Energy and environmentally efficient ship design

Introduction to main principles

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Agenda

- Big picture of energy and environmental efficiency
  - Environmental legislation overview and examples
- Energy efficiency
  - Energy balance components
    - Fuels, machinery etc.
  - Modelling ship energy efficiency
  - Methods for energy saving during various phases of ship design
- Energy saving methods and energy efficient design principles
  - Largest consuming groups: propulsion etc.
  - HVAC energy saving principles
  - Heat process efficiency and waste heat recovery

Mia Elg

- Energy Efficiency analysis and improvements at Deltamarin since 2007
  - Current task R&D manager
- M.Sc. (Thermodynamics as major)
- Currently also making a Ph.D. at Aalto university
  - part time research scientist at VTT at the side of the work at Deltamarin 2014-2016

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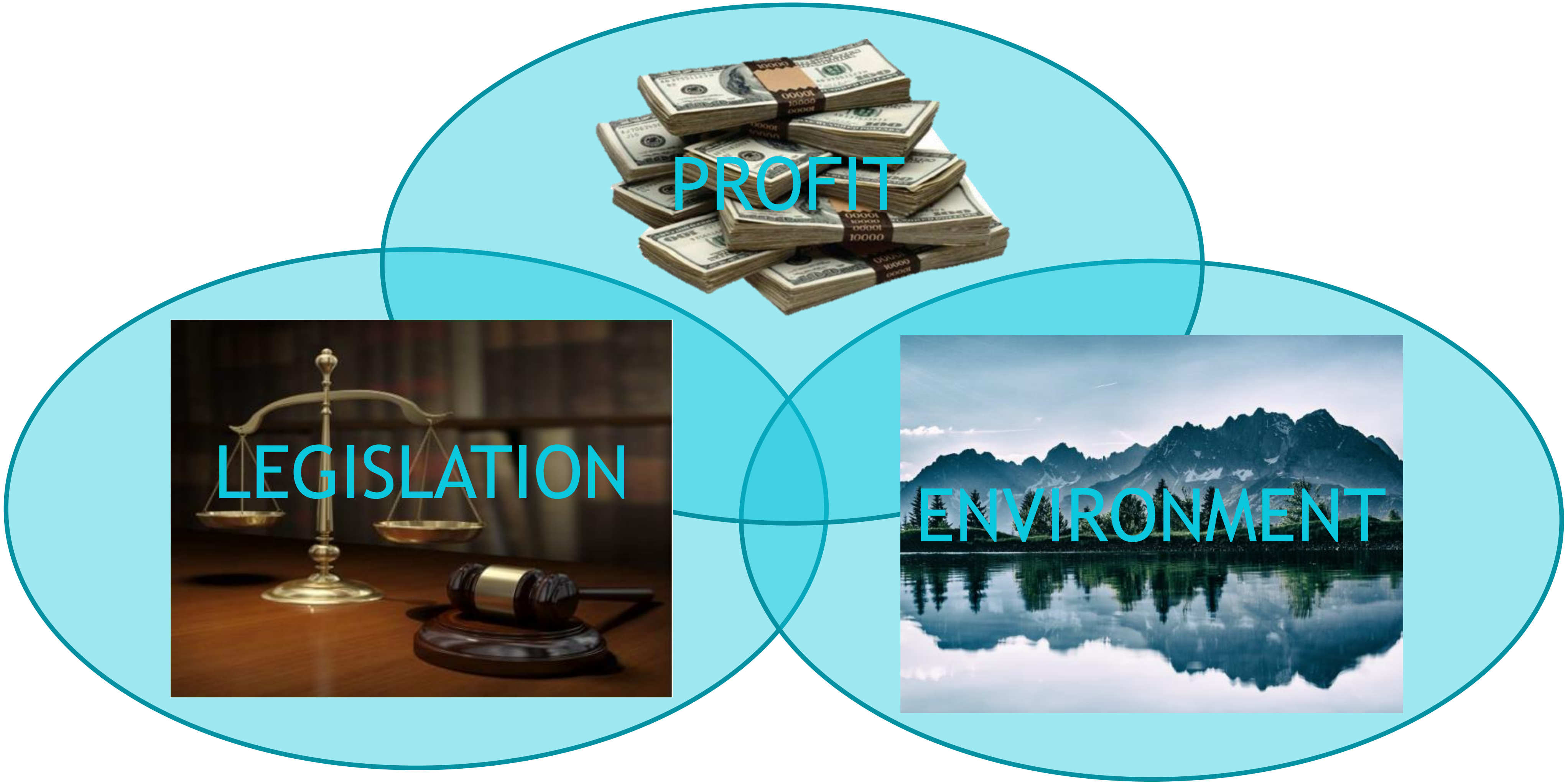
Why this is so important topic?

Drivers for new solutions



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Hierarchy of regulative and sanctioning bodies

IMO is a specialized agency of the UN

Safety, **environment**, legal matters, technical co-operation, security and efficiency

IMO
International Maritime Organization

MEPC
Maritime Environment Protection Committee

MARPOL
Maritime Pollution Convention

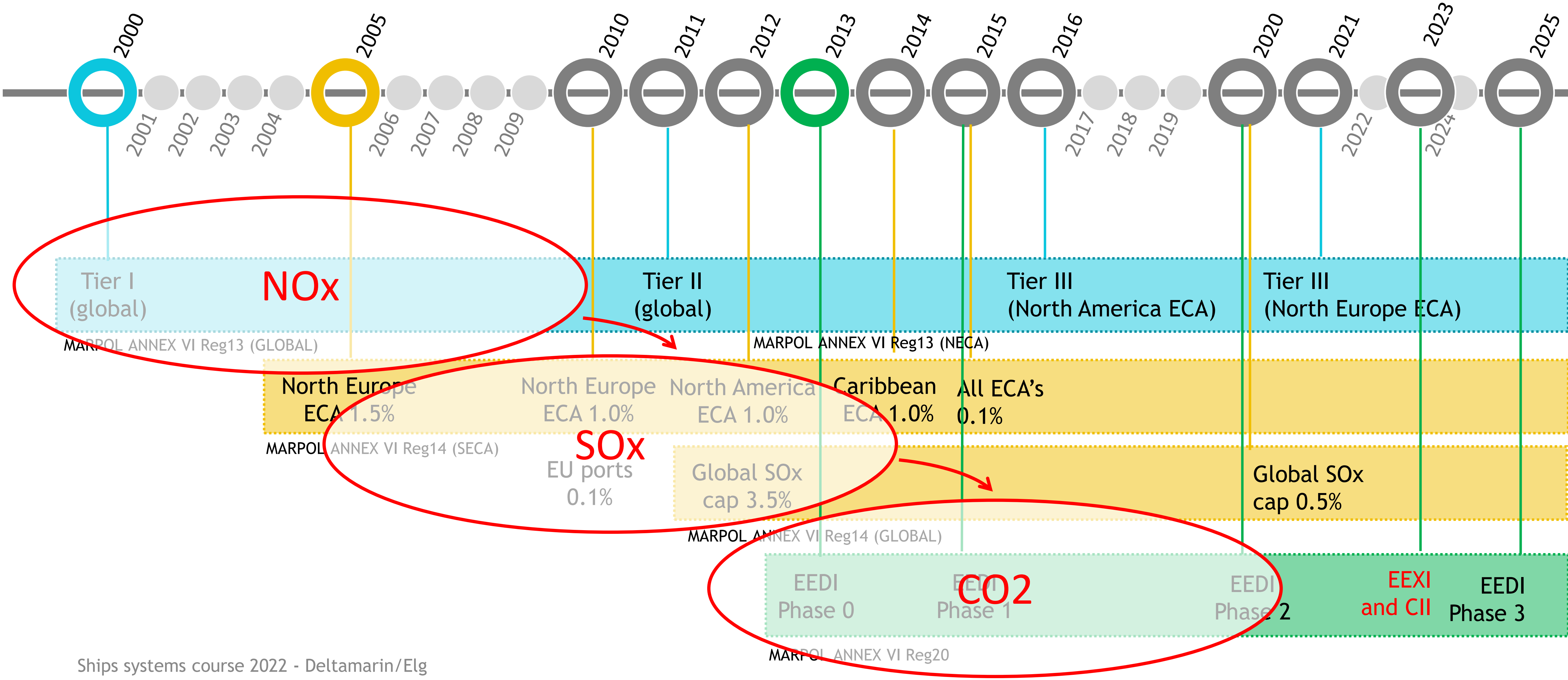
Also local regulations

- EU
- USA EPA
- National legislation

Annex I	Annex II	Annex III	Annex IV	Annex V	Annex VI
Oil	Noxious Liquid Substances in Bulk	Harmful Substances Carried in Packaged Form	Sewage	Garbage	Air

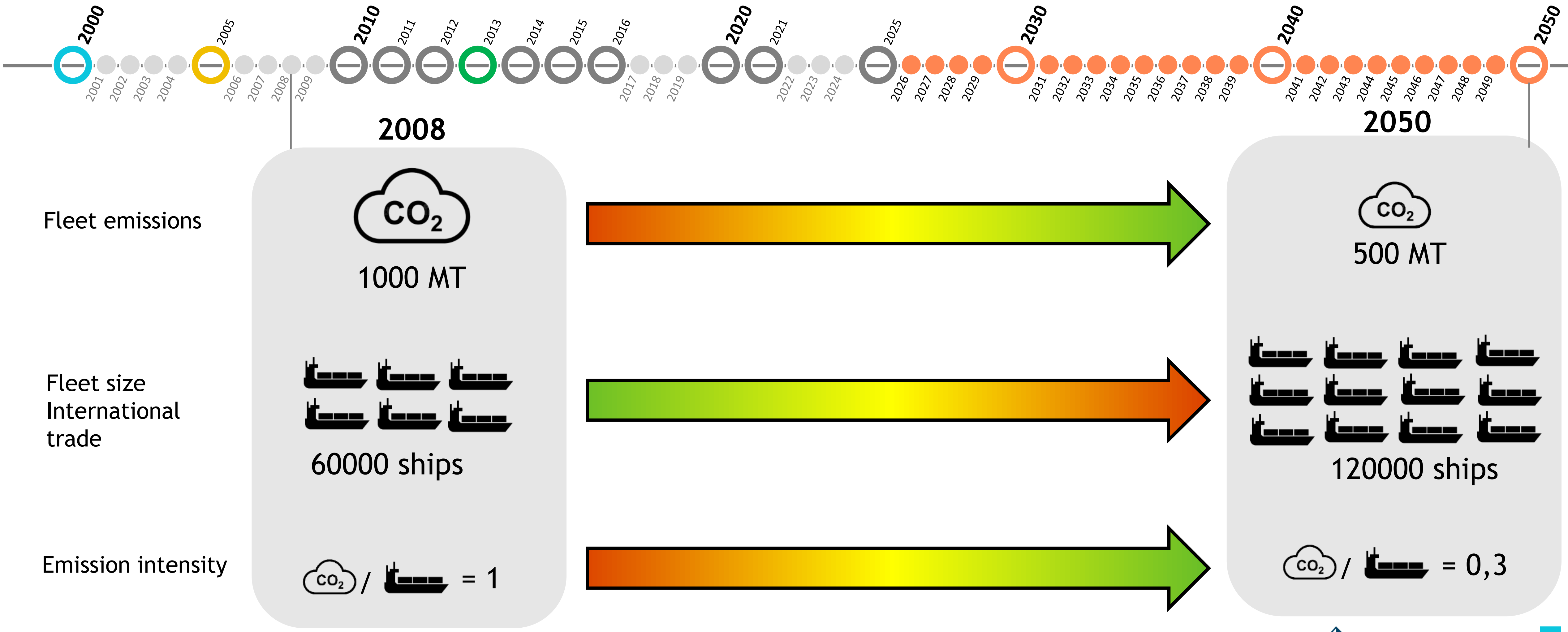
Emission legislation timeline

The future focus can be expected to be in GHG



GHG emission future targets

As defined by IMO



Carbon risks

Regulatory risk

Vessel not compliant with future GHG regulation and not allowed to opeate. Alternatively, requiring a costly modification or speed reduction making the vessel uncompetitive.

Charter risk

Environmental perfromance becoming increasingly essential requirement for Charterers who might have requirements beyond the IMO regulations.

Reputational risk

Potential negative publicity due to GHG related issues.

Finance risk

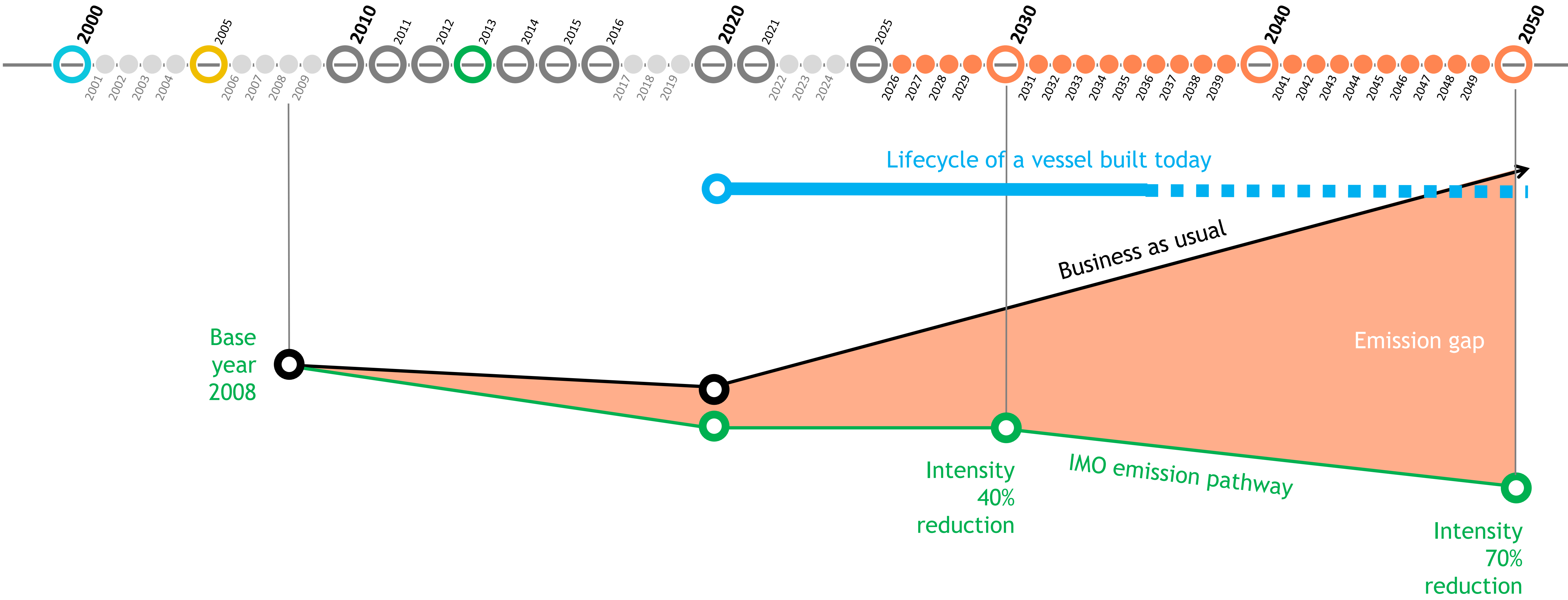
Carbon footprinting of financing and related considerations.

Resale value risk

Lower resale value for the asset.

Emission gap

IMO has an urgency to get the industry on the right track



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About dimensioning ship and her systems…

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Traditional ship "data sheet"

T.Delta115
115,000 DWT Oil Product Tanker

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General description

Member of Deltamarin's eco-friendly T.Delta Oil tanker fleet.

