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The 14th Annual Capital Link Shipping & Marine Services,

Dr Martin Stopford

18th October 2022

Shipping in the Era of Change

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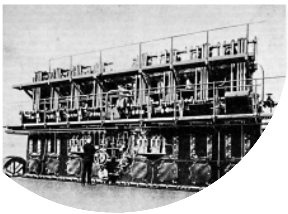

Diesel engine 110 years ago

Diesel ship today

1. THE GLOBAL SEA TRANSPORT SCENARIOS 2020-50 & THE "GREEN ENERGY GAP"
2. WORLD FLEET–WAVES OF INVESTMENT 2020-2050
3. MARITIME TECHNOLOGY – WHERE WE ARE NOW WITH TECHNICAL SOLUTIONS
4. OPTIONS FOR CLOSING THE GREEN ENERGY GAP IN THE 2030s & 2040s

1

1

The aim is to review the work to be done to DECARBONIZE sea transport by 2050

1. THE GLOBAL SEA TRANSPORT EMISSIONS SCENARIOS 2020-50 & THE "GREEN ENERGY GAP".

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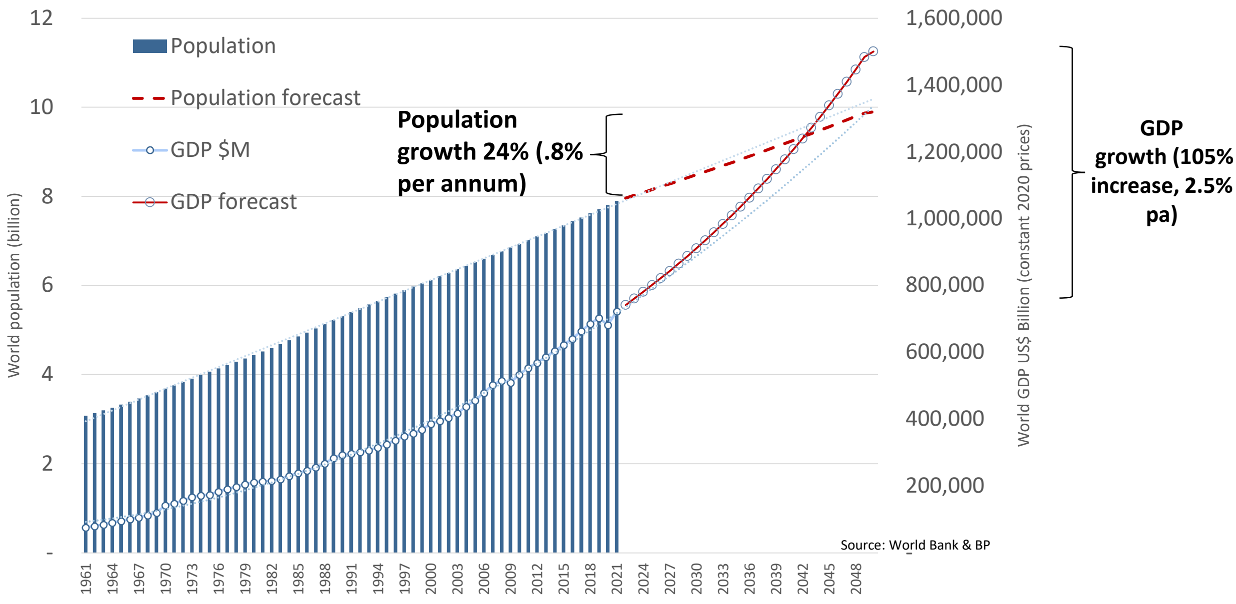
2

