MEYER TURKU
SHIPYARD 1737

# Machinery Concept Design – Cruise Ships & Ferries

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**Senior Marine Engineer**
**9th January 2023**

# AGENDA

**Philosophy according to Wikipedia**

While no definition of philosophy is not beyond doubt and philosophy sector has changed throughout history according to the issues have been discussed from time to time, in general, it is considered that philosophy is more method than a number of statements or doctrines. Philosophical analysis is based on reason and rational reasoning, and to avoid unjustified assumptions.

**The aim is systematic, universality and understanding of the issues.**

**SOLUTION**

⬇

# How to proceed?

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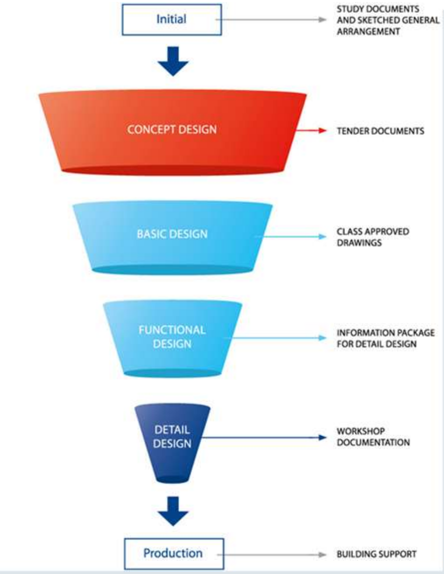
INQUIRY



Initial → STUDY DOCUMENTS AND SKETCHED GENERAL ARRANGEMENT

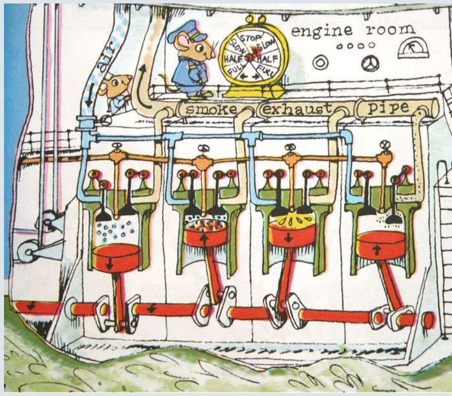
CONCEPT DESIGN → TENDER DOCUMENTS

BASIC DESIGN → CLASS APPROVED DRAWINGS

FUNCTIONAL DESIGN → INFORMATION PACKAGE FOR DETAIL DESIGN

DETAIL DESIGN → WORKSHOP DOCUMENTATION

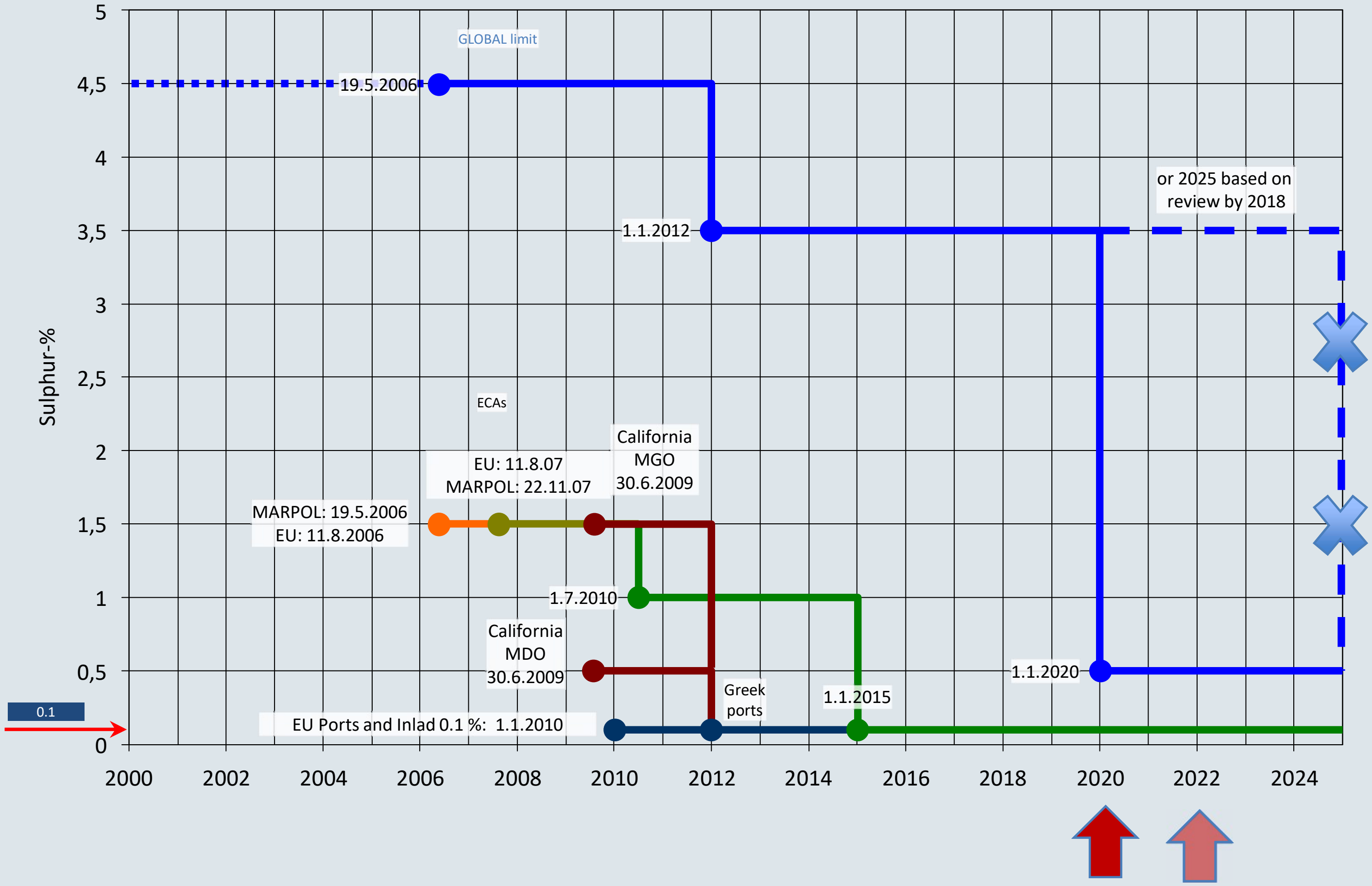
Production → BUILDING SUPPORT



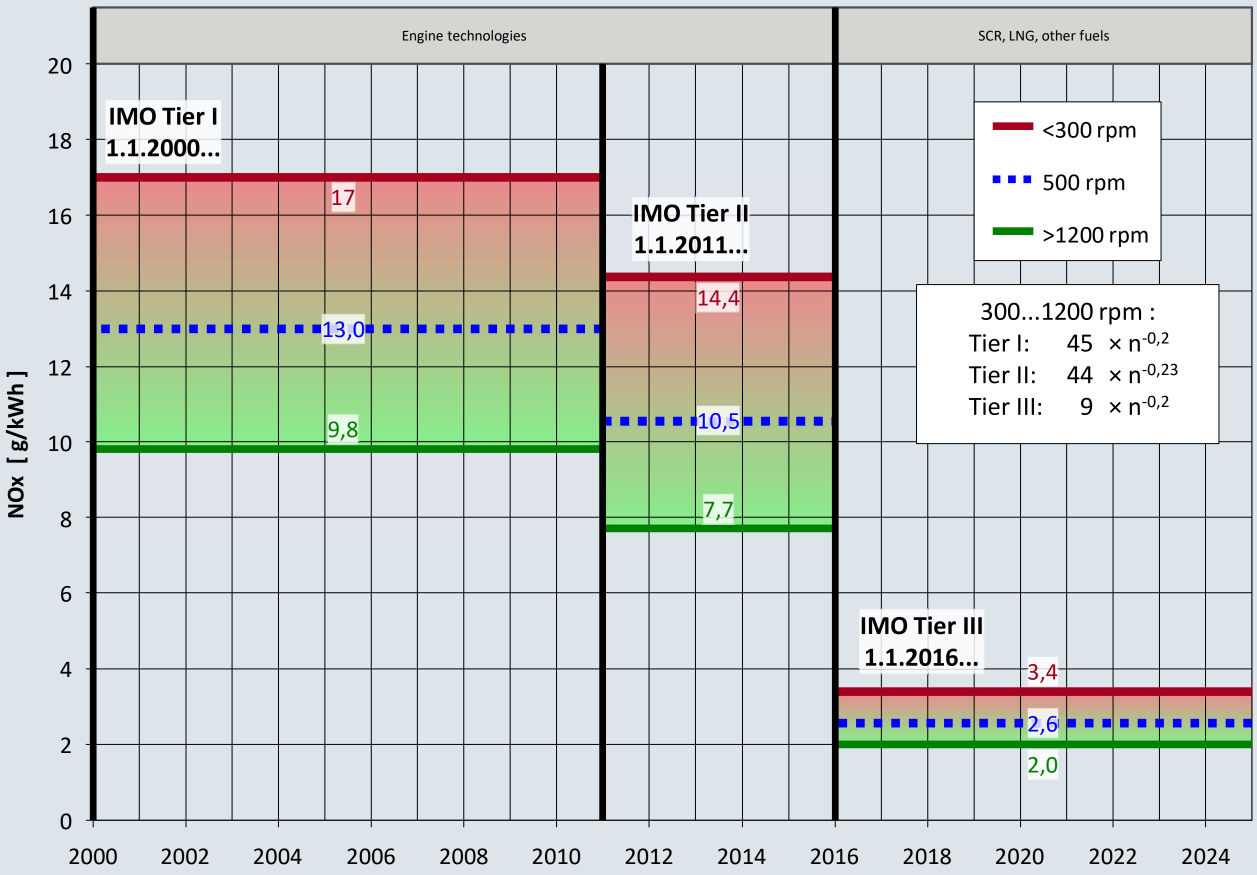
Google

# Propulsion –short history

# SOx - Fuel Oils (emission) Sulphur Content Limits



# NOx Limits for NEW Marine Engines > 130 kW



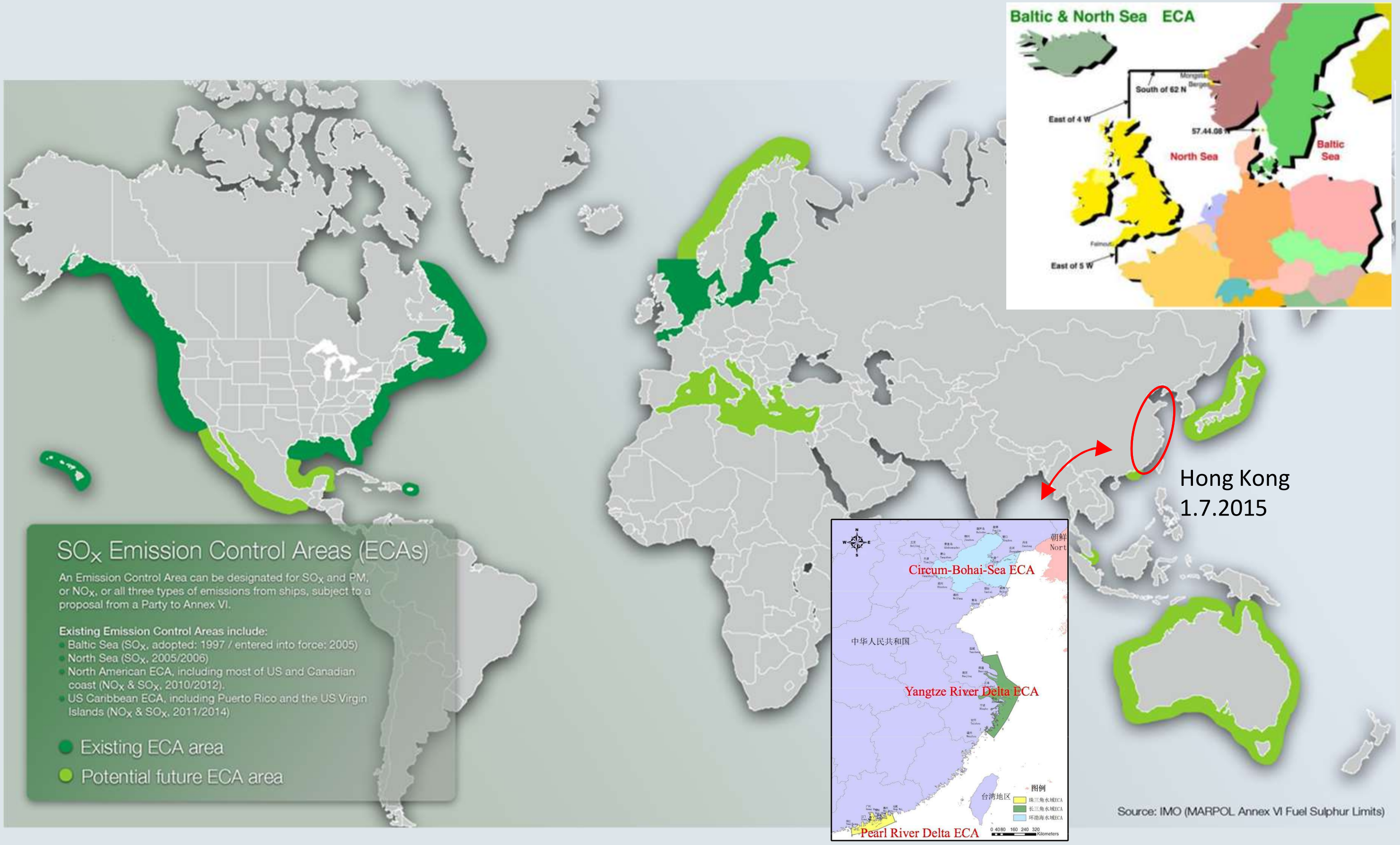
300...1200 rpm :

Tier I: $45 \times n^{-0,2}$

Tier II: $44 \times n^{-0,23}$

Tier III: $9 \times n^{-0,2}$

# Emission Control Areas



## SO$_X$ Emission Control Areas (ECAs)

An Emission Control Area can be designated for SO$_X$ and PM, or NO$_X$, or all three types of emissions from ships, subject to a proposal from a Party to Annex VI.

**Existing Emission Control Areas include:**

- Baltic Sea (SO$_X$, adopted: 1997 / entered into force: 2005)
- North Sea (SO$_X$, 2005/2006)
- North American ECA, including most of US and Canadian coast (NO$_X$ & SO$_X$, 2010/2012).
- US Caribbean ECA, including Puerto Rico and the US Virgin Islands (NO$_X$ & SO$_X$, 2011/2014)

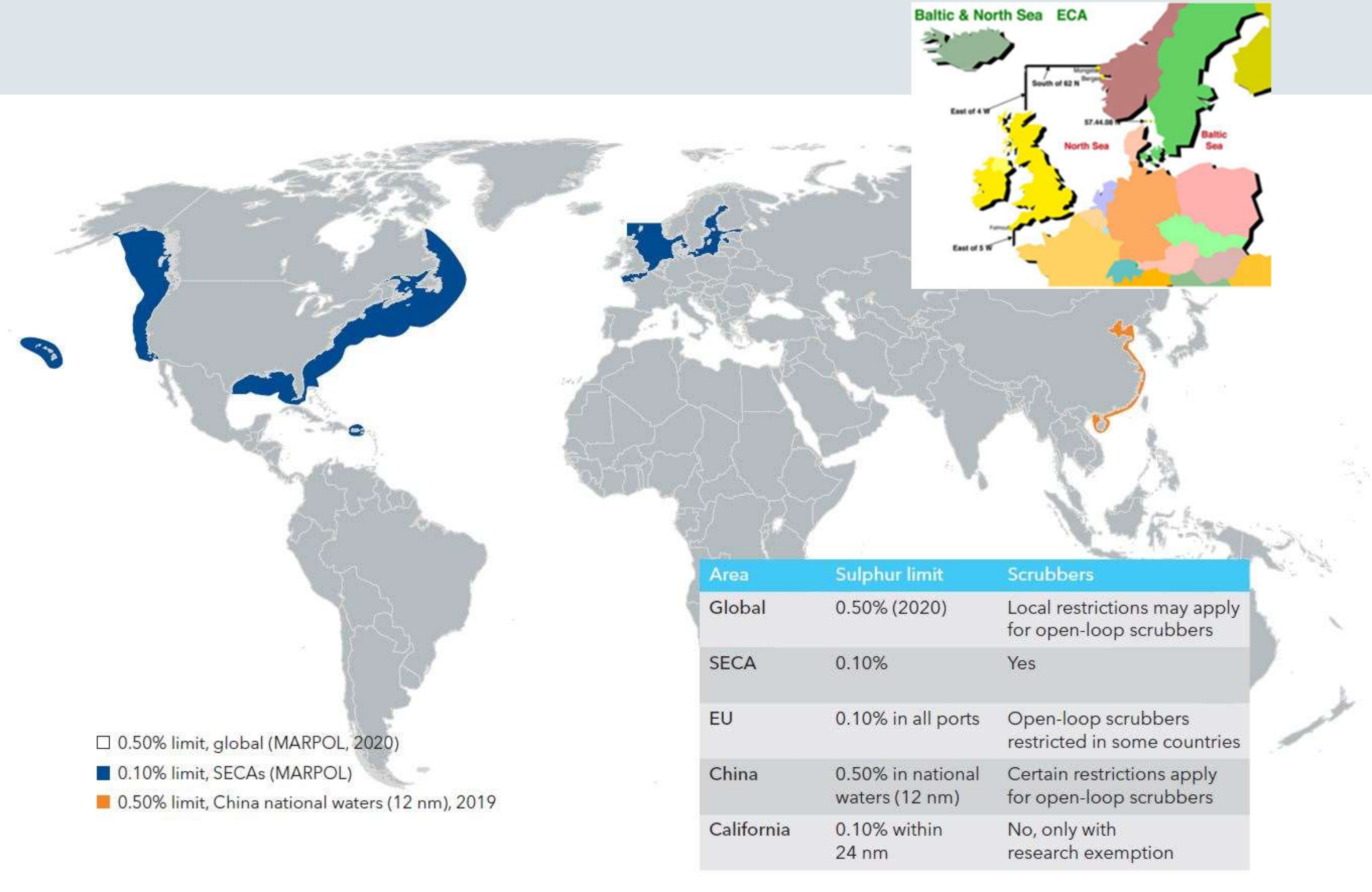
● Existing ECA area

● Potential future ECA area

Hong Kong
1.7.2015

Source: IMO (MARPOL Annex VI Fuel Sulphur Limits)

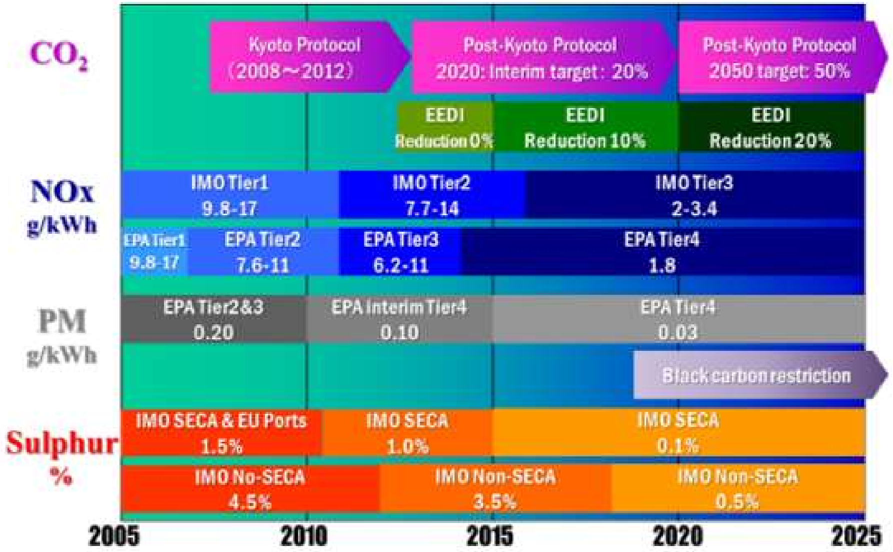
# Sulphur Emission Control Areas



☐ 0.50% limit, global (MARPOL, 2020)
🟦 0.10% limit, SECAs (MARPOL)
🟧 0.50% limit, China national waters (12 nm), 2019

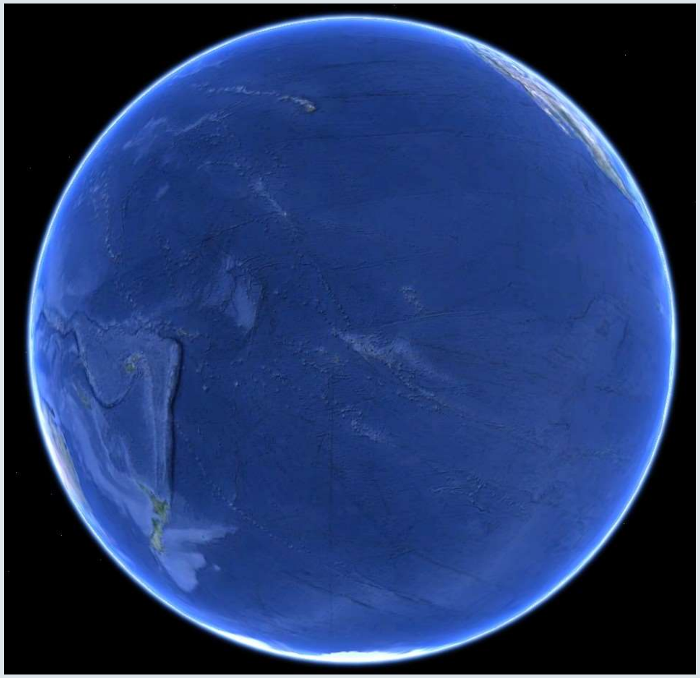
| Area | Sulphur limit | Scrubbers |
|---|---|---|
| Global | 0.50% (2020) | Local restrictions may apply for open-loop scrubbers |
| SECA | 0.10% | Yes |
| EU | 0.10% in all ports | Open-loop scrubbers restricted in some countries |
| China | 0.50% in national waters (12 nm) | Certain restrictions apply for open-loop scrubbers |
| California | 0.10% within 24 nm | No, only with research exemption |

# Marine Emissions

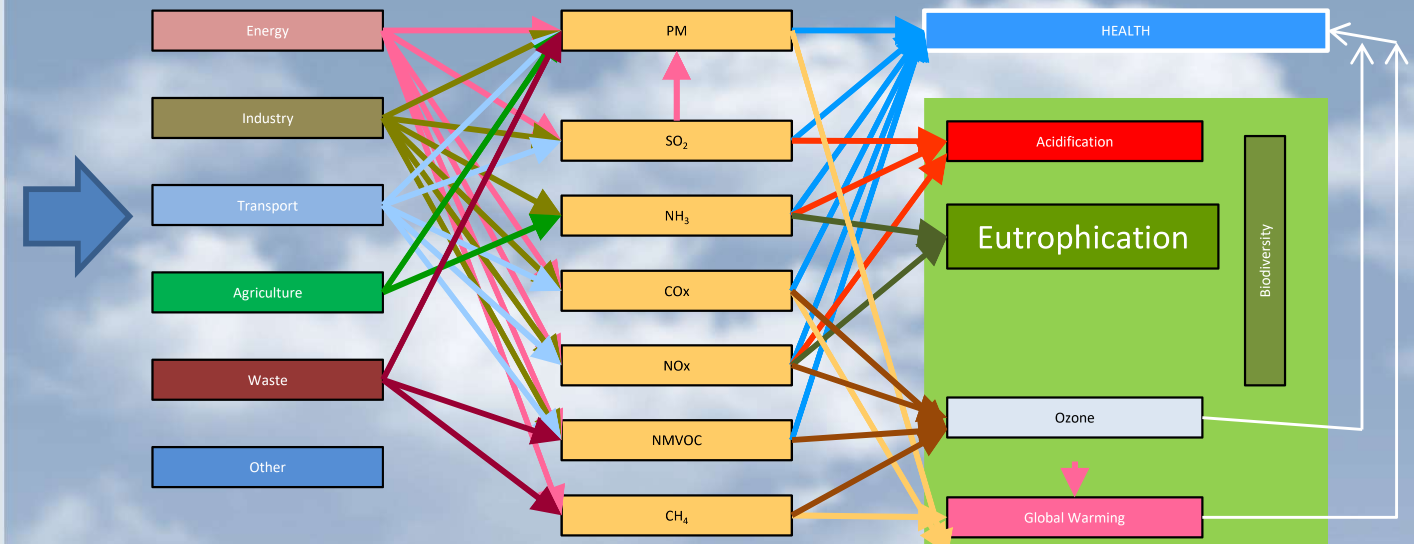


Note: Because NOx emission standards differ depending on engine speed, the minimum-to-maximum range is shown

# SRtP (Safe Return to Port)



# Air Pollution – Local vs Global effect



Energy

Industry

Transport

Agriculture

Waste

Other

PM

SO$_2$

NH$_3$

COx

NOx

NMVOC

CH$_4$

Other

HEALTH

Acidification

Eutrophication

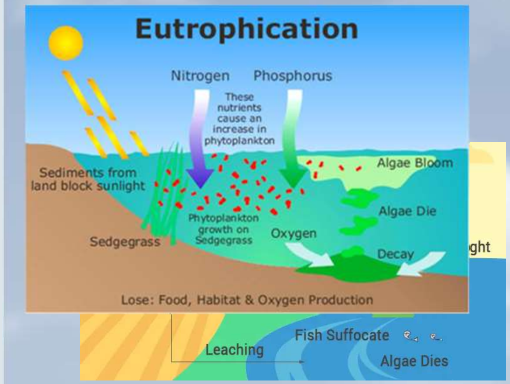
Biodiversity

Ozone

Global Warming

ENVIRONMENT

Other



NMOVOC= Non-methane volatile orhanic carbons

NH$_3$= Ammonia

# Environmental drivers

- The **International Maritime Organization** (IMO), as the main regulatory body for shipping, has in recent years devoted significant time and effort to the issue of regulating shipping energy efficiency in order to control marine greenhouse gas (GHG) emissions.
- The IMO has developed a number of technical measures that include:
  - the Energy Efficiency Design Index (EEDI)
  - the Energy Efficiency Operational Indicator (EEOI)
  - the Ship Energy Efficiency Management Plan (SEEMP)

