

Ken Goh - **KNUD E. HANSEN** Australia

NOVEL HYDROGEN FUELLING FOR SMALL SHIPS

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SHIP DESIGN SINCE 1937

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KNUD E. HANSEN A/S

- Ship design, engineering, HVAC & ShipSpace VR
- Concept design of highly specialised vessels
- Vessels types include Cruise, Ferries, Ro-Ro, Icebreakers, Research, Offshore wind, Fish farming
- ShipPax & Significant Ships awards
- 90 staff, offices in Denmark, USA, UK, Spain & Australia



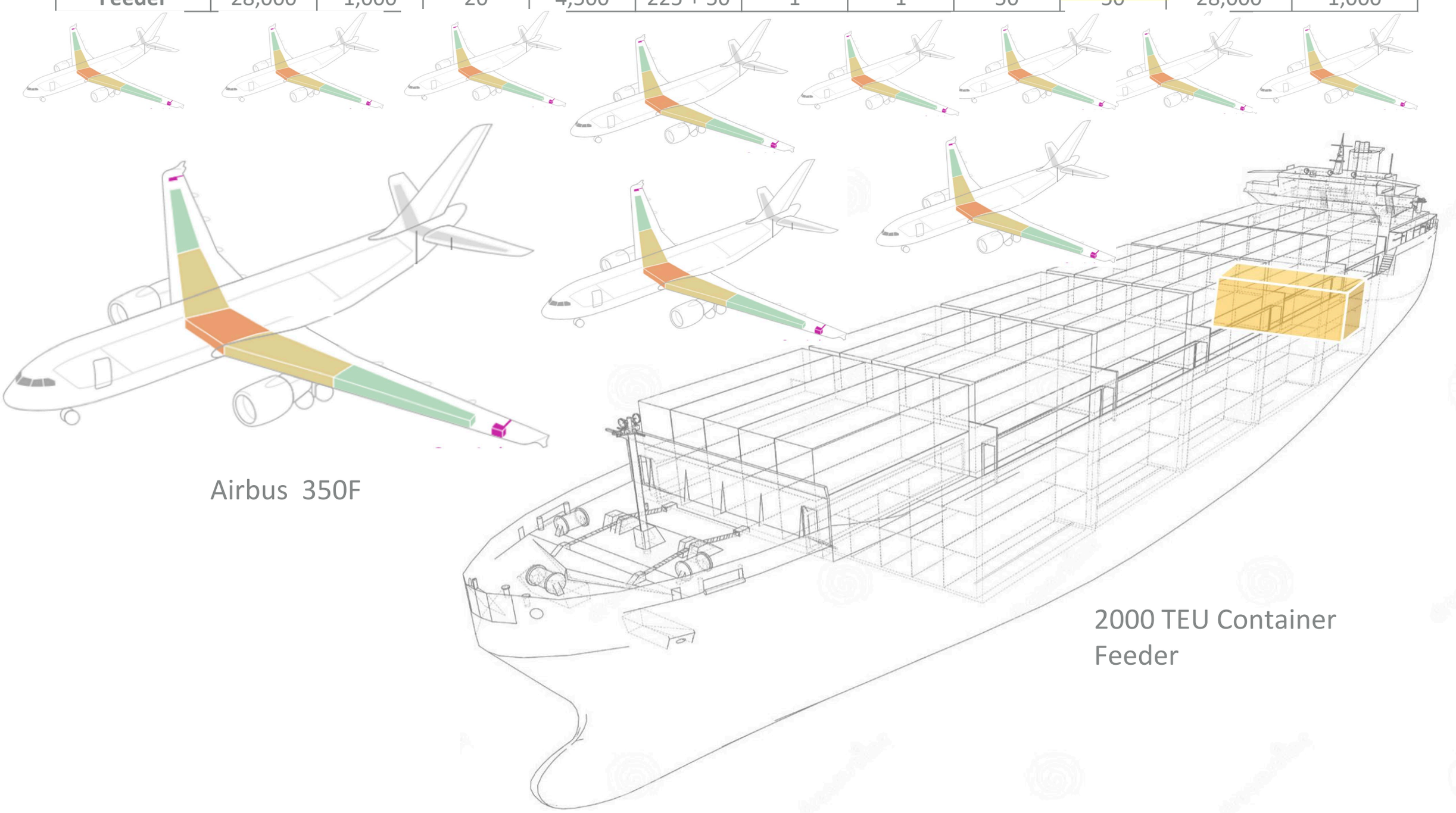








	Cargo	Fuel	Speed	Range	Time	Fleet	Voyages	Unit cost	Fleet cost	Cargo shipped	Fuel consumed
	tons	tons	kn	nm	hr	No.	No.	MUSD	MUSD	tons	tons
Airbus 350F	110	100	450	4,500	10 + 2	11	23	350	3,850	28,000	25,000
2000TEU Feeder	28,000	1,000	20	4,500	225 + 50	1	1	50	50	28,000	1,000



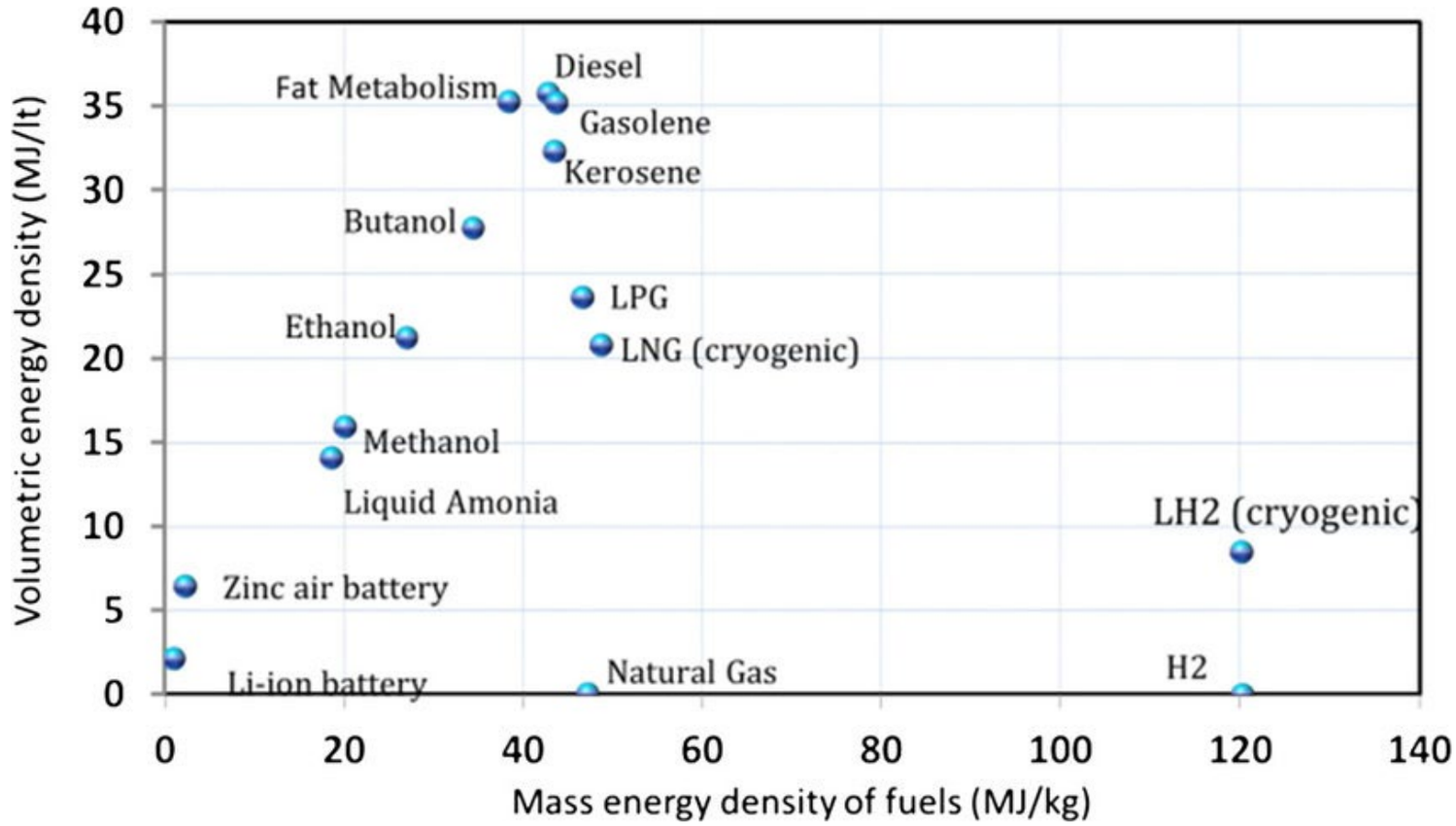
Airbus 350F

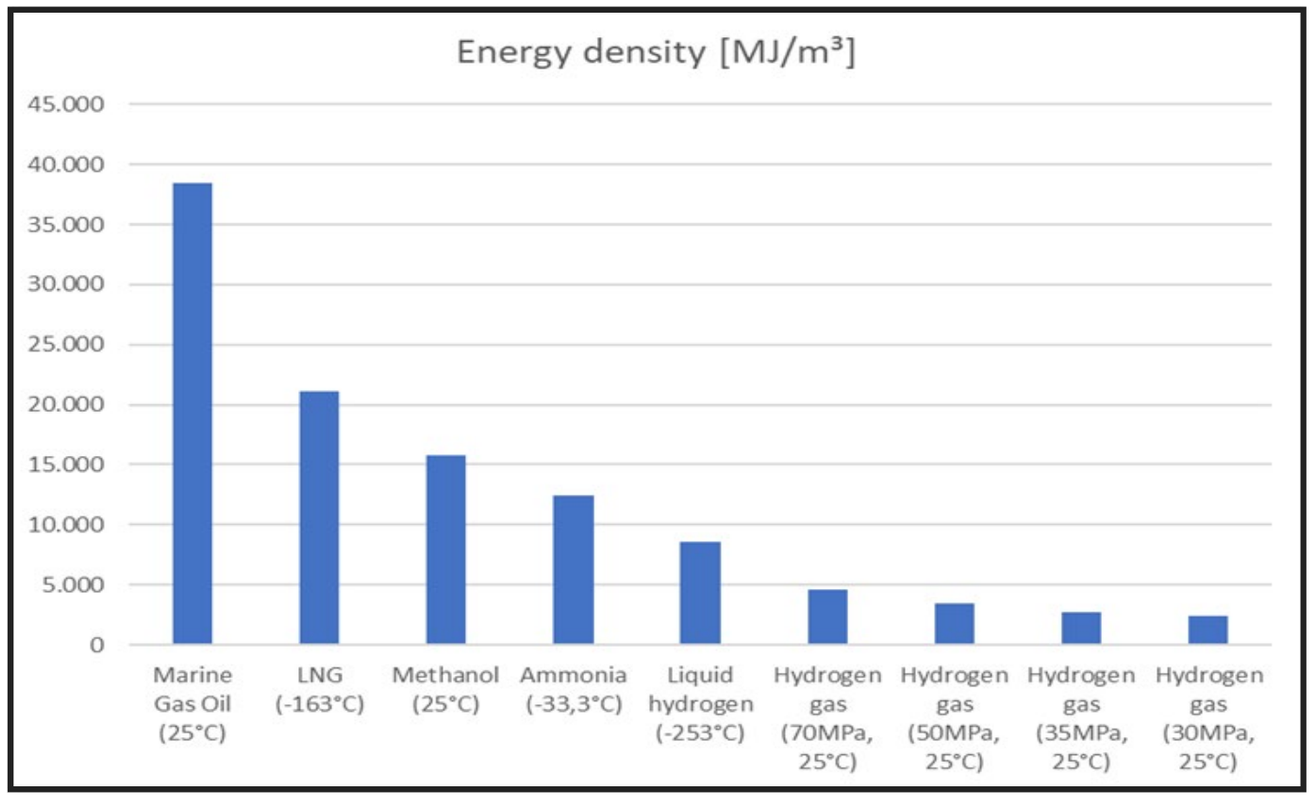
2000 TEU Container Feeder

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ALTERNATIVE FUELS

- Compared to fossil fuels:
- MeOH & NH3 only half energy density
- H2 = 3 x energy density per <u>weight</u>
- LH2 = ¼ x energy density per <u>volume</u>
- 500barH2 = 1/10th x energy density per <u>volume</u>

