Choosing Correctly
Future Fuels and Marine Power

Fuel economics dictate propulsion technology

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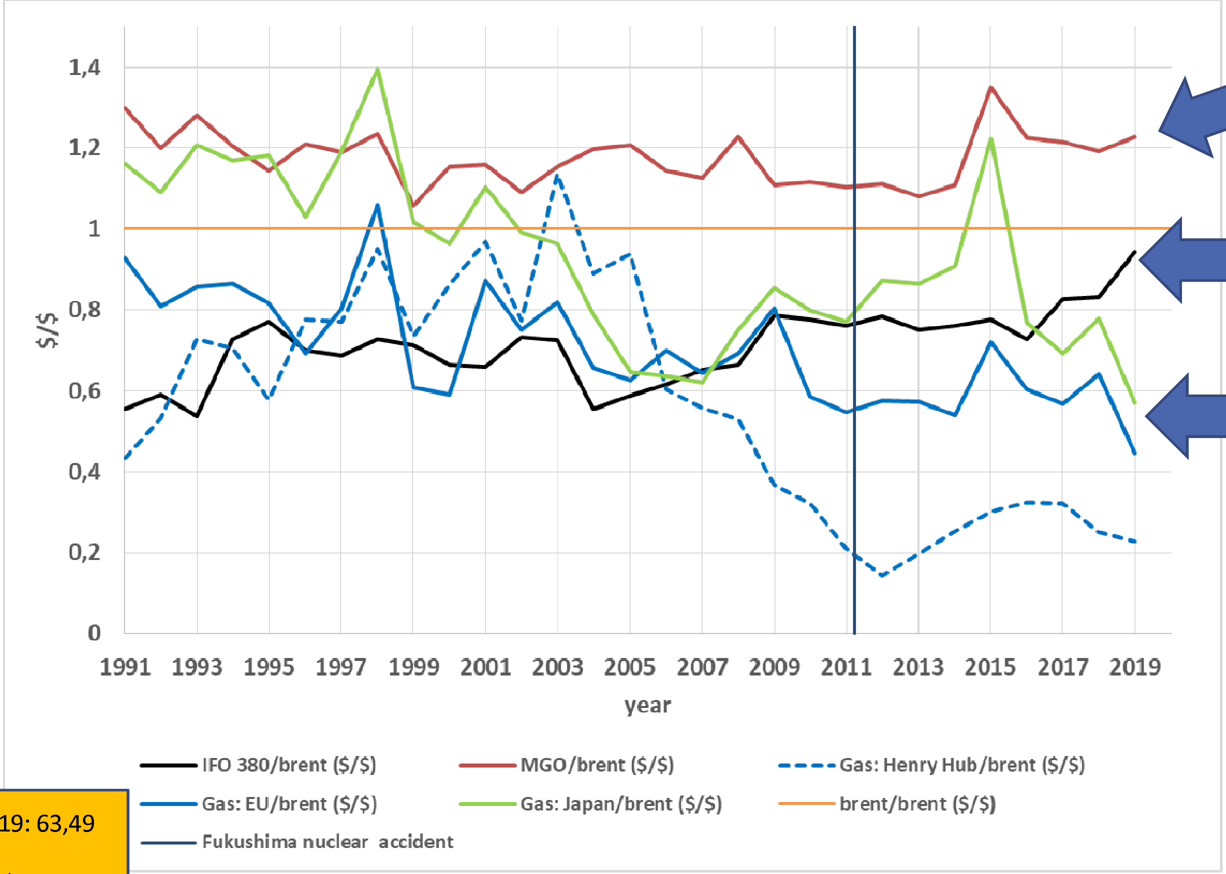
Learning from the Past
Understanding the Future



Refined product price is always above the raw

Heavy Fuel Oil $ rising

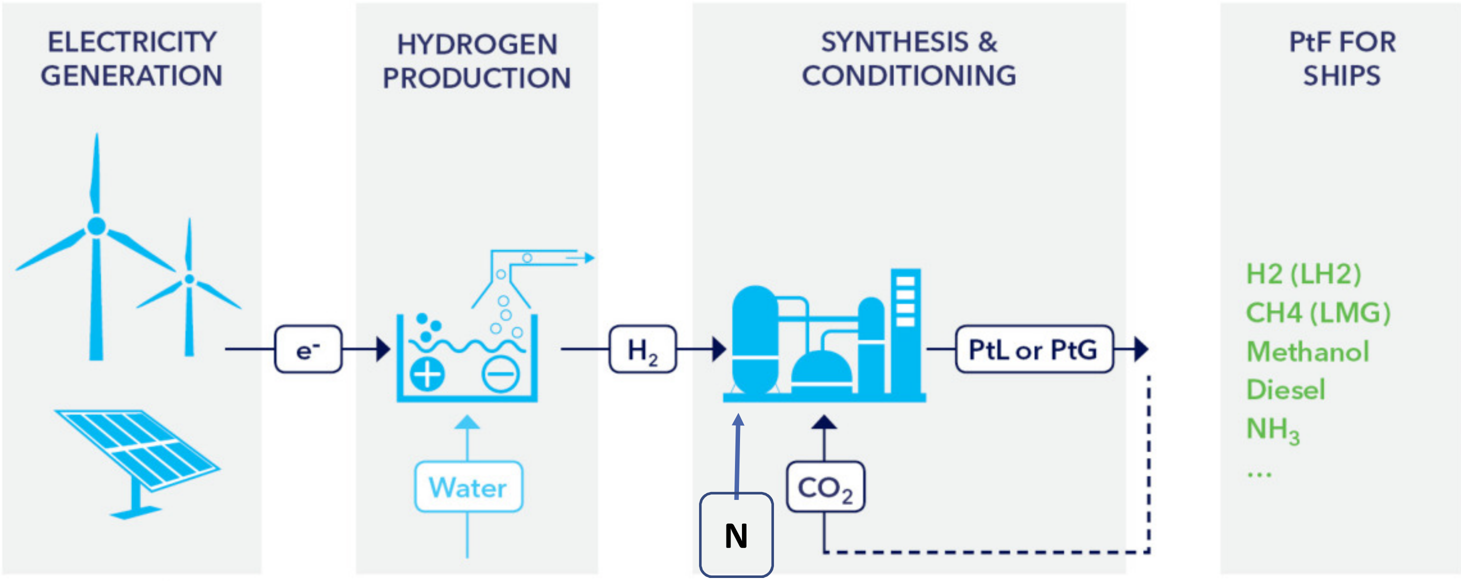
Gas prices fragmented due to transportation LNG will level prices

Continued discovery of gas reserves keeping price low

Crude oil Brent 19.09.2019: 63,49 $/barrel
(12 $/mmBTU; 463 $/t)

Hydrogen (H2) … Our Future Hope?