- Able to carry crude oil and oil products
- Double hull construction meeting Harmonised Common Structural Rules
- Vessel to meet Tier III level

Main dimensions	
Length overall	250.0 m
Length between p.p.	245.5 m
Breadth	42.0 m
Depth	22.0 m
Deadweight at design draft	100,000 t / 13.5 m
Deadweight at scantling draft	115,000 t / 15.0 m

Cargo tanks and capacities	
Cargo tanks	12 + 2 slop tanks
Segregation	3 grades
Cargo tank lining	Pure epoxy
Cargo tank vol. (incl. slop tanks)	140,000 m^3
LNG	2,400 m^3
Marine Gas Oil	1,200 m^3
Fresh water	500 m^3
Ballast water	40,000 m^3

Class

LR +100A1, Double Hull Oil and Product Tanker, H-CSR, ESP, Shipright (1A1), SPM, IGS, UMS, VCS-2, TMON, IWS

Alternatively DNVGL, BV, ABS, RINA or any Class Society member of IACS can be selected

Machinery and equipment	
Main engines	2 x Wartsila 10V31DF
MCR	11,000 kW
NCR (85 % MCR)	9,314 kW
Propeller	CPP
Diesel generators	3 x 940 kWe
Emergency generator	260 kWe
PTO/PTI	Optional
Oil fired boiler	2 x 25 t/h
Exhaust gas boiler	1.7 t/h
Cargo pumps	3 x 3,000 m^3/h
Ballast pumps (centrifugal)	2 x 1,500 m^3/h

Performance

Service speed at NCR at design draft (incl. 15% sea margin)	14.5 kn

ME fuel oil consumption at NCR:

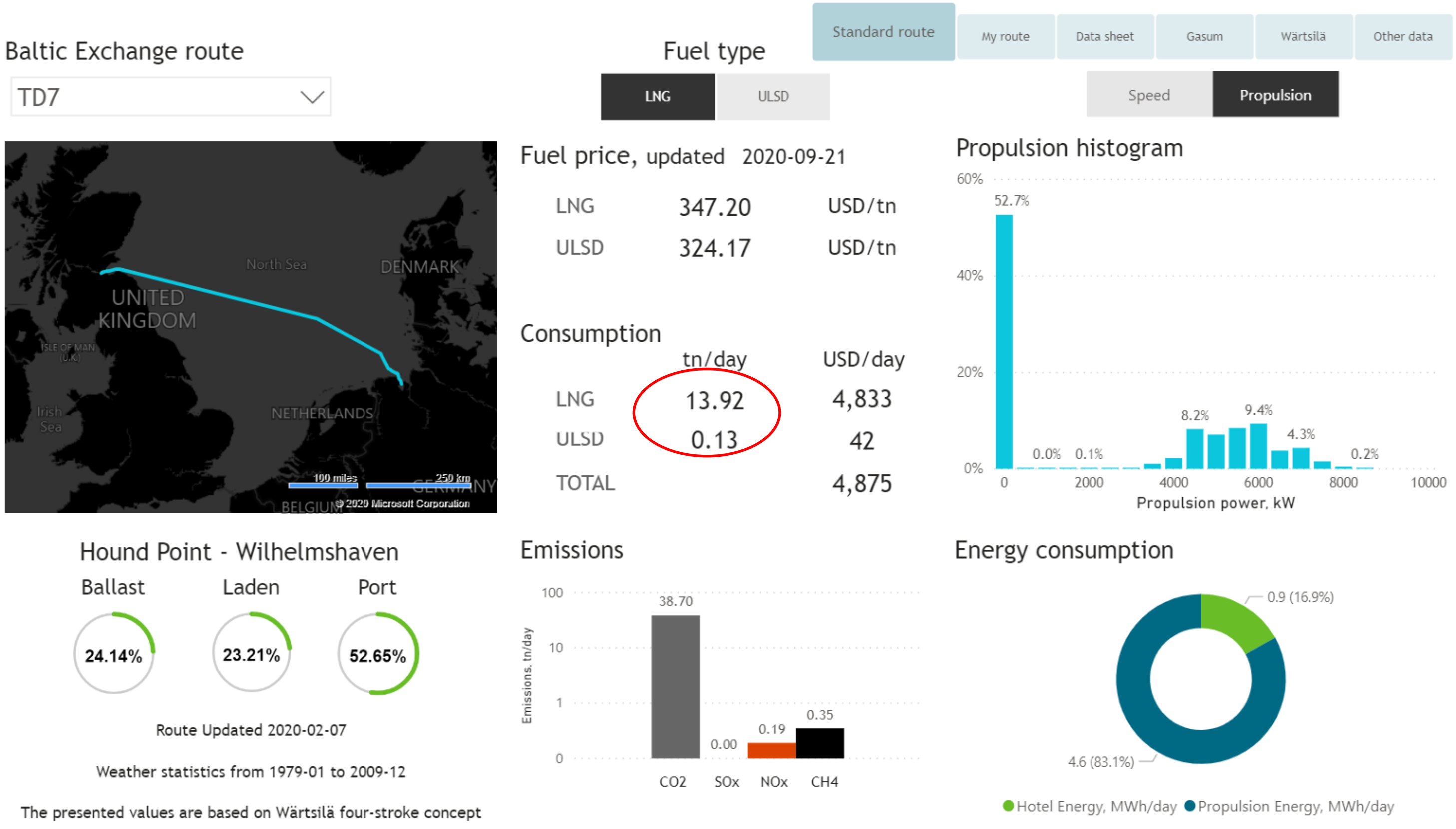
- In gas mode (LNG + pilot oil, Tier III) 31.7 + 1,0 mt/d
- In diesel mode (MGO, Tier II) 39.1 mt/d

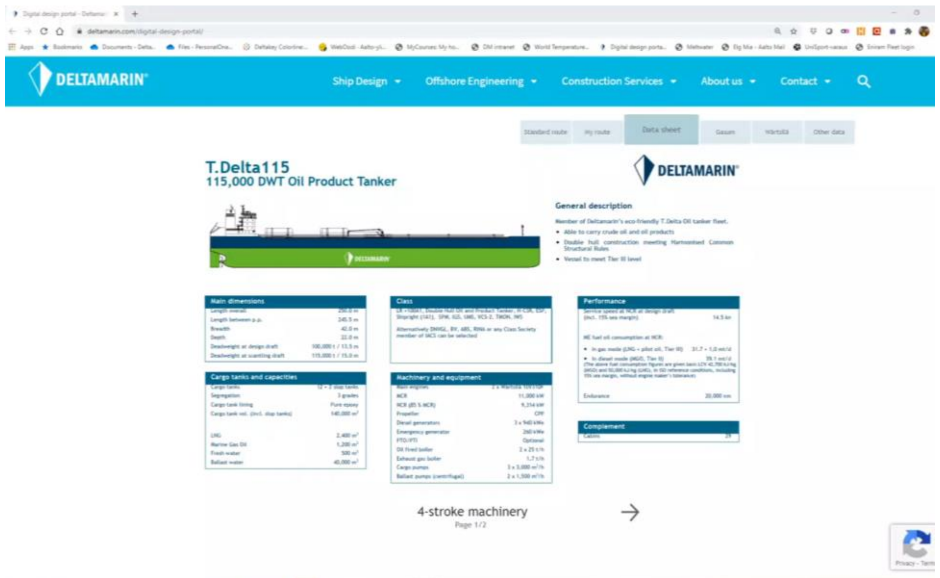
(The above fuel consumption figures are given basis LCV 42,700 kJ/kg (MGO) and 50,000 kJ/kg (LNG), in ISO reference conditions, including 15% sea margin, without engine maker's tolerance)

Endurance	20,000 nm

Complement	
Cabins	29

Digital ship ”data sheet”





https://deltamarin.com/digital-design-portal/

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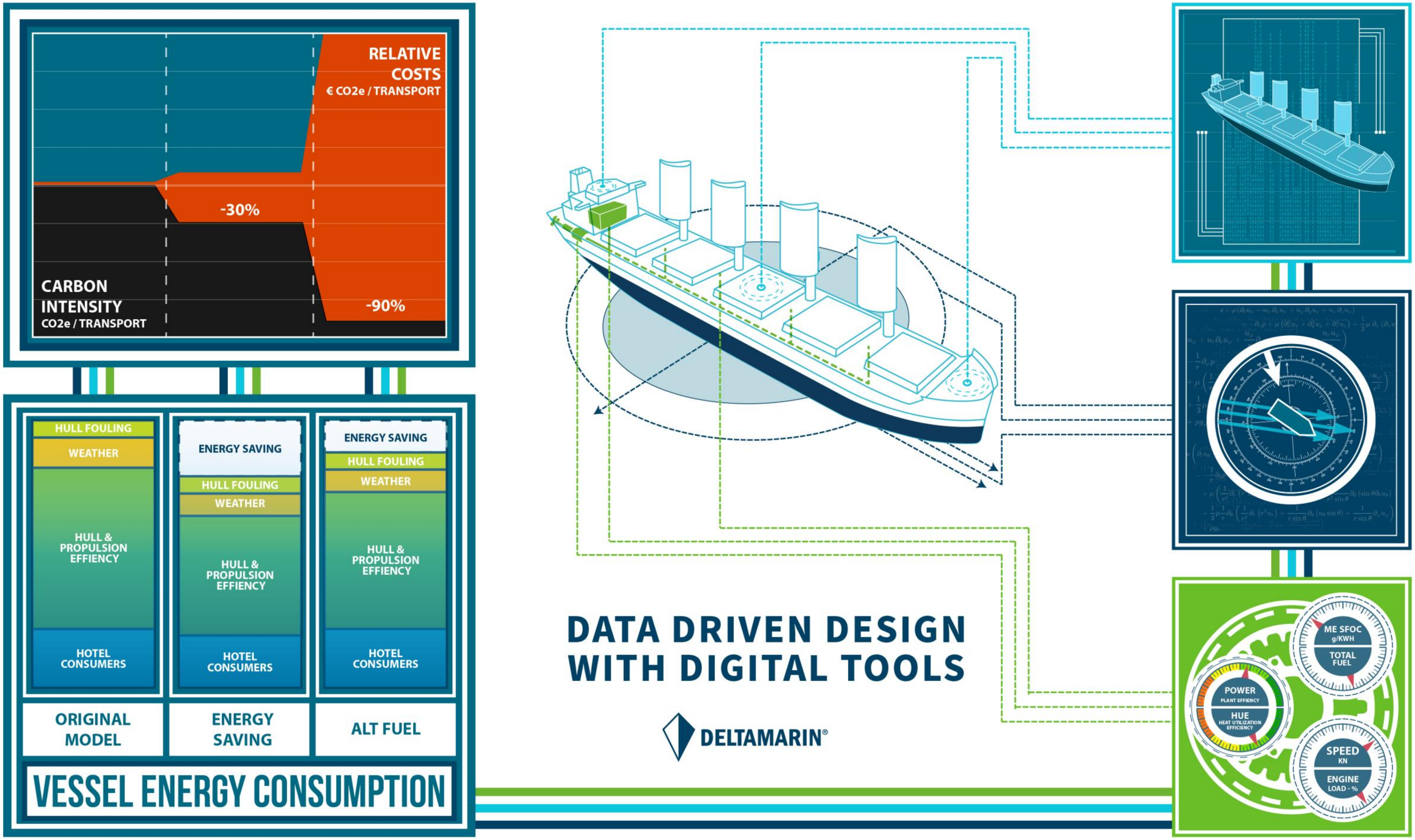
RELATIVE COSTS
€ CO2e / TRANSPORT
-30%
CARBON INTENSITY
CO2e / TRANSPORT
-90%
HULL FOULING
WEATHER
HULL & PROPULSION EFFIENCY
HOTEL CONSUMERS
ENERGY SAVING
HULL FOULING
WEATHER
HULL & PROPULSION EFFIENCY
HOTEL CONSUMERS
ENERGY SAVING
HULL FOULING
WEATHER
HULL & PROPULSION EFFIENCY
HOTEL CONSUMERS
ORIGINAL MODEL
ENERGY SAVING
ALT FUEL
VESSEL ENERGY CONSUMPTION
DATA DRIVEN DESIGN WITH DIGITAL TOOLS
DELTAMARIN®
ME SFOC g/KWH
TOTAL FUEL
POWER PLANT EFFIENCY
HUE HEAT UTILIZATION EFFICIENCY
SPEED KN
ENGINE LOAD - %

Energy efficiency from ship designers perspective

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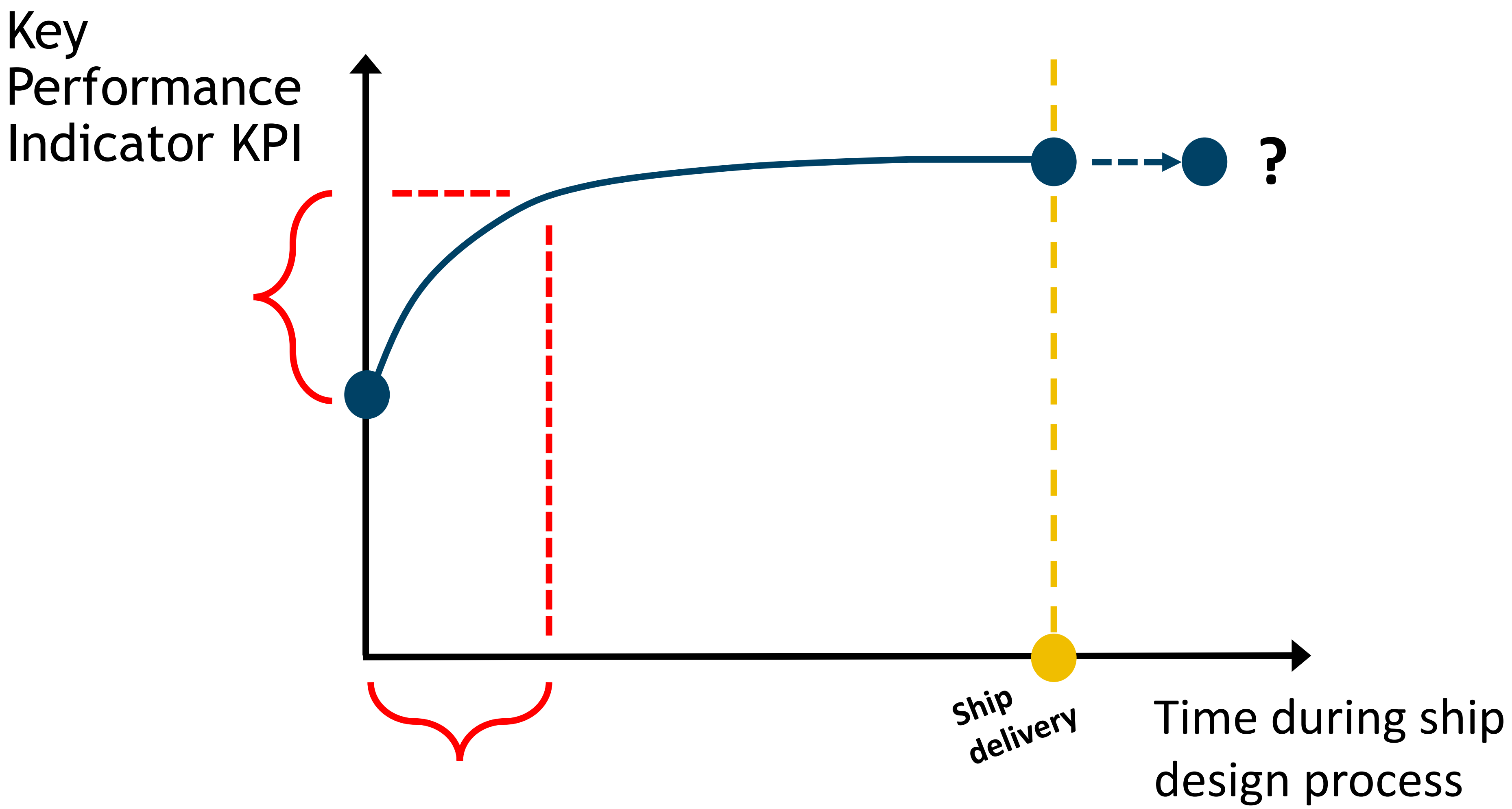
Ship design energy efficiency challenge



