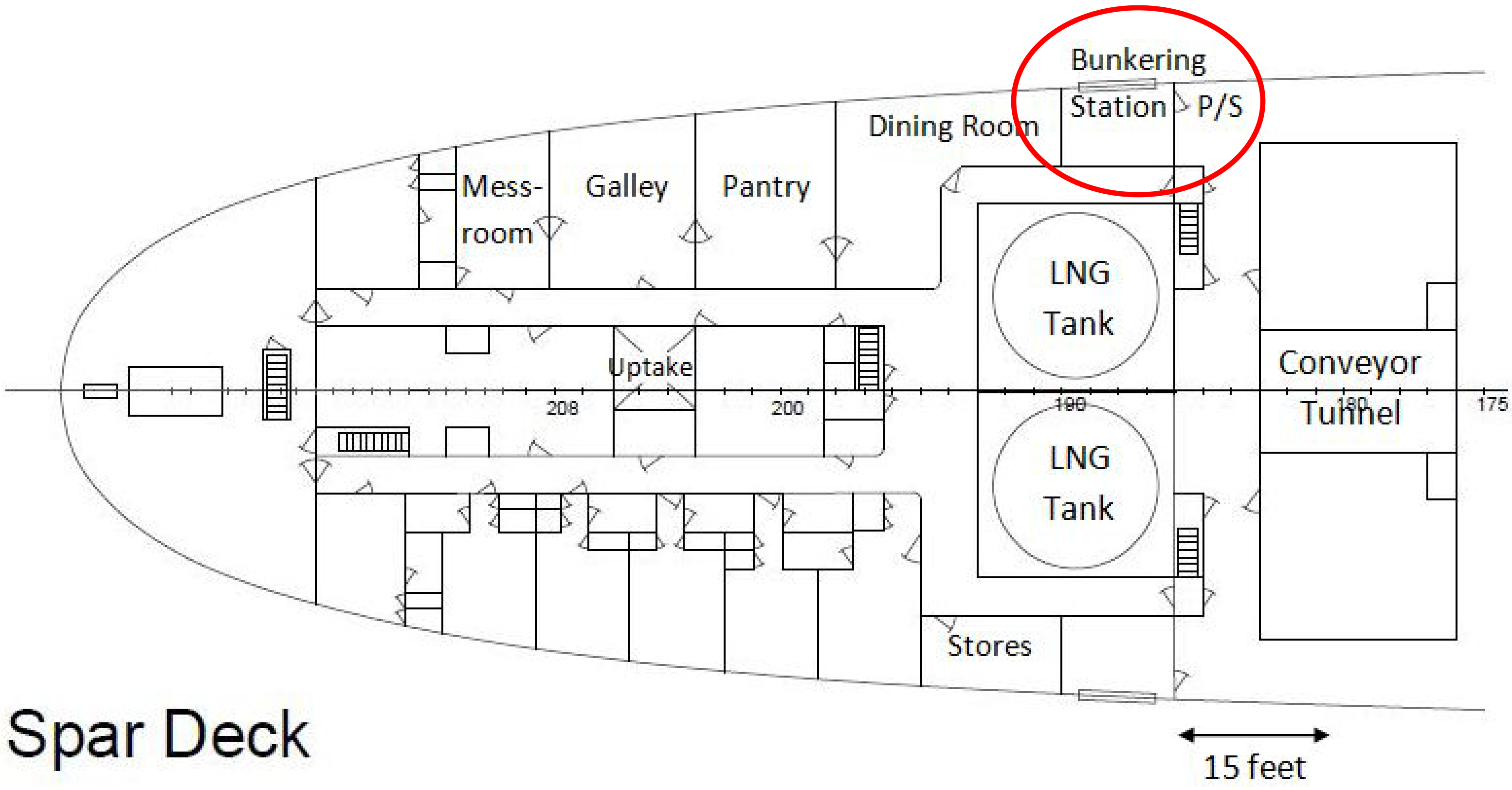


AAA Conversion Poop Deck

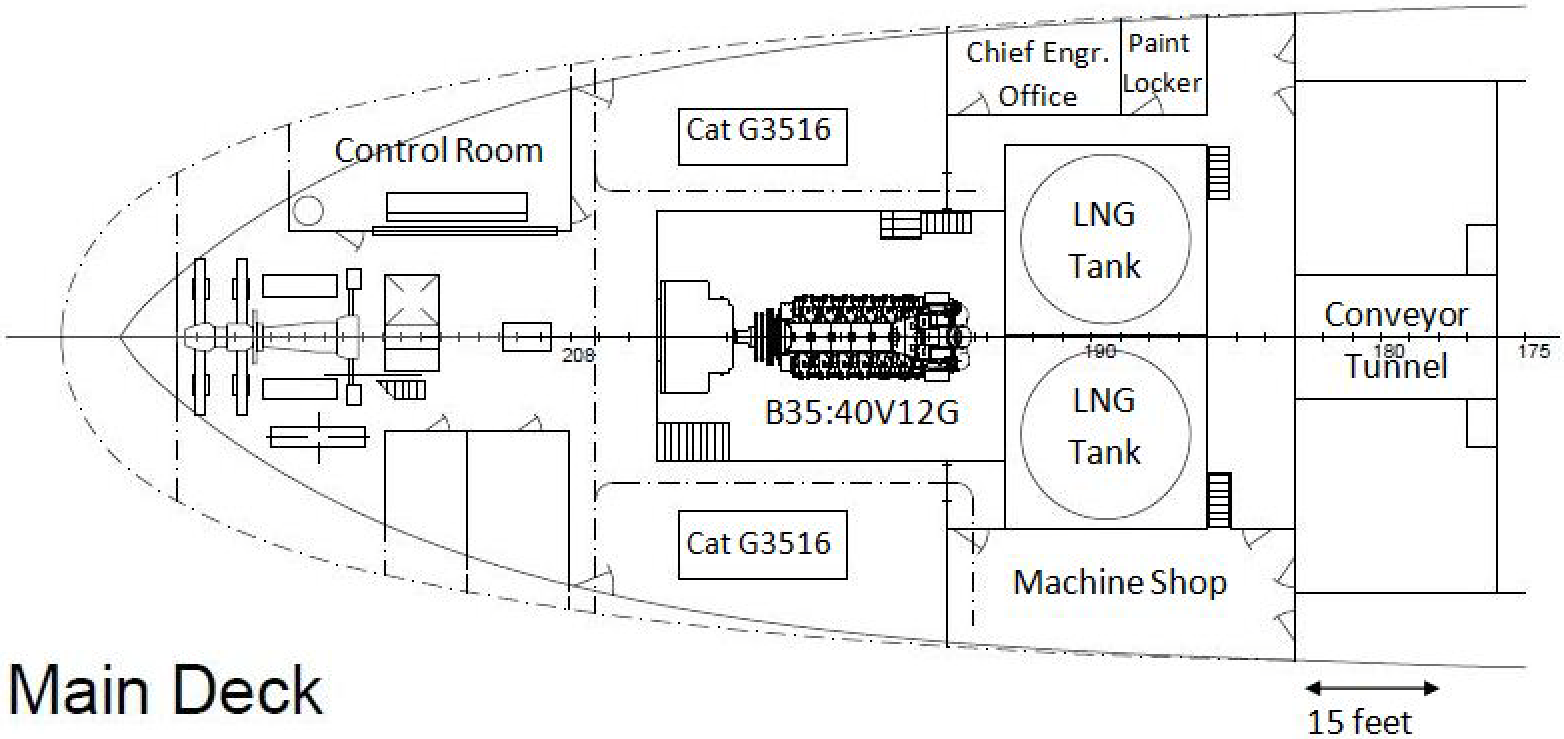


Poop Deck

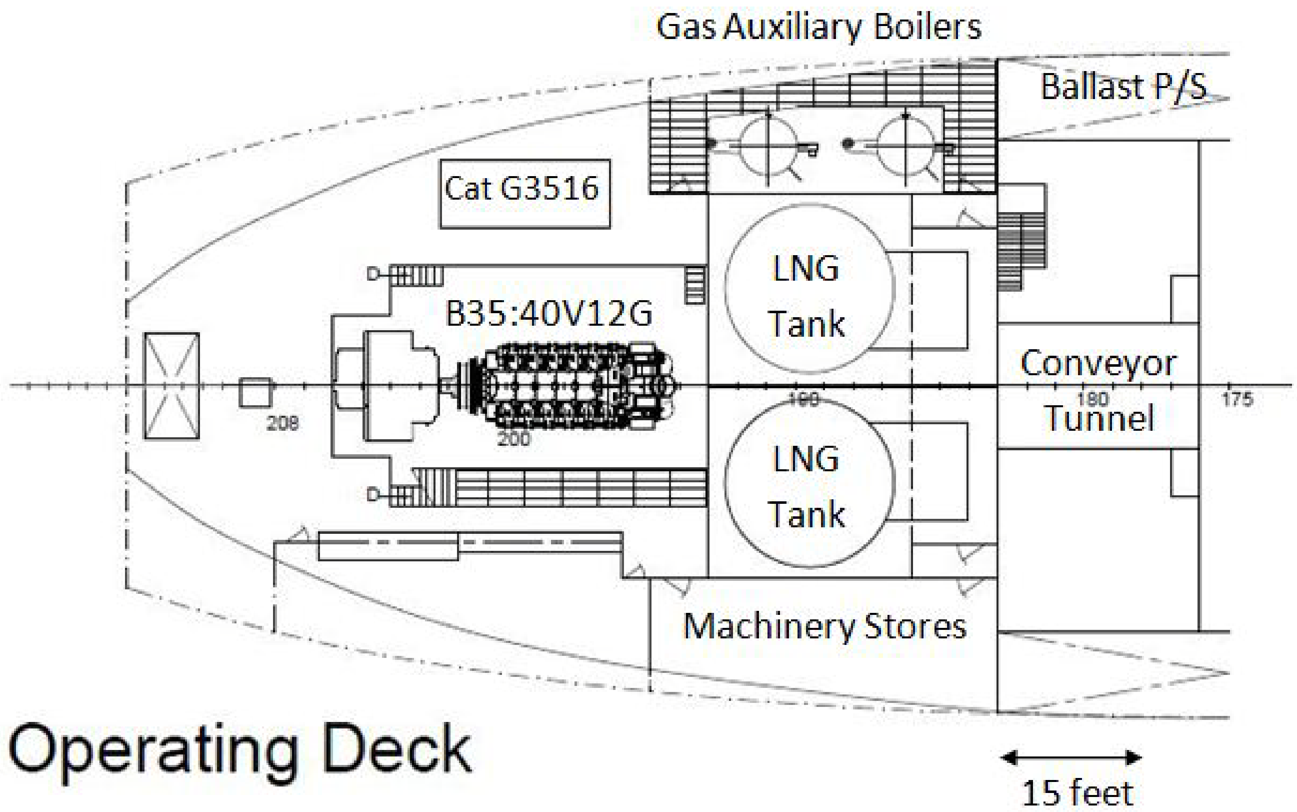
AAA Conversion Spar Deck



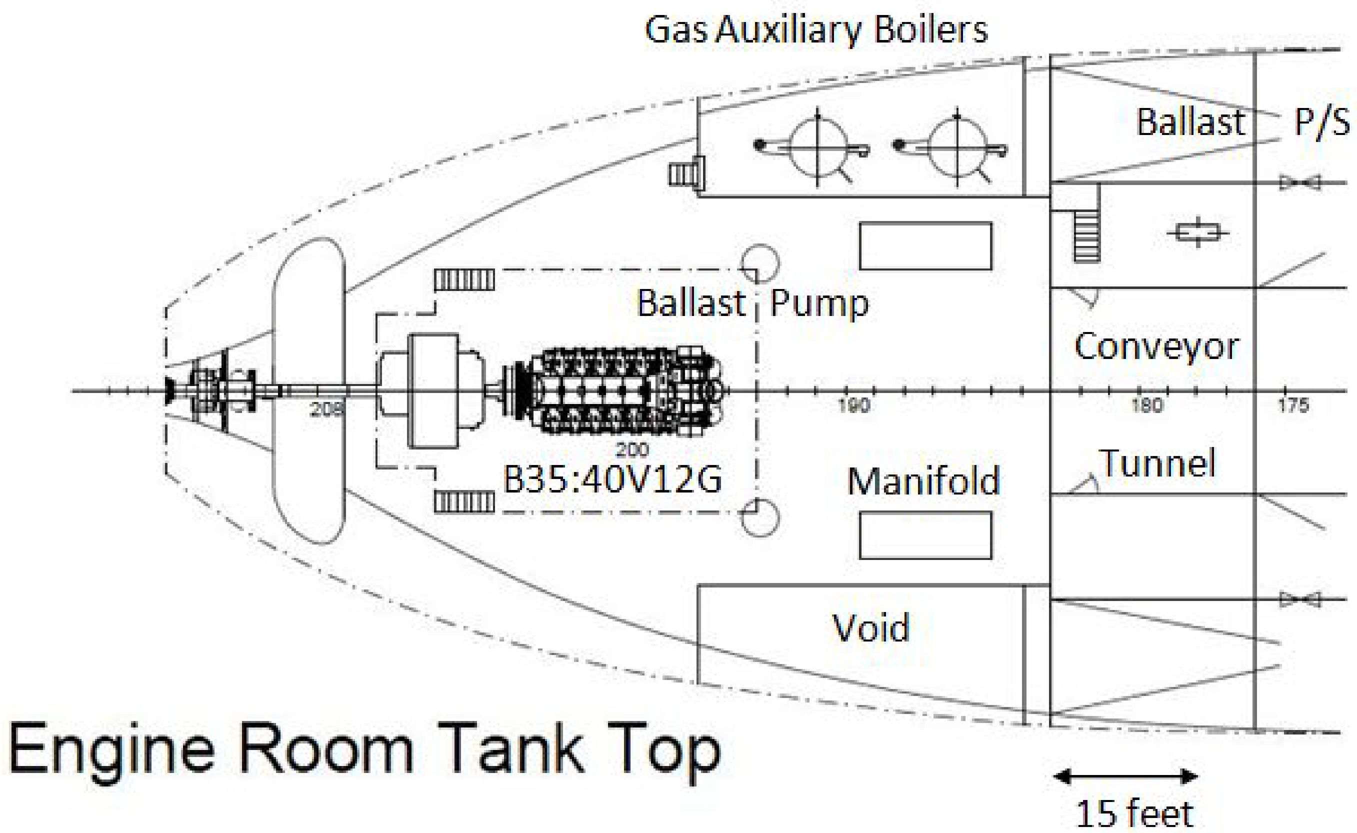
AAA Conversion Main Deck



AAA Conversion Operating Deck



AAA Conversion Tank Top



Conversion Thoughts

- No regulations at this time – case-by-case equivalency
- More regulatory overhead – recommend a Phase I
- Two vertical accesses – 100 tonne lifts for tanks
- Mechanical conversion ~ same as a diesel conversion
- Pre-outfitted control room – ballast control panel?
- Important to load tanks with cold boxes – FR183-FR193
- Gas generator set availability problematic for first few

Conclusions and Plans

Conclusions

- The availability of LNG at an appropriate price will be critical to the economic viability of conversion to LNG fuel rather than conversion to diesel.
- The other challenges appear to be workable.
- The arrangement of the AAA LNG conversions to ABS/DNV requirements appears feasible.

Next tasks for AAA class

- Weight study
- Stability study
- Ventilation
- Refine arrangements
- Air emissions comparison:
  steam, diesel, LNG
- Notional shipyard planning/cost
- Life-cycle cost/payback

Feasibility for other vessels

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Questions?