# Decarbonisation of shipping: an overview

11 October 2022

*for the Maritime Law Association of Australia and New Zealand*

Shipping Australia

# Acknowledgement of Country

- Shipping Australia acknowledges the Gadigal people of the Eora nation as the traditional custodians of the land upon which Shipping Australia is headquartered. We also acknowledge the long history of Aboriginal peoples and Torres Strait Islanders who navigated across the seas to trade with distant communities. We pay our respects to Elders past, present and emerging.

- **About Shipping Australia**
- We're a trade association focused on the ocean freight shipping industry in Australia
- We liaise with government on behalf of the industry; we provide information to industry about government & we engage with the media with comments, insight, facts

See: www.shippingaustralia.com.au for more information and contact details

# Overview: today's talk

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- Background
- IMO policy goals
- IMO regulatory background
- Decarbonising shipping:
  - Processes
  - Devices
  - Alternative fuels
- The "future"?

# Short disclaimer

- There is a ***vast amount*** of material
- Much of it is of a technical and / or ship-process nature
- A lot of the material is aimed at engineers, naval architects, ship captains etc
- Shipping Australia can only really give a high-level overview here

  - For the avoidance of doubt, I'm **not** going to go into processes such as who reports what, to who, when, deadlines for the same, what forms need to be filled out etc
  - In response to detailed technical questions about shipboard management, operations, data science or mathematics, I'll refer any interested questioners to the international Class Societies
  - Can only really give a high-level overview here

- This material is constantly and frequently subject to change, new discoveries, revisions etc. ***The material here may be rendered out of date by new developments!***