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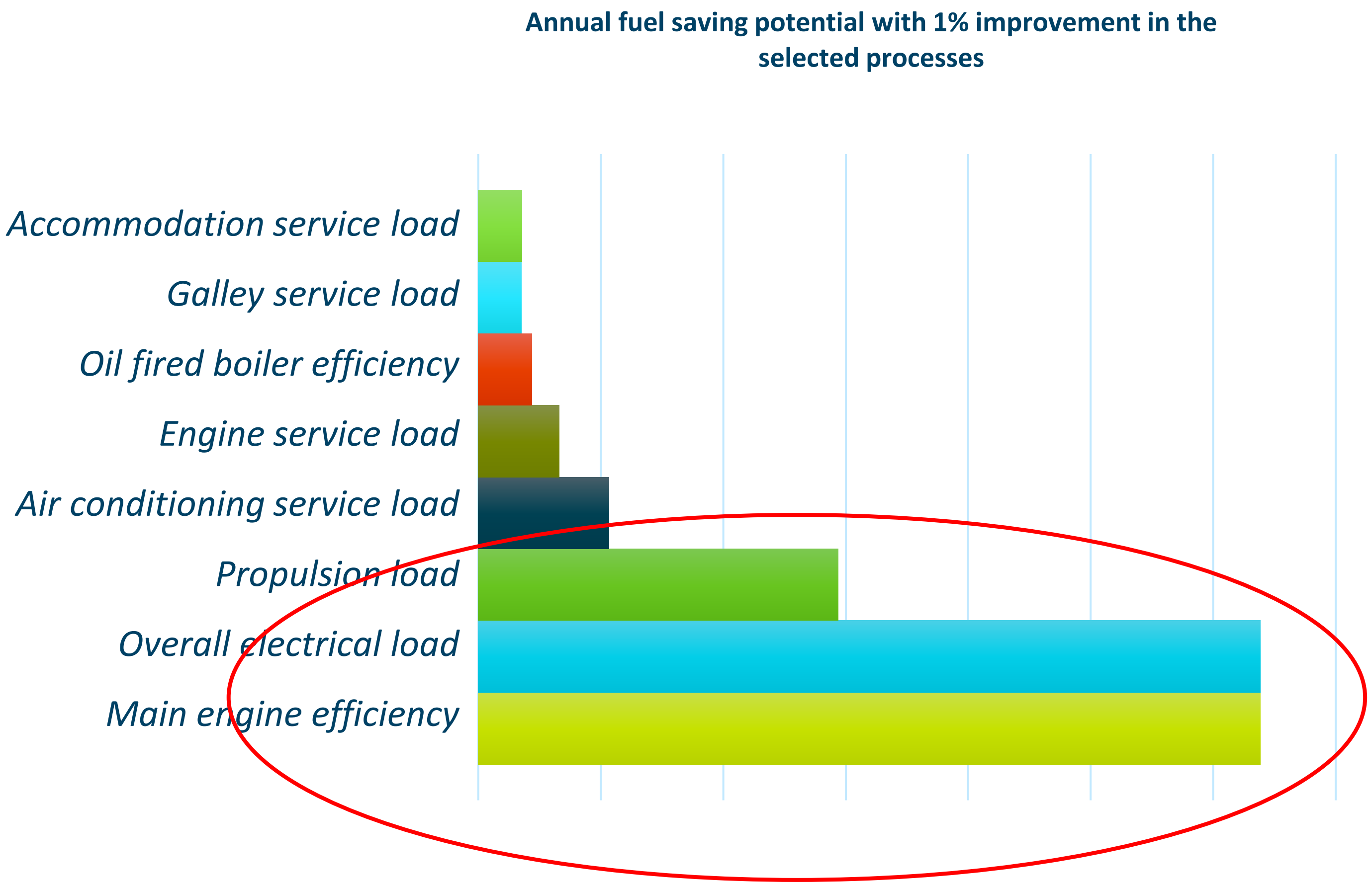
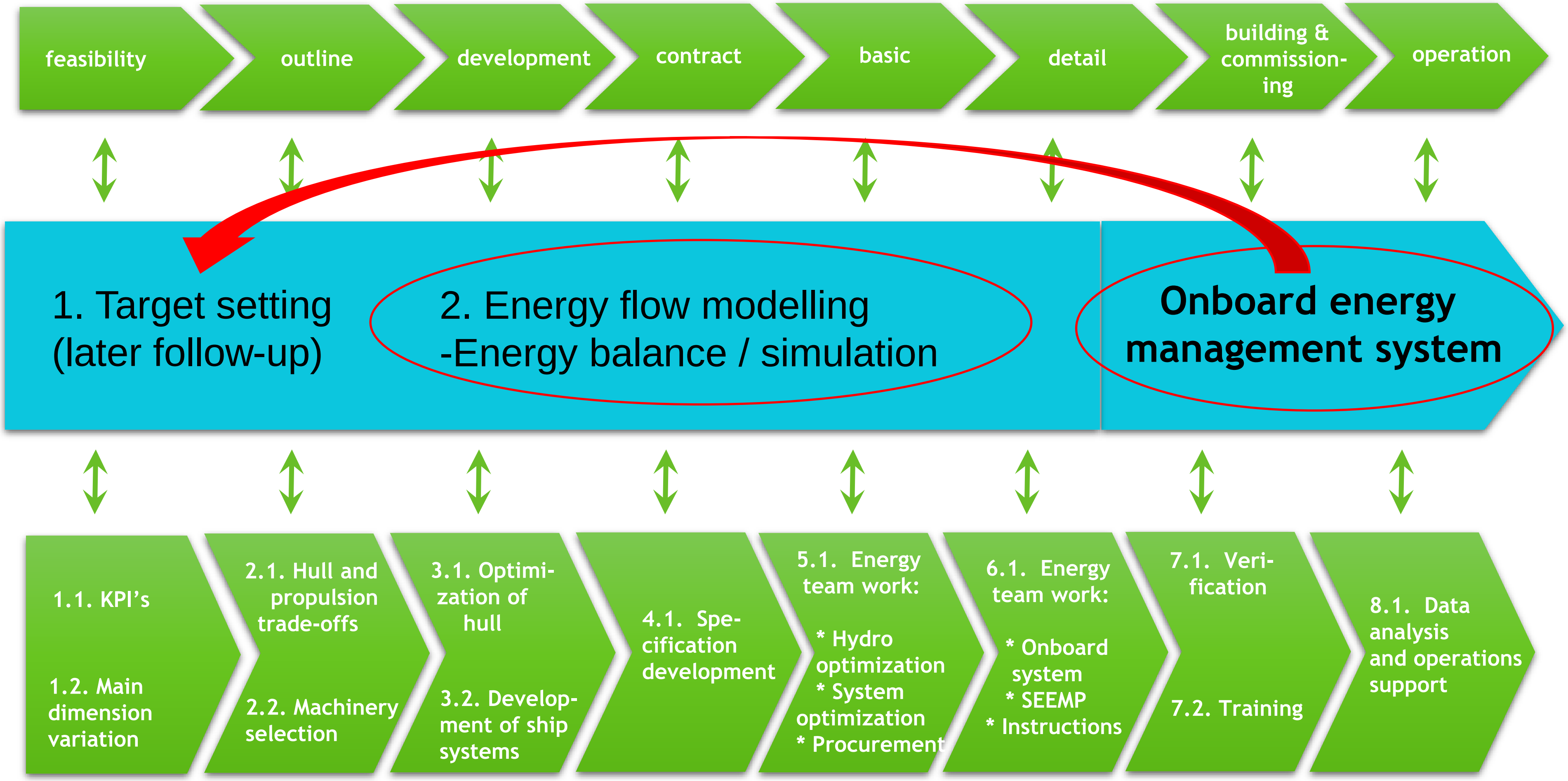
Energy Efficiency… where to start?

- Quantity
- Quality

→ both should be considered



Consistent energy modelling throughout ship life time



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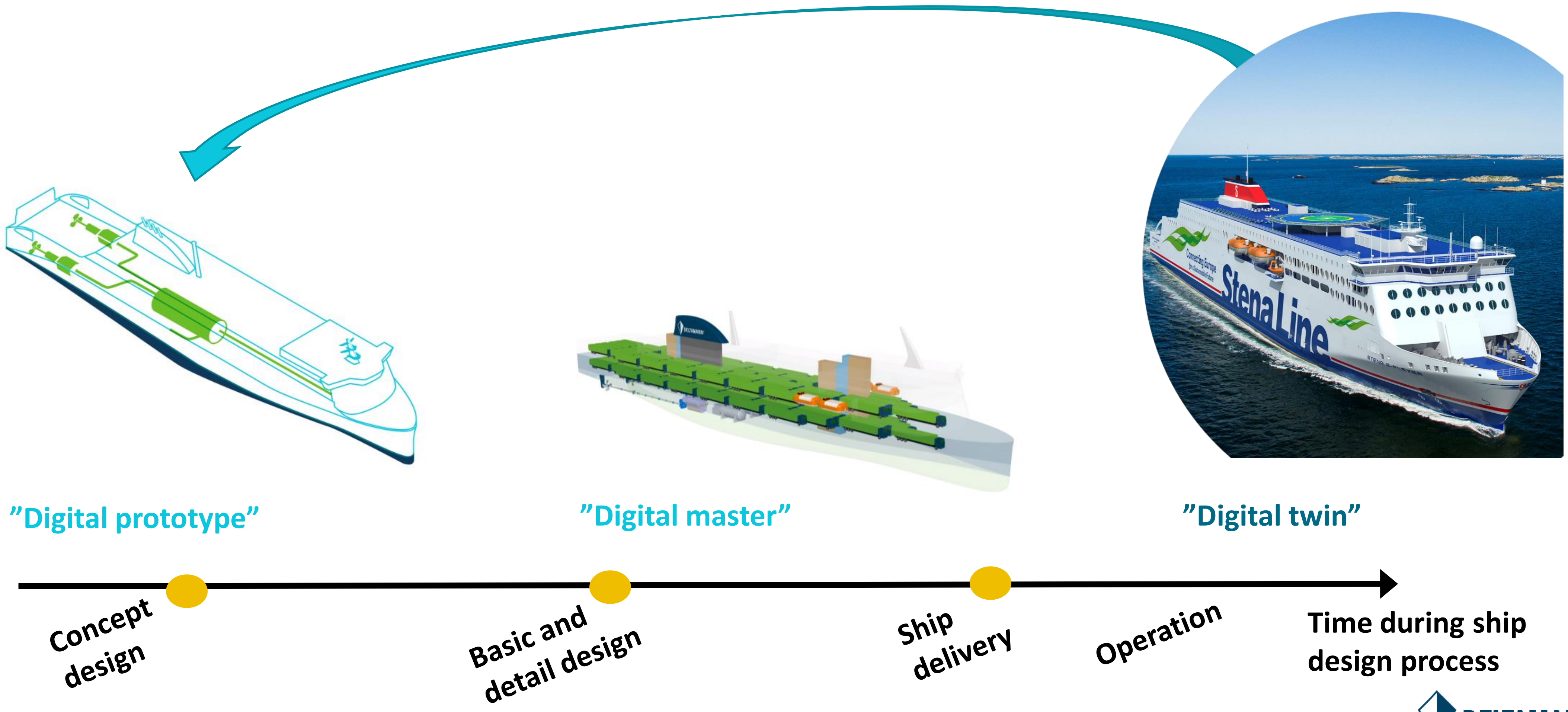
Digital thread - how ship model can evolve during ship life cycle



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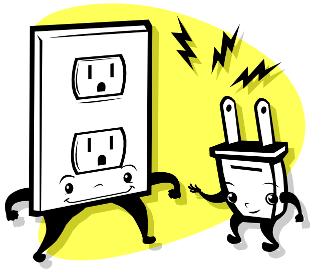
Energy Balance calculation

Energy efficiency factors

 x  = 

- Power x time = Energy
- kW x h = kWh

- Energy x SFC = consumed fuel
- kWh x $\frac{g/kWh}{1\ 000\ 000}$ = t fuel

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Energy Balance

- Based on the 1st principle of Thermodynamics:
- Energy conservation
- → Energy in fuel is transformed into mechanical power, heat, electricity… but never destroyed

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Energy Balance in practice

- Energy balance is a tool for quantifying energy flows

- Input – main issues
  - Operation profile
  - Power requirements of various systems
  - Machinery data + heat recovery
  - Fuel data

- Output - examples
  - Fuel consumption
  - Energy distribution inside the ship
  - Evaluations of ship autonomy
  - Emission calculation
  - Etc…

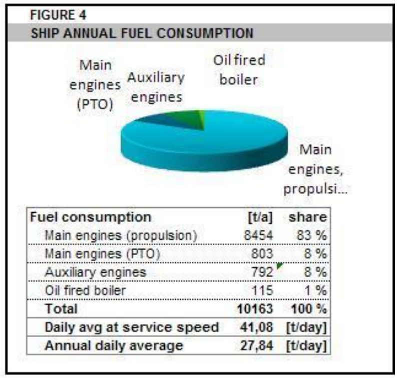
η

$Q=m_{dot}*c_p*dT$

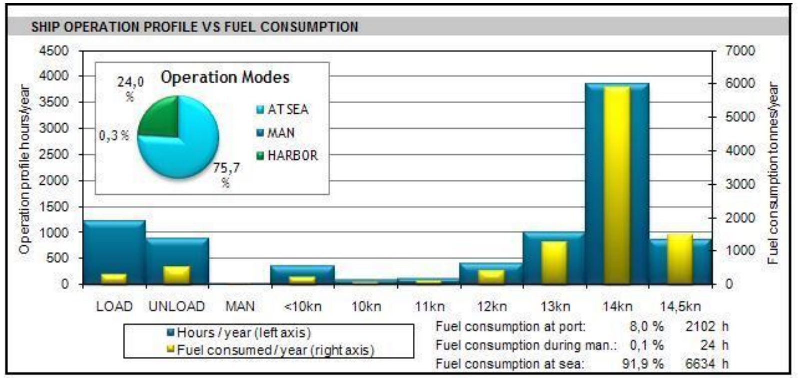
kWh

LHV

SFOC

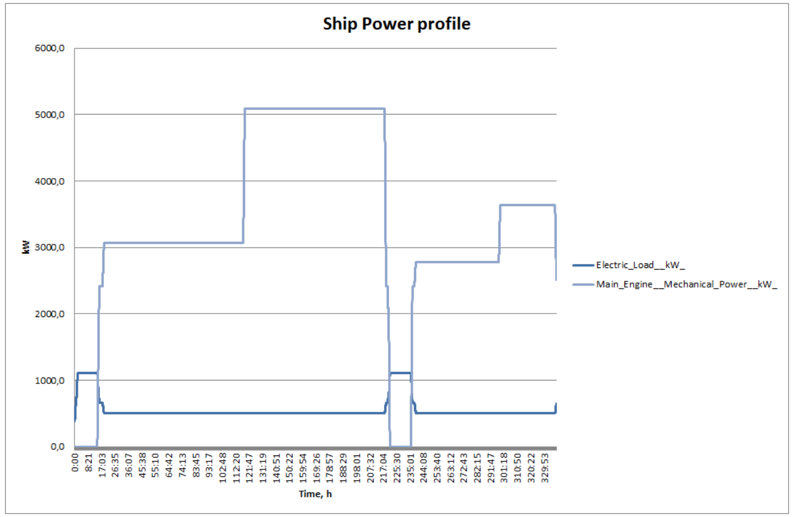


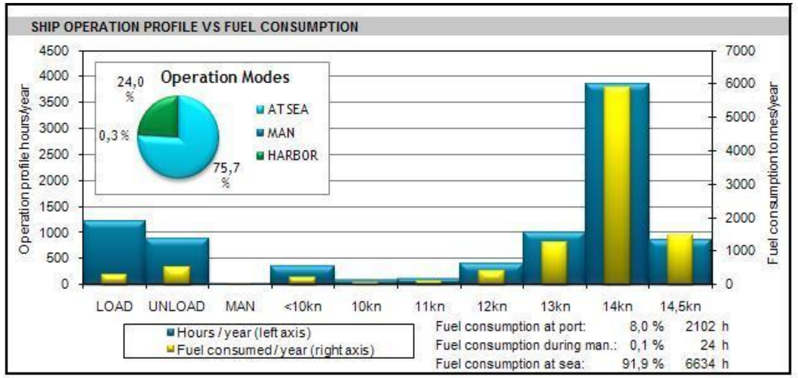
Fuel consumption	[t/a]	share
Main engines (propulsion)	8454	83 %
Main engines (PTO)	803	8 %
Auxiliary engines	792	8 %
Oil fired boiler	115	1 %
Total	10163	100 %
Daily avg at service speed	41,08	[t/day]
Annual daily average	27,84	[t/day]



Defining the operation profile

- A key item in energy efficiency evaluation
- Power (kW) x **TIME (h)** = Energy (kWh)



