Altering Course

Plotting the Maritime Energy Transition

Aug 2, 2022

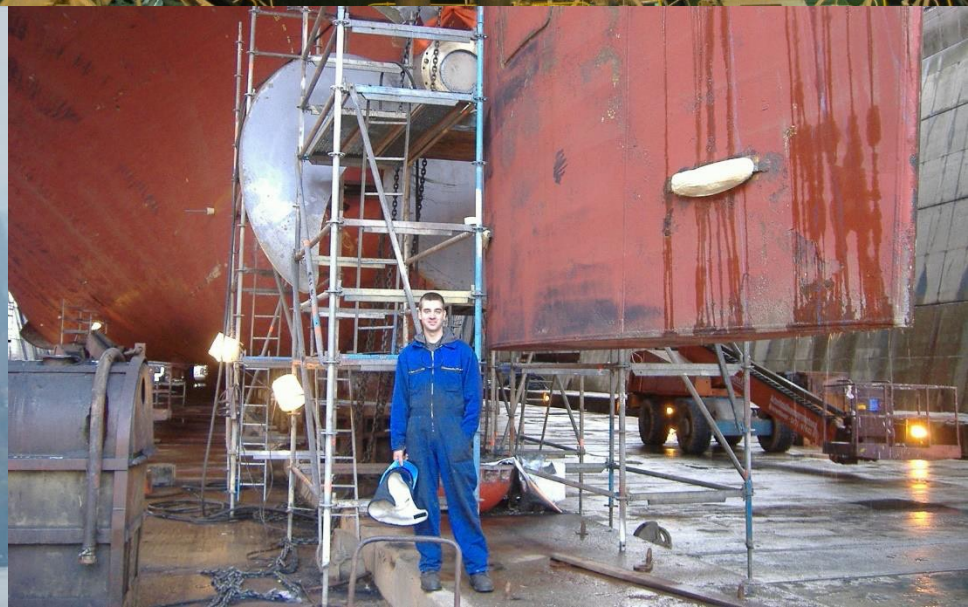
David Hume

M&O, EERE, Maritime Decarbonization Lead
U.S. Department of Energy
david.hume@ee.doe.gov

Marine Energy Manager
Pacific Northwest National Lab
david.hume@pnnl.gov

Grew-up working on Boats…

…Then Graduated to Ships



What is the Maritime Industry?

SHIPS

Transportation of materials, products, and people on the sea or connected waterways and the supporting coastal infrastructure.

PORTS

The Maritime Industry is Truly Global

The Global Fleet of Commercial Vessels

- **Ships are getting bigger on average**
- **Many ships operating are 20 years old or more (e.g. General cargo)**

Vessel type, country grouping by flag of registration and indicator		Years					Average age	
		0–4	5–9	10–14	15–19	More than 20	2021	2020
World								
Bulk carriers	Percentage of total ships	18	37	24	10	10	10.6	10.2
	Percentage of dead-weight tonnage	22	40	23	9	6	9.5	9.3
	Average vessel size (dead-weight tonnage)	90 447	78 409	68 583	68 087	46 623	NA	NA
Container ships	Percentage of total ships	14	19.21	32	17	17	13.2	12.7
	Percentage of dead-weight tonnage	20	29	29	14	7	10.4	9.9
	Average vessel size (dead-weight tonnage)	74 632	78 802	46 897	42 345	21 975	NA	NA
General cargo	Percentage of total ships	5	10	16	9	59	27.1	26.3
	Percentage of dead-weight tonnage	8	20	23	10	40	19.9	19.3
	Average vessel size (dead-weight tonnage)	5 992	7 493	5 494	4 372	2 660	NA	NA
Oil tankers	Percentage of total ships	14	17	21	13	35	19.5	19
	Percentage of dead-weight tonnage	25	21	28	19	8.	10.9	10.4
	Average vessel size (dead-weight tonnage)	96 122	65 148	72 208	80 802	12 346	NA	NA
Other types of ships	Percentage of total ships	10	17	17	9	47	23.6	23.0
	Percentage of dead-weight tonnage	20	16	23	11	30	16.1	15.8
	Average vessel size (dead-weight tonnage)	9 236	4 562	6 524	5 953	3 014	NA	NA
All ships	Percentage of total ships	11	18	19	10	42	21.6	21.1
	Percentage of dead-weight tonnage	22	29	25	13	11	11.2	10.80
	Average vessel size (dead-weight tonnage)	43 364	34 175	28 112	27 809	5 505	NA	NA