- IMO: MARPOL 73/78, Annex VI
  - Global limit of 3,5% from 1.1.2012 and 0,5% from 1.1.2020
  - Sulphur Emission Control Areas: from 1,5% 2006 to 0,1% 2015
- Maritime $CO_2$ emissions are not covered in Kyoto Protocol
- European Union (EU)
  - SECAs
  - 20 % cut to overall $CO_2$ emissions from year 1990 levels to year 2020?
  - Applies to all $CO_2$ producing activities
  - EU Ports sulphur max 0.1%
- Regional regulations
  - Stockholm: port dues depend on amount of sulphur on fuel

# Environmental drivers

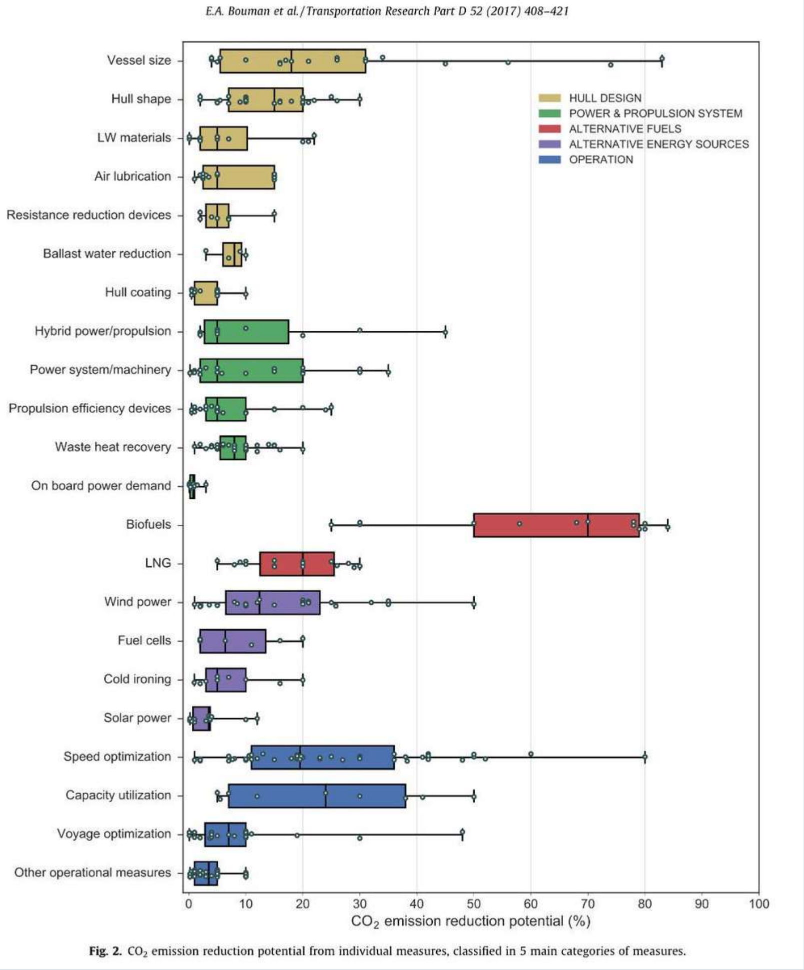
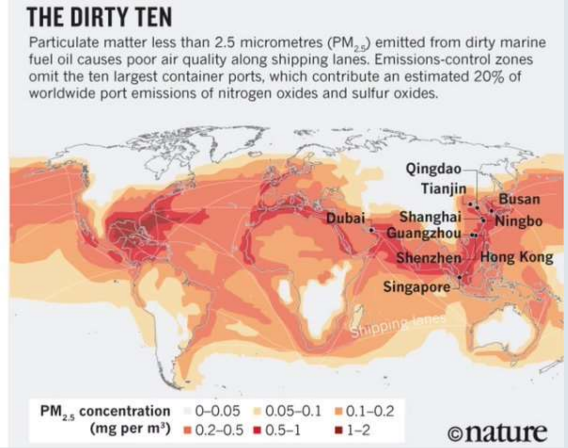
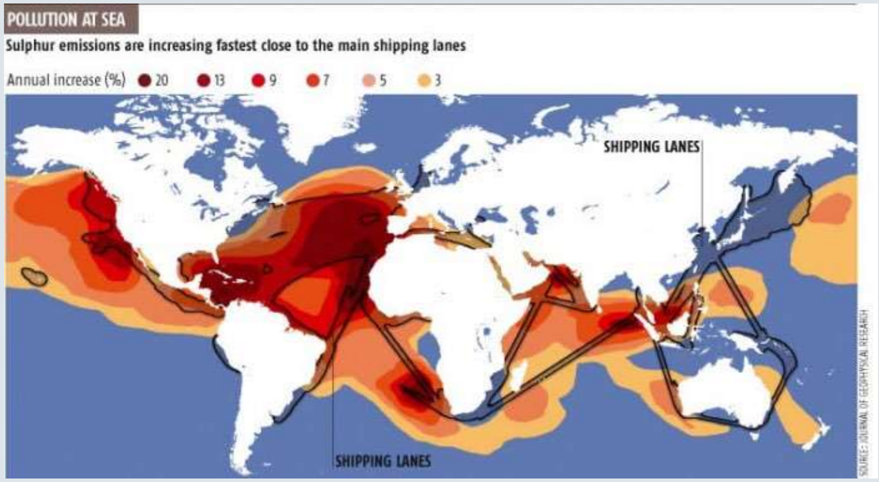

E.A. Bouman et al. / Transportation Research Part D 52 (2017) 408–421

**Fig. 2.** $CO_2$ emission reduction potential from individual measures, classified in 5 main categories of measures.


**THE DIRTY TEN**

Particulate matter less than 2.5 micrometres ($PM_{2.5}$) emitted from dirty marine fuel oil causes poor air quality along shipping lanes. Emissions-control zones omit the ten largest container ports, which contribute an estimated 20% of worldwide port emissions of nitrogen oxides and sulfur oxides.


**POLLUTION AT SEA**

**Sulphur emissions are increasing fastest close to the main shipping lanes**

# Pressure from public opinion and legislation

- 1. EXHAUST GAS EMMISSIONS INTO THE AIR
- 2. WASTE WATER INTO THE SEA
- 3. EXTERNAL NOISE
- 4. WAVE MAKING
- 5. TRAFFIC INCREA

# Future - What Carmakers are doing?

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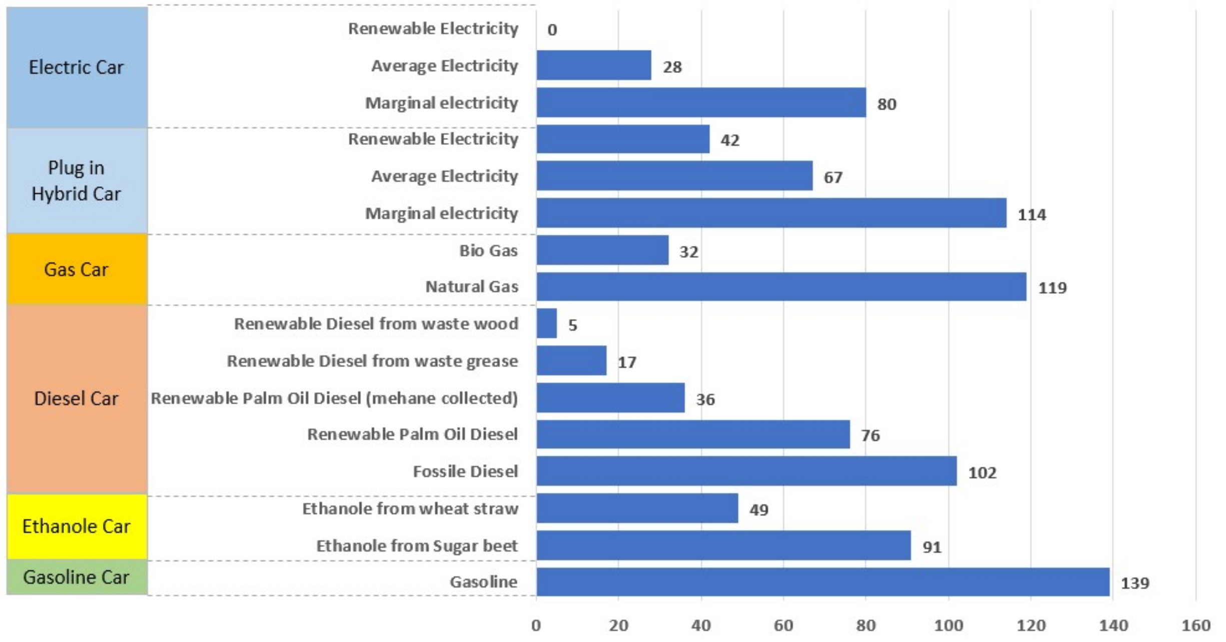
Diesel Fuel Sulphur at road 0.001% vs 0.1% at sea



Personal Car well-to-wheel CO2 g/km

Source: VTT 2015 Road trafic 40% CO2 reduction until 2030

•**Euro 1** (1992):

- For passenger cars—91/441/EEC.[2]
- Also for passenger cars and light trucks—93/59/EEC.

https://en.wikipedia.org/wiki/European_emission_standards

# PREWORK

# Background – Machinery Concept Mind Mapping

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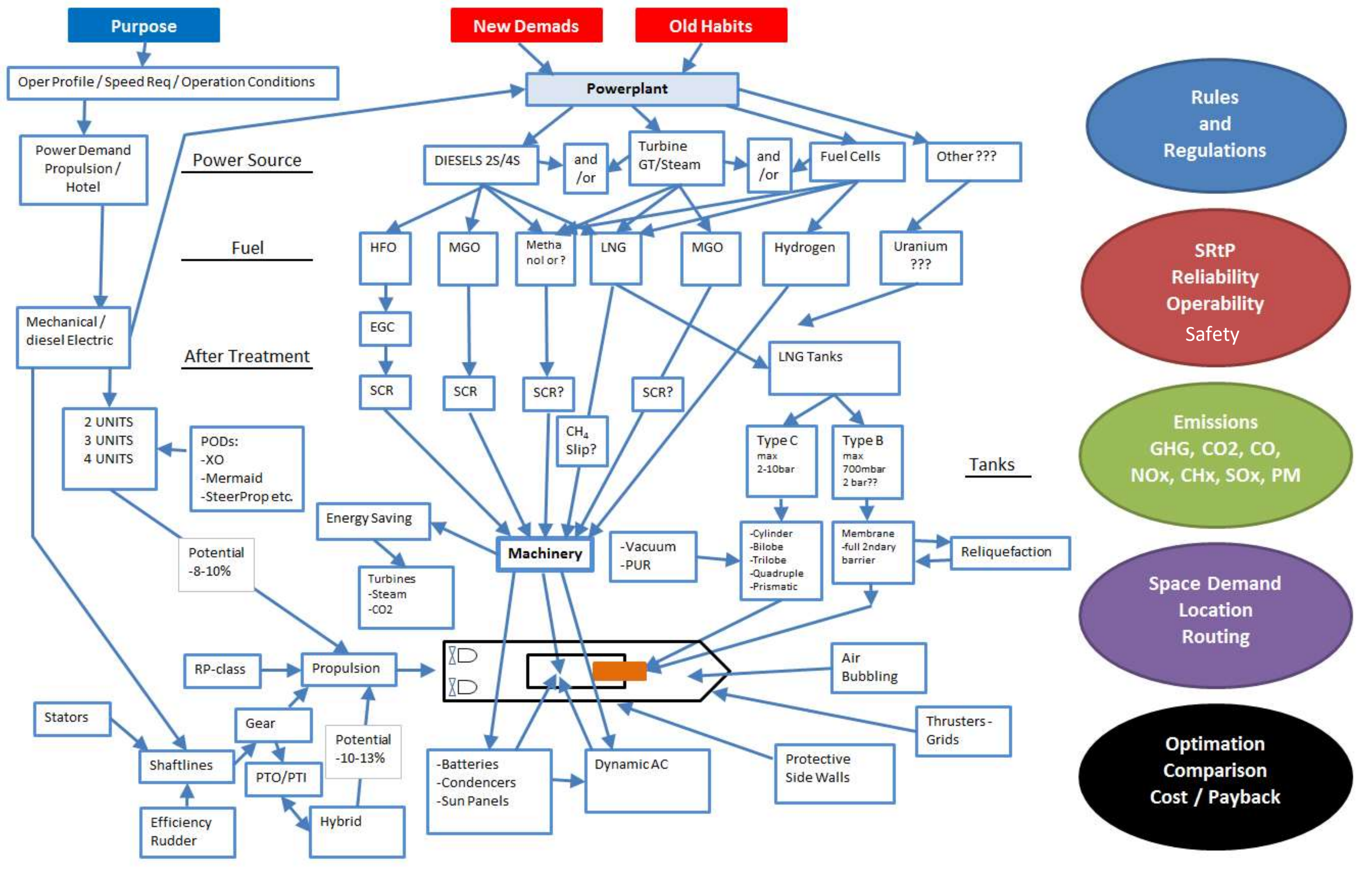


**Purpose**

**New Demads**

**Old Habits**

Oper Profile / Speed Req / Operation Conditions

**Powerplant**

Power Demand
Propulsion /
Hotel

Power Source

DIESELS 2S/4S

and
/or

Turbine
GT/Steam

and
/or

Fuel Cells

Other ???

Fuel

HFO

MGO

Metha
nol or ?

LNG

MGO

Hydrogen

Uranium
???

Mechanical /
diesel Electric

After Treatment

EGC

SCR

SCR

SCR?

SCR?

$CH_4$
Slip?

LNG Tanks

Type C
max
2-10bar

Type B
max
700mbar
2 bar??

Tanks

2 UNITS
3 UNITS
4 UNITS

PODs:
-XO
-Mermaid
-SteerProp etc.

Energy Saving

**Machinery**

-Vacuum
-PUR

-Cylinder
-Bilobe
-Trilobe
-Quadruple
-Prismatic

Membrane
-full 2ndary
barrier

Reliquefaction

Potential
-8-10%

Turbines
-Steam
-CO2

RP-class

Propulsion

Air
Bubbling

Thrusters -
Grids

Stators

Gear

Potential
-10-13%

Shaftlines

PTO/PTI

-Batteries
-Condencers
-Sun Panels

Dynamic AC

Protective
Side Walls

Efficiency
Rudder

Hybrid

**Rules**
**and**
**Regulations**

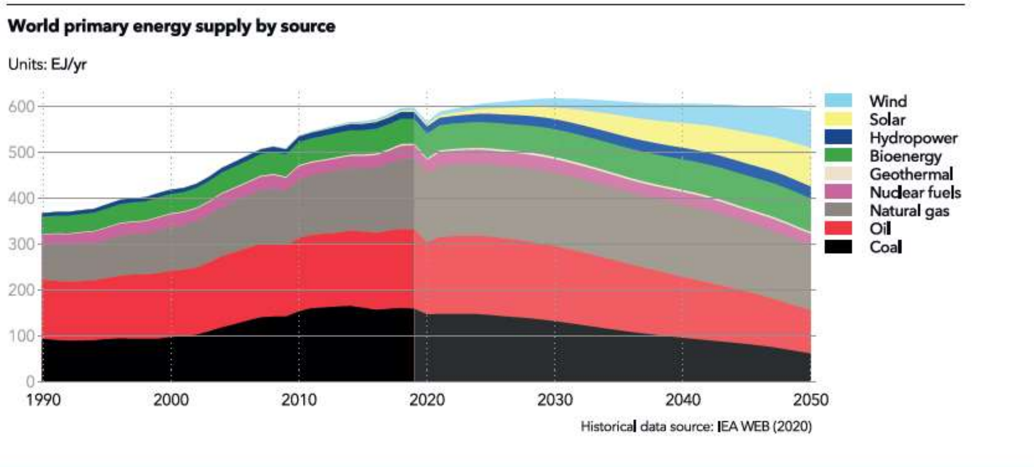
**SRtP**
**Reliability**
**Operability**
Safety

**Emissions**
**GHG, CO2, CO,**
**NOx, CHx, SOx, PM**

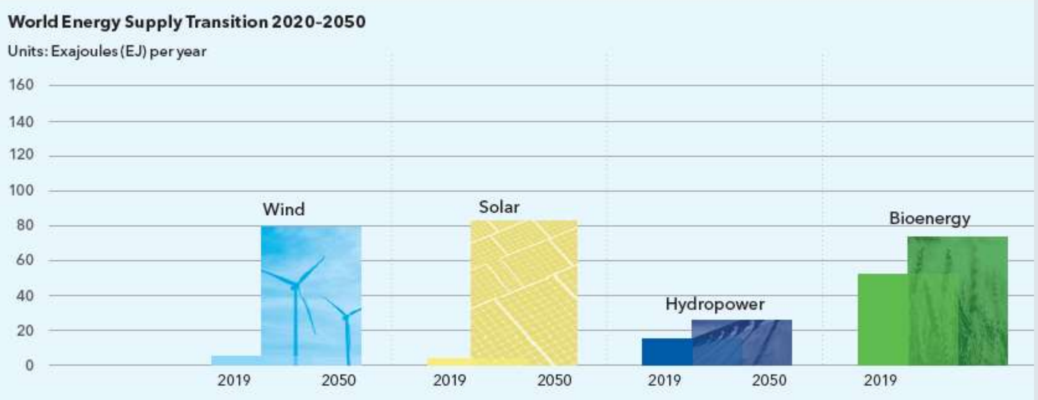
**Space Demand**
**Location**
**Routing**

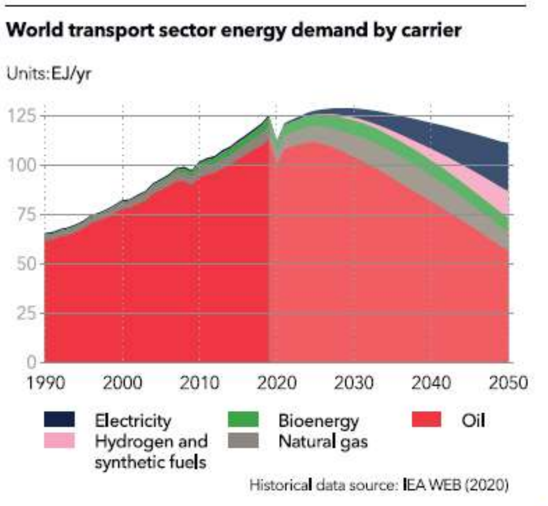
**Optimation**
**Comparison**
**Cost / Payback**

# Fuels:

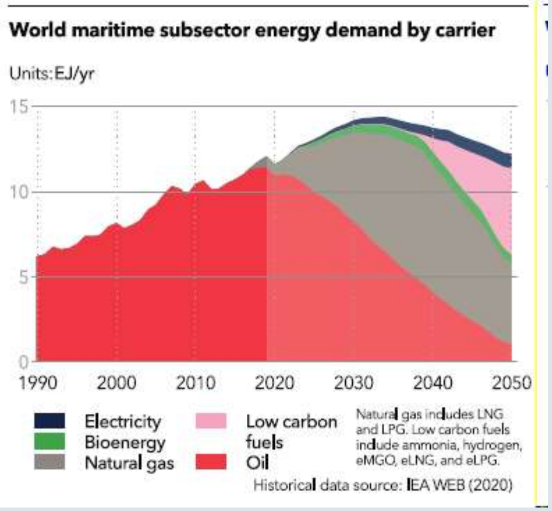

World primary energy supply by source

Historical data source: IEA WEB (2020)


World Energy Supply Transition 2020-2050


World transport sector energy demand by carrier

Historical data source: IEA WEB (2020)


World maritime subsector energy demand by carrier

Natural gas includes LNG and LPG. Low carbon fuels include ammonia, hydrogen, eMGO, eLNG, and eLPG.

Historical data source: IEA WEB (2020)

Source:DNV Energy Transition Outlook 2021

# Marine Fuels towards 0% Carbon:

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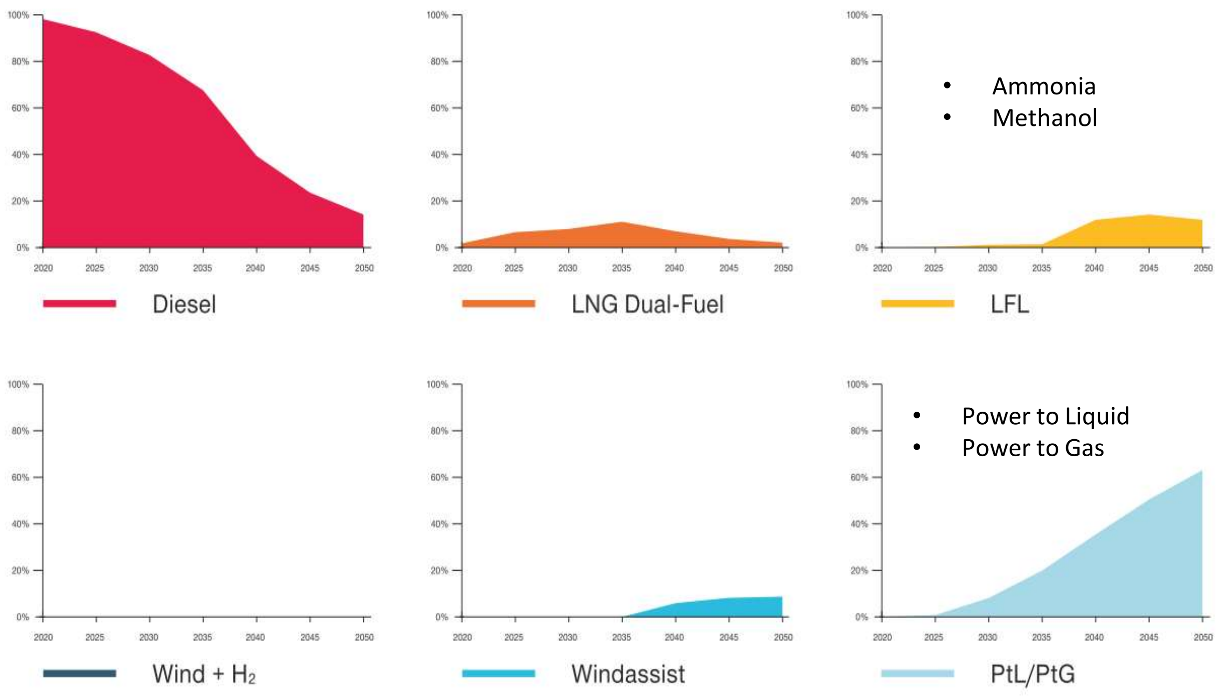


- Ammonia
- Methanol

- Power to Liquid
- Power to Gas

**MATISSE-SHIP Scenario A**

Scenario A is dominated by a constant decrease in diesel oil propulsion over time. At the same time LNG peaks in 2035 and lays the foundation for the switch to PtL/PtG as fossil fuels will be banned by 2035. At the same time, LFL fuels like ammonia and methanol are picking up and growing. The major fuels in 2050 with over 60 % share will be PtL/PtG.

Source:

**MAN Energy Solutions**
**#AHOY2050 – Scenario Study**

# Engine Room – Ship propulsion systems

**The main components of a propulsion system :**

Prime Mover Power Plant → Transmission → Propulsor

## Prime mover:

The function of the prime mover is to deliver mechanical energy to the propulsor. The prime mover may be one of the following:

- Diesel engine
- Gas turbine
- Steam turbine
- Electric motor

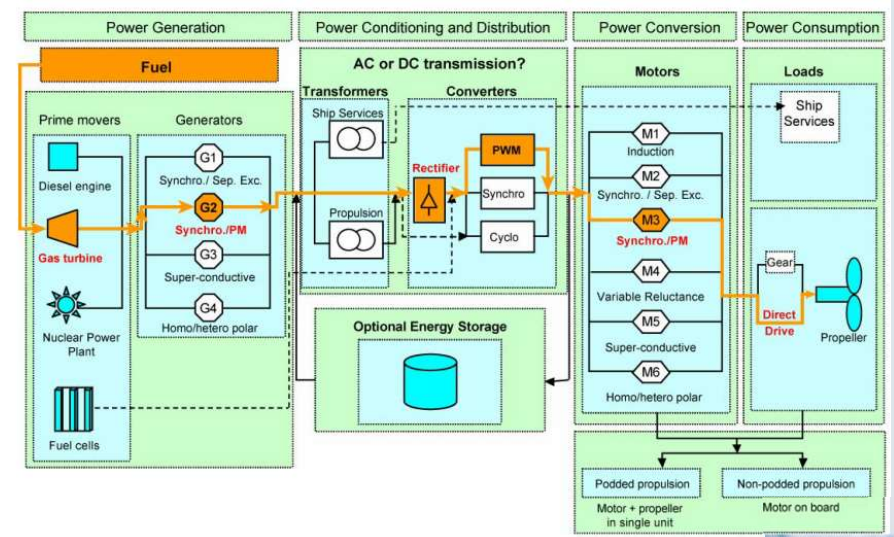
The diesel engine is the most common prime mover in the merchant marine, mainly due to its low fuel consumption in comparison with other prime movers.

Gas turbines find their application in fast and advanced ship types and naval vessels. The power to weight ratio of gas turbines is higher than that of diesel engines.

