Gas Fuelled ships

LNG-Fuelled Engines and Fuel Systems for Medium- Speed Engines in Maritime Applications

Dag Stenersen, MARINTEK

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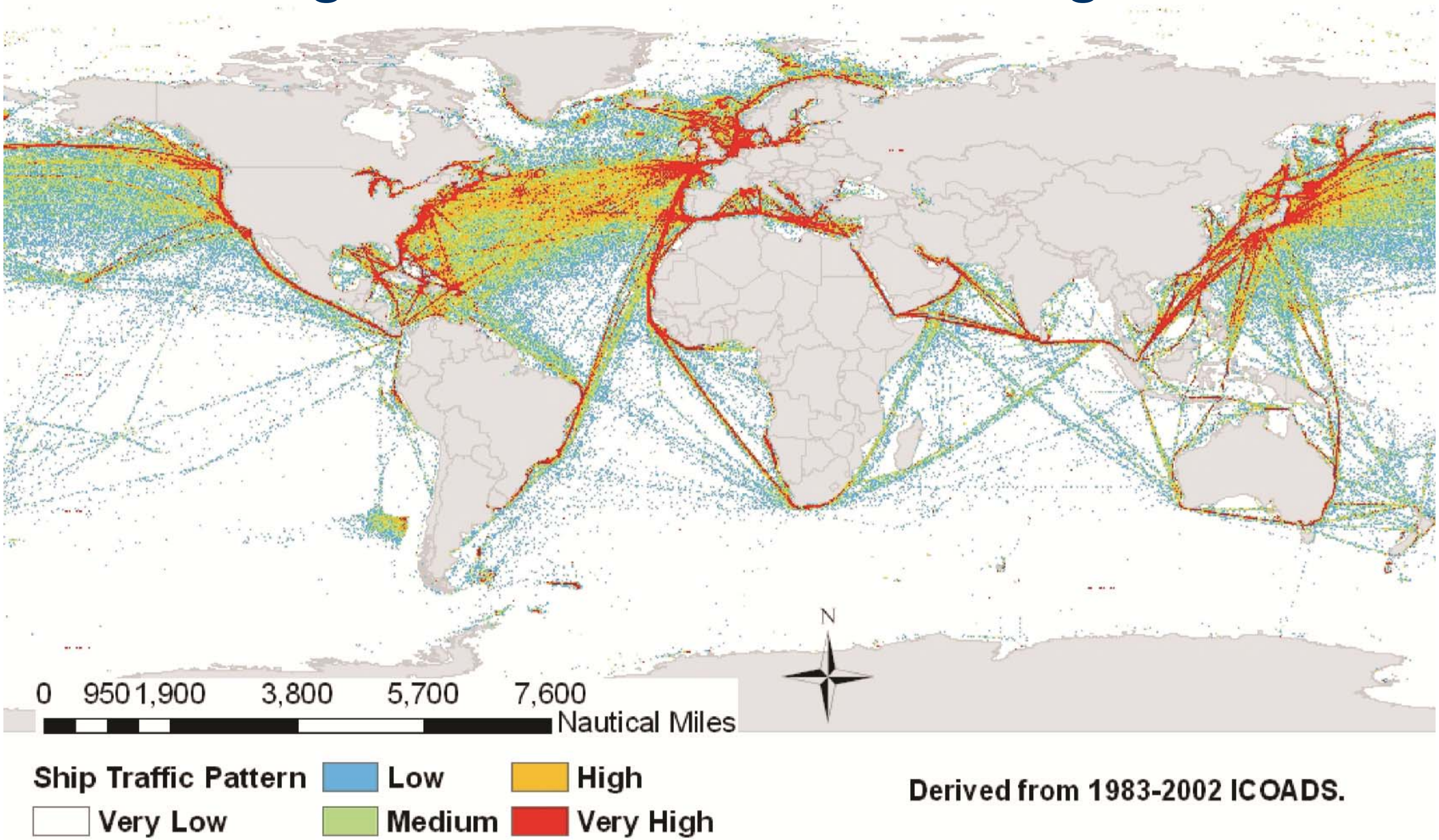
Presentation outline

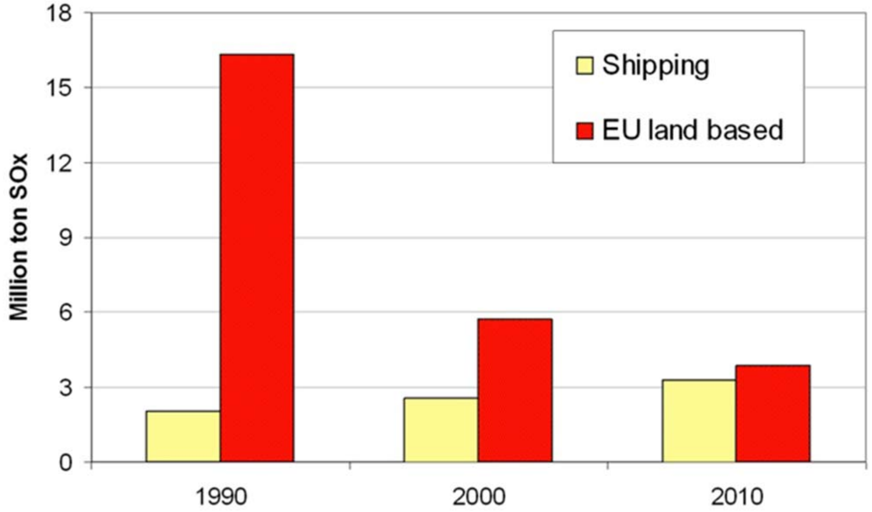
- Background
  - Environmental challenges and emission restrictions at sea
  - Need for alternative fuels (to replace HFO)
  - ”Small scale LNG” and LNG fueled ships
- Natural Gas fueled marine engines
- Propulsion systems and onboard LNG fuel systems
- Bunkering - fuel supply infrastructure
- Safety - rules and regulations
- LNG in short sea shipping in Norway
- R&D Challenges
- Summary and conclusions

Global shipping –
Regional and local challenges



IMO MARPOL Annex VI - SOx /NOx emission limits in ECA from 2015/2016

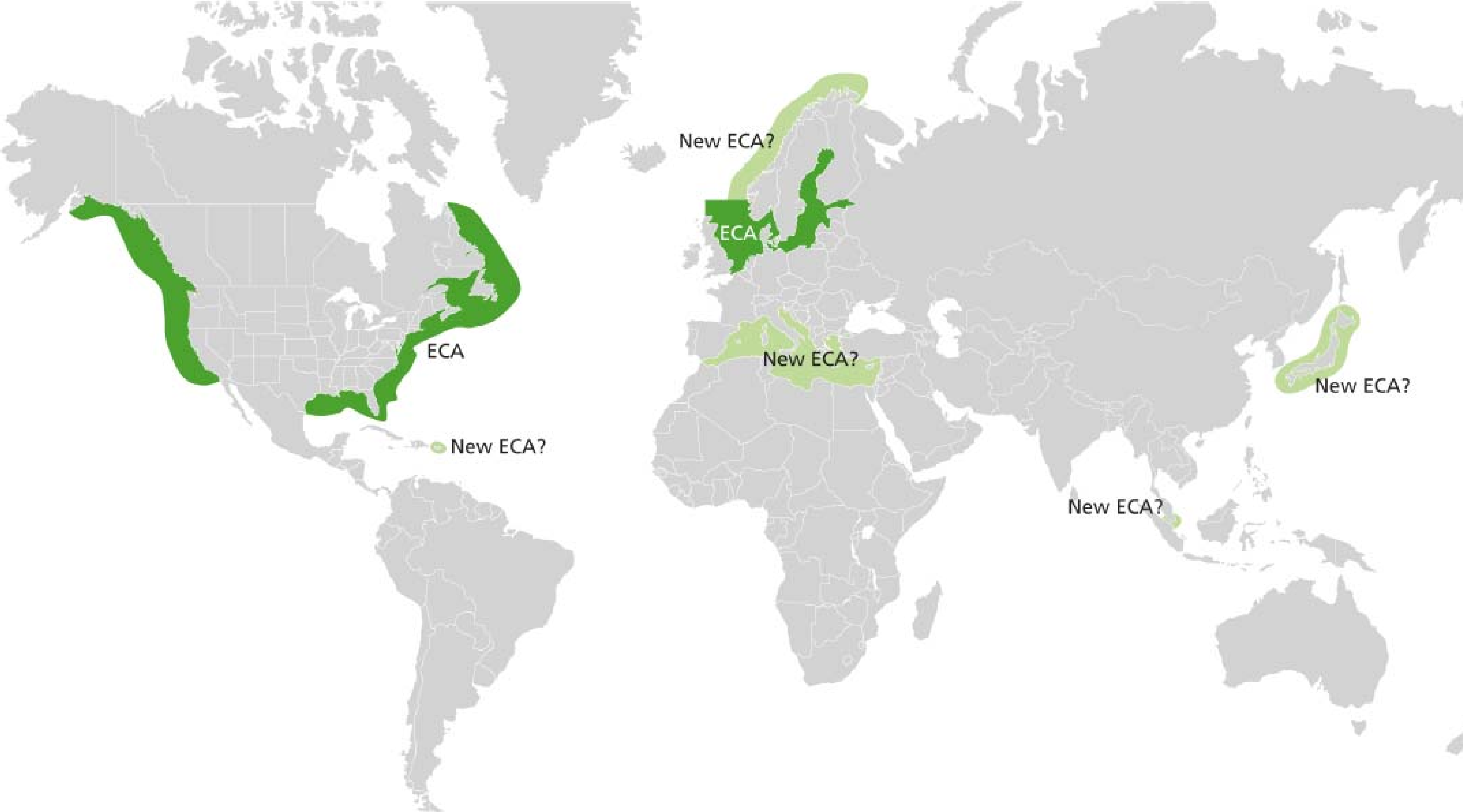
- New stringent limits for SOx and NOx in Emission Control Area (ECA)
  - SOx for all ships after 2015.
  - NOx for new ships after 2016.



- Demand for reduction of Green House Gases (GHG) from shipping which mainly consists of CO_2
- Expecting new special limits for Particular Matter (PM)

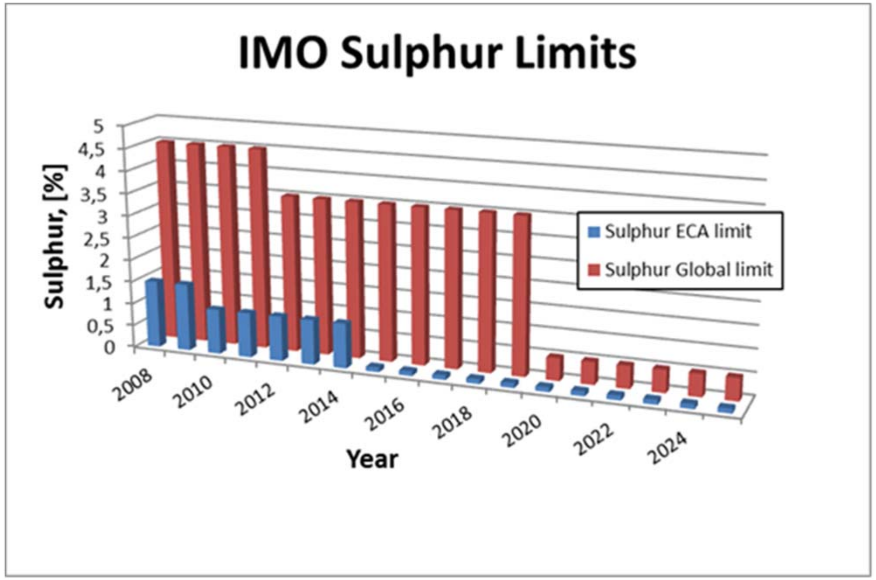
Marpol 73/78 is the International Convention for the Prevention of Pollution From Ships, 1973 as modified by the Protocol of 1978

Emission Control Areas (ECA)



IMO MARPOL Annex VI - SOx emission limits

Stricter IMO limitation on SOx



Global sulphur limitations

- Global cap from 4,5% to 3,5% effective from 1. January 2012
- Global cap from 3,5% to 0,5% effective from 1. January 2020