Source: “Review of Maritime Transport 2021” UNCTAD

The U.S. Fleet of Maritime Vessels

11 million motorized recreational boats

6,500 government owned boats and ships

16,000 fishing vessels

600 Ferries

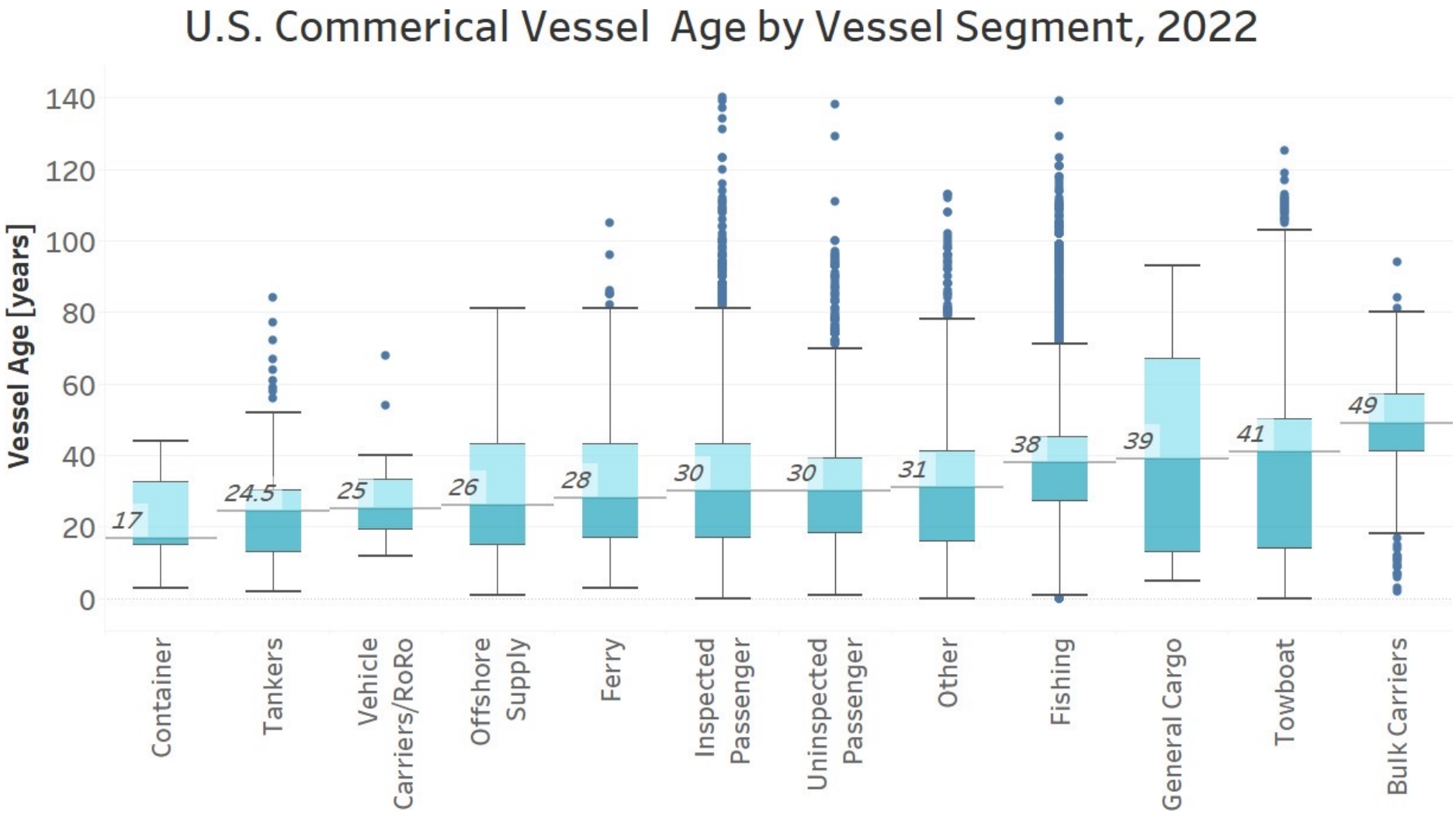
180 Ocean-going cargo ships

6,000 Tugboats

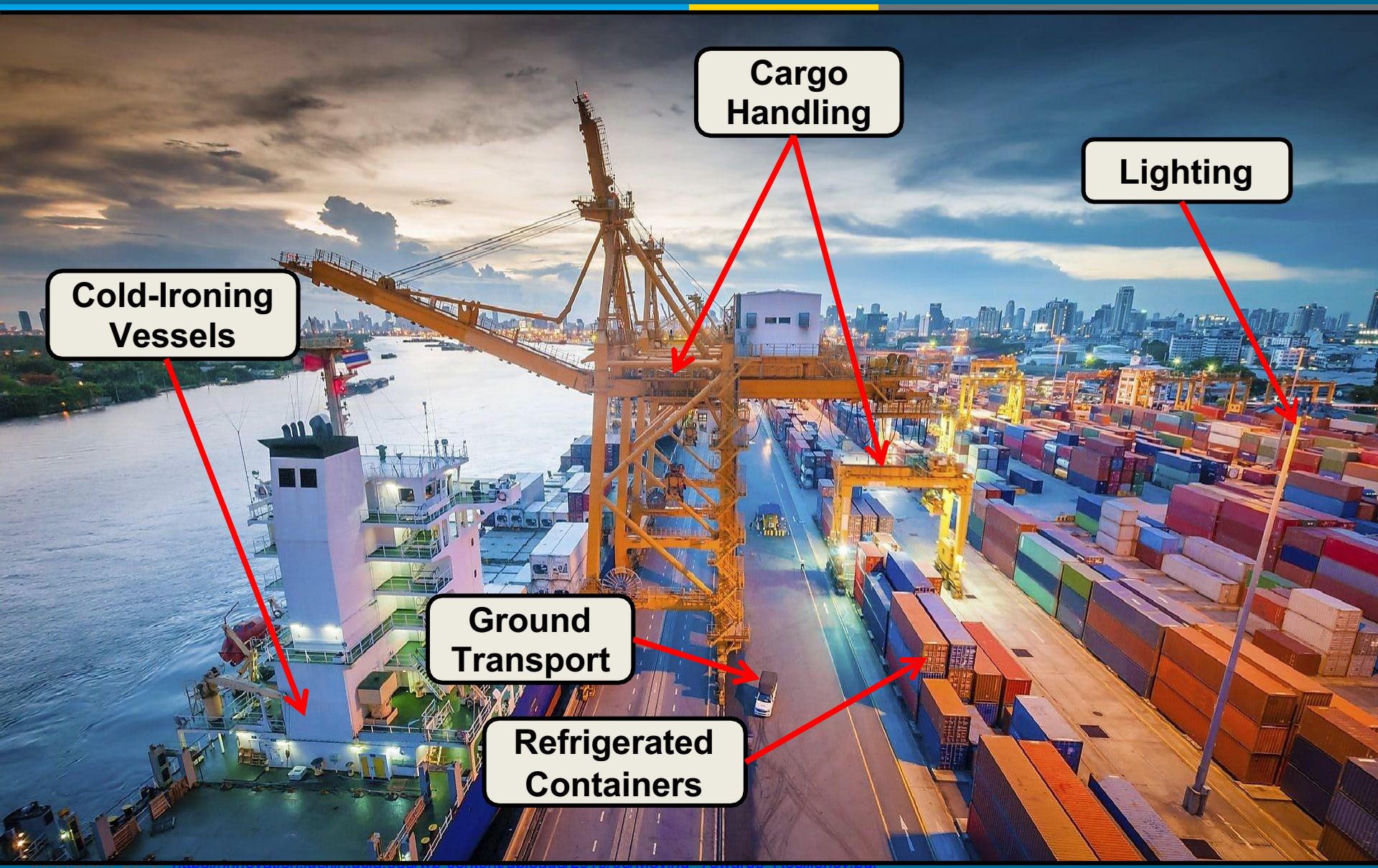
and more…

38,000 commercial vessels

The U.S. Commercial Fleet is Old

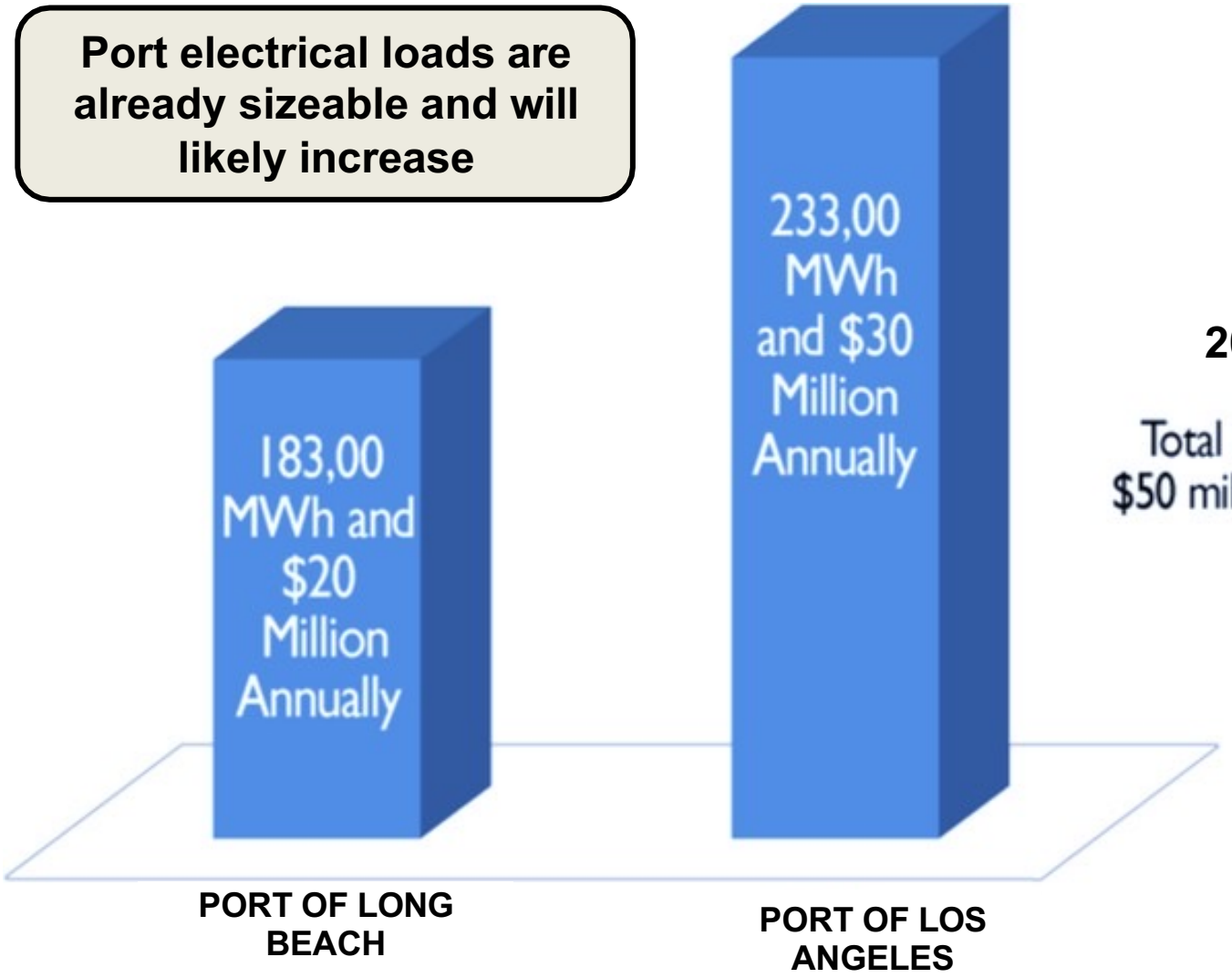


Port Energy Consumers



Ports Consume Lots of Energy

Port electrical loads are already sizeable and will likely increase



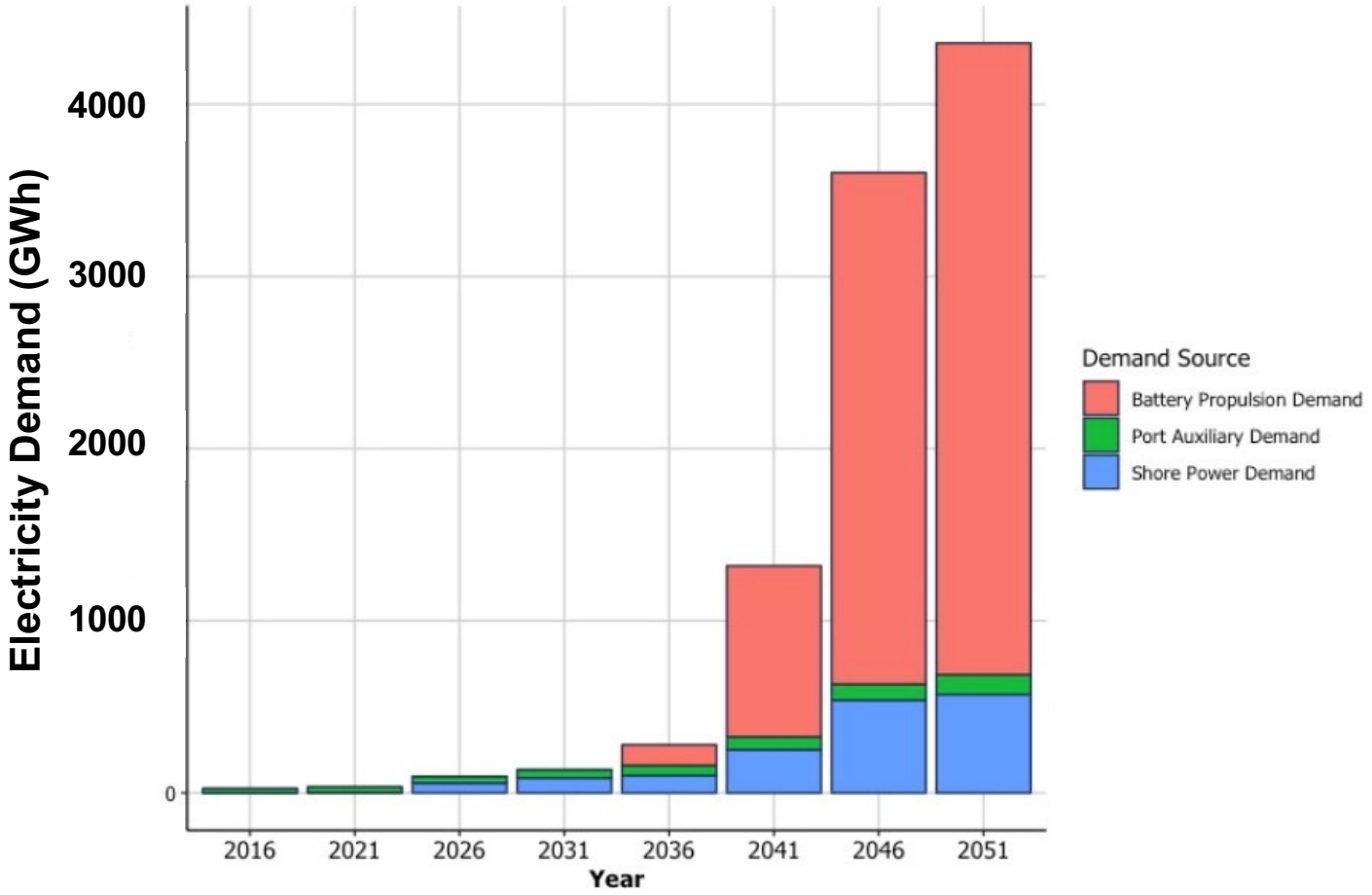
2013 Values

Total Electricity Cost = $50 million total each year

Source: "Moving Towards Resiliency: *An Assessment of the Costs and Benefits of Energy Security Investments for the San Pedro Bay Ports". UCLA Luskin Center for Innovation. 2013.* https://innovation.luskin.ucla.edu/wp-content/uploads/2019/03/Moving_Towards_Resiliency.pdf

Electricity Demand at Ports is Forecasted to Grow

Annual Total UK Port Electricity Demand Under an Ambitious Decarbonization Scenario

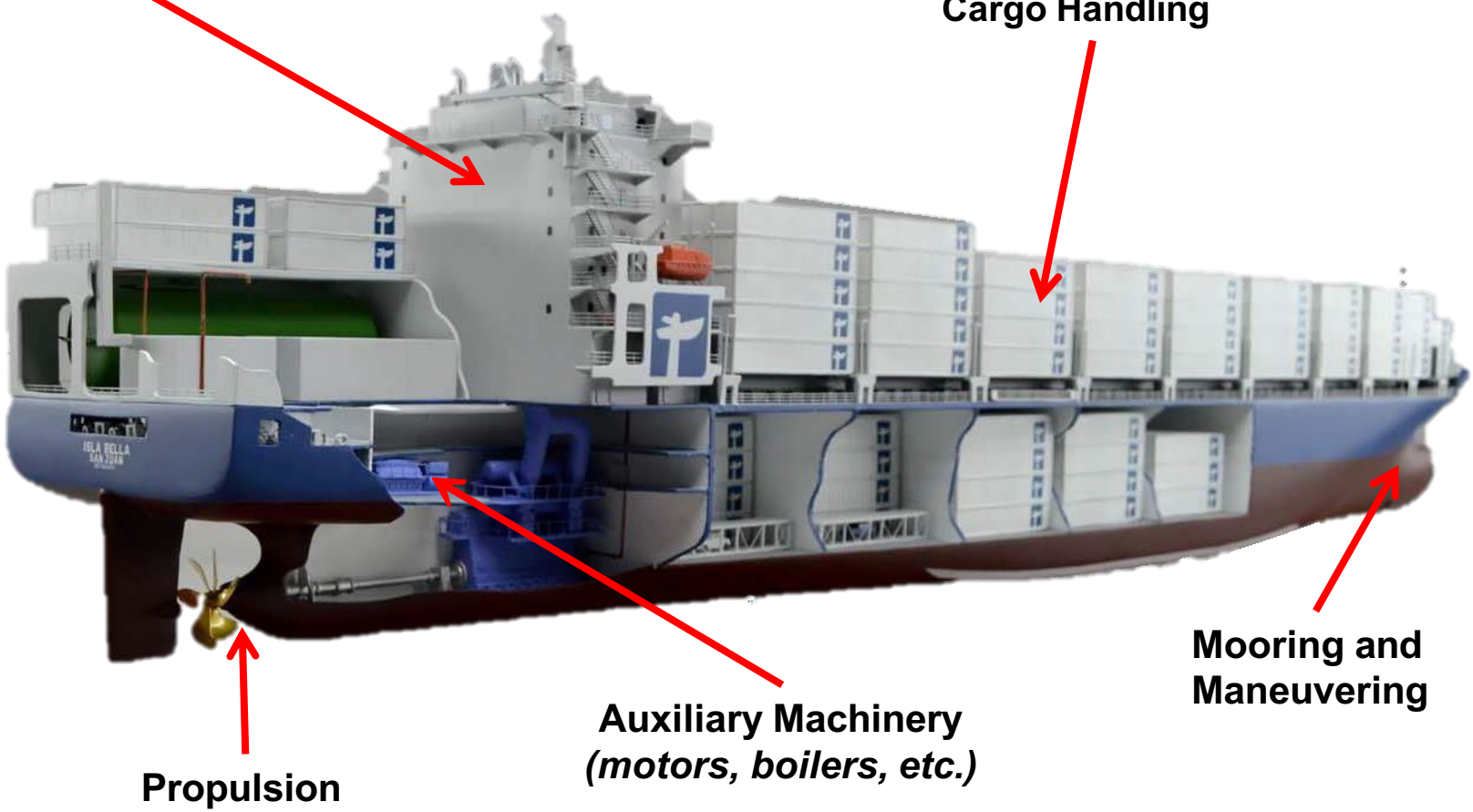


Source: *UMAS modelling*

Note: *The three components of energy demand are battery propulsion which refers to the energy demand from electrified ships (recharging batteries); port auxiliary power demand which refers to the electrification of port infrastructure; and shore power.*