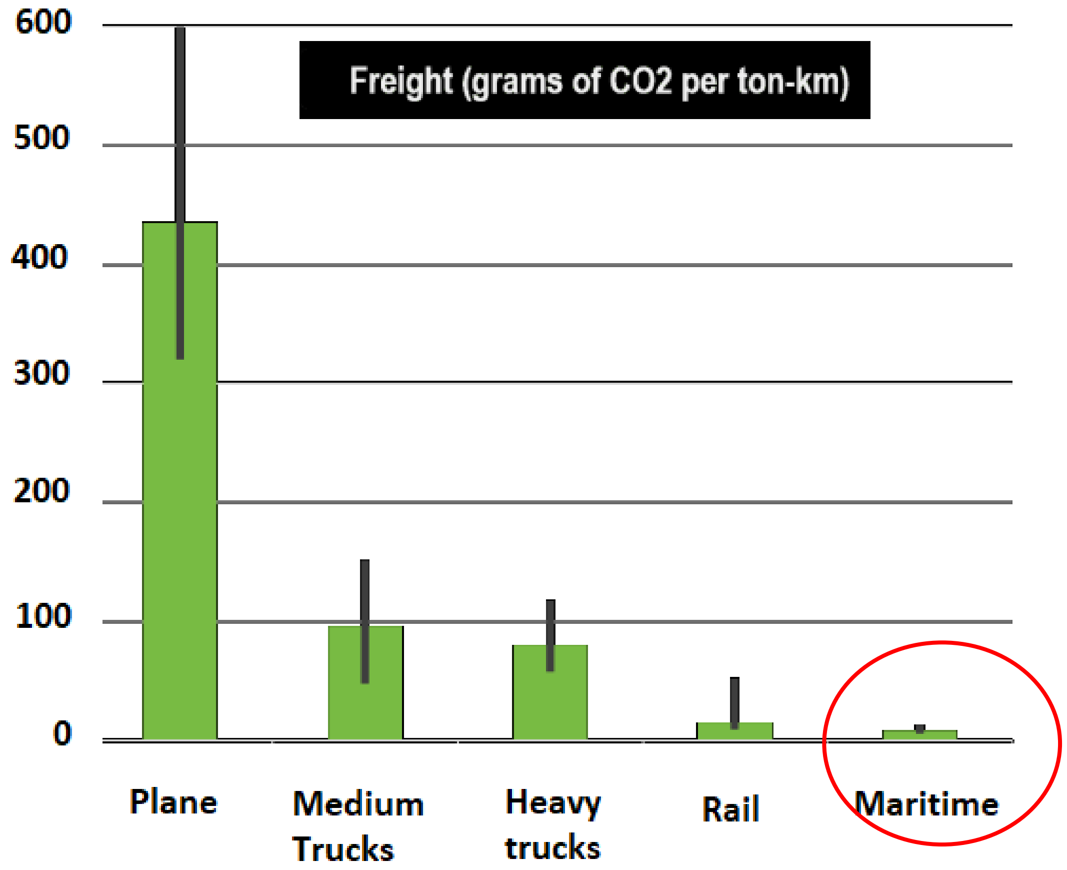
# Social and customer demand for change



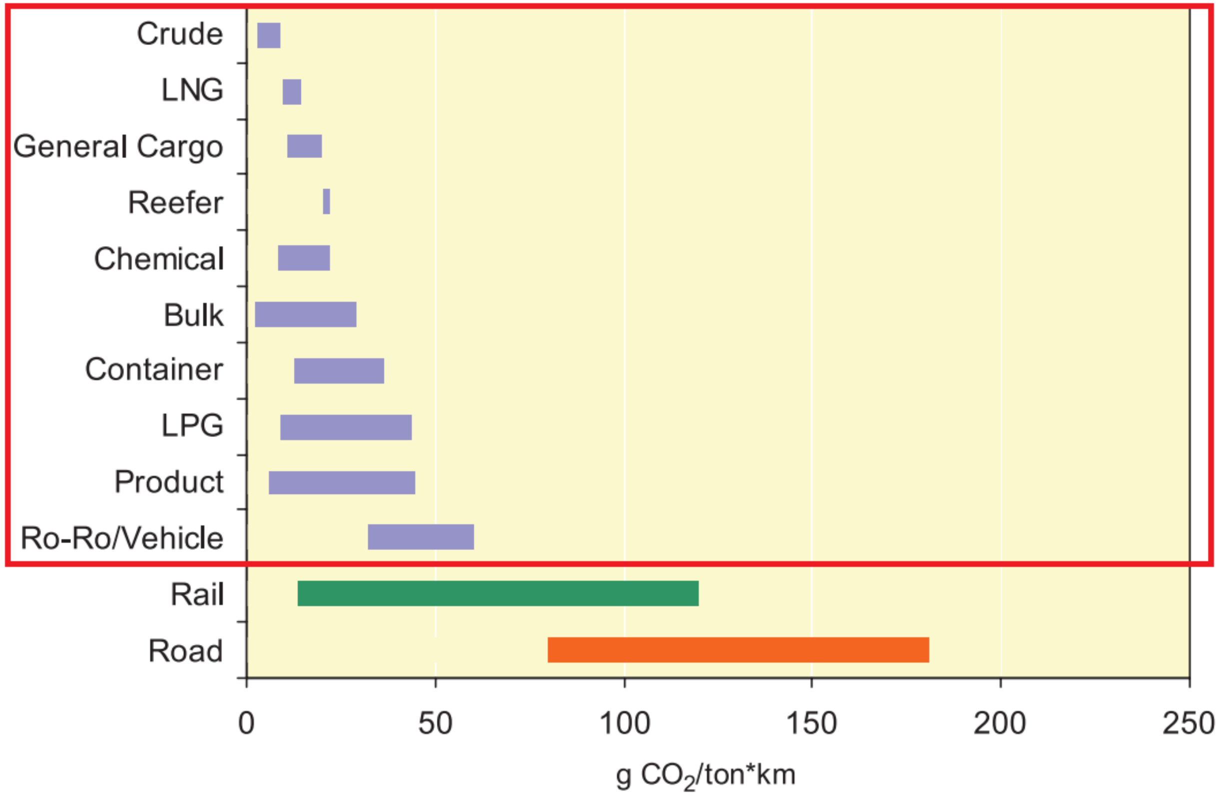
Major shippers want change


- Amazon ($470 bn revenues)
- Beiersdorf
- Brooks Running
- Dupont
- Electrolux
- ETTLI Kaffee
- Frog Bikes
- IKEA
- Inditex
- Michelin
- Moose Toys
- Ohana Beverage Company
- Patagonia
- Philips
- REI Co-op
- Sisley
- Target
- Tchibo
- Unilever

# Remember: **shipping is the least polluting form of freight transport**




Source: IEA (2019); quoted by Rodrique in "The Geography of Transport Systems"




Typical ranges of C02 efficiencies of ships (by type) compared to road / rail.
Source: Figure 1.3, IMO Second Greenhouse Gas Study (2009)