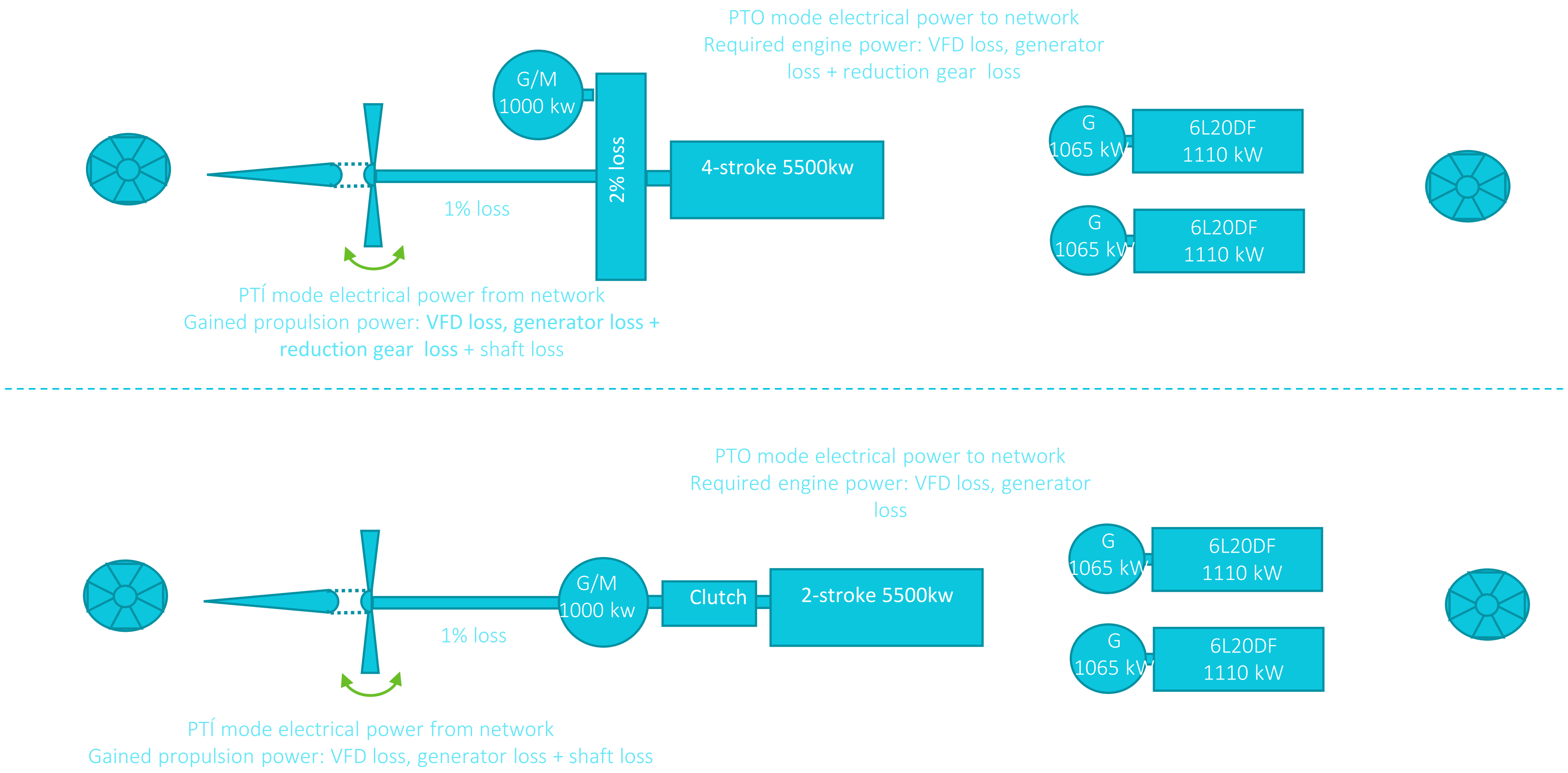


Power requirements of systems

- Propulsion power consumption based on CFD analysis, model tests, etc.
- Electricity consumption based on electrical load analysis etc. Estimation
- Heat load based on heat balance calculation etc.

- Alternatively, measured data from the ship (in case of ”retrofit work” or reference ship data for a newbuilding project) can be utilized for more accurate results

Example: Main propulsion options



To be considered:

- Fuel
- Ratio between propulsion and hotel power
- Vessel maneuverability
- → "Energy efficiency + safety view"
- Effect to arrangement
- CAPEX
- Operating costs
- ...

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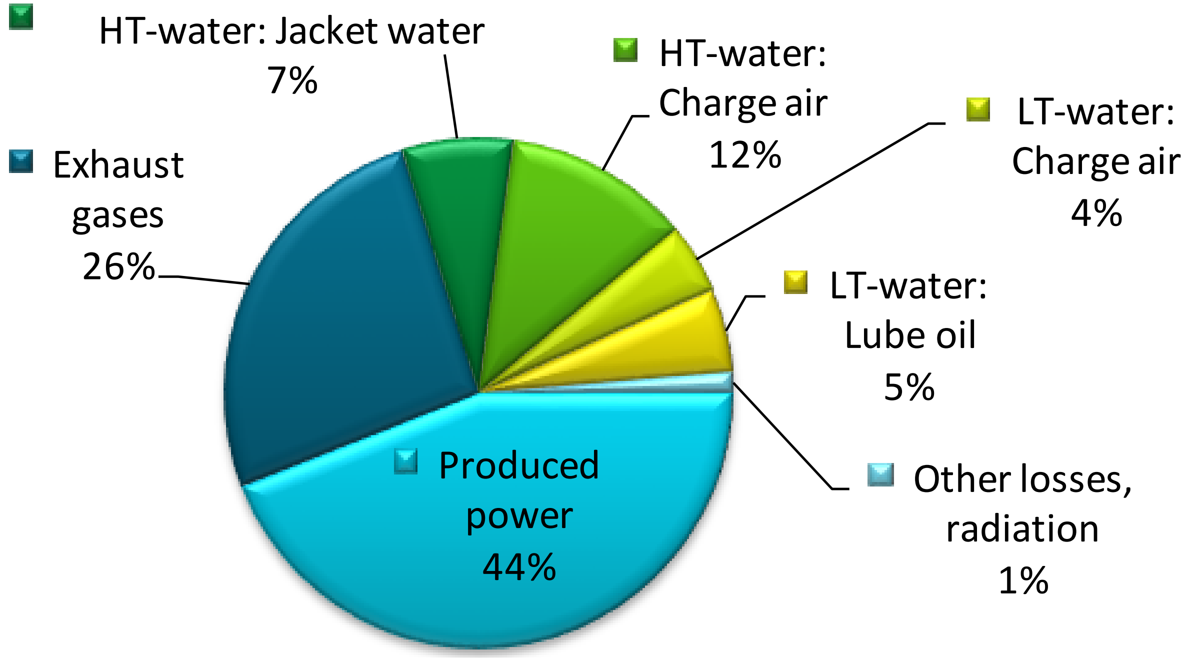
Diesel engine energy balance example

- 4-stroke, medium speed marine dual fuel engine as basis for the analysis

Engine energy production	%
Produced power	44 %
Exhaust gases	26 %
HT-water: Jacket water	7 %
HT-water: Charge air	12 %
LT-water: Charge air	4 %
LT-water: Lube oil	5 %
Other losses, radiation	1 %



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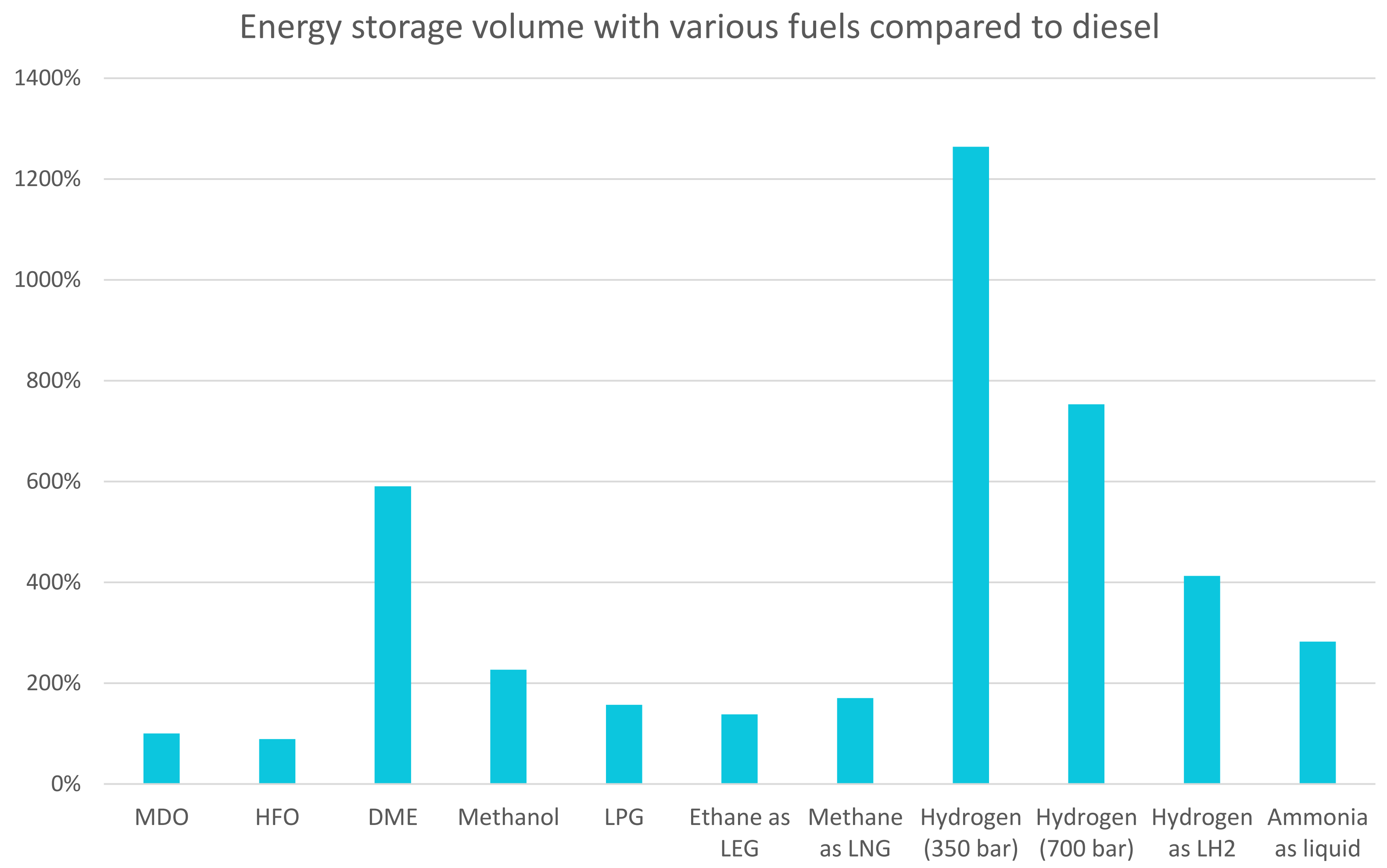
Fuel data

- LHV
- Methane number in gas etc…

Fuel			LHV [MJ/kg]	Density [kg/dm3]	Carbon Factor	Sulfur [% m/m]	HV/Volume [%]	CO2	SOx	NOx	Required Energy [MJ]	Required Fuel [kg]	CO2 [kg]	SO2 [kg]	NOx
Heavy Fuel Oil	Residual fuel	IFO-380	40,4	0,991	3,114	3,5	ref	ref	ref	ref	1000	24,8	77,1	1,7	100,0
Heavy Fuel Oil	Residual fuel	IFO-180	40,5	0,991	3,114	3,5	100 %	-0,2 %	-0,2 %	0,0 %	1000	24,7	76,9	1,7	100,0
LS Heavy Fuel Oil	Residual fuel	LS-380	40,4	0,991	3,114	1,0	100 %	0,0 %	-71,4 %	0,0 %	1000	24,8	77,1	0,5	100,0
LS Heavy Fuel Oil	Residual fuel	LS-180	40,5	0,991	3,114	1,0	100 %	-0,2 %	-71,5 %	0,0 %	1000	24,7	76,9	0,5	100,0
Marine Diesel Oil	Distillate fuel	DMC	41,5	0,920	3,151	1,0	95 %	-1,6 %	-72,2 %	0,0 %	1000	24,1	75,9	0,5	100,0
Marine Gas Oil	gas oil	LS-MGO	42,7	0,865	3,206	0,1	92 %	-2,6 %	-97,3 %	-6,0 %	1000	23,4	75,1	0,0	94,0
LNG	LNG	LNG	47,1	0,450	2,750	0,0	53 %	-24,3 %	-100,0 %	-85,0 %	1000	21,2	58,4	0,0	15,0
Biodiesel 100%	Biodiesel	B-100 S15	37,5	0,880	3,100	0,0015	82 %	+7,2 %	-100,0 %	+10,0 %	1000	26,7	82,7	0,0	110,0
Biodiesel 100%	Biodiesel	B-100 S500	37,5	0,880	3,100	0,0500	82 %	+7,2 %	-98,5 %	+10,0 %	1000	26,7	82,7	0,0	110,0
Biodiesel 20%	Biodiesel	B-20 S15	41,5	0,858	3,100	0,0015	89 %	-3,1 %	-100,0 %	+2,0 %	1000	24,1	74,7	0,0	102,0
Biodiesel 20%	Biodiesel	B-20 S500	41,5	0,858	3,100	0,0500	89 %	-3,1 %	-98,6 %	+2,0 %	1000	24,1	74,7	0,0	102,0

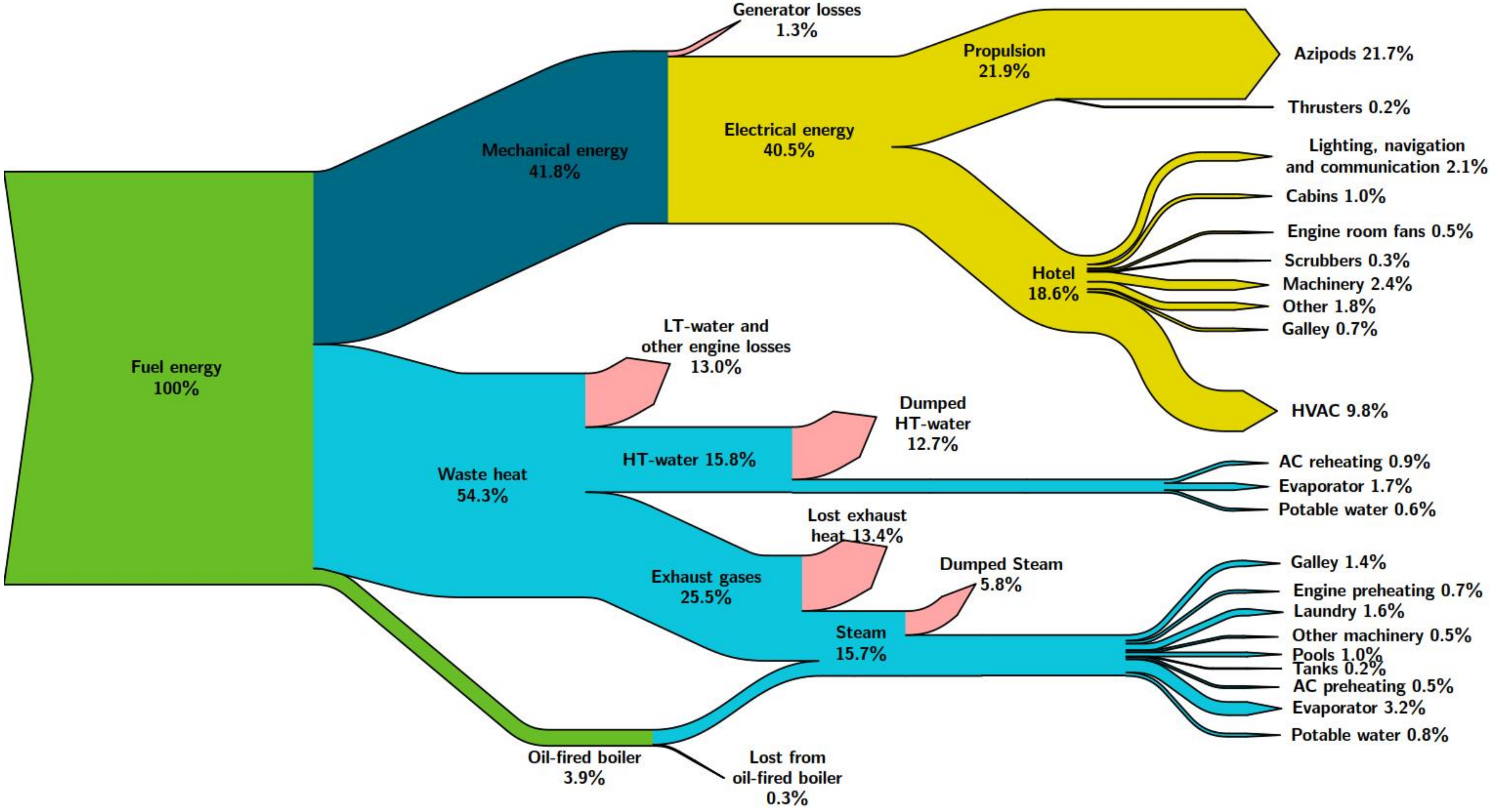
Low emissions impact on ship - volume



- → Fuel storage usually the main challenge
- Fuel infrastructure and general availability + price are also issues to consider

Results

- In addition to the absolute consumption figures, the relative distribution of fuel energy is achieved
- Also further analysis of the separate processes can be made
- Sankey diagram on the right illustrates how the fuel energy is distributed in an example ship (cruise ship with diesel electric ship power plant)



