Alteration Course

Plotting the Maritime Energy Transition

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Grew-up working on Boats...
...Then Graduated to Ships
What is the Maritime Industry?

Transportation of materials, products, and people on the sea or connected waterways and the supporting coastal infrastructure.
The Maritime Industry is Truly Global

Shipping underlies the global economy – 90% of all world trade is carried by ship
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)

<table>
<thead>
<tr>
<th>Vessel type, country grouping by flag of registration and indicator</th>
<th>Years</th>
<th>Average age</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0–4</td>
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<tr>
<td>World</td>
<td>Bulk carriers</td>
<td>Percentage of total ships</td>
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<tr>
<td></td>
<td></td>
<td>Percentage of dead-weight tonnage</td>
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<td></td>
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<td>Average vessel size (dead-weight tonnage)</td>
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<tr>
<td></td>
<td>Container ships</td>
<td>Percentage of total ships</td>
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<td></td>
<td></td>
<td>Percentage of dead-weight tonnage</td>
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<td></td>
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<td>Average vessel size (dead-weight tonnage)</td>
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<tr>
<td></td>
<td>General cargo</td>
<td>Percentage of total ships</td>
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<tr>
<td></td>
<td></td>
<td>Percentage of dead-weight tonnage</td>
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<td></td>
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<td>Average vessel size (dead-weight tonnage)</td>
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<td></td>
<td>Oil tankers</td>
<td>Percentage of total ships</td>
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<tr>
<td></td>
<td></td>
<td>Percentage of dead-weight tonnage</td>
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<td></td>
<td></td>
<td>Average vessel size (dead-weight tonnage)</td>
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<tr>
<td></td>
<td>Other types of ships</td>
<td>Percentage of total ships</td>
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<tr>
<td></td>
<td></td>
<td>Percentage of dead-weight tonnage</td>
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<td></td>
<td></td>
<td>Average vessel size (dead-weight tonnage)</td>
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<tr>
<td></td>
<td>All ships</td>
<td>Percentage of total ships</td>
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<tr>
<td></td>
<td></td>
<td>Percentage of dead-weight tonnage</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Average vessel size (dead-weight tonnage)</td>
</tr>
</tbody>
</table>

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

6,000 Ferries

180 Ocean-going cargo ships

6,000 Tugboats

38,000 commercial vessels

and more…
The U.S. Commercial Fleet is Old

U.S. Commerical Vessel Age by Vessel Segment, 2022

- Container: 17 years
- Tankers: 24.5 years
- Vehicle Carriers/RoRo: 25 years
- Offshore Supply: 26 years
- Ferry: 28 years
- Inspected Passenger: 30 years
- Uninspected Passenger: 30 years
- Other: 31 years
- Fishing: 38 years
- General Cargo: 39 years
- Towboat: 41 years
- Bulk Carriers: 49 years
Port Energy Consumers

[Image of a port with labels for different energy consumers: Cargo Handling, Lighting, Cold-Ironing Vessels, Ground Transport, Refrigerated Containers]
Ports Consume Lots of Energy

Port electrical loads are already sizeable and will likely increase.

PORT OF LONG BEACH
183,00 MWh and $20 Million Annually

PORT OF LOS ANGELES
233,00 MWh and $30 Million Annually

2013 Values
Total Electricity Cost = $50 million total each year

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.

Major Energy Consumers on a Vessel

- Hotel Loads
- Cargo Handling
- Propulsion
- Auxiliary Machinery (*motors, boilers, etc.*)
- Mooring and Maneuvering
Use of propulsion energy on board a small well-maintained cargo ship in rough head sea

**Energy Demands of a Container Ship**

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

<table>
<thead>
<tr>
<th>Main propulsion power</th>
<th>60 Megawatt (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auxiliary power and boiler</td>
<td>2 - 7 MW</td>
</tr>
<tr>
<td>Annual operating hours</td>
<td>4,000 – 7,000+ hours</td>
</tr>
<tr>
<td>Annual energy demand</td>
<td>200,000 MWh</td>
</tr>
</tbody>
</table>
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

The Maersk Triple E Class Vessels are powered by two large slow-speed diesel engines.