# Shipping's C02e emissions

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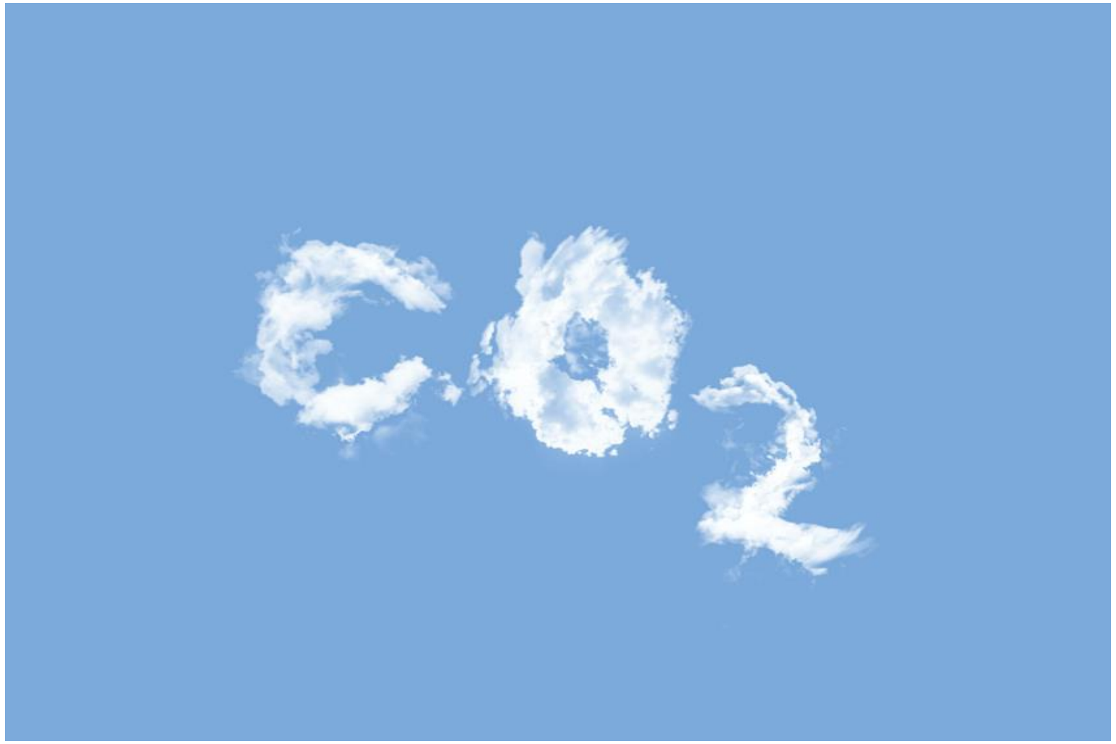

- Carbon dioxide equivalent* emissions from all types of shipping**:
  - 977 million tonnes in 2012
  - 1,076 million tonnes in 2018
  - A 9.6% increase
- Ships' emissions account for 2.89% of world human-made emissions

**includes carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O); expressed as Carbon Dioxide Equivalents (C02e); **includes total shipping (including international, domestic and fishing).* **Source: IMO 4th GHG Study 2020.**

# The challenge: C02e emissions (2)

- Emissions from shipping are roughly equivalent to Germany's emissions

- if shipping were at country it would be No. 6 in the world by C02 (equivalent) emissions

# The Paris Agreement

- UN Framework Convention on Climate Change
- Agreement in Paris in December 2015
- **Goal**: to limit global warming to below 2 degrees Celsius, preferably to 1.5 degrees compared to pre-industrial levels

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# IMO carbon reduction goals

- 2018 Greenhouse Gas Strategy (aligns with Paris Agreement goals):
- to reduce new ship carbon intensity
- Reductions in C02 emissions (compared to 2008):
    - cut, on average, 40% by 2030; and
    - cut total emissions by 50% by 2050
    - working towards a 70% cut by 2050
    - complete phase-out by century's end

# IMO Energy Efficiency regulations – some dates


- EEDI: adopted at MEPC 62 (July 2011) with amendments to MARPOL Annex VI; mandatory 2013 onwards
- Amendments to MARPOL Annex VI (MEPC.328(76))
  - Adopted at MEPC 76 (10 to 17 June 2022)
  - Amendments enter into force November 2022
  - The requirements (EEXI, SEEMP Part 3 (CII)) enter into force in January 2023
  - Further revisions / reviews are scheduled

# IMO Ship Energy Efficiency Management Plan

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- Idea is to create a mechanism for a company / ship to continuously improve the energy efficiency of a ship's operation
- Originally in force as of 2013; now has 3 parts:
- **Part 1** – for monitoring and improving ship's energy efficiency (IMO recommended EEOI as a tool to set goals and monitor KPIs); applies to ships above 400gt
- **Part 2** – mandated collection & reporting of fuel consumption data, distance travelled, hours underway; applies to ships >5,000 gt
- **Part 3** – Carbon Intensity Index applies to ships >5,000 gt

