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2050

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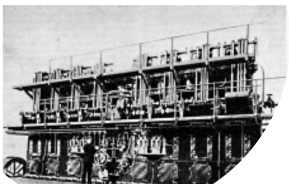


This engine powered globalisation But now it must get green fuel or be phased out

WHAT CHANGE AND WHAT CAN WE DO ABOUT IT NOW?

1. ENERGY SCENARIOS 2020-50 REVEAL GREEN ENERGY GAP
2. THE POTENTIAL OF NUCLEAR & GEOTHERMAL ENERGY
3. FLEET INVESTMENT 2020-2050 WILL BE RISKY
4. THE ZERO CARBON VOYAGE PLAN
5. GOVERNANCE – RESPONSIBILITY FOR CHANGE

2

2

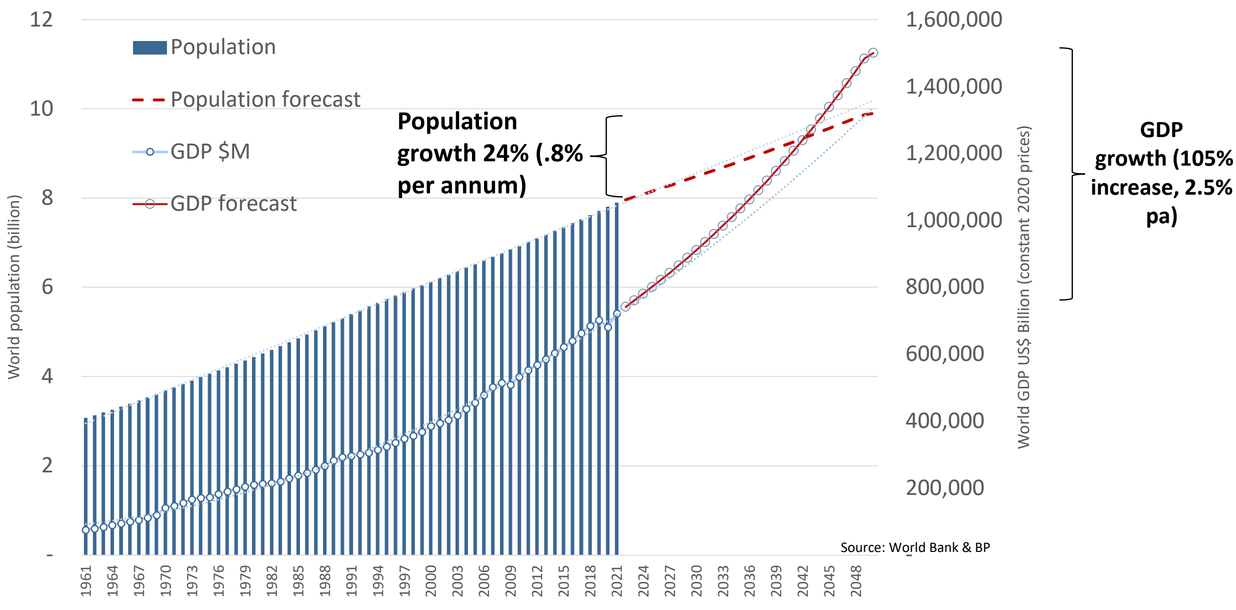
Where the green energy will come from.

Current technology suggests that the cost of global renewable energy supplies will be very high

1. ENERGY SCENARIOS 2020-50 REVEAL "GREEN ENERGY GAP"

3

Population and GDP growth will increase cargo volumes and ship demand



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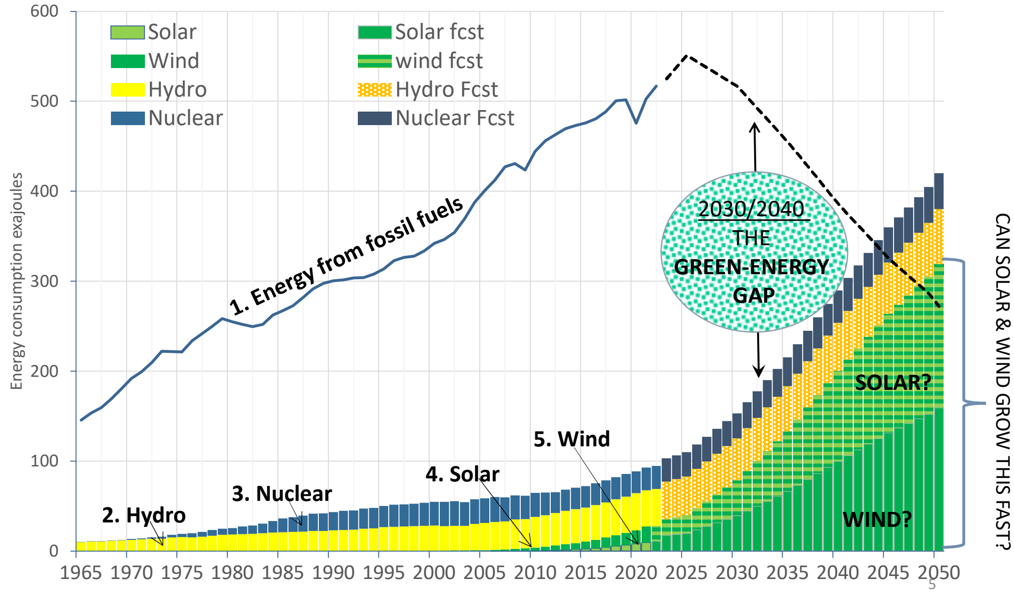
Much competition for limited supply of green fuel in 2020s