Population and GDP growth will increase cargo volumes and ship demand



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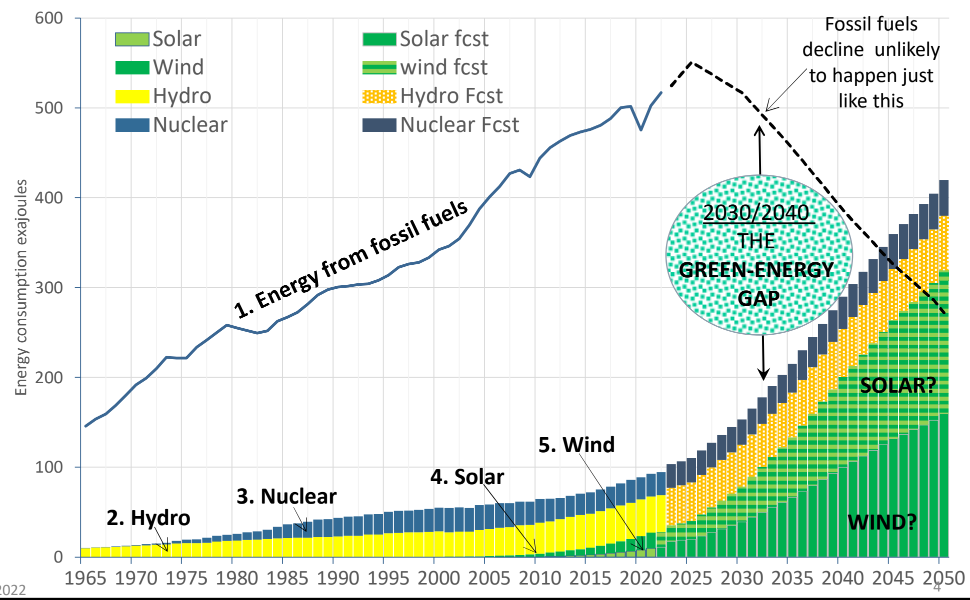
Much competition for limited supply of green fuel in 2020s

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

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



4

36 wind turbines 10 MW each needed to power containership like this with about 400 tonnes a day of green methanol
1. FUEL COST
36 offshore turbines cost about $1.1 billion and $100k/day to run
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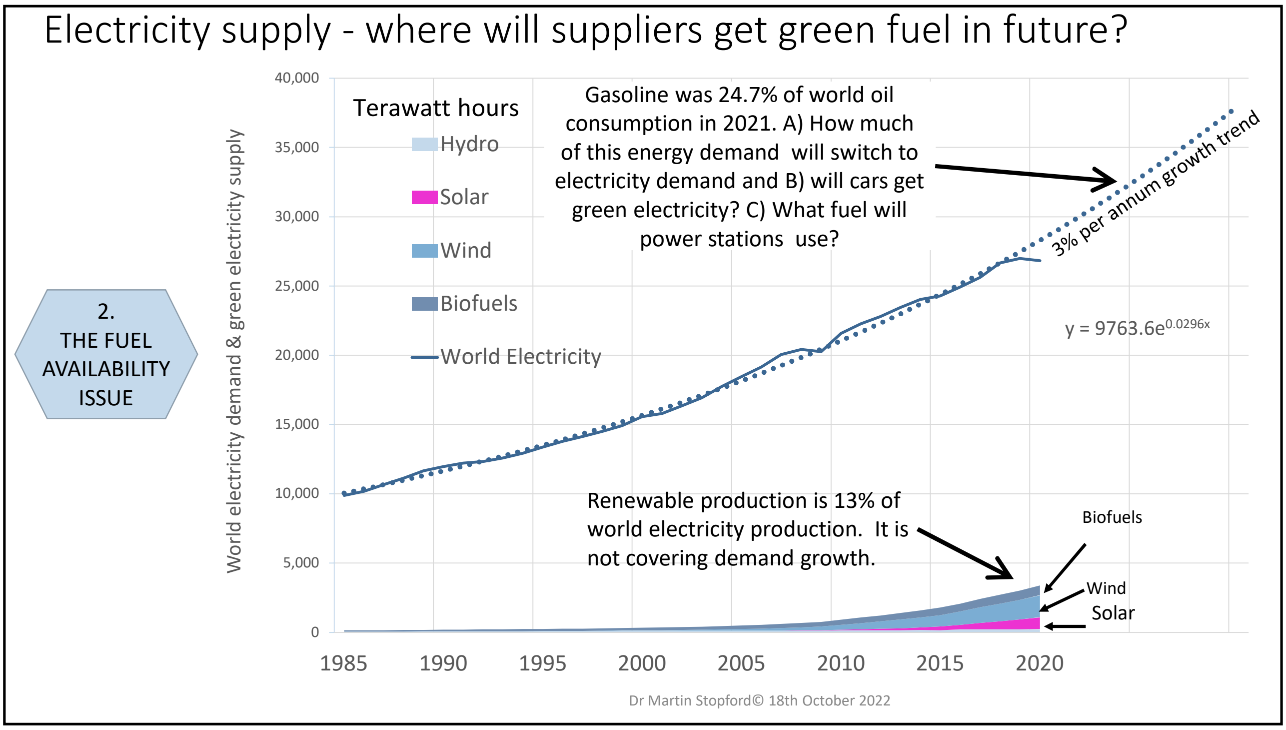
5