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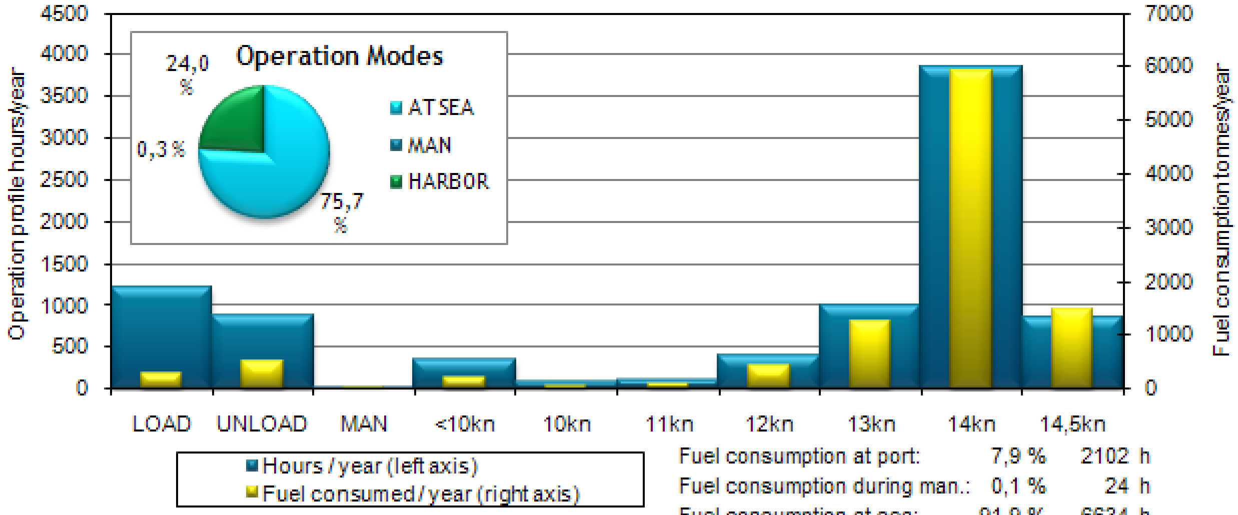
Energy Balance examples

Bulk carrier - 70 000 DWT

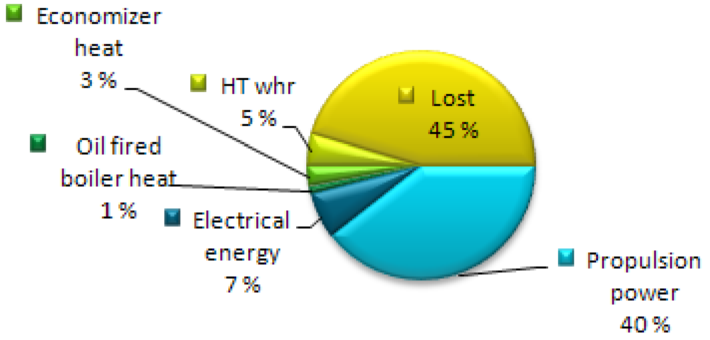
SHIP OPERATION PROFILE VS FUEL CONSUMPTION



Fuel consumption at port:	7,9 %	2102 h
Fuel consumption during man.:	0,1 %	24 h
Fuel consumption at sea:	91,9 %	6634 h

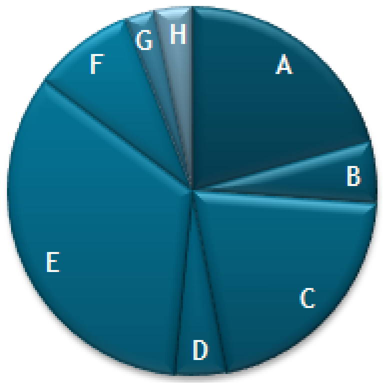
FUEL ENERGY UTILIZATION

Energy production	MWh/a
Propulsion power	45731
Electrical energy	7573
Oil fired boiler heat	1100
Economizer heat	3285
HT whr	5240
Lost	52518
Total fuel energy used	115446
Total fuel energy utilized	62928
Overall fuel efficiency	**54,5 %**



ELECTRICITY CONSUMPTION DISTRIBUTION

	Consumed mech. energy	MWh/a	FO t/a	share
	Propulsion	45731	8545	**100 %**
	Consumed electric energy	**MWeh/a**	**FO t/a**	**share**
A	Aux mach for propulsion	1568	315	21 %
B	Aux mach for ship	411	83	5 %
C	HVAC and heating	1585	324	21 %
D	Galley, laundry, workshop	338	69	4 %
E	Cargo, deck and hull	2551	577	34 %
F	Lighting	675	139	9 %
G	Navigation and automation	198	40	3 %
H	Cargo fans	245	51	3 %
I	Thrusters	3	1	0 %
J				
K				
L				
	Total	**7573**	**1600**	**100 %**



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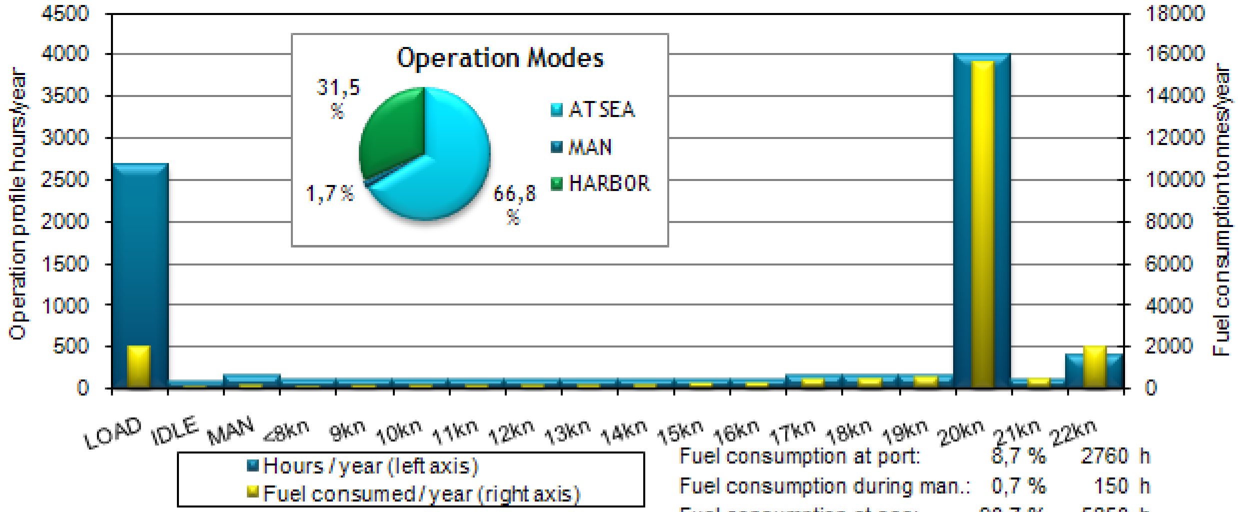
PCTC, 1A ice - 7000 lane meters

SHIP OPERATION PROFILE VS FUEL CONSUMPTION

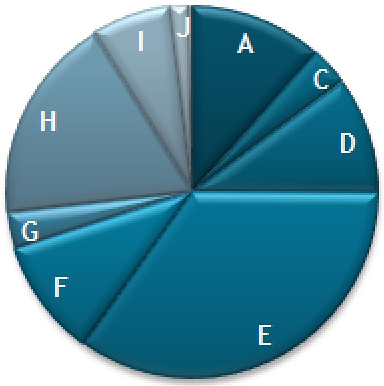


Fuel consumption at port:	8,7 %	2760 h
Fuel consumption during man.:	0,7 %	150 h
Fuel consumption at sea:	90,7 %	5850 h

ELECTRICITY CONSUMPTION DISTRIBUTION

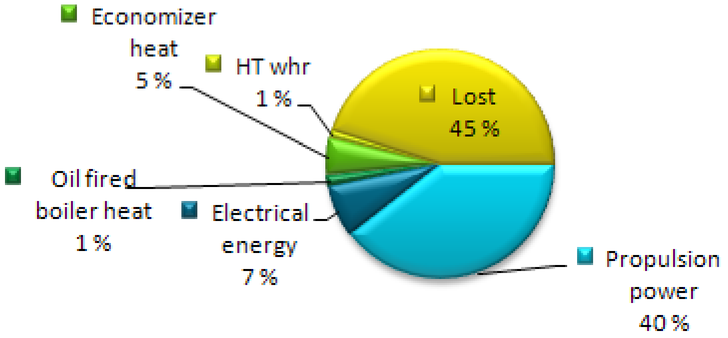
	Consumed mech. energy	MWh/a	FO t/a	share
	Propulsion	101897	18655	**100 %**

	Consumed electric energy	MWeh/a	FO t/a	share
A	Aux mach. for propulsion	2202	422	12 %
B				
C	Aux mach. for ship use	636	118	3 %
D	Ventilation, AC and heating	1928	379	10 %
E	Refrigeration devices	6612	1324	35 %
F	Cargo, hull and deck machiner	1943	419	10 %
G	Galley and laundry equipment	587	114	3 %
H	Cargo fans	3408	700	18 %
I	Lighting and socket outlets	1309	259	7 %
J	Navigation	306	60	2 %
K	Thrusters	60	13	0 %
L				
	Total	**18931**	**3794**	**100 %**



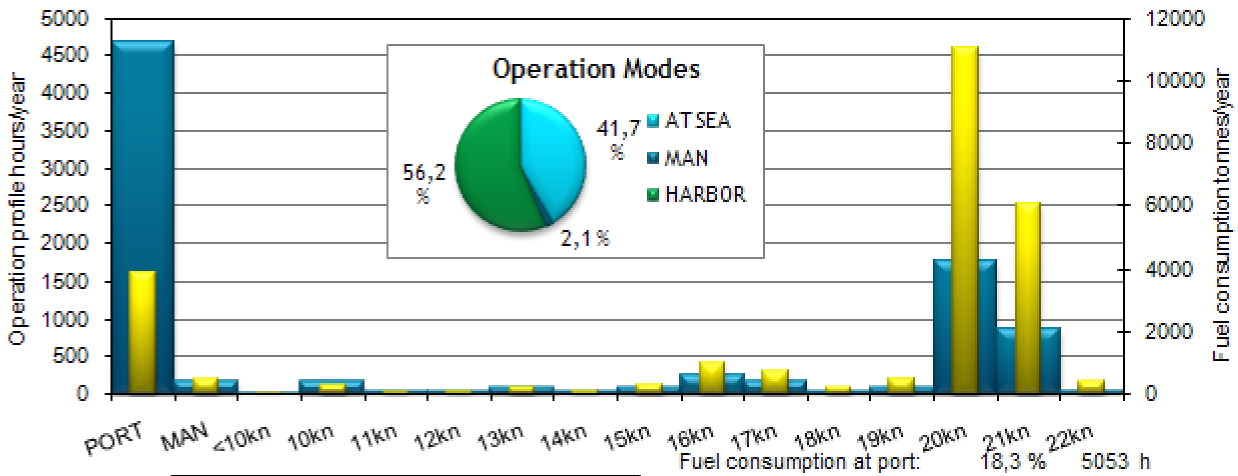
FUEL ENERGY UTILIZATION

Energy production	MWh/a
Propulsion power	101897
Electrical energy	18931
Oil fired boiler heat	3809
Economizer heat	13019
HT whr	3057
Lost	116367
Total fuel energy used	257079
Total fuel energy utilized	140712
Overall fuel efficiency	**54,7 %**



RoPax - 1300 Passengers, 750 LM

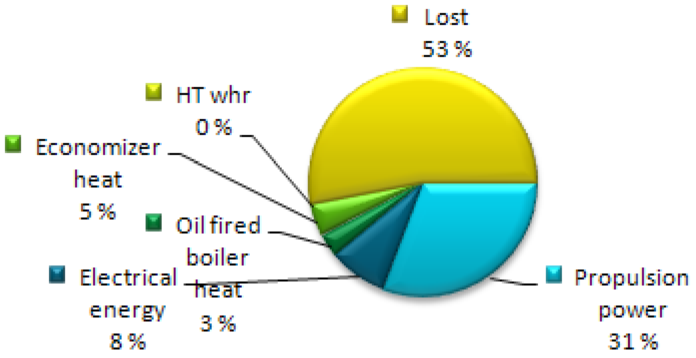
SHIP OPERATION PROFILE VS FUEL CONSUMPTION



Fuel consumption at port:	18,3 %	5053 h
Fuel consumption during man.:	0,3 %	45 h
Fuel consumption at sea:	81,4 %	3566 h

FUEL ENERGY UTILIZATION

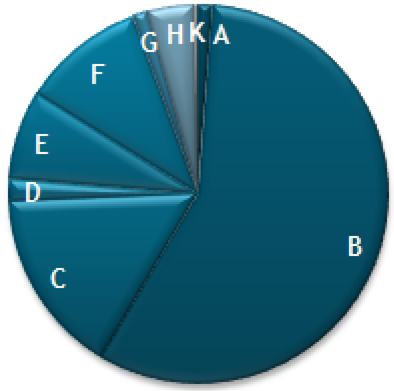
Energy production	MWh/a
Propulsion power	87778
Electrical energy	23819
Oil fired boiler heat	9254
Economizer heat	13473
HT whr	0
Lost	151345
Total fuel energy used	285670
Total fuel energy utilized	134324
Overall fuel efficiency	**47,0 %**



ELECTRICITY CONSUMPTION DISTRIBUTION

	Consumed mech. energy	MWh/a	FO t/a	share
	Propulsion	87778	19316	**100 %**

	Consumed electric energy	MWeh/a	FO t/a	share
A	Hull and deck	285	67	1 %
B	Aux mach for ship (engine se	13700	2956	58 %
C	HVAC	3783	830	16 %
D	Galley, laundry, ws	451	99	2 %
E	Cargo	1822	321	8 %
F	Lighting service	2515	552	11 %
G	Navig, radio autom	317	69	1 %
H	Accommodation	944	215	4 %
I				
J				
K	Thrusters	72	17	0 %
L				
	Total	**23819**	**5109**	**100 %**



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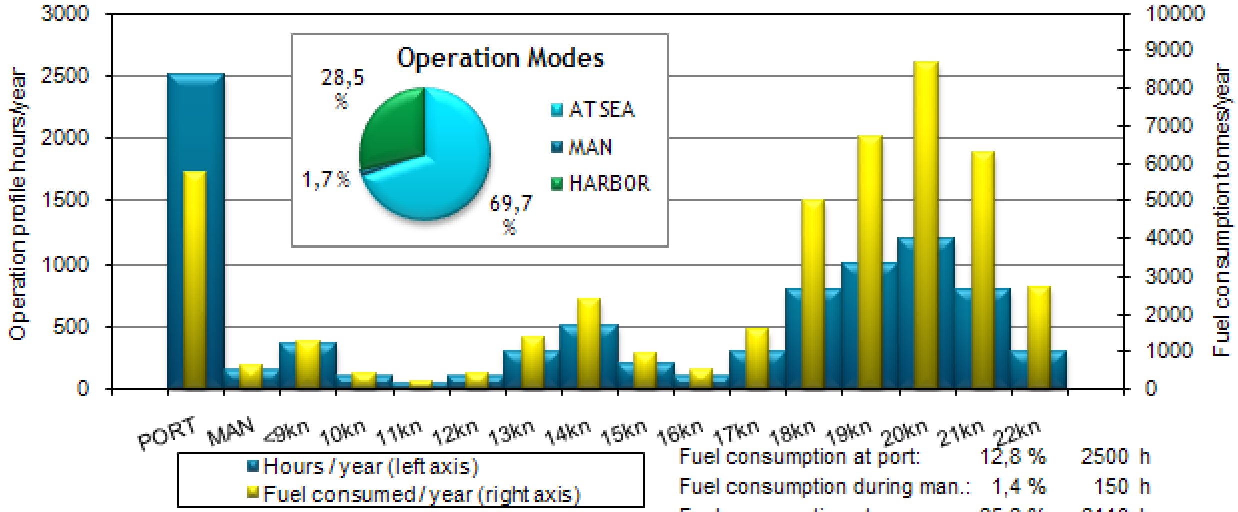
Cruise Ship - 3600 Passengers

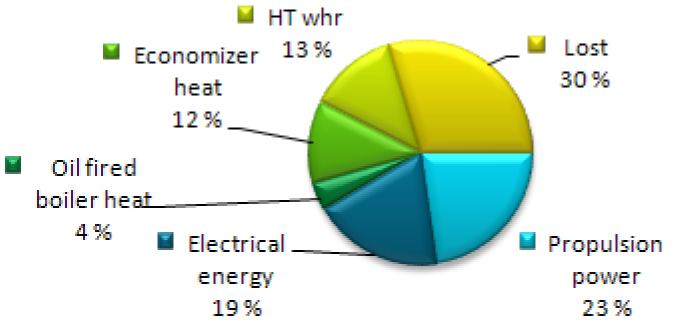
SHIP OPERATION PROFILE VS FUEL CONSUMPTION



Fuel consumption at port:	12,8 %	2500 h
Fuel consumption during man.:	1,4 %	150 h
Fuel consumption at sea:	85,8 %	6110 h