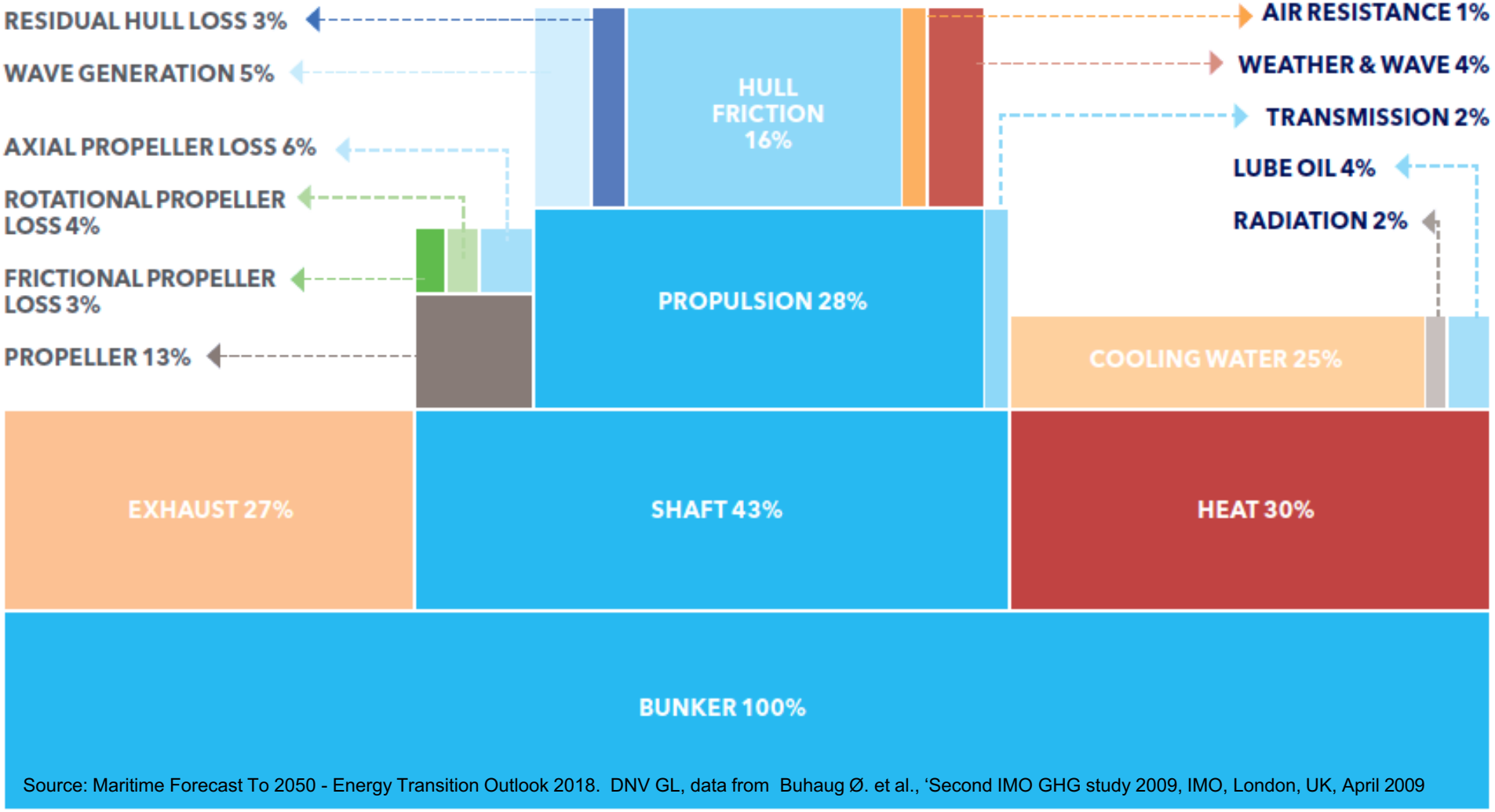
Source: "Reducing the UK Maritime Sector's Contribution to Climate Change and the Potential Role of Targets and Economic Instruments: A Report for the Department for Transport", July 2019.

Major Energy Consumers on a Vessel



Energy Flows on a Vessel

Use of propulsion energy on board a small well-maintained cargo ship in rough head sea



Source: Maritime Forecast To 2050 - Energy Transition Outlook 2018. DNV GL, data from Buhaug Ø. et al., 'Second IMO GHG study 2009, IMO, London, UK, April 2009

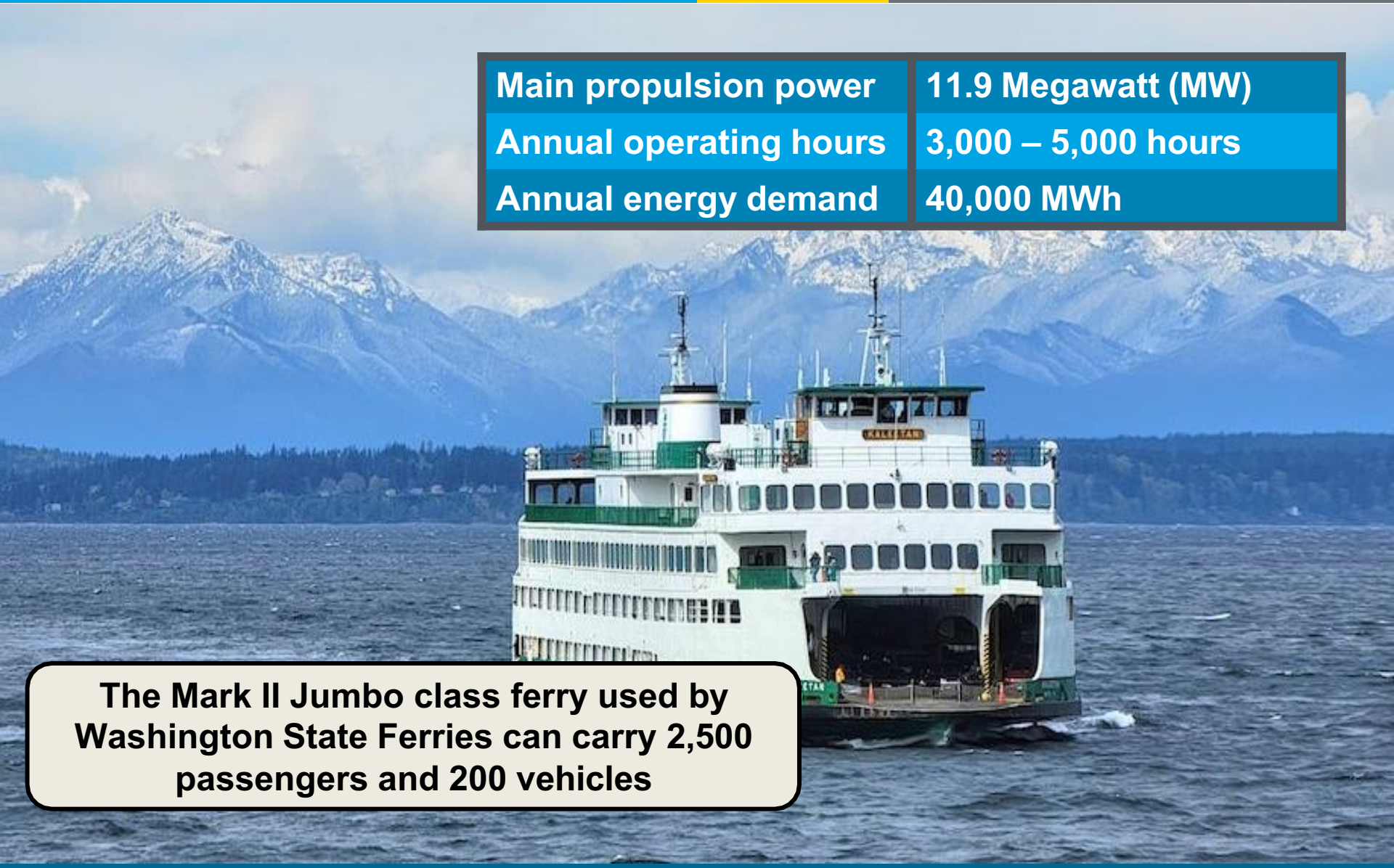
Energy Demands of a Container Ship

This Maersk Triple E Class vessel can carry more than 18,000 containers

Main propulsion power	60 Megawatt (MW)
Auxiliary power and boiler	2 - 7 MW
Annual operating hours	4,000 – 7,000+ hours
Annual energy demand	200,000 MWh

Energy Demands of a Ferry

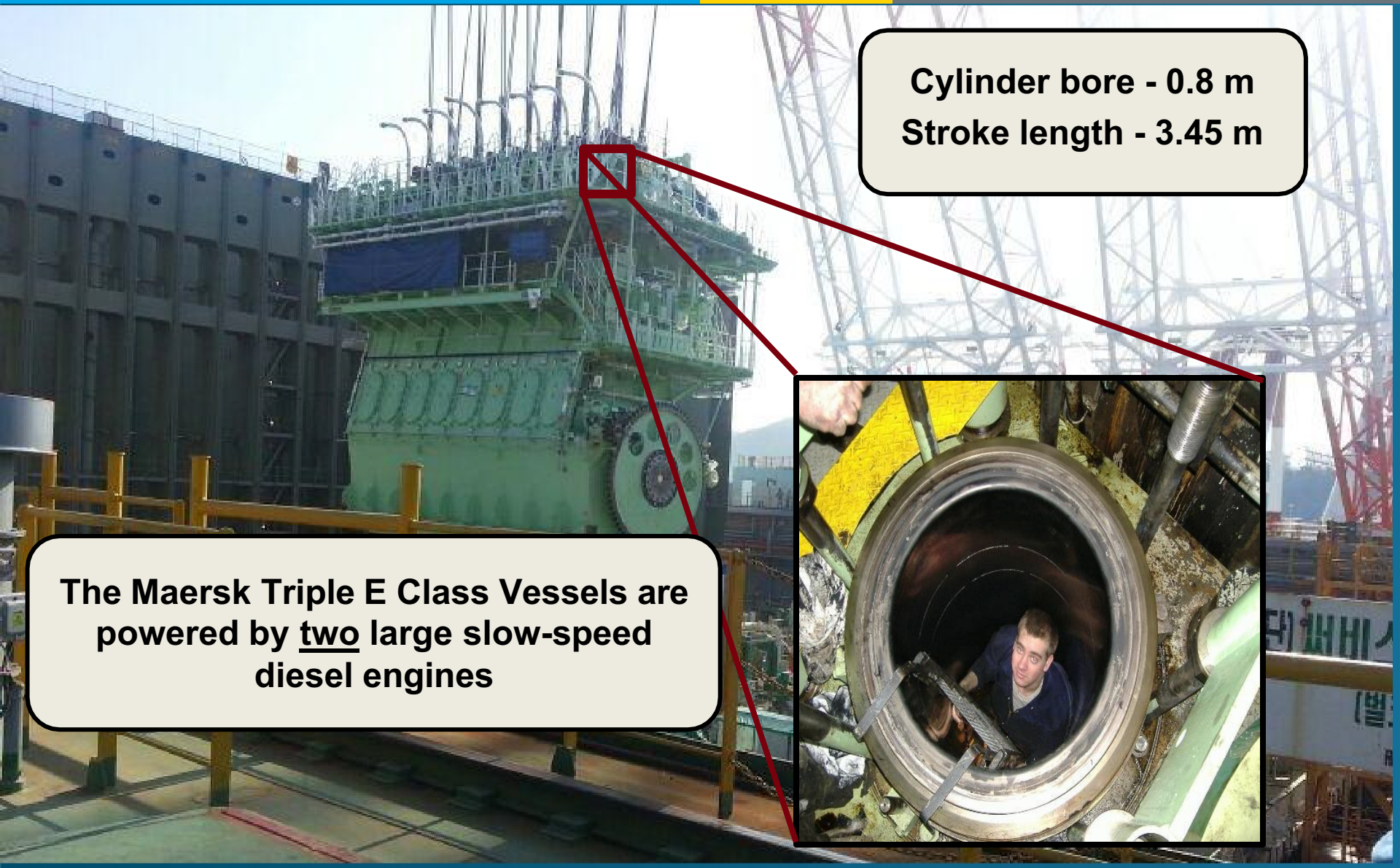
Main propulsion power	11.9 Megawatt (MW)
Annual operating hours	3,000 – 5,000 hours
Annual energy demand	40,000 MWh



The Mark II Jumbo class ferry used by Washington State Ferries can carry 2,500 passengers and 200 vehicles