Electricity supply - where will suppliers get green fuel in future?
2. THE FUEL AVAILABILITY ISSUE
World electricity demand & green electricity supply
Terawatt hours
Hydro
Solar
Wind
Biofuels
World Electricity
Gasoline was 24.7% of world oil consumption in 2021. A) How much of this energy demand will switch to electricity demand and B) will cars get green electricity? C) What fuel will power stations use?
3% per annum growth trend
y = 9763.6e0.0296x
Renewable production is 13% of world electricity production. It is not covering demand growth.
Biofuels
Wind
Solar
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
1985
1990
1995
2000
2005
2010
2015
2020
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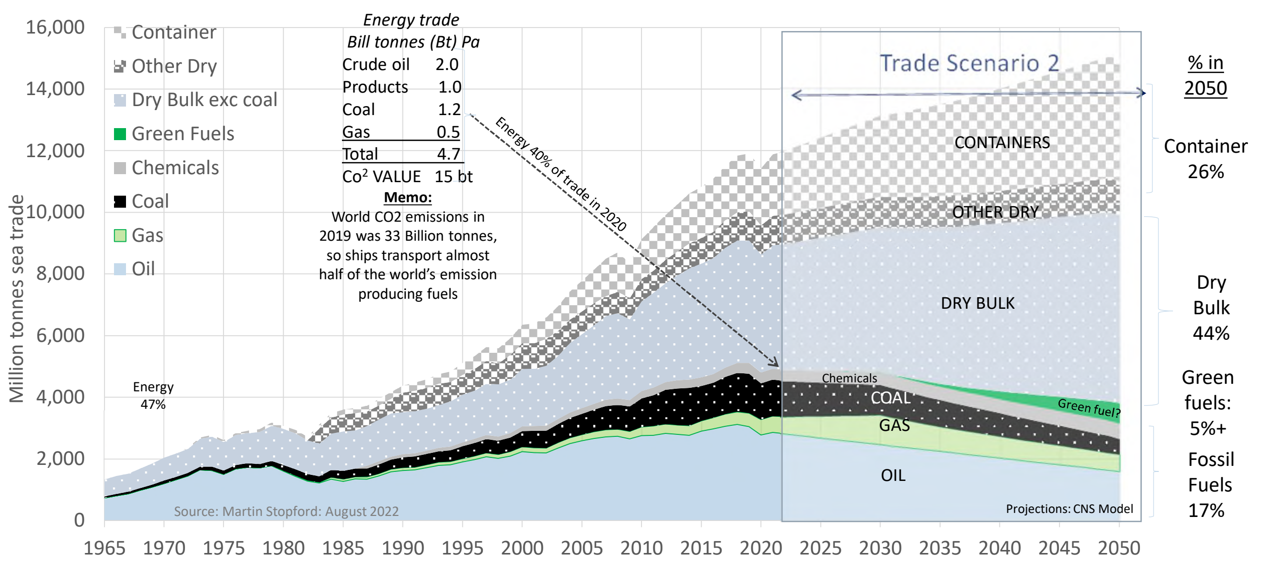
6

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)