FUEL ENERGY UTILIZATION

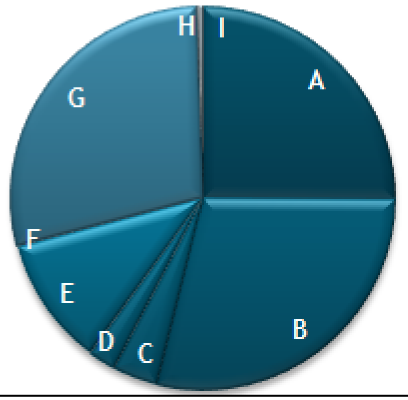
Energy production	MWh/a
Propulsion power	114704
Electrical energy	94978
Oil fired boiler heat	20568
Economizer heat	59716
HT whr	64752
Lost	149389
Total fuel energy used	504107
Total fuel energy utilized	354718
Overall fuel efficiency	**70,4 %**



ELECTRICITY CONSUMPTION DISTRIBUTION

	Consumed mech. energy	MWh/a	FO t/a	share
	Propulsion	114704	23268	**100 %**

	Consumed electric energy	MWeh/a	FO t/a	share
A	Aux mach for ship, engine, pr	23931	4897	25 %
B	HVAC	27435	5622	29 %
C	Refrigeration devices	3632	744	4 %
D	Hull and deck machinery	2239	459	2 %
E	Galley and laundry	10350	2120	11 %
F	Working machinery	22	4	0 %
G	Lighting and socket outlets	27213	5576	29 %
H	Navigation, radio autom	147	30	0 %
I	Aux for thrusters	10	2	0 %
J				
K	Thrusters	348	0	0 %
L				
	Total	**94978**	**19455**	**100 %**



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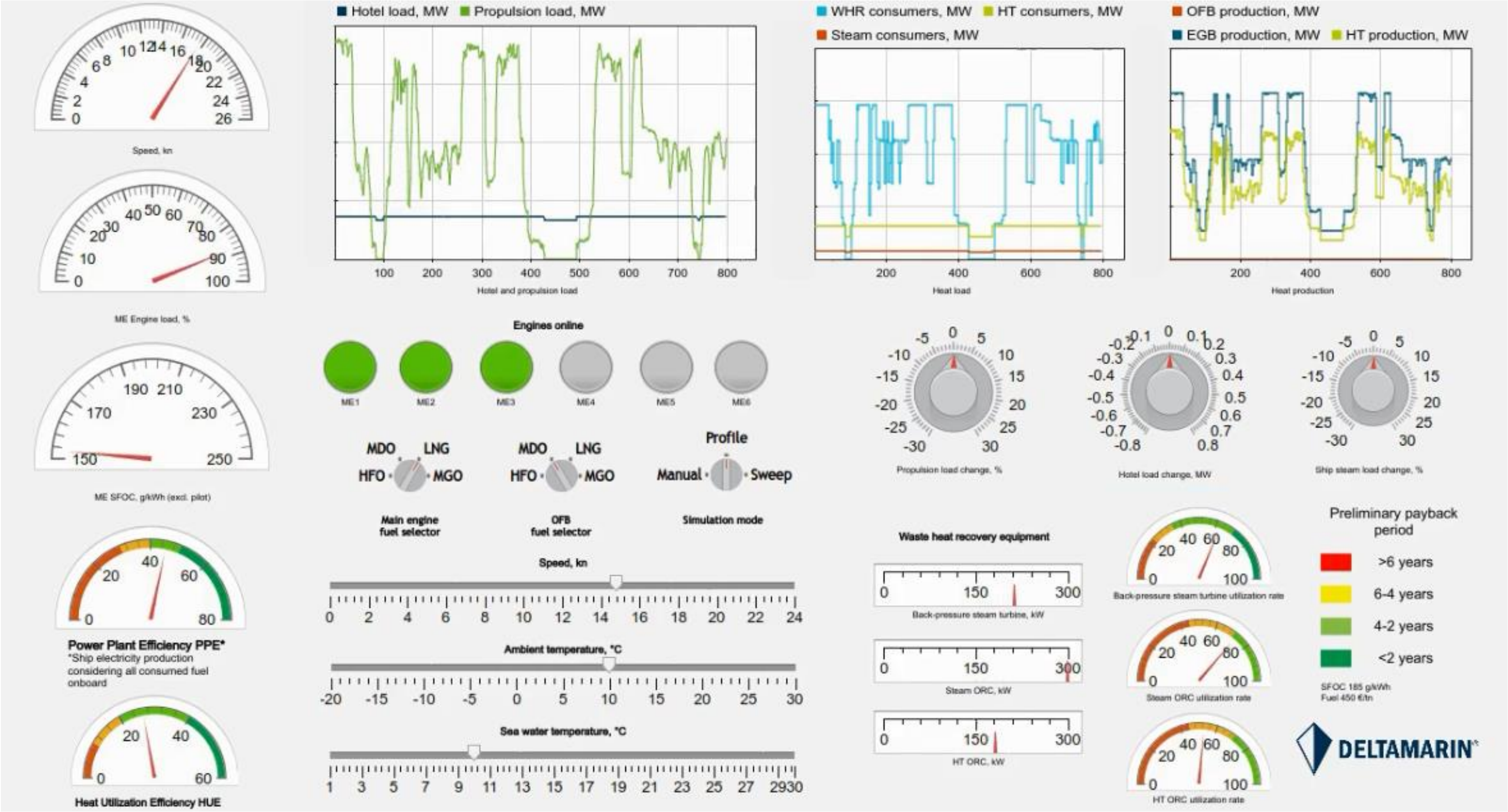
Example of Deltamarin's energy flow simulation tool

- Utilized in all projects from concept design all the way to operation
- A case specific dashboard is configured
- Displaying the most relevant results or items that are studied



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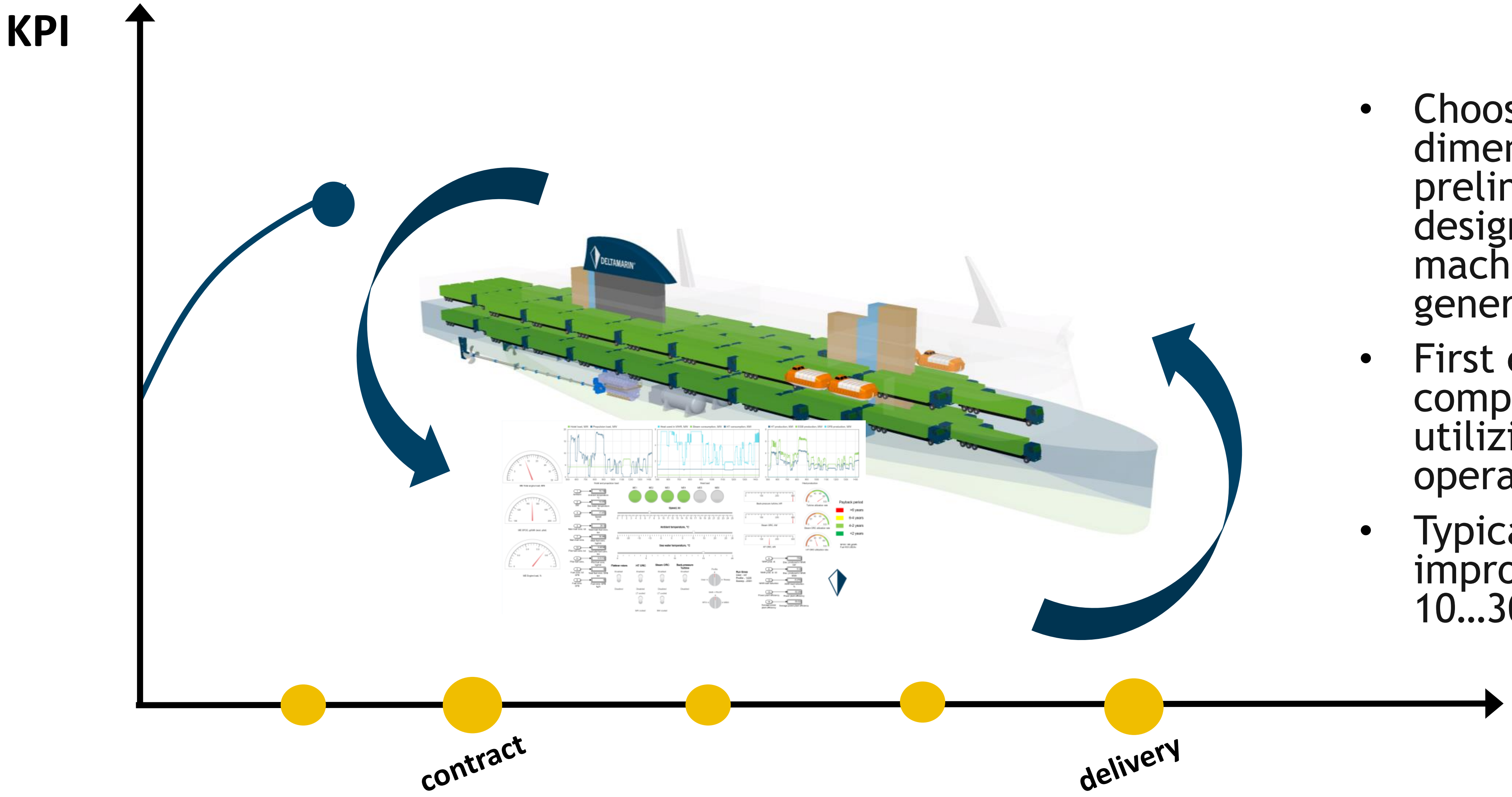
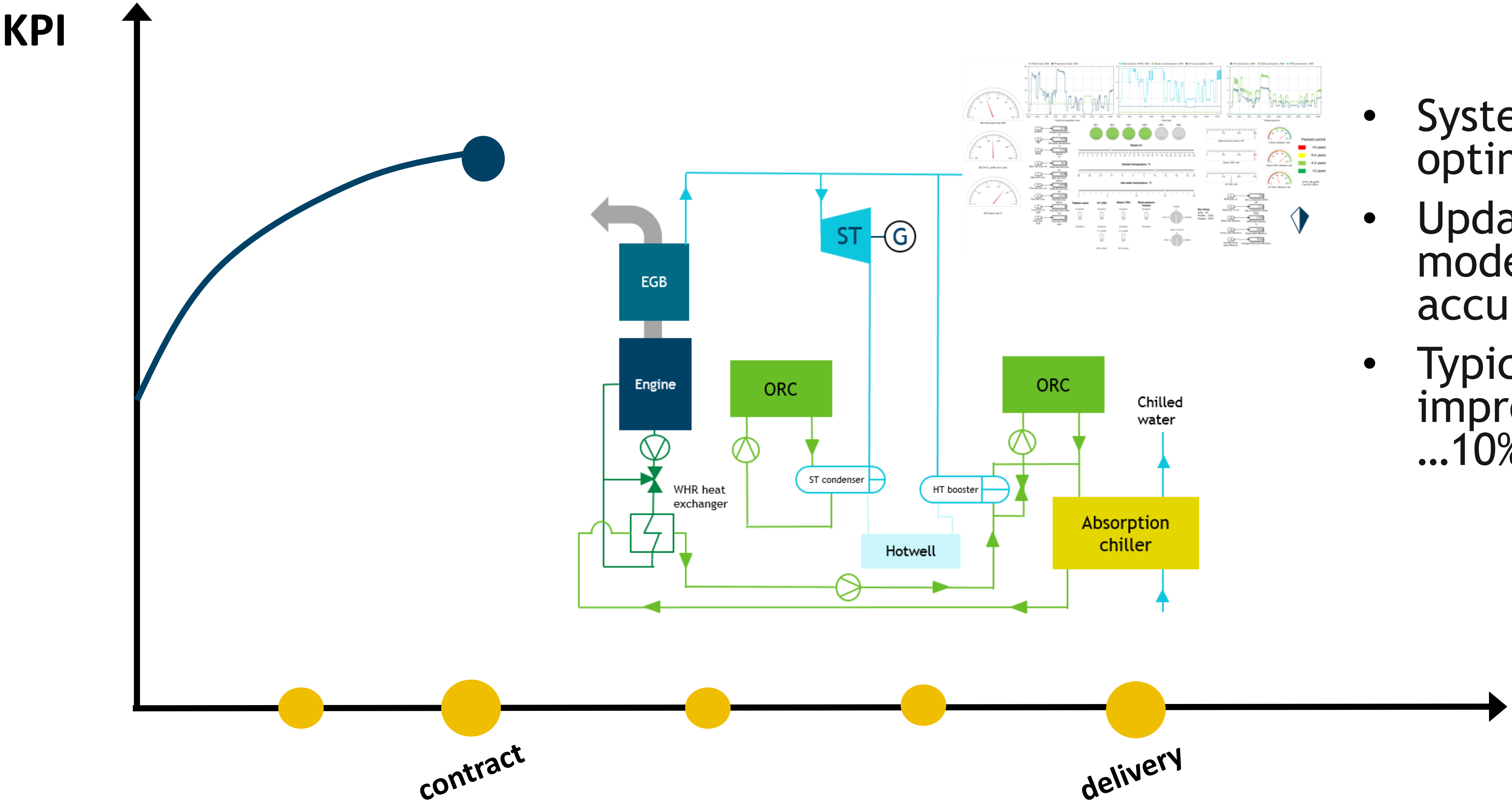
Energy modelling during ship project phases

Early conceptualizing



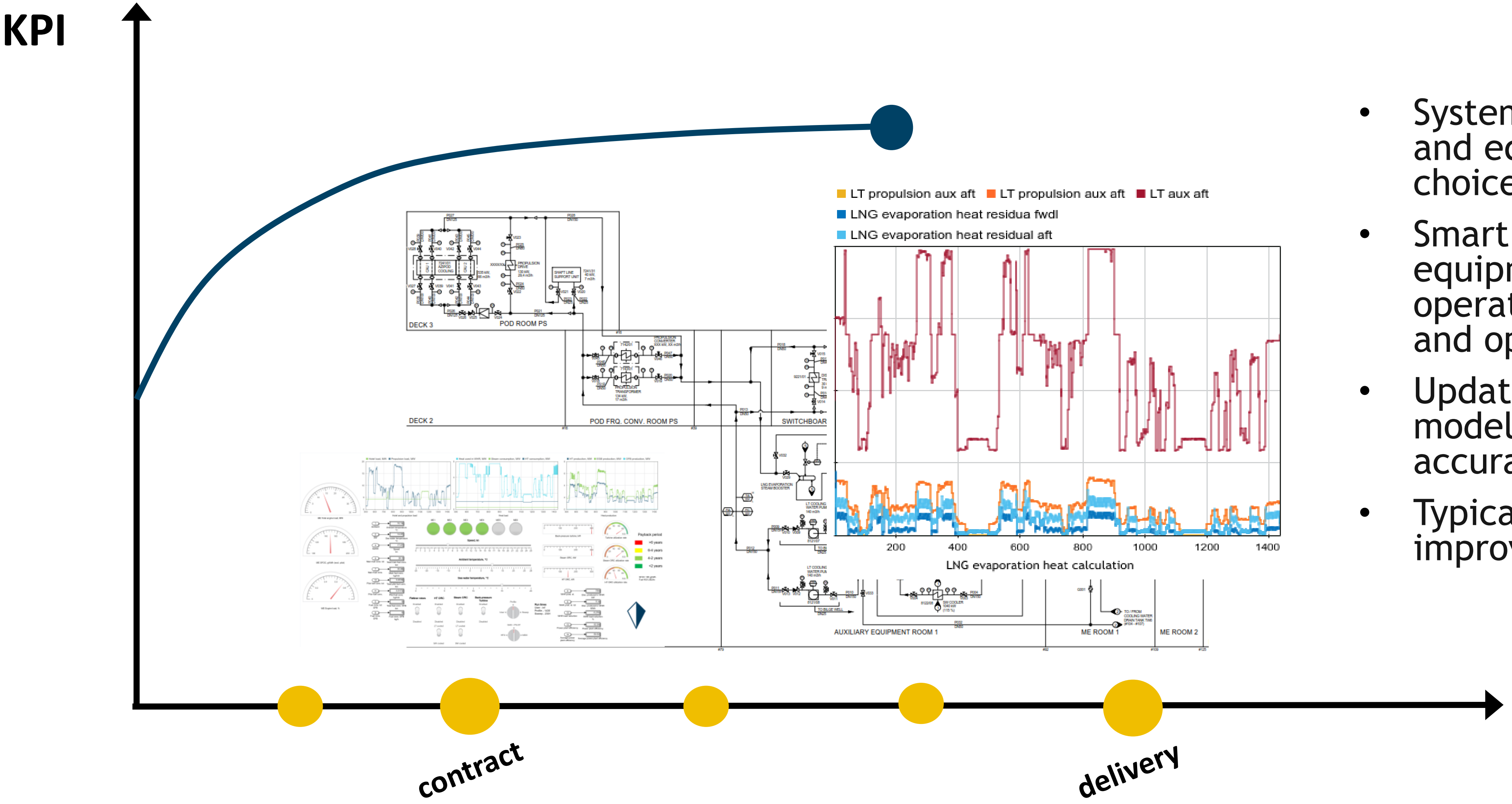
- Choosing the main dimensions, preliminary hull design and machinery concept generation
- First energy model compiled by utilizing suitable operational data
- Typical efficiency improvement 10…30%