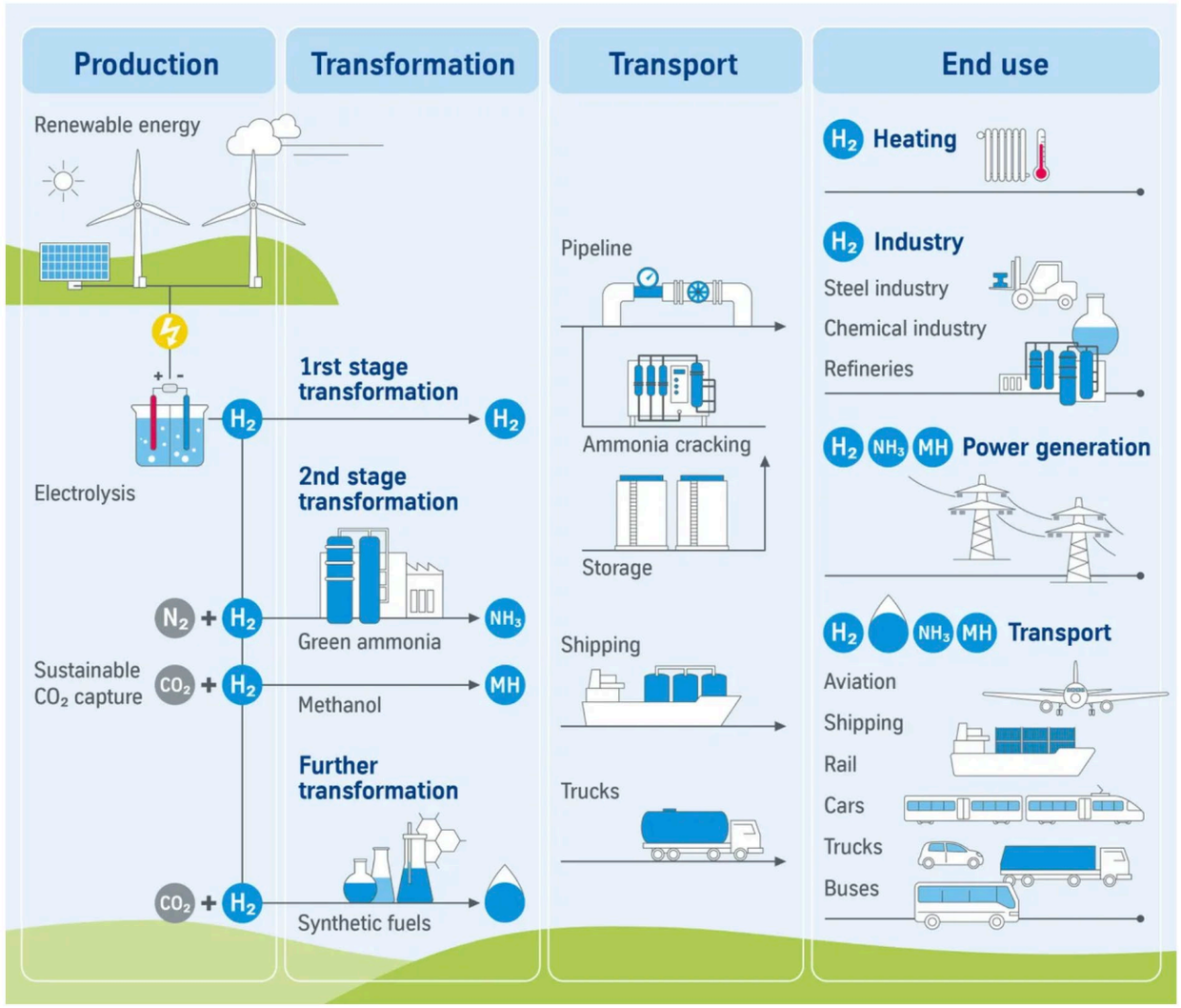




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ALTERNATIVE FUELS

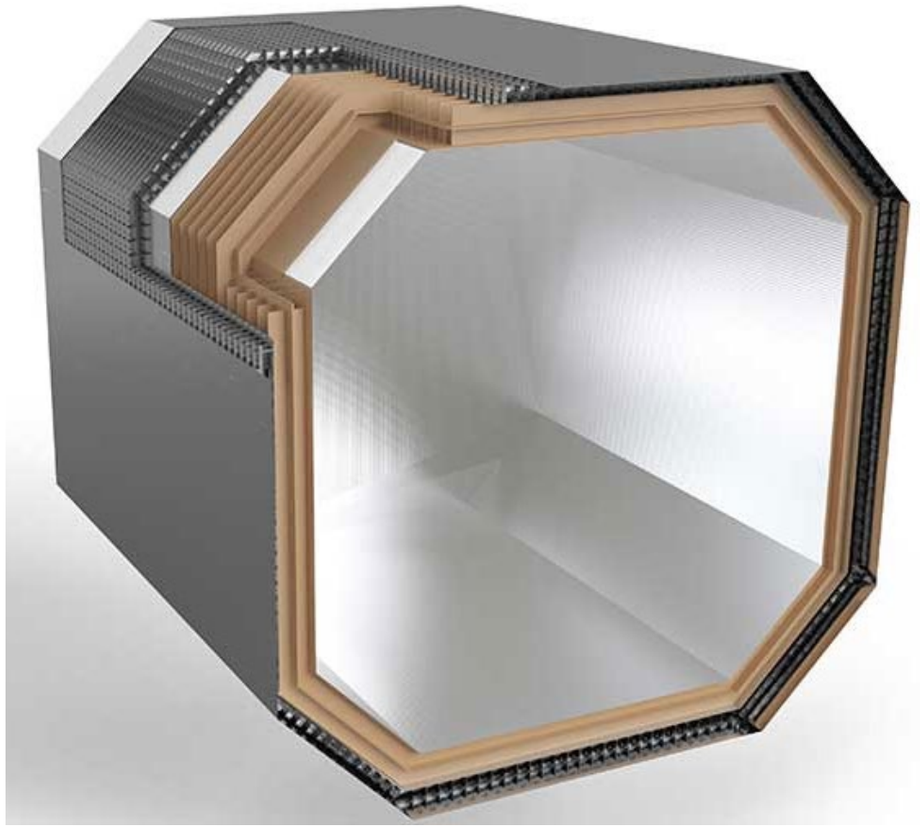
- MeOH & NH3 need H2 feedstock
- Energy ratio or well-to-tank is key to future costs
- Large variation in cost predictions



Fuel	Energy density (MJ/kg)	Energy to produce (MJ/kg)	Well-to-Tank Efficiency	2030 Cost (USD per ton)	2030 Cost (USD per GJ)
Diesel	43	54 (Heat)	80 %	500 - 1,000	12 - 23
Green Methanol (MeOH)	20	39 (Elec.)	50 %	700 - 1,200	35 - 60
Green Ammonia (NH3)	19	43 (Elec.)	45 %	1,000 - 1,500	53 - 79
Green 500 bar Hydrogen (500bar H2)	120	170 (Elec.)	70 %	2,250 - 4,500	19 - 38
Green Liquid Hydrogen (LH2)	120	185 (Elec.)	65 %	2,500 - 5,000	21 - 42

FUEL STORAGE





Fuel	Storage Temp. (°C)	Storage Pressure (bar)	Tank fuel space ratio	Challenges	Tank type
Fuel Oil (HFO)	50 - 60	1	1.2	Heat	Integral, coated
Liquified Natural Gas (LNG)	-169	1	3 - 4	Boil-off	Pressure, membrane
Green Methanol (MeOH)	5 - 40	1	2 - 3	Corrosive, gas	Stainless steel, cofferdams
Green Ammonia (NH3)	-33	1	3 - 4	Toxic gas, boil-off	Stainless steel, cofferdams, insulated
Green 500 bar Hydrogen (500bar H2)	5 - 40	500	15 - 20	HP, explosive	Unitary carbon fibre wrapped
Green Liquified Hydrogen				Boil-off	Unitary pressurised

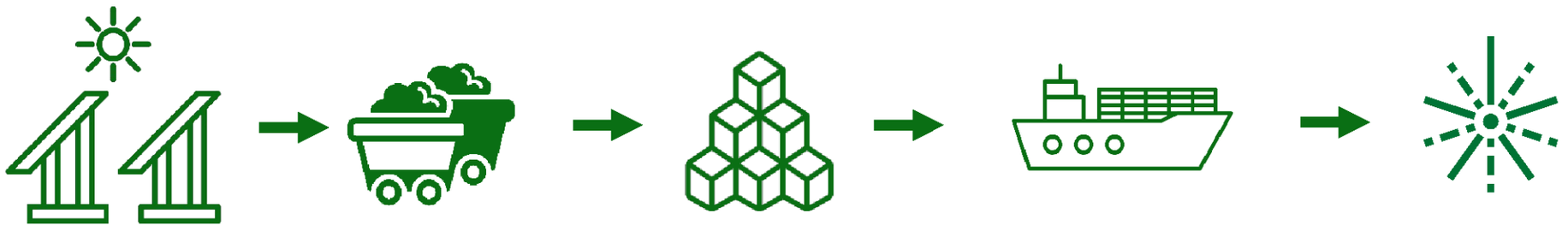
GREEN HYDROGEN PRODUCTION

- Green Hydrogen using Electrolysis



Green power → **Electrolysis** (requires pure water + electricity in the same place) → **Specialised storage** → **Inefficient distribution** → **Consumer**

- Green Hydrogen using ***Hyrea Process***

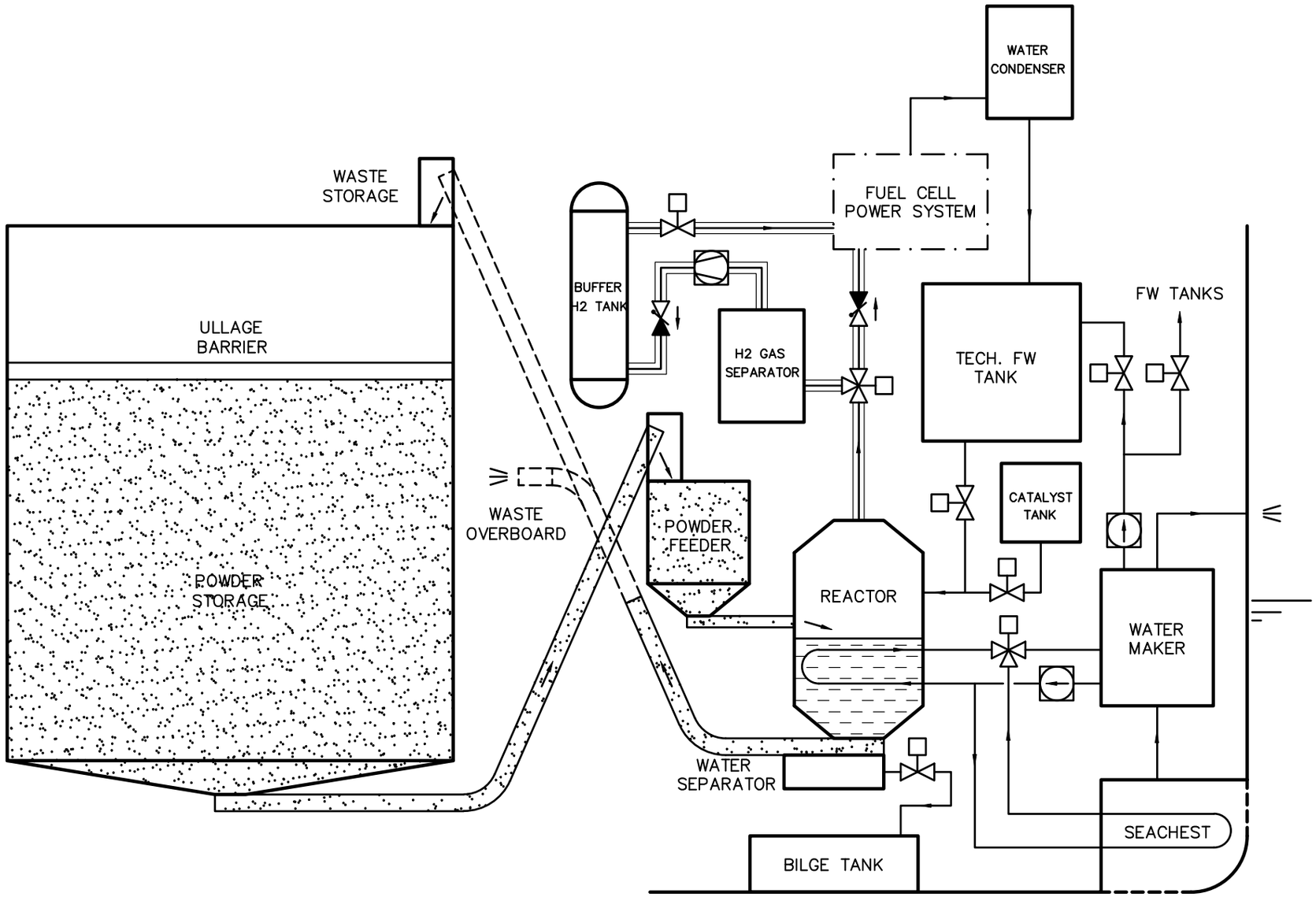


Green power → **Ores** → **Hydrogen pods** → **Established distribution** → **On-site H2 production**