Power to X production principled



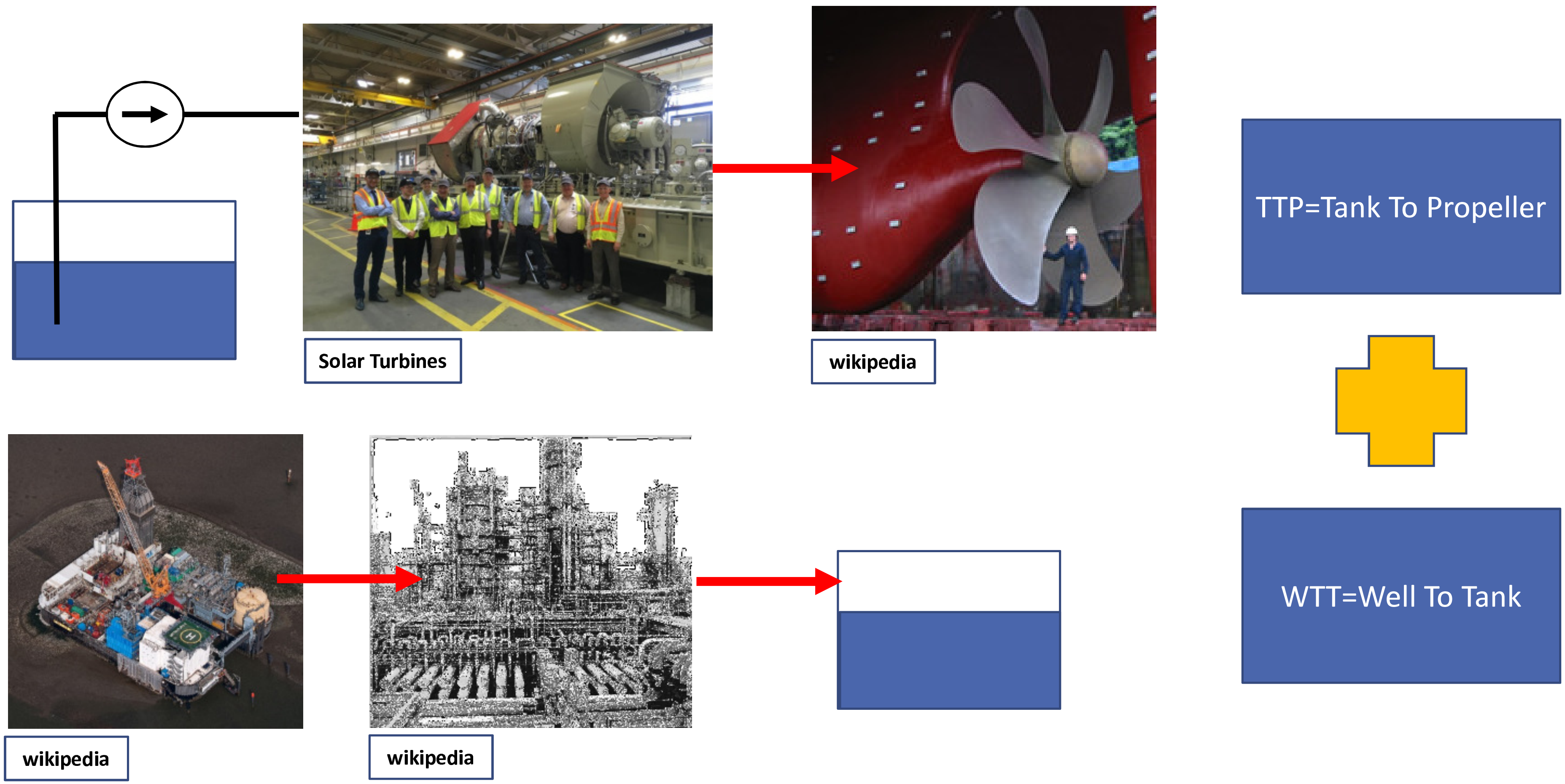
A carbon free fuel

A reminder for those who missed all their chemistry lessons in school

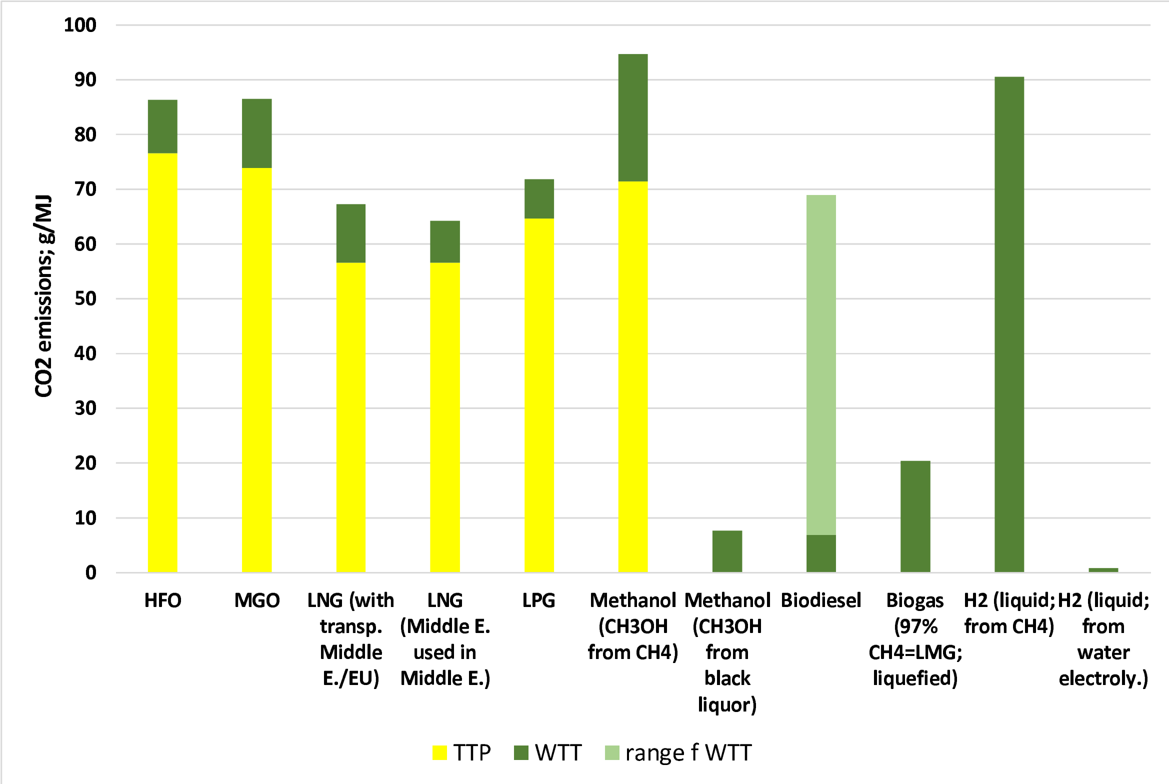
Name	Molecule
Hydrogen	H_2
Methane	CH_4
MGO, HFO	$C_{10}H_{22}$
Methanol	CH_3OH
Ammonia	NH_3

$C_{10}H_{22}$ (n-decan) used as model molecule for MGO and HFO

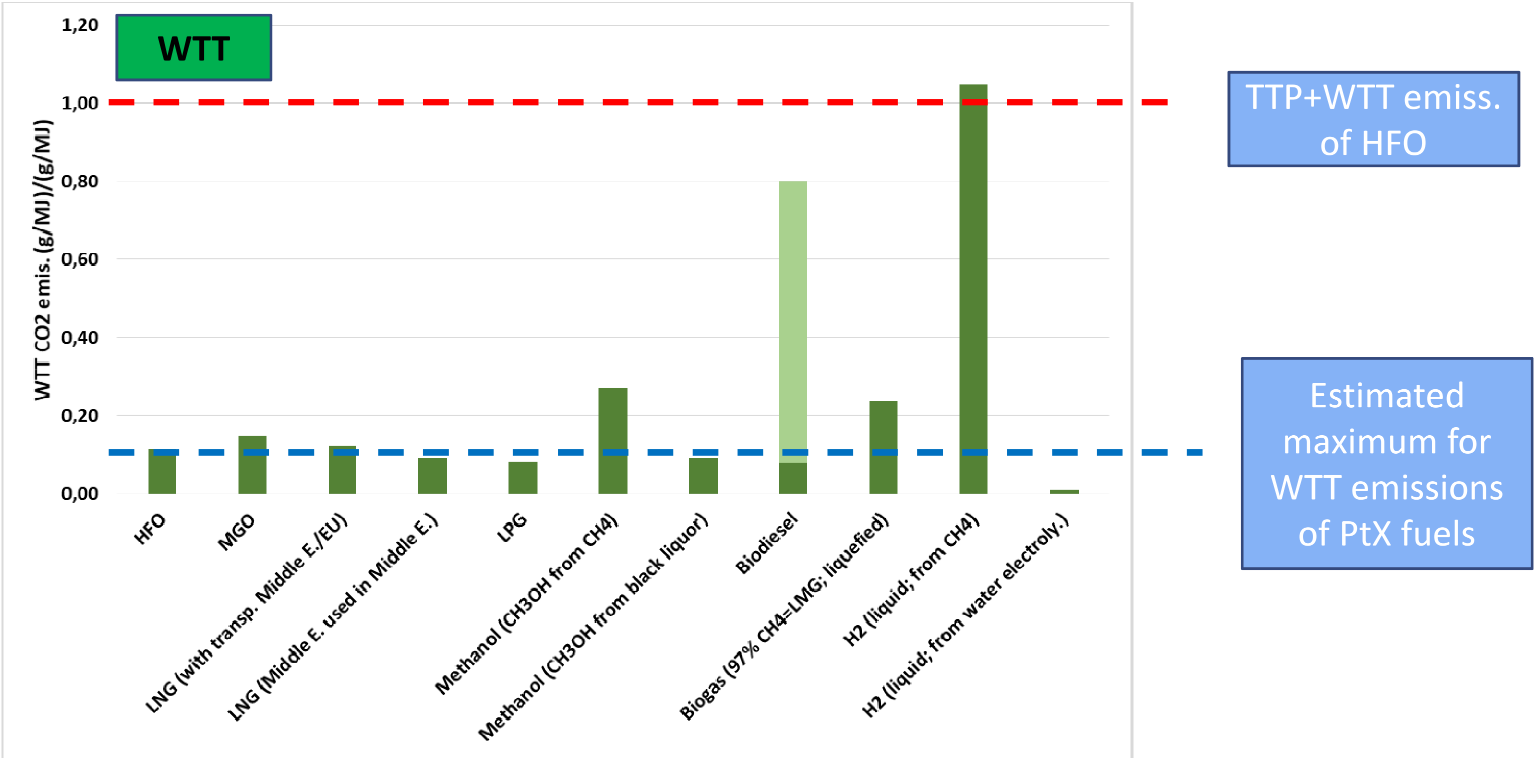
Why Power to X (PtX)?
- The two parts of CO2 emissions -



Well to Tank and Tank To Propeller CO2-emissions of possible ship fuels



Minimum reduction potential of Power to X fuels (PtX)



- PtX fuels have a CO_2 reduction potential of at least 90% of the HFO Tank to Propeller emissions
- Well to Tank (WTT) emissions of PtX fuels will be below the WTT emissions of their fossil twins