SECA (Sulphur Emission Control Area) limitations*

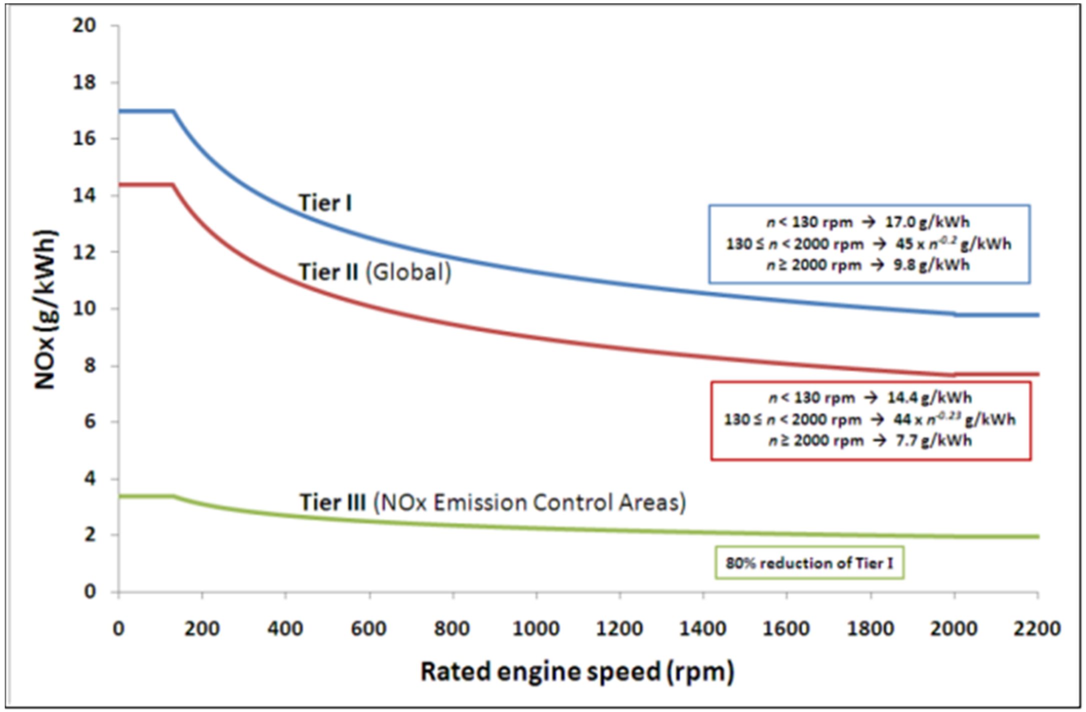
- New sulphur limit from 1,5% to 1,0 % effective from 1. March 2010
- New sulphur limit from 1,0% to 0,1 % effective from 1. January 2015

PM (Particulate Matter) regulated indirectly by the sulphur reduction

*(SECA=ECA)

IMO requirements to prevent pollution from ships

IMO MARPOL Annex VI - NOx emission limits



Global NOx limitations

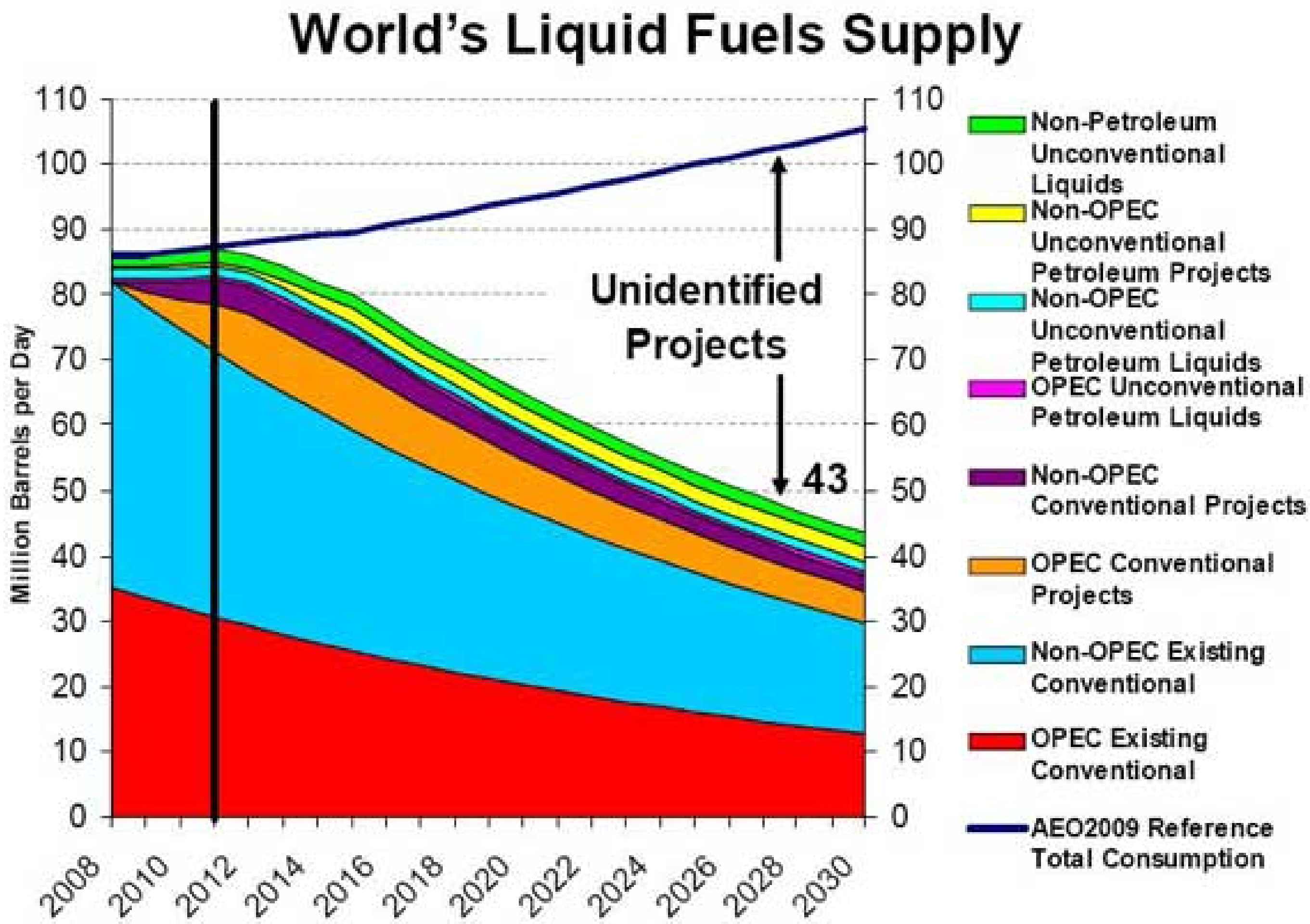
- Tier II ⇒ 20% reduction of Tier I limit for new ships after 1. January 2011

Emission Control Area (ECA)

From 1. January 2016

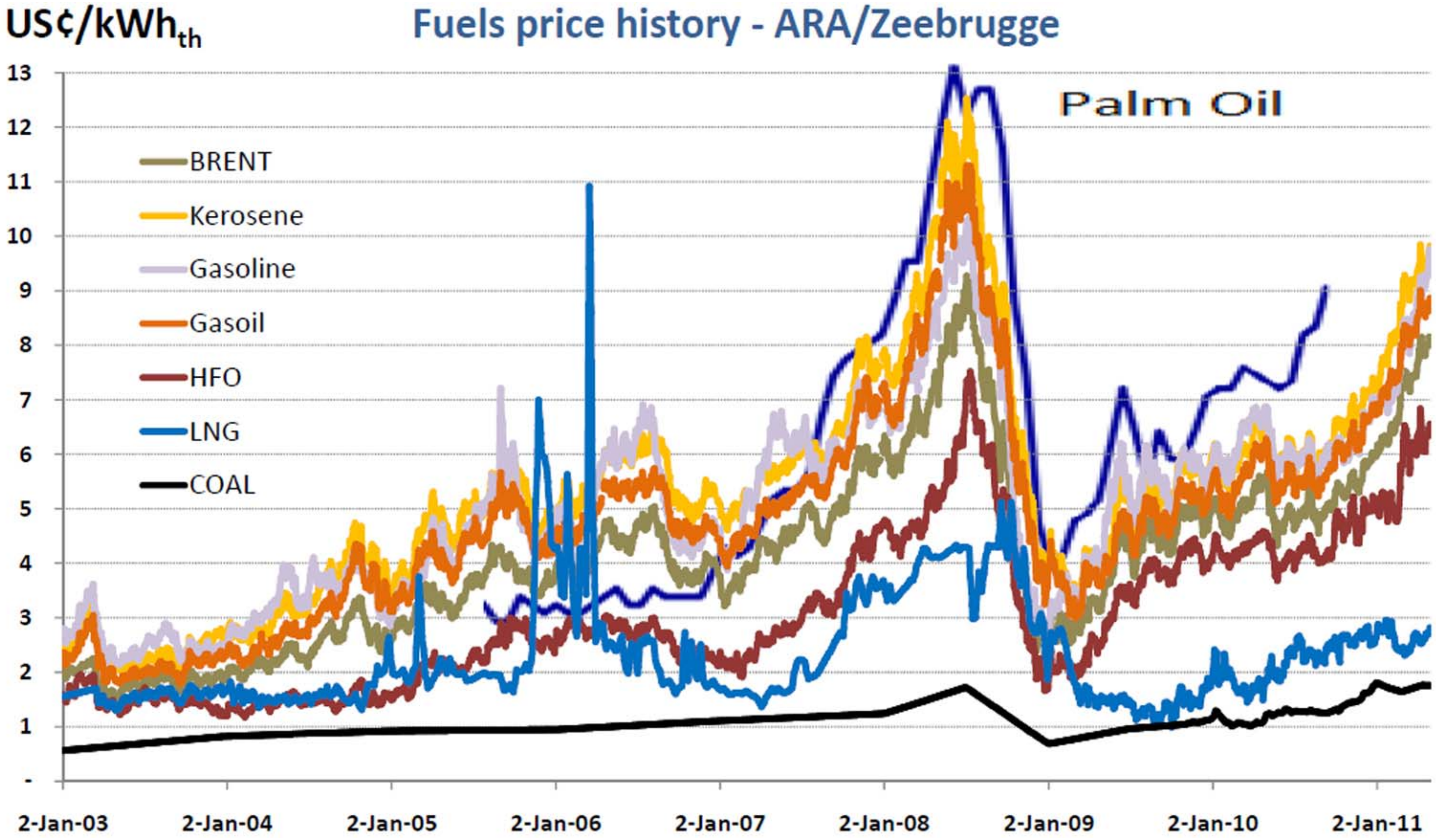
- NOx Tier III ⇒ 80% reduction from Tier I limit (new ships)