HYREA HYDROGEN PROCESS

- Solid powder reactant
- 10-15% H2 yield per powder mass
- Similar mass of water reactant
- A lot of waste heat
- Use waste heat for water maker
- Solid waste mass = 2x powder mass
- May not be able to dump solid waste

Reactant	Powder density	Reactant input	Water input	Input mass	Heat energy output	Waste output	Hydrogen output
Reactant A	1.5 g/cm3	7 kg	9 kg	16 kg	24.0 kWh	15 kg	1 kg
Reactant B	1.2 g/cm3	10 kg	9 kg	19 kg	24.3 kWh	18 kg	1 kg

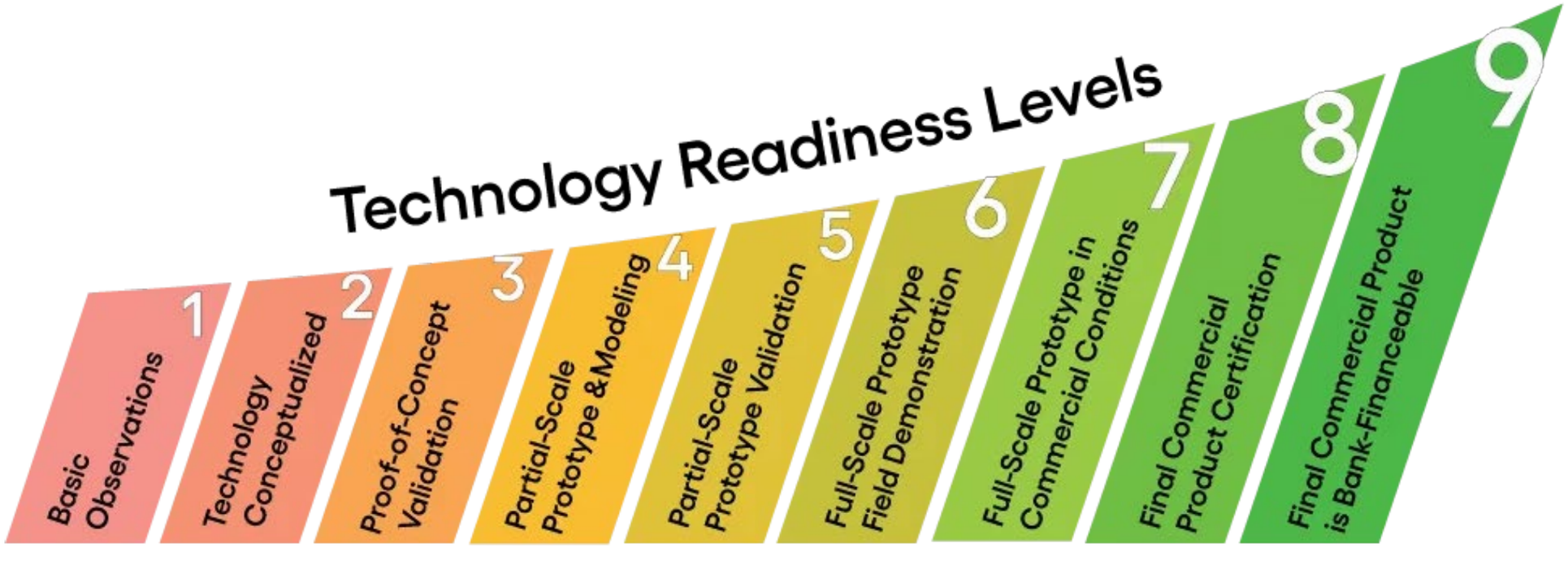


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HYREA REACTOR DESIGN

- Hyrea currently at TRL 4
- Recover waste heat from reactor
- Reactor design temperature & pressure TBC
- Reactor control & safety systems challenging





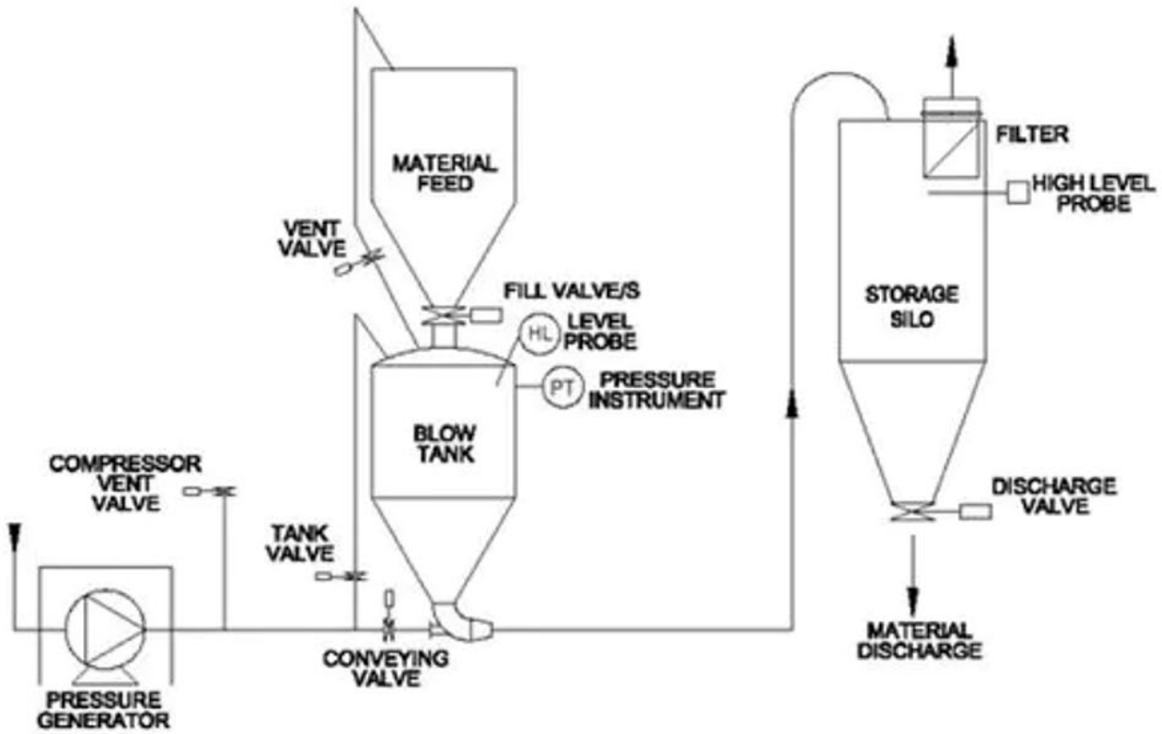
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BULK POWDER HANDLING

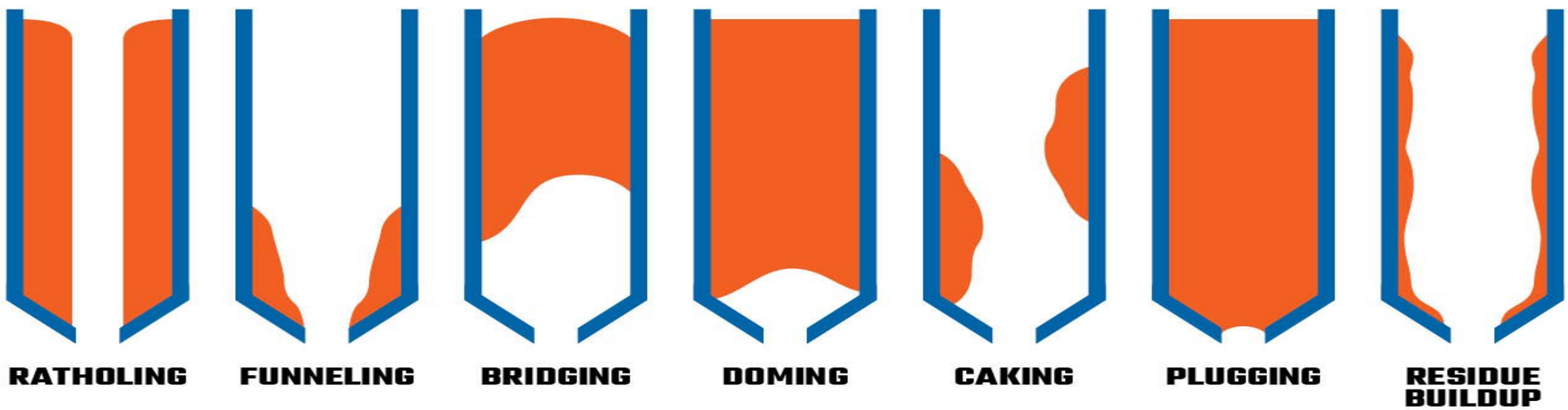
- Food & Pharmaceutical industries
- Pneumatic conveyance & Screw feeders