- Cylinder bore - 0.8 m
- Stroke length - 3.45 m
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

CRUDE OIL FRACTIONATING COLUMN

SMALL MOLECULES
- Low boiling point
- Very volatile
- Flows easily
- Ignites easily

LARGE MOLECULES
- High boiling point
- Not very volatile
- Doesn’t flow easily
- Doesn’t ignite easily

Refinery Gases < 40°C
- Bottled Gas

Petrol 40°C - 205°C
- Petrol (Gasoline)

Naptha 60°C - 100°C
- Chemicals

Kerosene 175°C - 325°C
- Jet Fuel and Paraffin

Diesel 250°C - 350°C
- Diesel Fuels

Lubricating Oil 300°C - 370°C
- Oil, Waxes, Polishes

Fuel Oil 370°C - 600°C
- Fuel for heating and ships

Residue > 600°C
- Bitumen for roads and roofing

HEATED CRUDE OIL

Water

Power

Program

eere.energy.gov
Bunker Fuel Spot Market Experiences Volatility

Spot Market Rates - Very Low Sulfur Fuel Oil (VLSFO)
Maritime Emissions from Internal Combustion Engines

- CH$_4$
- CO$_2$
- N$_2$O
- NO$_x$
- SO$_x$
- PM
- O$_2$
- H$_2$O
- N$_2$
- CO
Annual Emissions and Fuel Consumption Comparison

Mark II Jumbo Ferry

- 1,670,000 gallons fuel
- $6,700,000 in fuel costs
- 18,000 metric tons CO$_{2}$e
- Equivalent to the emissions of 3,700 passenger vehicles

Commercial Container ship

- 15,230,000 gallons fuel
- $49,300,000 in fuel costs
- 200,000 metric tons CO$_{2}$e
- Equivalent to the emissions of 48,500 passenger vehicles
Commercial Fleet Energy Needs Similar to Government

T- AO

<table>
<thead>
<tr>
<th>Annual Fuel Consumption</th>
<th>1,890,000 gallons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual Fuel Costs</td>
<td>$7,500,000</td>
</tr>
<tr>
<td>Annual Emissions</td>
<td>19,000 metric tons CO2e</td>
</tr>
</tbody>
</table>
Domestic Maritime Emissions


Includes domestic and international vessel fuel consumption. Source Data - 2019 EPA GHG Inventory Assessment Table 3-13
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 CO₂ Emitting Countries

<table>
<thead>
<tr>
<th>Rank</th>
<th>Country</th>
<th>2018 CO₂ emissions (gigatons)¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>China</td>
<td>10.06</td>
</tr>
<tr>
<td>2</td>
<td>United States</td>
<td>5.41</td>
</tr>
<tr>
<td>3</td>
<td>India</td>
<td>2.65</td>
</tr>
<tr>
<td>4</td>
<td>Russia Federation</td>
<td>1.71</td>
</tr>
<tr>
<td>5</td>
<td>Japan</td>
<td>1.16</td>
</tr>
<tr>
<td>6</td>
<td><strong>Global Shipping</strong></td>
<td><strong>1.056</strong></td>
</tr>
<tr>
<td>7</td>
<td>Germany</td>
<td>0.75</td>
</tr>
<tr>
<td>8</td>
<td>Islamic Republic of Iran</td>
<td>0.72</td>
</tr>
<tr>
<td>9</td>
<td>South Korea</td>
<td>0.65</td>
</tr>
<tr>
<td>10</td>
<td>Saudi Arabia</td>
<td>0.62</td>
</tr>
</tbody>
</table>

¹ Source: Union of Concerned Scientists - [https://www.ucsusa.org/resources/each-countrys-share-co2-emissions](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,
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.