Need for alternative fuels



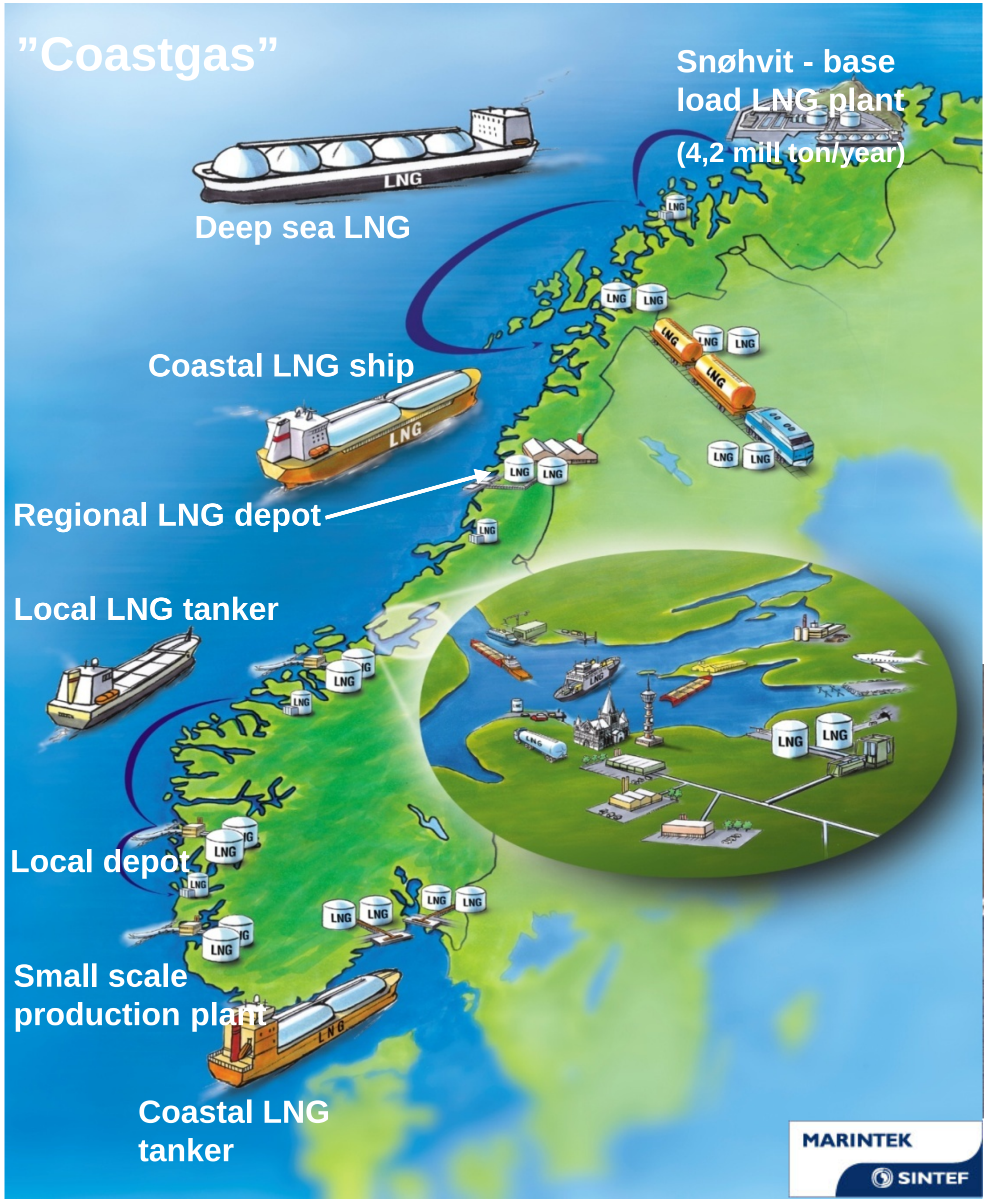
Source: EIA, AEO2009

Fuel cost development



Source: AIR-LNG SA elaborations, based on eia.doe & Platts statistics

“Small scale LNG” distribution system



<u>Covering the long coast of Norway</u>

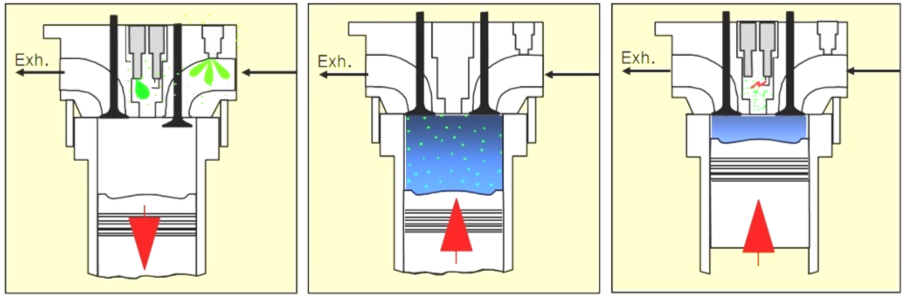
- LNG source
  - Base load LNG to receiving terminals
  - Small scale LNG production plants (4) 10.000-300.000 ton/year
- LNG distribution
  - Coastal tankers (1000 m^3 – 7500 m^3)
  - Trailers (50m^3), rail or local pipeline
- LNG terminals (~40)

  100m^3 - 6500m^3 LNG

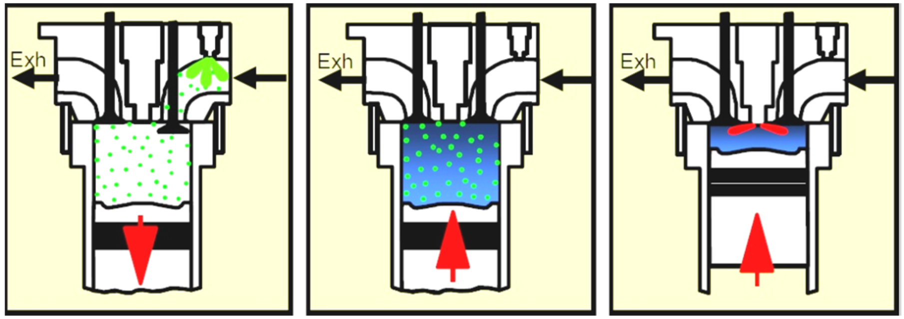
Development of LNG fueled marine engines

- Started in 1980 to develop engines for LNG carriers utilizing boil-off gas as fuel
- Commercial engine development started 1984 - resulting in 3 engine concepts released 1988-1996:
  - Spark Ignited Lean Burn engine (Otto cycle)
  - Dual fuel engine (Combined Otto/Diesel cycle)
  - High pressure direct injection engine (Diesel cycle)
- Application – stationary power and heat generation (COGEN)
- First marine application in 2000 – The “prototype” LNG fuelled ship “MF Glutra”
- 2003: Commercial market growing from the Small scale LNG project
  - Engine and fuel system development continues to improve performance and safety for marine applications
- 2011: Fast growing interest in deep-sea shipping applications
  - Driven by emission control legislation and fuel cost
  - Large slow speed engines under development
  - New ships and retrofit installations in existing vessels

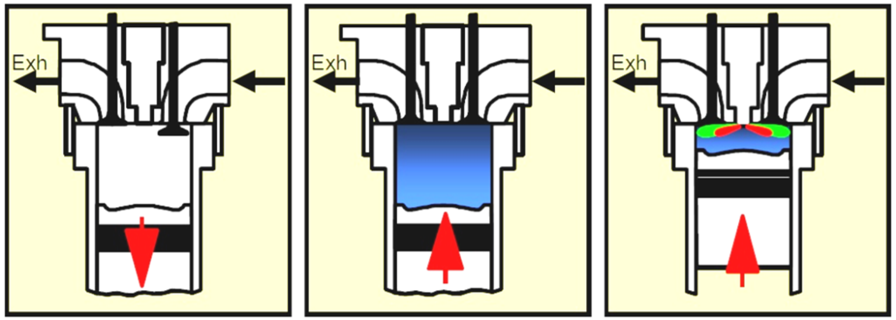
LNG fueled marine engine concepts



LEAN BURN SPARK IGNITED ENGINE (LBSI)



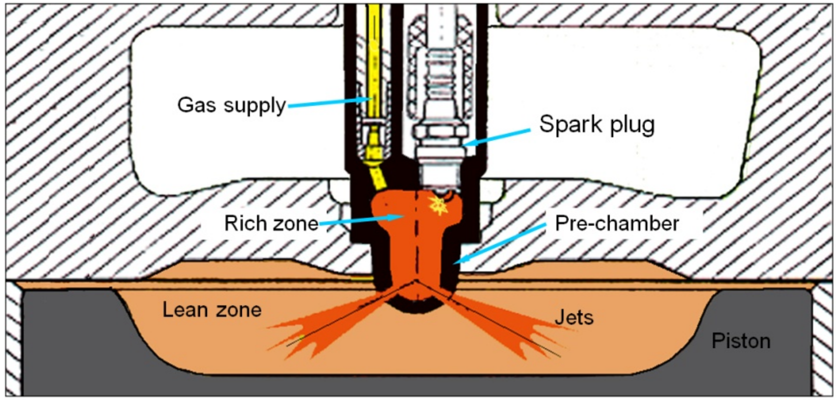
DUAL FUEL GAS ENGINE (DF) –
PILOT DIESEL IGNITION



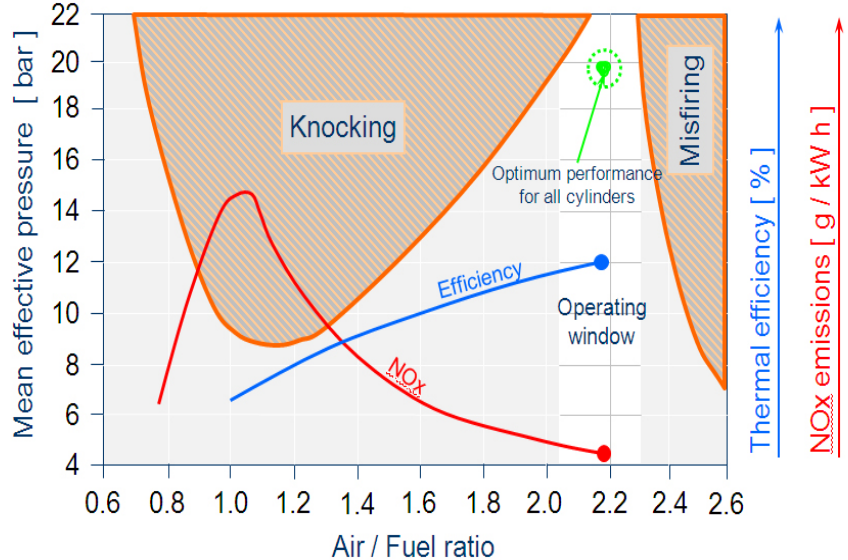
High pressure gas injection -
“Gas Diesel engine” –(GD)

Spark Ignited Lean Burn gas engine (LBSI)

- Single fuel LNG, low pressure gas supply (4-5 bar)
- High energy efficiency at high load, higher than the corresponding diesel engine
- Low emissions, meets IMO tire III
- GHG reduction potential in the range of 20-30% ref. to HFO (incl. methane)