WORLD ENERGY – loosely based on BP "accelerated" scenario 2022,

Fossil fuel and green energy consumption: 1965-2021 and forecasts to 2050



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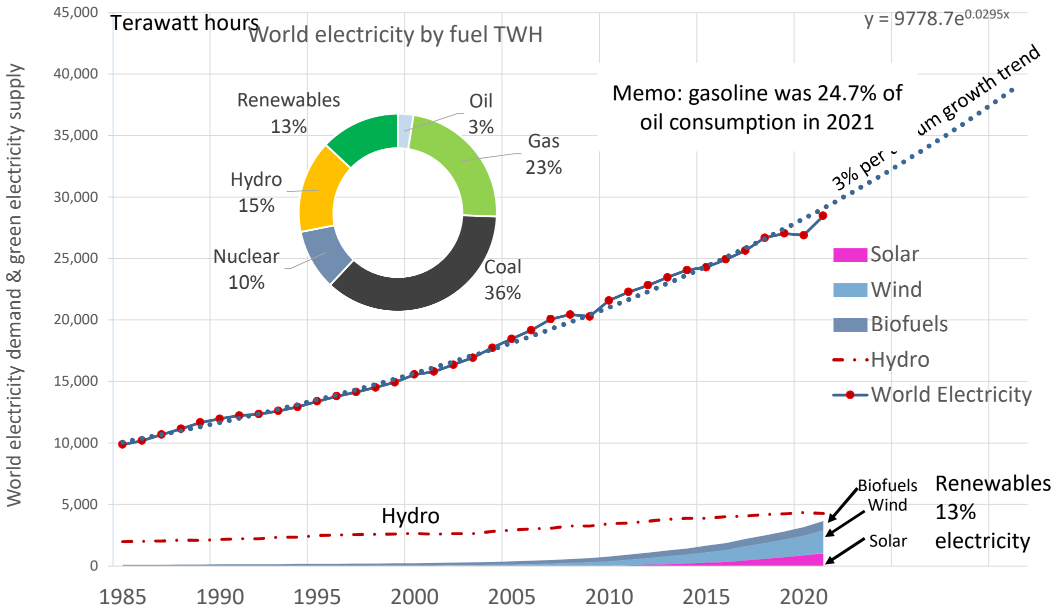
Electricity supply - where will suppliers get green fuel in future?

2. THE FUEL AVAILABILITY ISSUE



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Four Fuel Options: methanol, hydrogen, ammonia and nuclear

GREEN FUEL OPTIONS

Table 1: Liquid fuels which are, or could be, used to power merchant ships

all numbers relate to liquid product

Ref			CHEMICAL: ENERGY+CARBON EMISSIONS HFO	LNG	LPG	LEG	Methanol	CHEMICAL: NO CARBON Hydro-gen	Amm-onia	FISSION (1) Uranium
	memo: Chemical composition		Composit	C_2H_6,	C_3H_8	C_2H_6	CH3OH	H2	NH3	U235
1	Boiling point	˚C at 1 bar pressure	150	-166	-26.2	-89	65	-253	-33	4131
2	Energy density by volume (per litre)	MJ/litre	41.0	21.6	24.9	53.2	15.7	9.2	15.7	67,443,012
3	Energy density by weight (per kilogram)	MJ/kilogram	41.8	48.0	46.1	51.9	19.7	120.2	22.5	3,898,440
4	Auto Ignition	Temp ˚C to ignite	398	650	428	472	450	535	630	NA
5	Ratio of liquid volume to HFO*	based on m^3 per kg	1	1.85	1.6208		2.54	4.33	2.55	0.05
6	Flammable range	% vol in air to burn		5-15%	8.9-18.8%		5.5-26%	4-74%	15-28%	N/A
7	Carbon content per kg	%	**88%**	**75%**	**82%**		**38%**	**0%**	**0%**	**0%**
8	CO_2 emissions/kg when burnt	Kg CO_2 per Kg fuel burnt	3.11	2.75	2.99		1.37	0	0	0
9	*CO_2 emissions/kg % reduction*	*Compared to HFO*	-	*12%*	*3%*		*56%*	*100%*	*100%*	*100%*
10	CO_2 emissions per kWh output	kg CO_2 kWh	0.27	0.21	0.24		0.25	0	0	0
11	*CO_2 emissions reduction/ kWh*	*kg CO_2/kWh less than HFO*	-	*24%*	*15.60%*		*11%*	*100%*	*100%*	
12	Low flashpoint fuel		Yes	Yes	Yes		Yes	Yes	No	N/A

(1) **NUCLEAR FISSION**: nuclear reaction in which a heavy nucleus splits spontaneously or on impact with another particle, releasing energy

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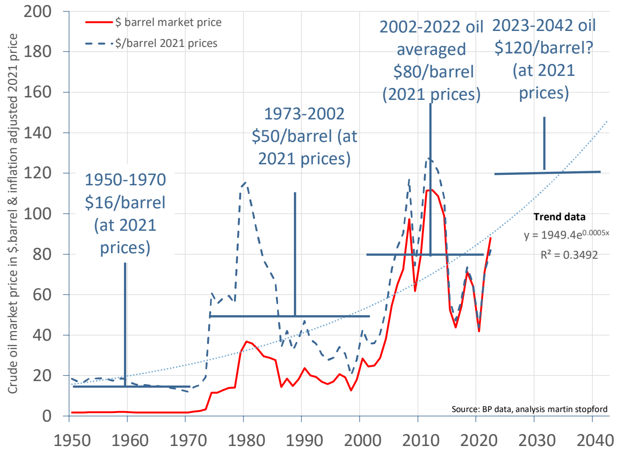
Oil price 1950-2022(red line) and inflation adjusted to 2021 prices (blue line)

- Oil price has quadrupled in real terms since 1950s (6.3% per annum trend 1950).
- Price spikes in the 1970s and the early 2000's obscure trend.
- If trend continues oil will cost $120/barrel (at 2021 prices) in next 20 years
- Financial evaluation of the cost of green energy compared with fossil fuels should take future oil prices into account. They may increase substantially.