International Emissions by Ship Class

Maritime Regulator Hierarchy

- **UN**
- **Supranational**
- **Flag State**
- **Port State**

- **International Maritime Organization**
  - e.g. European Union
  - e.g. Panama
  - e.g. California
**International Emission Regulation Milestones from the IMO**

- **Creation of MARPOL 73/78**
  - 1978

- **MARPOL Annex VI, Tier II and III**
  - 1997

- **Initial IMO GHG Strategy**
  - 2008

- **Limit NOx and SOx from Engines (MARPOL Annex VI, Tier 1)**
  - 2012

- **Energy Efficiency Design Requirements (EEDI, SEMP)**
  - 2018

- **Limit SOx through IMO Sulfur Cap**
  - 2020

- **Revised IMO GHG Strategy**
  - 2023
International Shipping Emissions Projected to 2050

Ship Operating Life = 25-30 years

Business as usual

IMO 2050 Goal

IPCC 1.5°C Goal

Note – pathways shown are notional

Source: Fourth IMO GHG Study 2020, IMO, London, UK,
Stacking Emission Reduction Measures to Reach Goals

Potential Maritime Decarbonization Pathways

There is no silver bullet for the industry, different technologies and fuels will be needed.
Emissions Reduction Measures of Varying Potential
Many fuels and production pathways to consider, each with unique lifecycle emissions.

Source: Frontier Economics for DfT
Not All Fuels are Created Equal - Lifecycle Assessment is Needed

Image source: Argonne National Lab, GREET Model, personal communication
Vessel owners/operators are hesitant to commit to a fuel for a vessel that may operate for 30 years.

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
<table>
<thead>
<tr>
<th>Maritime Decarbonization Pathway</th>
<th>Low-carbon Liquid and Gaseous Fuels</th>
<th>Hybridization and All-electric</th>
<th>Energy efficiency and optimization</th>
<th>Exhaust treatment and carbon capture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Example Technologies</td>
<td>• Methanol • Hydrogen • Ammonia • Advanced Biofuels</td>
<td>• Marine Batteries • Hybrid-electric Engines • Cold-ironing • Fast charging</td>
<td>• Waste heat recovery • Wind assist • Voyage optimization • Hull cleaning</td>
<td>• Onboard carbon capture • PM Control • Scrubbers • Combustion strategy</td>
</tr>
<tr>
<td>GHG Reduction Potential</td>
<td><strong>0 – 100%</strong></td>
<td><strong>0 – 100%</strong></td>
<td><strong>5 – 30%</strong></td>
<td><strong>0 – 30%</strong></td>
</tr>
<tr>
<td>Timeframe for large-scale impact</td>
<td>2030 and beyond</td>
<td>2030 and beyond</td>
<td>2022 and beyond</td>
<td>2025 and beyond</td>
</tr>
</tbody>
</table>
## How DOE Offices Support Maritime Decarbonization Pathways

**DRAFT – DO NOT CITE**

<table>
<thead>
<tr>
<th>Office</th>
<th>Low-Carbon Fuels</th>
<th>Hybrid &amp; Electric</th>
<th>Energy Efficiency</th>
<th>Exhaust Treatment &amp; CC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advanced Research Projects Agency – Energy (ARPA-E)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>OS - Advanced Scientific Computing Research</td>
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<td>X</td>
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<tr>
<td>OS - Biological &amp; Environmental Research</td>
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<td>X</td>
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<tr>
<td>FE - Oil and Natural Gas</td>
<td>X</td>
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<tr>
<td>FE - Clean Coal and Carbon Management (NETL)</td>
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<tr>
<td>NE - Reactor Fleet and Advanced Reactor Deployment</td>
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<td>X</td>
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<tr>
<td>OE - Energy Planning and Strategy</td>
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<td>X</td>
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<tr>
<td>OE - Recovery and Critical Energy Infrastructure</td>
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<td>EERE - Vehicle Technologies Office (VTO)</td>
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<td>EERE - Bioenergy Technologies Office (BETO)</td>
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<td>EERE - Water Power Technologies Office (WPTO)</td>
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<td>EERE - Wind Energy Technologies Office (WETO)</td>
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<td>EERE - Solar Energy Technologies Office (SETO)</td>
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<td>EERE - Building Technologies Office (BTO)</td>
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<td>EERE - Advanced Manufacturing Office (AMO)</td>
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<tr>
<td>Loan Program Office (LPO)</td>
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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: 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.

Three Mission Pillars

- Vessel
- Fuel
- Port

Ocean-going commercial vessels

- 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
What is DOE Doing on Maritime Decarbonization?

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