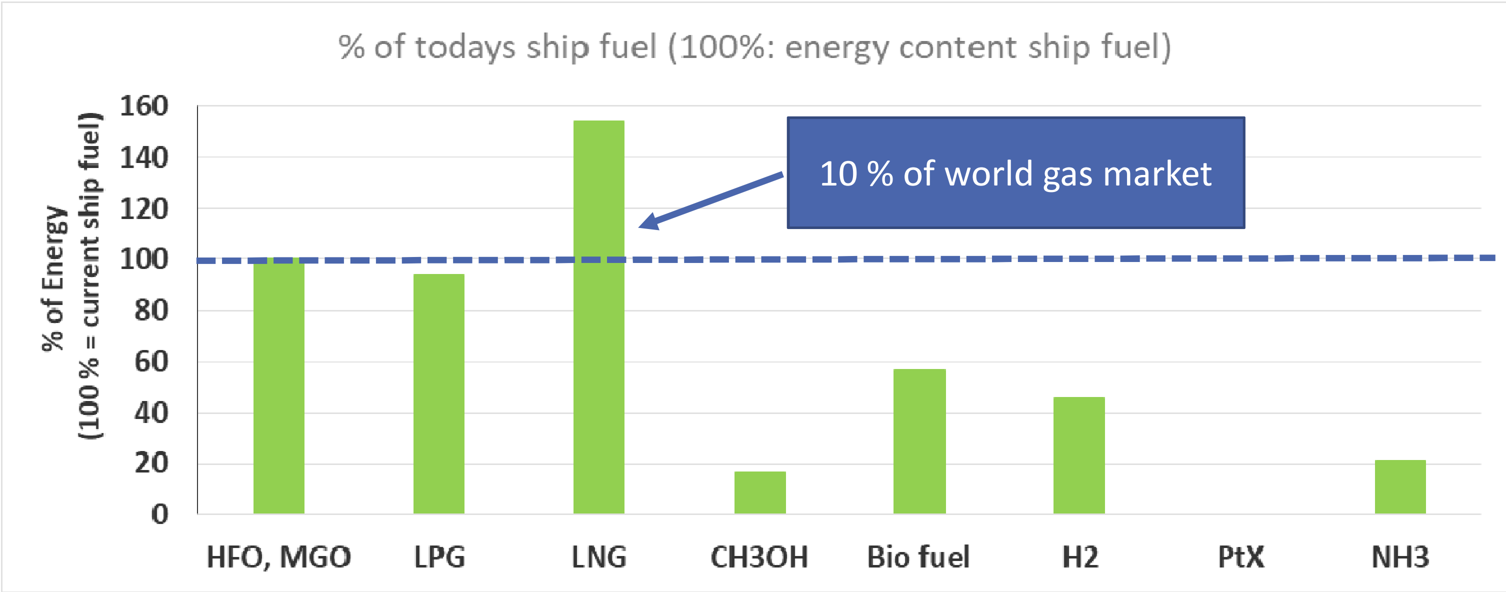
Current Availability of Marine Fuels

Today's Fuel

HFO,MGO	assumed consumption 2020 (330 Mio t/a)
LPG	production in 2015
LNG	production capacity end 2018 (approx. 10% of natural gas production)

Possible Future Fuel

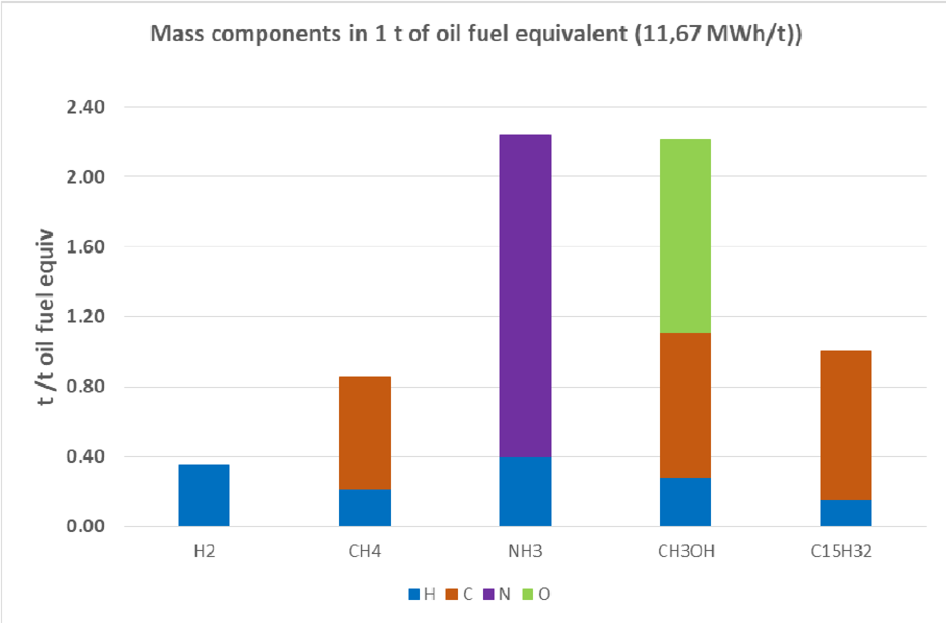
CH3OH (Methanol)	production capacity 2016
Bio fuel	production 2016 (Bio Diesel and straight vegetable oil)
H2 (Hydrogen)	production 2016
PtoX	Power to Liquid and Power to Gas: CO2+H2 --> fuel
NH3 (Ammonia)	Production 2016:



Natural Gas reserves and liquefaction capacity far exceed the demands of shipping

Ships are moved by <u>energy</u> not by <u>tons</u> of fuel

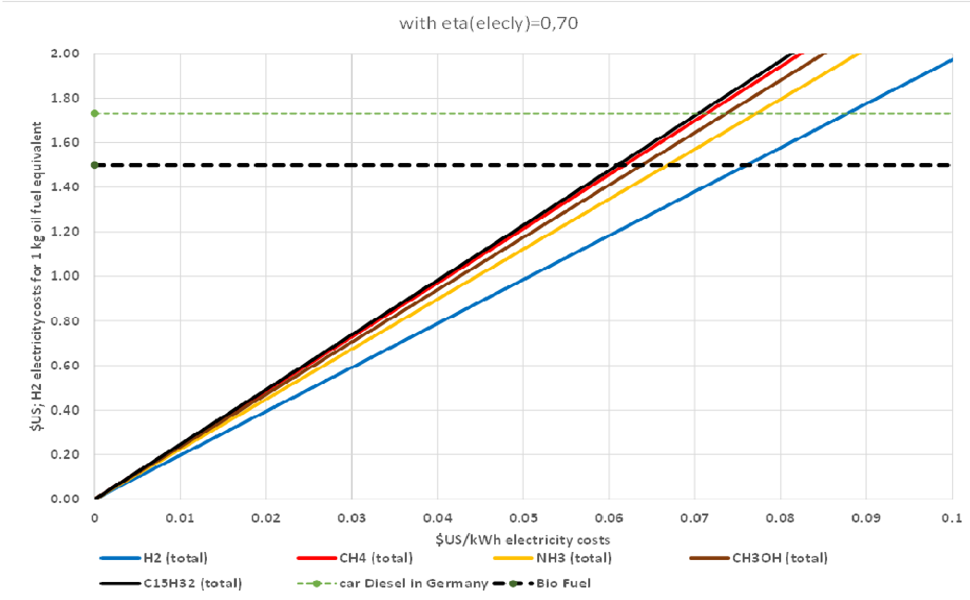
- Only the hydrogen needed for a given energy is relevant **not the hydrogen per ton.**
- **FT Diesel, LMG and Methanol** need **less hydrogen** than **hydrogen itself** to provide **11,67 MWh.**
- **Ammonia** need **more hydrogen** than **hydrogen itself** to provide **11,67 MWh.**



Hydrogen may be a great fuel for weight sensitive ships running on short routes such as ferries

Note that this figure does not consider the hydrogen may be needed for the process.