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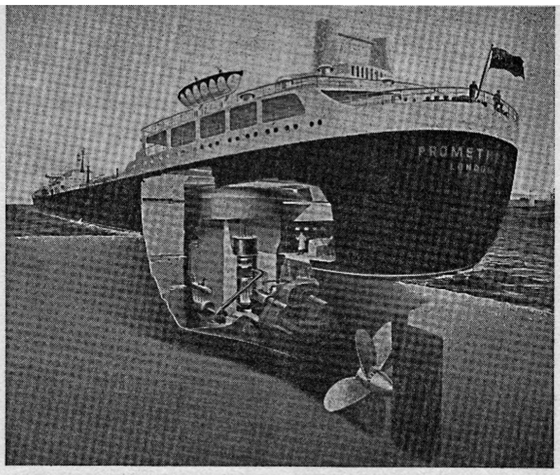
2. THE POTENTIAL OF NUCLEAR & GEOTHERMAL ENERGY

- photo from a book written in 1957, by technology correspondent of the Daily Telegraph, UK.
- It shows a drawing by the atomic energy authority of a 50,000 tonne tanker with nuclear propulsion.
- Nuclear power was already being used in submarines, and tanker transport was supervised by the oil majors, so no concern about the capacity to run nuclear powered ship.
- The ship was never built because nuclear technology was very expensive and oil was very cheap.



A United Kingdom Atomic Energy Authority artist's impression of a 50,000 ton tanker in which nuclear energy replaces the energy of conventional fuels like oil. In such a tanker, the reactor and propulsion machinery are placed in the stern, the reactor being heavily shielded and possibly supplying steam to conventional turbine machinery or, in later versions, even to gas turbines.

Three possible reactor systems have been considered for ship propulsion by the U.K.A.E.A.—a smaller version of the Calder Hall type, one using gas cooling and an operating medium of heavy water and a third type in which some other liquid would be used as operating medium and for cooling purposes.

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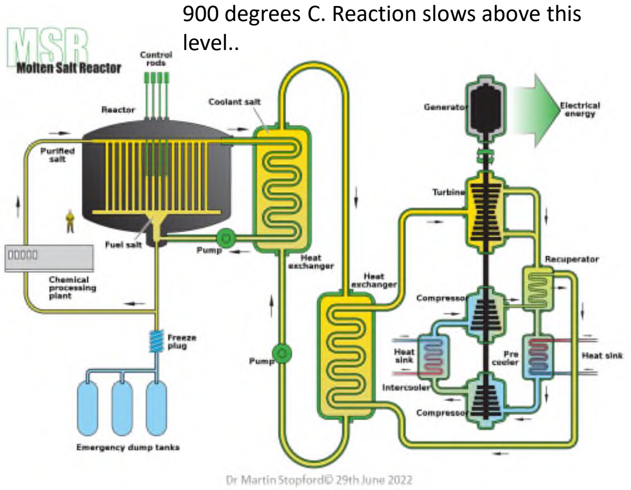
Plan of **Molten Salt Reactor(MSR) producing electricity**

A **MSR** 20-90 MW reactor is well sized for big merchant ships and has several advantages: -

1. The reactor can be constructed in a factory and transported to shipyard.
2. Runs 30 years without refueling & most fuel would be recovered at end of ship's life.
3. Safe because it works at AMBIANT PRESSURE, so no radiation plume if reactor shell fractures* Can use waste products.
4. Much cheaper than green fuels and possible comparable life cost with HFO.

Still NOT a done deal – lots to do to make it work commercially especially engineering risk tolerances. But it's a strong contender in a slim field.

Heat exchange is made in the range 750-900 degrees C. Reaction slows above this level..



*A plume is a cloud which spreads over the surrounding area.

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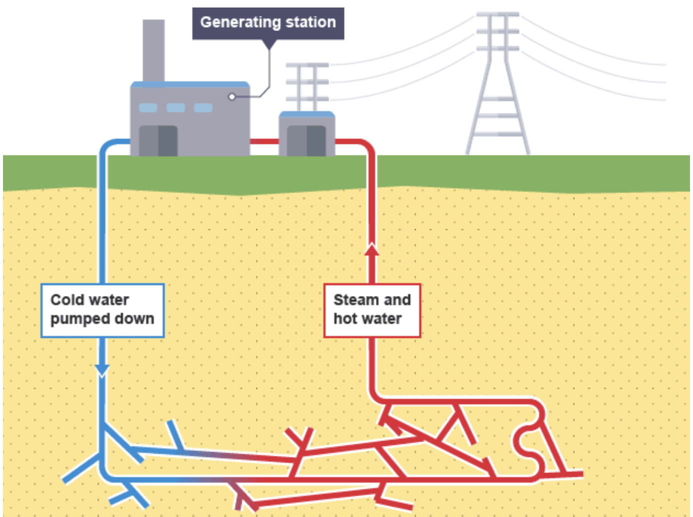
GEOTHERMAL ENERGY
Important way to help close the 2030s green energy gap: -

- Cold water pumped into the hot rock permeates through fissures
- A separate pipe system extracts steam and hot water which powers a turbine generating electricity



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Maritime industry needs $2-4 trillion investment in next 30 years

Table 1: Rough Ship Investment requirement 2020-2050 based on Scenario 2 trade and ship speed assumptions