Types of Silo Blockages

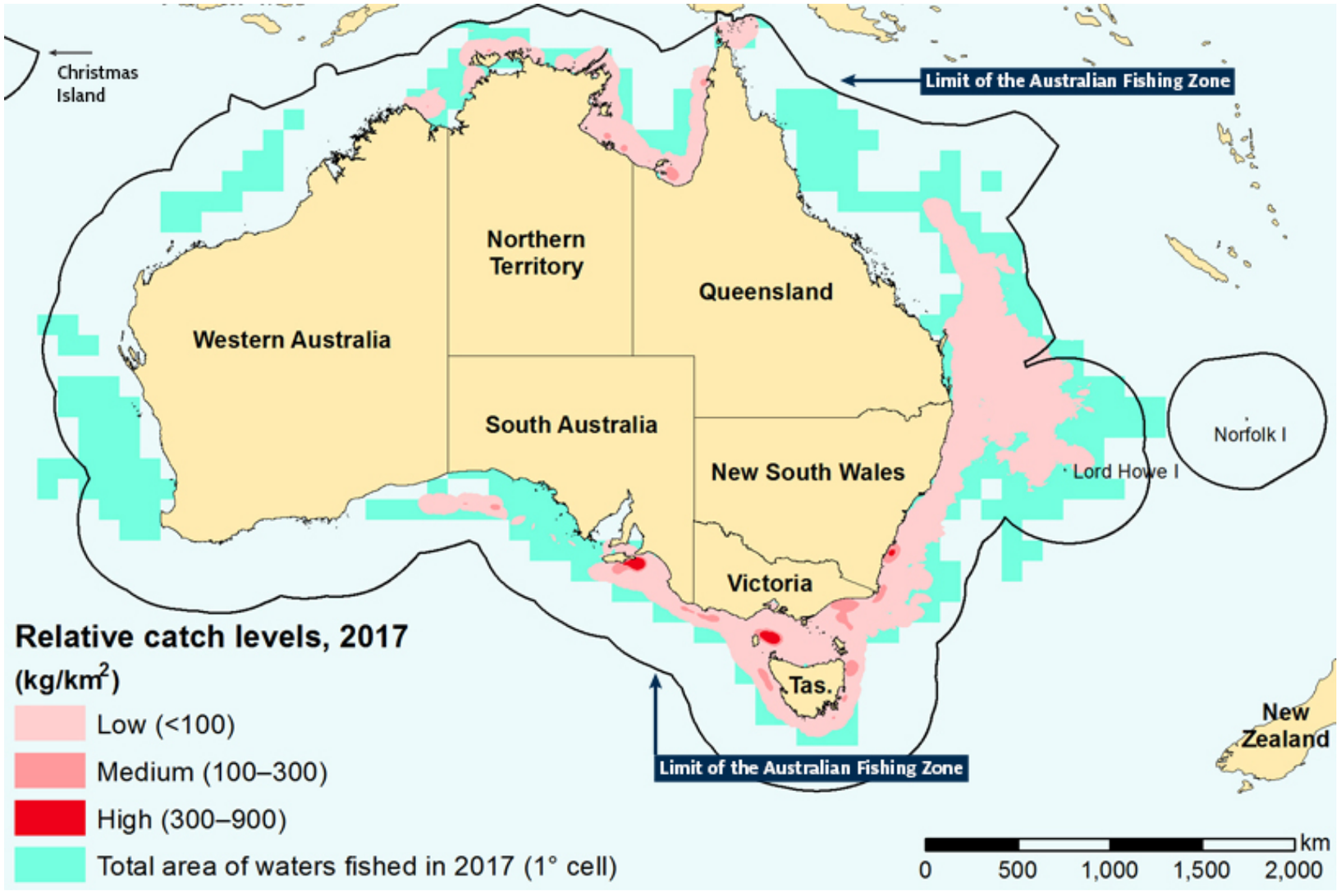


AUSTRALIAN FISHING FLEET

- Australian DCV registrations – Class 3 – Fishing Vessels
- 10,000 vessels commercial fishing fleet
- Trawling, long-line, siene-purse, tourism, aquaculture
- Most remote fishery – Heard Islands








...BUT THE BIG QUESTION IS,
HOW WILL PENGUINS PAY TARIFFS?
TIMES NOW WORLD
Reciprocal Tariffs
Country
Tariffs Charged to the U.S.A.
U.S.A. Discounted Reciprocal Tariffs
China 67% 34%
European Union 39% 20%
Vietnam 90% 46%
Taiwan 64% 32%
Japan 46% 24%
India 52% 26%
South Korea 50% 25%
Thailand 72% 36%
Switzerland 61% 31%
Indonesia 64% 32%
Malaysia 47% 24%
97% 49%
10% 10%

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AUSTRALIAN FISHING INDUSTRY

- Australian FRDC questionnaire to fishing operators
- Many varying operations, from day tourism & pot fishing to multi-week 24hr fishing
- Main engines 60% transit, 25% fishing
- Gensets average 40% load or less
- Engines oversized, run occasionally at high loads to decarbonise cylinders





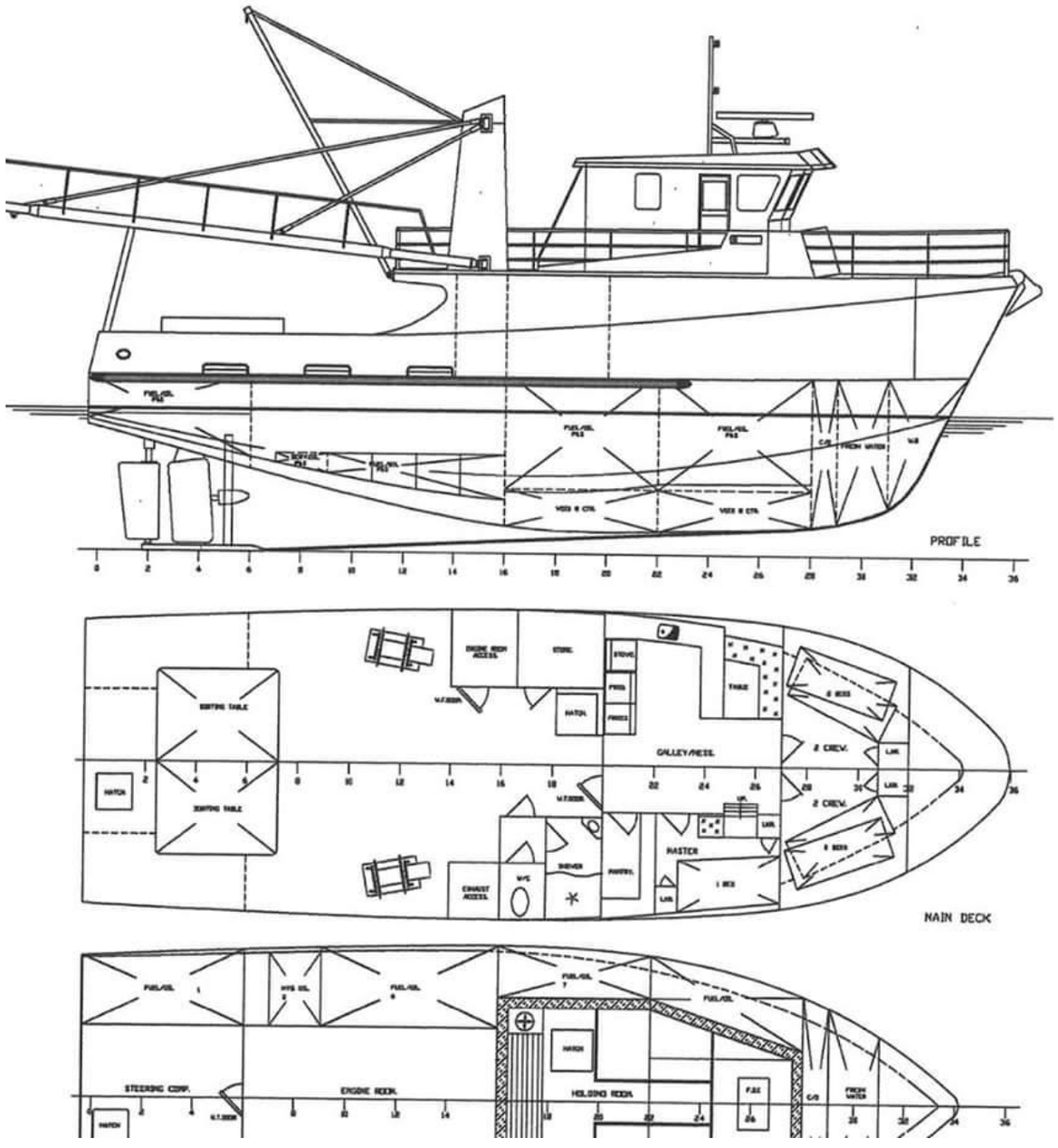




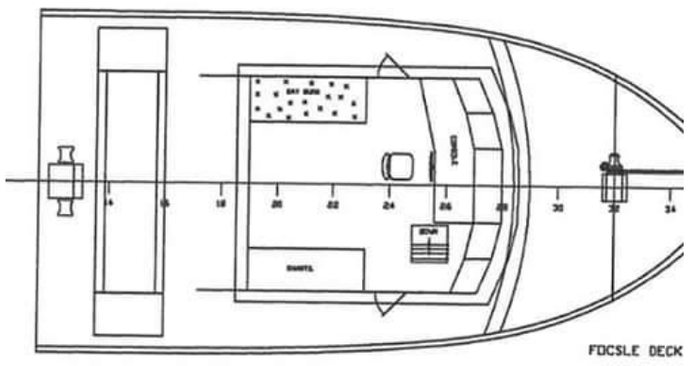
Vessel Length	No. Vessels	Transit fuel (tons)	Fishing fuel (tons)	Genset fuel (tons)	TOTAL FUEL (tons)	Fishing trips (n)	Hours per trip (h)	Fuel per trip (kg)	Fuel type
Up to 7.5m length	6,293	39,017	13,215	0	52,232	125	6.8	66	Petrol
Between 7.5m and 12m	1,643	35,489	15,773	0	51,262	125	10	250	Diesel
Between 12m and 24m	2,232	133,920	224,986	30,132	389,038	25	120	6,972	Diesel
Between 24m and 35m	124	15,401	35,935	5,022	56,358	12	375	37,875	Diesel
Between 35m and 45m	31	7,700	17,968	3,348	29,016	6	1000	156,000	Diesel
More than 45m	12	3,928	9,166	2,678	15,773	4	1500	318,000	Diesel
	10,335	**235,455**	**317,043**	**41,180**	**593,678**				

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STUDY VESSEL – 18M TRAWLER







L.O.A 18.2m
BEAM 6m
DEPTH 3m
L.W.L 16.9m
DRAFT 2.75m

18m Steel Prawn Trawler	
Length OA	18.2 m
Length WL	16.9 m
Beam	6.0 m
Depth	3.0 m
Draught	2.8 m
Main Engine	350 kW
Gensets	2 x 90 kWe
Diesel Fuel	20,000 L
Fresh Water	3,000 L
Refrigerater Hold	10,000 L
Crew	5 persons
Displacement	100 T