The lowest electricity costs for H2 production are related to hydrogen itself. The other fuels are close together



PtX technology presumes to solve future problems

PtX electricity costs highly influences the conclusion

Biofuel beats PtX because no electrolysis costs

Biofuel is limited due to the biomass required

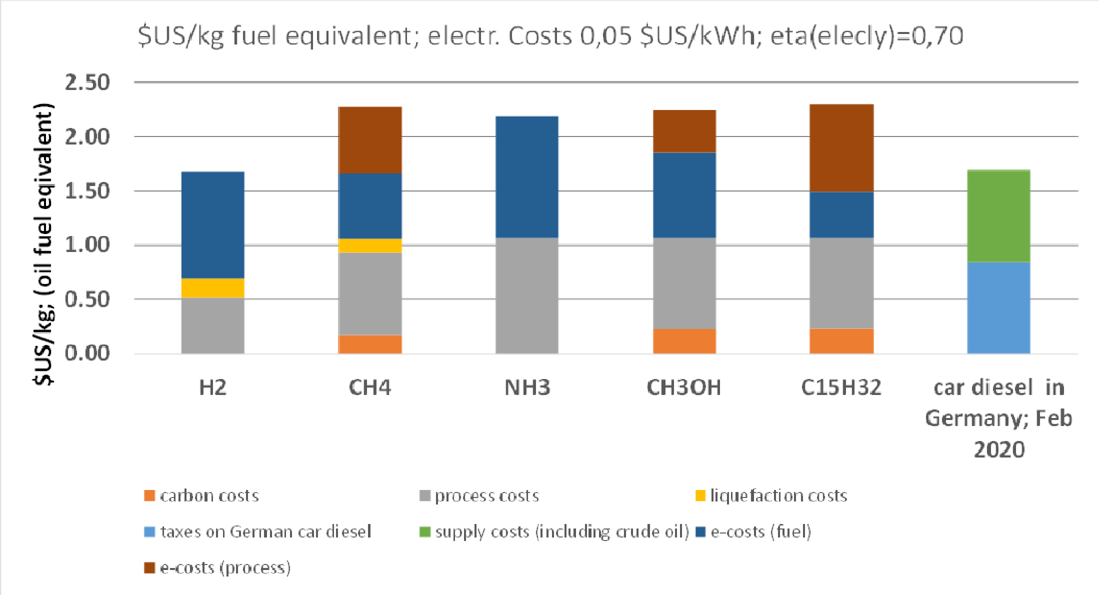
The major cost drivers
- Cost Analysis of PtX fuels -

Bio-gasoline and **LH2** are the **winners** among the PtX fuels.

FT Fuels (Diesel) and **LMG** (Liquefied Methane Gas) are nearly the same

Methanol and Ammonia are at the **upper end of costs**

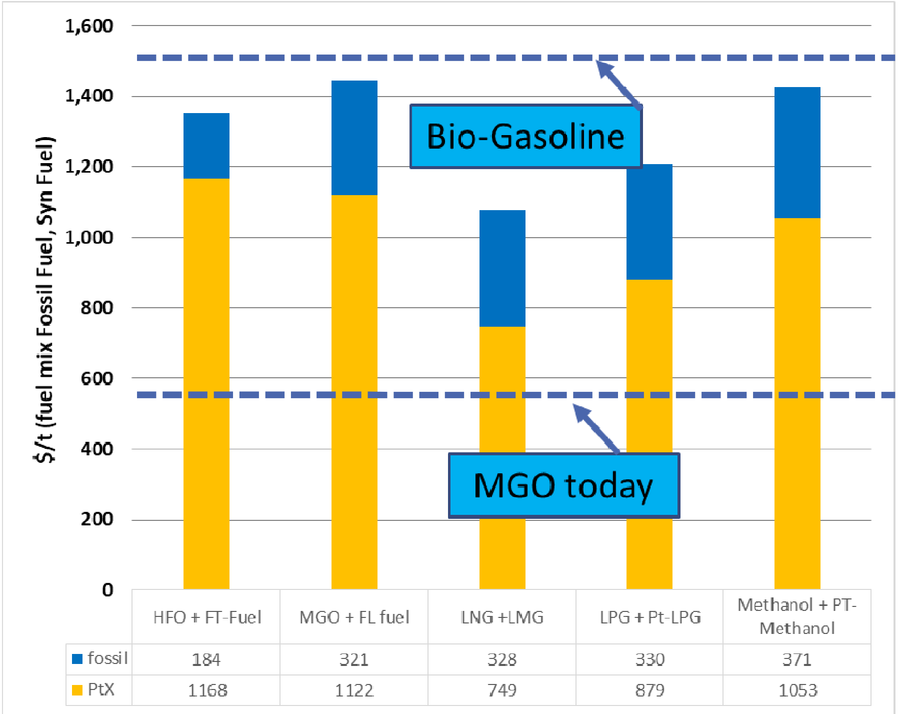
Methanol and Ammonia are in the same range as the other PtX fuels.



Electricity costs assumed: 0,05 US $/kWh

What does it mean to fulfil IMO 2050 target by drop in fuel only?

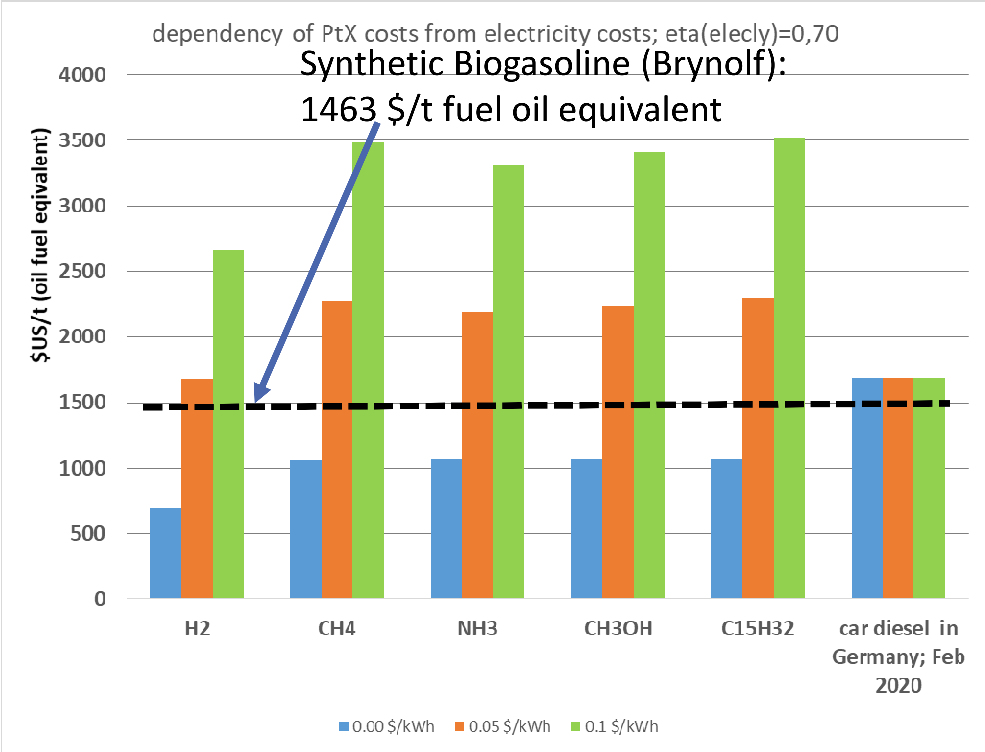
Target: reduce CO2 emissions by 50% of TTP emissions



Potential cost of a fuel mix between fossil fuel and synthetic fuel (50% TTP CO2 reduction, electricity costs 0,05 US$/kWh);
Data based on DENA, Brynolf (2018); LNG liquefaction costs from DENA; LPG: costs assumed to be equal to CH4 gas; electricity costs for hydrogen production: 0,05 US$/kWh

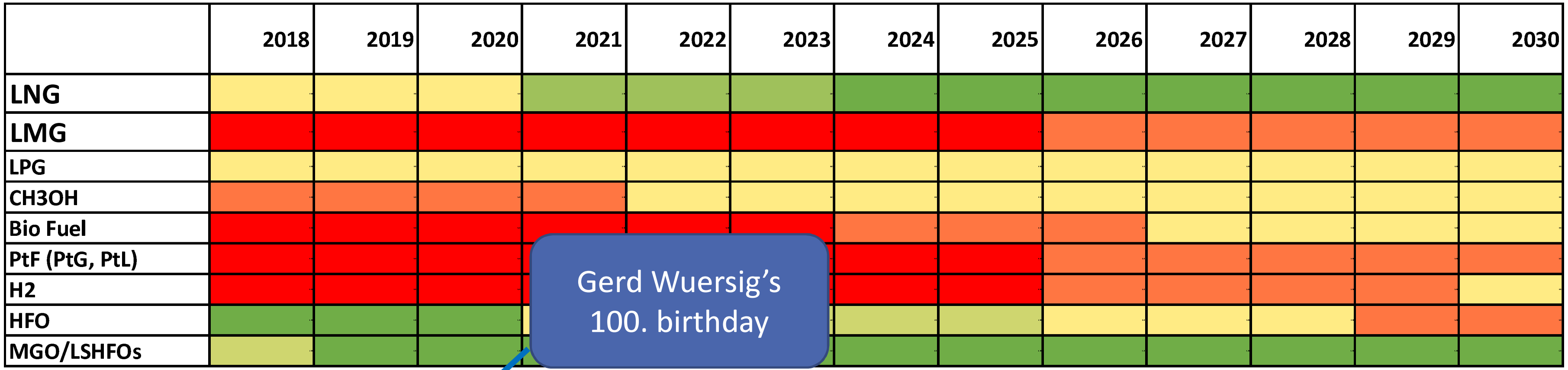
What will be the best ship fuel beyond 2030? The race is open!