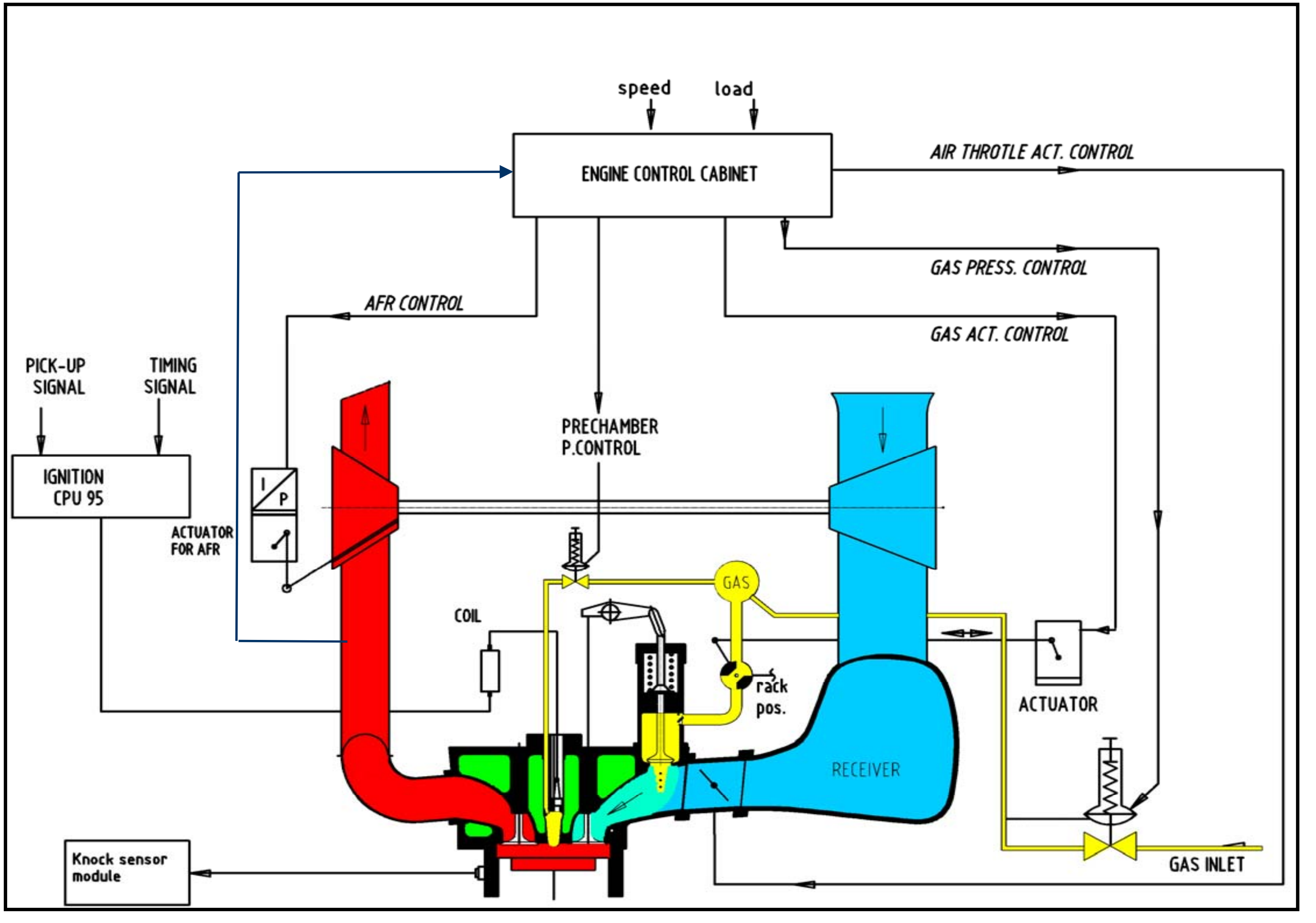


- Challenge on methane slip, minimized by design and combustion process control
- Sensitive to gas quality (Methane Number)
- Not suitable for retrofit of existing engines



Rolls-Royce C26:33L9

Engine control principles (LBSI)

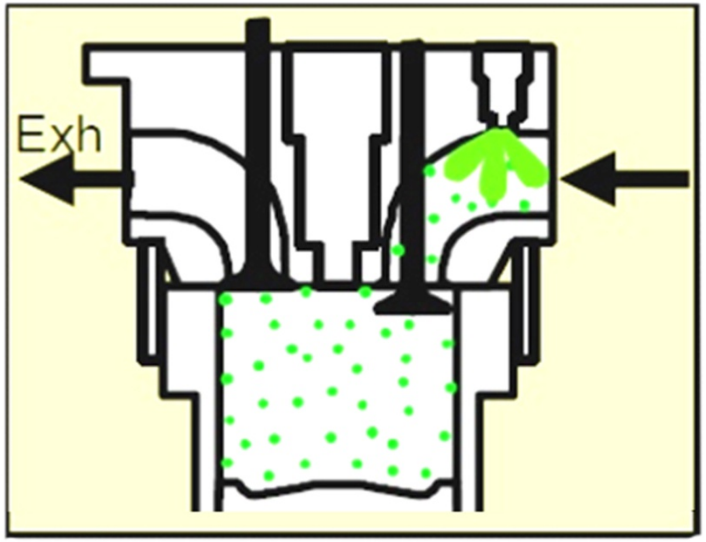


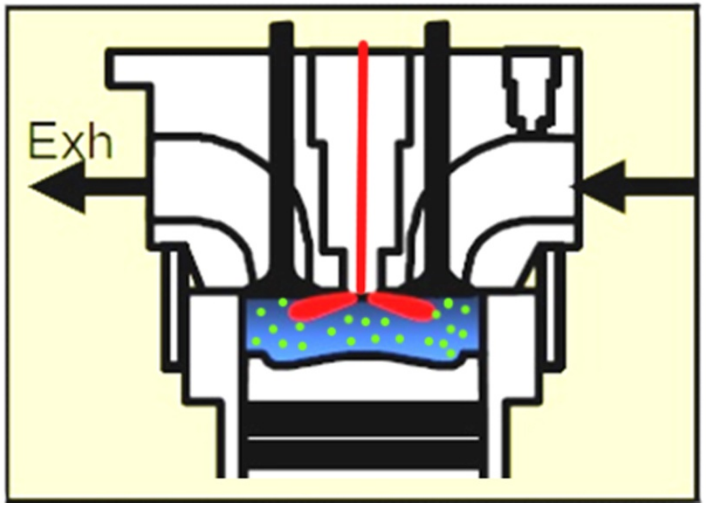
Dual-Fuel engine (DF)

- Dual fuel capability (LNG-MDO)
- Low gas pressure supply (4-5 bar)
- High energy efficiency at high load
- Low emissions, meets IMO tire III
- Flexibility in fuel mix
- GHG reduction potential in the range of 20-30% ref. to HFO (reduction is dependant on level of methane slip)

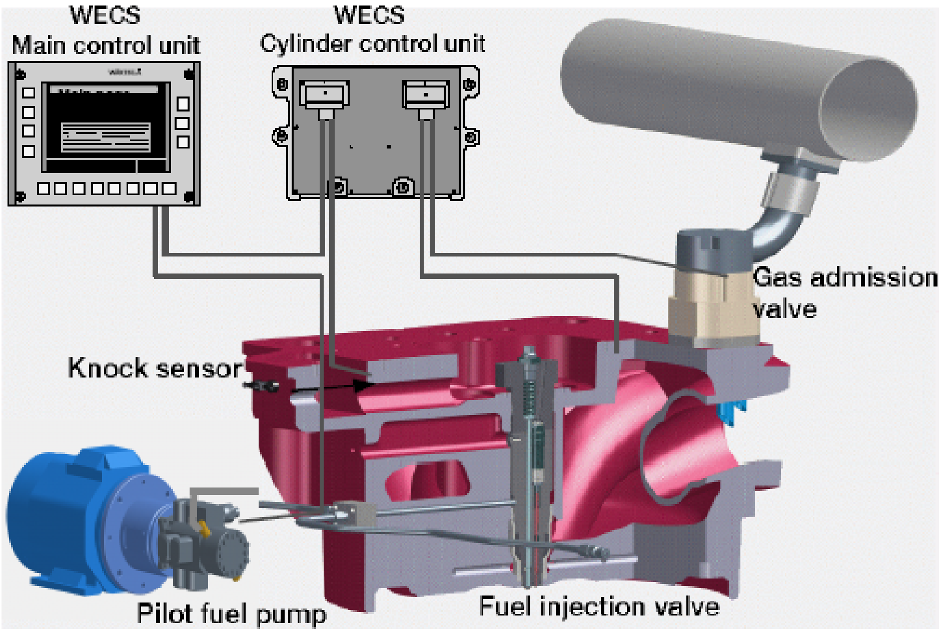
- Challenge on methane slip, limited possibility to combustion process control
- Sensitive to gas quality (Methane Number)
- Possible for conversion of existing engines (extensive rebuilding)

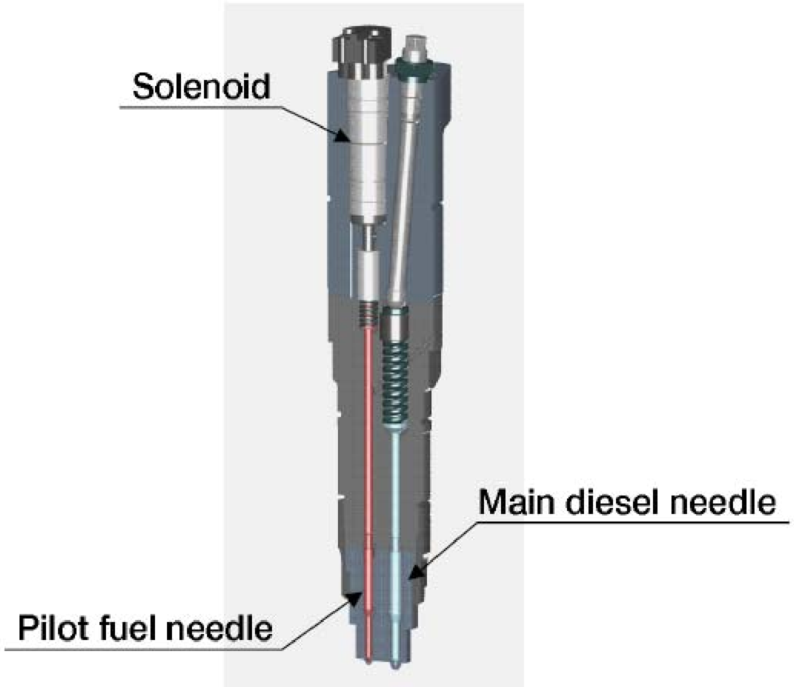
Wärtsilä 6L50DF





”Micro Pilot” Dual Fuel concept
(Wärtsilä 32)





DF - fuel injector

- Separate micro pilot injection - only 0,5 – 1,0% of fuel at full load
- Common rail - high injection pressure (>1000 bar)
- Central location of pilot sprays

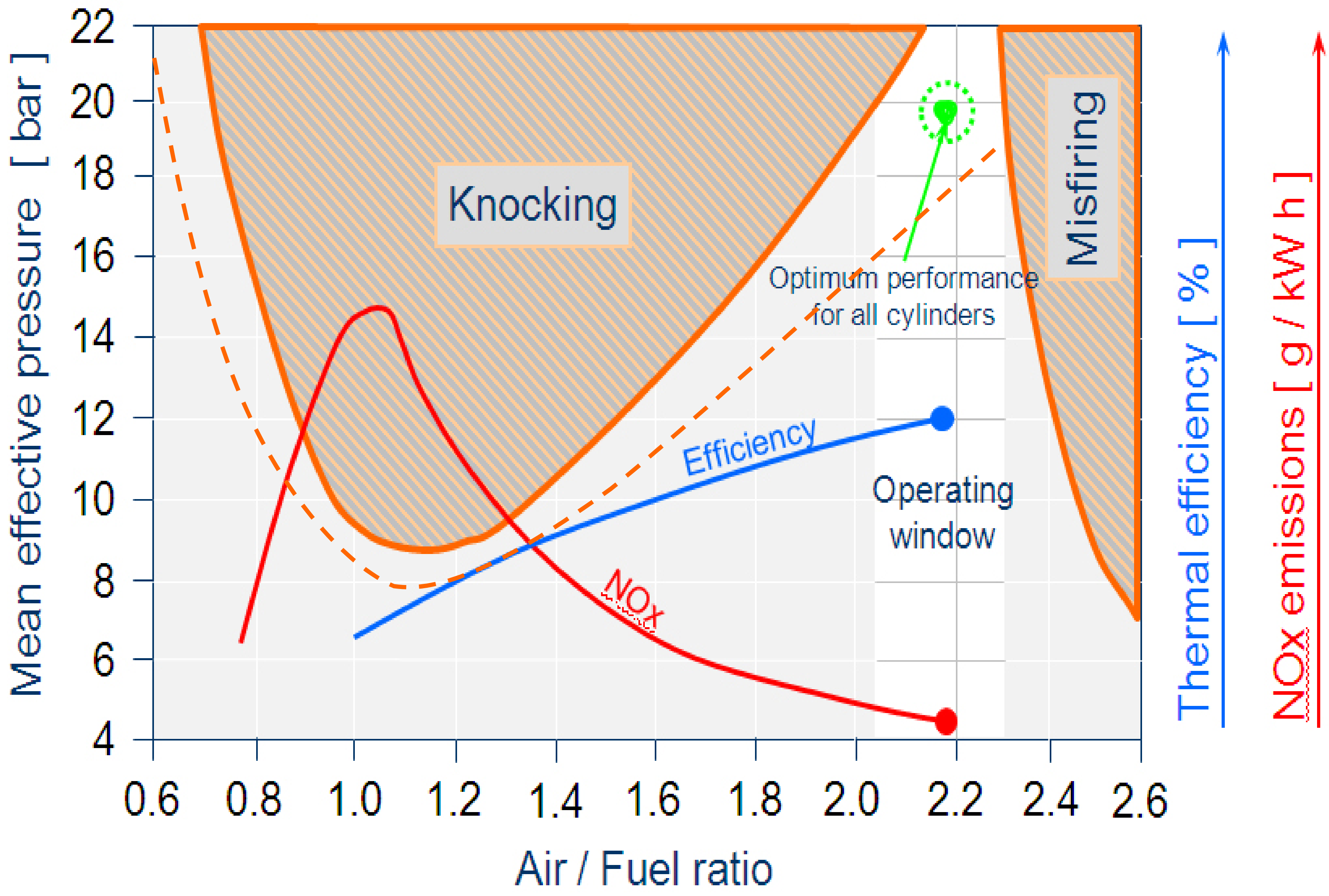
LNG fuel qualities – variable composition