Contract design



- System optimization
- Updated energy model with more accurate data
- Typical efficiency improvements …10%

Basic and detail design



- System development and equipment choices
- Smart dimensioning of equipment for operational efficiency and optimized costs
- Updated energy model with more accurate data
- Typical efficiency improvements …5%

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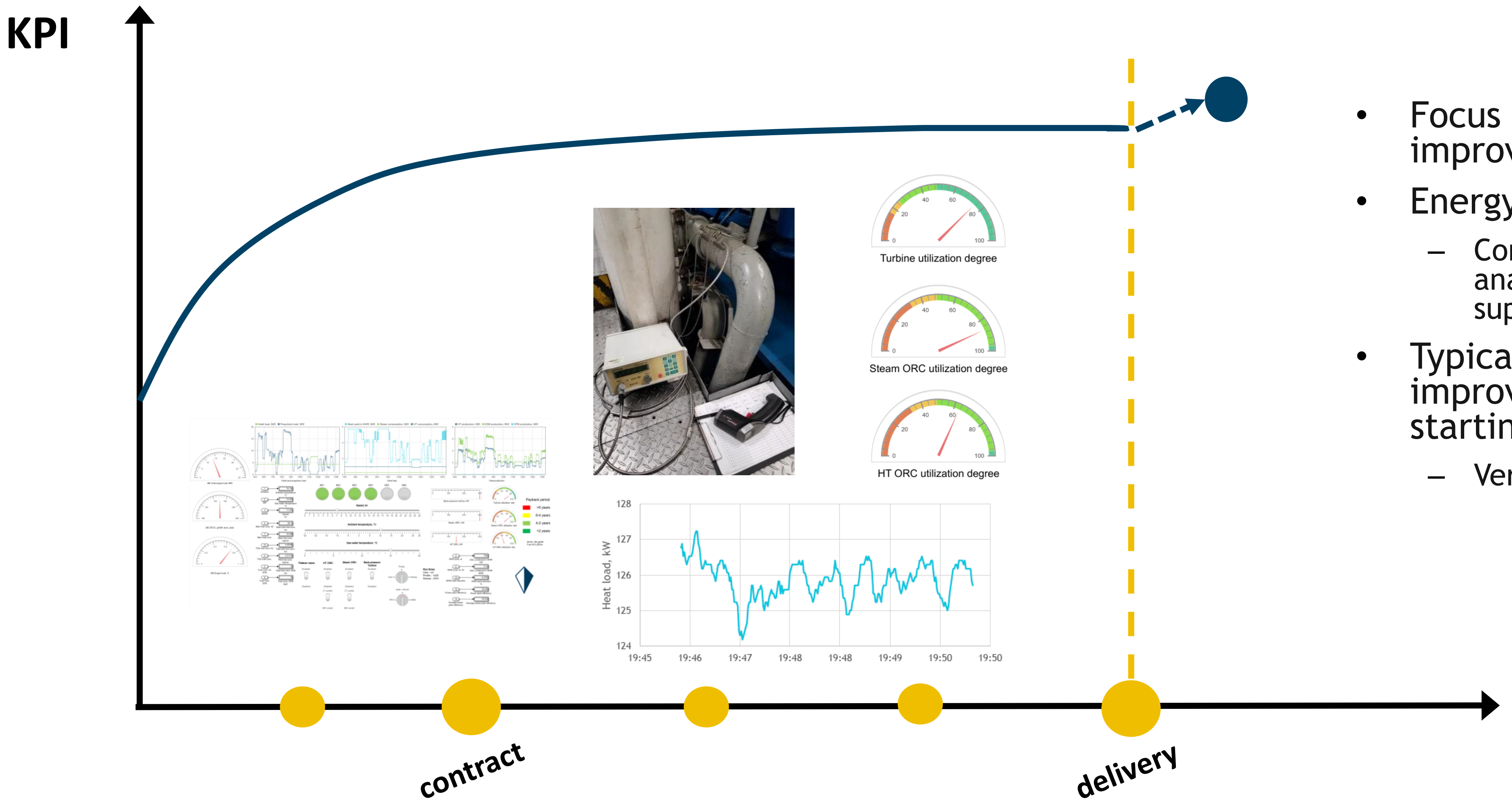
Operations

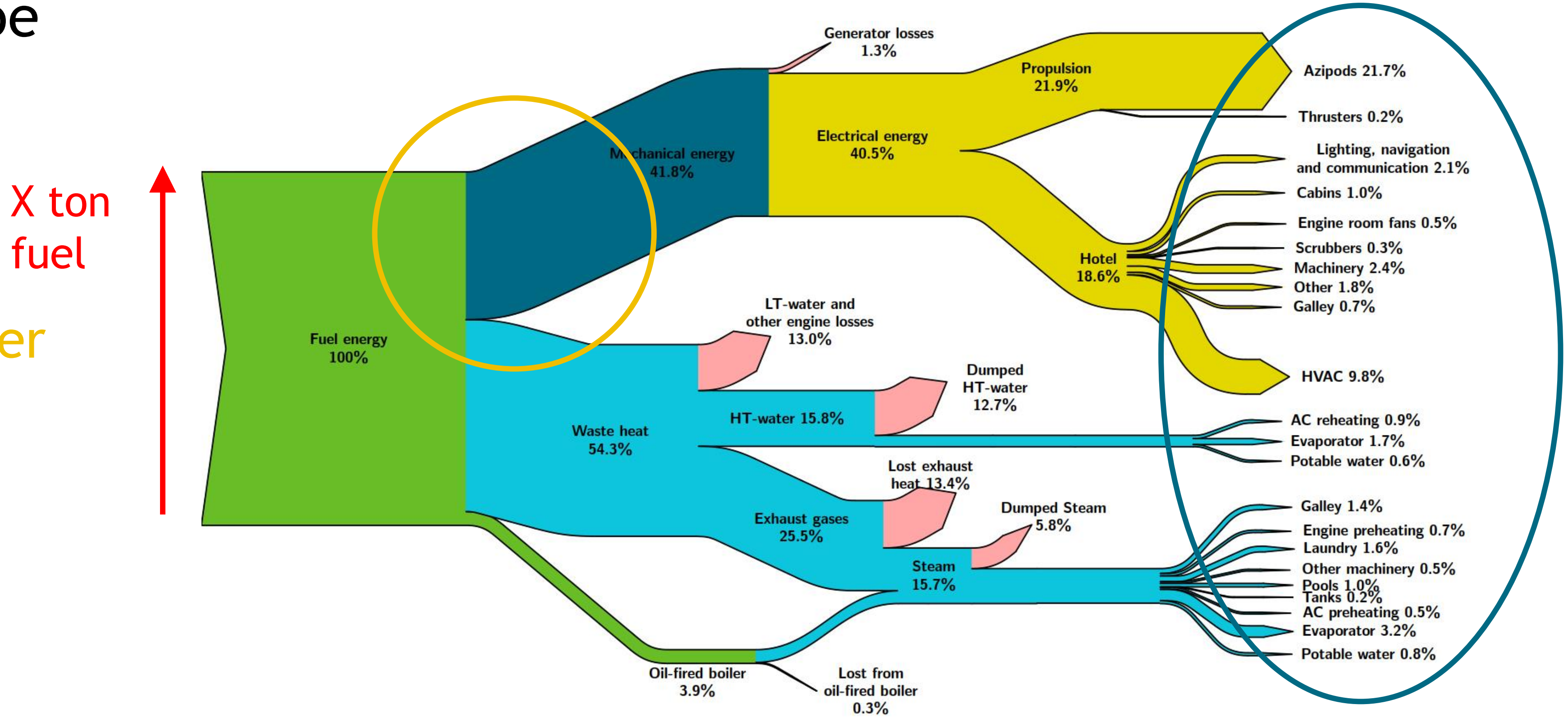


- Focus on operational improvements
- Energy management
  - Continuous data analysis and decision support
- Typical efficiency improvements starting from 5%
  - Very case dependent

Energy saving -overview to methods and technology

Main focus

- Energy (=fuel) can be saved both by minimizing:
  - process energy consumption
  - Increasing the power plant efficiency
- The result can be evaluated with the energy model



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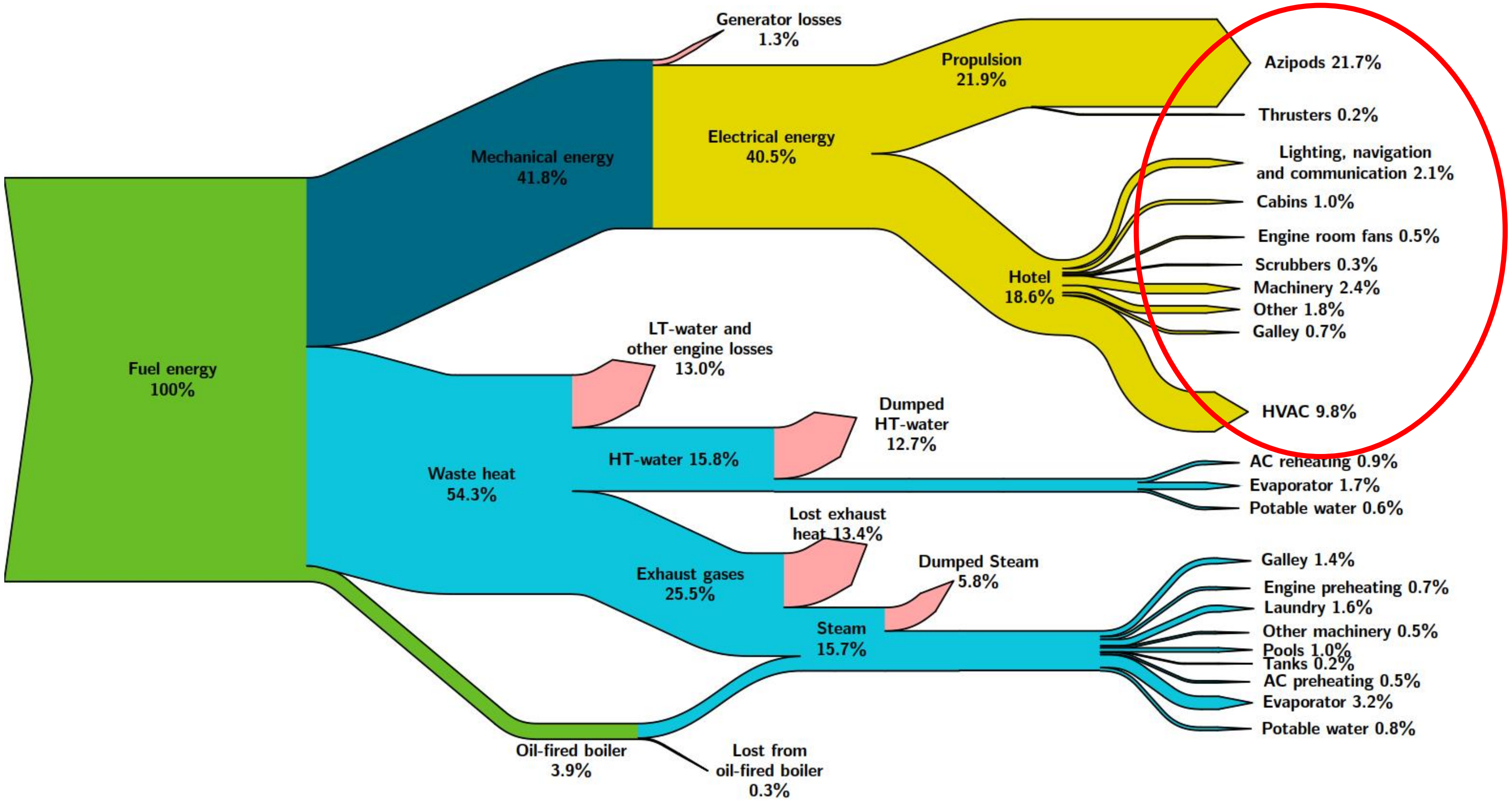
Lowering the energy consumption

Energy saving in the (electricity) consumption



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Energy saving in propulsion - examples

Design aspects

- Development of the hull details
  - Appendages
  - Optimization of the hull form
  - Variations
  - Bulbous bow
  - Ducktail
  - Central Skeg
  - …

Operational/maintenance

- Operational speed control
  - Itinerary adjusting, faster maneuvering
- Route optimization
  - Based on weather etc.
- Trim control
- Regular hull cleaning
- Propeller polishing
- …

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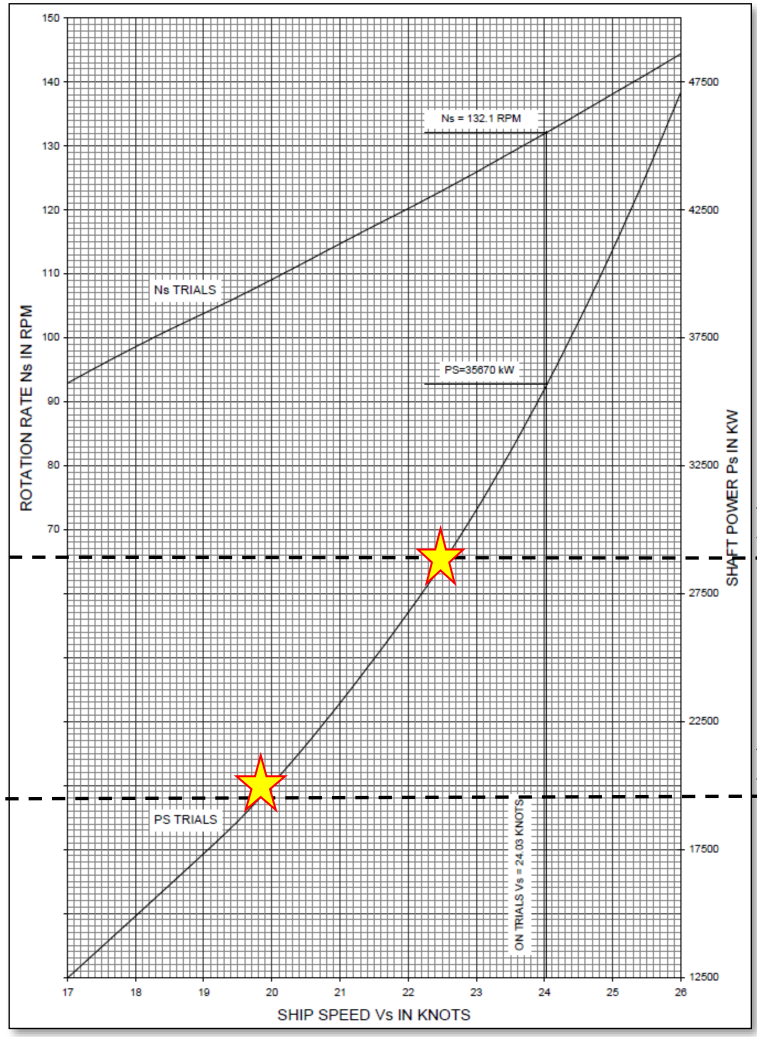
Slow steaming example

- Lowering the operational speed is one of the most efficient ways to save fuel
- The speed-power figure (on the right side) illustrates the exponential increasing of the power requirements with increased ship speed

Δ2kn = 8 750kW
(44% higher)