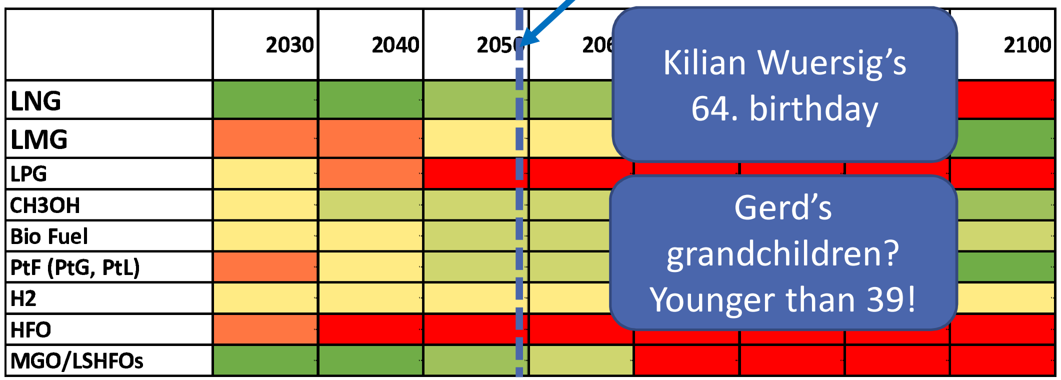
total costs $/t oil fuel equiv (e-costs, plant costs, CO2-costs, liquefaction costs (H2 and CH4))						
E-costs $/kWh	H2	CH4	NH3	CH3OH	C15H32	car diesel in Germany; Feb 2020
0.00	695	1058	1064	1064	1064	1690
0.05	1681	2271	2186	2240	2294	1690
0.10	2667	3485	3309	3415	3524	1690



Total costs (fuel equivalence to oil) for of PtX for different electricity costs for hydrogen production

GMW Consultancy Predictions for fuel supply in deep sea shipping



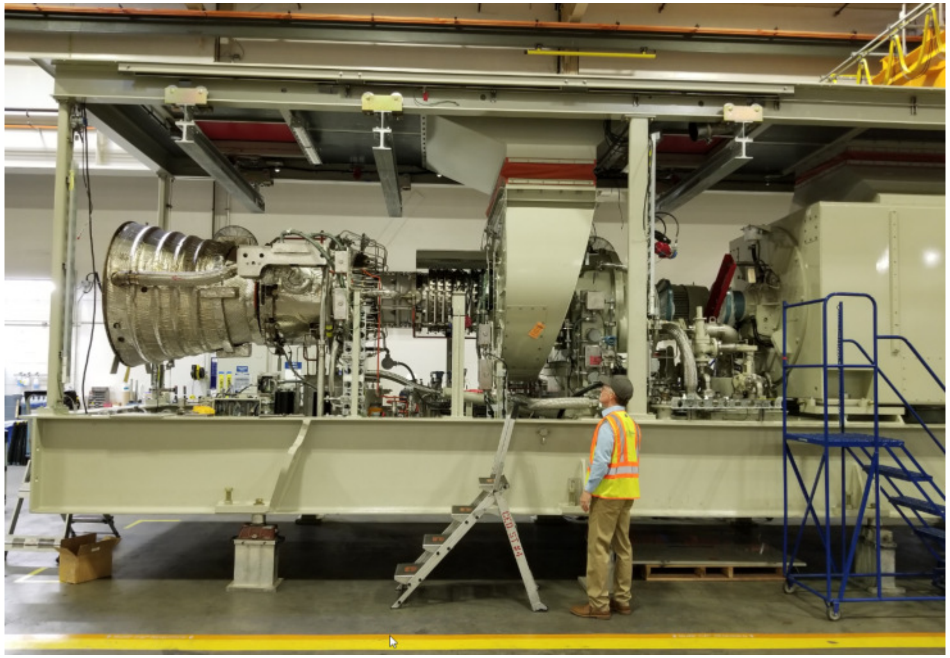


- HFO phased out over time
- MGO and may be LSHFO survive the decade
- LNG is increasingly used and solely substituted by LMG
- LPG may be used also
- Hydrogen plays no role and a minor role beyond 2030
- PtF+PtL (includes LMG) starts to be market relevant at the end of the decade
- Methanol and Biofuel may play a role

Considering future fuels today
- what propulsion technology can be selected today? -

Answers to some questions on Gas turbines

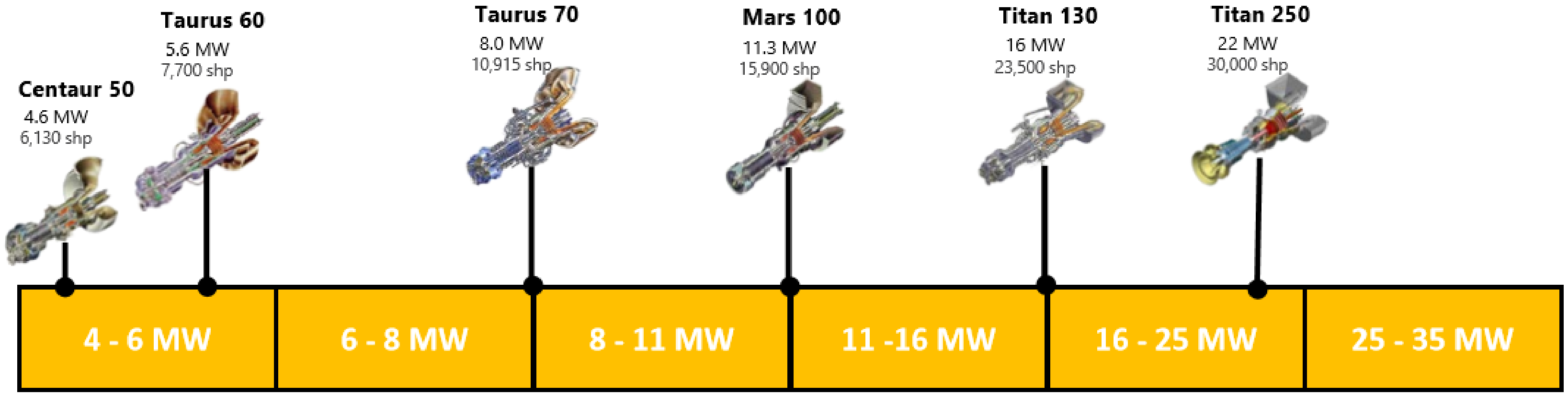
- Can burn different fuels?
- Can handle varying methane numbers?
- Can produce significantly lower emissions?
- Can compete efficiently?
- Can reduce volume and weight to be more competitive?



How "green" future fuels and gas turbines?

	Emission	HFO; 0,5 LSHFO	0,1 MGO	MGO (FT process)	LNG (Liquefied Natural Gas)	LMG (Liquefied Methane Gas)
Medium speed piston engines	NOx	Tier III, SCR or EGR	Tier III, SCR or EGR	Tier III, SCR or EGR	Better than compliant	Better than compliant
	SOx	Scrubber	compliant	No SOx	No SOx	No SOx
	PM	high	high	high	Very low	Very low
	CO2	high	high	Very low	Low (methane slip)	Low (methane slip)
Combined cycle gas/steam turbines (electric drive)	NOx	Not applicable	Better than compliant	Better than compliant	Better than compliant	Better than compliant
	SOx	Not applicable	compliant	No SOx	No SOx	No SOx
	PM	Not applicable	low	low	Very low	Very low
	CO2	Not applicable	high	Very low	Low (nearly no methane slip)	Very low (nearly no methane slip)