FUEL OIL & COMBUSTION ENGINE VESSEL

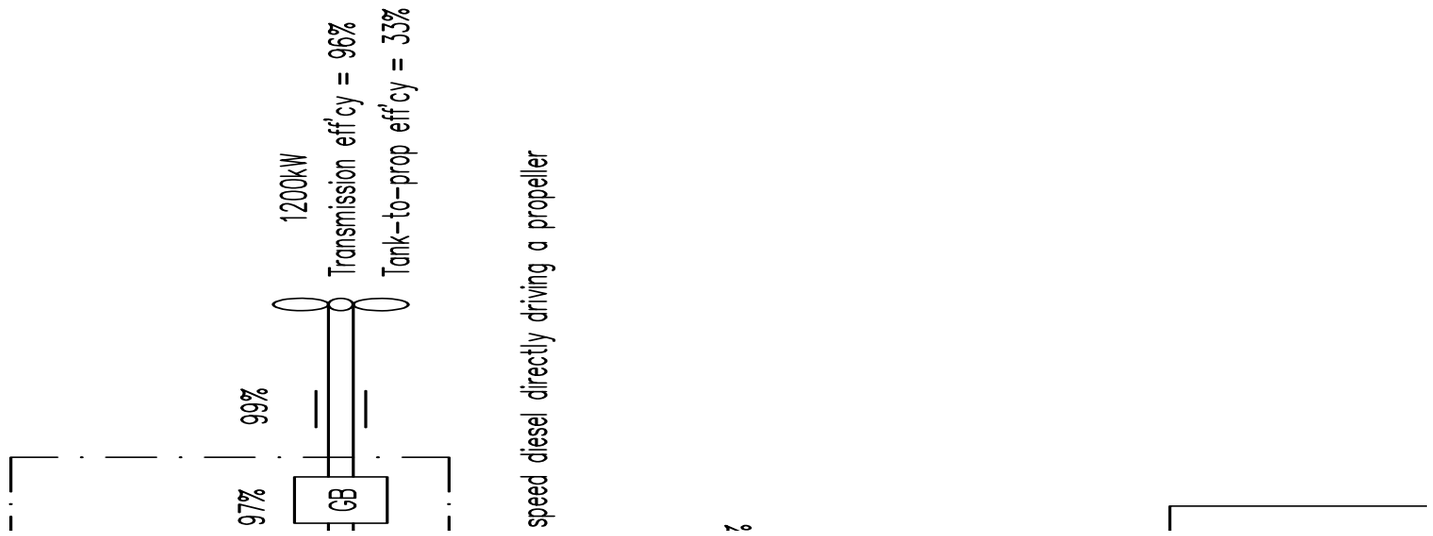
LIQUID HYDROGEN & FUEL CELL VESSEL

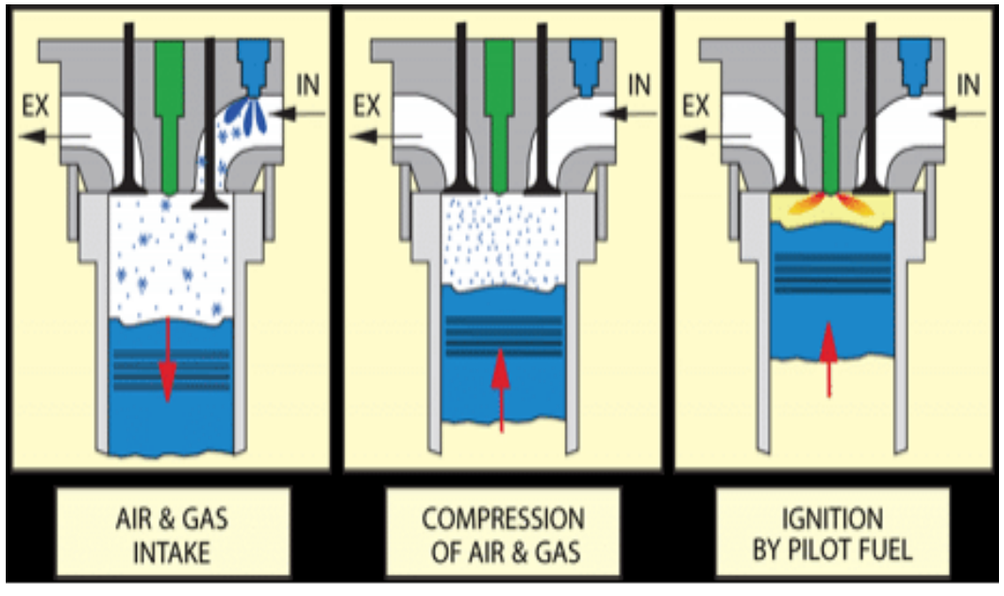
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COMBUSTION ENGINES PROPULSION & POWER SYSTEMS

4-Stroke High-speed Engines

- MGO (Diesel)
- Methanol
- Ammonia
- Hydrogen
- Diesel pilot fuel needed

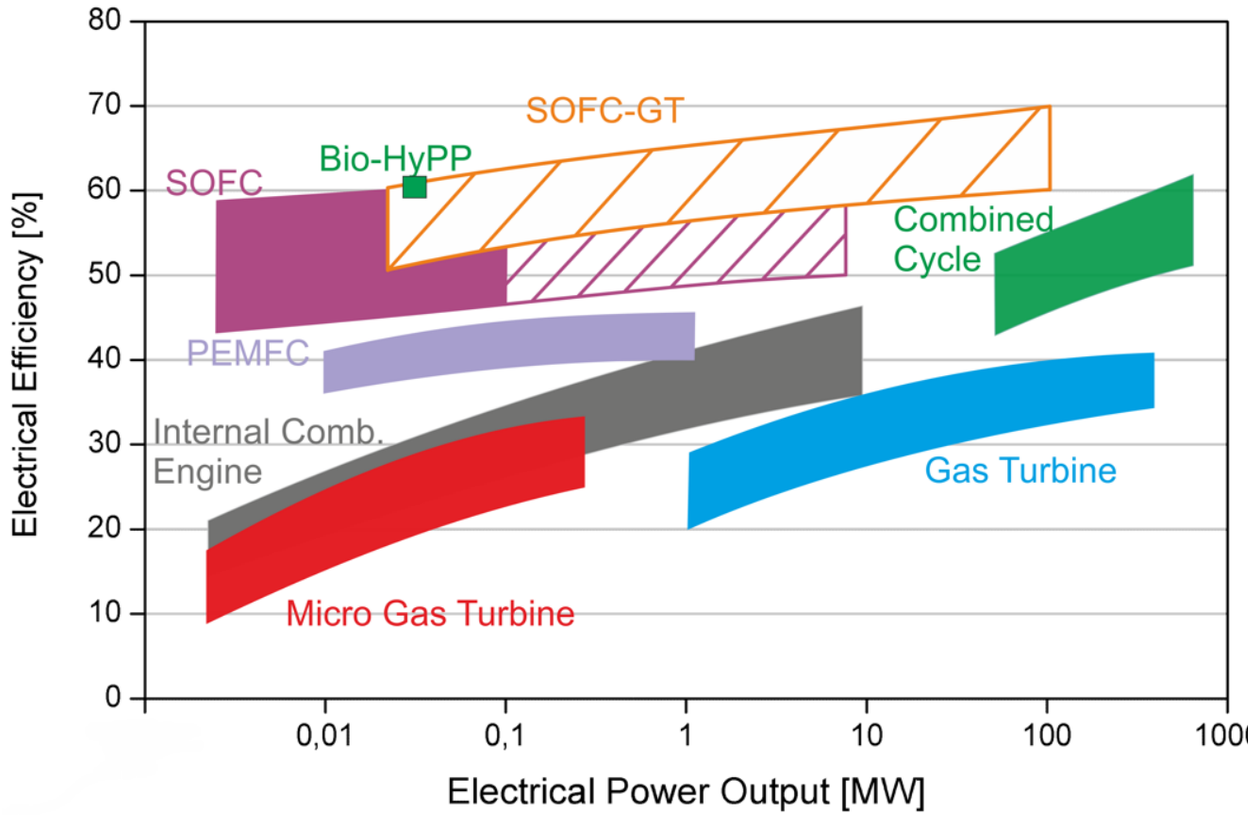


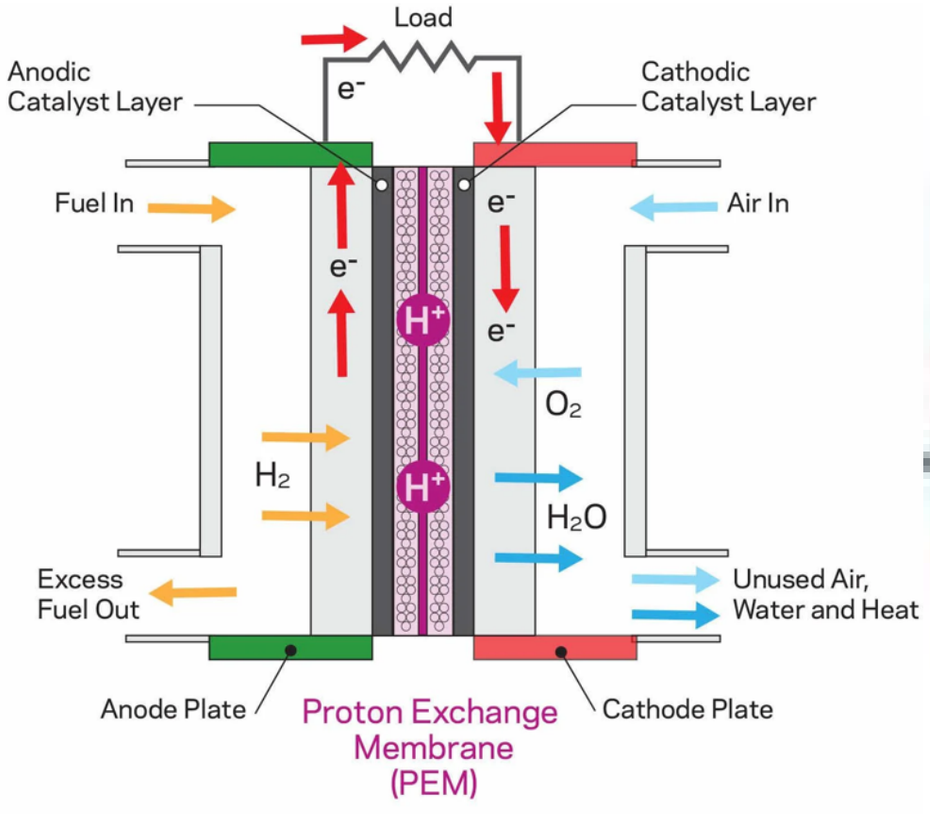


Engine Maker	Biofuel	Methanol - DF	Ammonia - DF	Hydrogen - DF	Hydrogen - Spark
Caterpillar	Ready	Ready	2026		
Cummins	Ready	2025	Planned	2025	
Yanmar	Ready	2026	???		2026
Volvo Penta	Ready		???	2025	
MTU	Ready	???	???	???	

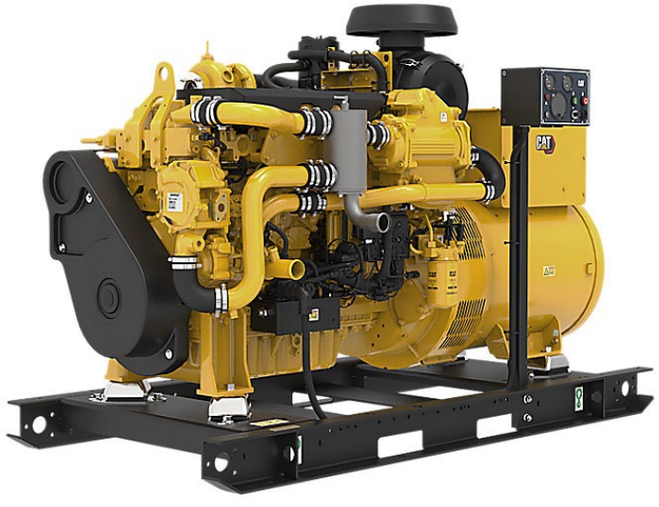
FUEL CELLS

- High Efficiency (50-55%)
- Lighter & smaller than ICE
- Flexible installation
- Fewer support systems
- No moving parts
- Zero noise & pollution
- Exhaust water vapour