Commercial Ships are Industrial Power Plants

Commercial Ships Have Really Big Engines



Ships and Energy

Sail

1570s – 1860s

Steam and Coal

1820s – 1920s

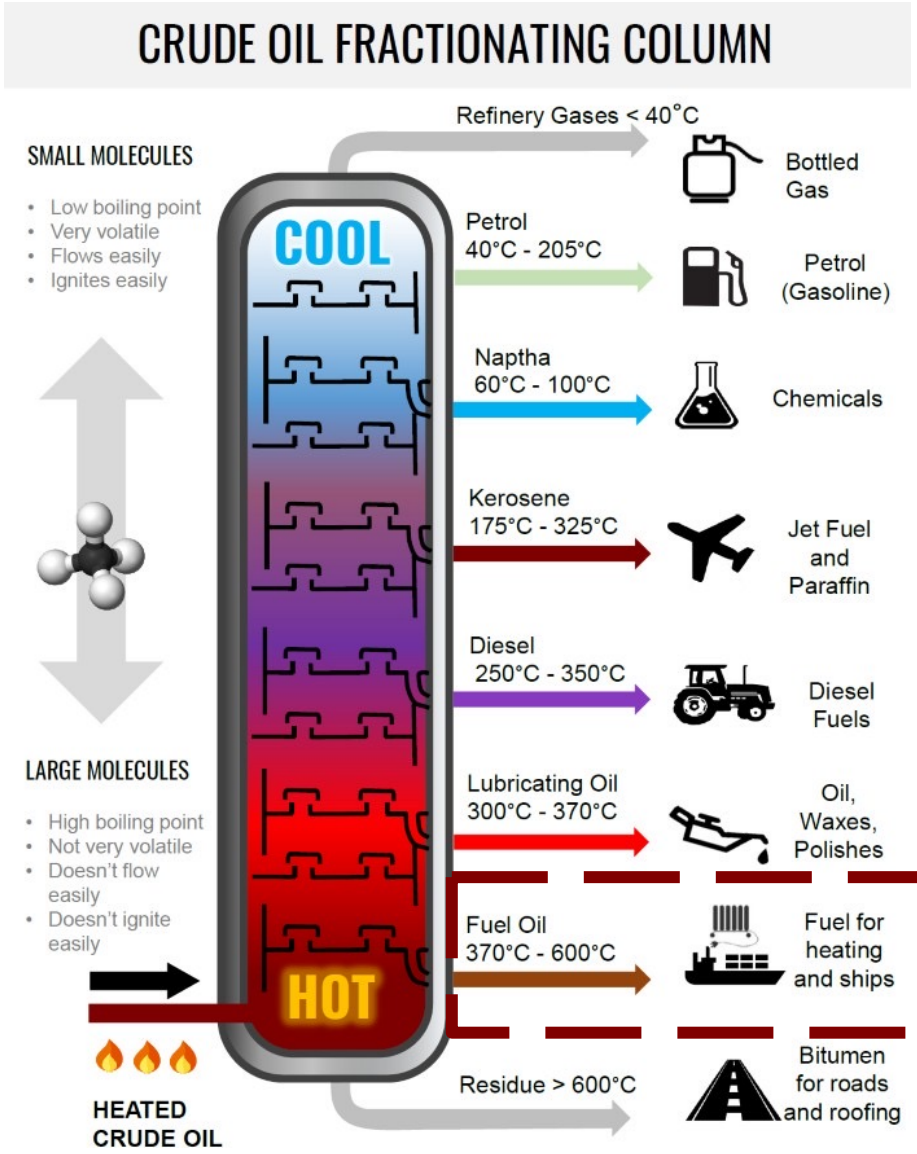
Heavy Fuel Oil

1910s - Present

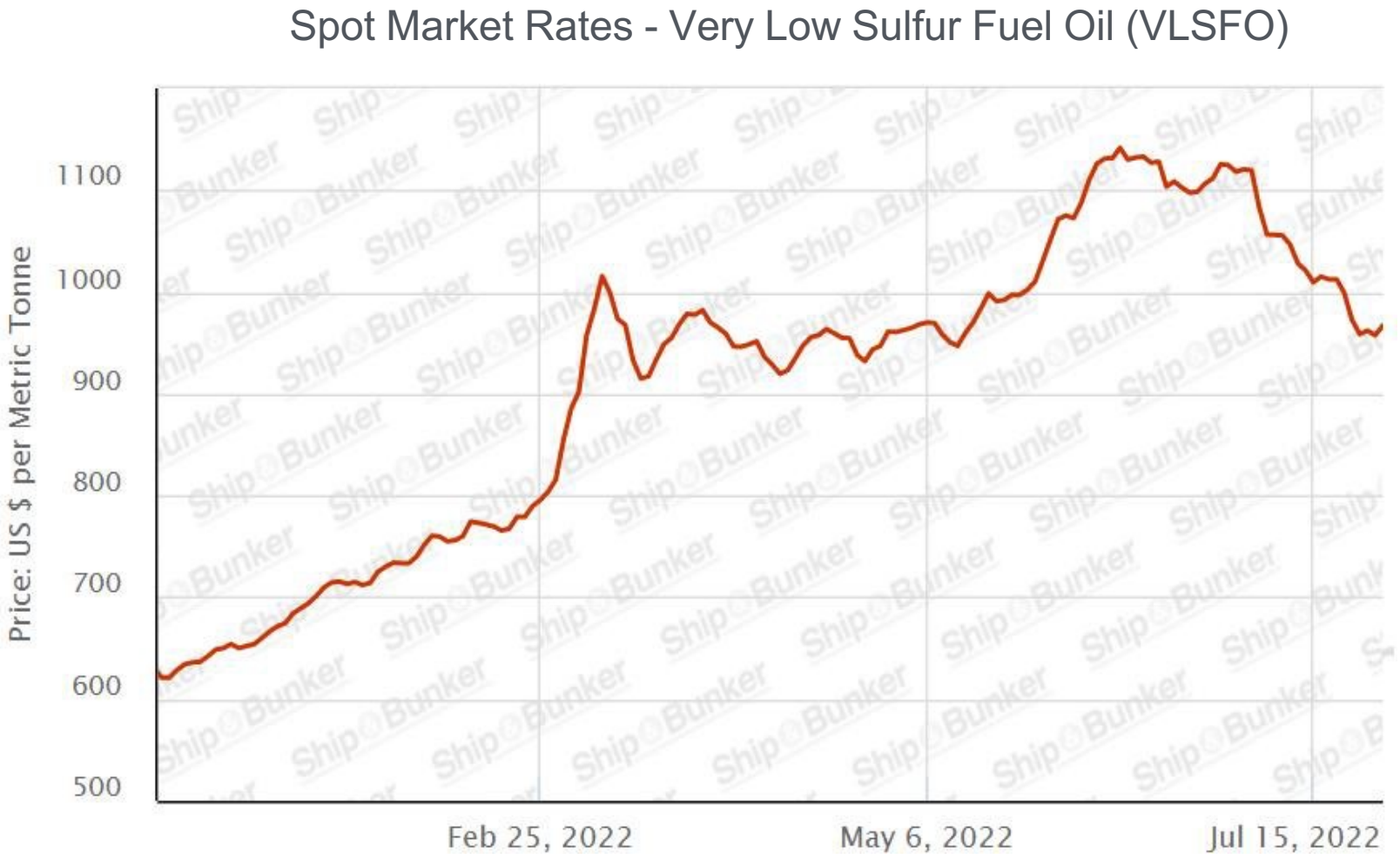
Vessels have trended towards energy sources that are readily available, on-demand, energy dense, and cheap

?

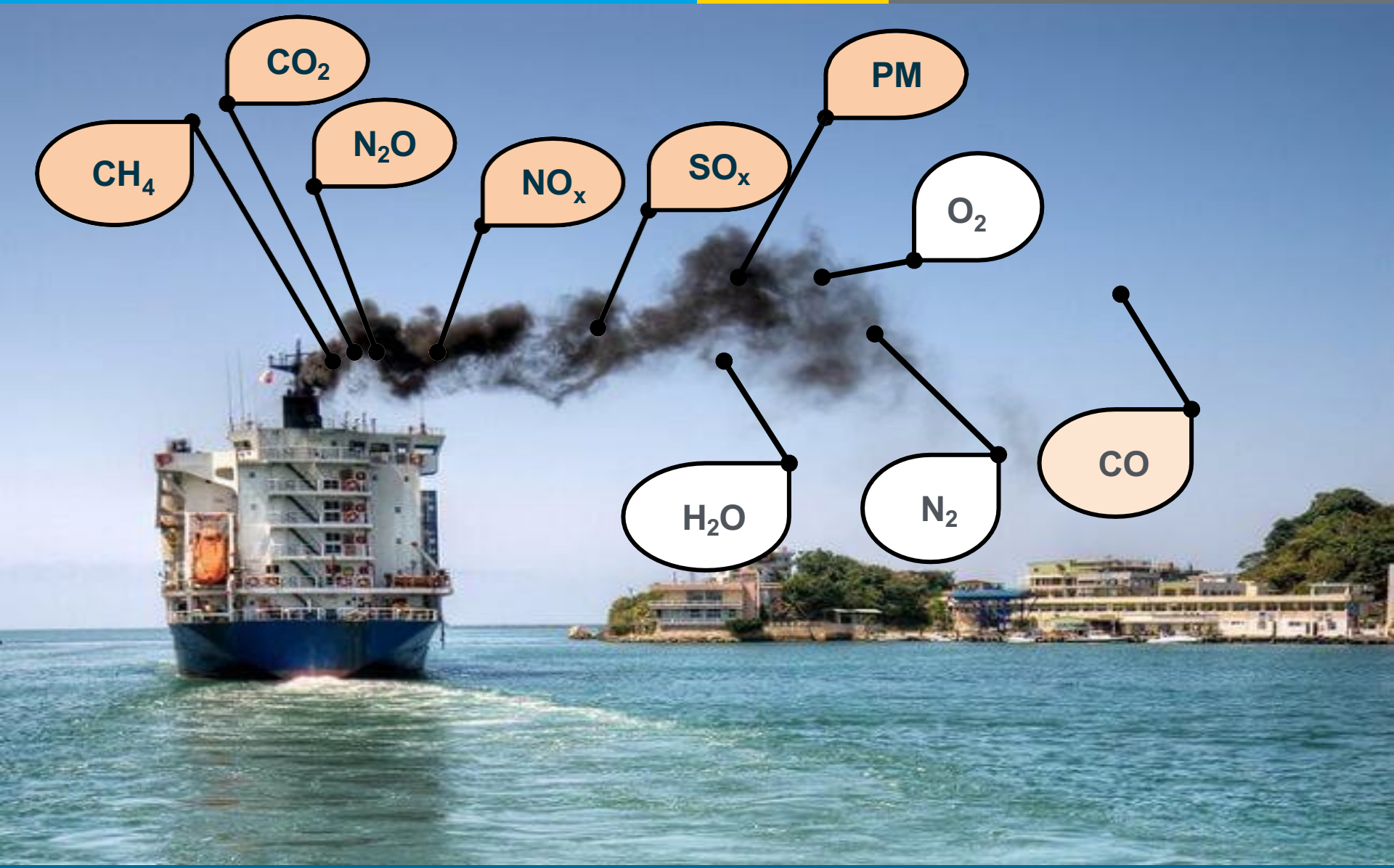
Heavy Fuel Oil is Industry Standard for International Shipping



Bunker Fuel Spot Market Experiences Volatility



Maritime Emissions from Internal Combustion Engines



Annual Emissions and Fuel Consumption Comparison

Mark II Jumbo Ferry

- **1,670,000 gallons fuel**
- **$6,700,000 in fuel costs**
- **18,000 metric tons CO_2e**

- **Equivalent to the emissions of 3,700 passenger vehicles**

Commercial Container ship

- **15,230,000 gallons fuel**
- **$49,300,000 in fuel costs**
- **200,000 metric tons CO_2e**

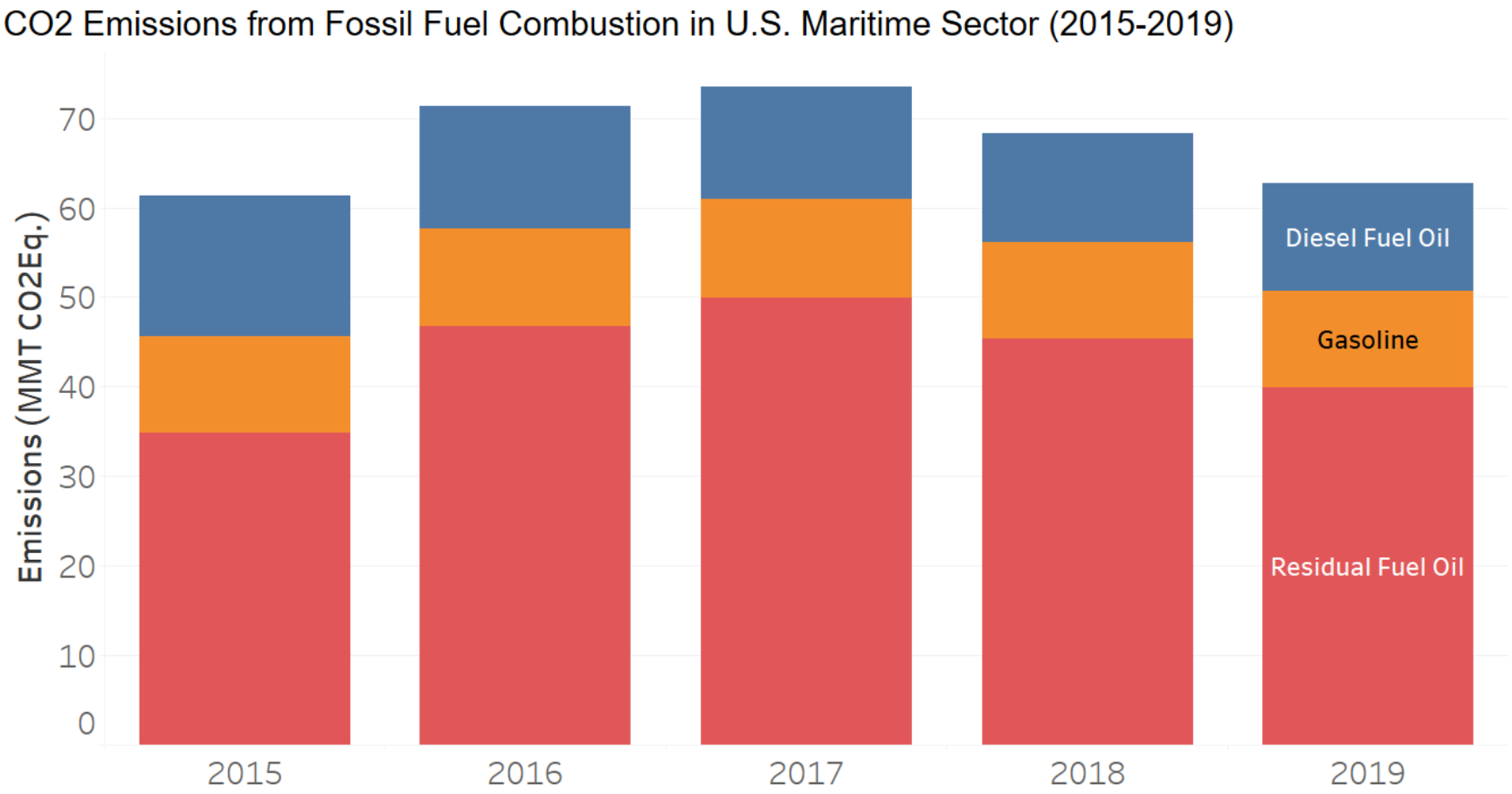
- **Equivalent to the emissions of 48,500 passenger vehicles**

Commercial Fleet Energy Needs Similar to Government

T-AO

Annual Fuel Consumption	1,890,000 gallons
Annual Fuel Costs	$7,500,000
Annual Emissions	19,000 metric tons CO2e