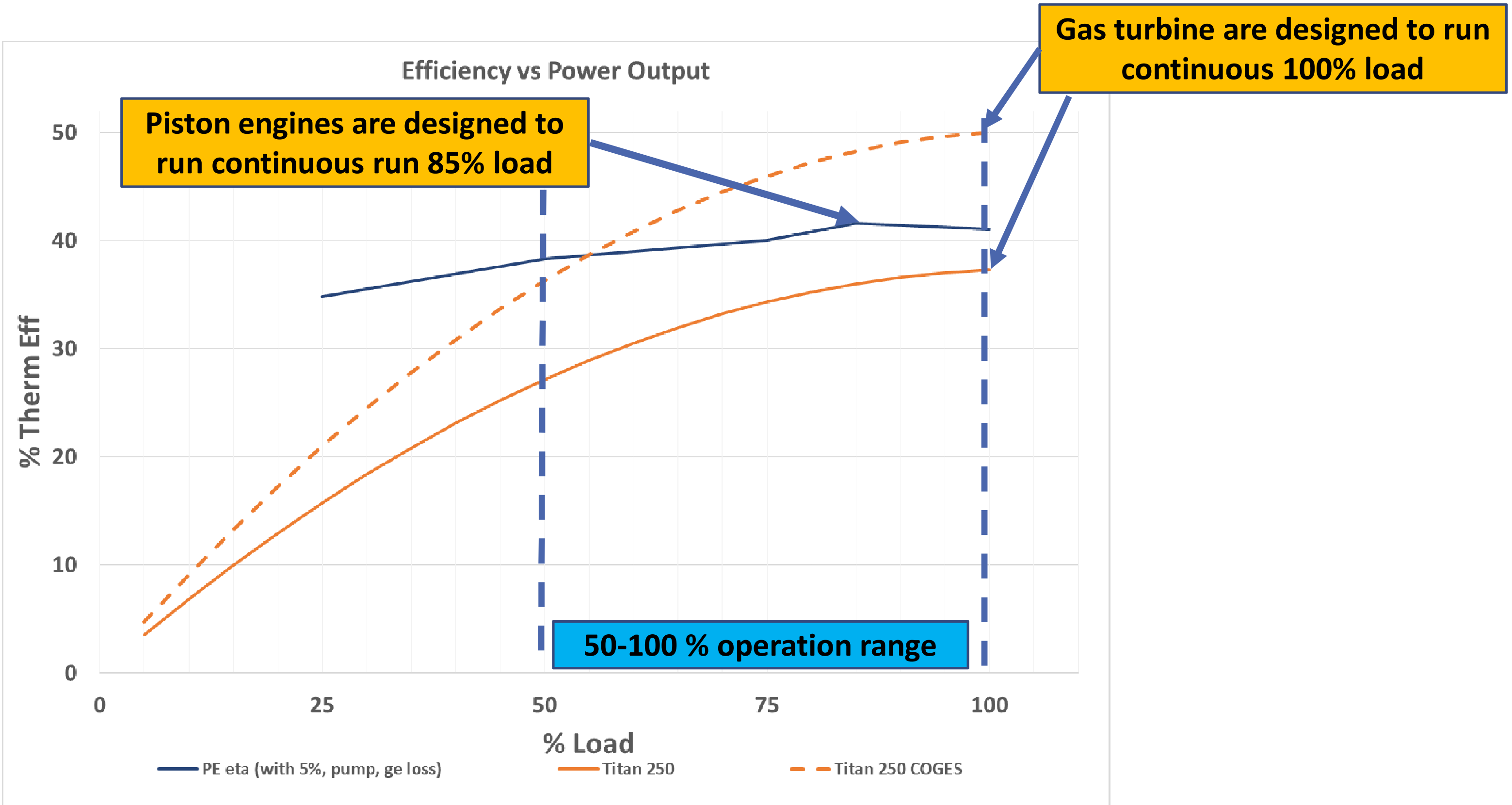
Proper selection can optimize efficiency



Great distribution of power
Allows right size selection for best operational profile fit

Between 50-100% Gas Turbines maintain efficiency

- Optimize the ship's power range with the correct turbines
- Combined Cycle systems can increase efficiency further

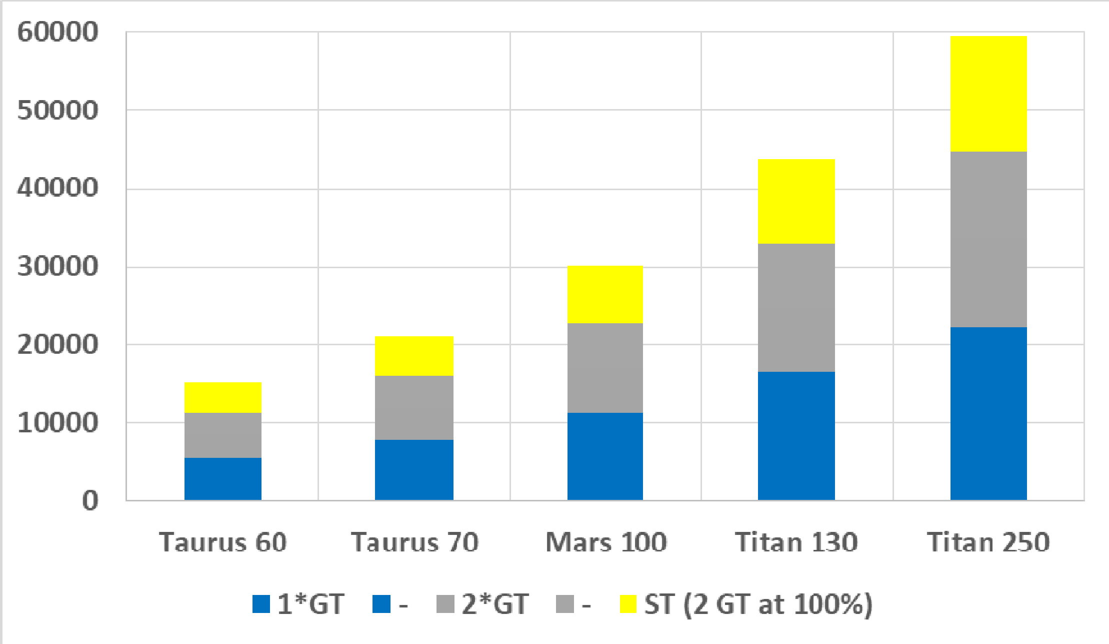


Gas turbines run on nearly constant efficiency between 50 to 100 % Load

2 GT running at 100 % load

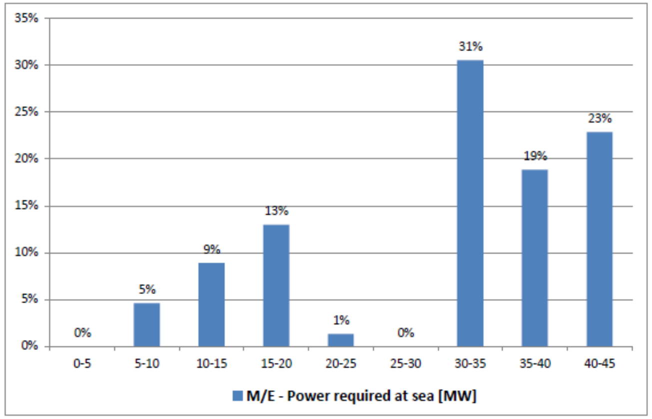
5670 to 15082 kW (2*Taurus 60)

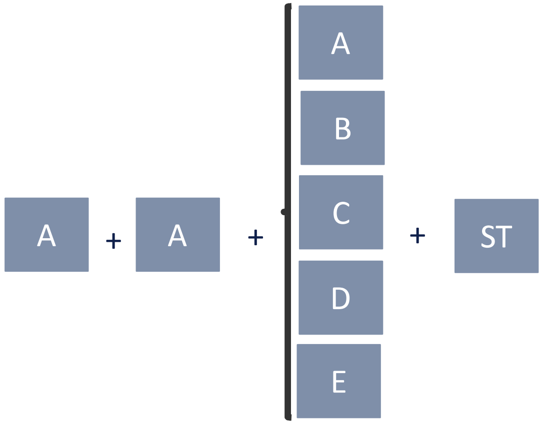
22330 to 59397 kW (2*Titan 250)

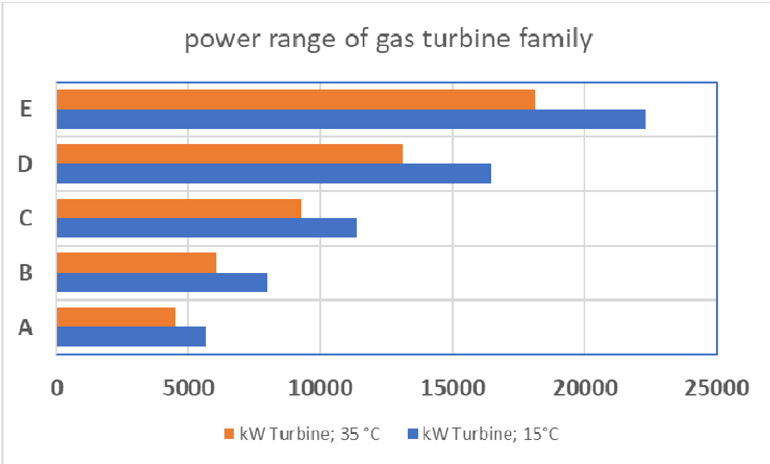


2*Taurus 60+1*ST: 3700 kW → 15000 kW at approx. 41 % efficiency
2*Titan 250+1*ST: 14900 kW to 59400 kW at approx. 51 % efficiency

Creating a PERFECt ship system with a gas turbine "family"