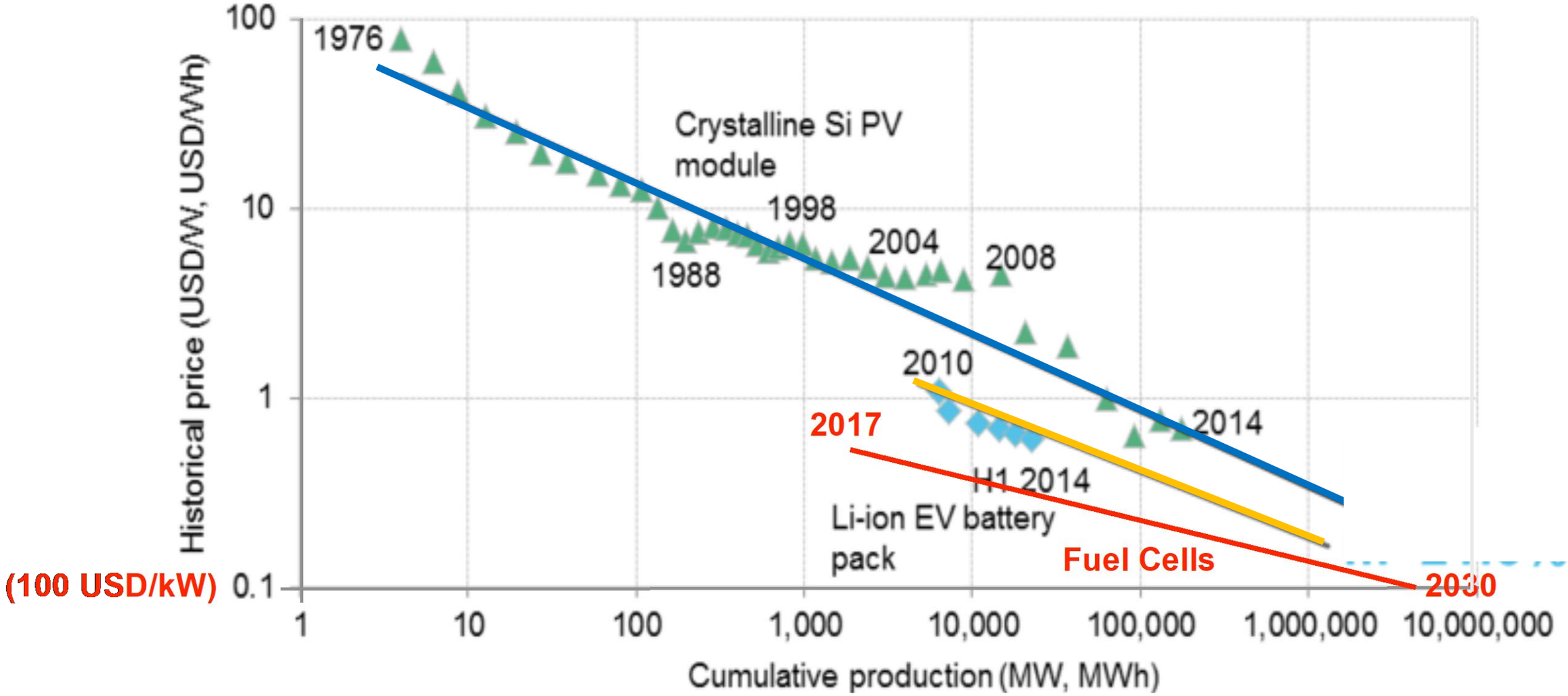




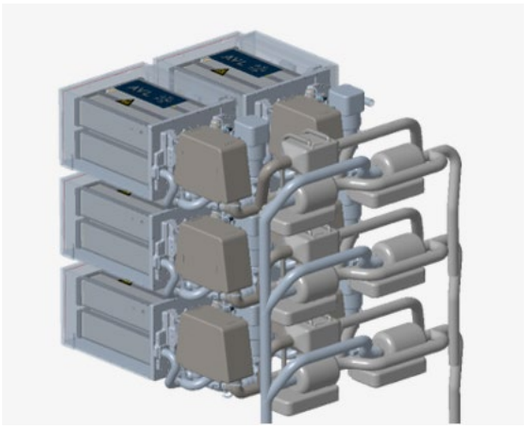




FUEL CELLS


100
10
1
0.1
Historical price (USD/W, USD/Wh)
1976
1988
1998
2004
2008
2010
2014
2017
H1 2014
Crystalline Si PV module
Li-ion EV battery pack
Fuel Cells
2030
(100 USD/kW)
1
10
100
1,000
10,000
100,000
1,000,000
10,000,000
Cumulative production (MW, MWh)



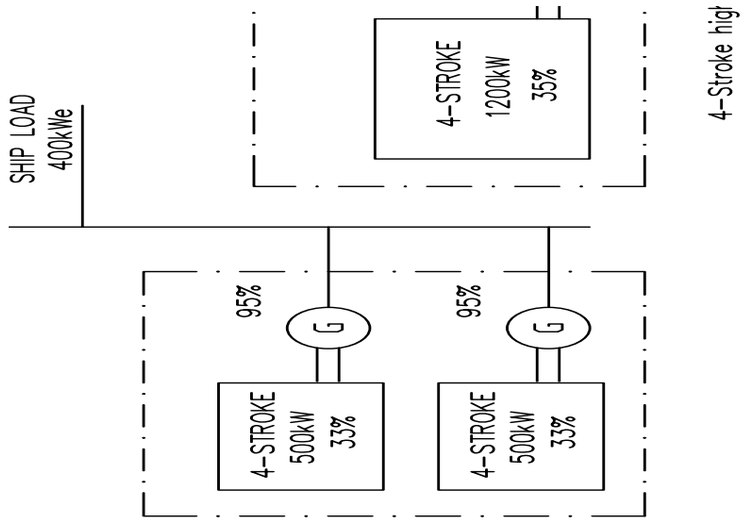


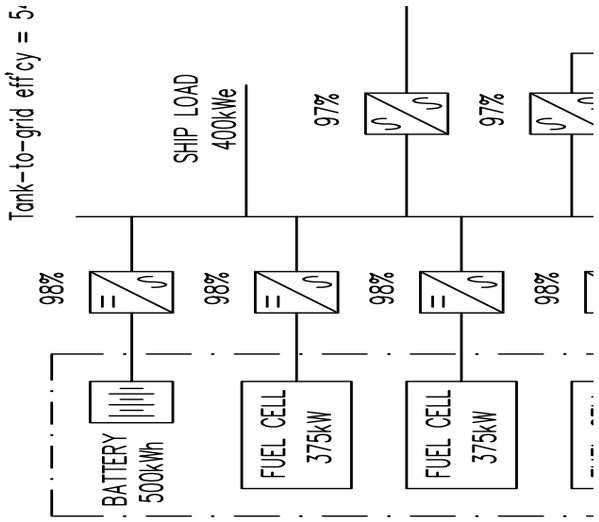


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HYREA REACTOR DESIGN

- 1000 kWe Fuel Cell for 35m fishing vessel
- 500 kWe Fuel Cell for 20m fishing vessel
- Much waste heat from reactor to recover
- Heat recover from fuel cells also possible

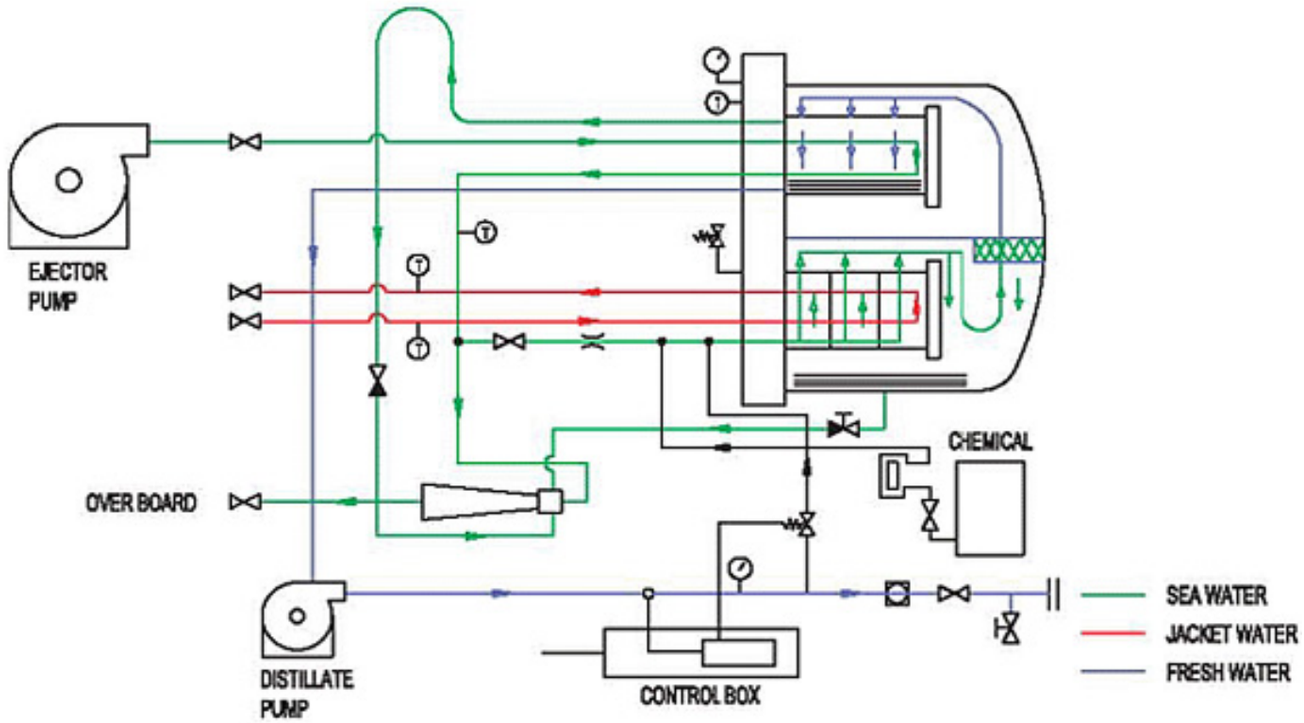




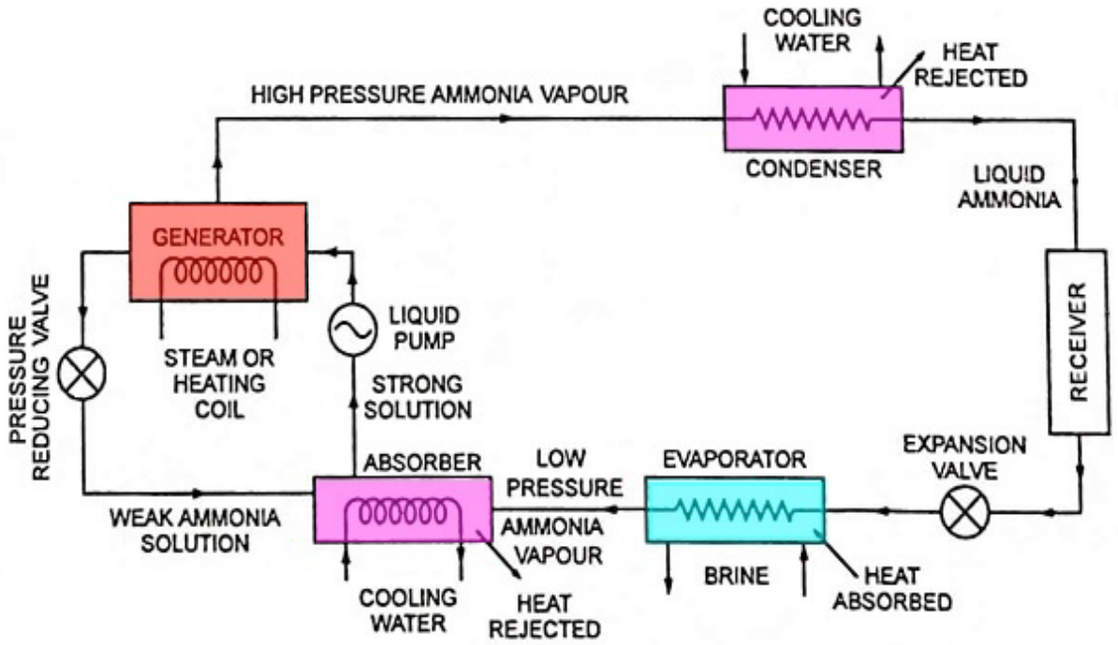
Reactant	PEMFC power	Reactant input	Water input	Input mass	Heat power output	Waste output	Hydrogen output
Reactant A	1000 kWe	504 kg/h	648 kg/h	1152 kg/h	1728 kW	1080 kg/h	72 kg/h
Reactant B	1000 kWe	720 kg/h	648 kg/h	1368 kg/h	1750 kW	1296 kg/h	72 kg/h
Reactant A	500 kWe	252 kg/h	324 kg/h	576 kg/h	864 kW	540 kg/h	36 kg/h
Reactant B	500 kWe	360 kg/h	324 kg/h	684 kg/h	875 kW	648 kg/h	36 kg/h