Domestic Maritime Emissions



Includes domestic and international vessel fuel consumption. Source Data - 2019 EPA GHG Inventory Assessment Table 3-13

International Maritime Emissions

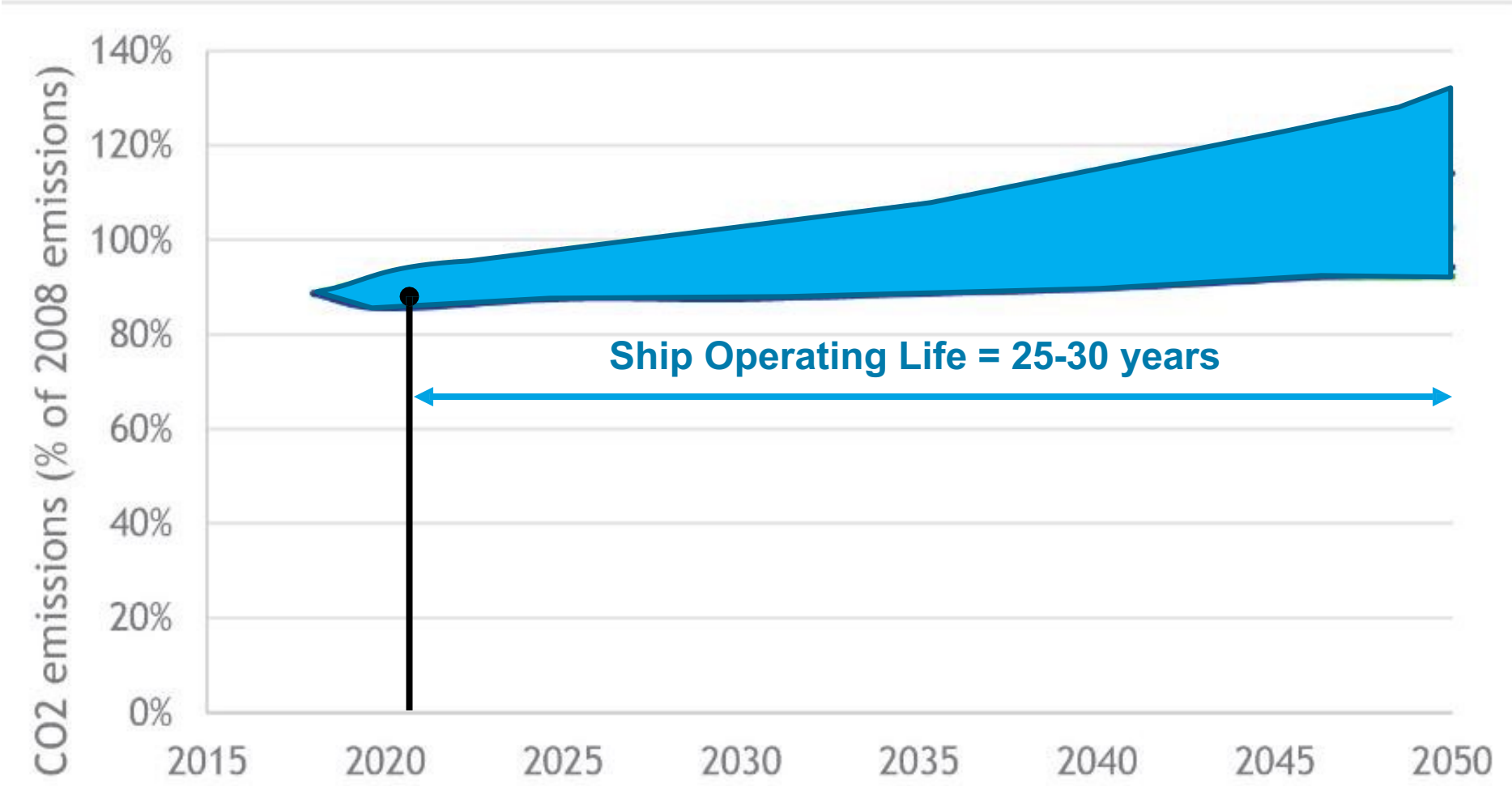
The GHG emissions of global shipping is more than one gigaton per year as of 2018, or about 2.9% of global GHG emissions.

Top CO_2 Emitting Countries

Rank	Country	2018 CO_2 emissions (gigatons) [1]
1	China	10.06
2	United States	5.41
3	India	2.65
4	Russa Federation	1.71
5	Japan	1.16
6	**Global Shipping**	**1.056** [2]
7	Germany	0.75
8	Islamic Republic of Iran	0.72
9	South Korea	0.65
10	Saudi Arabia	0.62

[1] Source: Union of Concerned Scientists - https://www.ucsusa.org/resources/each-countrys-share-co2-emissions
[2] Source: IMO Fourth GHG Study (2020)

International Shipping Emissions Projected to 2050 with Business as Usual



Source: Fourth IMO GHG Study 2020, IMO, London, UK,

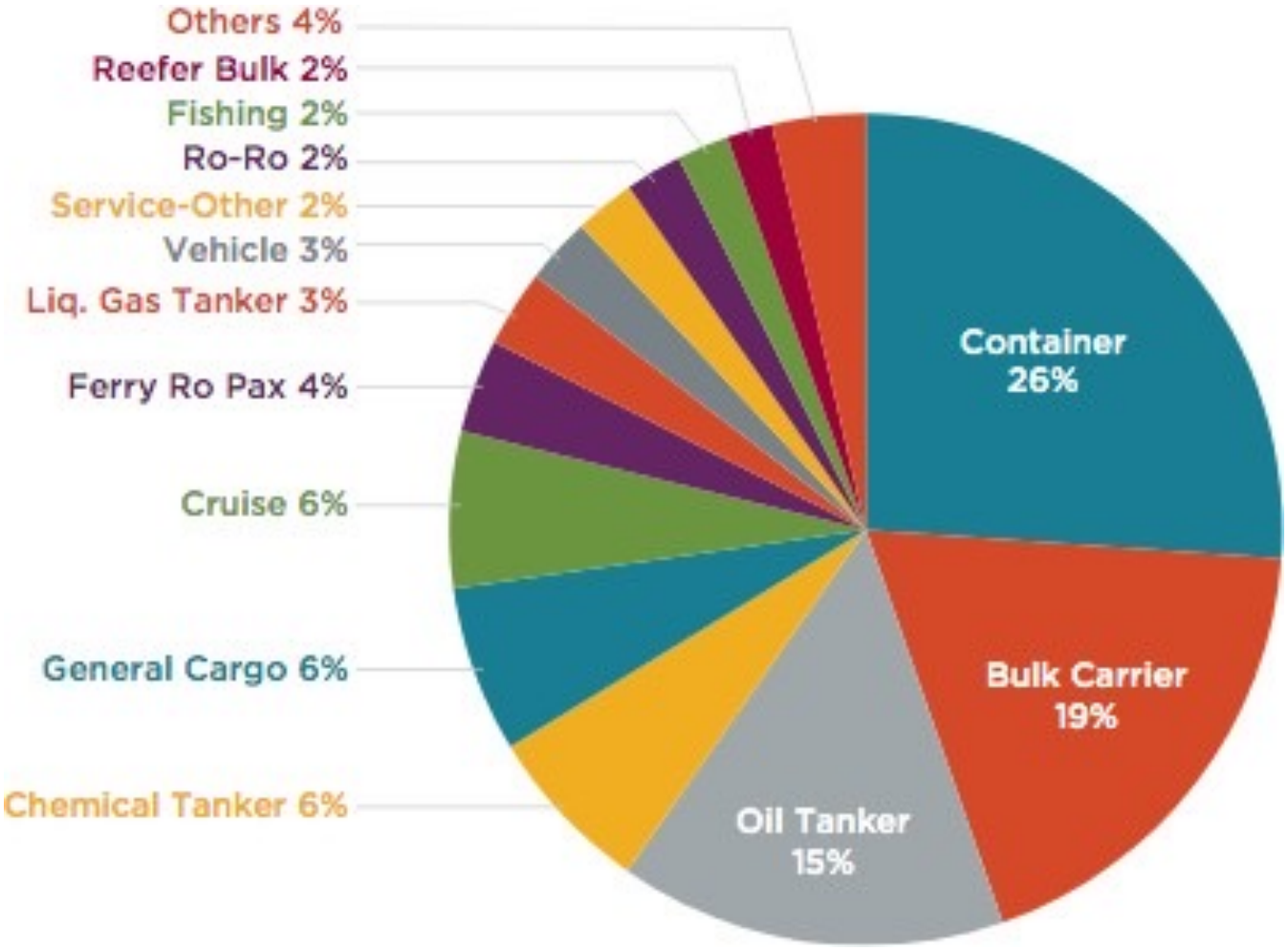
It's Not Just About Carbon

Shipping is believed to be responsible for an estimated 18% of global NOx and 9% of global SOx pollution

An estimated 70% of shipping emissions occur within 250 miles of land, exposing hundreds of millions of people in coastal communities to NOx and SOx pollutants

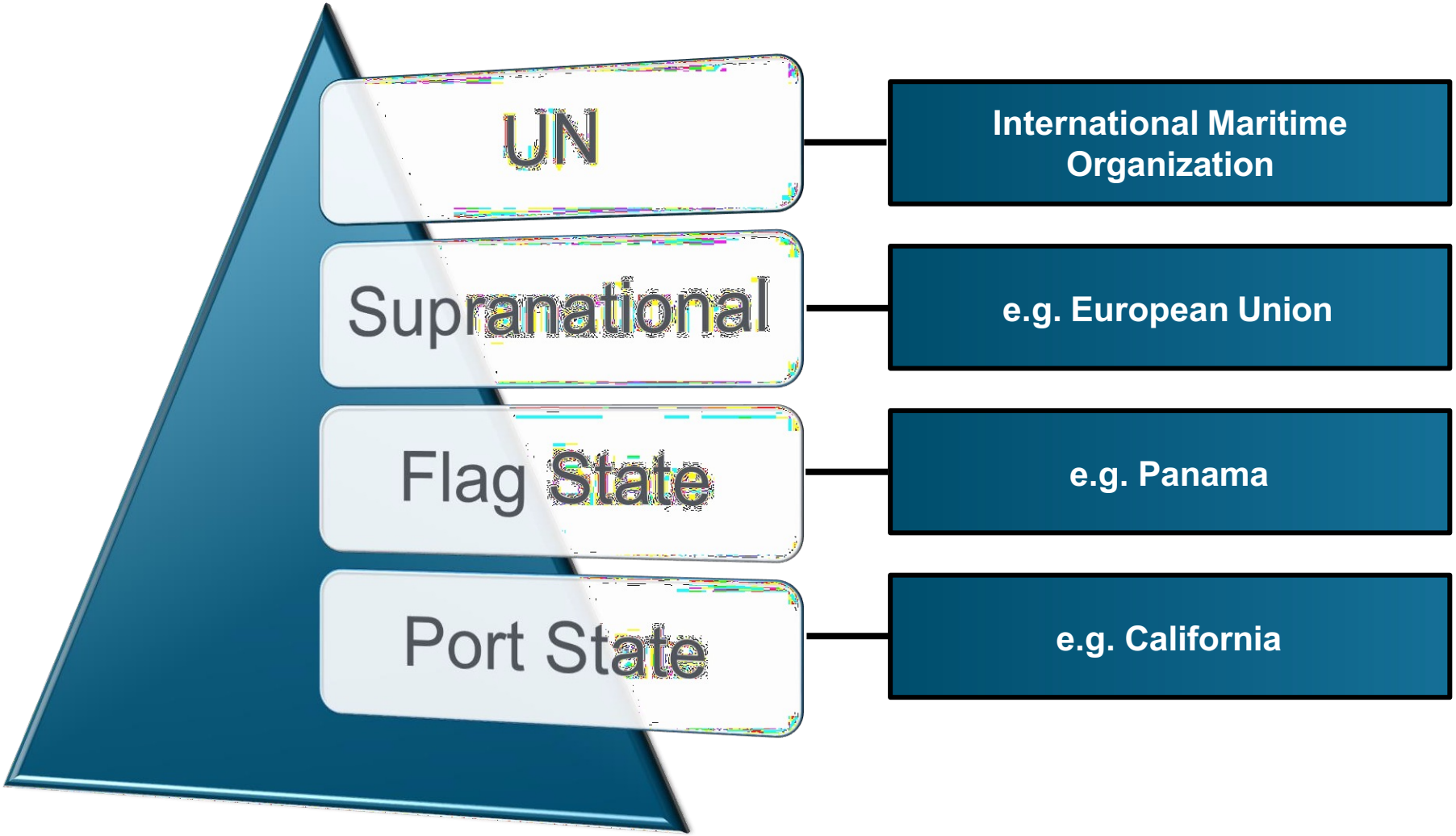
"Health risks of shipping pollution have been 'underestimated'" The Guardian, 2009. https://www.theguardian.com/environment/2009/apr/09/shipping-pollution