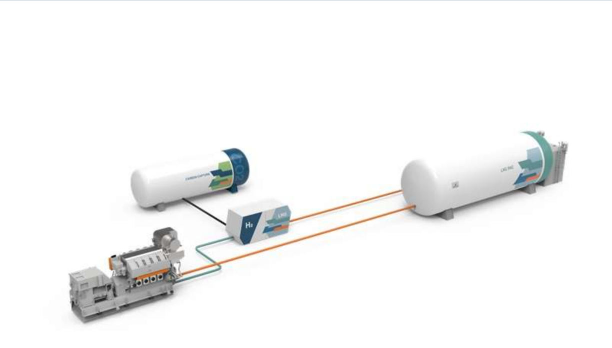
Some ship types, such as naval vessels and LNG carriers may have a steam turbine as propulsion engine.
Electric motors found their way as prime mover in the 90's; they are used with electric generation plant combined of an engine (one of the above types) and an electric generator. They are mainly found in advanced passenger ships, some new designs of offshore support vessels (OSV) are intended to use electric motors especially for dynamic positioning applications.

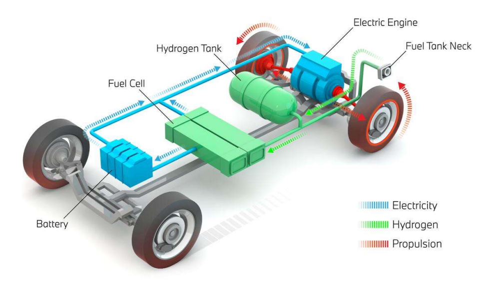
# Electric / Hydrogen Powertrain:

pic 1.



pic 3.





pic 2.

Source pic 1: Electric ship power system - research at the University of Texas, Austin Robert E. Hebner
pics 2and 3:Wärtsilä Hydrogen Machinery

# Electric Propulsion

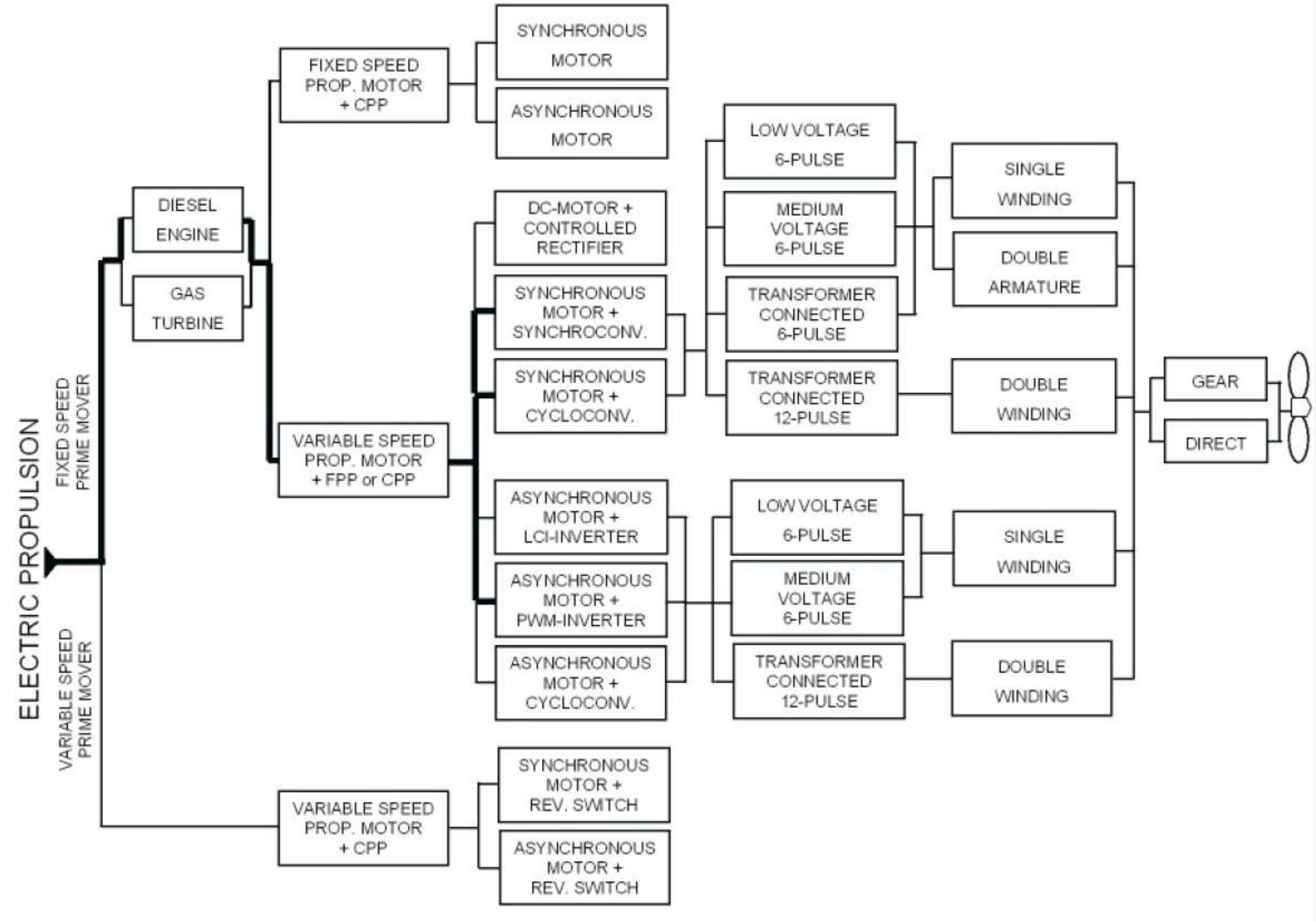


Figure 1-24 Possible options in selecting electric machinery

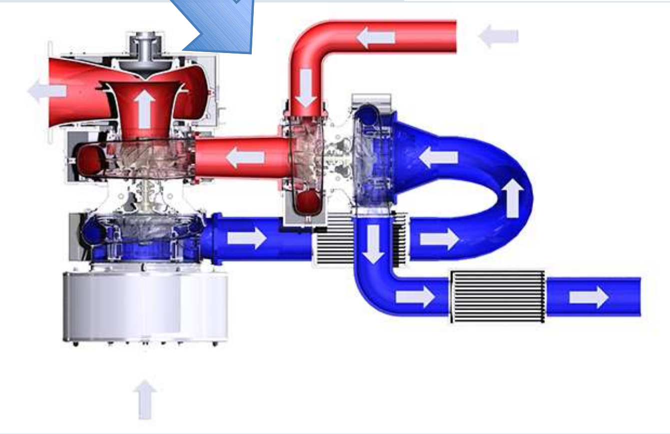
Source: The Future of Ship Design - DELTAMARINE

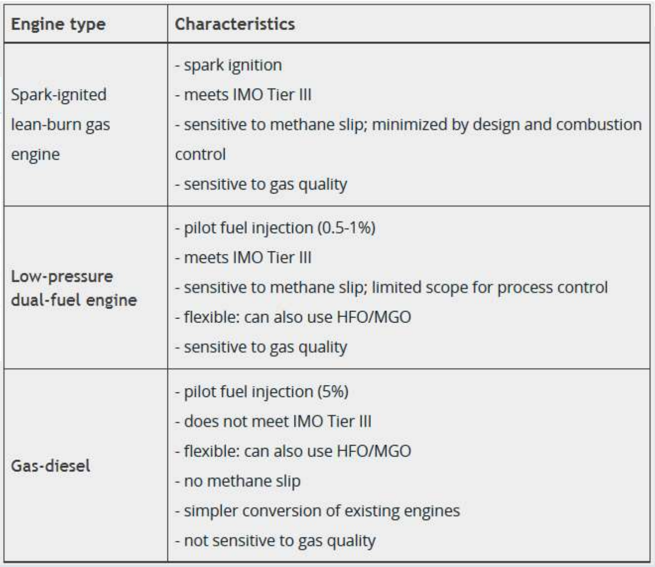
# Commonly selected Engine Makers :

- Wärtsilä (low-,medium-, high speed)
- MAN (low-,medium-, high speed)
- MaK – Caterpillar (medium-, high speed)
- MTU – RR (high speed)
- Bergen Engines – RR (medium speed)
- Mitsubishi (medium-, high speed)
- Cummins

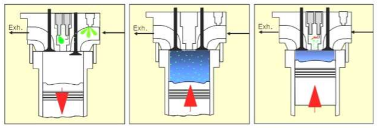
# Medium Speed Engine Types

| Wärtsilä 31 | |
|---|---|
| Cylinder bore | 310 mm |
| Piston stroke | 430 mm |
| Cylinder output Diesel | 610 kW/cyl |
| Cylinder output Dual-Fuel | 550 kW/cyl |
| Diesel | 30.1 bar |
| Dual-Fuel | 27.1 bar |
| Piston speed | 10.75 m/s |

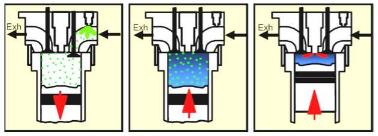




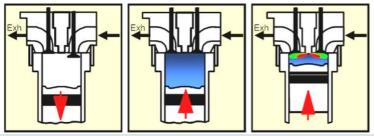
| Engine type | Characteristics |
|---|---|
| Spark-ignited lean-burn gas engine | - spark ignition<br>- meets IMO Tier III<br>- sensitive to methane slip; minimized by design and combustion control<br>- sensitive to gas quality |
| Low-pressure dual-fuel engine | - pilot fuel injection (0.5-1%)<br>- meets IMO Tier III<br>- sensitive to methane slip; limited scope for process control<br>- flexible: can also use HFO/MGO<br>- sensitive to gas quality |
| Gas-diesel | - pilot fuel injection (5%)<br>- does not meet IMO Tier III<br>- flexible: can also use HFO/MGO<br>- no methane slip<br>- simpler conversion of existing engines<br>- not sensitive to gas quality |



**LEAN BURN SPARK IGNITED ENGINE (LBSI)**



**DUAL FUEL GAS ENGINE (DF) –
PILOT DIESEL IGNITION**

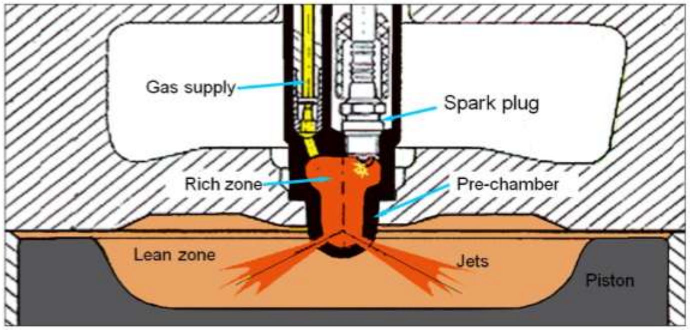


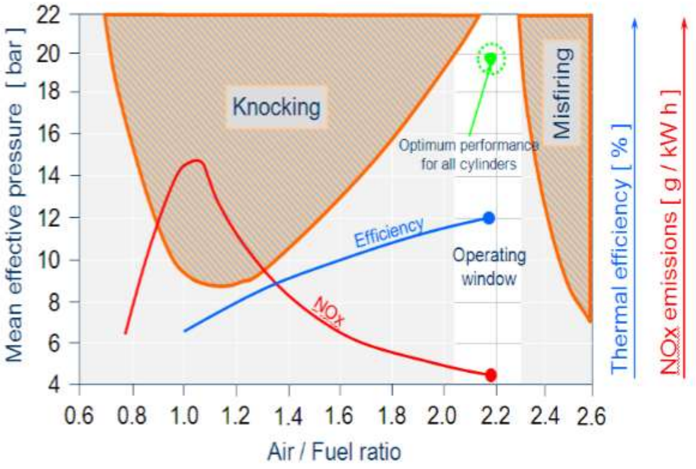
**High pressure gas injection -
"Gas Diesel engine" –(GD)**

By means of two-stage turbocharging the charge air pressure can be increased substantially.
The result is optionally higher power density and, in conjunction with Miller engine cycle, reduced exhaust emissions and lower fuel consumption.

# Spark Ignited Lean Burn gas engine (LBSI)

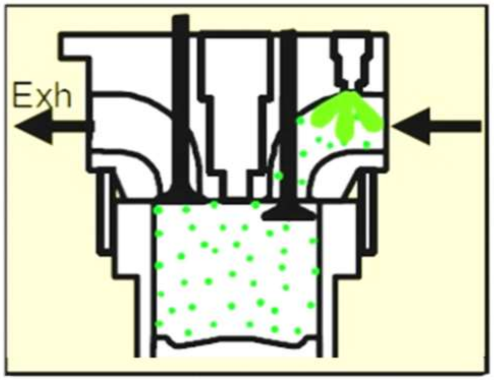
- ❑ Single fuel LNG, low pressure gas supply (4-5 bar)
- ❑ High energy efficiency at high load, higher than the corresponding diesel engine
- ❑ Low emissions, meets IMO tire III
- ❑ GHG reduction potential in the range of 20-30% ref. to HFO (incl. methane)
- ❑ Challenge on methane slip, minimized by design and combustion process control
- ❑ Sensitive to gas quality (Methane Number)
- ❑ Not suitable for retrofit of existing engines

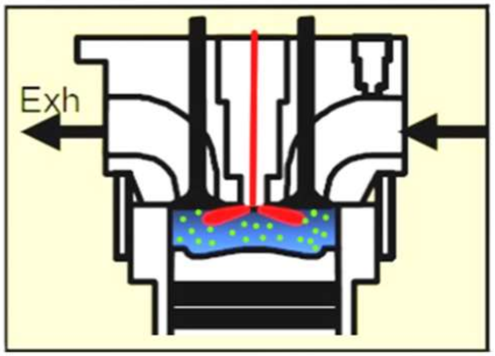




# Dual-Fuel Engine (DF)

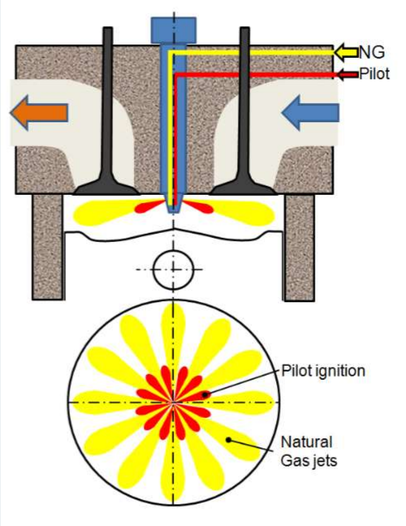
- Dual fuel capability (LNG-MDO)
- Low gas pressure supply (4-5 bar)
- High energy efficiency at high load
- Low emissions, meets IMO tire III
- Flexibility in fuel mix
- GHG reduction potential in the range of 20-30% ref. to HFO (reduction is depending on level of methane slip)
- Challenge on methane slip, limited possibility to combustion process control
- Sensitive to gas quality (Methane Number)
- Possible for conversion of existing engines (extensive rebuilding)

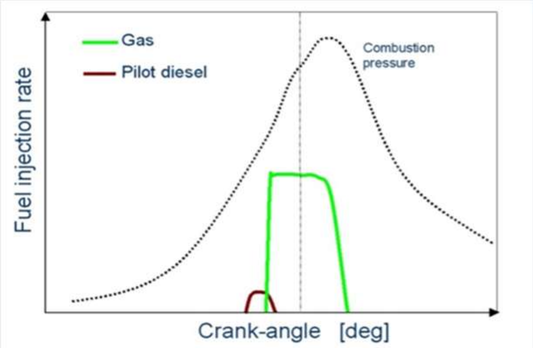




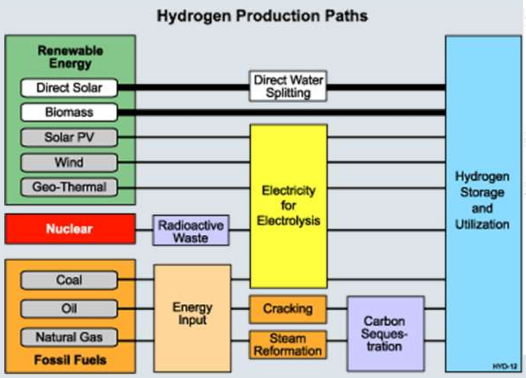
# Direct injection high pressure engine

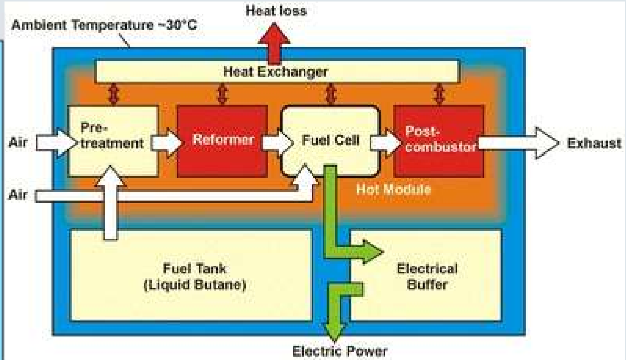
- Multi-fuel capability (LNG-MDO-HFO)
- High pressure gas injection (300 -350 bar) 4-stoke and 2- stroke
  Maintain diesel engine performance
- No methane slip, GHG reduction in the range of 30% ref. to HFO
- Need NOx reduction techniques to meet IMO tier III
- Not sensitive to gas quality
- Pumping 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)

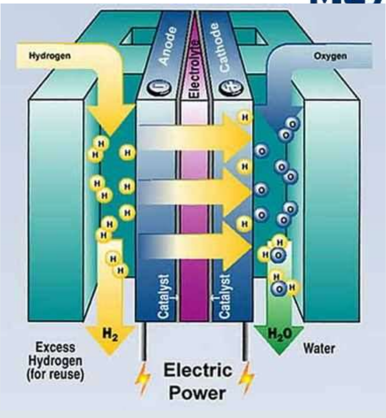


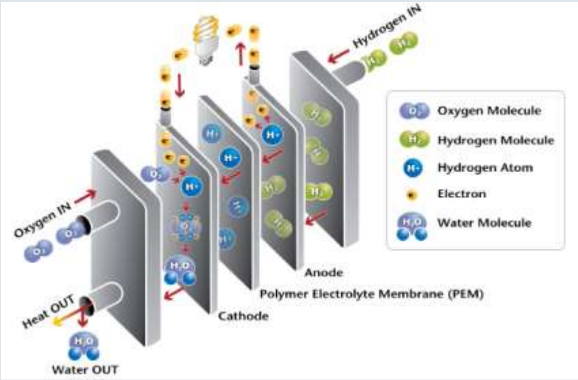


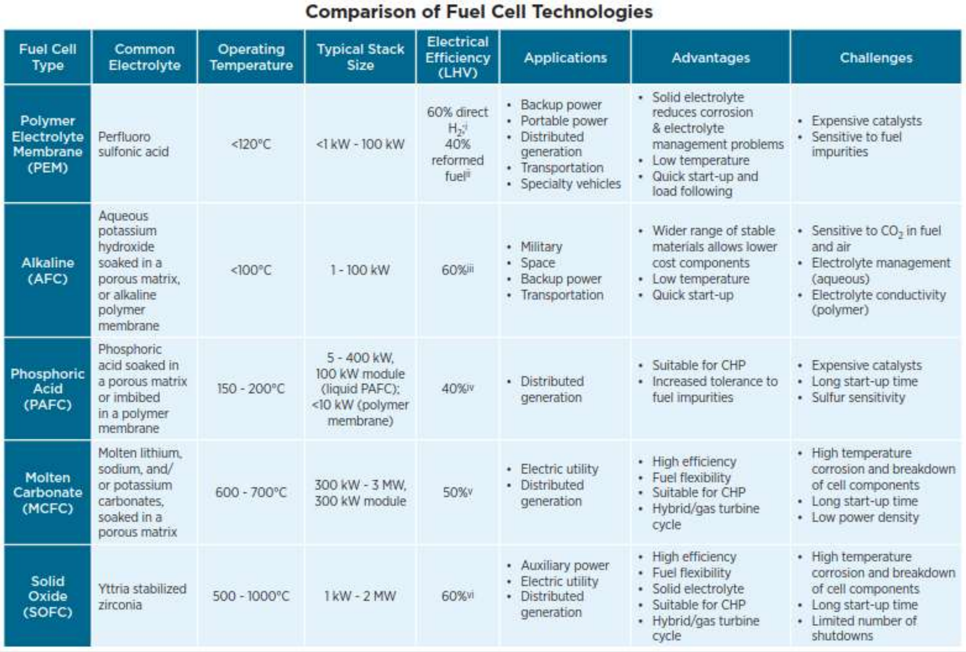
# FUEL CELLS









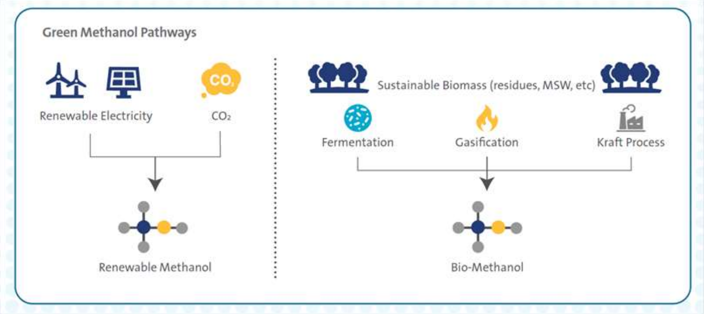


### Comparison of Fuel Cell Technologies

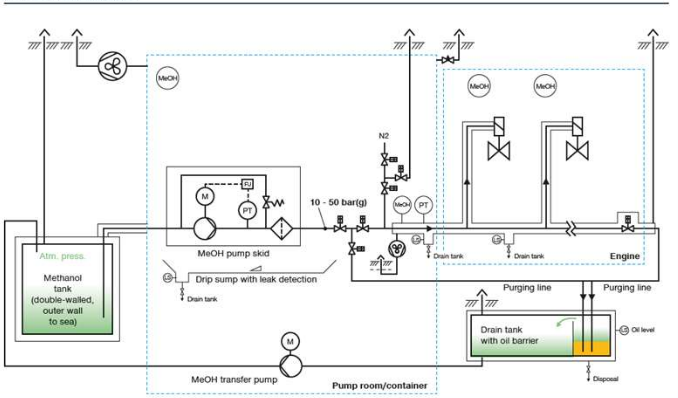
| Fuel Cell Type | Common Electrolyte | Operating Temperature | Typical Stack Size | Electrical Efficiency (LHV) | Applications | Advantages | Challenges |
|---|---|---|---|---|---|---|---|
| Polymer Electrolyte Membrane (PEM) | Perfluoro sulfonic acid | <120°C | <1 kW - 100 kW | 60% direct $H_2$;[i] 40% reformed fuel[ii] | • Backup power<br>• Portable power<br>• Distributed generation<br>• Transportation<br>• Specialty vehicles | • Solid electrolyte reduces corrosion & electrolyte management problems<br>• Low temperature<br>• Quick start-up and load following | • Expensive catalysts<br>• Sensitive to fuel impurities |
| Alkaline (AFC) | Aqueous potassium hydroxide soaked in a porous matrix, or alkaline polymer membrane | <100°C | 1 - 100 kW | 60%[iii] | • Military<br>• Space<br>• Backup power<br>• Transportation | • Wider range of stable materials allows lower cost components<br>• Low temperature<br>• Quick start-up | • Sensitive to $CO_2$ in fuel and air<br>• Electrolyte management (aqueous)<br>• Electrolyte conductivity (polymer) |
| Phosphoric Acid (PAFC) | Phosphoric acid soaked in a porous matrix or imbibed in a polymer membrane | 150 - 200°C | 5 - 400 kW, 100 kW module (liquid PAFC); <10 kW (polymer membrane) | 40%[iv] | • Distributed generation | • Suitable for CHP<br>• Increased tolerance to fuel impurities | • Expensive catalysts<br>• Long start-up time<br>• Sulfur sensitivity |
| Molten Carbonate (MCFC) | Molten lithium, sodium, and/or potassium carbonates, soaked in a porous matrix | 600 - 700°C | 300 kW - 3 MW, 300 kW module | 50%[v] | • Electric utility<br>• Distributed generation | • High efficiency<br>• Fuel flexibility<br>• Suitable for CHP<br>• Hybrid/gas turbine cycle | • High temperature corrosion and breakdown of cell components<br>• Long start-up time<br>• Low power density |
| Solid Oxide (SOFC) | Yttria stabilized zirconia | 500 - 1000°C | 1 kW - 2 MW | 60%[vi] | • Auxiliary power<br>• Electric utility<br>• Distributed generation | • High efficiency<br>• Fuel flexibility<br>• Solid electrolyte<br>• Suitable for CHP<br>• Hybrid/gas turbine cycle | • High temperature corrosion and breakdown of cell components<br>• Long start-up time<br>• Limited number of shutdowns |

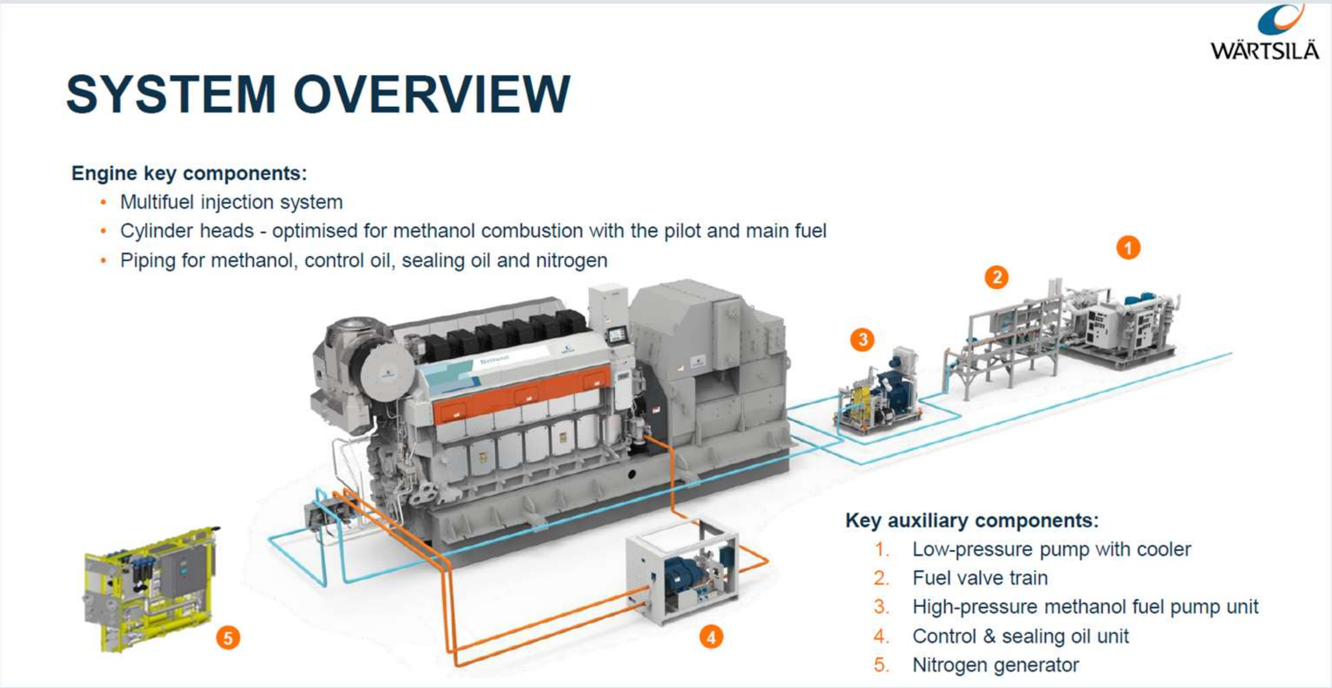
# Methanol as Fuel

- Possibility to total renewable fuel
- Low flash point Fuel
- Safety aspects
- Rules and regulations still developing



**MAN methanol solution**





## SYSTEM OVERVIEW

**Engine key components:**

- Multifuel injection system
- Cylinder heads - optimised for methanol combustion with the pilot and main fuel
- Piping for methanol, control oil, sealing oil and nitrogen

**Key auxiliary components:**

1. Low-pressure pump with cooler
2. Fuel valve train
3. High-pressure methanol fuel pump unit
4. Control & sealing oil unit
5. Nitrogen generator

# Engine Room – Ship propulsion systems

**Transmission:**

Transmission is a sub-system of the propulsion system. It is a system itself built up from components such as shafts, gearboxes and bearings or cables and transformers. The transmission's functions are:

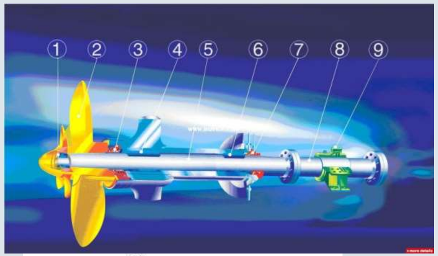
1. To transfer the mechanical energy generated from the prime mover to the propulsor

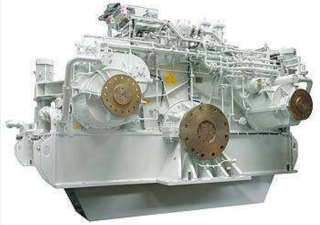
2. To transfer the thrust generated by the propulsor to the ship's hull

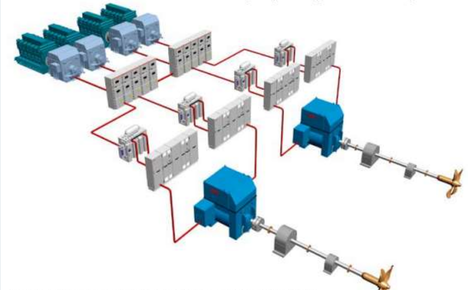
The latter is done by means of a thrust bearing; a component that is found in every transmission system.