WASTE HEAT RECOVERY

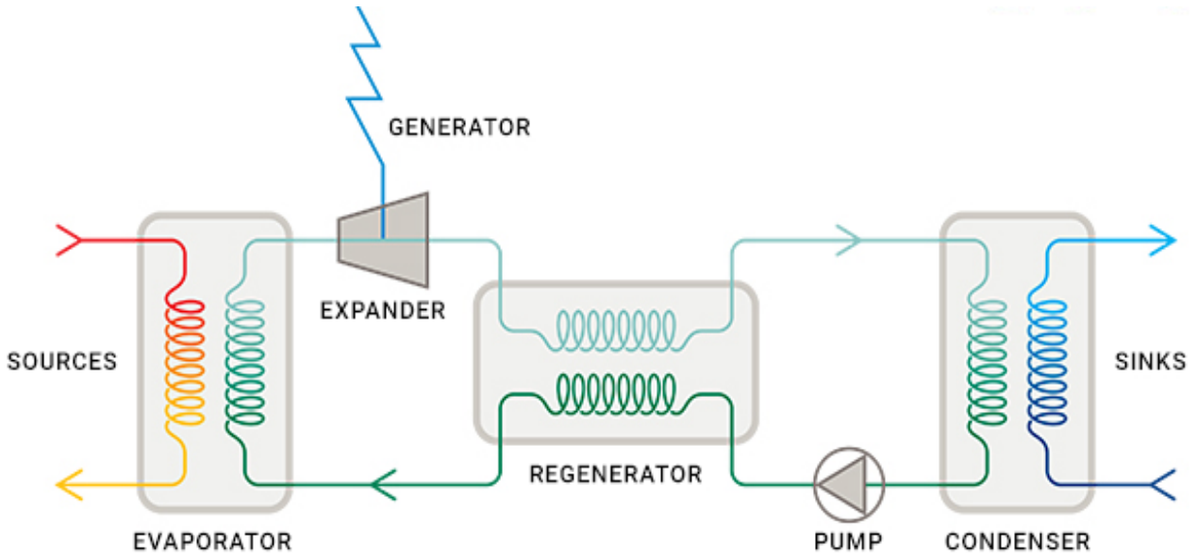
Water maker
500kWh/m3



Absorption refrigeration
CoP = 0.4 kWr/kW

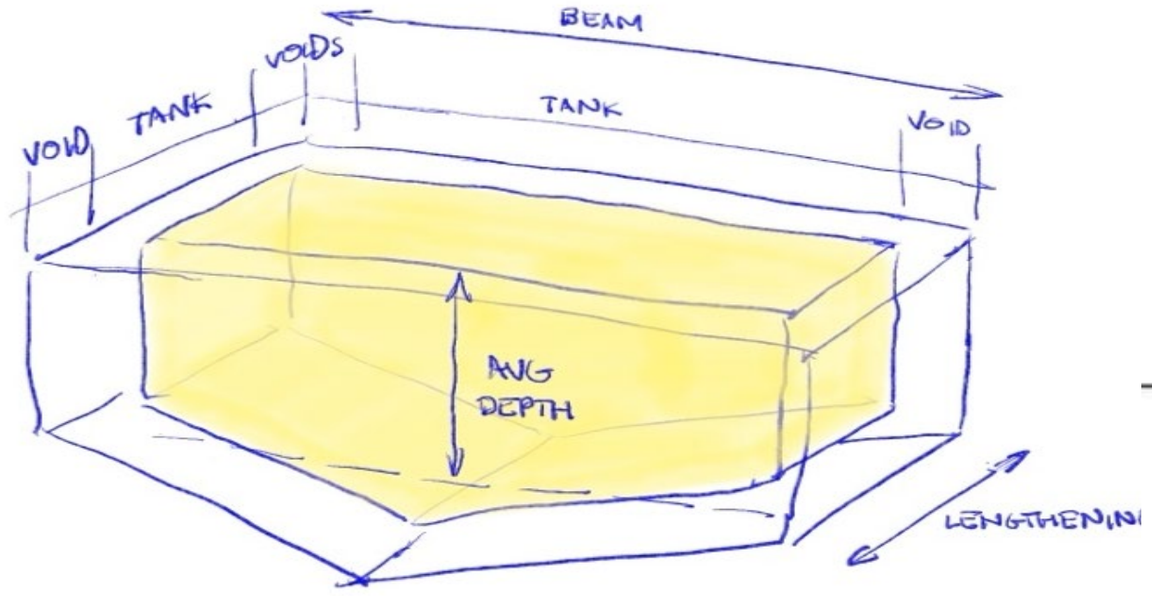


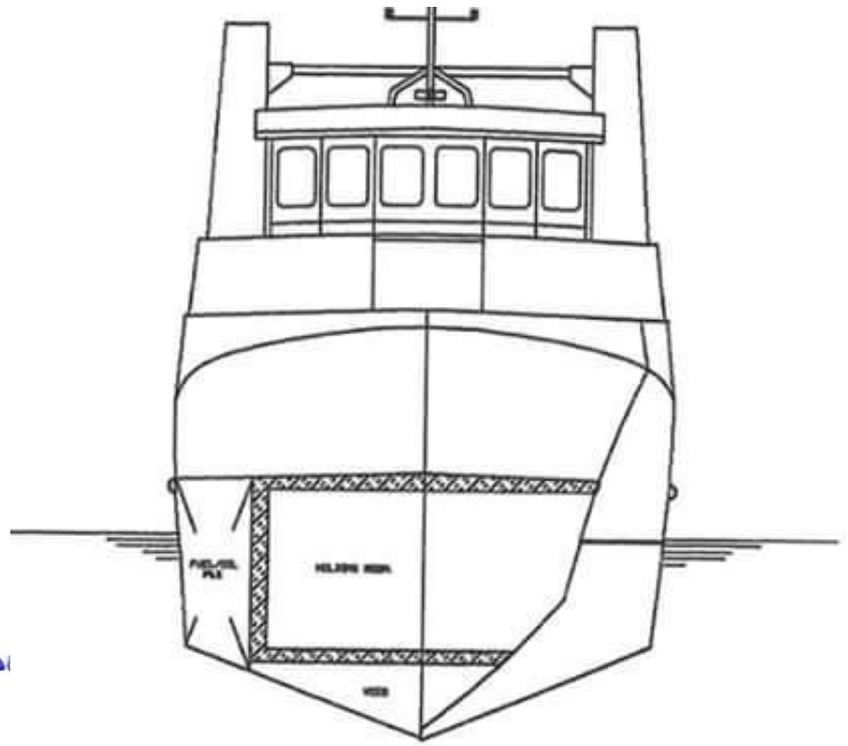
ORC Generator CoP =
0.1 kWe/kW



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GREEN FUEL TANK LENGTHENING





18m Vessel with Combustion Engine Propulsion & Ammonia Fuel												
Ref. tank	**IC Engine**	**Ammonia**	**Pilot fuel**	**Alt. fuel tank**	**LOA**	**Beam**	**Hull depth**	**Safety voids**	**Insulation**	**Tank area**	**Tank length**	**New LOA**
(m3)	(eff'y ratio)	(fuel vol. ratio)	(fuel ratio)	(m3)	(m)	(m)	(avg. m)	(m)	(m)	(m2)	(m)	(m)
20	1.00	0.35	0.15	48.6	18	6	2.5	0.6	0.20	9.24	6.46	24.46
15	1.00	0.35	0.15	36.4	18	6	2.5	0.6	0.20	9.24	5.14	23.14
10	1.00	0.35	0.15	24.3	18	6	2.5	0.6	0.20	9.24	3.83	21.83

18m Vessel with Combustion Engine Propulsion & 500bar H2 Fuel												
Power & Fuel System					**Hull**		**500bar gas cylinder**			**Tank space**		
Ref. tank	**IC Engine**	**500bar H2**	**Pilot fuel**	**Alt. fuel tank**	**LOA**	**Beam**	**Volume**	**Quantity**	**Area**	**Area**	**Length**	**New LOA**
(m3)	(eff'y ratio)	(fuel vol. ratio)	(fuel ratio)	(m3)	(m)	(m)	(m3)	(n)	(m2)	(m2)	(m)	(m)
20	1.00	0.07	0.2	228.6	18	6	0.20	1143	0.30	343	57.1	75.14
15	1.00	0.07	0.2	171.4	18	6	0.20	857	0.30	257	42.9	60.86
10	1.00	0.07	0.2	114.3	18	6	0.20	571	0.30	171	28.6	46.57

FUEL OIL & COMBUSTION ENGINE VESSEL

LIQUID HYDROGEN & FUEL CELL VESSEL

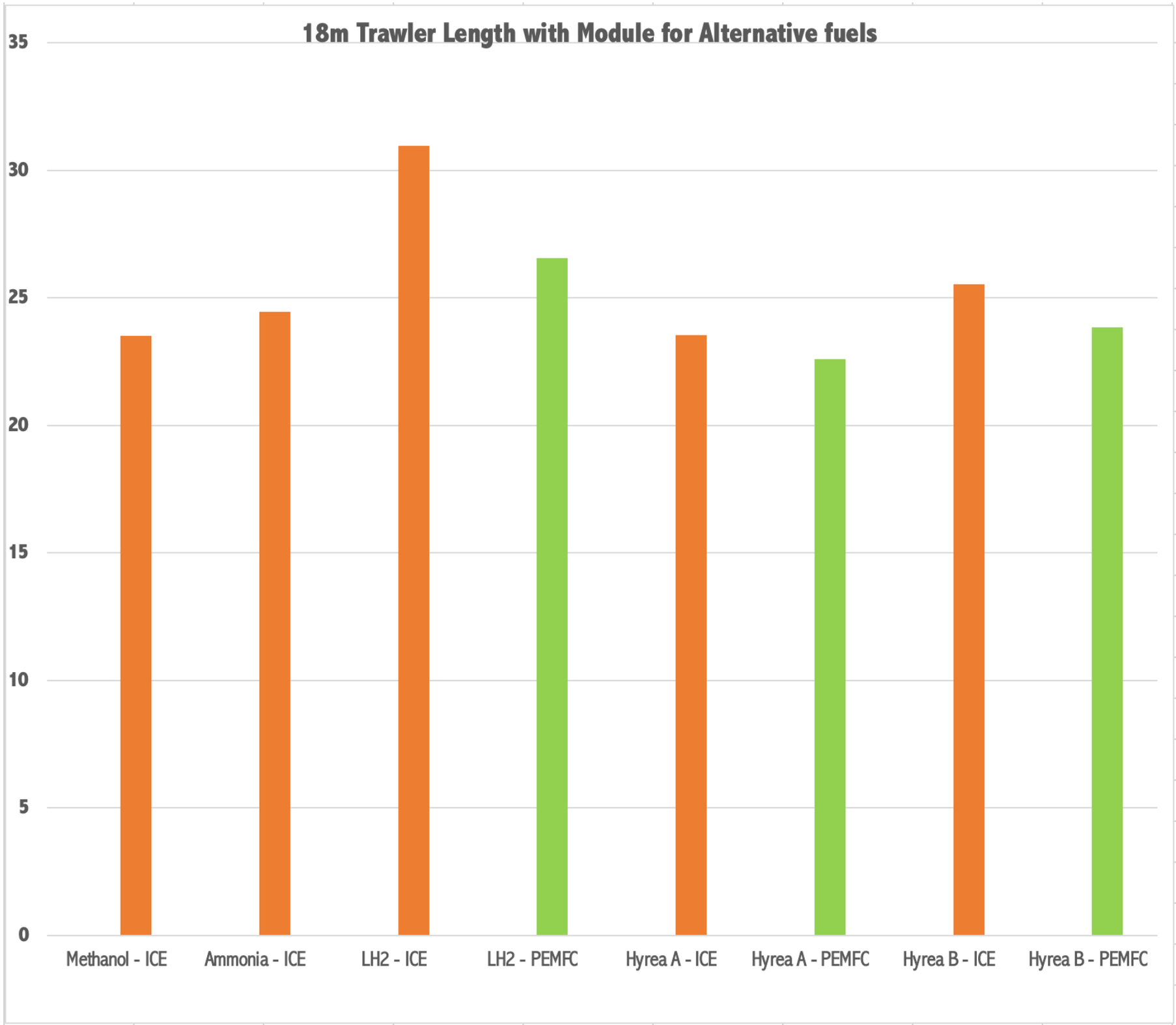
HYREA SYSTEM LENGTHENING

18m Vessel with Combustion Engine Propulsion & Hyrea (Reactant A) H2 Fuel												
Power & Fuel System					Hull			Reactant A		Tank space + Reactor		
Ref. tank	IC Engine	H2 to diesel	Pilot fuel	H2 mass	LOA	Beam	Avg. depth	Mass	Volume	Silo factor	Length	New LOA
(m3)	(eff'y ratio)	(mass ratio)	(fuel ratio)	(t)	(m)	(m)	(m)	(t)	(m3)	(area ratio)	(m)	(m)
20	1.00	0.42	0.2	5.7	18	6	2.5	40.0	26.7	0.70	5.5	23.54
15	1.00	0.42	0.2	4.3	18	6	2.5	30.0	20.0	0.70	4.9	22.90
10	1.00	0.42	0.2	2.9	18	6	2.5	20.0	13.3	0.70	4.3	22.27