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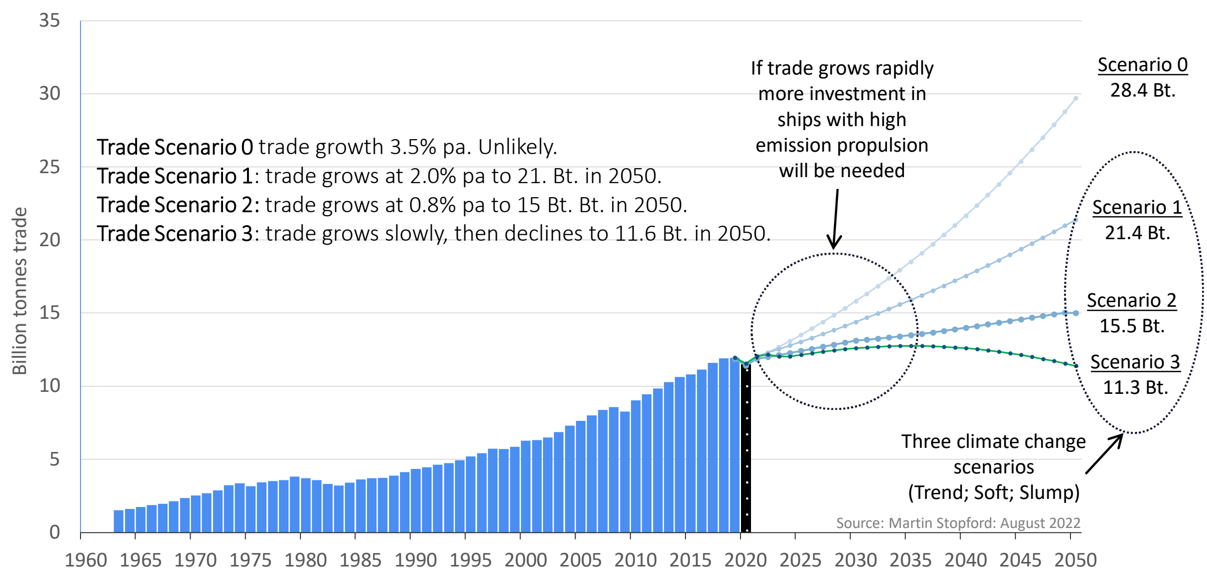
7

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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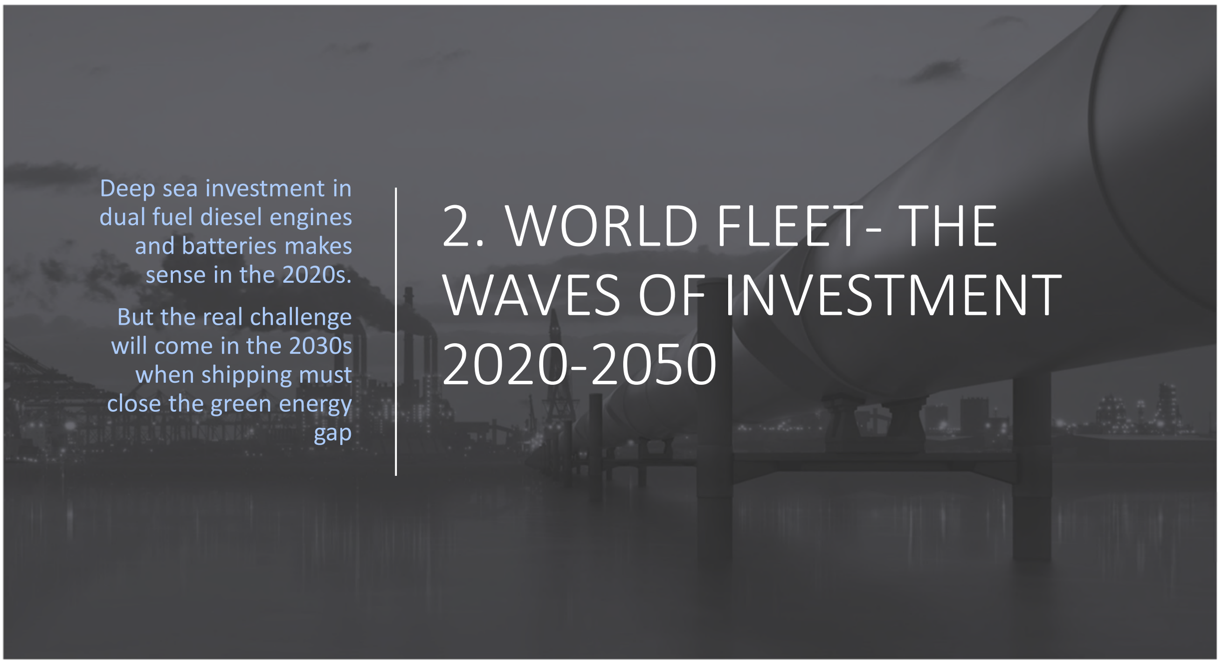
8