Three types of transmission are used:

- **Direct**: the prime mover is coupled directly, through a shaft to the propulsor (this is the case with low speed diesel engines)
- **Geared**: the prime mover delivers its energy through a gearbox and a shaft to the propulsor. The function of the gearbox is to reduce the rotational speed of the engine to match the desired rotational speed of the propulsor.
- **Electrical**: the prime movers are coupled into generators and power is transported into electrical propulsion motors directly or through transformers. Speed is adjusted by means of converters.





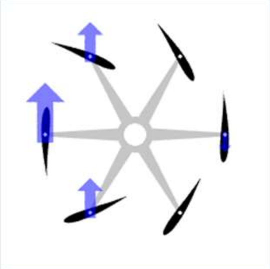


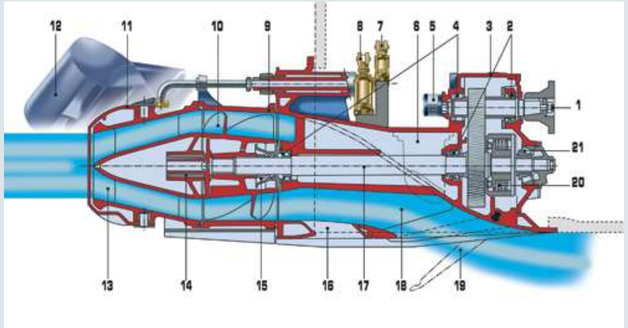
An example of Direct Drive – Full Redundant Drive solution for a passenger vessel

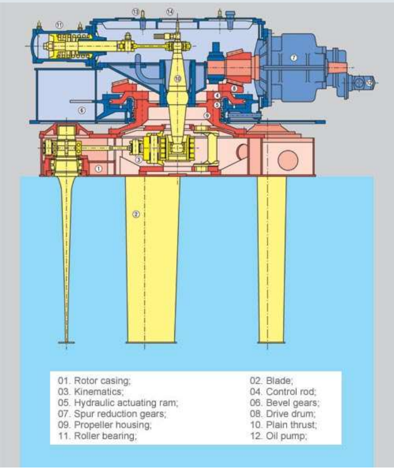
# Engine Room – Ship propulsion systems

**Propulsor:**

The propulsor converts the rotating mechanical power delivered by the engine into translating mechanical power to propel the ship. The most common propulsor is the propeller. In general, two types of propeller are distinguished, fixed pitch and controllable pitch propellers. Other types of propulsors are for example, PODs, waterjets and Voith-Schneider propulsors (vertical axis propeller).

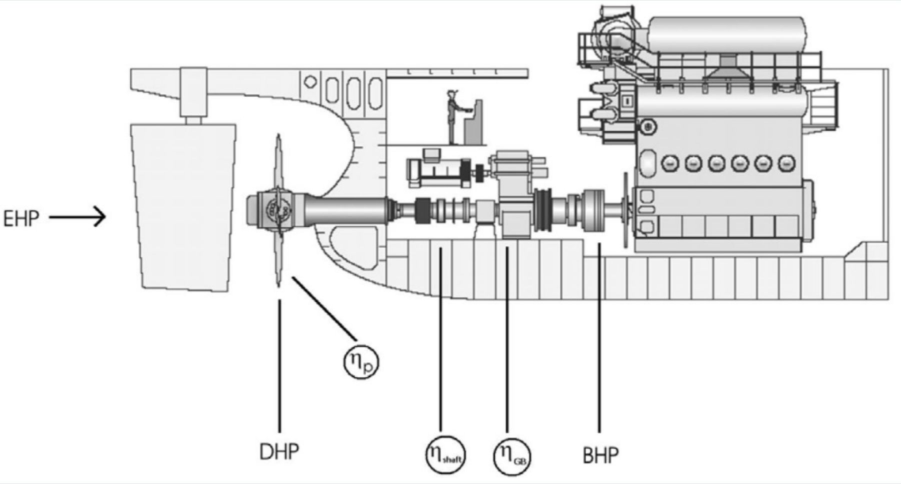






# Engine Room – Concept Design

MEYER TURKU
SHIPYARD 1737



BHP = brake horsepower kW

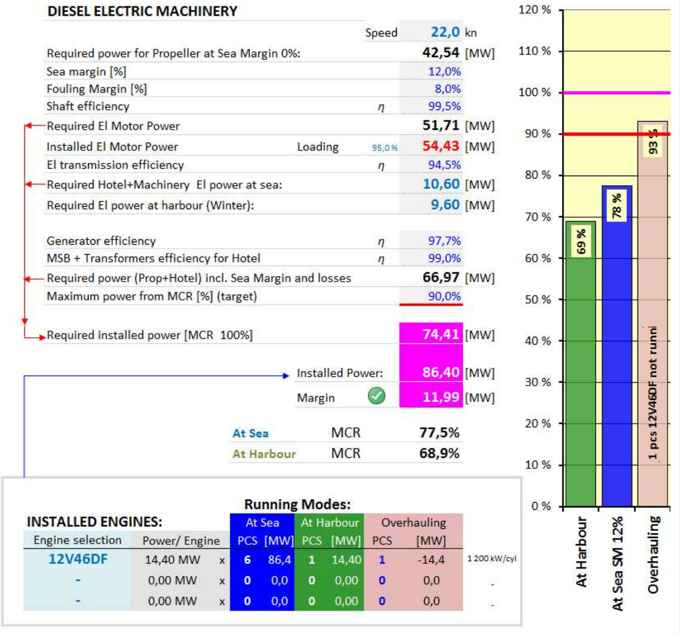
DHP = developed horsepower kW

EHP = effective horsepower kW

$\eta_{GB}$ = gearbox efficiency (1% ~ 3%)

$\eta_{shaft}$ = shafting efficiency (1% ~ 2%)

$\eta_P$ = propeller open water efficiency (30% ~ 60%)



**DIESEL ELECTRIC MACHINERY**

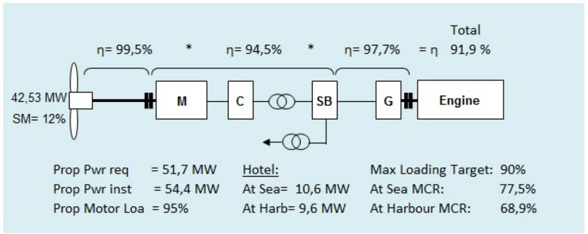
| | | | | |
|---|---|---|---|---|
| | Speed | | 22,0 | kn |
| Required power for Propeller at Sea Margin 0%: | | | 42,54 | [MW] |
| Sea margin [%] | | | 12,0% | |
| Fouling Margin [%] | | | 8,0% | |
| Shaft efficiency | | η | 99,5% | |
| Required El Motor Power | | | 51,71 | [MW] |
| Installed El Motor Power | Loading | 95,0 % | 54,43 | [MW] |
| El transmission efficiency | | η | 94,5% | |
| Required Hotel+Machinery El power at sea: | | | 10,60 | [MW] |
| Required El power at harbour (Winter): | | | 9,60 | [MW] |
| Generator efficiency | | η | 97,7% | |
| MSB + Transformers efficiency for Hotel | | η | 99,0% | |
| Required power (Prop+Hotel) incl. Sea Margin and losses | | | 66,97 | [MW] |
| Maximum power from MCR [%] (target) | | | 90,0% | |
| Required installed power [MCR 100%] | | | 74,41 | [MW] |
| | Installed Power: | | 86,40 | [MW] |
| | Margin | ✓ | 11,99 | [MW] |

| | | |
|---|---|---|
| At Sea | MCR | 77,5% |
| At Harbour | MCR | 68,9% |

**Running Modes:**

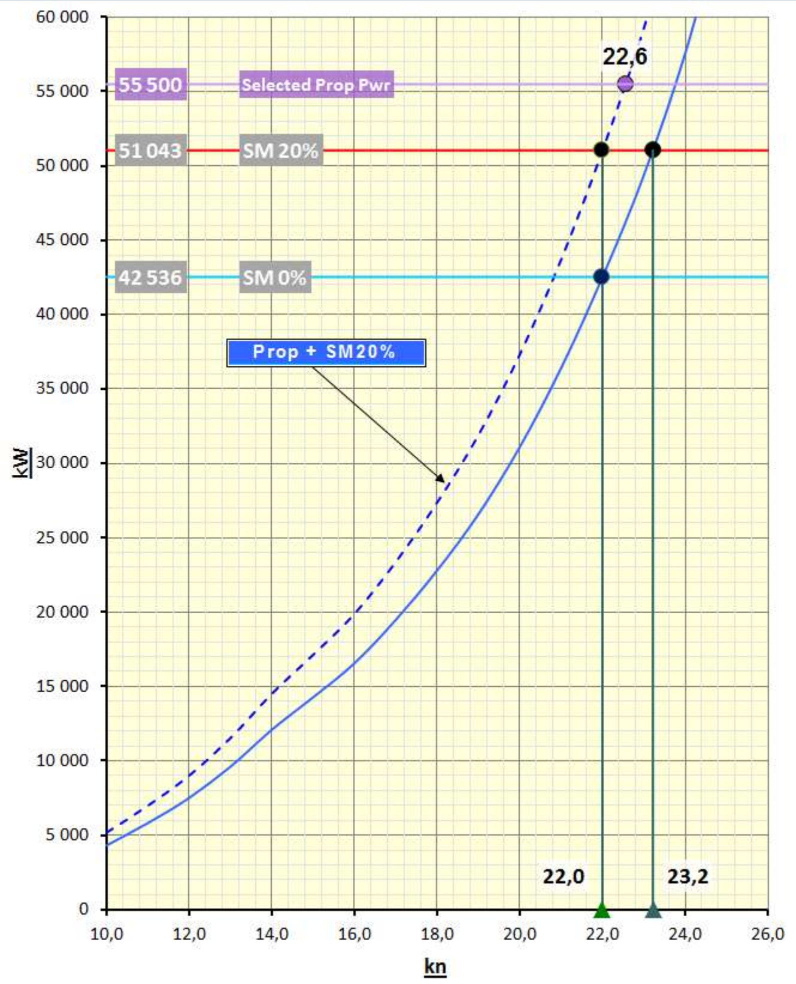
**INSTALLED ENGINES:**

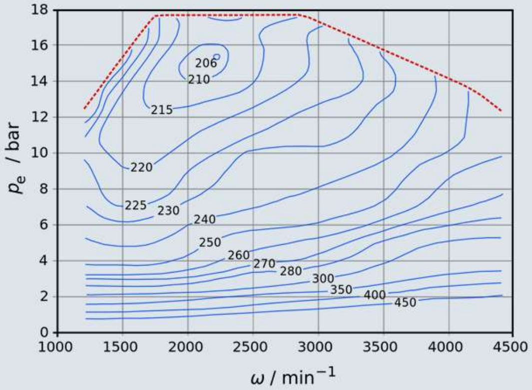
| | | | At Sea | | At Harbour | | Overhauling | | |
|---|---|---|---|---|---|---|---|---|---|
| Engine selection | Power/ Engine | | PCS | [MW] | PCS | [MW] | PCS | [MW] | |
| 12V46DF | 14,40 MW | x | 6 | 86,4 | 1 | 14,40 | 1 | -14,4 | 1 200 kW/cyl |
| - | 0,00 MW | x | 0 | 0,0 | 0 | 0,00 | 0 | 0,0 | - |
| - | 0,00 MW | x | 0 | 0,0 | 0 | 0,00 | 0 | 0,0 | - |

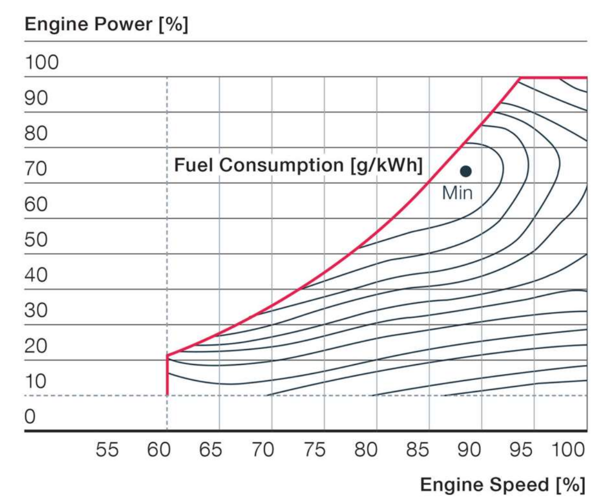


| | | |
|---|---|---|
| Prop Pwr req = 51,7 MW | Hotel: | Max Loading Target: 90% |
| Prop Pwr inst = 54,4 MW | At Sea= 10,6 MW | At Sea MCR: 77,5% |
| Prop Motor Loa = 95% | At Harb= 9,6 MW | At Harbour MCR: 68,9% |

# Engine Room – Speed & Power







SRS1 Cubic Spline for Excel (free tool)

**How many Engines ?**

Power Demand – Propulsion /Auxiliaries

Direct Drive – Electrical (propulsion)

SRtP / SRtP-power demand

At least 2 independent compartments (System, Fire, Water Integrity

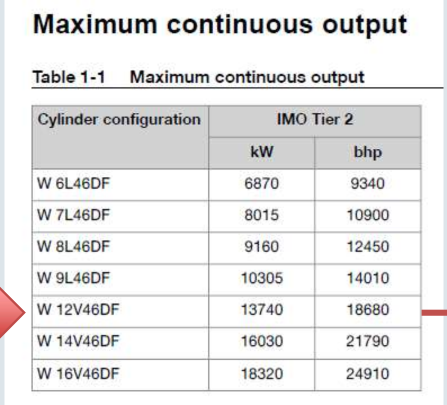
At least 2 Engines running when leaving Port → In practise minimum 2+2

**Engine type / Cylinders ?**

**3 - 4 - 5 - 6 - 7 - 8 - 9 - 10 -12 - 14 - 16 - 18**

- Minimize amount of cylinders and Engine Types
- Fuel type
- Available Space ( ER is non profit space!)
- DB to Bulkhead Deck height
- Length of WT-compartment(s)
- Weight of Engines

# WÄRTSILÄ 46 DF Product Guide – Weight Estimation



## Maximum continuous output

Table 1-1 Maximum continuous output

| Cylinder configuration | IMO Tier 2 | |
|---|---|---|
| | kW | bhp |
| W 6L46DF | 6870 | 9340 |
| W 7L46DF | 8015 | 10900 |
| W 8L46DF | 9160 | 12450 |
| W 9L46DF | 10305 | 14010 |
| W 12V46DF | 13740 | 18680 |
| W 14V46DF | 16030 | 21790 |
| W 16V46DF | 18320 | 24910 |

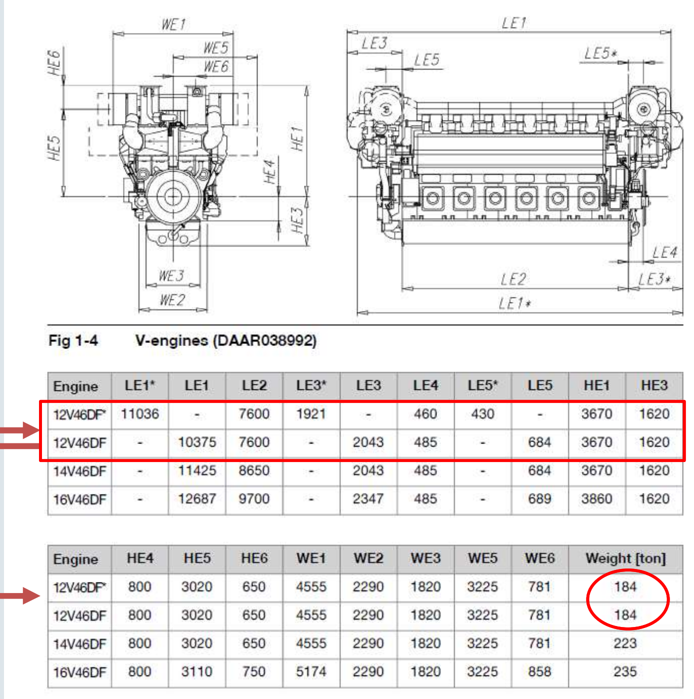


Fig 1-4 V-engines (DAAR038992)

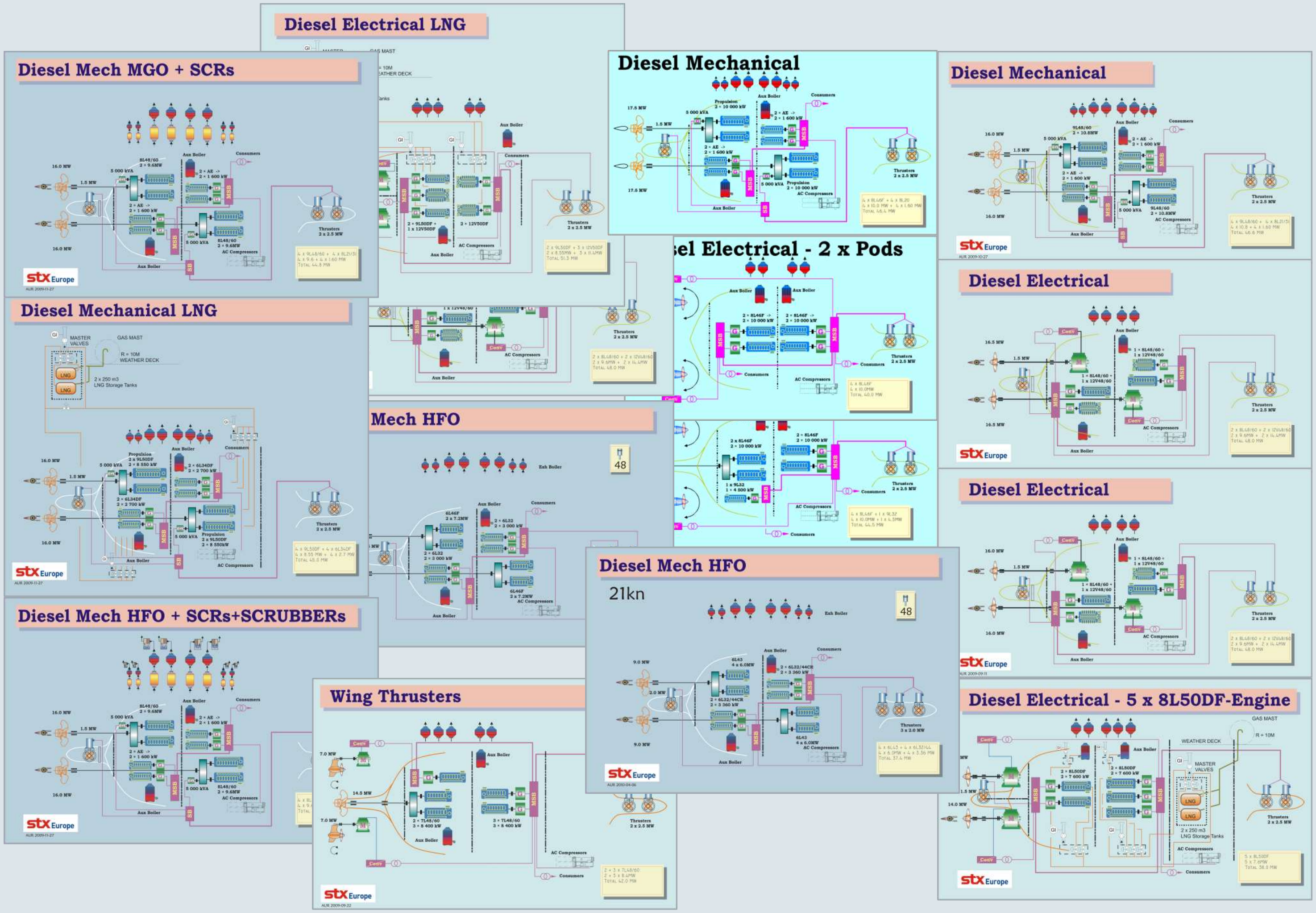
| Engine | LE1* | LE1 | LE2 | LE3* | LE3 | LE4 | LE5* | LE5 | HE1 | HE3 |
|---|---|---|---|---|---|---|---|---|---|---|
| 12V46DF* | 11036 | - | 7600 | 1921 | - | 460 | 430 | - | 3670 | 1620 |
| 12V46DF | - | 10375 | 7600 | - | 2043 | 485 | - | 684 | 3670 | 1620 |
| 14V46DF | - | 11425 | 8650 | - | 2043 | 485 | - | 684 | 3670 | 1620 |
| 16V46DF | - | 12687 | 9700 | - | 2347 | 485 | - | 689 | 3860 | 1620 |

| Engine | HE4 | HE5 | HE6 | WE1 | WE2 | WE3 | WE5 | WE6 | Weight [ton] |
|---|---|---|---|---|---|---|---|---|---|
| 12V46DF* | 800 | 3020 | 650 | 4555 | 2290 | 1820 | 3225 | 781 | 184 |
| 12V46DF | 800 | 3020 | 650 | 4555 | 2290 | 1820 | 3225 | 781 | 184 |
| 14V46DF | 800 | 3020 | 650 | 4555 | 2290 | 1820 | 3225 | 781 | 223 |
| 16V46DF | 800 | 3110 | 750 | 5174 | 2290 | 1820 | 3225 | 858 | 235 |

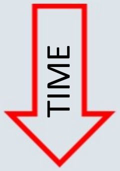
Machinery (room) Weight:
Sum of Main Components (including HVAC) + LNG Tanks + Piping (inc. components PPackets) + Ducts + Cables + etc.
20% of items is 80% of weight