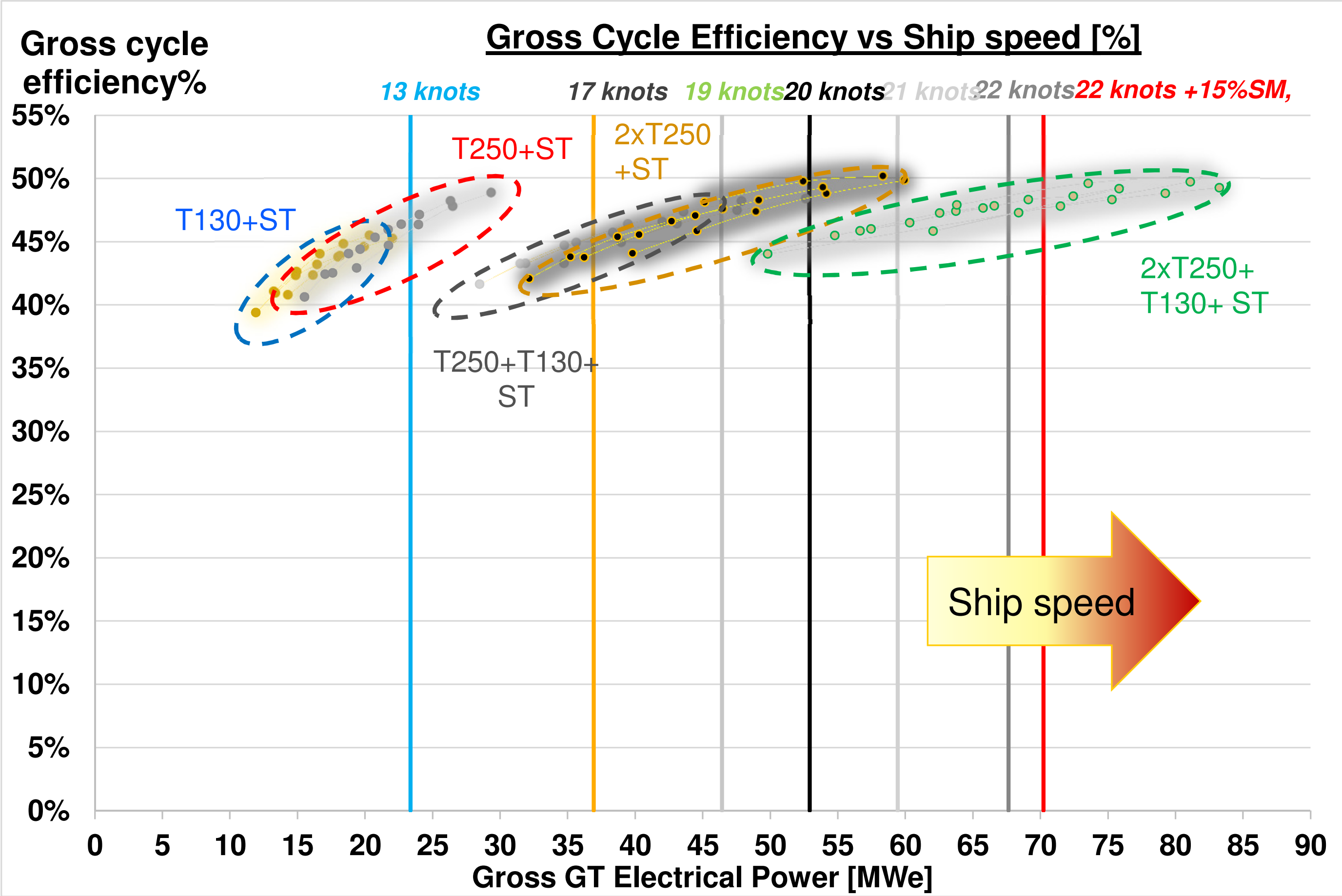


Start with load demand of ship

Choose best fit of power to meet demand

Best efficiency also means best CAPEX selection for the ship

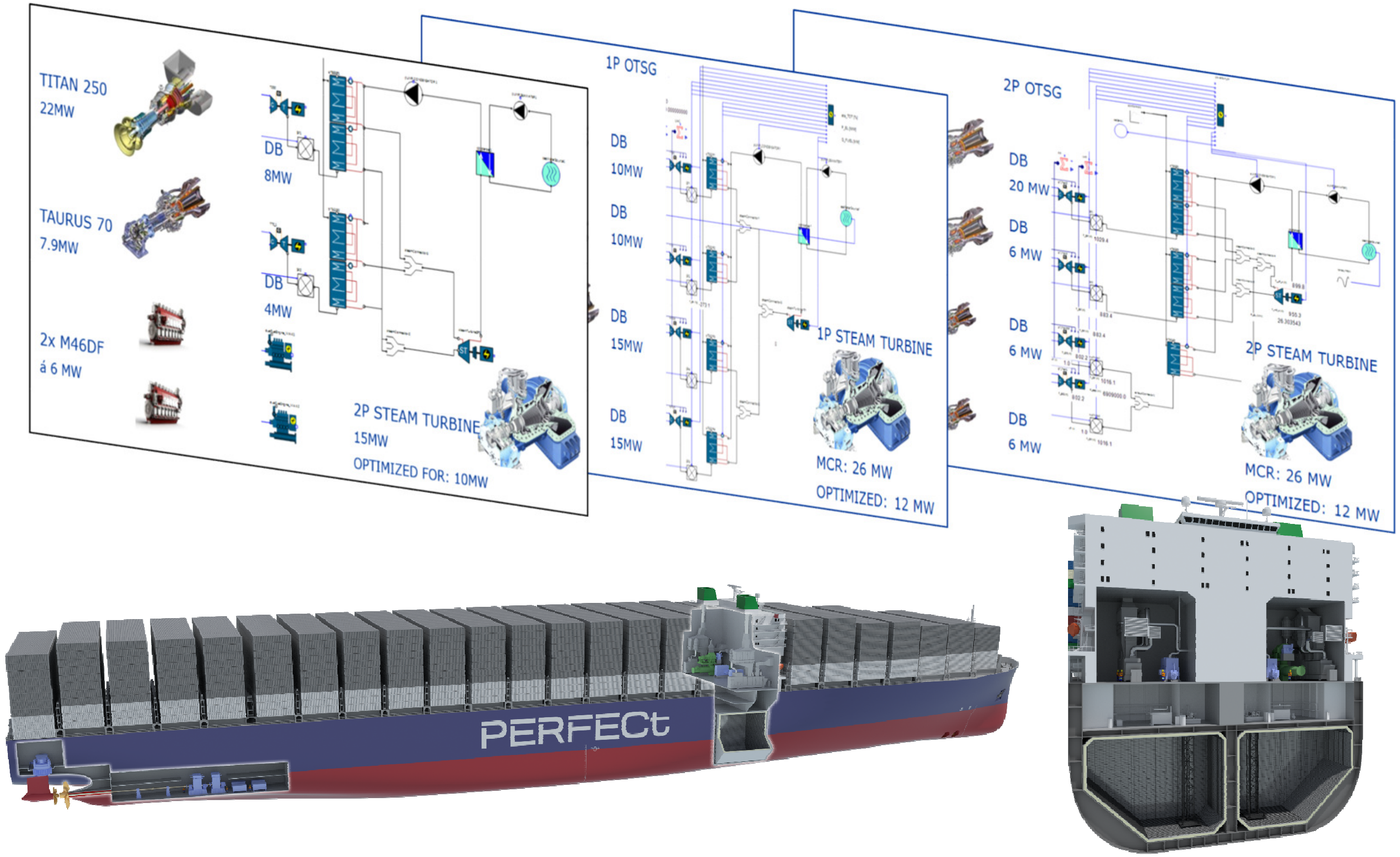
Optimize power configuration with ship



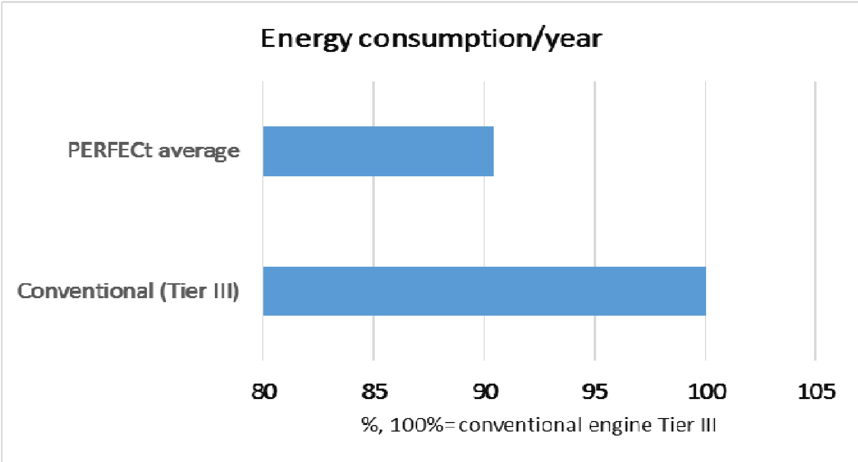
Developing the PERFECt Ship

**** Video PERFECt Ship ****

SIMULATION EASES SELECTION: COMPARISON OF VARIANTS



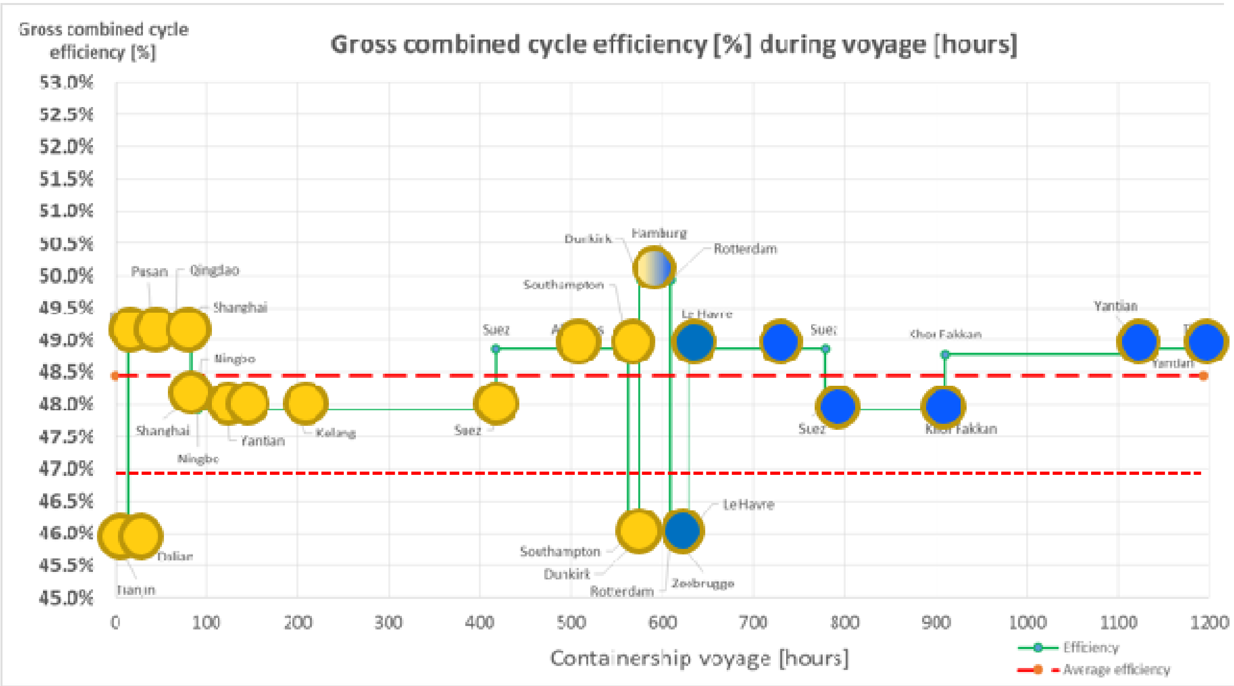
PERFECt Ship: nearly 10% lower fuel energy consumption



- Propulsion efficiency (average/year)
  - PERFECt Ship: 48,1 %
  - Conventional ship: 46,5 %
- PERFECt ship: better efficiency

- Fuel efficiency (consumption: average/year)
  - Conventional ship: 100 %
  - PERFECt Ship: 90,4 %
- PERFECt ship: **9,6%** less consumption
  - 10,9 %/TEU reduction

PERFECT Ship concept
- High efficiency at all load conditions-



PERFECt Ship

Conventional Ship

The PERFECt container ship project evolved to the cruise ships

**** Video from Solar Turbines ****

Power density could be a game changer

More revenue generating space
More fuel tank space

Gas Turbines and Steam

1 steam turbine (16 MW) 33% of GT power

3* GTs 47 MW

- 1 Taurus 70, 1 Titan 130, 1 Titan 240
- **Weight: 285 t**

Piston engine with Steam

1 steam turbine (6,3 MW) 10% of engine power

4*14,2 MW (100% rating)

- **Weight: 792 t**

Fast Ferries can benefit further

HSC: weight sensitive

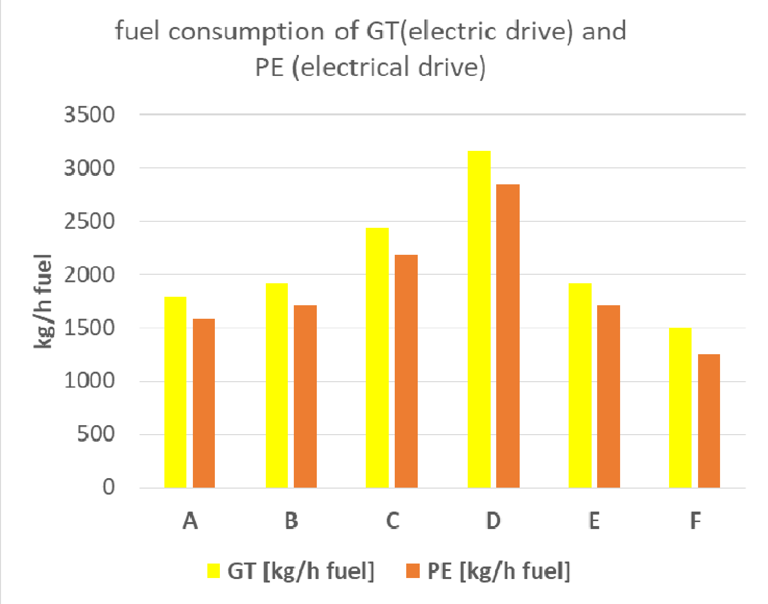
- Constant power equal to max needed power:
- Part load only close to harbor;
- Speeding up to max speed and keep this power level for crossing.
- Gas Turbine (GT) run on 100 % continuous load
- Piston Engine (PE) run on 85% continuous load