Worldwide LNG composition

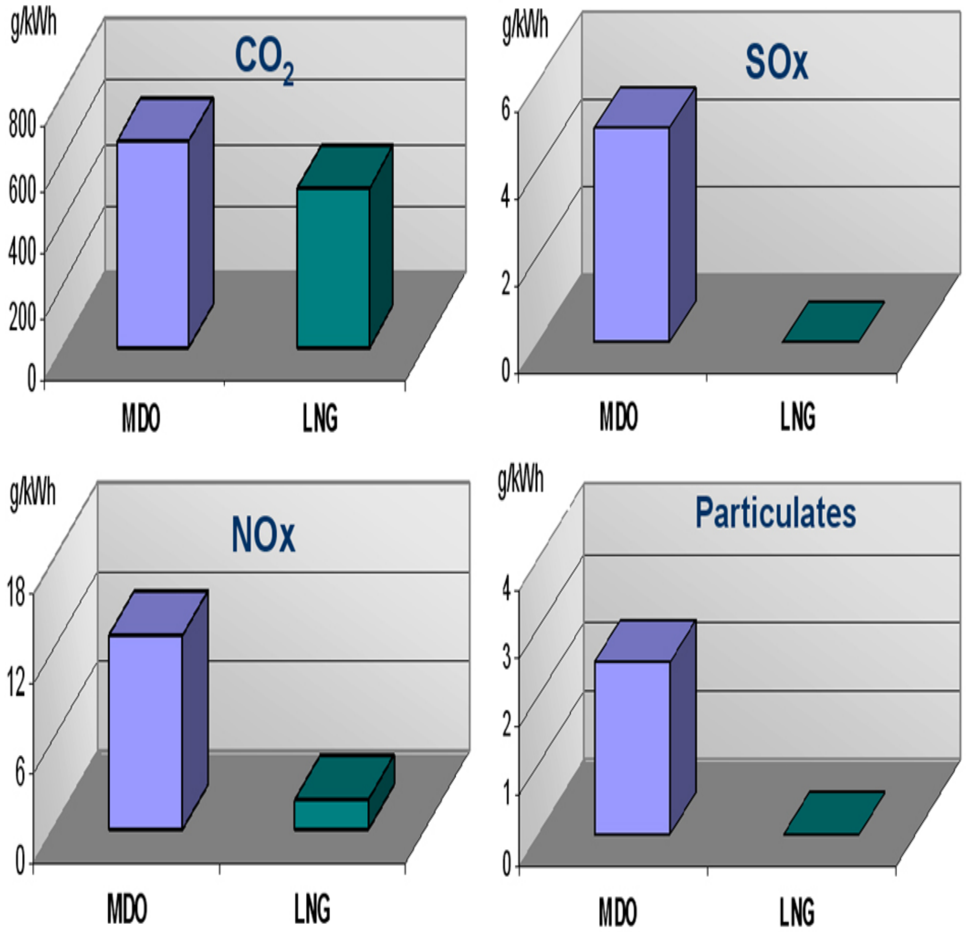
	Typical LNG composition in volime %							
LNG export terminals	C1	C2	C3	C4	C5+	N2	LHV[MJ/kg]	MN
Arun (Indonesia)	89,33	7,14	2,22	1,17	0,01	0,08	49,4	70,7
Arzew (Algeria)	87,4	8,6	2,4	0,05	0,02	0,35	49,1	72,3
Badak (Indonesia)	91,09	5,51	2,48	0,88	0	0,03	49,5	72,9
Bintulu (Malaysia)	91,23	4,3	2,95	1,4	0	0,12	49,4	70,4
Bonny (Nigeria)	90,4	5,2	2,8	1,5	0,02	0,07	49,4	69,5
Das Island (Emirates)	84,83	13,39	1,34	0,28	0	0,17	49,3	71,2
Lumut (Brunei)	89,4	6,3	2,8	1,3	0,05	0,05	49,4	69,5
Point Fortin (Trinidad)	96,2	3,26	0,42	0,07	0,01	0,01	49,9	87,4
Ras Laffan (Qatar)	90,1	6,47	2,27	0,6	0,03	0,25	49,3	73,8
Skida (Algeria)	91,5	5,64	1,5	0,5	0,01	0,85	49	77,3
Snøhvit (Norway)	91,9	5,3	1,9	0,2	0	0,6	49,2	78,3
Withnell (Australia)	89,02	7,33	2,56	1,03	0	0,06	49,4	70,6

Note the variation of Methane Number (MN) 87.4 – 69.5

Lean Burn combustion (LBSI and DF)



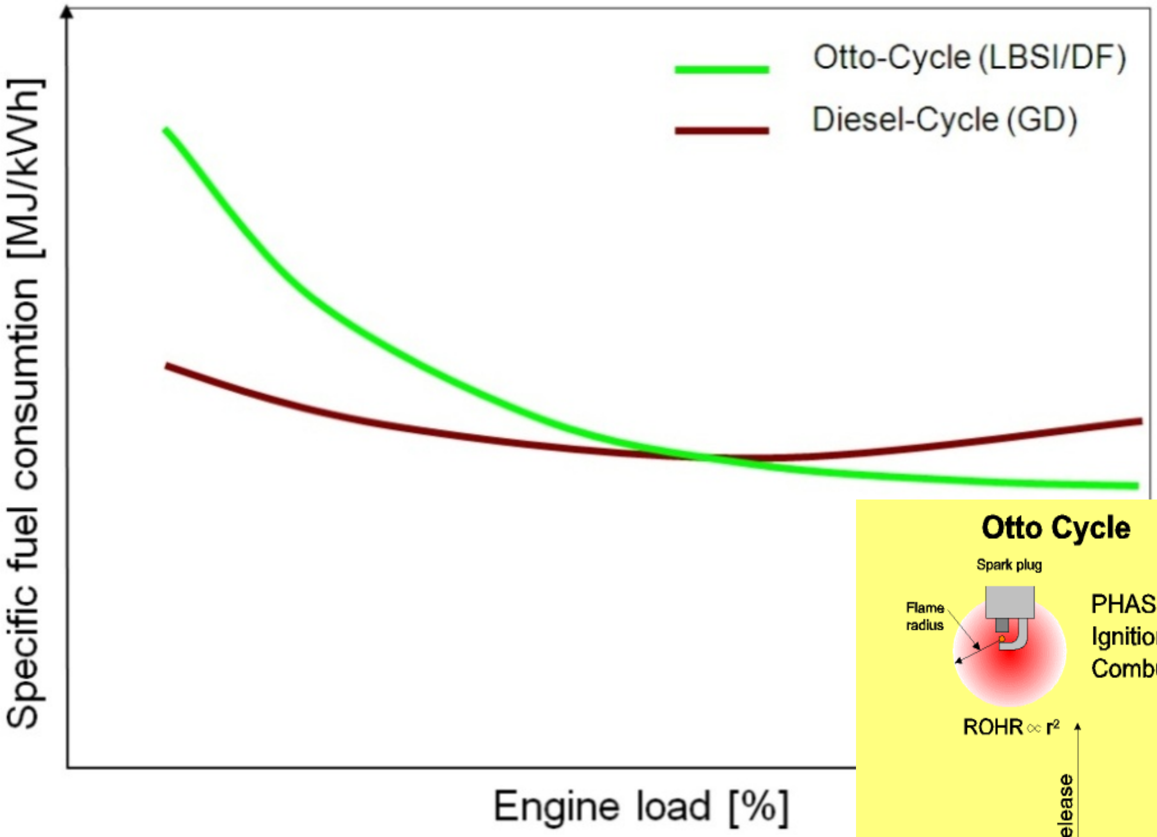
Exhaust emission - Natural gas vs. MDO



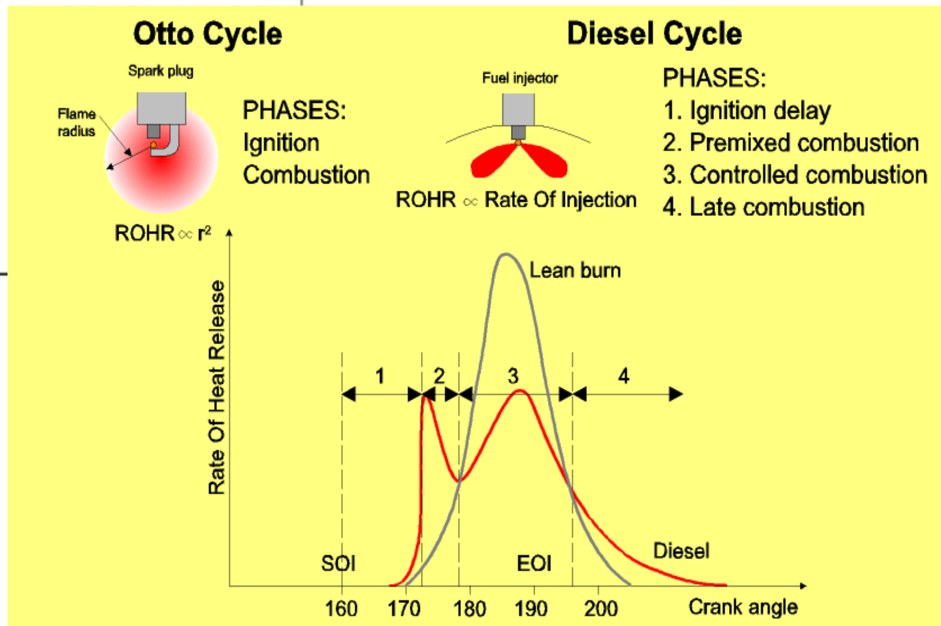
Source: Rolls-Royce Marine

- Sulphur emission is eliminated
- Particulate matters is close to zero
- CO_2 is reduced by up to 30%
  (Due to unburned methane the net reduction of GHG are in the range of 0% - 15%)
- NOx is reduced by 80-90%