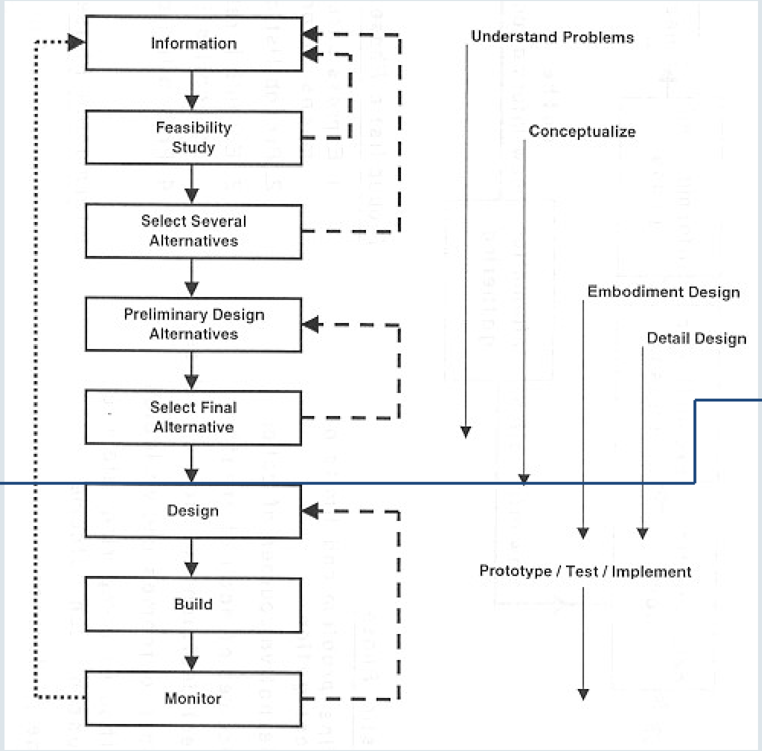
# SELECTIONS

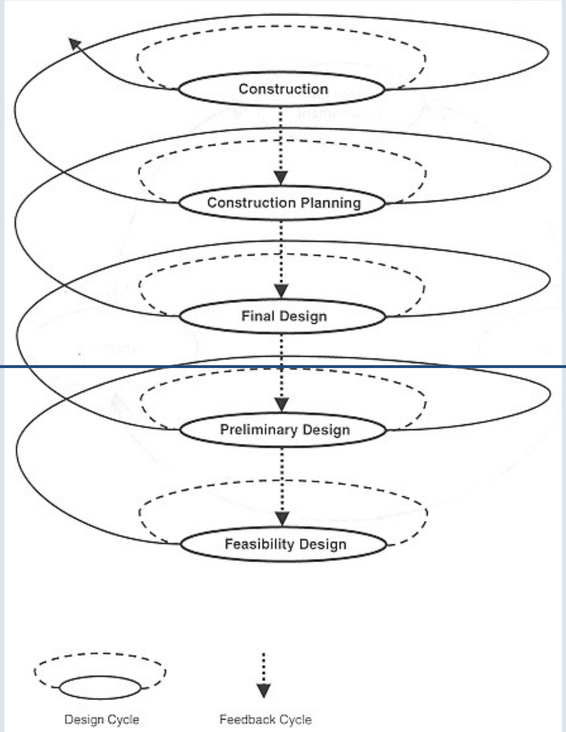
# Machinery Comparison – Matrix of Alternatives

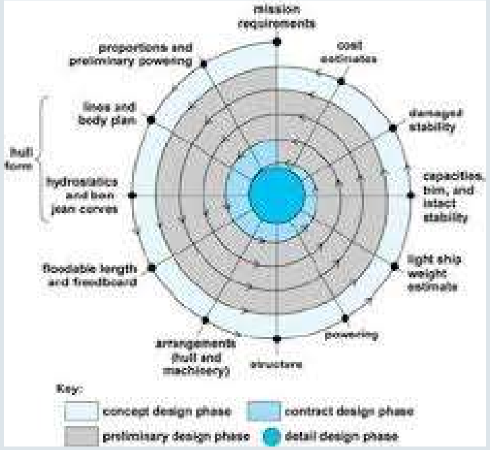


# Design Process



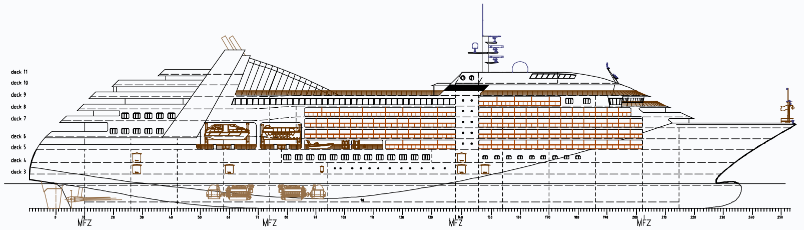






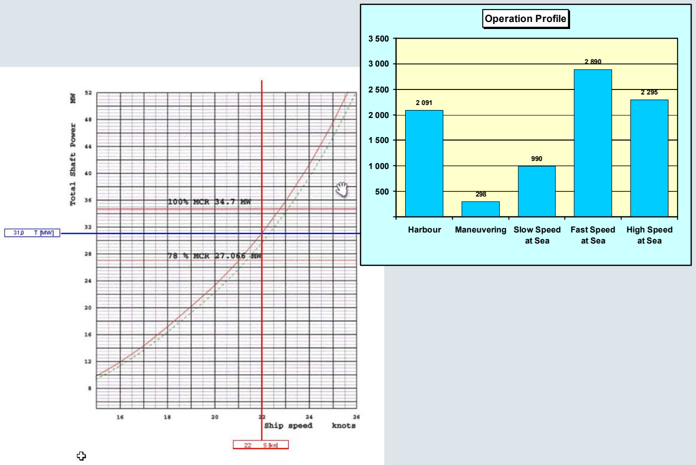
# ELIMINATION AND SORTING

# Feasibility Study



The SHIP

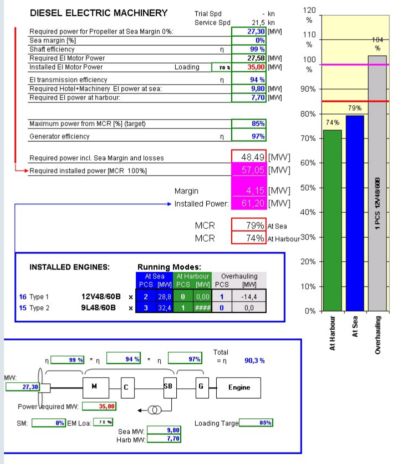
## Speed / Power



Selections/calculations

Hotel Load statistics

## Powerplant



**DIESEL ELECTRIC MACHINERY**

Trial Spd - kn
Service Spd 21,5 kn

| | | | |
|---|---|---|---|
| Required power for Propeller at Sea Margin 0%: | | 27,30 | [MW] |
| Sea margin [%] | | 0% | |
| Shaft efficiency | η | 99 % | |
| Required El Motor Power | | 27,58 | [MW] |
| Installed El Motor Power | Loading 78 % | 35,00 | [MW] |
| El transmission efficiency | η | 94 % | |
| Required Hotel+Machinery El power at sea: | | 9,80 | [MW] |
| Required El power at harbour: | | 7,70 | [MW] |
| Maximum power from MCR [%] (target) | | 85% | |
| Generator efficiency | η | 97% | |
| Required power incl. Sea Margin and losses | | 48,49 | [MW] |
| Required installed power [MCR 100%] | | 57,05 | [MW] |
| Margin | | 4,15 | [MW] |
| Installed Power: | | 61,20 | [MW] |
| MCR | | 79% | At Sea |
| MCR | | 74% | At Harbour |

**INSTALLED ENGINES:** **Running Modes:**

| | | | | At Sea | | At Harbour | | Overhauling | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | PCS | [MW] | PCS | [MW] | PCS | [MW] |
| 16 | Type 1 | 12V48/60B | x | 2 | 28,8 | 0 | 0,00 | 1 | -14,4 |
| 15 | Type 2 | 9L48/60B | x | 3 | 32,4 | 1 | #### | 0 | 0,0 |

η 99 % * η 94 % * η 97% Total = η 90,3 %

MW: 27,30

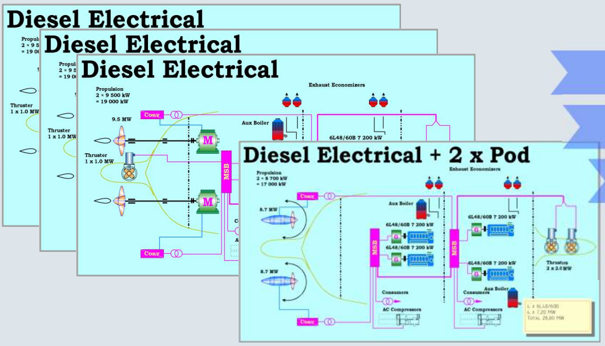
Power required MW: 35,00

SM: 0% EM Loa: 78 %

Sea MW: 9,80
Harb MW: 7,70

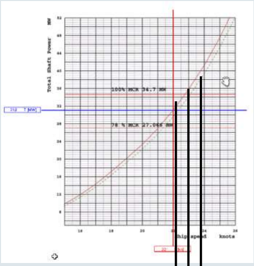
Loading Targe 85%

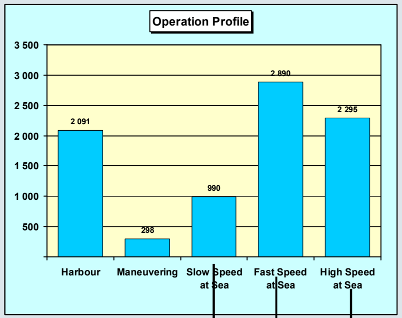
## Powerplant + Propulsor altenatives 1 to n



# Feasibility Study

## Fuel and Maintenance for each Alternative





Operator/route specific operation profile

Selections/calculations

- Engine Loading %
- SFC g/kWh
- Margins %
- Sum of losses Π
- Fuel quality
- Fuel Price EUR/ton
- Maint. EUR/kWh

1. Fuel cons/mode= P(power needed)/Π*SFC*h(running hours/a)

2. Fuel cons/mode= P(power needed)/Π*SFC*h(running hours/a)

n. Fuel cons/mode= P(power needed)/Π*SFC*h(running hours/a)

$\Sigma_{(1\ \text{to}\ n)}$=total fuel consumption for each mode **(ton)**

ton*Fuel price (EUR/ton) = **Total fuel cost (EUR) / a**

$\Sigma_{(1\ \text{to}\ n)}$=kWh*maintenance cost (EUR/kWh) = **EUR/a**

To Summary Sheet

# Feasibility Study

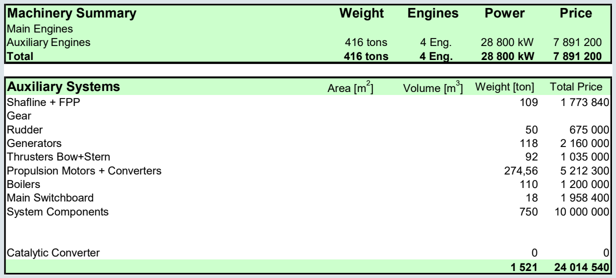
Initial Cost and Weight for each Alternative

Components

Quotations

Statistics

Initial Cost



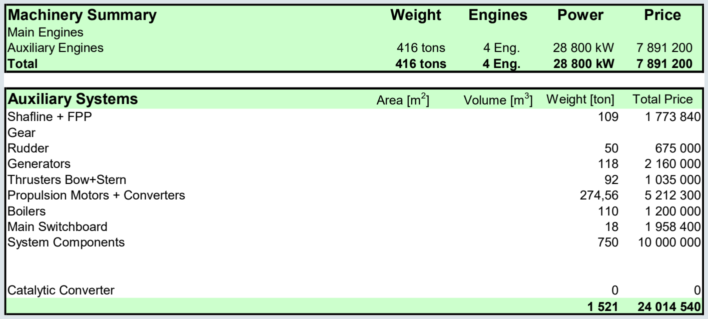
| Machinery Summary | Weight | Engines | Power | Price |
|---|---|---|---|---|
| Main Engines | | | | |
| Auxiliary Engines | 416 tons | 4 Eng. | 28 800 kW | 7 891 200 |
| **Total** | **416 tons** | **4 Eng.** | **28 800 kW** | **7 891 200** |

| **Auxiliary Systems** | Area [$m^2$] | Volume [$m^3$] | Weight [ton] | Total Price |
|---|---|---|---|---|
| Shafline + FPP | | | 109 | 1 773 840 |
| Gear | | | | |
| Rudder | | | 50 | 675 000 |
| Generators | | | 118 | 2 160 000 |
| Thrusters Bow+Stern | | | 92 | 1 035 000 |
| Propulsion Motors + Converters | | | 274,56 | 5 212 300 |
| Boilers | | | 110 | 1 200 000 |
| Main Switchboard | | | 18 | 1 958 400 |
| System Components | | | 750 | 10 000 000 |
| Catalytic Converter | | | 0 | 0 |
| | | | **1 521** | **24 014 540** |

Σtotal inital cost = **EUR**

To Summary Sheet

Component weights



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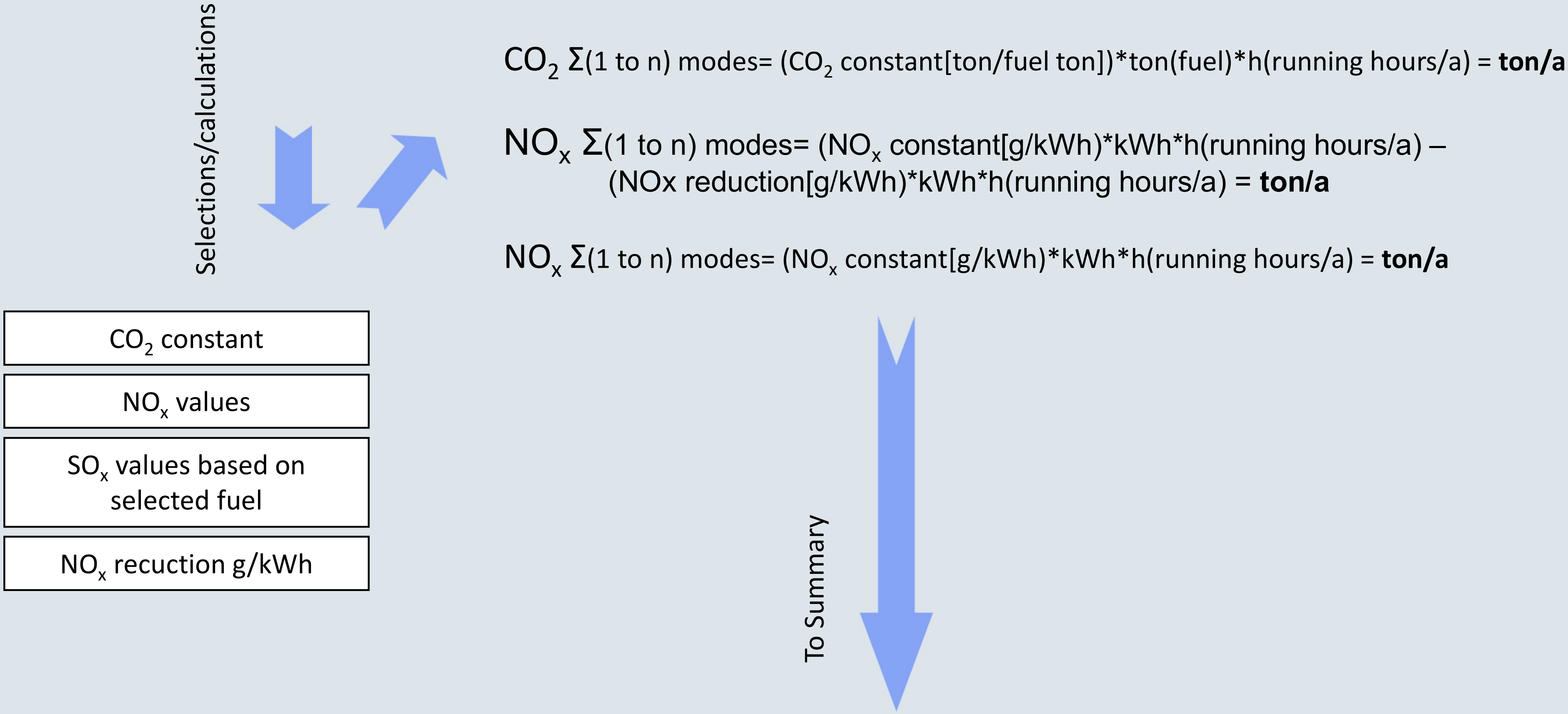
| Catalytic Converter | | | 0 | 0 |
| | | | **1 521** | **24 014 540** |

To Summary

# Feasibility Study



Emissions for each Alternative

Selections/calculations

$CO_2$ Σ(1 to n) modes= ($CO_2$ constant[ton/fuel ton])*ton(fuel)*h(running hours/a) = **ton/a**

$NO_x$ Σ(1 to n) modes= ($NO_x$ constant[g/kWh)*kWh*h(running hours/a) –
(NOx reduction[g/kWh)*kWh*h(running hours/a) = **ton/a**

$NO_x$ Σ(1 to n) modes= ($NO_x$ constant[g/kWh)*kWh*h(running hours/a) = **ton/a**

- $CO_2$ constant
- $NO_x$ values
- $SO_x$ values based on selected fuel
- $NO_x$ recuction g/kWh

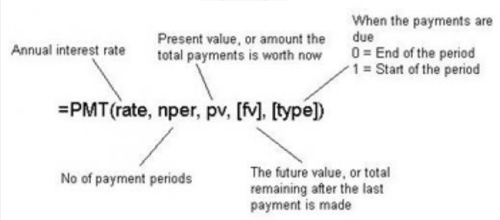
To Summary

# Feasibility Study

Σ(yearly cost for each alternative)=*capital(PMT)+ Fuel cost* + *Maintenance* = **EUR/a**

Summary

Selections/calculations


Annual interest rate

Present value, or amount the total payments is worth now

When the payments are due
0 = End of the period
1 = Start of the period

=PMT(rate, nper, pv, [fv], [type])

No of payment periods

The future value, or total remaining after the last payment is made

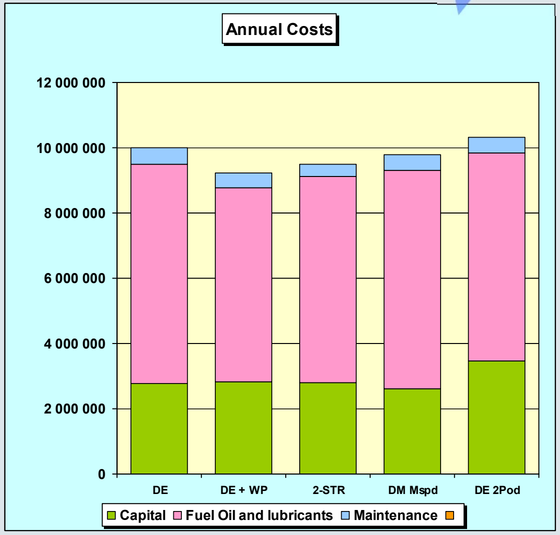
Interest rate 6%

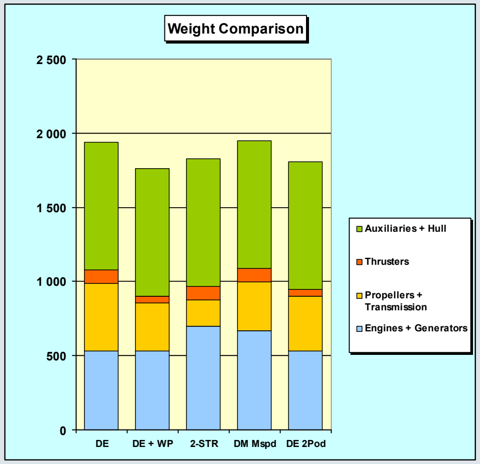
nper=20

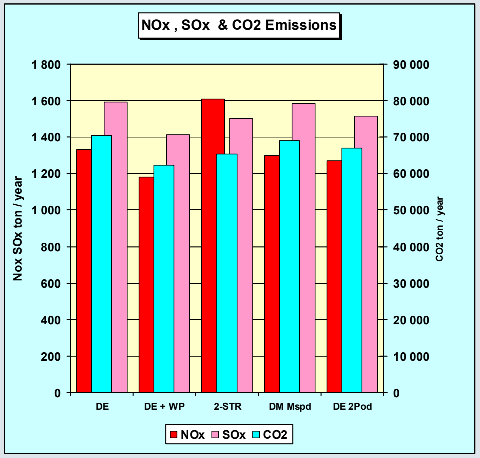
pv=initial cost

fv=0

type=0







# LAY-OUT AND GEOMETRY

# Engine Room

MEYER TURKU
SHIPYARD 1737

**Main Components**

- **Engines + Generators /Aux Engines**

- **Propulsion**
    - **PODs**
    - **Shaflines**
    - **Propeller Motors**
    - **Gears**
    - **Thrusters**

- **Electric**
    - **MSBs - Generators**
    - **Converters + Transformers**
    - **Emergency Generator**

- **Casing**
    - **Exhaust Gas Economisers**
    - **SCRs**
    - **Scrubbers**

# Engine Room

- **Internal**
  - **Compartment Lengths – WT – MFB – Fire insulation**
  - **SRtP requirements – RP-class**
  - **Compact systems**
  - **Deck heights – lift beams**
  - **Service Spaces- transport routes – stairs - hatches**
  - **Accessibility – Stairs – Escape routes/trunks**
  - **Sea Chests**

- **Tanks**
  - **HFO – MDO – MGO - BioF – LNG – Different qualities - ; Range**
  - **Fresh Water ; persons / operation profile / harbour days**
  - **GW / operation profile /harbour days**

- **Specification**

# Engine Room

- HVAC
  - AC Chillers
  - Evaporators / RO-plants

- Waste Treatment
  - AWP
  - Incinerators

- Operation
  - Workshops + Stores

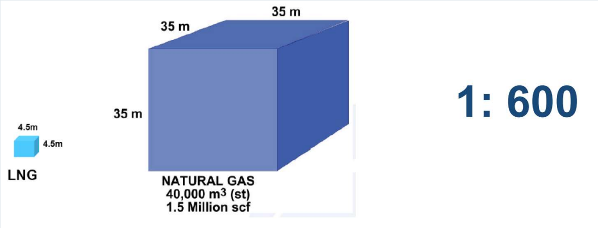
- Building and operation
  - Main Pipe routes - Casing
  - Main Cable Routes
  - Agregates and Modules
  - LNG safety measures

# LNG

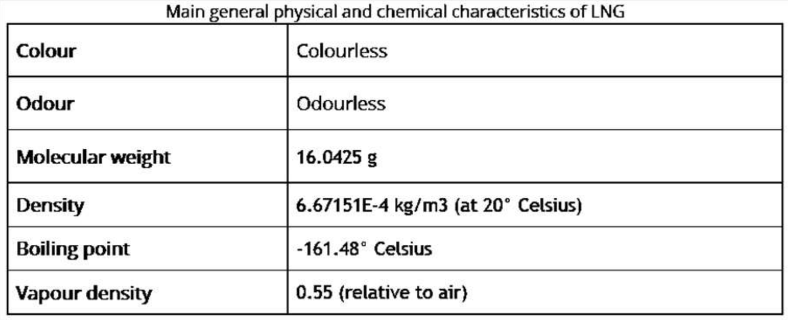
# Natural Gas and LNG

- Natural gas is consisting primarily of methane, a typical composition is:

| | |
|---|---|
| Methane | 94% |
| Ethane | 4.7% |
| Propane | 0.8% |
| Butane | 0.2% |
| Nitrogen | 0.3% |

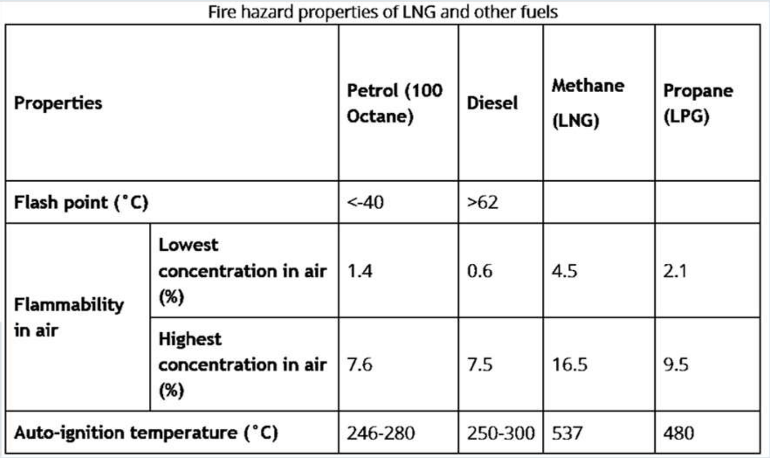


- Natural gas burns more cleanly than all other fossil fuels.