1	2	3	4	5	6	7	8	9	10	11
Vessel Type	2019 Investment			World Fleet 2019		Rough investment required 2020-2050 $ Billion				
	M GT	$ billion	$/GT	Fleet M GT	No	Replacement	Growth(1)	Expansion	Total	% Total
Tankers etc	14.0	$12.3	878.6	325.0	11,095	$286	-25%	-$71	$214	6%
Bulk Carriers	17.4	$11.1	637.9	478.0	11,820	$305	67%	$204	$509	15%
Gas tankers	7.4	$14.2	1918.9	82.7	2,039	$159	149%	$236	$395	12%
Containerships	7.1	$6.7	943.7	243.0	5,326	$229	126%	$289	$518	15%
Cruise	2.7	$18.9	7000.0	23.2	448	$162	120%	$195	$357	10%
Offshore	1.0	$7.1	7100.0	59.9	8,977	$425	-25%	-$106	$319	9%
Ferry	0.9	$3.9	4333.3	20.6	7,878	$89	120%	$107	$196	6%
Other	1.5	$5.5	3666.7	147.5	49,888	$541	70%	$379	$919	27%
Total	52.1	$79.7	1,529.8	1,379.9	97,471	$2,196	34%	$1,233	$3,429	100%

Col 4 = (Col3 x 1000)/Col 2 Col 7 = (Col 5 x Col 4)/1,000 Col 9 = (Col 5 x Col 8 x Col 4)/1000 Col 10 = (Col 7 + Col 9)

(1) Rough fleet growth estimate 2020 to 2050 based on Scenario 2 trade scenario

Source:The Shipping Carbon Model Version 2, data from Clarkson Research World Fleet Register

When looking ahead it is important to recognize the market segments. The eight listed in this table have very different roles in the shipping market and will require different technologies and levels of investment

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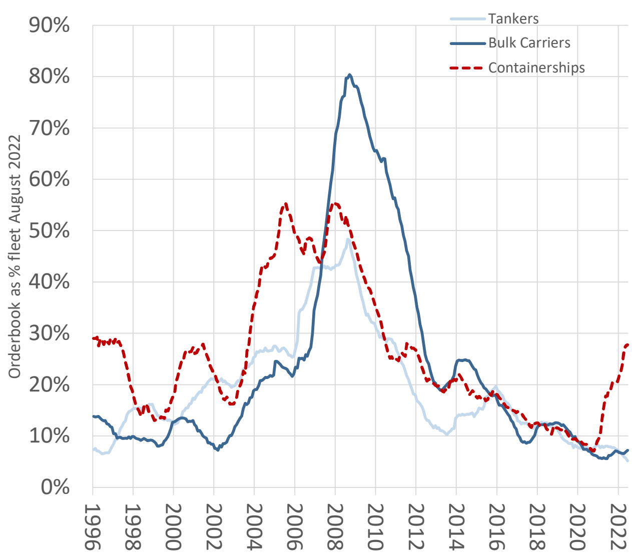
SLUGGISH INVESTMENT IN GREEN SHIPS

- Investment running at a low level (O/B 10% fleet)
- Containers investing quite heavily.
- Dry bulk and tanker investment very low, despite firm markets.
- Dual fuel LNG orders in specialist sectors & some Methanol



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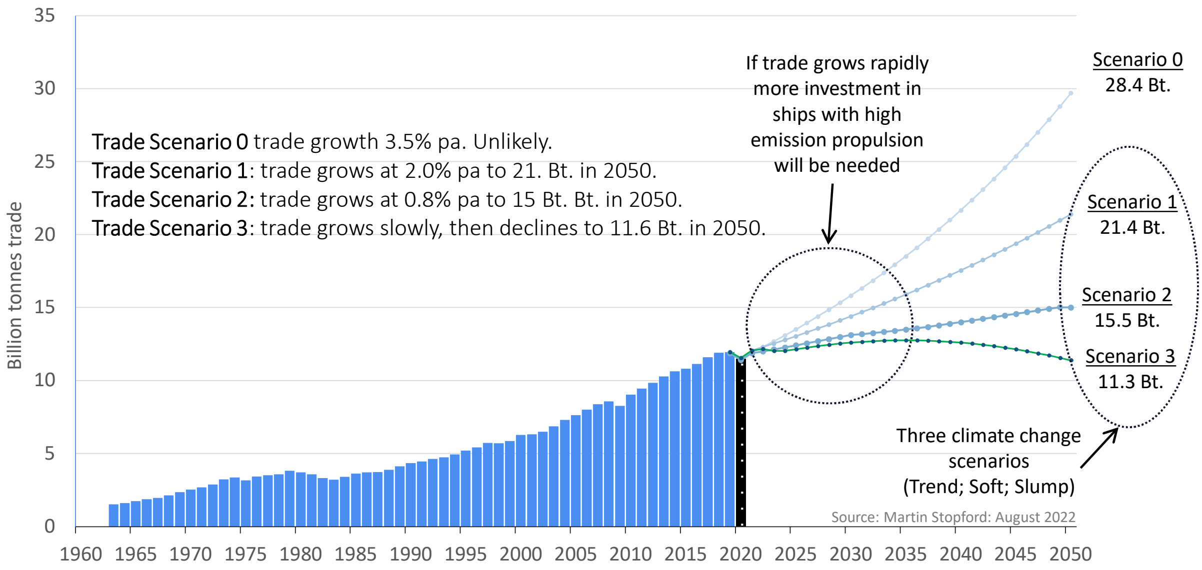
SCENARIOS AUGUST 2022 – revised to reflect progress of pandemic and changing world economic outlook

The trend: sea trade will follow a different trend – but which one?