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9

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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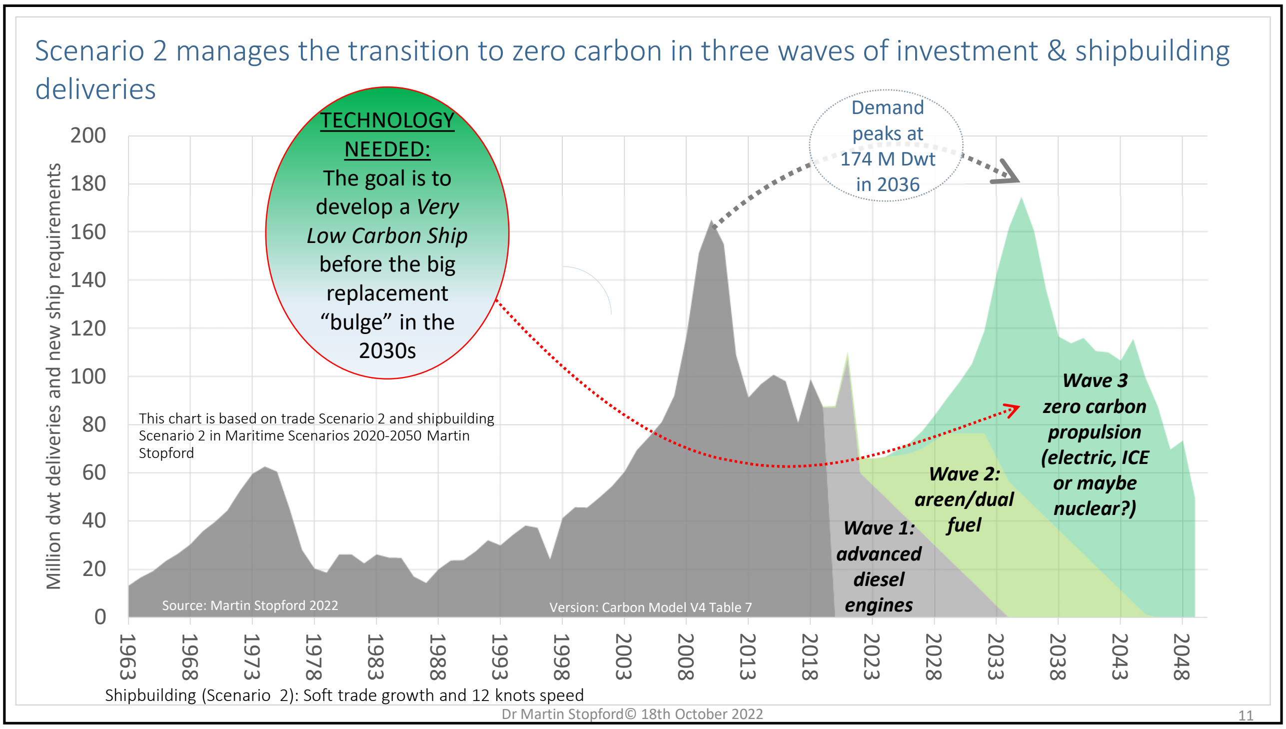
10