International Emissions by Ship Class

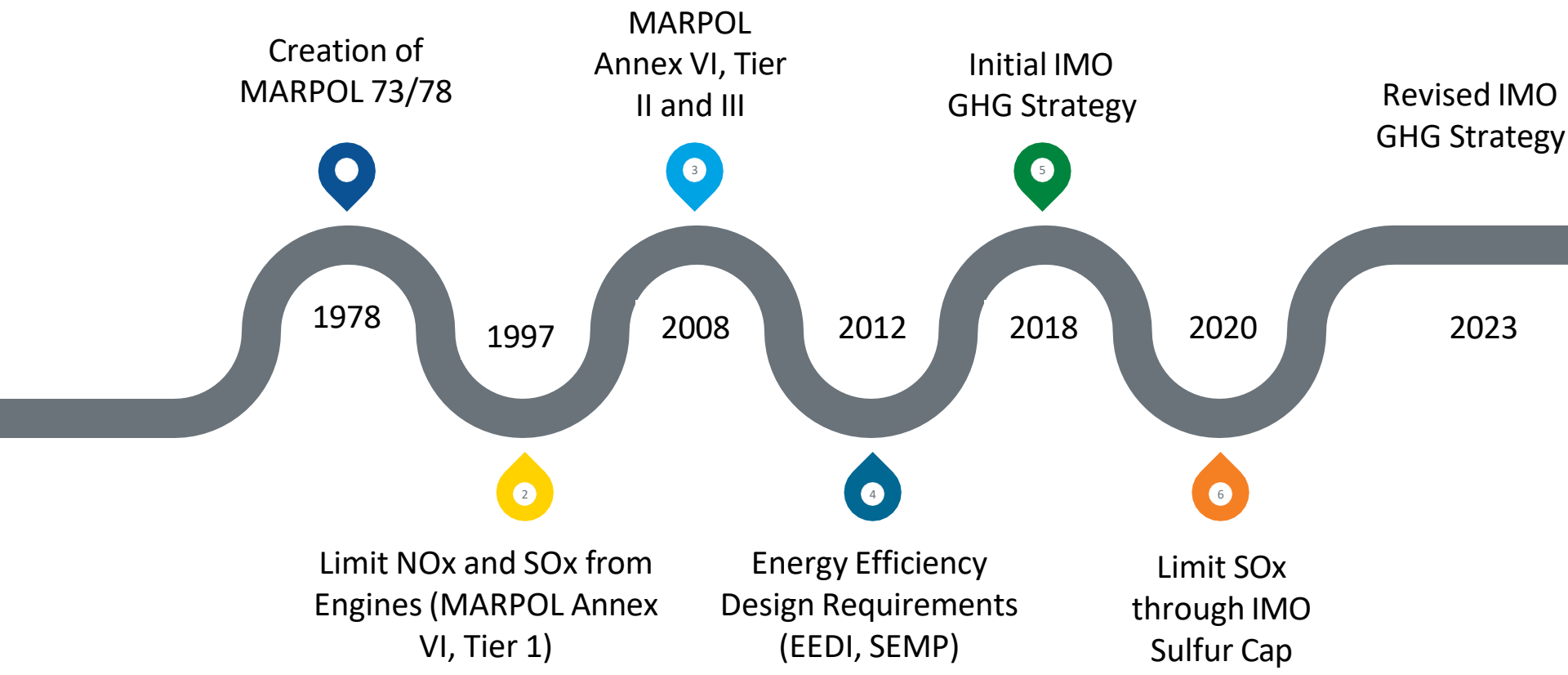


"Black Carbon Emissions and Fuel Use in Global Shipping, 2015." The ICCT. https://theicct.org/sites/default/files/publications/Global-Marine-BC-Inventory-2015_ICCT-Report_15122017_vF.pdf

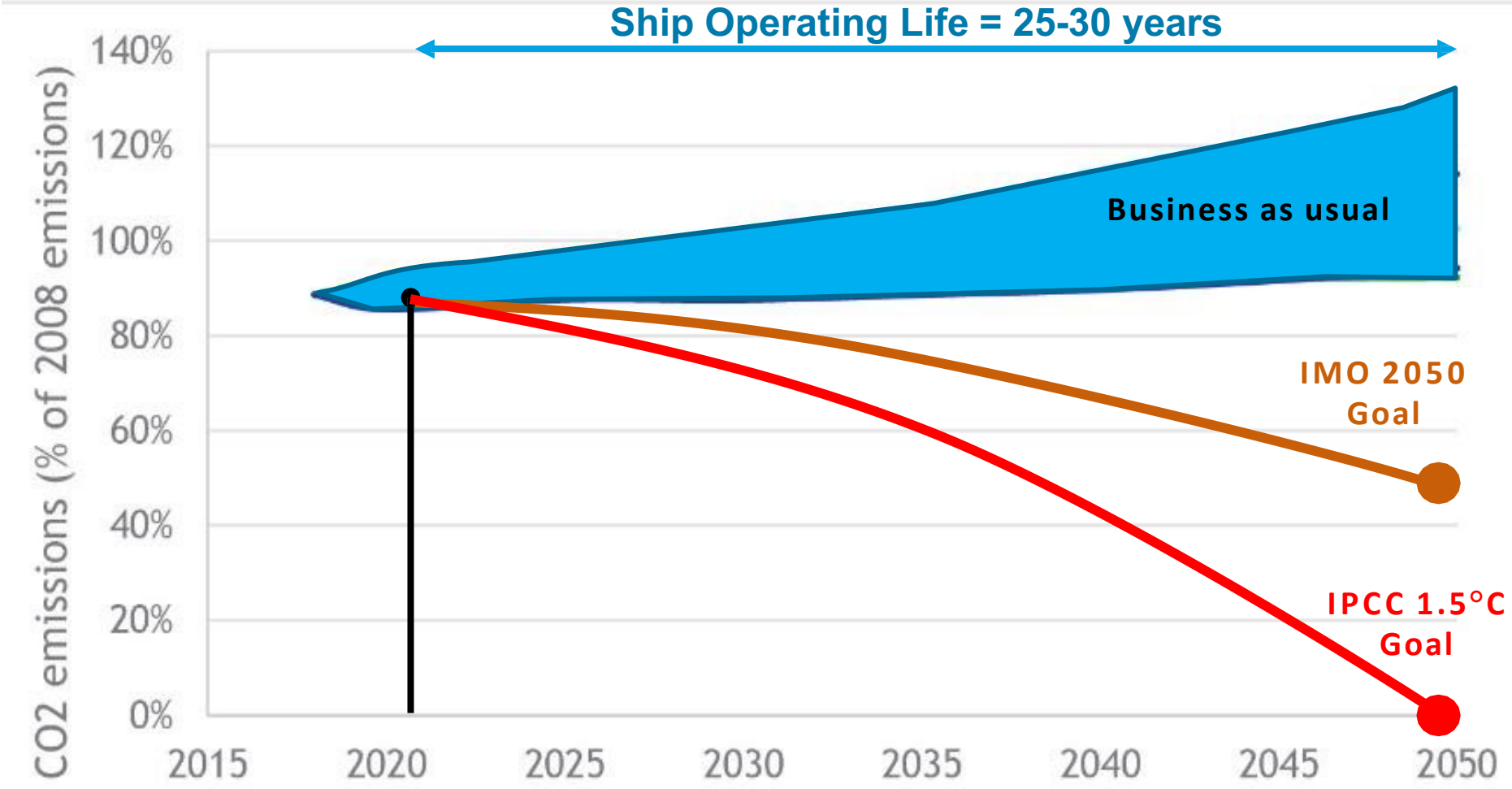
Maritime Regulator Hierarchy



International Emission Regulation Milestones from the IMO



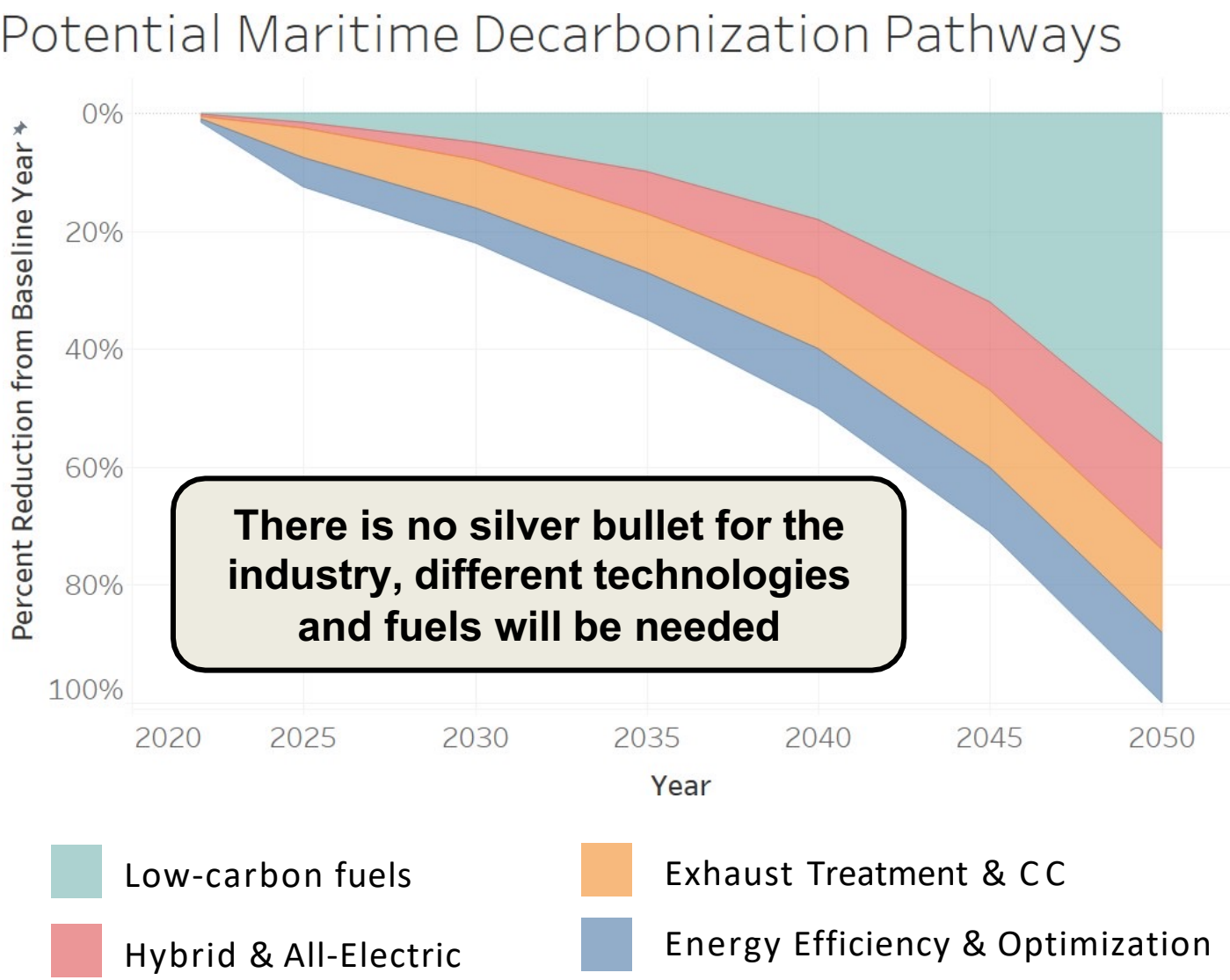
International Shipping Emissions Projected to 2050