Performance – lean burn vs. diesel

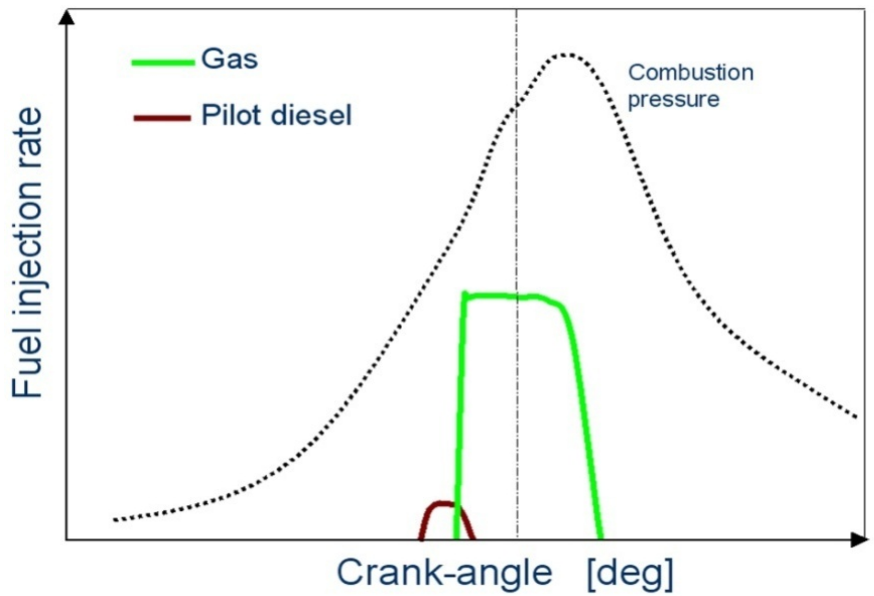


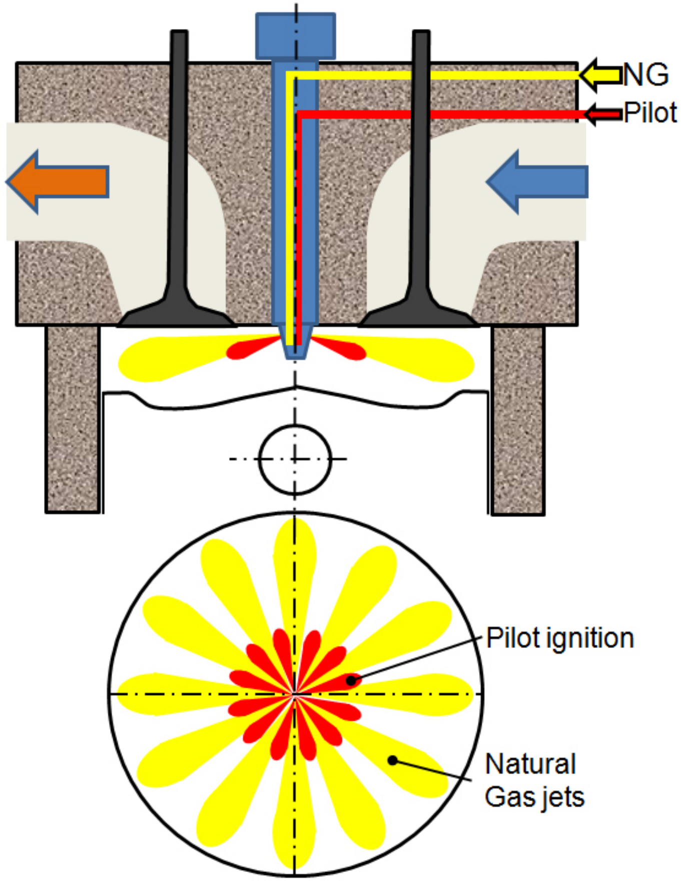
Rolls-Royce C26:33L9



Direct injection high pressure engine

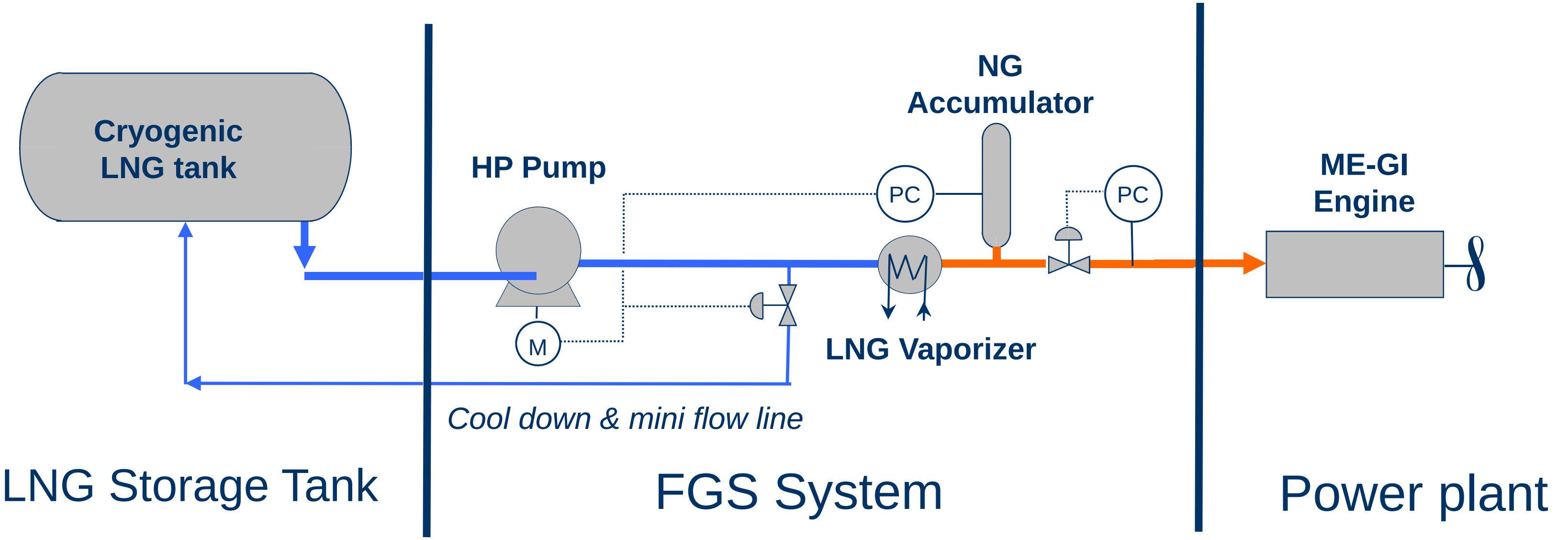
- Multi-fuel capability (LNG-MDO-HFO)
- High pressure gas injection
  (300 -350 bar) 4-stoke and 2- stroke
  Maintain diesel engine performance
- No methane slip, GHG reduction in the range of 30% ref. to HFO
- Need NOx reduction techniques to meet IMO tier III
- Not sensitive to gas quality
- Pumping LNG to 350 bar and evaporate is simple and with low energy requirement
- Flexibility in fuel mix
- Suitable for conversion of existing engines (simple rebuilding)





High Pressure Fuel Gas Supply System

Process flow diagram



Source: B&W / Cryostar

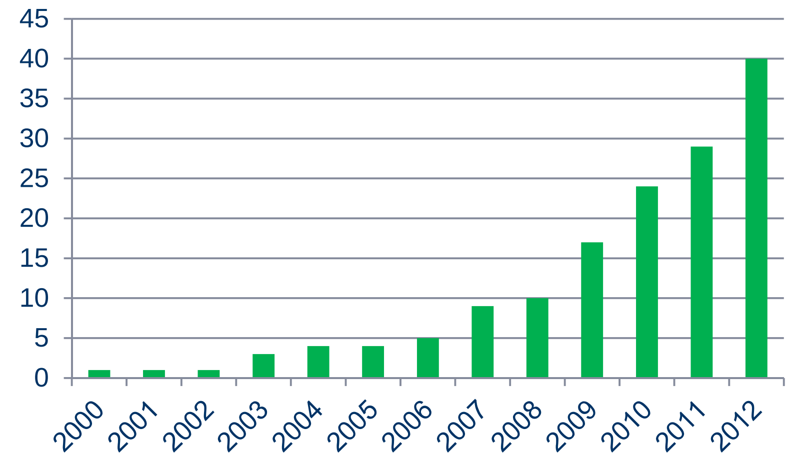
LNG powered ship design

26 LNG propelled ships in operation:

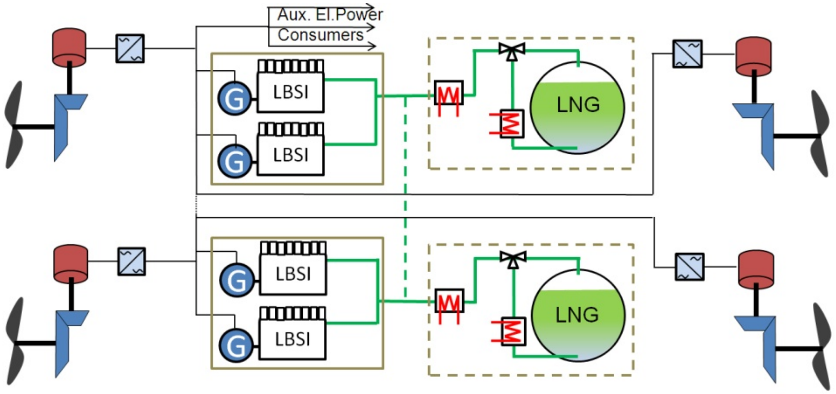
- **Ferries (15)**
- **Offshore support vessels (5)**
- **Coast guard vessels (3)**
- **Product tanker (1)**
- **LNG tanker (2)**

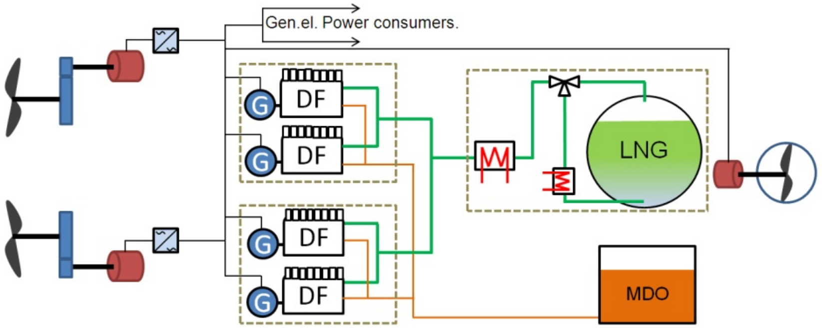
15 LNG propelled ships under construction