Main general physical and chemical characteristics of LNG

| | |
|---|---|
| **Colour** | Colourless |
| **Odour** | Odourless |
| **Molecular weight** | 16.0425 g |
| Density | 6.67151E-4 kg/m3 (at 20° Celsius) |
| Boiling point | -161.48° Celsius |
| Vapour density | 0.55 (relative to air) |



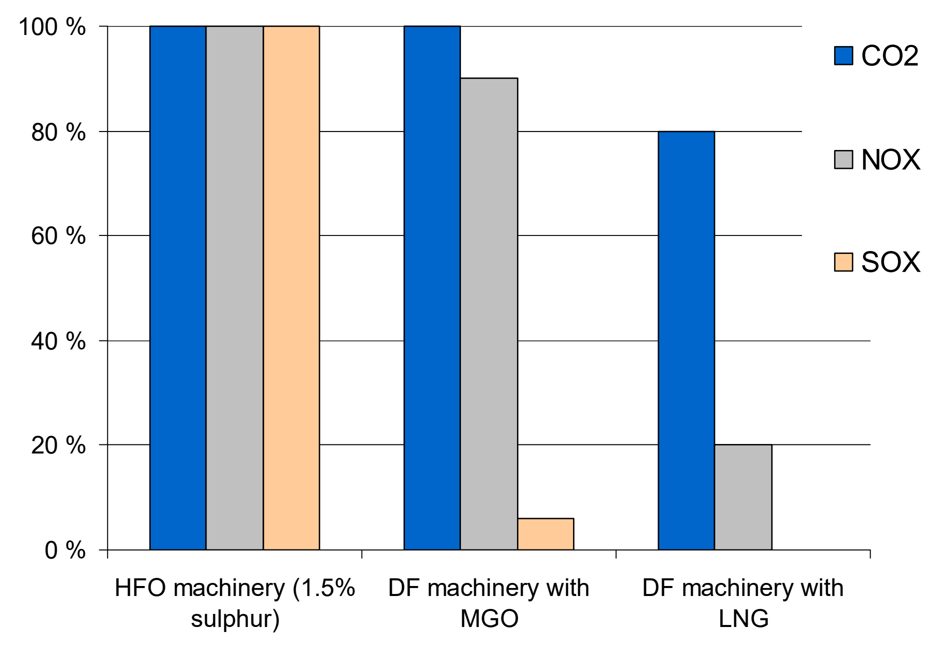
Fire hazard properties of LNG and other fuels

| **Properties** | | **Petrol (100 Octane)** | **Diesel** | **Methane (LNG)** | **Propane (LPG)** |
|---|---|---|---|---|---|
| **Flash point (°C)** | | <-40 | >62 | | |
| **Flammability in air** | **Lowest concentration in air (%)** | 1.4 | 0.6 | 4.5 | 2.1 |
| | **Highest concentration in air (%)** | 7.6 | 7.5 | 16.5 | 9.5 |
| **Auto-ignition temperature (°C)** | | 246-280 | 250-300 | 537 | 480 |

**In the Ship same energy takes abt. 3 x volume compared to MGO!**

# Driving factors to shift into LNG - Emissions

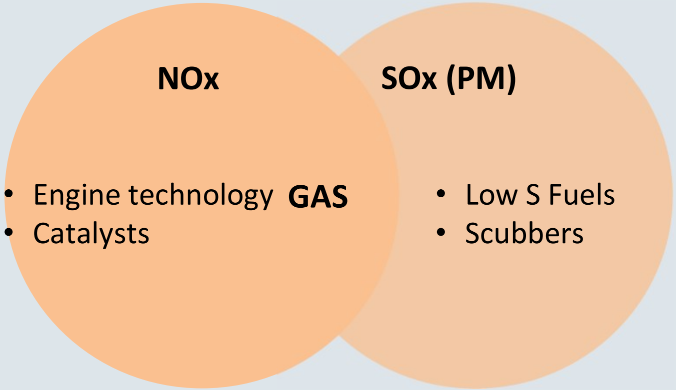
- **CO2 reduction 25-30% (GHG reduction ~15% Methane slip)**
- **NOx reduction 85% (fulfils IMO Tier III In NOx Emission Control Areas)**
- **SOx reduction 100%**
- **PM reduction almost 100%**
- **No visible smoke**



# Operating within ECA – What to do?

**The optimal compromise regarding**
- **Investment and operational costs**
- **Space requirements**

**need to be investigated for each case.**



**NOx**

- Engine technology
- Catalysts

**GAS**

**SOx (PM)**

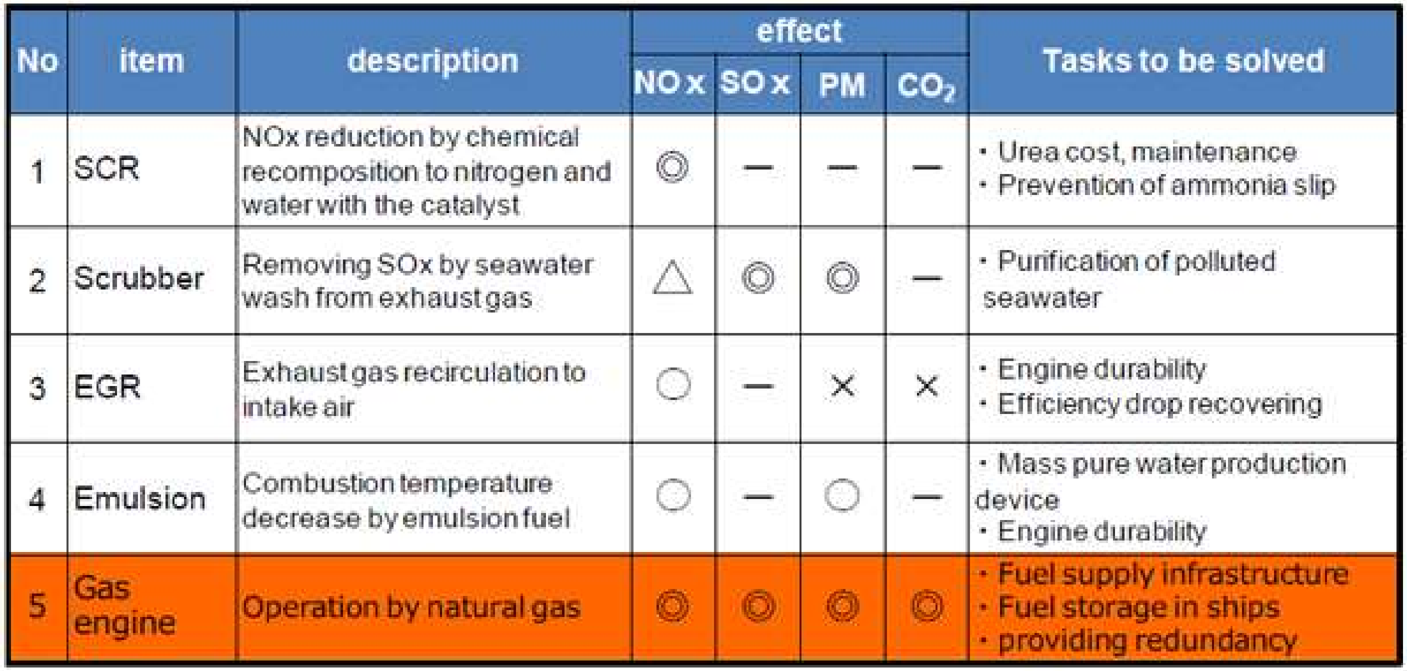
- Low S Fuels
- Scubbers

- **Only short periods in ECA:**
  - MGO -operation with SCR in ECA
  - MGO -operation with EGR in ECA

- **Long periods in ECA:**
  - HFO -operation with SCR and scrubbing system (wet/closed/dry)
  - MGO -operation with SCR
  - MGO -operation with EGR
  - Gaseous fuel operation - **LNG**

* EGR - perhaps not coming into Medium Speed Diesels

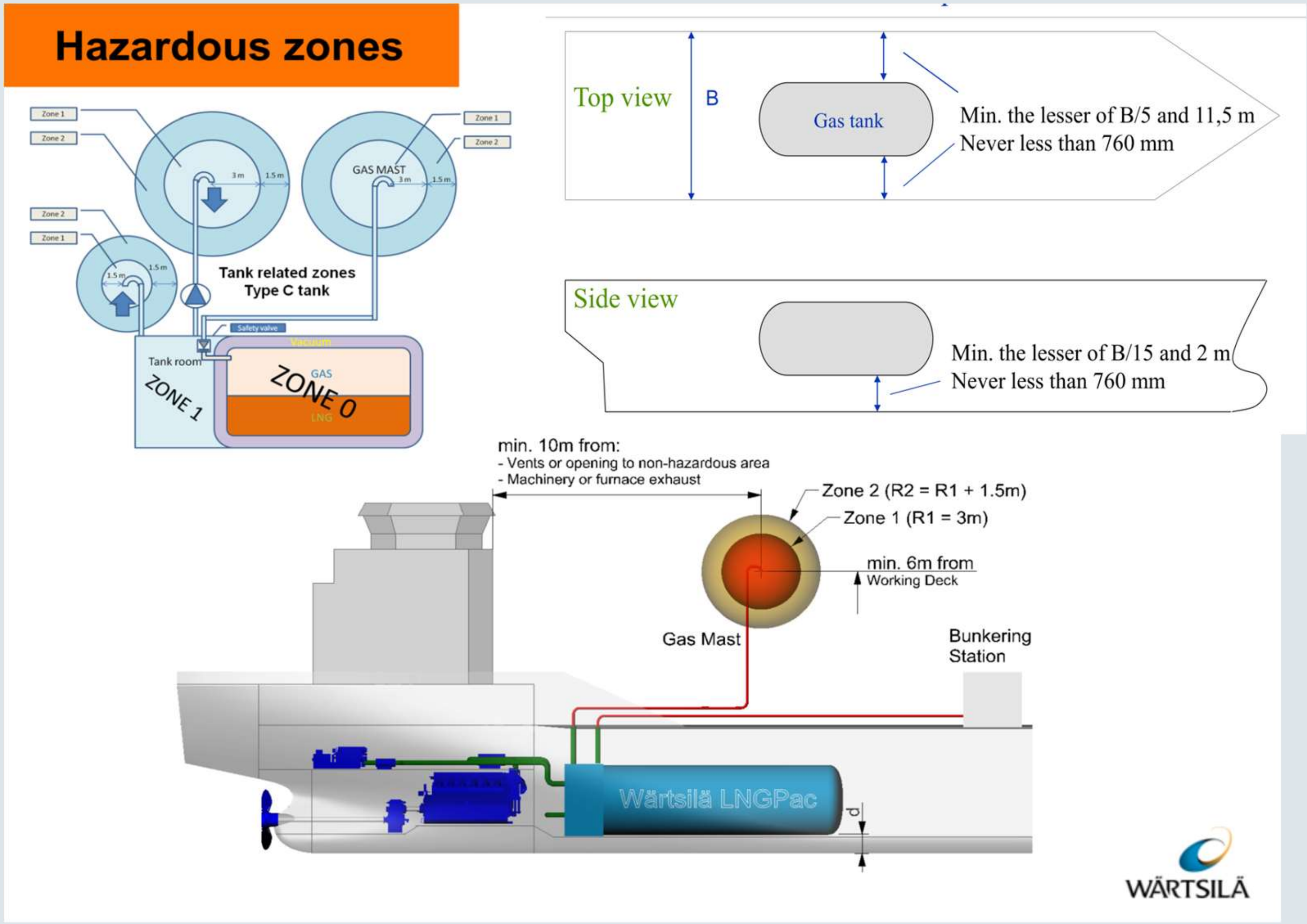
# Emissions - What Technology available?



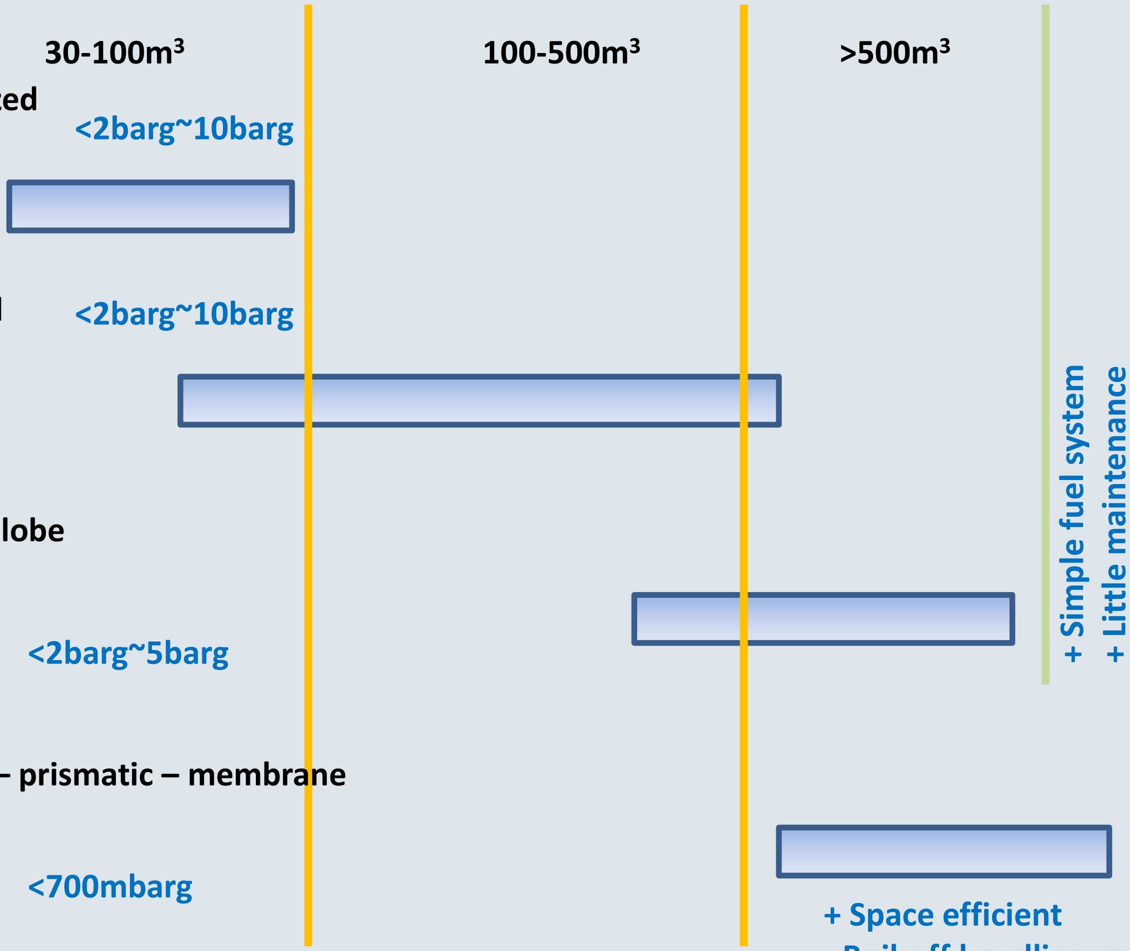
| No | item | description | effect | | | | Tasks to be solved |
|---|---|---|---|---|---|---|---|
| | | | NOx | SOx | PM | $CO_2$ | |
| 1 | SCR | NOx reduction by chemical recomposition to nitrogen and water with the catalyst | ◎ | — | — | — | · Urea cost, maintenance<br>· Prevention of ammonia slip |
| 2 | Scrubber | Removing SOx by seawater wash from exhaust gas | △ | ◎ | ◎ | — | · Purification of polluted seawater |
| 3 | EGR | Exhaust gas recirculation to intake air | ○ | — | × | × | · Engine durability<br>· Efficiency drop recovering |
| 4 | Emulsion | Combustion temperature decrease by emulsion fuel | ○ | — | ○ | — | · Mass pure water production device<br>· Engine durability |
| 5 | Gas engine | Operation by natural gas | ◎ | ◎ | ◎ | ◎ | · Fuel supply infrastructure<br>· Fuel storage in ships<br>· providing redundancy |

Note: SCR (Selective Catalytic Reduction)
EGR (Exhaust Gas Recirculation)

# LNG Tank Location limitations – Hazardous Zones



# LNG Tank Types



30-100$m^3$

100-500$m^3$

>500$m^3$

**Containerized pressurized**

<2barg~10barg

**Pressurized cylindrical**

<2barg~10barg

**Pressurized bilobe - trilobe**

<2barg~5barg

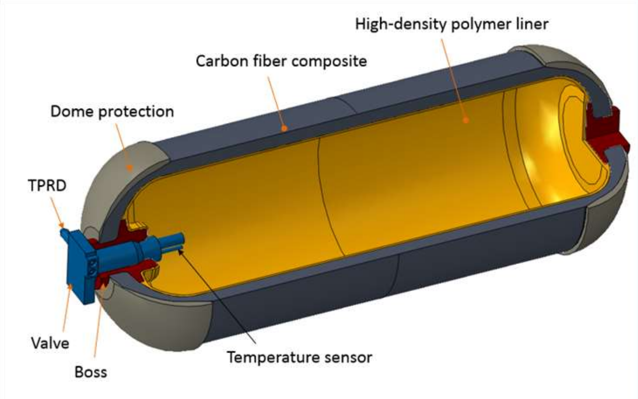
**Atmospheric pressure – prismatic – membrane**

<700mbarg

+ Simple fuel system
+ Little maintenance
+ Easy Inslallation
- Space Demand (3x Volume)

+ Space efficient
- Boil-off handling required

# Hydrogen Tank



**TPRD = Thermally Activated Pressure Relief Device**

*Credit:* Process Modeling Group, Nuclear Engineering Division. Argonne National Laboratory (ANL)

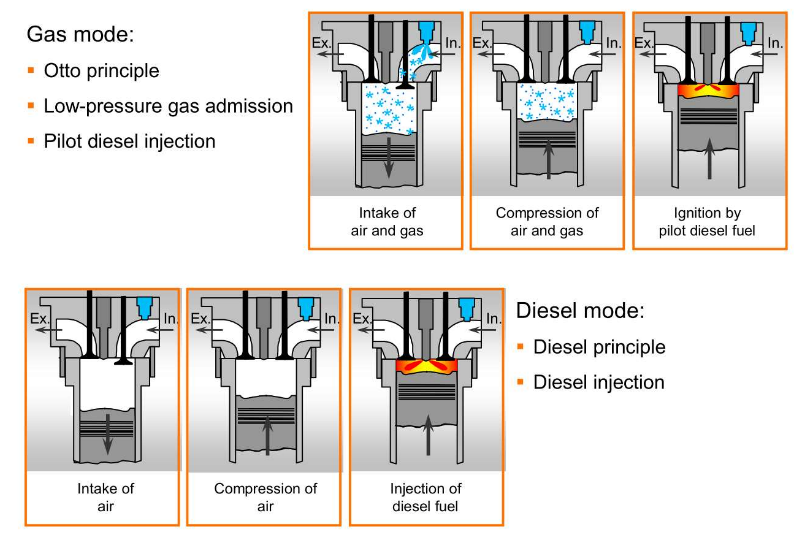
# DF Engine principle

Dual-fuel (DF) engines run on gas with 1% diesel (gas mode) or alternatively on diesel (diesel mode); Combustion of gas and air mixture in Otto cycle, triggered by pilot diesel injection (gas mode), or alternatively combustion of diesel and air mixture in Diesel cycle (diesel mode); Low-pressure gas admission.

Lower Cylinder Power

->

More Cylinders

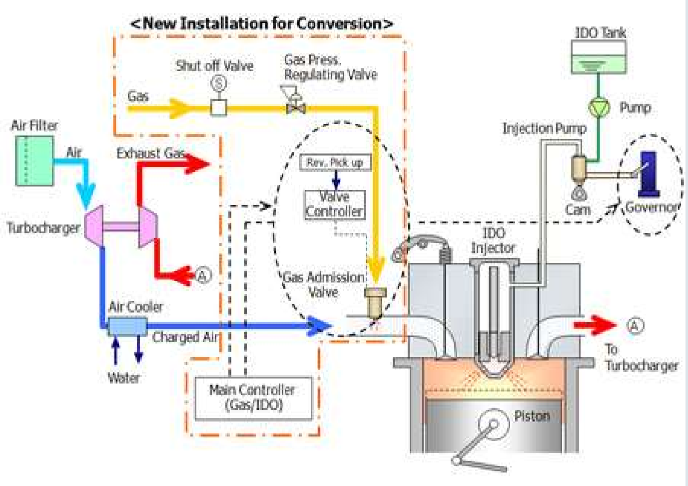


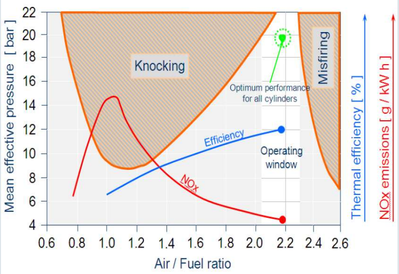
Gas mode:

- Otto principle
- Low-pressure gas admission
- Pilot diesel injection

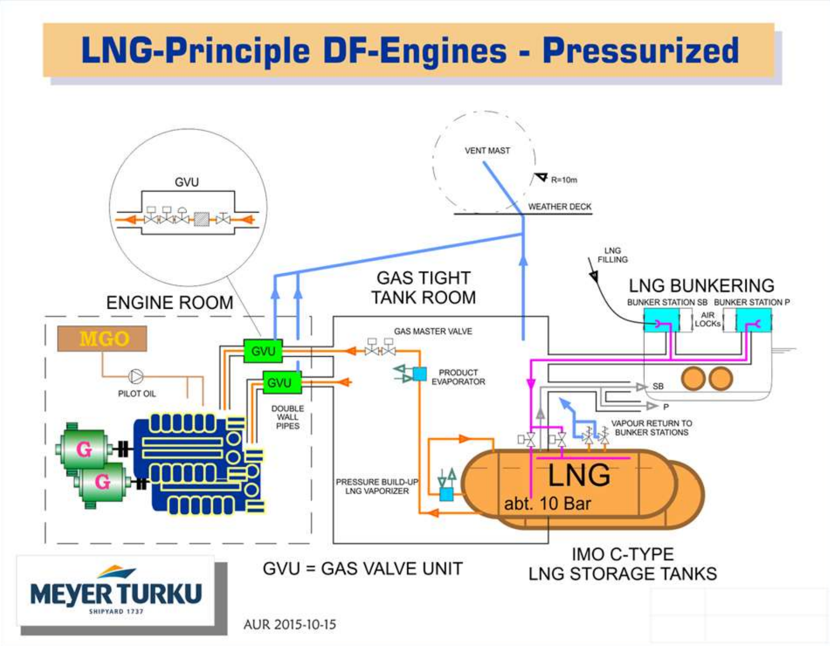
Diesel mode:

- Diesel principle
- Diesel injection





## LNG-Principle DF-Engines - Pressurized



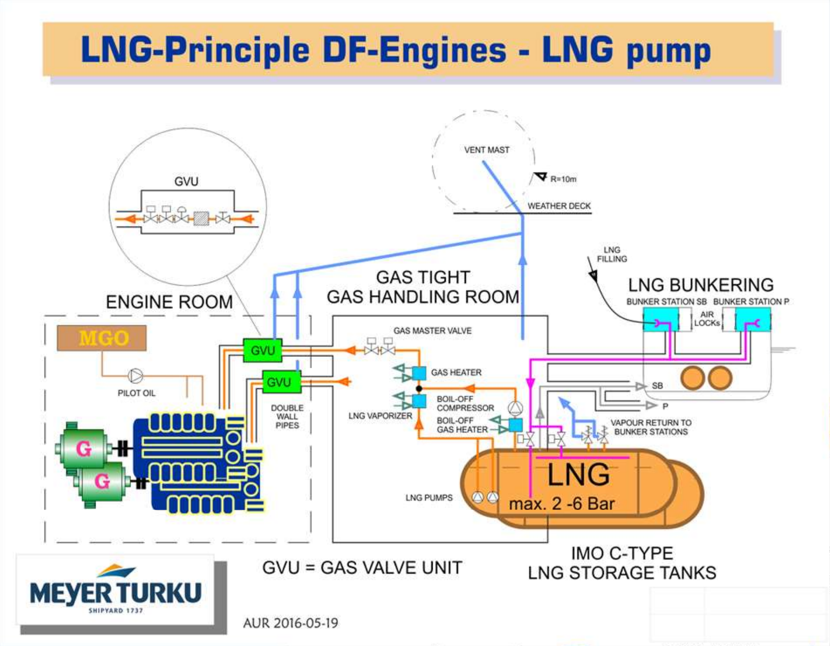
GVU = GAS VALVE UNIT

IMO C-TYPE
LNG STORAGE TANKS

MEYER TURKU
SHIPYARD 1737

AUR 2015-10-15

## LNG-Principle DF-Engines - LNG pump



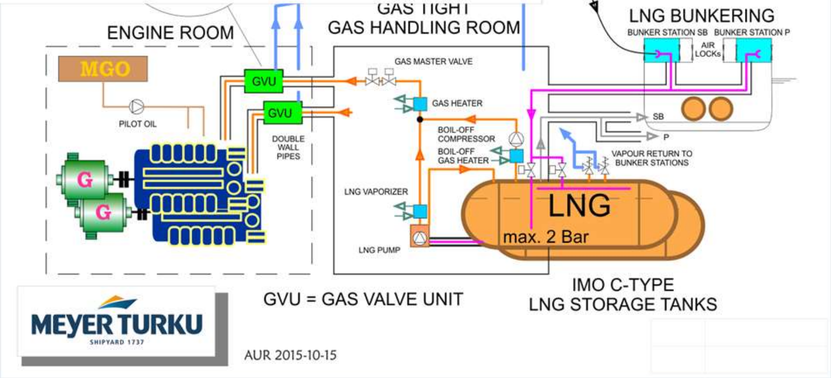
GVU = GAS VALVE UNIT

IMO C-TYPE
LNG STORAGE TANKS

MEYER TURKU
SHIPYARD 1737

AUR 2016-05-19

LNG pump



GVU = GAS VALVE UNIT

IMO C-TYPE
LNG STORAGE TANKS

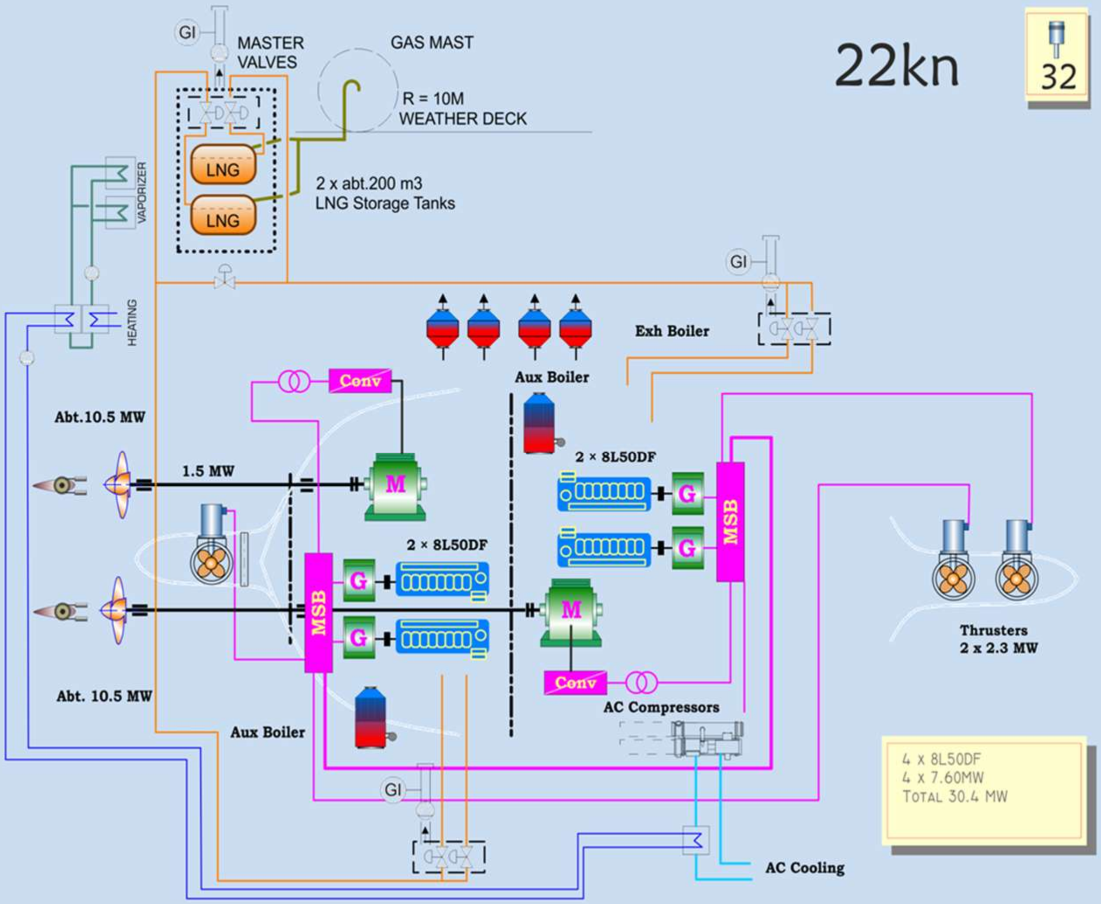
MEYER TURKU
SHIPYARD 1737

AUR 2015-10-15

# CASE VIKING GRACE

# Machinery – LNG Diesel Electric Machinery

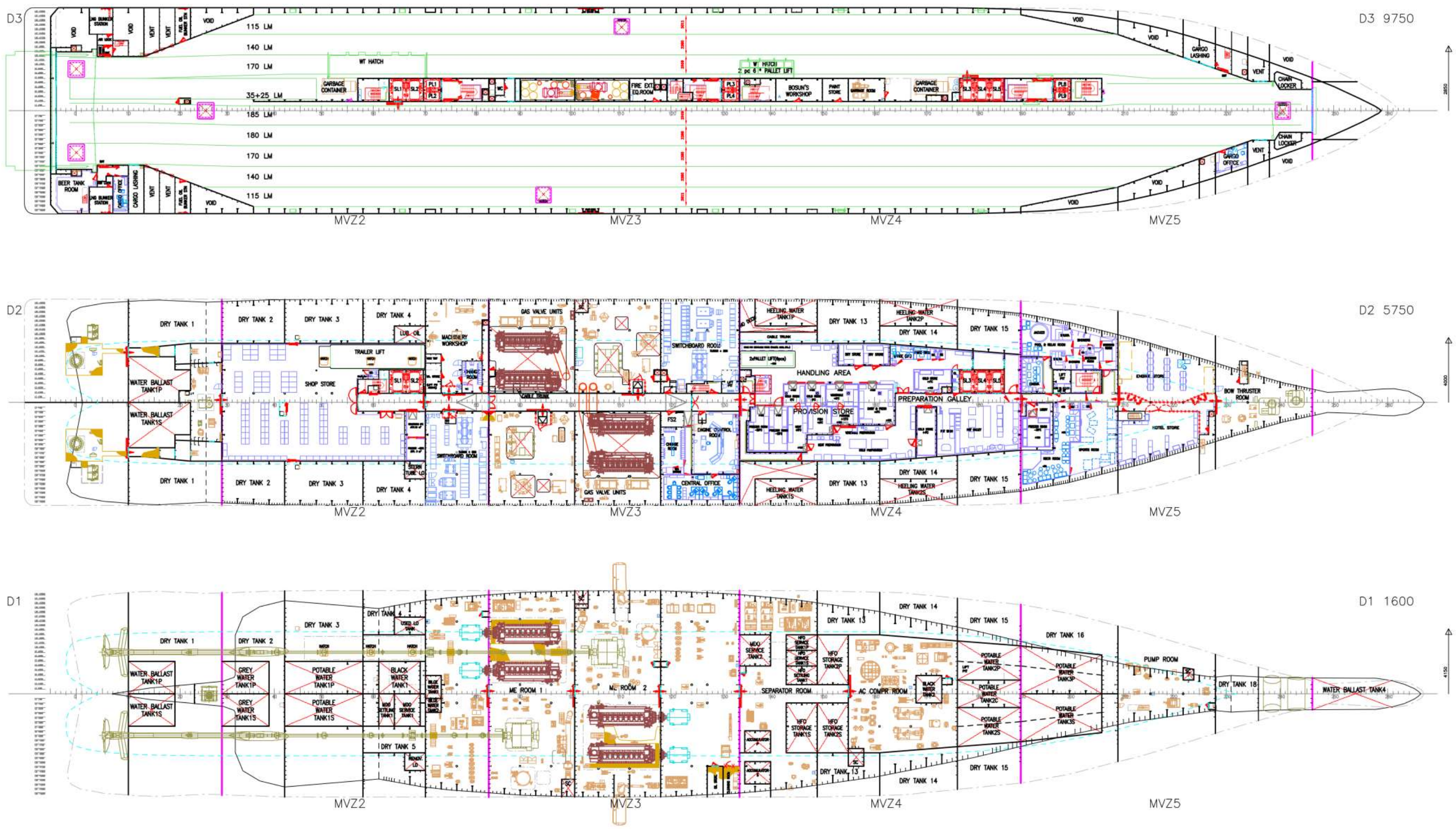
MEYER TURKU
SHIPYARD 1737



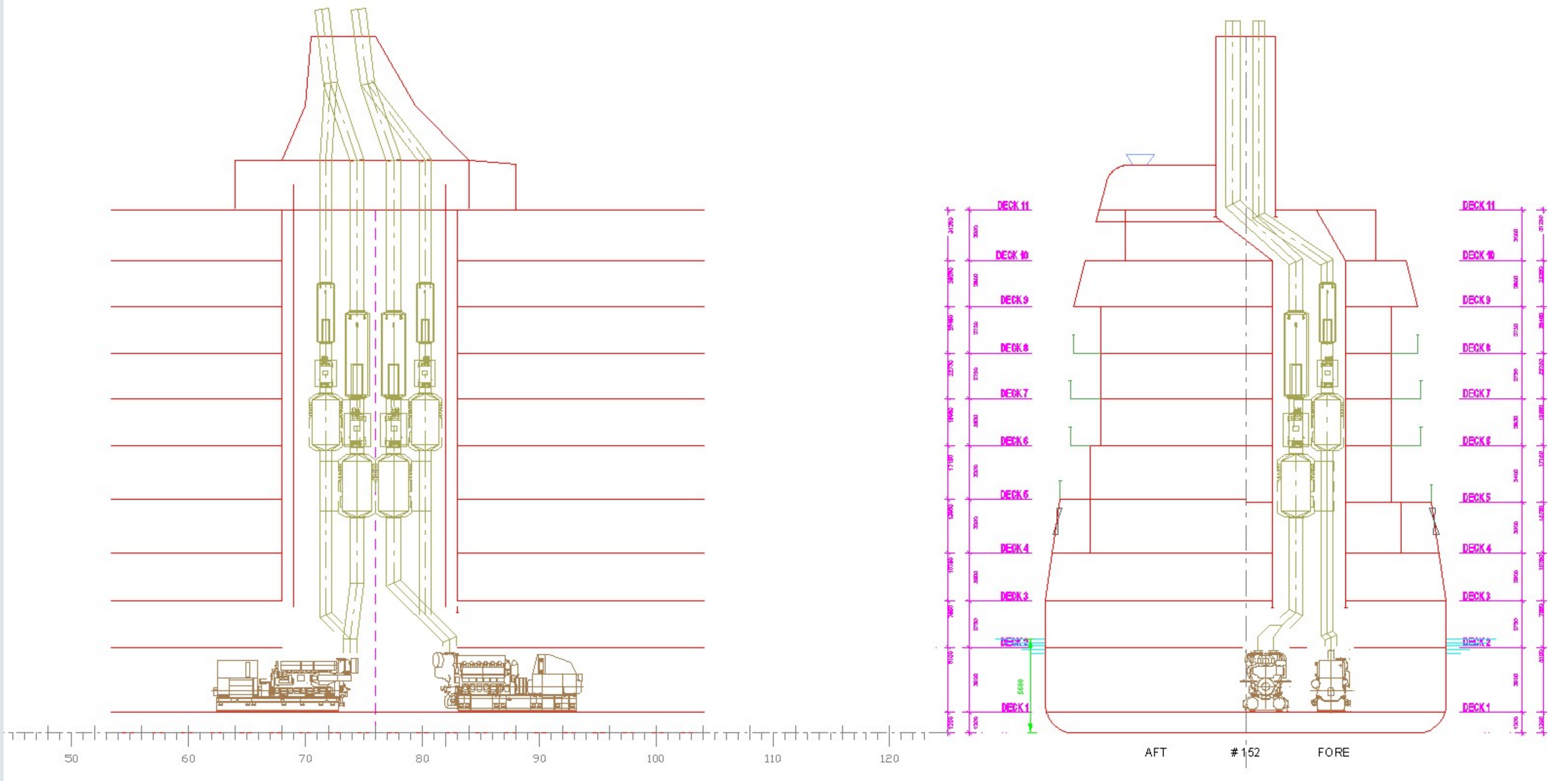
22kn

4 x 8L50DF
4 x 7.60MW
Total 30.4 MW

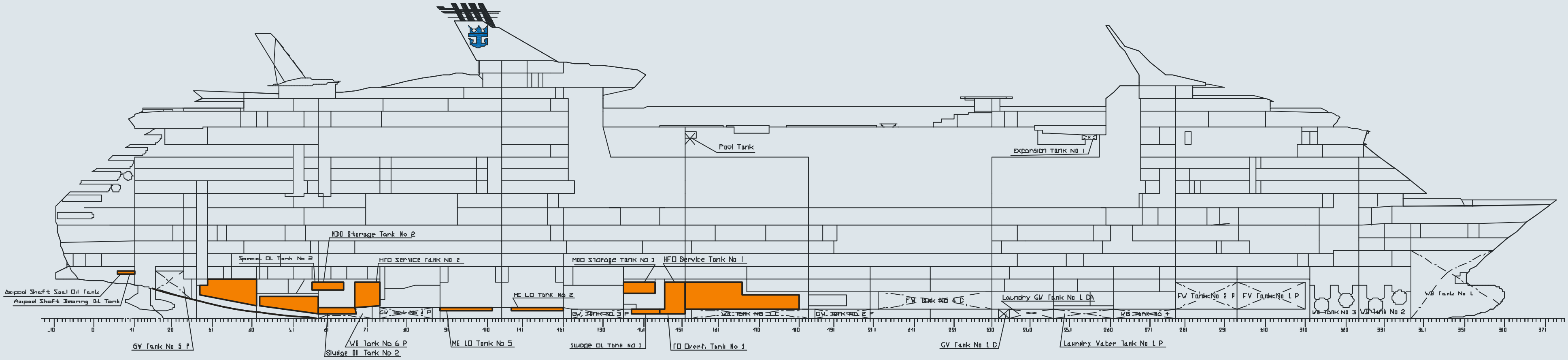
# Machinery Arrangement on Viking Grace

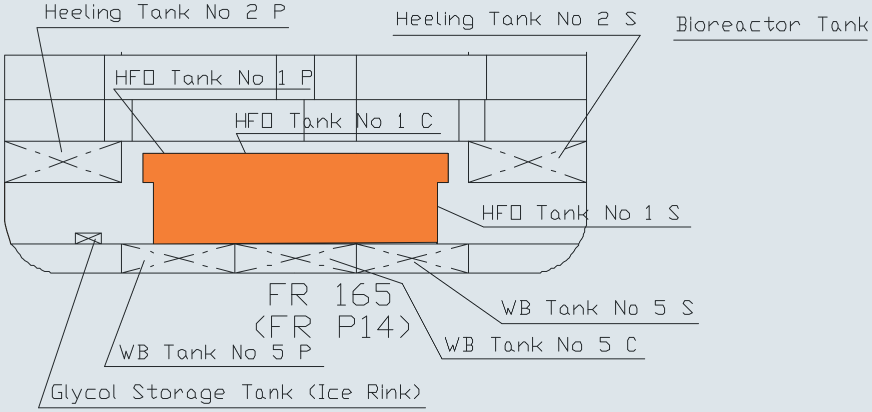


# Machinery Arrangement - Casing



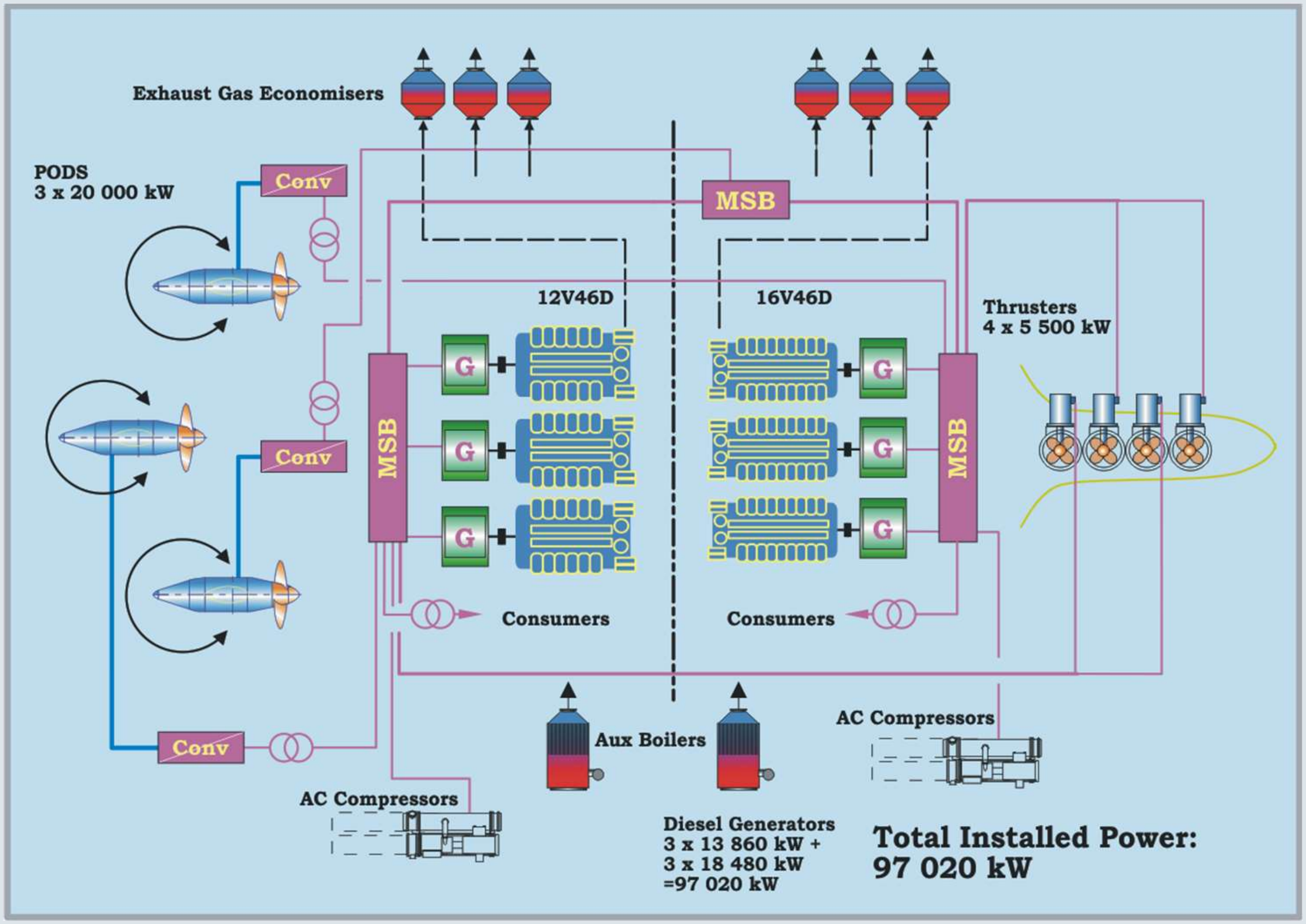
# Location of Lub Oil and Fuel Oil





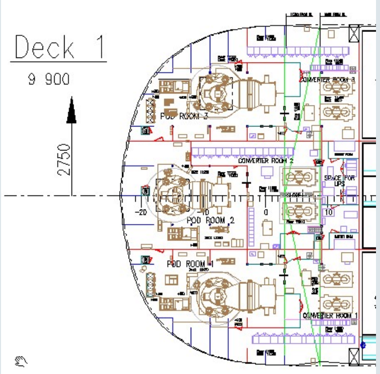
# CASE OASIS

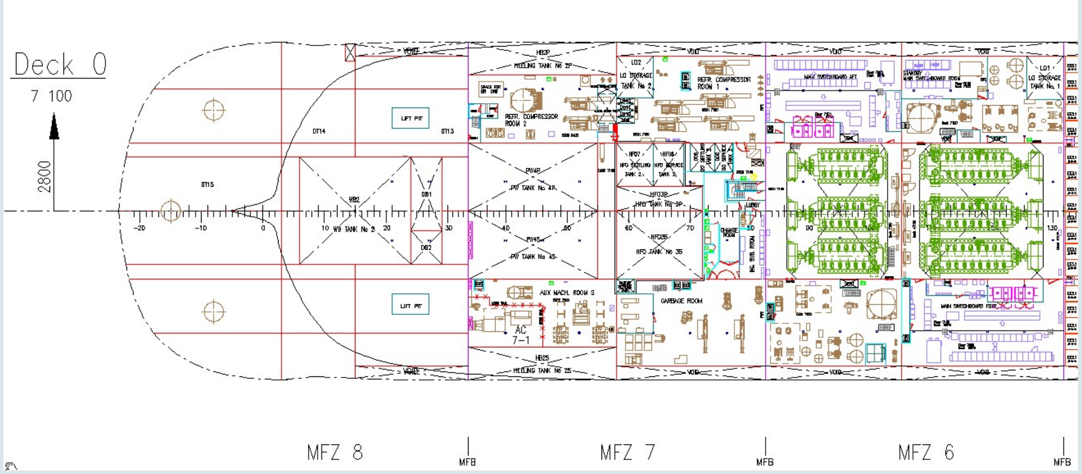
# Machinery – Diesel Electric

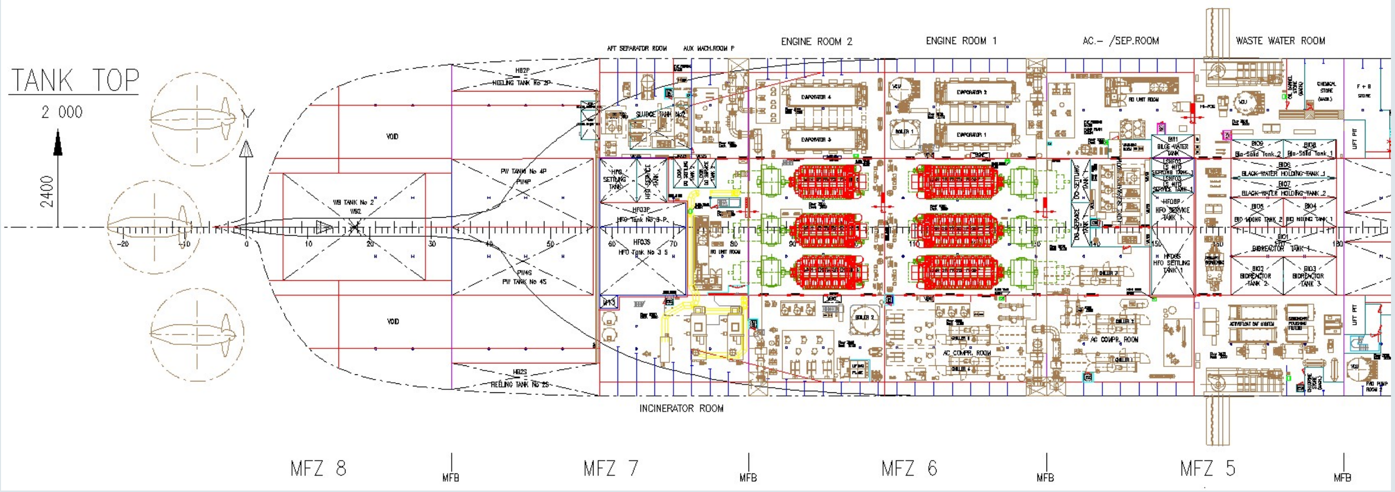


**Total Installed Power:**
**97 020 kW**

# Machinery Arrangement on Oasis

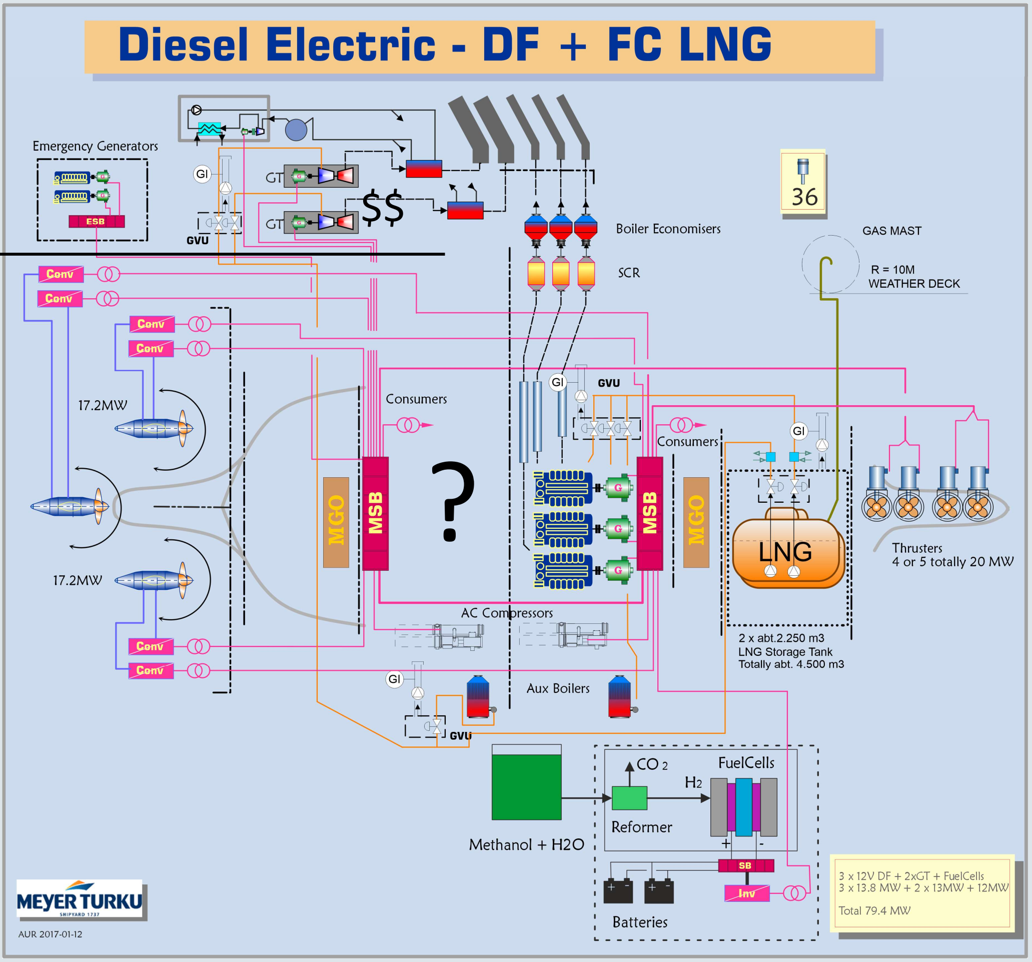






# Cruise Ship Machinery – Study only

Upper Decks near Funnel



Diesel Electric - DF + FC LNG

3 x 12V DF + 2xGT + FuelCells
3 x 13.8 MW + 2 x 13MW + 12MW

Total 79.4 MW

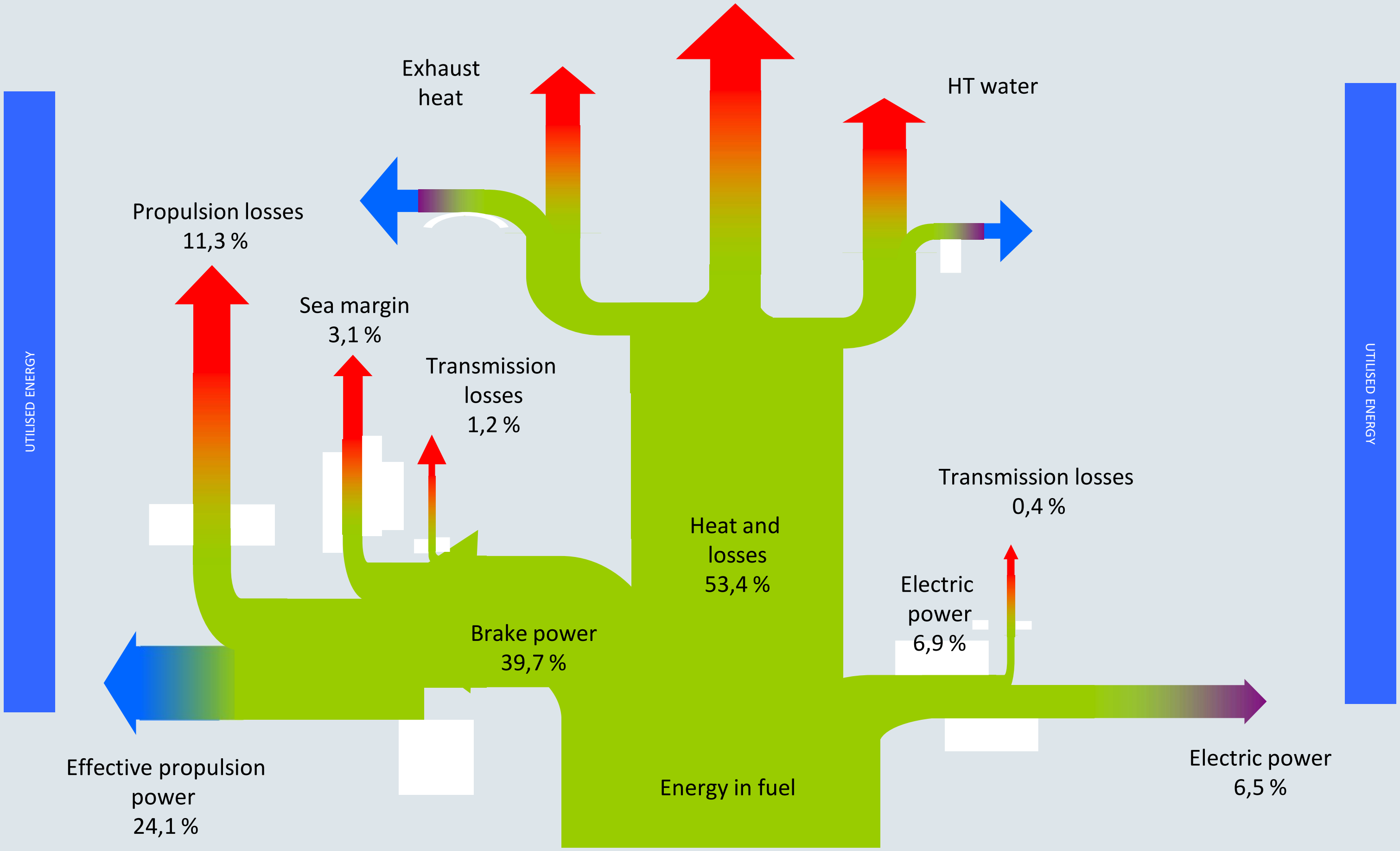
AUR 2017-01-12

# ENERGY SAVING

MEYER TURKU
SHIPYARD 1737

at 19 knot

LOSSES AND UNUSED ENERGY



Heat radiation

Exhaust heat

HT water

Propulsion losses 11,3 %

Sea margin 3,1 %

Transmission losses 1,2 %

Heat and losses 53,4 %

Transmission losses 0,4 %

Electric power 6,9 %

Brake power 39,7 %

Effective propulsion power 24,1 %

Energy in fuel

Electric power 6,5 %

UTILISED ENERGY

UTILISED ENERGY

# Comprehensive Energy Efficiency

Low Energy Demand

Economical Operation

Efficient Energy Production

Passengers

Hotel Functions

Ship Functions

Electric Energy

Heat Energy

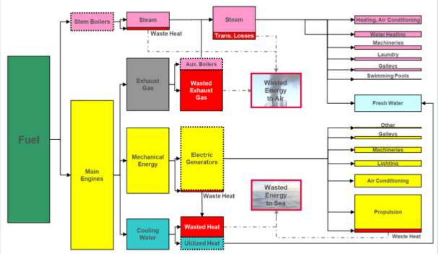
Fuel

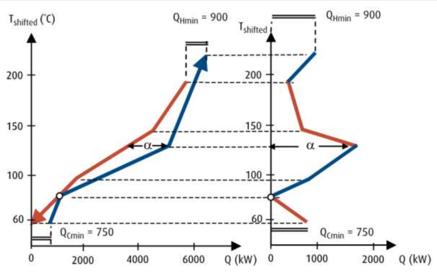
Low Energy Demand
- Energy efficiency driven concept design
- Volume reduction
- Weight optimisation
- Reduced heat emissions
- High efficiency equipment
- Optimised capacities
- Low hull and appendage friction
- Efficient propulsion