Scenario 2 manages the transition to zero carbon in three waves of investment & shipbuilding deliveries
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
Million dwt deliveries and new ship requirements
This chart is based on trade Scenario 2 and shipbuilding Scenario 2 in Maritime Scenarios 2020-2050 Martin Stopford
Wave 3 zero carbon propulsion (electric, ICE or maybe nuclear?)
Wave 2: green/dual fuel
Wave 1: advanced diesel engines
Source: Martin Stopford 2022
Version: Carbon Model V4 Table 7
Shipbuilding (Scenario 2): Soft trade growth and 12 knots speed
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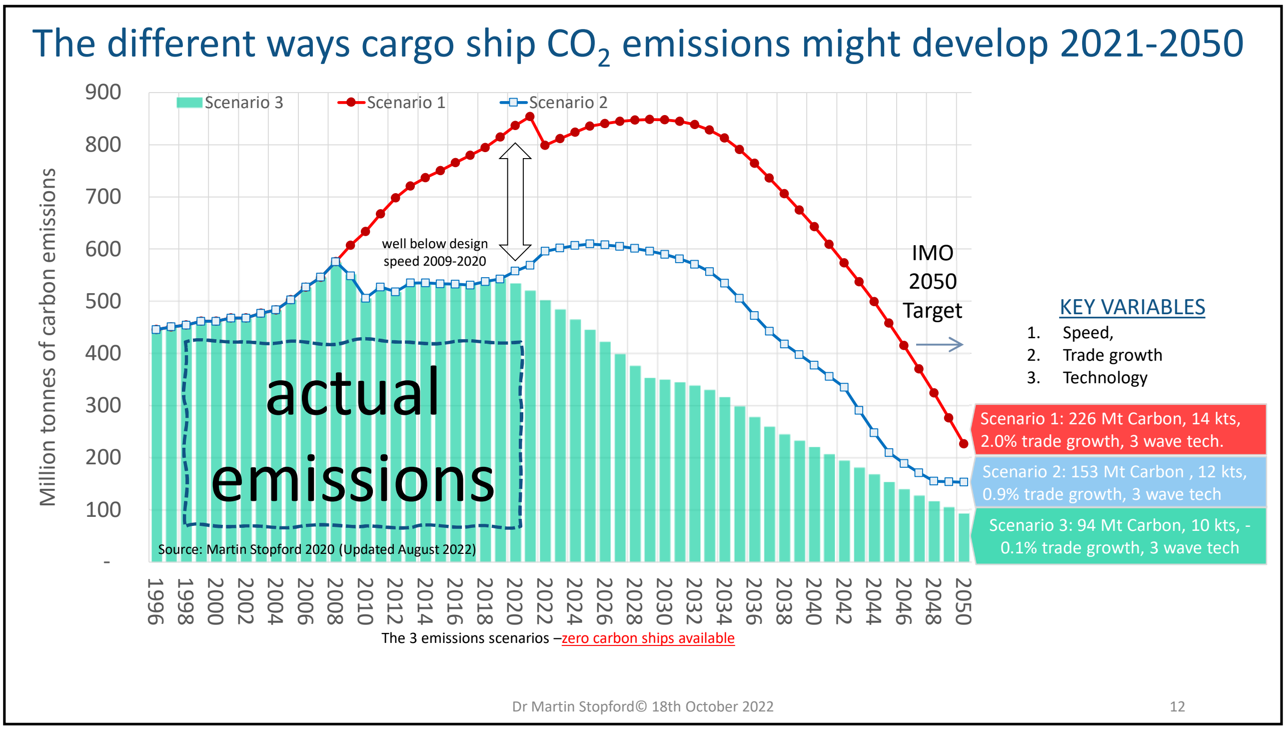
11



The different ways cargo ship CO2 emissions might develop 2021-2050
Scenario 3
Scenario 1
Scenario 2
Million tonnes of carbon emissions
well below design speed 2009-2020
actual emissions
IMO 2050 Target
KEY VARIABLES
1. Speed,
2. Trade growth
3. Technology
Scenario 1: 226 Mt Carbon, 14 kts, 2.0% trade growth, 3 wave tech.
Scenario 2: 153 Mt Carbon , 12 kts, 0.9% trade growth, 3 wave tech
Scenario 3: 94 Mt Carbon, 10 kts, -0.1% trade growth, 3 wave tech
Source: Martin Stopford 2020 (Updated August 2022)
The 3 emissions scenarios –zero carbon ships available
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12

12

3. MARITIME TECHNOLOGY – WHERE ARE WE NOW WITH TECHNICAL SOLUTIONS?

Investment not easy – holistic approach needed. with many technologies and uncertain costs, commercial decisions will be difficult.

DEEP SEA TRADES – "dual fuel" engines available for deep sea trades, mainly ammonia & methanol

SHORT SEA SHIPS: electric propulsion becoming viable over shorter distances. Battery costs falling.

CLOSING THE GREEN ENERGY GAP: still searching for the best way to produce LARGE NUMBERS OF ZERO CARBON SHIPS IN 2030s and 2040s

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13

Holistic design difficult - many technologies & uncertain costs are making decisions complex: -

1. GREEN FUEL

1. **"Cleaner" fossil fuels**: - e.g. LNG, LPG (limited)
2. **Biofuels; (**limited)
3. **Green electricity from**: -
   1. Solar panels
   2. Wind turbines
   3. Nuclear reactors.
   4. Batteries

4. FUEL from green electricity: -
   a) Hydrogen
   b) Methanol
   c) Ammonia
   d) Batteries

5. Carbon capture *(CCS):*

2. PROPULSION SYSTEMS

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

3. SHIP DESIGN "TUNING"

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

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

3. Wave making 13%
   a) Speed
   b) Hull design,/dimensions

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

4. TRANDPORT PRODUCTIVITY

1. Operations
a) Cargo size.
b) Voyage plan: -
- Passage management
- Ballast management
- Trim management
- Dead freight
- Port operations
- Off hire plan