18m Vessel with Combustion Engine Propulsion & Hyrea (Reactant B) H2 Fuel												
Power & Fuel System					Hull			Reactant B		Tank space + Reactor		
Ref. tank	IC Engine	H2 to diesel	Pilot fuel	H2 mass	LOA	Beam	Avg. depth	Mass	Volume	Silo factor	Length	New LOA
(m3)	(eff'y ratio)	(mass ratio)	(fuel ratio)	(t)	(m)	(m)	(m)	(t)	(m3)	(area ratio)	(m)	(m)
20	1.00	0.42	0.2	5.7	18	6	2.5	57.1	47.6	0.70	7.5	25.53
15	1.00	0.42	0.2	4.3	18	6	2.5	42.8	35.7	0.70	6.4	24.40
10	1.00	0.42	0.2	2.9	18	6	2.5	28.6	23.8	0.70	5.3	23.27

18m Vessel with Fuel Cell Power & Hyrea (Reactant A) H2 Fuel												
Power & Fuel System					Hull			Reactant A		Tank space + Reactor		
Ref. tank	Fuel Cell	H2 to diesel	Pilot fuel	H2 mass	LOA	Beam	Avg. depth	Mass	Volume	Silo factor	Length	New LOA
(m3)	(eff'y ratio)	(mass ratio)	(fuel ratio)	(t)	(m)	(m)	(m)	(t)	(m3)	(area ratio)	(m)	(m)
20	0.50	0.42	0	3.6	18	6	2.5	25.0	16.7	0.70	4.6	22.59
15	0.50	0.42	0	2.7	18	6	2.5	18.7	12.5	0.70	4.2	22.19
10	0.50	0.42	0	1.8	18	6	2.5	12.5	8.3	0.70	3.8	21.79

18m Vessel with Fuel Cell Power & Hyrea (Reactant B) H2 Fuel												
Power & Fuel System					Hull			Reactant B		Tank space + Reactor		
Ref. tank	Fuel Cell	H2 to diesel	Pilot fuel	H2 mass	LOA	Beam	Avg. depth	Mass	Volume	Silo factor	Length	New LOA
(m3)	(eff'y ratio)	(mass ratio)	(fuel ratio)	(t)	(m)	(m)	(m)	(t)	(m3)	(area ratio)	(m)	(m)
20	0.50	0.42	0	3.6	18	6	2.5	35.7	29.8	0.70	5.8	23.83
15	0.50	0.42	0	2.7	18	6	2.5	26.8	22.3	0.70	5.1	23.13
10	0.50	0.42	0	1.8	18	6	2.5	17.9	14.9	0.70	4.4	22.42


18m Trawler Length with Module for Alternative fuels
35
30
25
20
15
10
5
0
Methanol - ICE
Ammonia - ICE
LH2 - ICE
LH2 - PEMFC
Hyrea A - ICE
Hyrea A - PEMFC
Hyrea B - ICE
Hyrea B - PEMFC

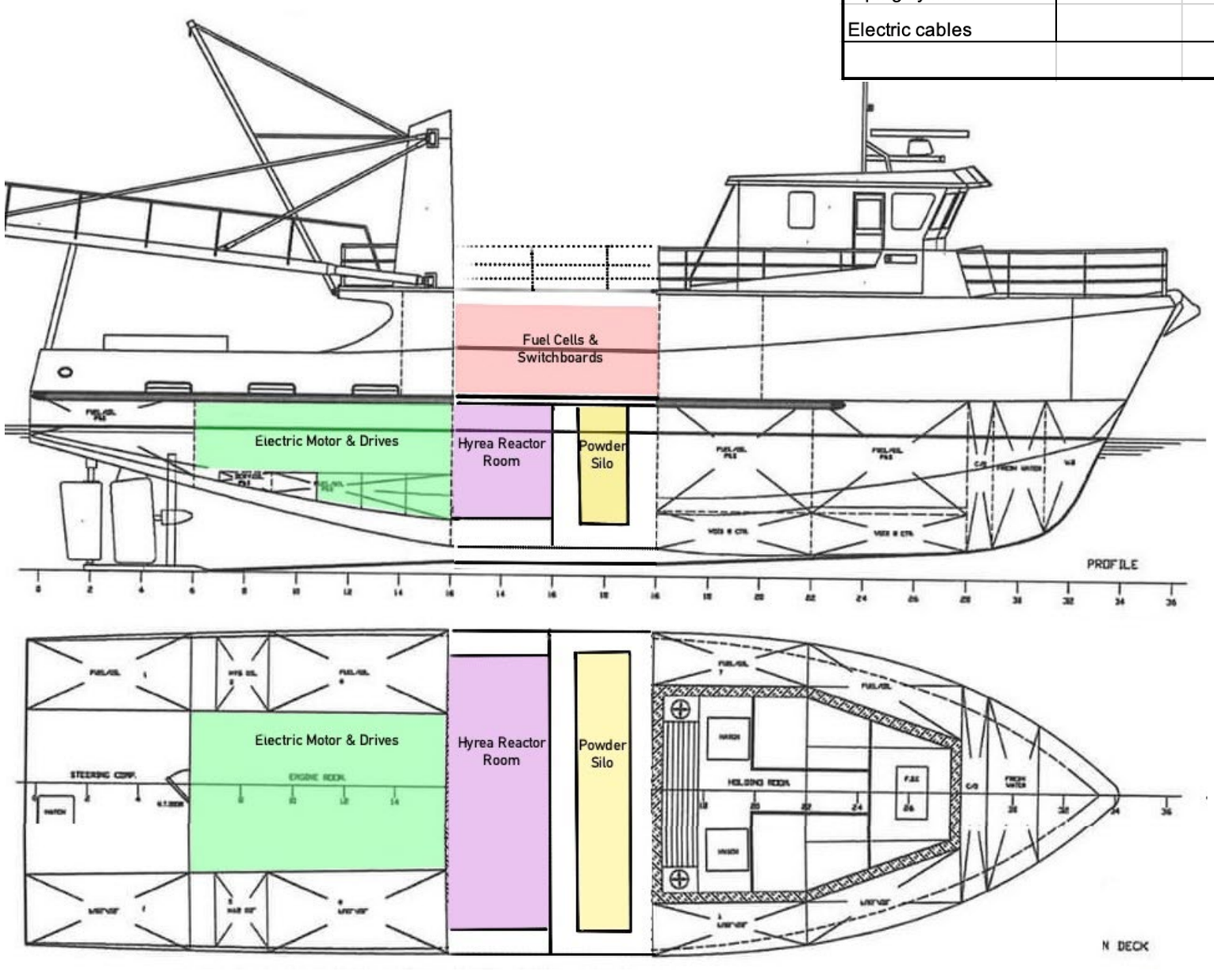
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CONCEPT DESIGN STUDY

HYREA HYDROGEN & FUEL CELL VESSEL

500 kW Diesel Engine Propulsion & Power System				
Item	Capacity	Quantity	Unit weight	Total weight
		(n)	(kg)	(kg)
Main engine	350 kW	1	2000	2000
Propulsion gearbox	500 kW	1	1500	1500
Gensets	100 kWe	2	1500	3000
Main switchboard	200 kWe	1	500	500
Ventilation systems		1	500	500
Piping systems		1	1250	1250
Electric cables		1	250	250
				9000

Hull Module - 500 kWe Hyrea System	
Item	Unit weight
	(kg)
Steel structure	10000
Powder storage silo	2000
Powder reactant (Si)	3000
Feeder hopper	800
Hyrea reactor	1000
Water maker	1500
Water feeder tank	500
Water reactant	1000
Catalyst tank	200
Catalyst (NaOH)	500
H2 Gas separator	1000
H2 Buffer tank (500 bar)	500
Piping & valves	3000
Outfitting	2000
	27000



500 kW Fuel Cell Propulsion & Power System				
Item	Capacity	Quantity	Unit weight	Total weight
		(n)	(kg)	(kg)
Fuel cells	250 kWe	2	800	1600
Fuel cell converters	250 kWe	2	250	500
Battery	100 kWh	5	650	3250
Propulsion motors	175 kW	2	300	600
Propulsion gearbox	500 kW	1	1500	1500
Motor drives	175 kWe	2	250	500
Main switchboard	1000 kWe	1	1000	1000
Ventilation systems		1	250	250
Piping systems		1	800	800
Electric cables		1	750	750
				10750

CONCLUSIONS

- **Hyrea - No technology barriers**
- **Reactor design, control & safety systems most challenging**
- **Fuel cells & battery hybrid likely replace IC engines**
- **Hyrea system more space efficient than storing H2 onboard**
- **Downstream study only. Upstream must also be viable.**

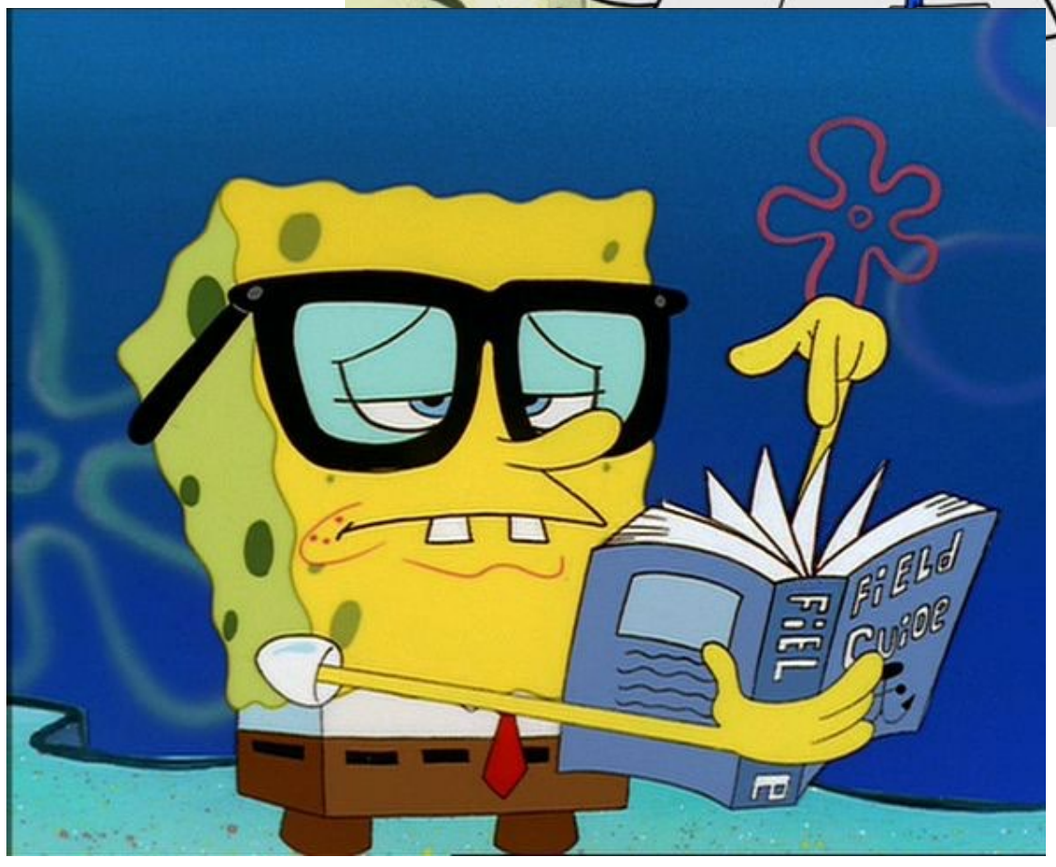


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FUTURE STUDY

- Apply to other vessel types, bulk, cruise
- Involve Class in reactor design, material handling
- Heat recovery systems
- Silo design, hull integration
- Waste handling, discharge at sea???





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QUESTIONS