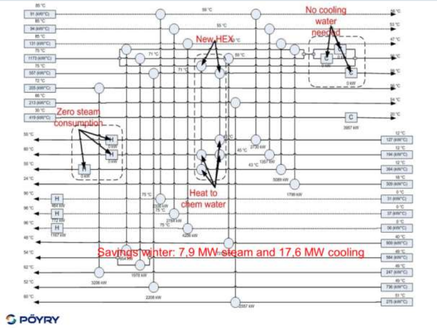
Economical Operation
- Training
- Best practises
- Energy Management
- Reduction of speed
- Route planning
- Trim control
- Optimised tank volume
- Presence monitoring
- Shore-side utilisation
- Recycling

Energy Production
- Efficient machinery
- Optimised machinery
- Waste heat recovery
- Emission reduction
- LNG and bio fuels
- Fuel Cells
- Wind energy
- Solar power

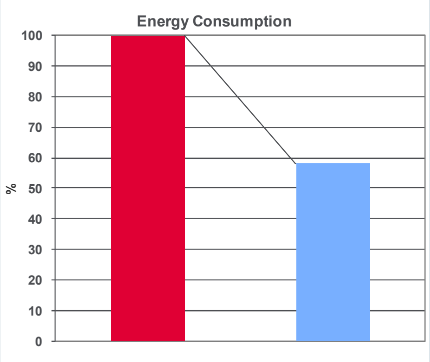
# Energy Flow Optimisation





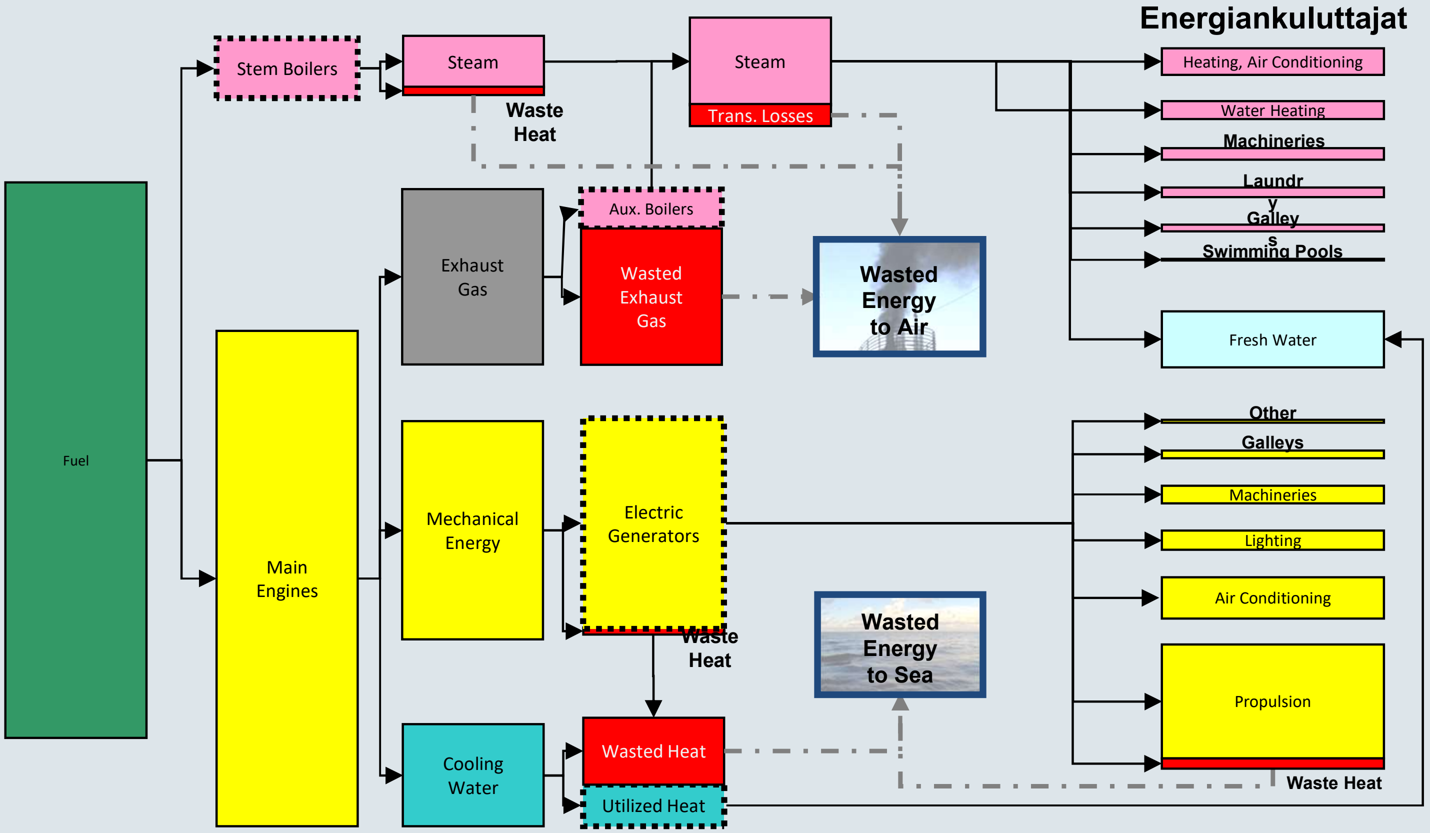


We use simulation tools and pinch analysis to optimise the cruise ships' energy flow.



1. Modelling of all energy producers and consumers
2. Utilising pinch analysis for energy flows and heat levels
3. Finding theoretically best possible solutions for improved efficiency
4. Determing of economically and technically feasible combinations for the ship and operation profile

# Cruise Ship Energy Flow



**Energiankuluttajat**

Fuel

Stem Boilers

Steam

**Waste Heat**

Steam

Trans. Losses

Main Engines

Exhaust Gas

Aux. Boilers

Wasted Exhaust Gas

**Wasted Energy to Air**

Mechanical Energy

Electric Generators

**Waste Heat**

Cooling Water

Wasted Heat

Utilized Heat

**Wasted Energy to Sea**

Heating, Air Conditioning

Water Heating

**Machineries**

**Laundry**

**Galleys**

**Swimming Pools**

Fresh Water

**Other**

**Galleys**

Machineries

Lighting

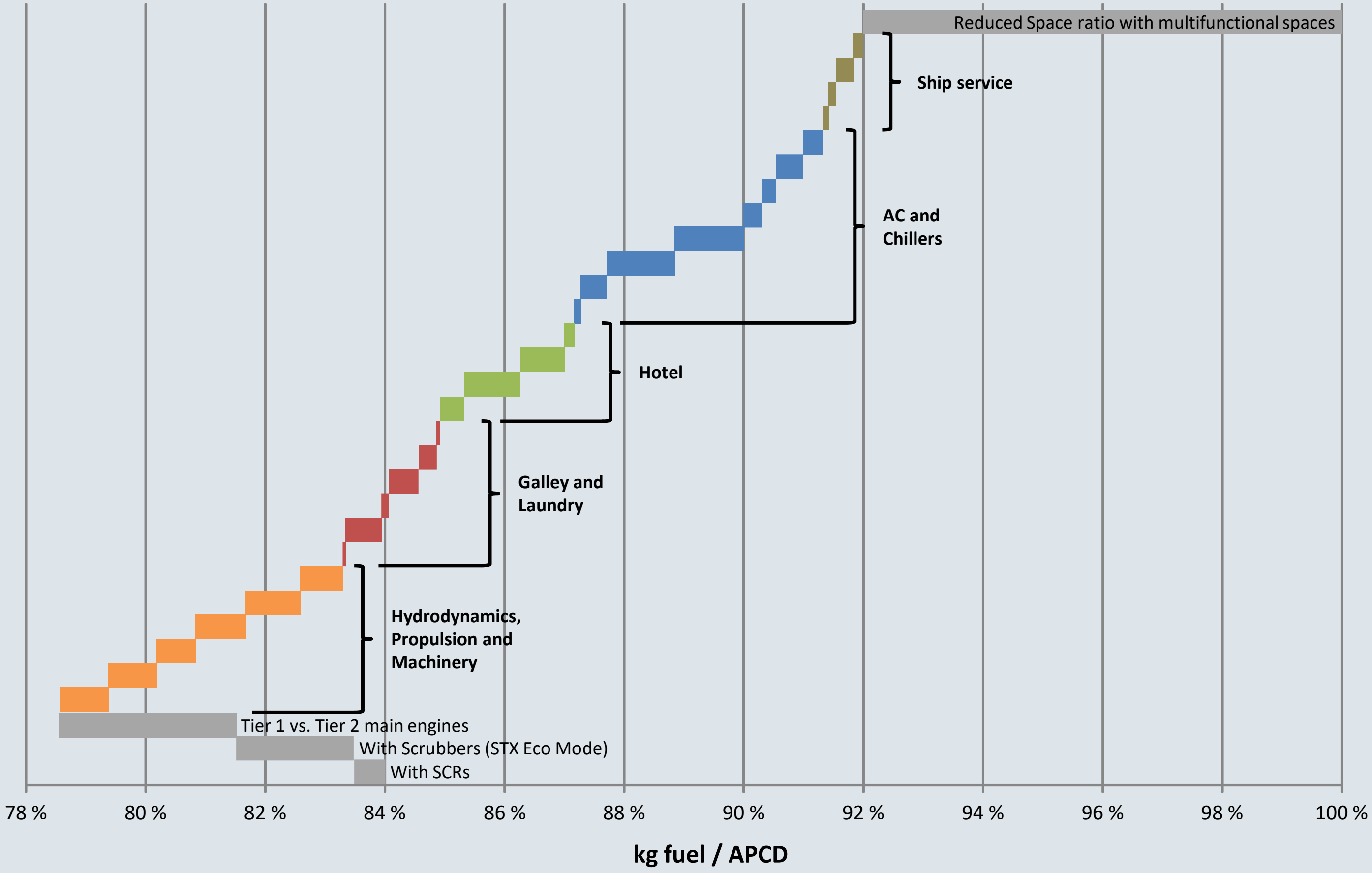
Air Conditioning

Propulsion

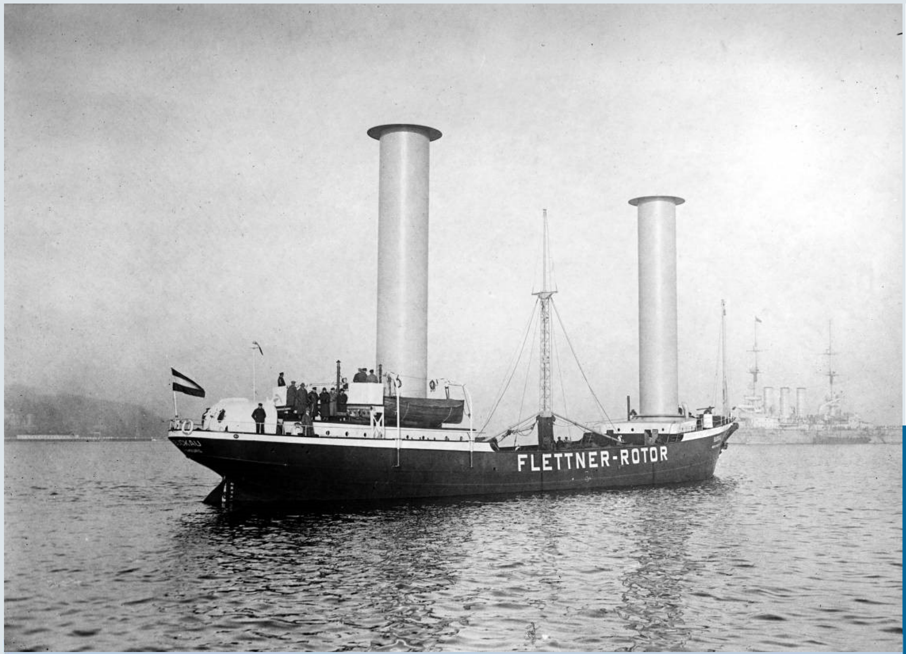
**Waste Heat**

# Improvement Potential

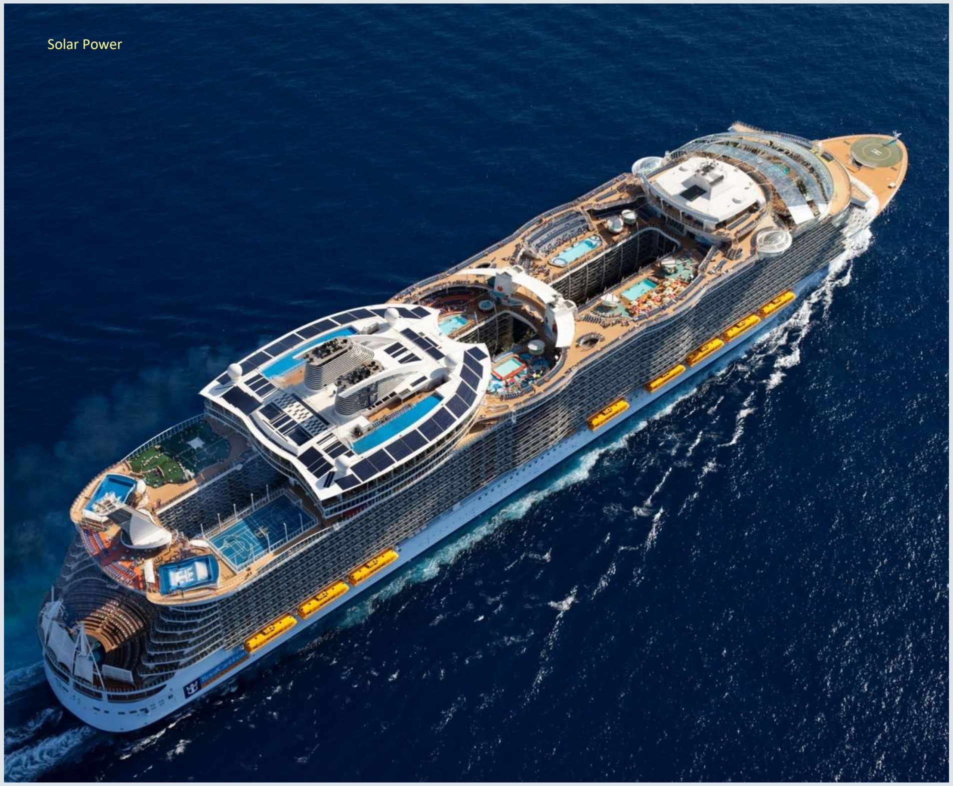
- Some economically feasible improvements compared to our earlier ships which itself are already some 15 to 40 % better than other existing ships of their size.



# Commercially (non finalized?) green ship concepts



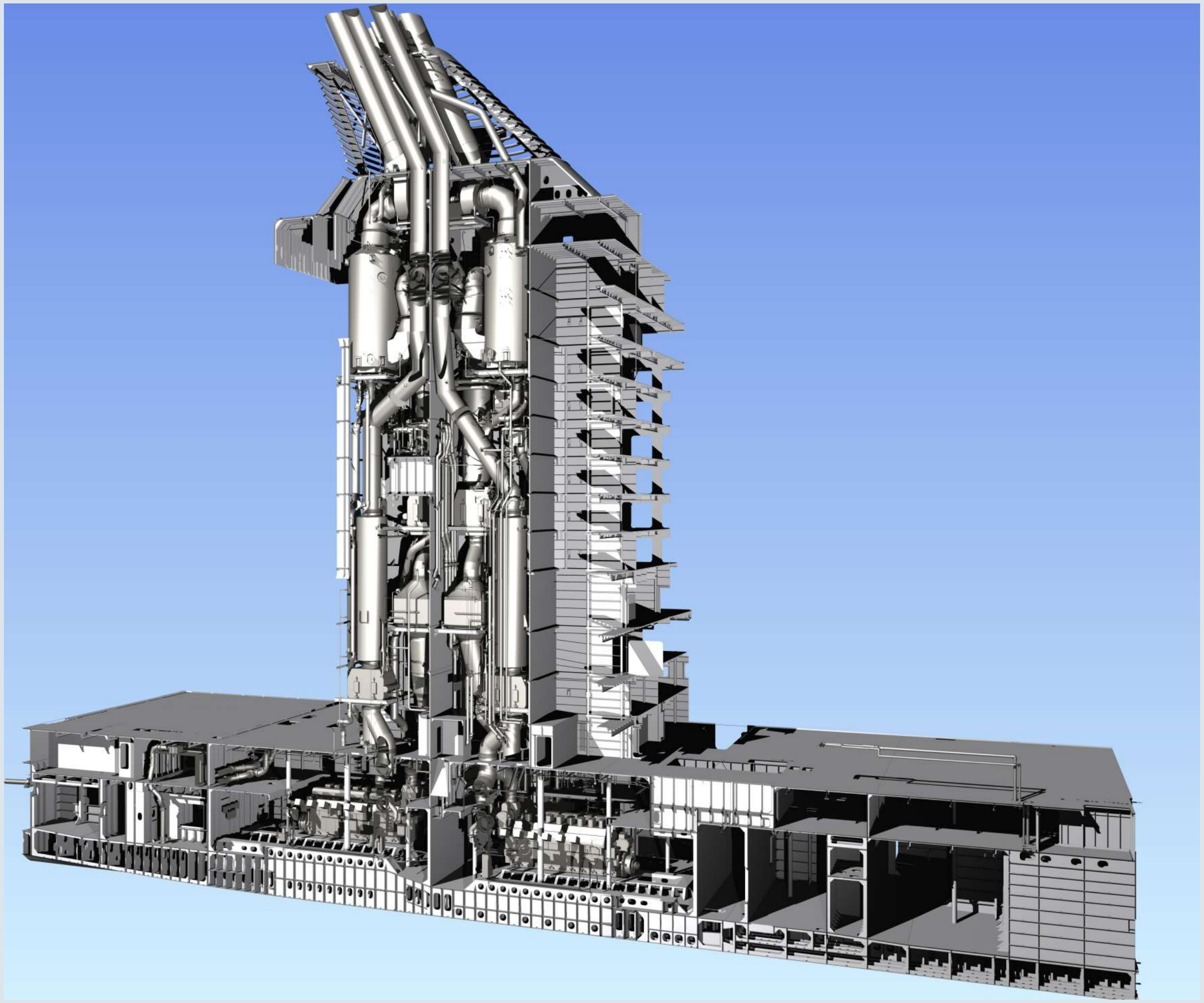
# Wind and Solar Power



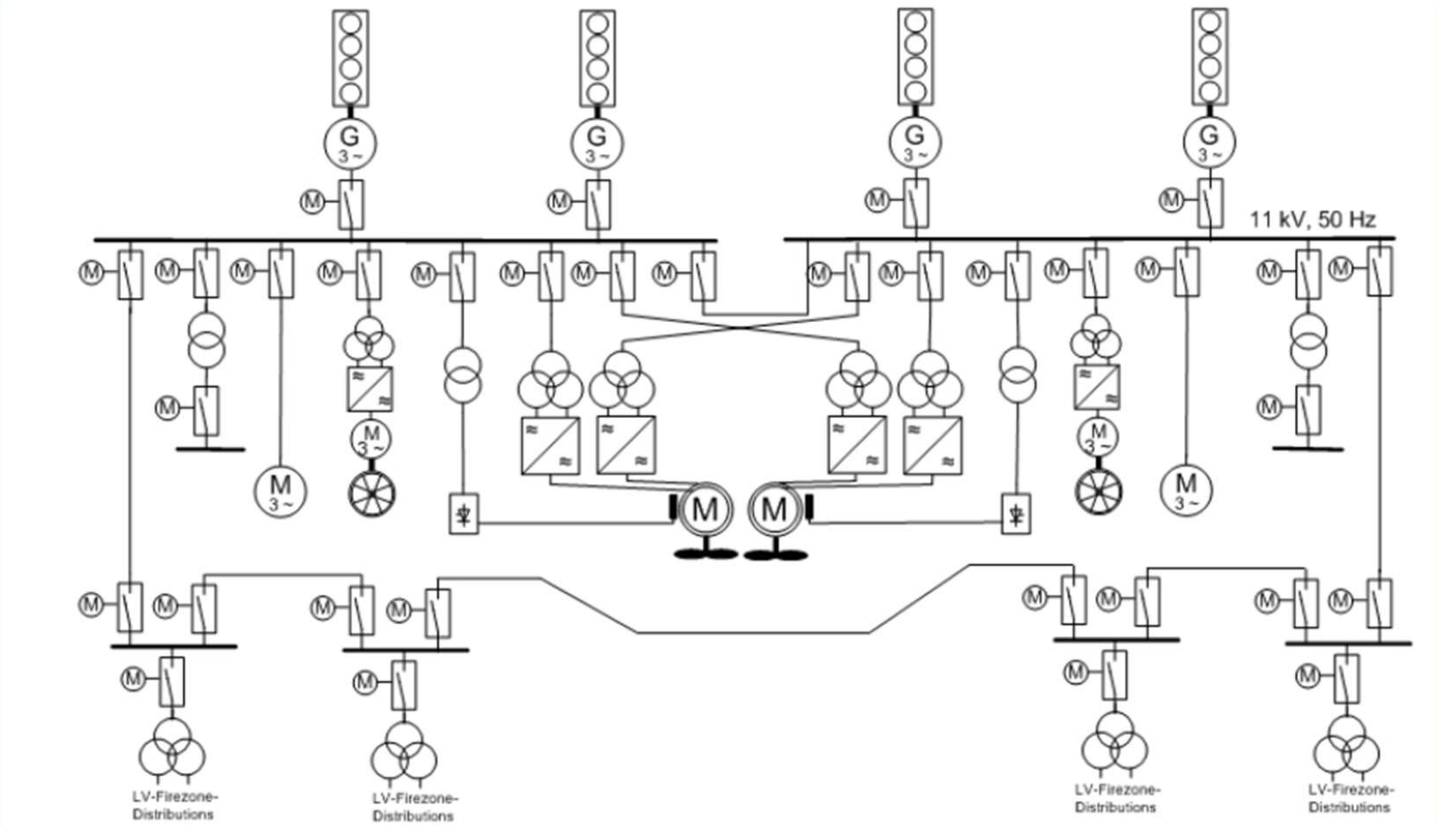
- Sails

# OTHER

# Machinery and Casing



# Engine Room –Typical Cruiser Single Line



Example: DE-configuration (redundant) of a cruise liner, twin screw, gear less

# Engine Room – realistic or not?

Find (at least) 5 mistakes!

# MACHINERY CONCEPT DESIGN

**Conclusion:**

- There are many ways to goal – there is not only one right solution
- Solutions are many, opinions even more
- Systematic goal seeking makes decisions easier
- Make it simple - Simple is beautiful

- Future is even more complicated
- More innovative solutions are needed

# Links:

Cubic Spline: https://www.srs1software.com/SRS1CubicSplineForExcel.aspx
Wärtsilä:
MAN:
MaK:

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FI-20101 Turku, Finland

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info@meyerturku.fi

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www.meyerturku.fi

# THANK YOU !