2. Service & ballast speed

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

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

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14

Four Fuel Options: methanol, hydrogen, ammonia and nuclear

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

all numbers relate to liquid product

FOUR GREEN FUEL OPTIONS

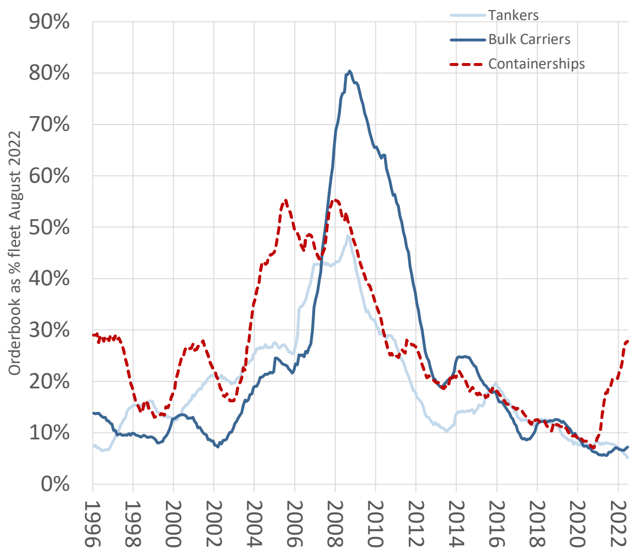
			CHEMICAL							FISSION (1)
			ENERGY+CARBON EMISSIONS					NO CARBON		
Ref			HFO	LNG	LPG	LEG	Methanol	Hydro-gen	Amm-onia	Uranium
	memo: Chemical composition		Composit	C_2H_6,	C_3H_8	C_2H_6	CH3OH	H2	NH3	U235
1	Boiling point	˚C at 1 bar pressure	150	-166	-26.2	-89	65	-253	-33	4131
2	Energy density by volume (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

15

SO FAR INVESTMENT IN GREEN SHIPS REMAINS SLUGGISH....

- Containers investing quite heavily.
- Dry bulk and tanker investment very low, despite firm markets.
- Dual fuel LNG orders in specialist sectors & some Methanol

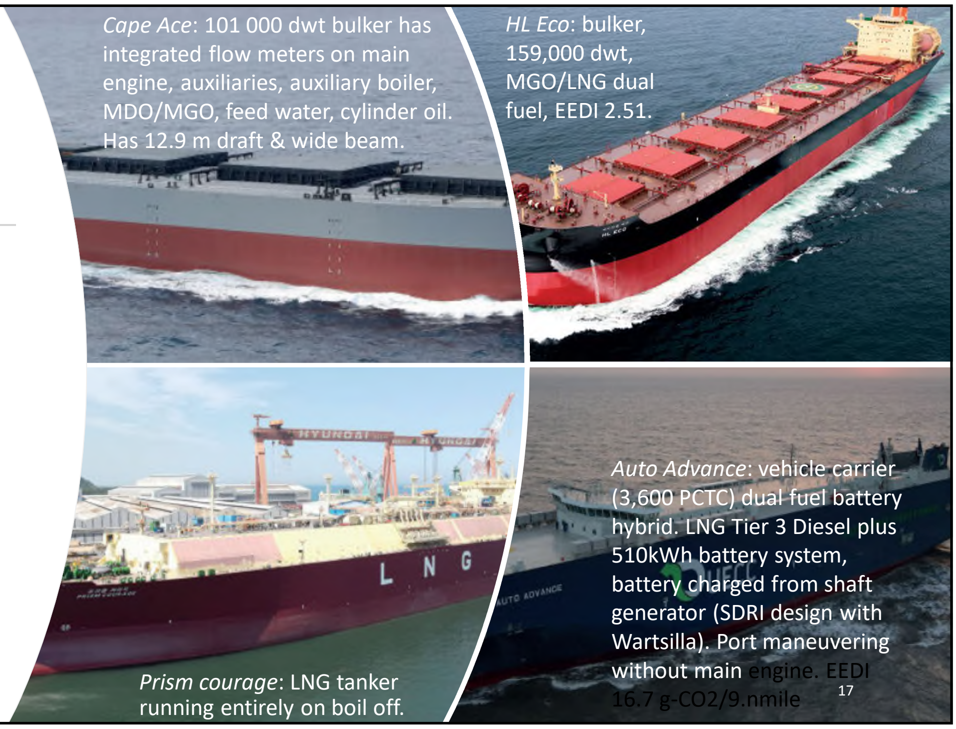


16

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.**



Cape Ace: 101 000 dwt bulker has integrated flow meters on main engine, auxiliaries, auxiliary boiler, MDO/MGO, feed water, cylinder oil. Has 12.9 m draft & wide beam.