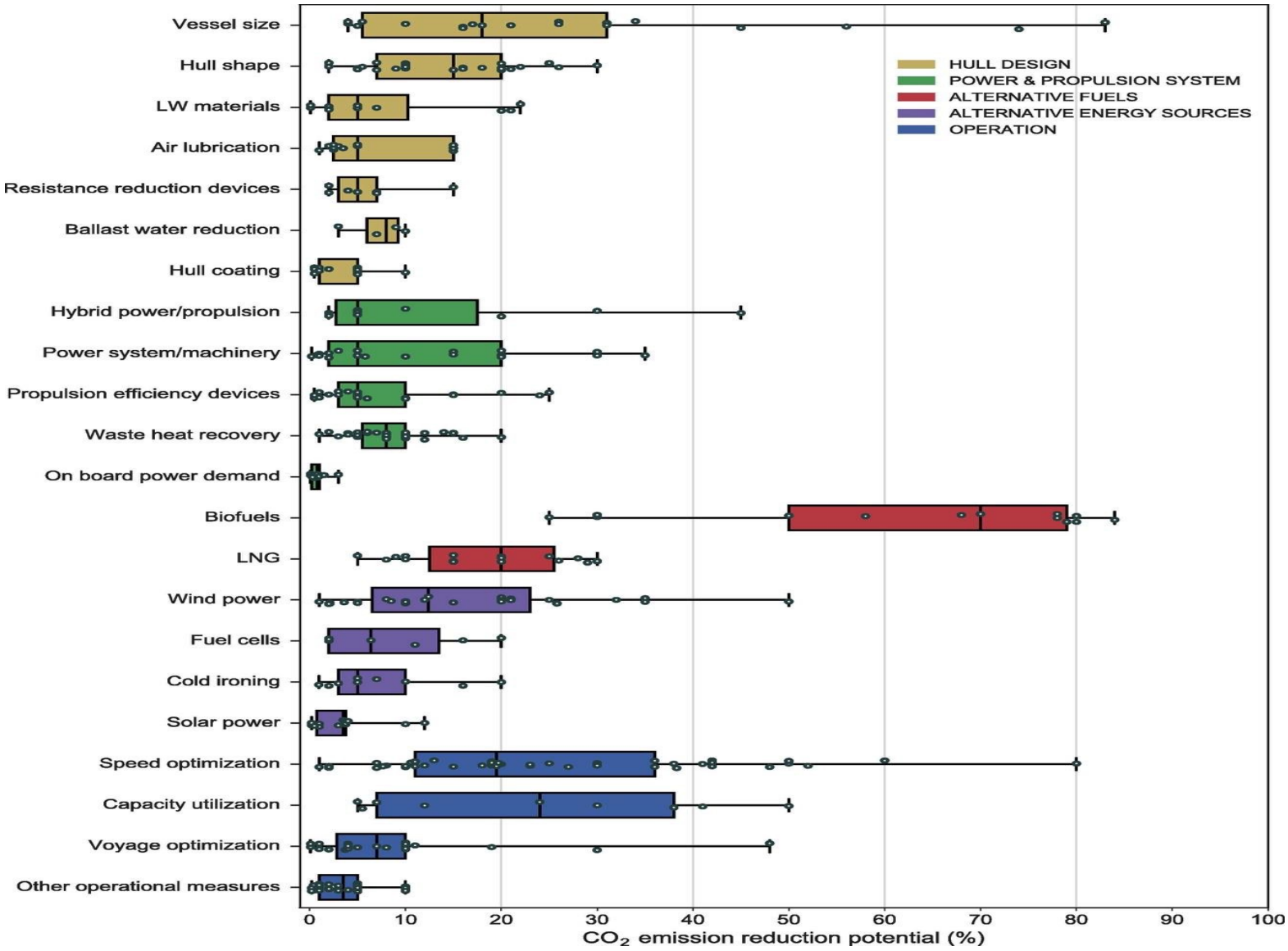
Note – pathways shown are notional

Source: Fourth IMO GHG Study 2020, IMO, London, UK,

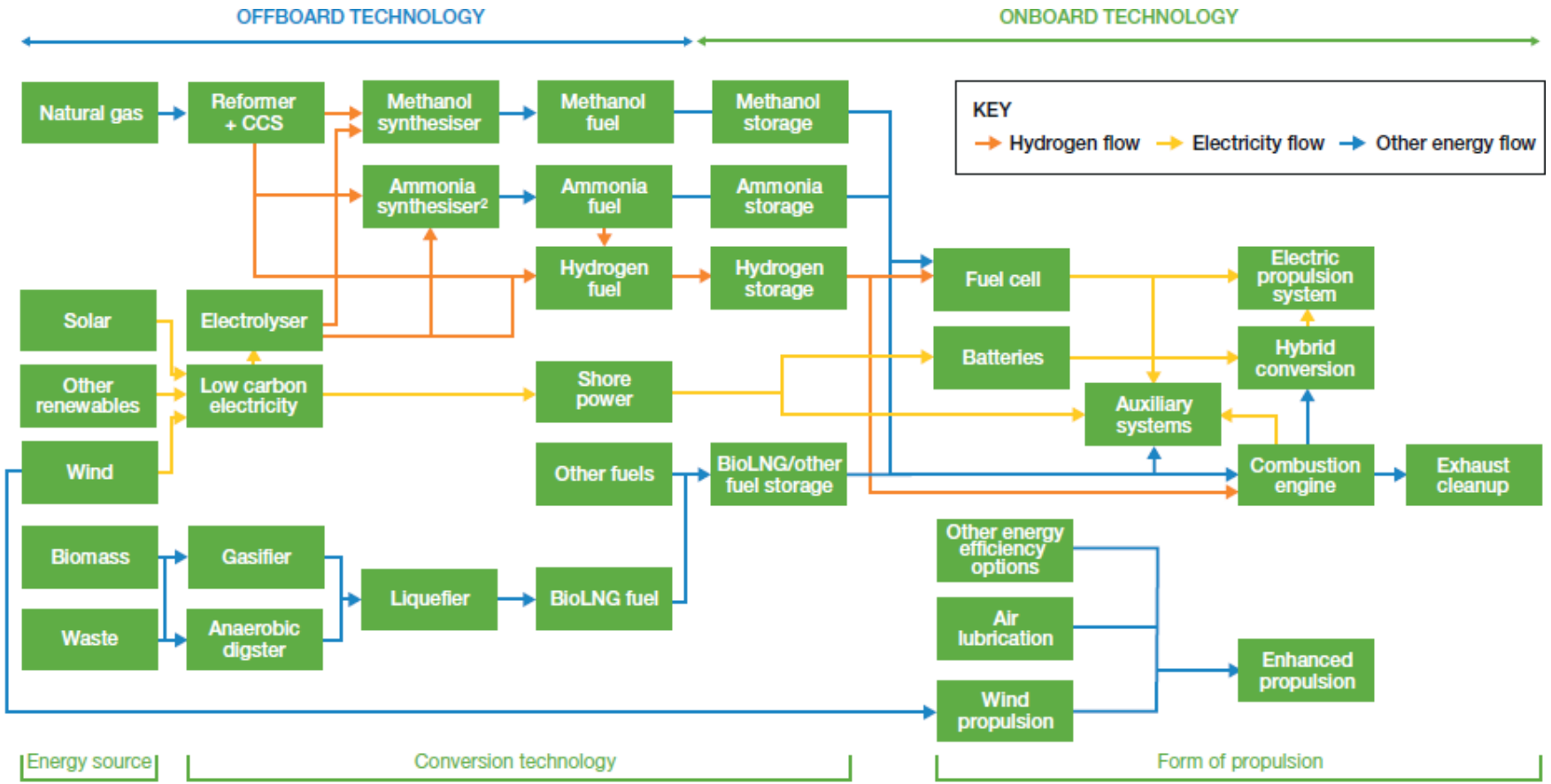
Stacking Emission Reduction Measures to Reach Goals



Emissions Reduction Measures of Varying Potential



Technology and Fuel Pathways



1 Steam Methane Reformer (SMR) + Carbon Capture & Storage
2 Equipment used for the Haber Bosch process

Source: Frontier Economics for DfT

Many fuels and production pathways to consider, each with unique lifecycle emissions

Not All Fuels are Created Equal - Lifecycle Assessment is Needed

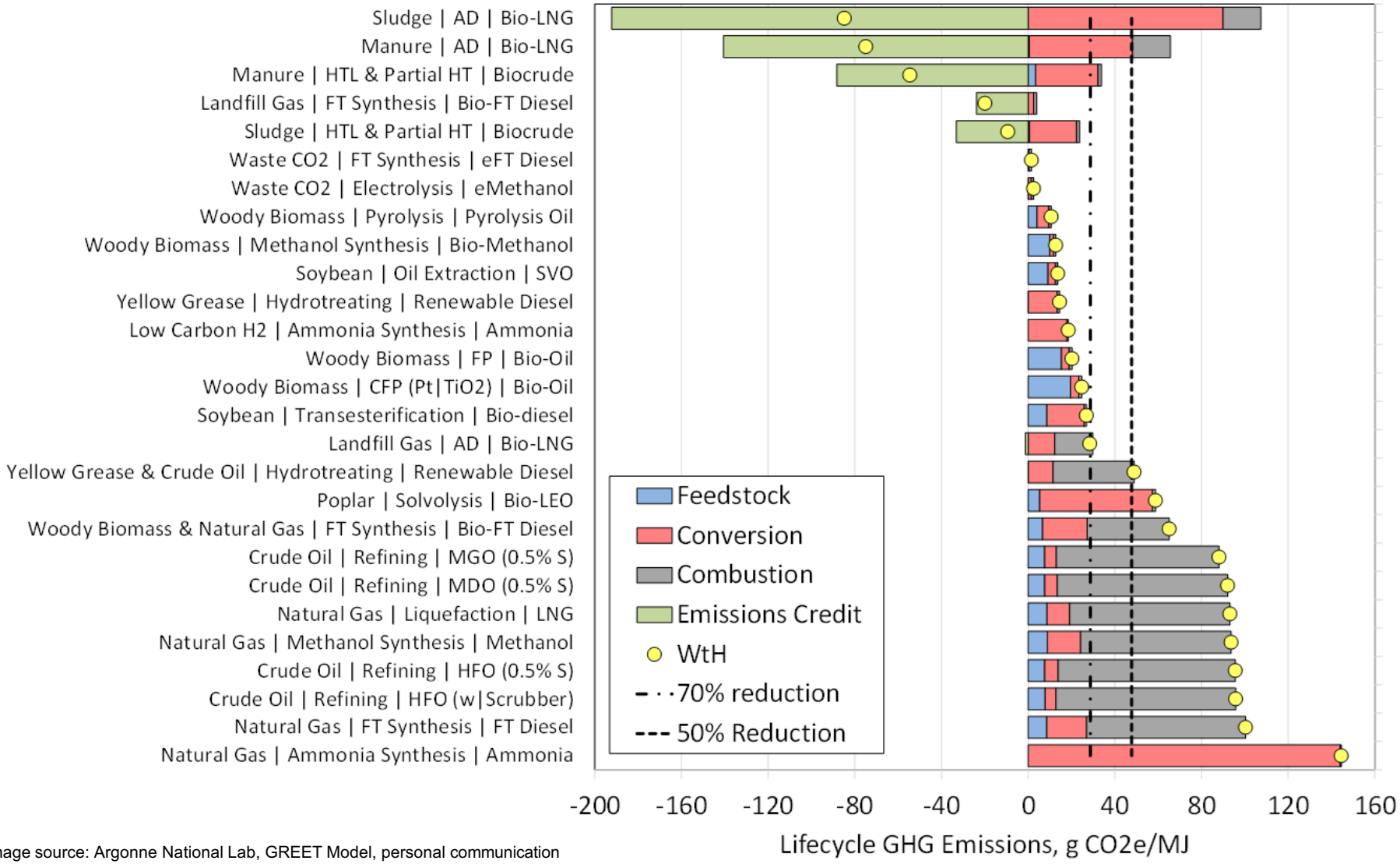
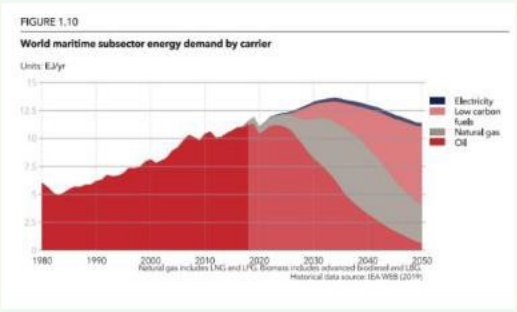


Image source: Argonne National Lab, GREET Model, personal communication

Uncertainty in the Future Fuel Fix is Creating Delayed Action

DNV GL Energy Transition Outlook

60% Low carbon fuels / 30% LNG / 10% Fuel Oil



ABS sustainability Outlook

40% Fuel Oil / 10% LNG / 35% Ammonia+ H2 /

7% Biofuels / 7% Methanol

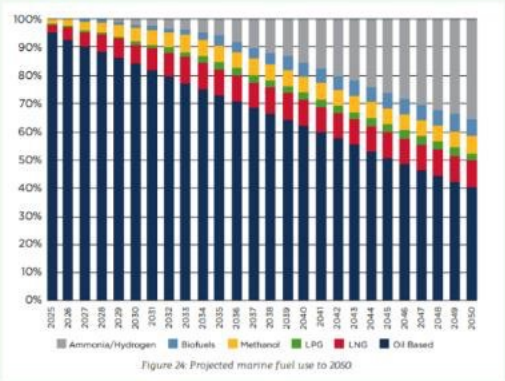
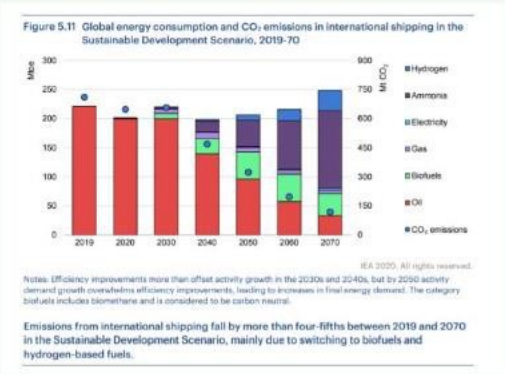