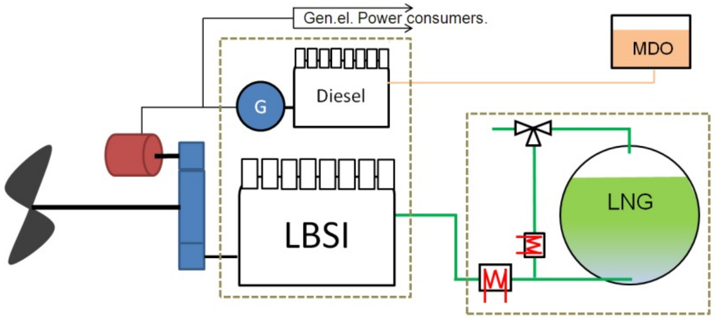
More than 40 LNG fuelled ships by 2012

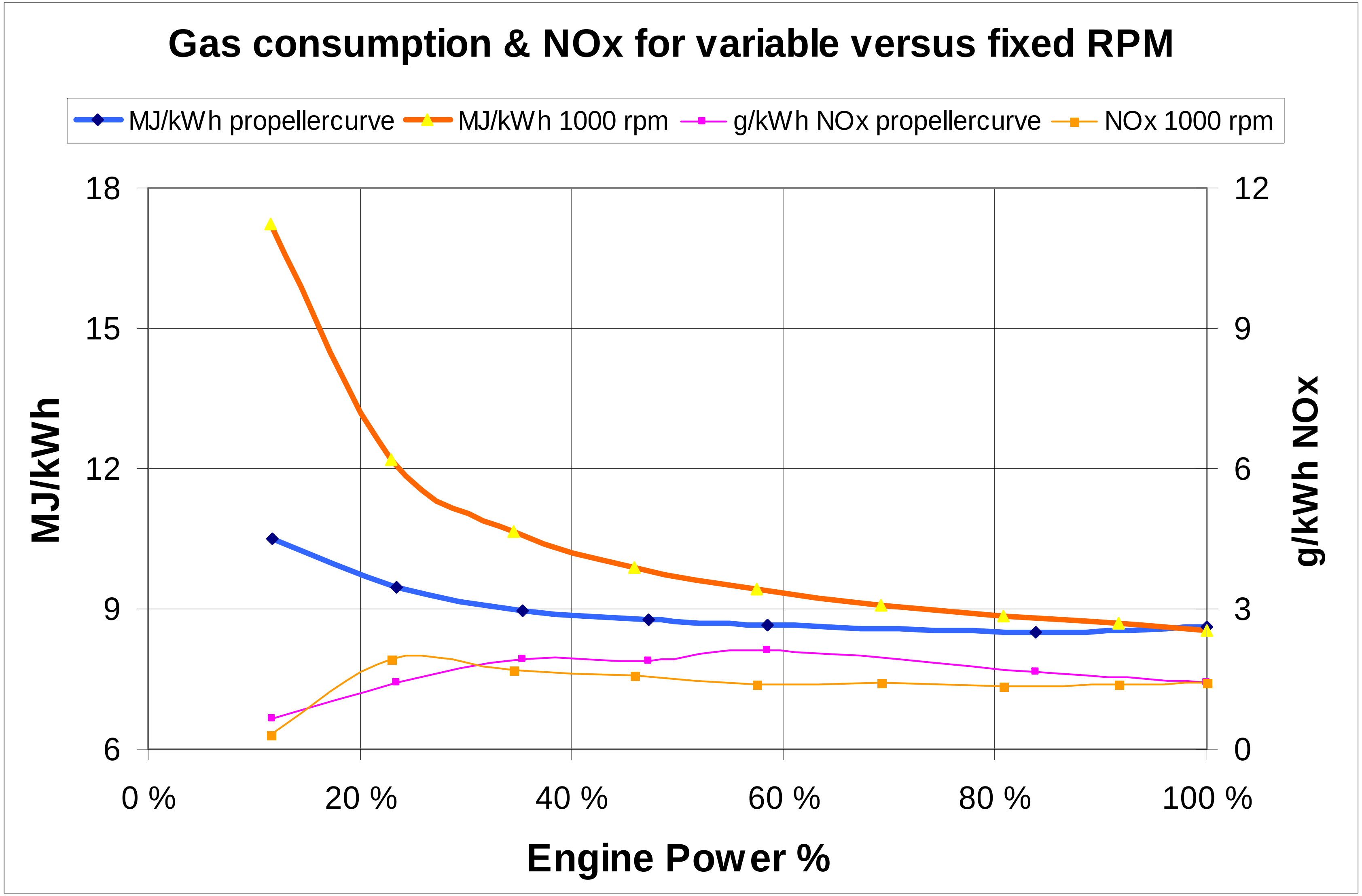


Propulsion system arrangements and fuel systems



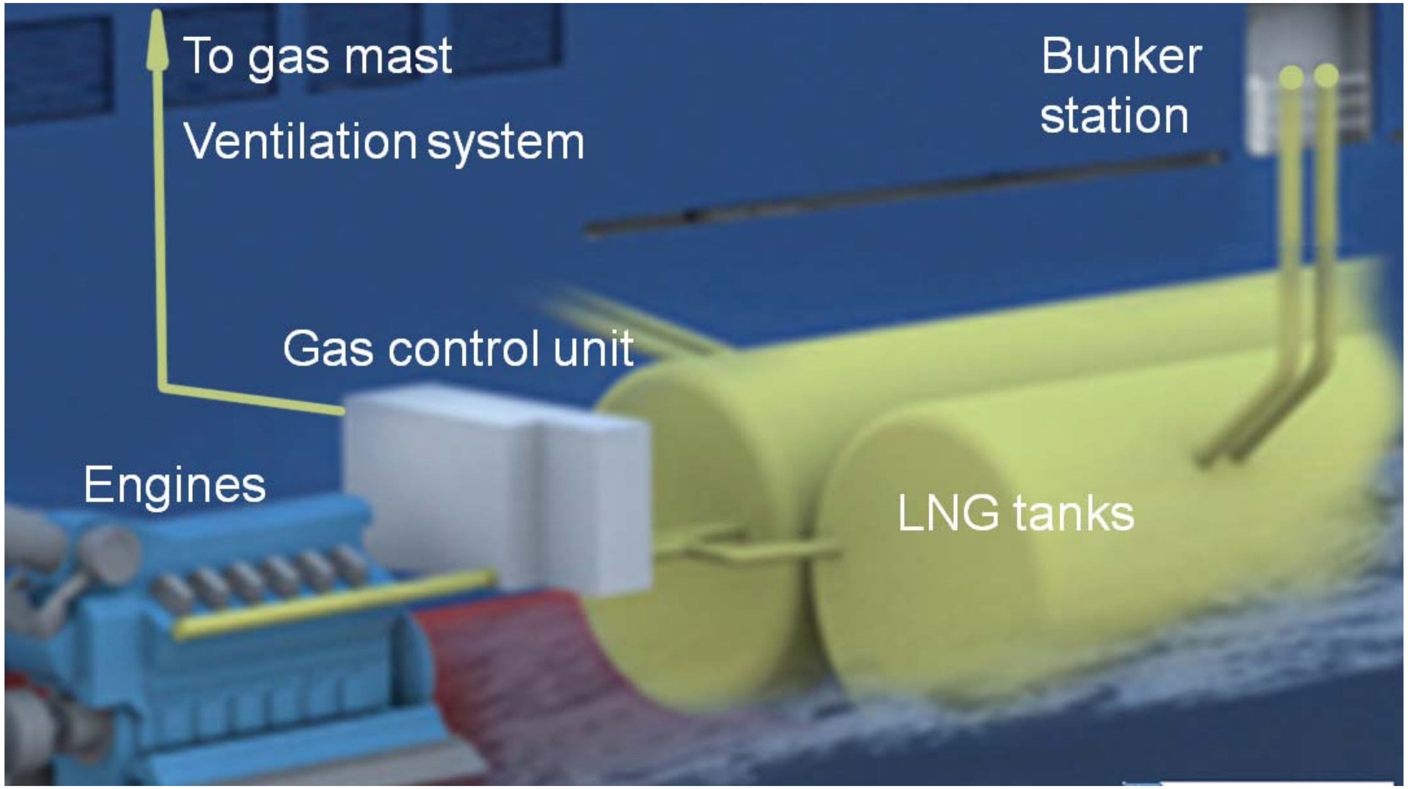






Rolls-Royce K-engine

LNG fuel system



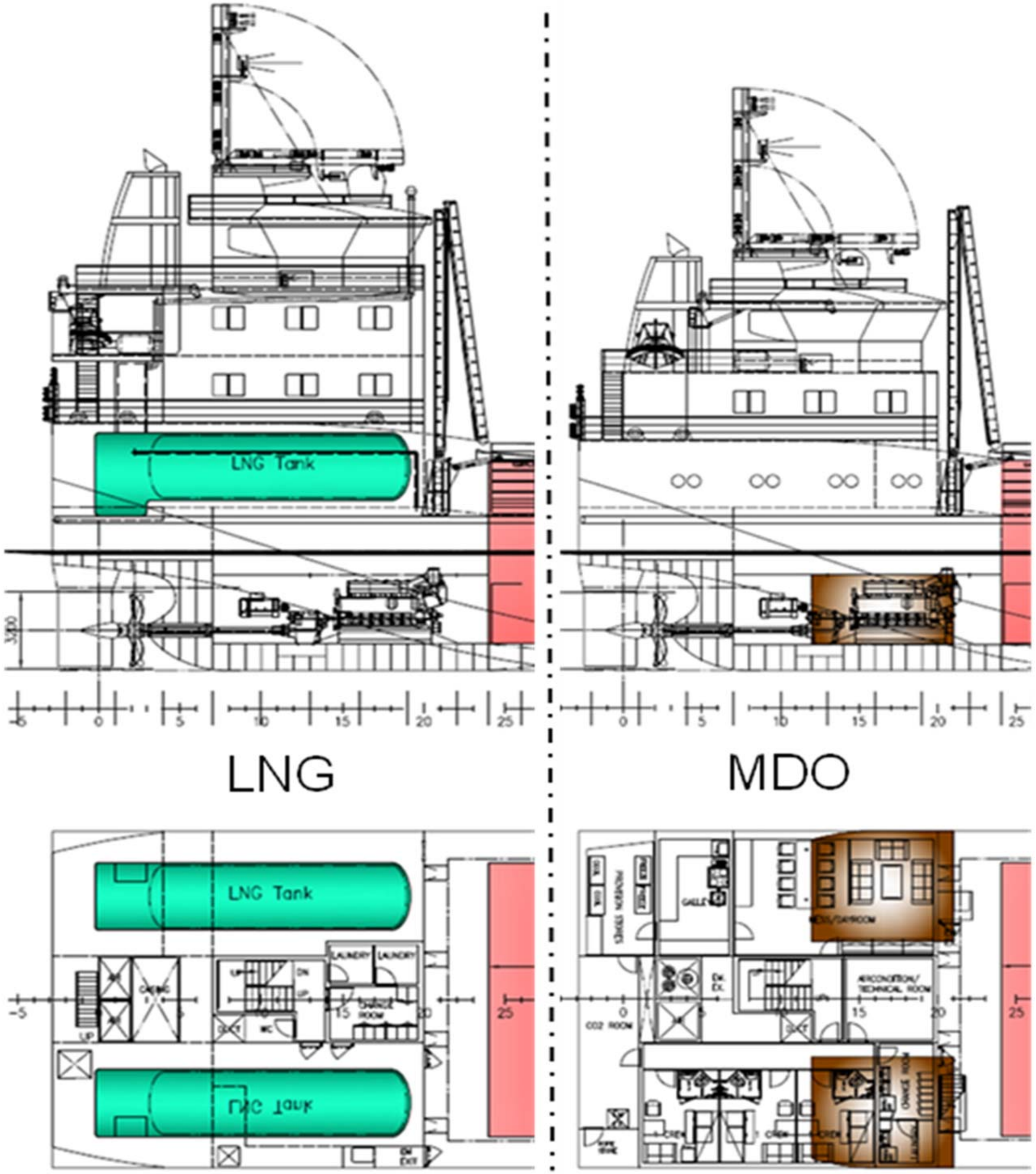
The challenges are handling and storing LNG onboard:

- Volume/space

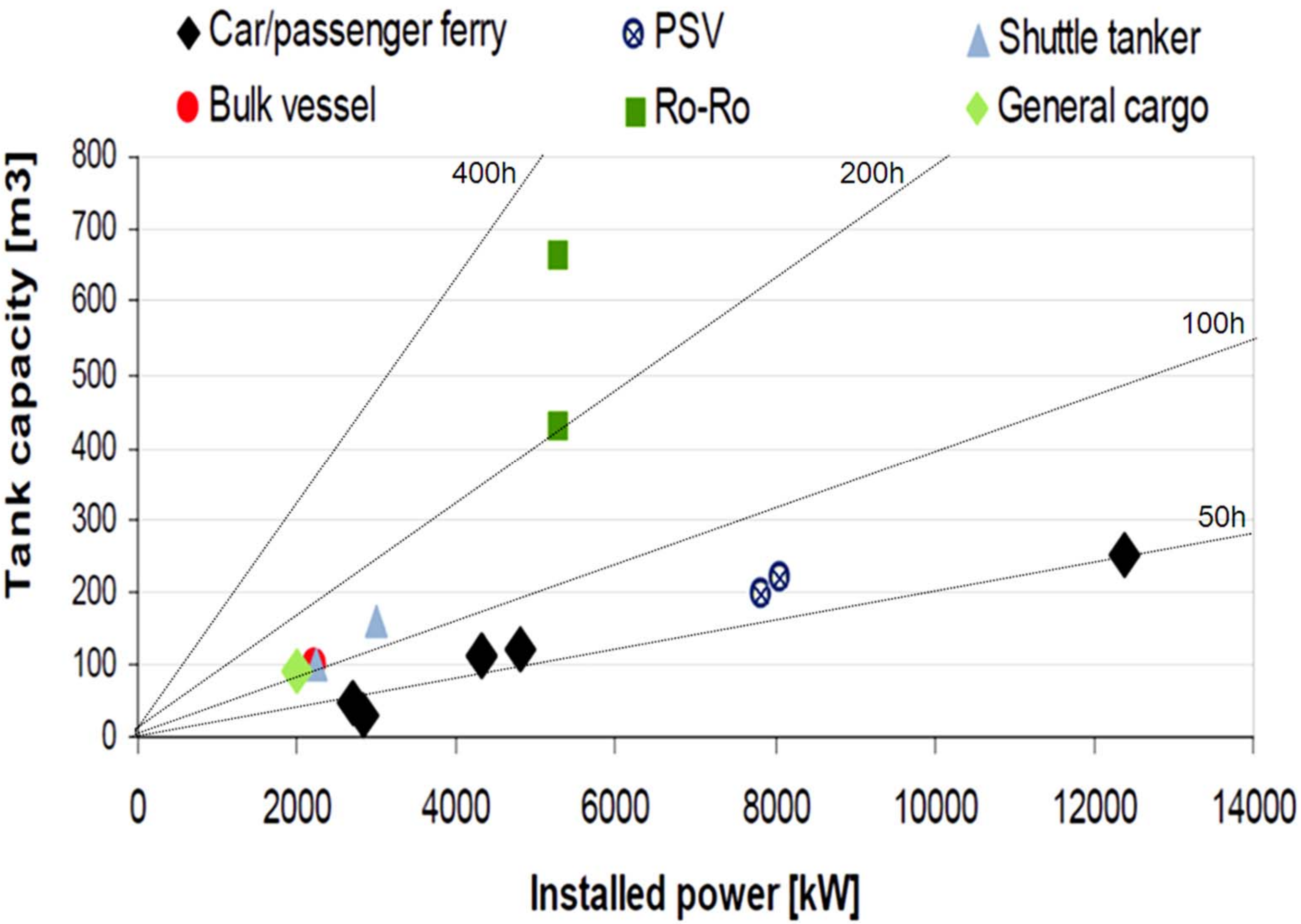
- Safety

- Infrastructure

Vacuum isolated pressure storage tanks – a volume factor 4-5 times of MDO/HFO


LNG Tank
LNG
MDO
LNG Tank
LNG Tank

Fuel capacity vs. installed power



Rules and regulations - Gas fuelled ships

IMO Interim guidelines for gas fuelled ships - 2009

Different engine room arrangements

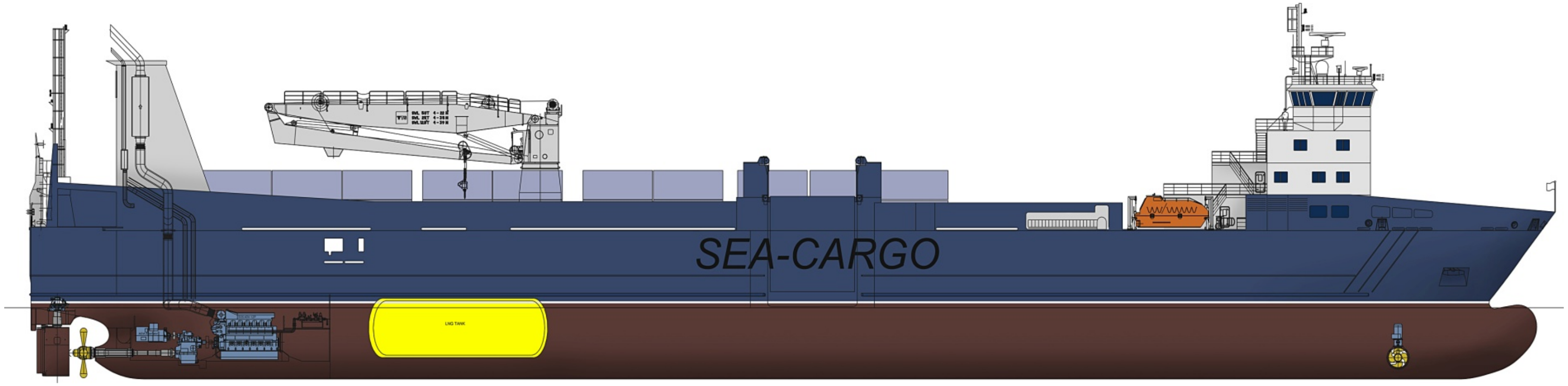
- **ESD (Emergency Shut Down) protected engine room**
  - Minimum two separate engine rooms
  - Redundant systems
  - Increased ventilation
  - Gas detection
  - Minimum of ignition sources

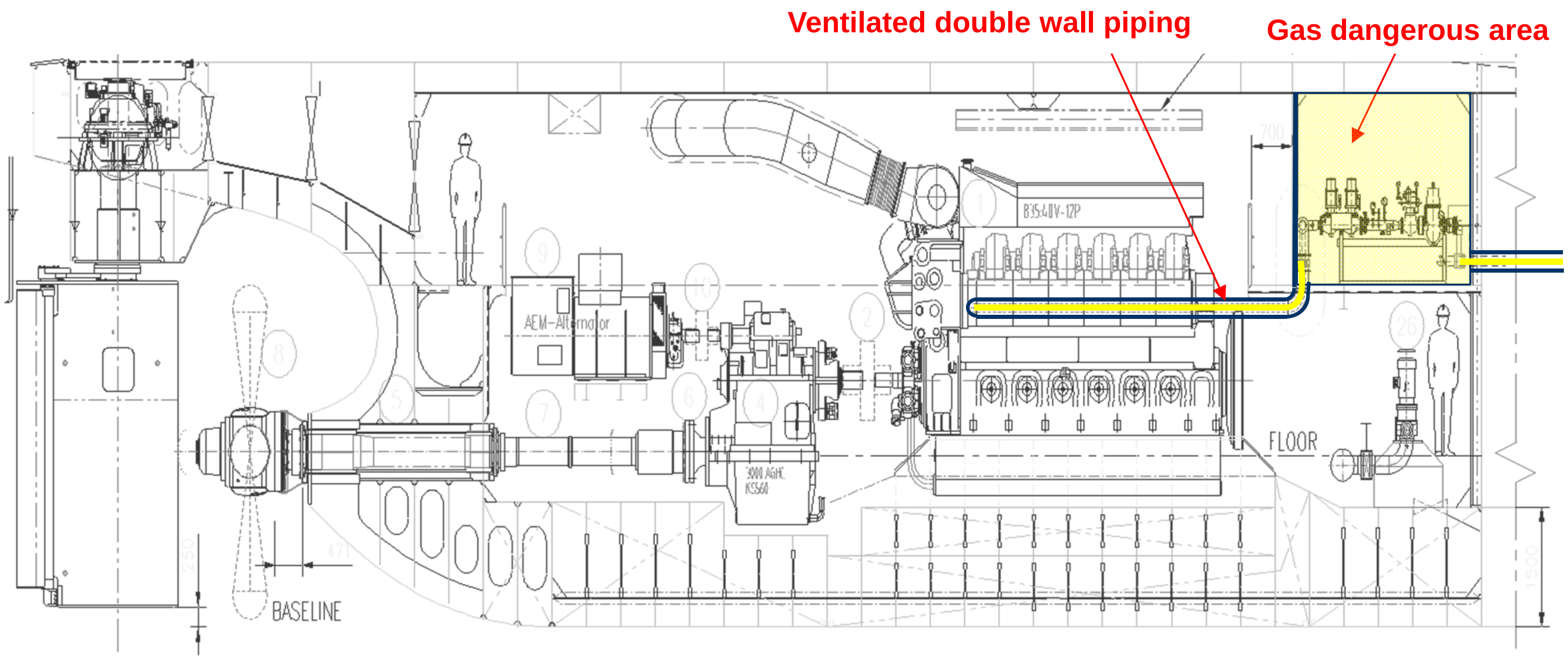
- **Inherently safe engine room**
  - Ventilated double piping to engine
  - No other special requirements for the engine room

IMO code in progress:

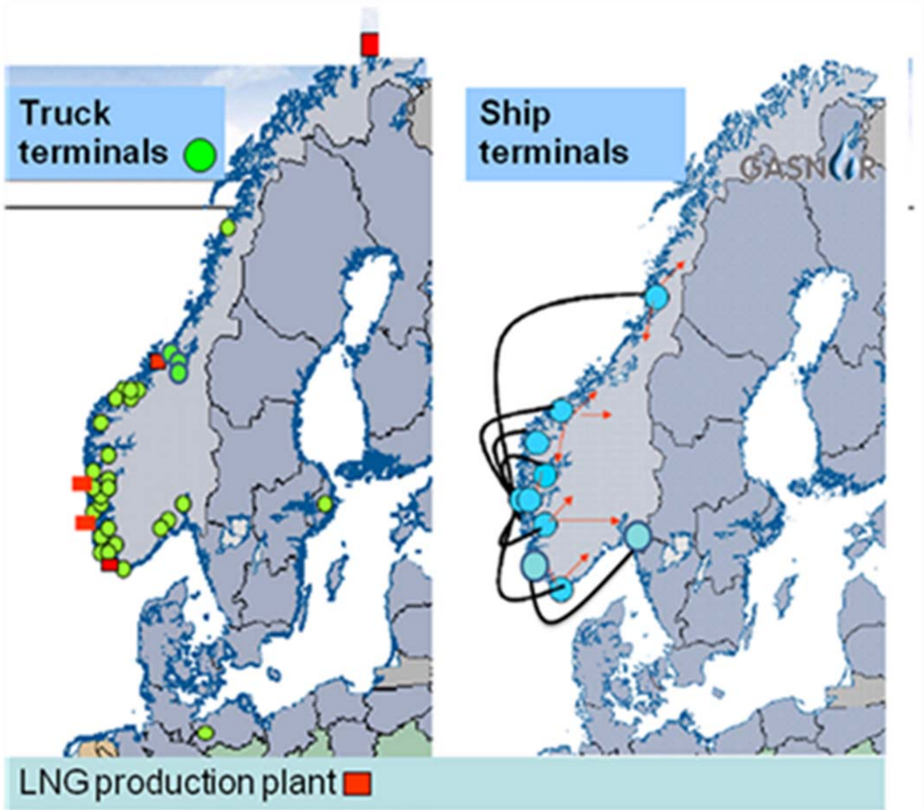
International code for gas fuelled ships – IGF - 2014

Inherently safe engine room





LNG in short sea shipping in Norway



Source: Gasnor

Covering the long coast of Norway

- LNG source
  - Base load LNG to receiving terminals
  - Small scale LNG production plants (4) 10.000-300.000 ton / year
- LNG distribution
  - Coastal tankers
  - Trucks
- Regional terminals (~40) 100m3 - 6500m3 LNG

LNG in short sea shipping in Norway

Production- Infrastructure – bunkering- use

Small scale LNG production

Source: Skangass

Source: Gasnor

LNG in short sea shipping – bunkering alternatives

Bunkering from trailer

Ship bunkering terminal, supply vessel

Ship bunkering terminal, ferry

LNG bunkering logistics, future

Ship to ship

- Necessary for large capacities
- Flexible
- (as todays MDO and HFO bunkering systems)

Capital cost related to LNG fuel

Additional cost factor	Car ferry (5 MW/ 250m³LNG)	Platform supply vessel (PSV) (8 MW / 200 m³LNG)	Ro-Ro (5 MW / 450m³LNG)
Engines	~3%	~3%	~2%
Fuel system	~4-5%	~2-3%	~5-8%
Arrangement and structure	~2-3%	~3-6%	~2-5%
Total	~10%	~8-12%	~9-15%

R&D challenges

- Engines and systems
  - Part load efficiency optimization
  - Methane slip reduction
  - Fuel gas quality
  - Cost reduction
- Fuel handling and storage
  - Better storage tank solutions (space and cost)
  - Improved fuel handling systems – bunkering logistics
  - Simpler and more robust fuel system design without reducing safety (space and cost)

Commersial challenge:

Cost elements – need more actors in the market…

Summary and conclusions

- LNG is considered to be the most promising alternative marine fuel
- Using LNG as ship fuel, harmful exhaust emissions are reduced significantly
- LNG is available world wide in large scale, and can be further distributed to small scale fuel market. Norway has demonstrated that small scale LNG production and distribution is competitive as marine fuel
- Proven engine technologies are available for medium speed natural gas engines, and under development for slow speed 2-stroke engines
- Energy efficiency is equal and even better using LNG compared to MDO/HFO
- LNG fuelled engines are environmental friendly, and meet all the known emission requirements (IMO tier III), without exhaust gas cleaning
- Engine R&D challenges are related to part load efficiency, methane slip and variable gas composition (Methane number)
- The main challenges using LNG are availability and on-board fuel storage and handling systems. LNG storage and handling technology for ships are under further development to reduce space requirement and cost
- LNG fuelled ships require significant higher capital investment in fuel system – typical 8-15% additional cost, which can be justified by lower operating costs (emissions and fuel)

Thank you for your attention !

Dag.Stenersen@marintek.sintef.no