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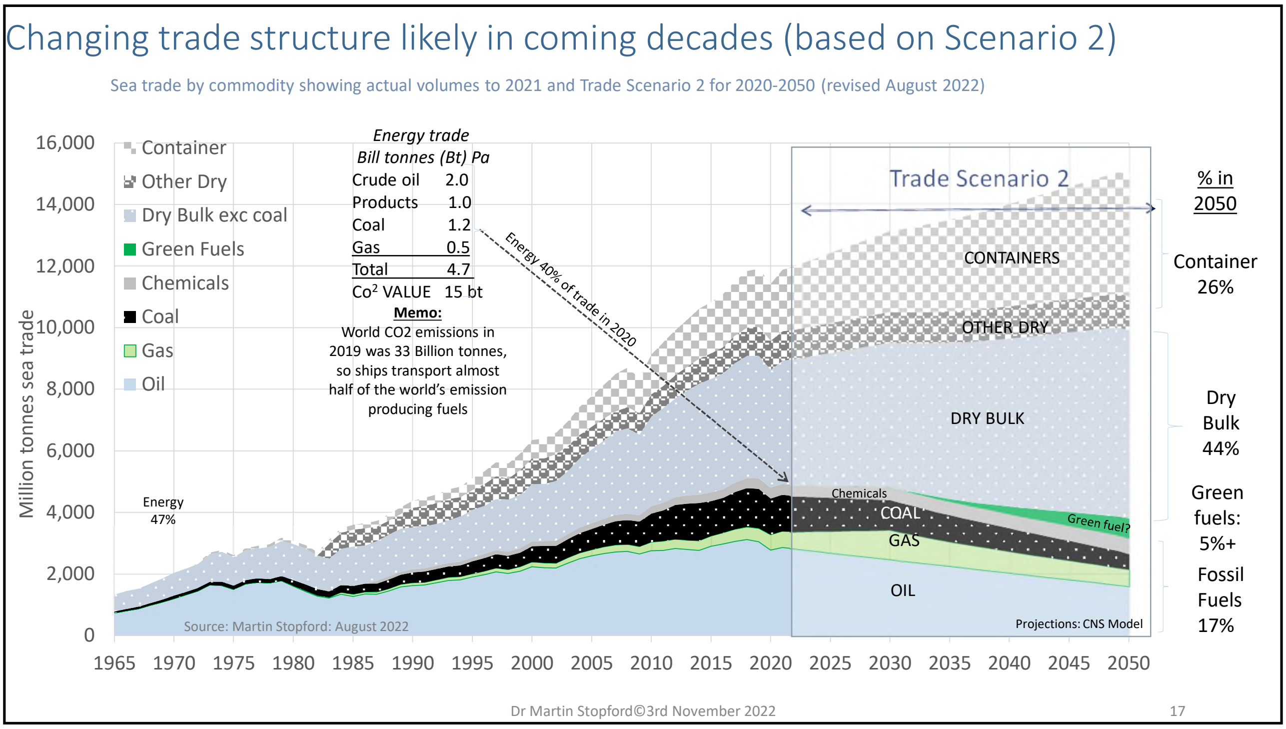

Changing trade structure likely in coming decades (based on Scenario 2)
Sea trade by commodity showing actual volumes to 2021 and Trade Scenario 2 for 2020-2050 (revised August 2022)
Container
Other Dry
Dry Bulk exc coal
Green Fuels
Chemicals
Coal
Gas
Oil
Energy trade
Bill tonnes (Bt) Pa
Crude oil 2.0
Products 1.0
Coal 1.2
Gas 0.5
Total 4.7
Co² VALUE 15 bt
Memo:
World CO2 emissions in 2019 was 33 Billion tonnes, so ships transport almost half of the world's emission producing fuels
Energy 40% of trade in 2020
Trade Scenario 2
CONTAINERS
OTHER DRY
DRY BULK
Chemicals
COAL
GAS
OIL
Green fuel?
Energy 47%
Million tonnes sea trade
Source: Martin Stopford: August 2022
Projections: CNS Model
% in 2050
Container 26%
Dry Bulk 44%
Green fuels: 5%+
Fossil Fuels 17%
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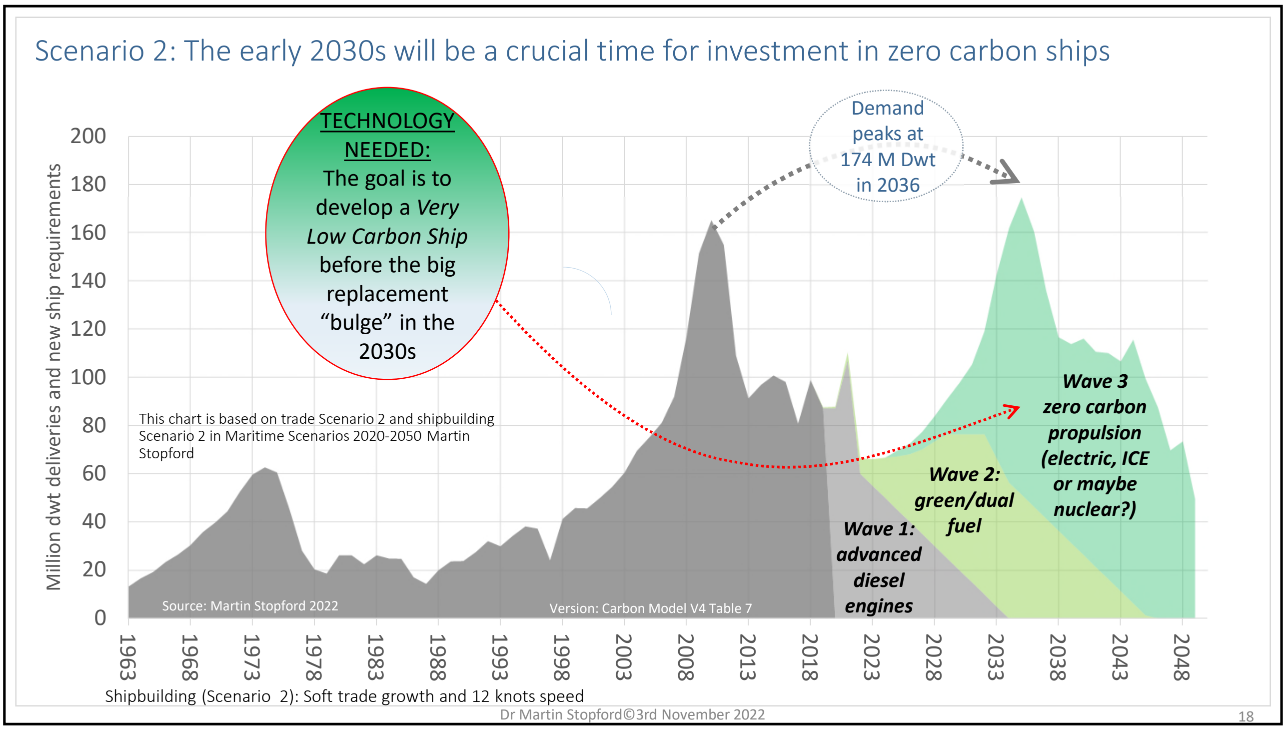