22,0kn = 28 750kW

20,0kn = 20 000kW

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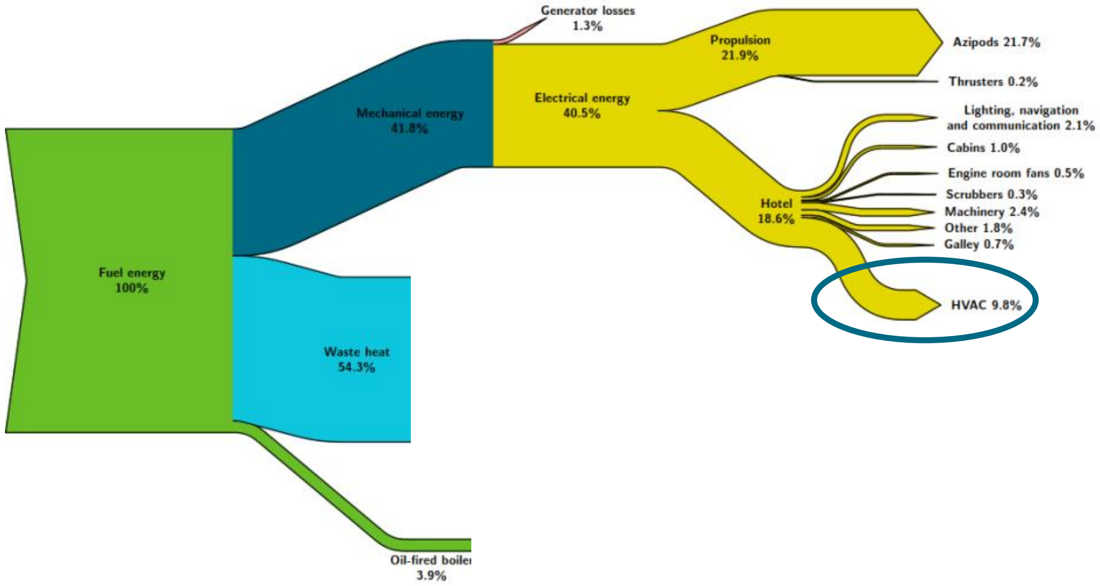
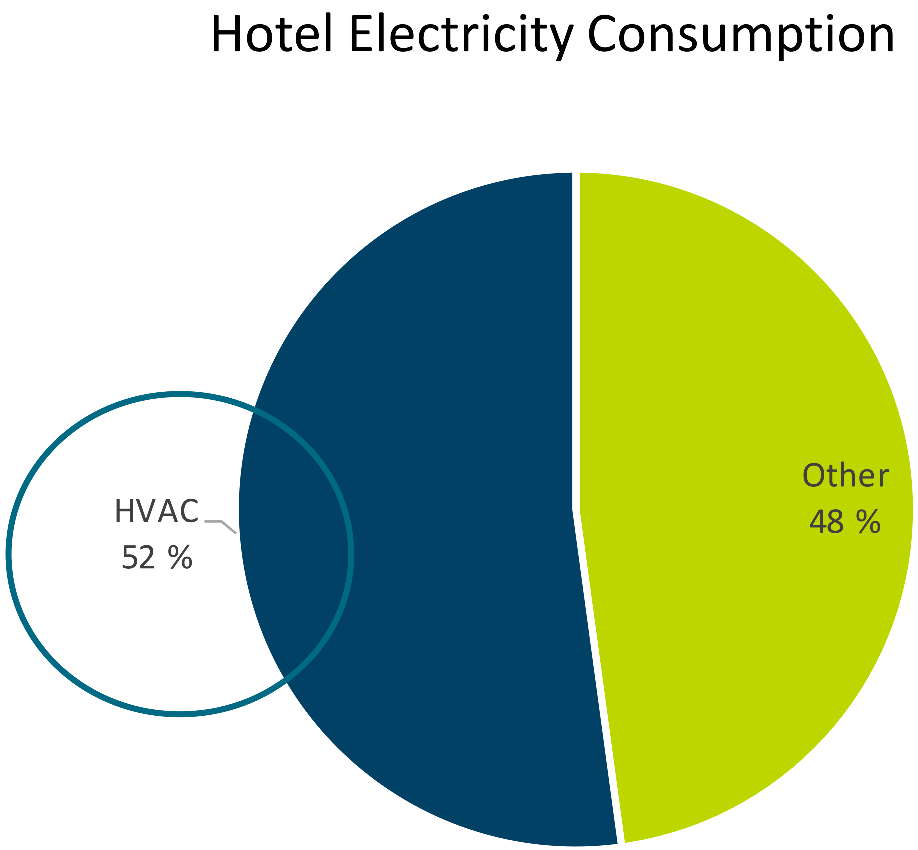
HVAC and energy balance





Affinity laws – for evaluating the energy saving with speed control of a pump or a fan

Example:

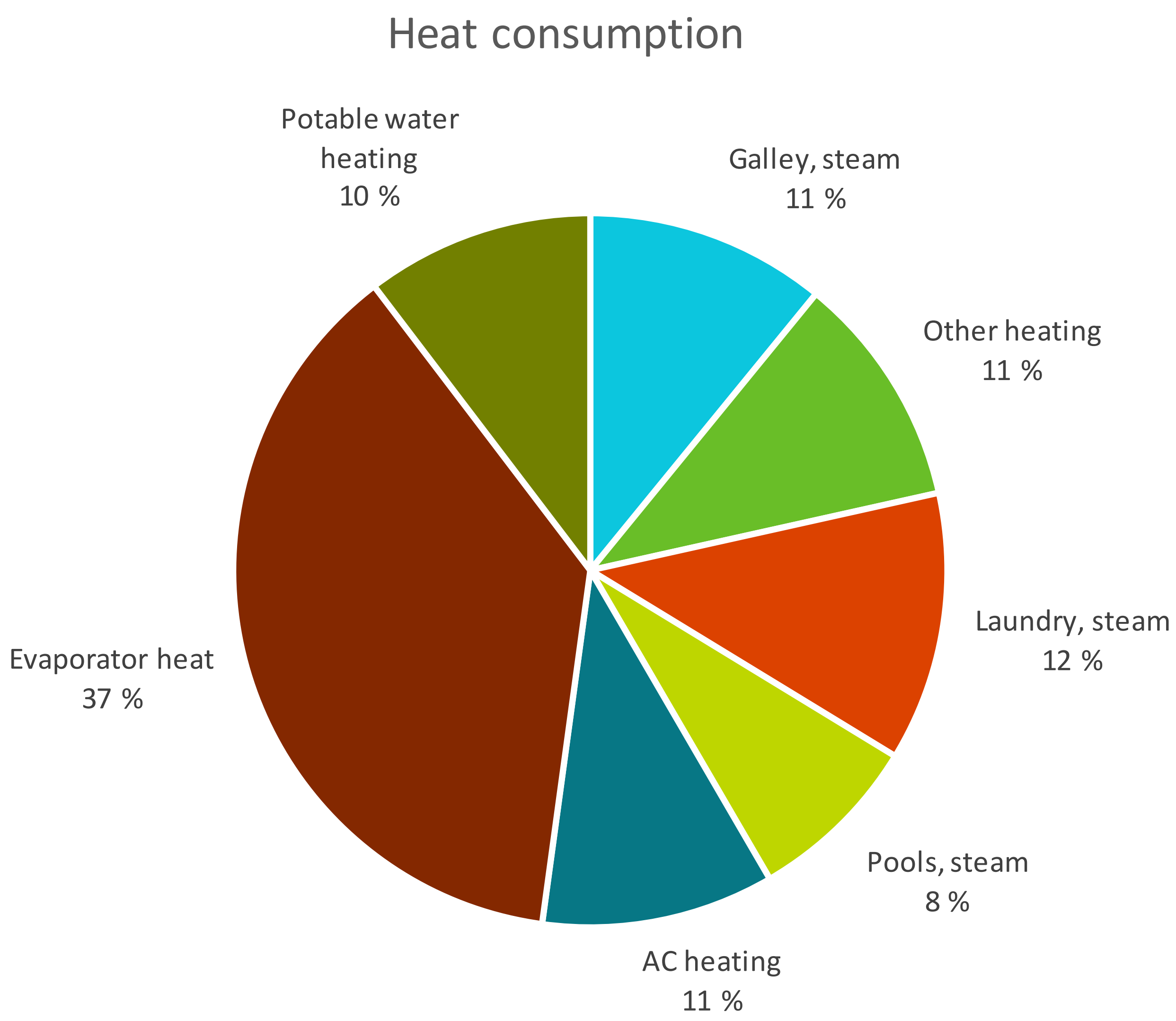
Changing the speed (rpm) of the pump will have the following influence:

RPM increase 10% → n1 = 1

n2 = 1,1

Simple rule: 50% speed =
1/8th of the nominal power!

Onboard Heat Consumers



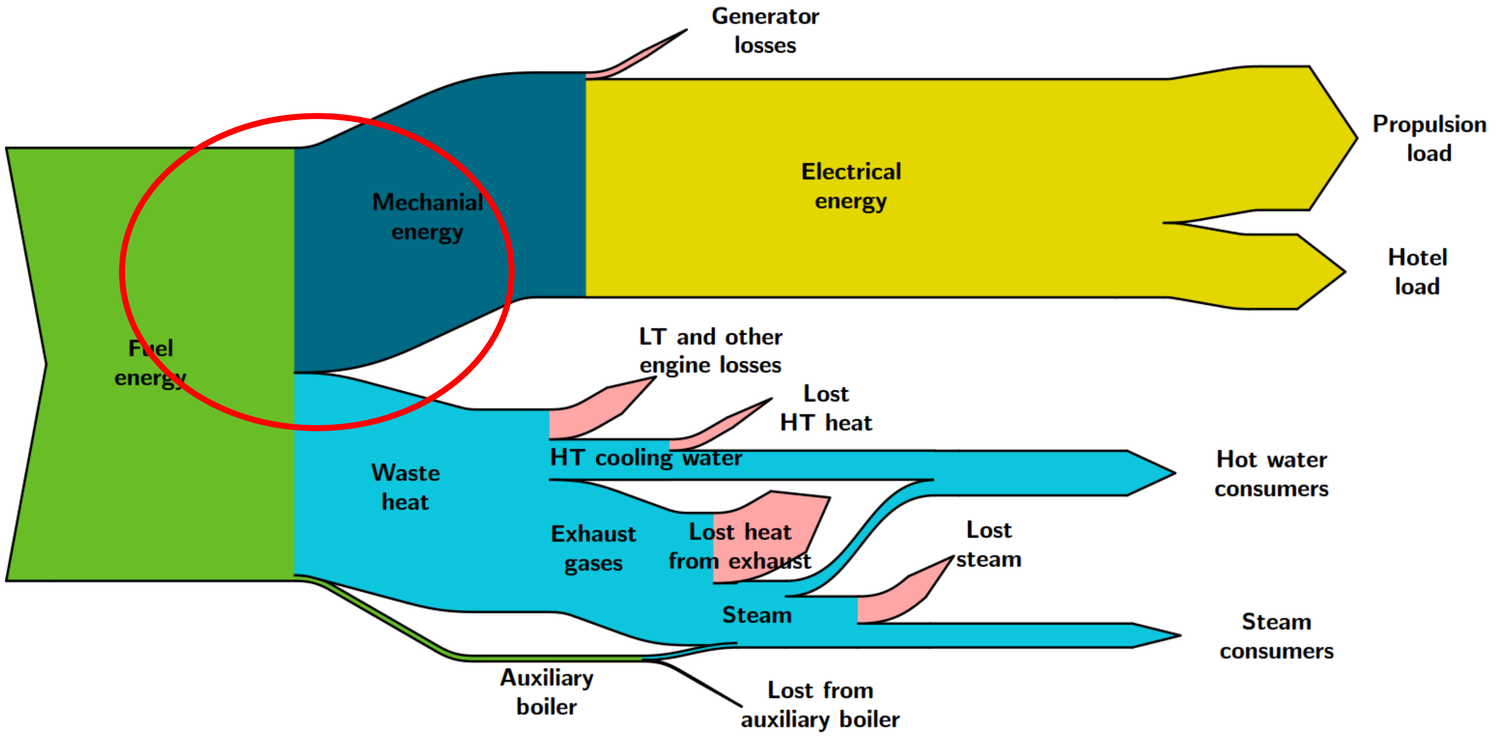
- Heat consumption can be 20-30% of a cruise ship total ENERGY use
- Majority of the heat production is normally covered with waste heat

Consumer	Usual temperature range
AC pre- and reheating	70-80˚C
Hot water heaters	55˚C
Evaporators	75-85˚C
Galleys and laundries	~100˚C and more!
Pool heating	27-37˚C

Power production efficiency - general

Power production efficiency

- Independent on the ship machinery, the ship machiney always has some ”power plant efficiency” figure that can be calculated
- The following examples focus on diesel engines



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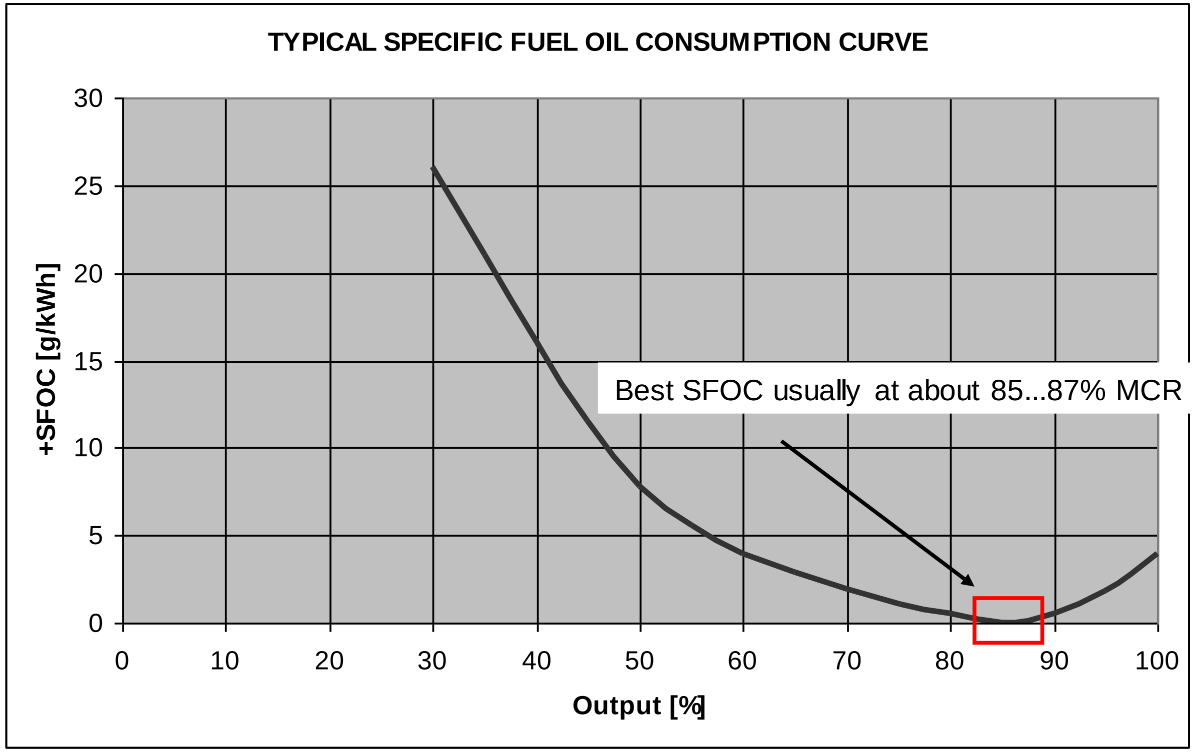
What is SFOC?

- **SFOC** = Specific Fuel Oil Consumption
- Unit = **g/kWh**
- SFOC is not a measure of fuel consumption, it is actually a measure of engine efficiency
- Fuel consumption = SFOC x kWh

What Affects on SFOC?

- **Engine internal parameters:**
  - Combustion process → fuel injection, air supply, exhaust...
  - Mechanical condition → cycle losses, engine driven pumps,...

- **External parameters:**
  - Fuel → type and quality..
  - Air → temperature, pressure, humidity
  - Coolant → temperature, flow
  - Operating point → % MCR



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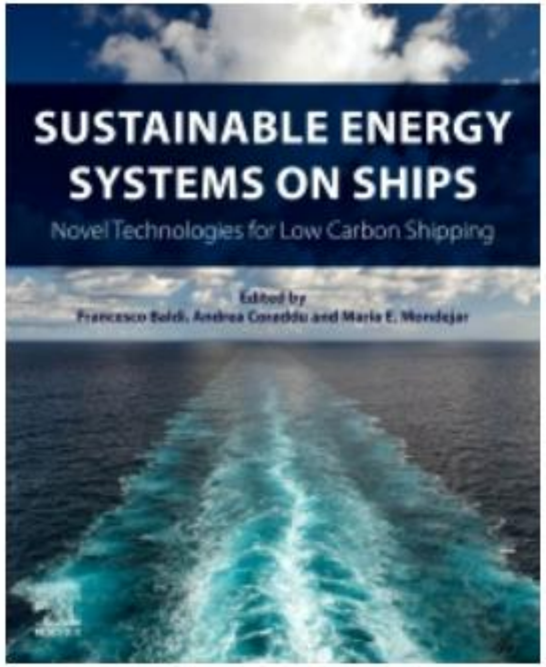
More information?

- A new book about ship energy efficiency came out in 2022!
- Chapter 12 includes the main principles presented in this lecture including three case studies from Deltamarin's projects



Preview

View on ScienceDirect ↗

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