Figure 24: Projected marine fuel use to 2050

IEA

50% Fuel Oil / 25% Ammonia + H2 / 20% Biofuels

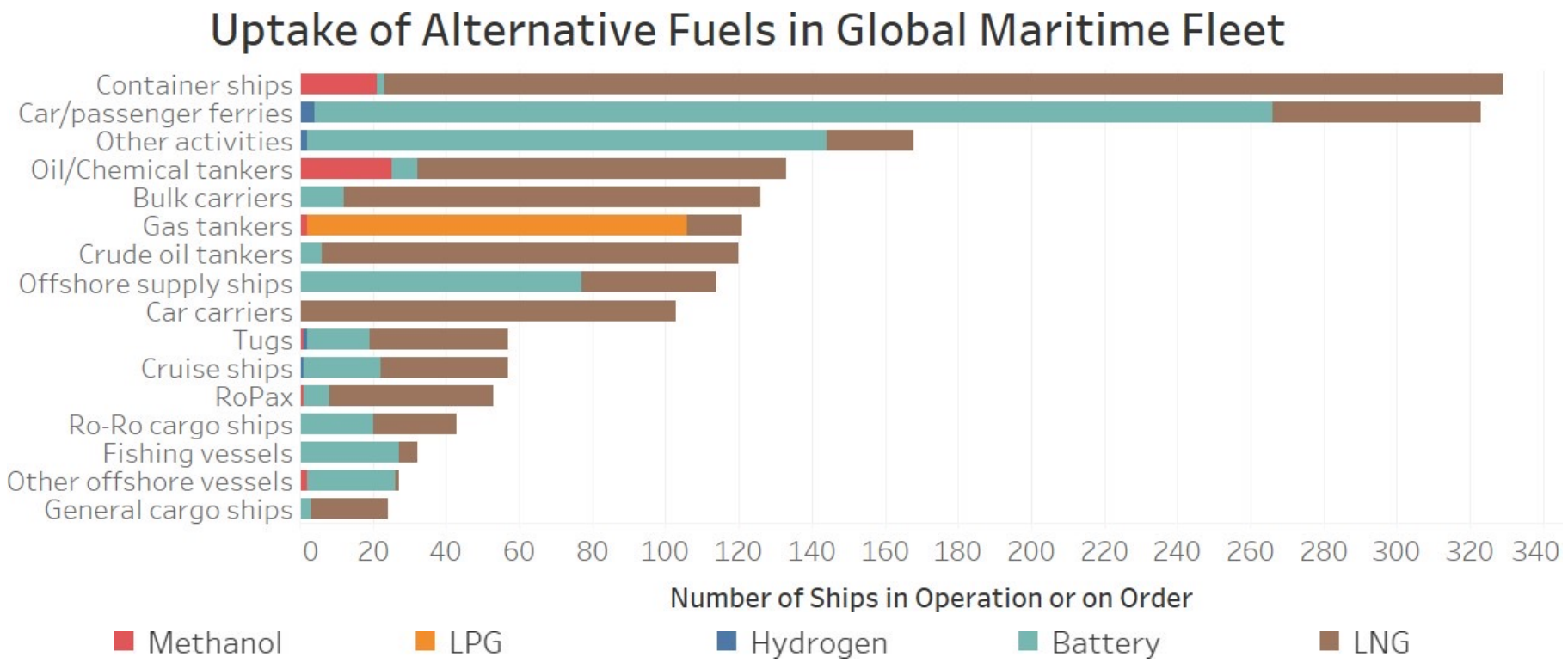
(Total consumption 210 MTOE)



Vessel owners/operators are hesitant to commit to a fuel for a vessel that may operate for 30 years

Image source: Ammonia Energy Conference 2020 (T. Johannessen) 19.11.2020

Alternative Fuels Still Have Low Adoption



Alternative fuels are not yet seeing widespread adoption across the global fleet of ~80,000 vessels

Source data: DNV Alternative Fuels Insight, accessed June 2022

To Recap…

- Ports and vessels need lots of energy for their operations, and every ship is unique. Heavy fuel oil and diesel have been the main energy carriers for more than 100 years
- The global maritime industry ranks amongst the top ten largest GHG emitting countries
- Pollutants such as NOx and SOx stemming from maritime activities near seaports can lead to local health issues for port communities
- The global regulator for shipping is moving too slowly and not aggressively enough to reduce maritime emissions.
- There are many different fuels, tools, and technologies that can reduce maritime emissions at varying levels of technology readiness
- We need zero-emissions by 2050 to keep us in-line with the Paris Agreement, this necessitates action TODAY

Decarbonization is part of a Broader Sustainable Transportation Approach

Meet Everyone's Needs

Reliable mobility solutions for people and goods recognizing diverse needs of different communities and stakeholders

Affordable

Affordable (for consumers) and competitive for industry by supporting economy/jobs

Environmental Quality

High quality local air and water in addition to GHG emissions

Maritime Decarbonization Pathways

DRAFT – DO NOT CITE

Maritime Decarbonization Pathway	Low-carbon Liquid and Gaseous Fuels	Hybridization and All-electric	Energy efficiency and optimization	Exhaust treatment and carbon capture
Example Technologies	• Methanol • Hydrogen • Ammonia • Advanced Biofuels	• Marine Batteries • Hybrid-electric Engines • Cold-ironing • Fast charging	• Waste heat recovery • Wind assist • Voyage optimization • Hull cleaning	• Onboard carbon capture • PM Control • Scrubbers • Combustion strategy
GHG Reduction Potential	**0 – 100%**	**0 – 100%**	**5 – 30%**	**0 – 30%**
Timeframe for large-scale impact	2030 and beyond	2030 and beyond	2022 and beyond	2025 and beyond

How DOE Offices Support Maritime Decarbonization Pathways

DRAFT – DO NOT CITE

Office	Low-Carbon Fuels	Hybrid & Electric	Energy Efficiency	Exhaust Treatment & CC
Advanced Research Projects Agency – Energy (ARPA-E)	X	X	X	X
OS - Advanced Scientific Computing Research			X	
OS - Biological & Environmental Research				
FE - Oil and Natural Gas	X			
FE - Clean Coal and Carbon Management (NETL)	X			X
NE - Reactor Fleet and Advanced Reactor Deployment	X	X	X	
OE - Energy Planning and Strategy		X	X	
OE - Recovery and Critical Energy Infrastructure		X	X	
EERE - Vehicle Technologies Office (VTO)	X	X	X	X
EERE - Bioenergy Technologies Office (BETO)	X			X
EERE - Hydrogen Fuel Cell Technologies Office (HFTO)	X	X		
EERE - Water Power Technologies Office (WPTO)	X	X	X	
EERE - Wind Energy Technologies Office (WETO)	X		X	
EERE - Solar Energy Technologies Office (SETO)			X	
EERE - Building Technologies Office (BTO)			X	
EERE - Advanced Manufacturing Office (AMO)			X	
Loan Program Office (LPO)	X	X		

DOE's International Maritime Engagements

- **Mission Innovation Zero-Emission Shipping Mission** – International PPP focused on innovation gaps that limit the adoption of zero-emission fuels for ocean-going vessels. DOE is a co-lead of the Mission.
- **The Clydebank Declaration and Green Shipping Corridors** – The Declaration commits signatories to establish >6 green shipping corridors by 2025. U.S. Framework for Green Shipping Corridors announced in April 2022 outlines desired ambition and how to build these routes. DOE working with other agencies on implementation.
- **International Maritime Organization** – DOE is supporting U.S. delegates to the IMO to evaluate new proposals and emission reduction measures
- **Quad Shipping Task Force** – Supporting DOT and USG actions with Australia, India, Japan to establish green shipping corridors in Indo-Pacific
- **Marine Battery Forum** – Supporting collaboration and innovation on vessel electrification. DOE participates as an observer.
- **International Energy Agency Technology Collaboration Programs** (IEA- TCP)
  - Bioenergy TCP - Task 39, Transport Biofuels
  - Hybrid and Electric Vehicle TCP - Task 38, Marine Applications

MISSION INNOVATION

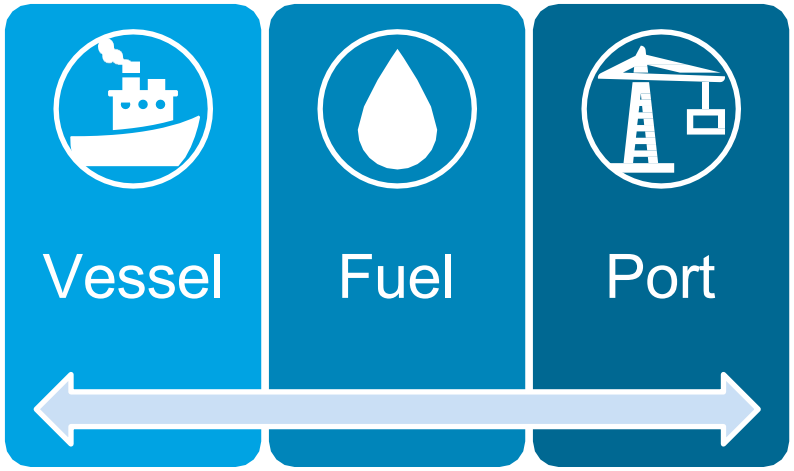
First Movers Coalition

Mission Innovation: Zero-emission Shipping Mission

The Goal: *By 2030 ships capable of running on well-to-wake zero-emission fuels make up at least 5% of the global deep-sea fleet measured by fuel consumption and that at least 200 of these ships primarily use these fuels across the main deep sea shipping routes.*

Ocean-going commercial vessels

Three Mission Pillars



- *Advanced Biofuels*
- *Green Ammonia*
- *Green Hydrogen*
- *Green Methanol*

Government Co-Leads

United States Denmark Norway

Industry Co-Leads

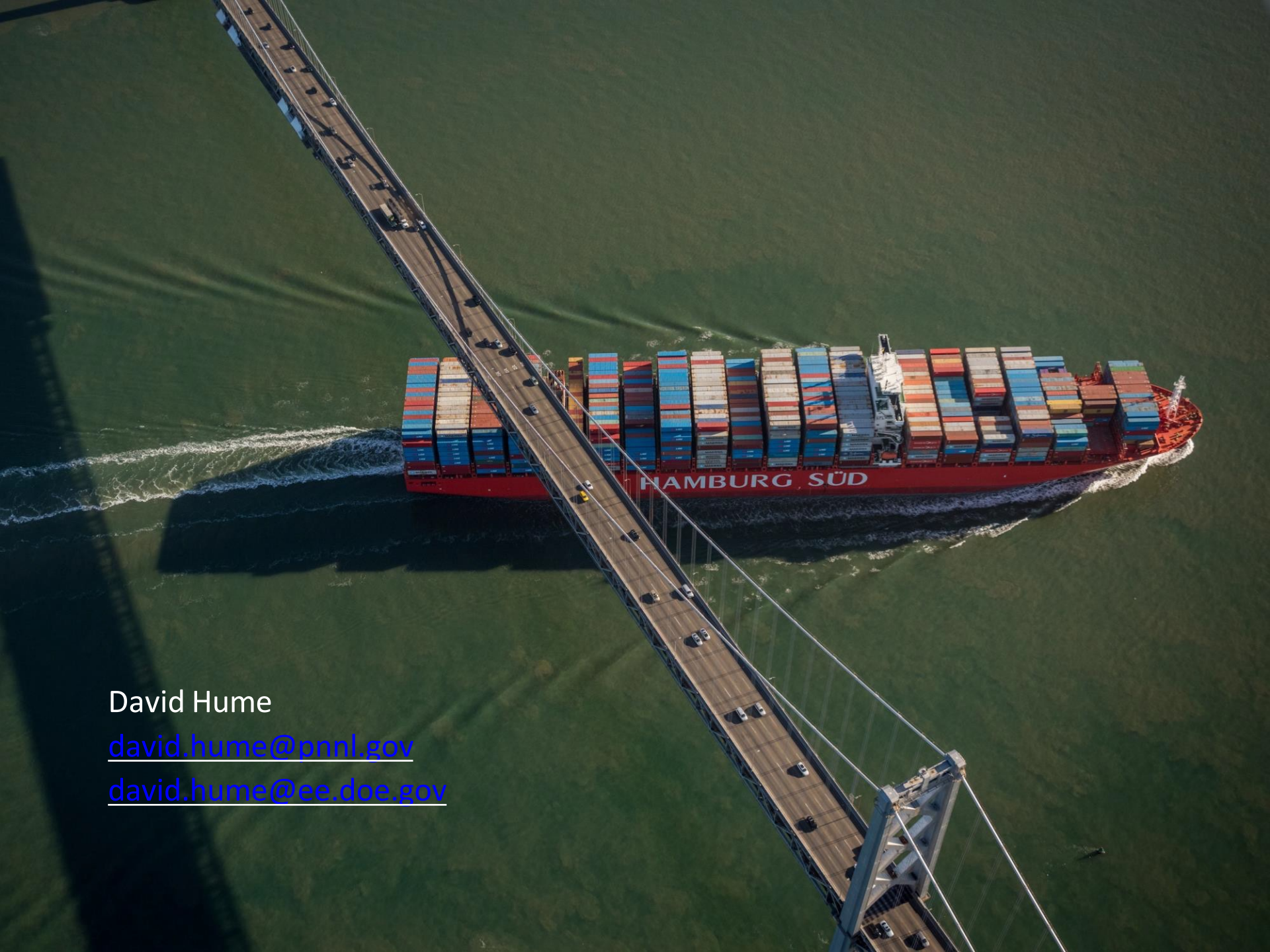
Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping

GLOBAL MARITIME FORUM

DRAFT – DO NOT CITE

DOE's Maritime RDD&D Activities

- Office of Electricity – Port Microgrids
- Office of Nuclear Energy – Small modular nuclear reactors for maritime
- Office of Carbon Management – Shipboard Carbon Capture
- Loan Program Office – AVTM loans and loan guarantees for vessels
- Office of Energy Efficiency and Renewable Energy
  - HFTO: hydrogen fuel cells for vessels, cold-ironing, hydrogen bunker barge
  - BETO: biofuels for marine diesel engines, life-cycle emissions inventories, fuel testing
  - VTO: improving engine technologies and combustion techniques for alternative fuels, electrification
  - WPTO: TA for coastal communities, fishing fleet and ferry electrification
  - WETO: Offshore wind support vessels, shipyard capacity
  - BTO: Cruise ship energy efficiency



David Hume
david.hume@pnnl.gov
david.hume@ee.doe.gov