Scenario 2: The early 2030s will be a crucial time for investment in zero carbon ships
TECHNOLOGY NEEDED:
The goal is to develop a Very Low Carbon Ship before the big replacement "bulge" in the 2030s
Demand peaks at 174 M Dwt in 2036
This chart is based on trade Scenario 2 and shipbuilding Scenario 2 in Maritime Scenarios 2020-2050 Martin Stopford
Wave 1: advanced diesel engines
Wave 2: green/dual fuel
Wave 3 zero carbon propulsion (electric, ICE or maybe nuclear?)
Million dwt deliveries and new ship requirements
Source: Martin Stopford 2022
Version: Carbon Model V4 Table 7
Shipbuilding (Scenario 2): Soft trade growth and 12 knots speed
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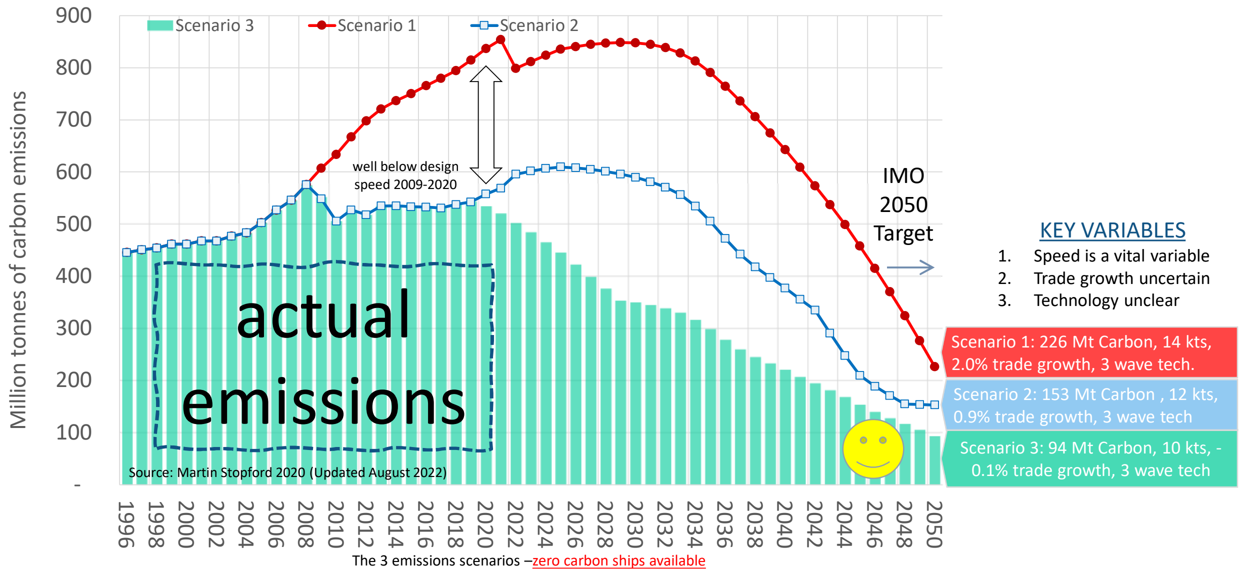
The different ways cargo ship CO_2 emissions might develop 2021-2050



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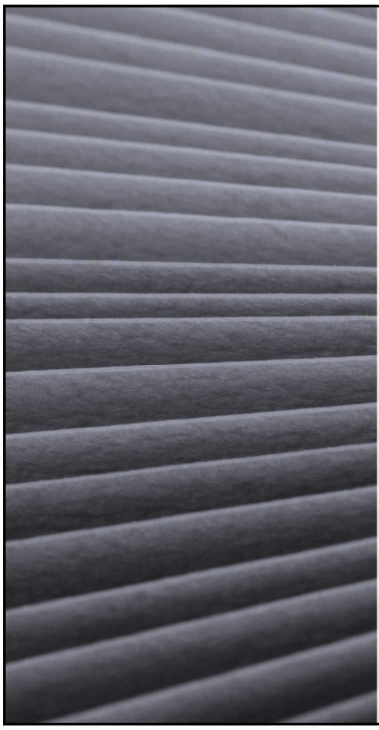

4. THE ZERO CARBON VOYAGE PLAN

2020s STRATEGY:

- 2020s-DEEP SEA: slow speed diesel engines with dual fuel capability (LNG, hydrogen, methanol, ammonia etc).
- 2020s -SHORT SEA- electric propulsion over shorter distances. Battery costs falling but “green recharge” an issue.