- PE are oversized because they sized for 100% load but run on 85%

Source: wikipedia

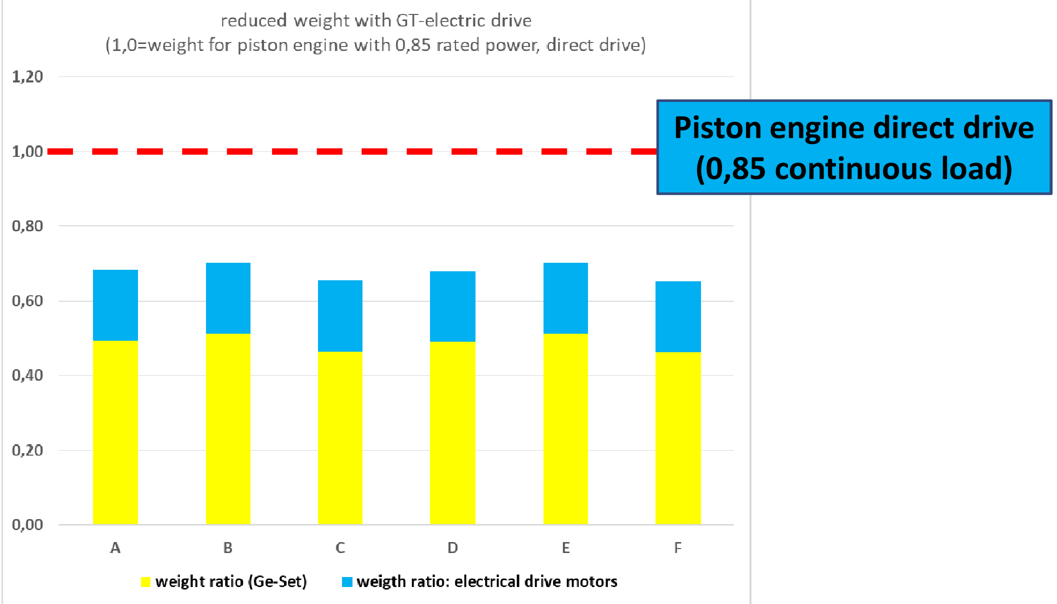
HSC (“Halbgleiter)

Gas Turbines provide weight savings

While GT fuel consumption is approx. 10% more



There is a approx. 30% weight saving



Actual HSC vessels could save fuel therefore reduce emissions

case	A	B	C	D	E	F
built	2005	2004	2004	2013	2010	2003
length	85	126	86,6	99	116,26	98
passengers	810	1291	774	1024	1400	0
cars	154	341	238	150	357	0
water jets and/or propellers	4	3	4	2	4	2
no engines	4	4	4	2	4	4
kn	39	36	45	51	38	49
engine weight [kg]	341190	426488	473875	41278	431226	120556

Example ships

case	A	B	C	D	E	F
	no GT Ge-Set	no GT Ge-Set	no GT Ge-Set	no GT Ge-Set	no GT Ge-Set	no GT Ge-Set
Taurus 60	1	0	0	1	0	1
Taurus 70	0	1	0	0	1	0
Mars 100	0	0	0	0	0	0
Titan 130	0	0	1	0	0	1
Titan 250	1	1	1	2	1	0
kW total	27999	30294	38779	50328	30294	22120
kW piston engines (rated power)	32940	35640	45622	59209	35640	26024
GT [kg/h fuel]	1790,4	1911,0	2433,7	3151,5	1911,0	1502,0
PE [kg/h fuel]	1578,5	1707,9	2186,3	2837,4	1707,9	1247,1

GT and PE propulsion system for comparison

- PE run on 85% rated power
- GT run on 100% rated power
- Electric drive for GT and PE systems

Concluding remarks

Current strategies will make achieving emission goals difficult

Slow steaming, exhaust cleaning, fuel tuning

Future fuels will have a significant role in meeting goals for CO2 reduction

Economics will dictate the evolution of future fuels

The fuel of the future will not be the fuel of today!

Gas Turbines when selected properly can exceed goals

Fuel flexibility

Low Emissions

Energy dense

Efficiency

Allowing sustainability goals to align with profitability goals!