HL Eco: bulker, 159,000 dwt, MGO/LNG dual fuel, EEDI 2.51.

Prism courage: LNG tanker running entirely on boil off.

Auto Advance: vehicle carrier (3,600 PCTC) dual fuel battery hybrid. LNG Tier 3 Diesel plus 510kWh battery system, battery charged from shaft generator (SDRI design with Wartsilla). Port maneuvering without main engine. EEDI 16.7 g-CO2/9.nmile

17

17

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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18

4. SHORT TERM VERSUS LONG TERM STRATEGY – KEY ISSUE IS TO CLOSE THE "GREEN ENERGY GAP" IN THE 2030s AND 2040s

SHORT-TERM STRATEGY: NOW FAIRLY CLEAR

- **2020s-DEEP SEA: slow speed diesel engines with dual fuel capability (LNG, hydrogen, methanol, ammonia etc).**
- **2020s -SHORT SEA- electric propulsion "interesting" over shorter distances. Battery costs falling.**

LONG-TERM STRATEGY: TWO OPTIONS or CHOICES?

- **Option 1: RENEWABLES** – **Build a new generation of ships integrating all the existing technology into zero carbon vessels.**
- **Option 2: NUCLEAR** – **Develop nuclear fission as on-board power for the biggest ships and to provide bunker supplies for electric ships**

19

Option 1: RENEWABLES -NYK Super Eco Ship 2050 illustrates one way to go

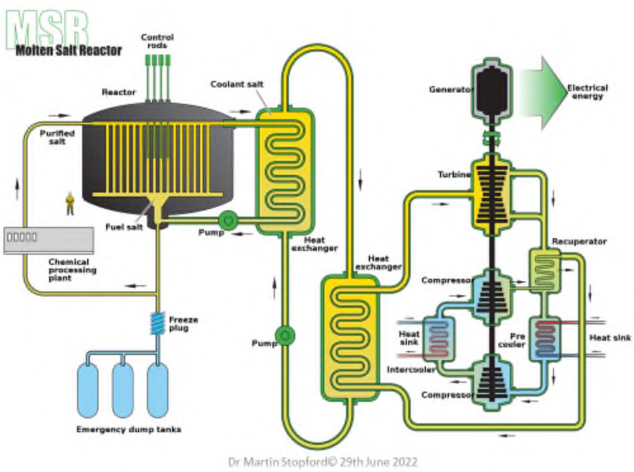
	Conventional Vessel	NYK Super Eco Ship 2050
Length Overall	199.9 m	199.9 m
Breadth	35.6 m	49.0 m
Draft	9.0 m	9.0 m
Air Draft	45.6 m	31.0 m
Main Power (Fuel)	Diesel Engine (C heavy oil)	Fuel Cells (Hydrogen)
Renewable Energy	None	Solar Power

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 and ship-to-ship cargo handling

20

Option 2: Now for something completely different – a Molten Salt Reactor(MSR)

- 20-90 MW reactor assembled in a factory. Weighs about 40 tonnes.
- Works at ambient pressure, so no risk of a radiation plume*
- Operates at 750 degrees C.
- Liquid fuel in the coolant cannot escape.
- 30 years without refueling & most fuel recovered.
- Reaction slows as temperature increases, a useful safety feature.
- Can consume waste fission products.
- High residual value.
- Still NOT a done deal – lots to do to make it work commercially especially engineering risk tolerances.



*A plume is a cloud which spreads into the surrounding area, such as a plume of smoke.

21

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21

In previous "revolutions" entrepreneurs drove change. Are we in revolution territory today? It's a question to take seriously.

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	1950 - 1980
5	Jacob Stolt Nielson	1955 on	Chemical parcel tanker	
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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22

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 that 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. Also to sell cargo and monitor fleet performance etc.
4. Supervised all detail for first 12 years, constantly “walking around” to check what was going on. “all staff started in the freight yard”
5. Persuaded regulators (initially ABS and the coast guard) and the unions that containers were safe.
6. Raised capital and managed the competition.
7. Stuck with it, year after year, even when things went badly, which was quite often.

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23

24


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25

25