2030s STRATEGY:

- **TECHNICAL PERFORMANCE** Use technology provides reliable zero carbon TRANSPORT performance for “normal” ships
- **ECONOMIC VIABILITY** Use economics to clarify what option cargo shippers will pay for and underwrite investment

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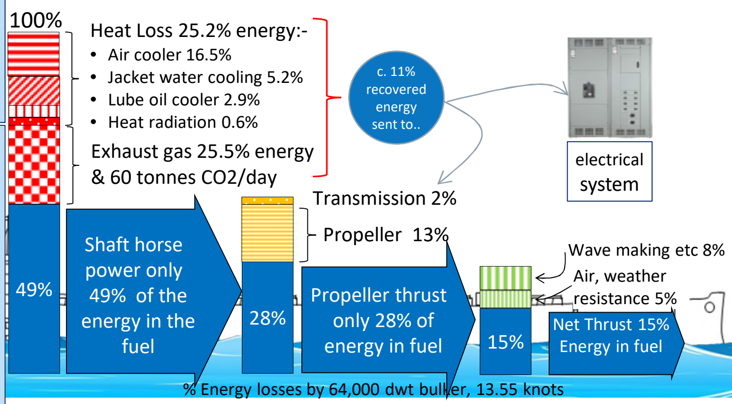
Future cargo transport – decisions about this technical hotch-potch only make sense by economic analysis!!

PROPULSION OPTIONS

I. Internal Combustion engine with shaft drive
II. Electric motor/s with: -
- Diesel-generators
- Battery, fuel cell

GREEN FUELS

1. **"Cleaner" fossil fuels**: - for example LNG, LPG
2. **Biofuels** *(organic)*
3. **Electricity:** from: -
   1. *Solar panels*
   2. *Wind turbines*
   3. *Nuclear boilers*
4. **Green fuels** *made with green electricity: -*
   - *a) Hydrogen*
   - *b) Methanol*
   - *c) Ammonia*
   - *d) Hydrogen*
5. **Carbon capture** *(CCS):*



6. Operations
   - a) Cargo size
   - b) Voyage plan: -
     - I. Just in time
     - II. Ballast
     - III. Trim
     - IV. Dead freight
     - V. Port operations
     - VI. Off hire plan

5. Speed in service & ballast

$$E6(4)\ \ F = F^{*}\left(\frac{S}{S^{*}}\right)^{a}$$

where:
F = actual fuel (tons/day)
S= actual speed
F*= design fuel (tons/day)
S*= design speed

1. Fuel "combustion" loss 51%
   - a) Waste heat recovery
   - b) Battery hybrid combi
   - c) Power optimization
   - d) Advanced maintenance
   - e) Tune management

2. Transmission loss 21 % Fuel
   - a) Propeller speed & size
   - b) Propeller design & condition
   - c) Wake equalizer
   - d) Pre-swirl (e.g. Mewis duct)
   - e) New propulsor (e.g. flipper)

3. Wave making 13%
   - a) Speed
   - b) Hull dimensions

4. Hull design 15%
   - a) Block coefficient,
   - b) Hull condition
   - c) Air lubrication
   - d) Ballast design
   - e) Lighter structure

Source: Compiled by Martin Stopford in 1979 from various sources, updated 2021

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QUICK OVERVIEW – NYK Eco Ship 2050 uses clever emission shaving techniques, but which will work commercially?

1. Powered by hydrogen fuel cells using renewable energy.
2. Waste heat recovered from fuel cells & solar power.
3. Hull weight reduced by light superstructure materials.
4. Computer-controlled gyro stabilizers.
5. An air-lubrication & auto hull-cleaning in port.
6. Propellers replaced by flapping foils like dolphins.
7. Maintenance is managed through digital twins.
8. Route planning at a fleet level from shore.
9. Automatic mooring
10. ship-to-ship cargo handling

HINT – FUTURE ENERGY COST CRUCIAL IN ANY INVESTMENT ANALYSIS!

	Conventional Vessel	NYK Super Eco Ship 2050
Length Overall	199.9 m	199.9 m
Breadth	35.6 m	49.0 m
Draft	9.0 m	9.0 m
Air Draft	45.6 m	31.0 m
Main Power (Fuel)	Diesel Engine (C heavy oil)	Fuel Cells (Hydrogen)
Renewable Energy	None	Solar Power

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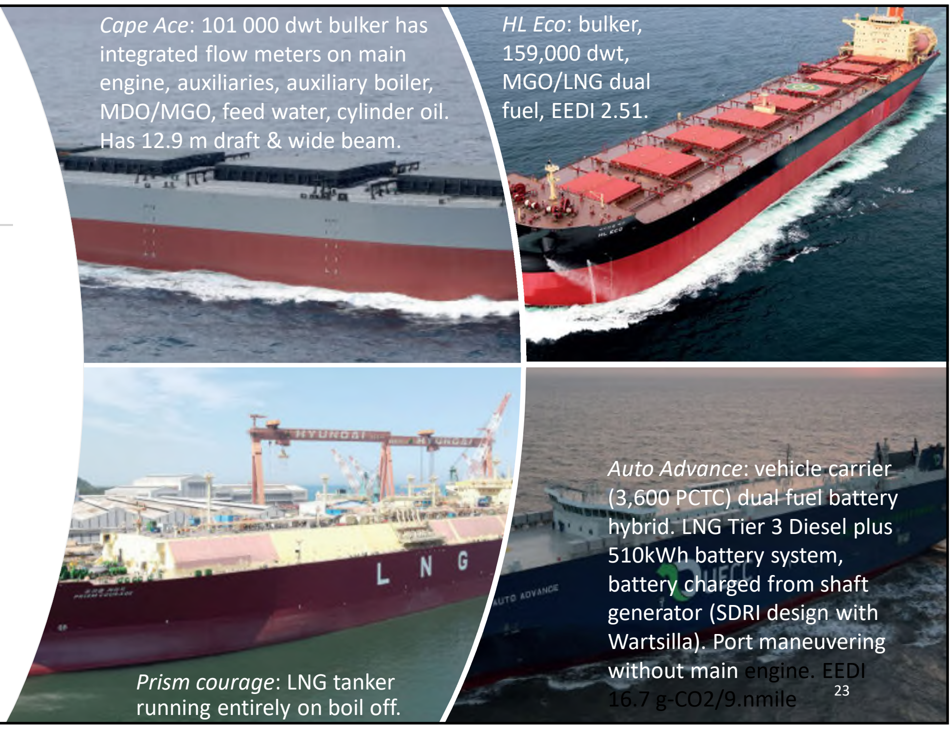
REFINEMENT ENGINEERING IN DEEP SEA SHIPS:

There are many ways of improving the efficiency of deep-sea ships.

- Real time digtal monitoring of oil/energy use.
- Big, shallow draft ship (if you can fill it).
- Burning cargo boil off.
- Battery support for port entry and electric load management.
- Dual fuel engines.



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Refinement engineering in short sea cargo and service ships: developing using battery and hybrid designs.

- *Altera wave*: - shuttle tanker, 4x MS engines, LNG/collected VOCs/ MDO (backup). Battery surge support for on board electrical supply (2x1.8 kWh units)
- *Bjorg Pauline*. Hybrid LNG and battery fish carrier (Has battery support for on board systems, chargeable on shore (Tersan)
- *Hydrobingo* – diesel & hydrogen
- *Yara Birkeland* – all electric containership

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5. THE ECONOMIC GOVERNANCE OF CHANGE

1. International Maritime Organisation (IMO)
2. The Flag States
3. The Shipping Company Boards
4. The Ship Master and his/her Officers

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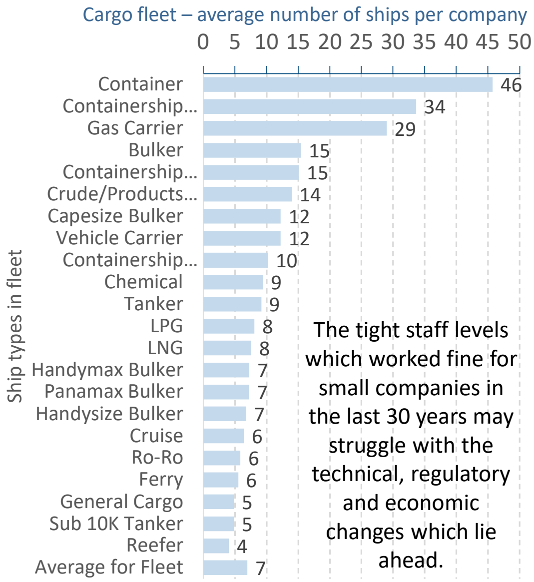
Average Shipping Company: seven ships and limited technical resources

1. Climate change and digital technology raise governance issues.
2. Maritime governance should not be a "top down" process.
3. The 4 tiers of governance are: -
   - Tier 1: IMO and ILO,
   - Tier 2: Nations (the flag states),
   - Tier 3: Shipping company board,
   - Tier 4: ship's master and officers.
4. Tier 3, the shipping companies, must execute the transition to zero carbon, were not developed to manage change on this scale.
5. Adapting Tier 3 organisational structures and resources will be crucial to achieve Tier 1 and Tier 2 zero carbon goals and introducing digital technologies to measure and improve performance.
6. Tier 4 shipboard governance raises many issues



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THE KEY ROLE OF ENTREPRENEURS IN MANAGING CHANGE

Entrepreneurs played a big part in making new technology work.

Table 1: Ten of merchant shipping's top entrepreneurs

	Name	Date	Innovation	
1	Alfred Holt	1855-65	Efficient marine steam engine	1860-1949
2	Ivor Knudsen	1898-1913	Marine diesel engine	
3	Gustav Eriksen	1920-49	Last commercial sailng ship	
4	Olaf Wallenius (OW)	1954-1970	Car carrier/deep sea roro	
5	Jacob Stolt Nielson	1955 on	Chemical parcel tanker	1950 - 1980
6	Kristian Gerhard Jebsen	1958-70	Open hatch bulk carriers	
7	D. K. Ludvig	Late 1960s	Combined carrier	
8	Dr Hisashi Shinto	1970s	Shipbuilding construction	
9	Henri Kummerman	1950s	Hatch covers	
10	Malcolm McLean	1950s-60s	Containerised sea transport	

Source: compiled by Martin Stopford on the back of an envelope

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Malcolm McLean, the entrepreneur who made containers work at sea, had to do a staggering amount of work. It took about 12 years to launch the first transatlantic service. Starting with a few old tankers, he : -

1. Believed containerisation needed a complete change in ships, organisation and cargo systems.
2. Endlessly calculated, quantified and monitored total cost savings by containers.
3. Built a new organisation, hiring top technical people to design & test containers, cranes, ships, cell guides. And to sell cargo. And to monitor fleet performance etc.
4. Supervised all detail for first 12 years, constantly “walking around” to check what was going on.
5. Persuaded regulators (initially ABS and the coast guard) and the unions that containers were safe.
6. Raised capital and managed the competition.
7. Stick with it for 12 years until his first N Atlantic container ships went into service in 1966.

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Conclusions on the new era of change

- After an era of little change shipping companies need a versatile voyage plan for the next 25 years.
- Ship propulsion will be a blend of internal combustion engines (ICE), batteries, fossil fuels, green fuels and nuclear.
- The ability to harvest digital information about the performance of the ship and transport will become increasingly important in automating processes and dealing with cargo, ports, customers and regulators.
- The new era would benefit from a new approach to company governance.

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