# IMO Energy Efficiency Design Index (EEDI) for ***new*** ships

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- Mandatory from 2013 onwards; new ships must meet a set minimum efficiency benchmark; that benchmark reduces on a five-yearly basis
- Different benchmarks for different ships, and for ships of different sizes
- EEDI gives a figure for an individual ship design, expressed in grams of carbon dioxide (CO2) per ship's capacity-mile; a more efficient ship has a smaller EEDI
- Concept calculation is *EEDI = C02 Emissions / Transport Work*
  - Takes into account installed power, vessel speed, cargo carried
- A one-off International Energy Efficiency Certificate proves that a ship's attained EEDI is below the required EEDI and there is an SEEMP aboard
- *"By 2025, all new ships will be a massive 30% more energy efficient than those built in 2014" - IMO*

# IMO Energy Efficiency *Existing* Ship Index

- EEXI is a companion to EEDI… the EEXI is considered to be the EEDI for existing ships.
- A baseline is set by the IMO for each ship type; ships can then be compared to the baseline
- Ships must then meet a target that is lower than the baseline (the attained EEXI); if not there must be corrective action
- The EEXI calculation takes into account installed engine power, transport capacity, ship speed; includes a wide range of conversion and correction factors (e.g. ice-classed ships)
- Applies to all types of ocean-going cargo ships of 400 gt and above on international voyages
- A one-off International Energy Efficiency Certificate is issued at a ship's initial survey / first annual / intermediate / renewal survey (as appropriate depending on the ship delivery date)

# IMO Carbon Intensity Indicator

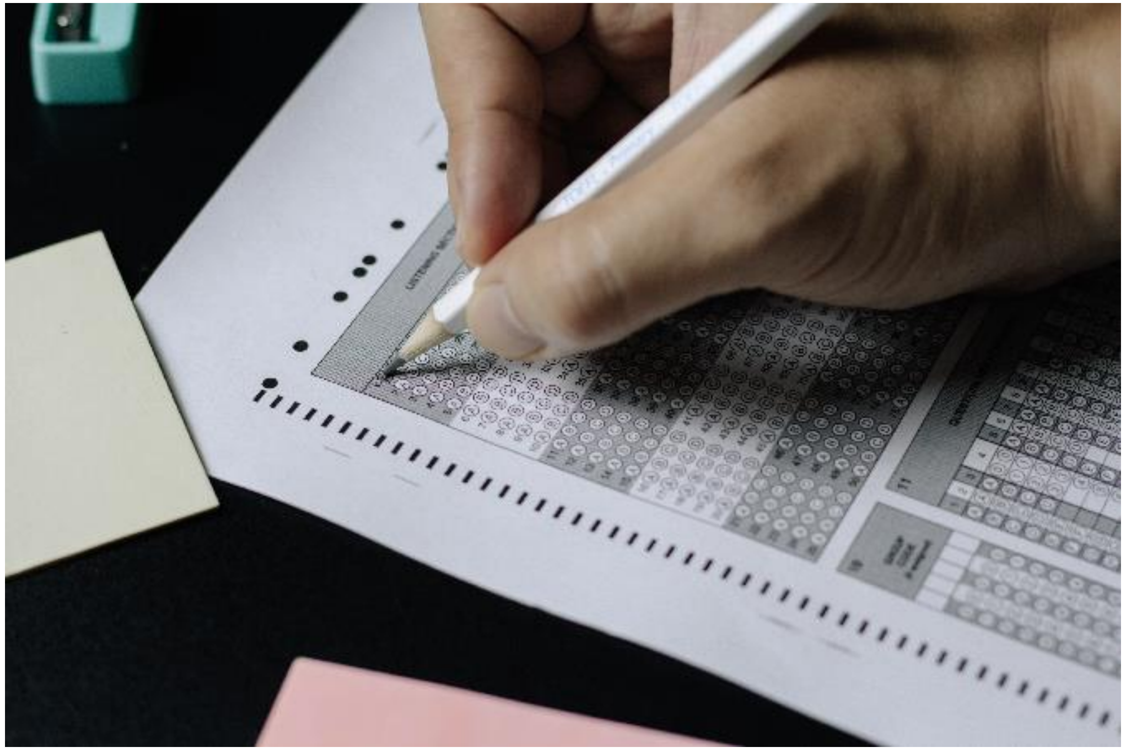
- **SEEMP Part 3** brings the **Carbon Intensity Indicator** into being; one of the amendments to MARPOL Annex VI from MEPC 76
- Applies as to all cargo ships > 5,000 gt as of January 2023
- "Carbon intensity" is the measure of a ship's GHG emissions relative to the cargo carried over distance
- Calculated annually on a calendar year basis
- Two main different ways of calculating the CII:
  - "AER": emission per DWT-mile; weight-based cargo e.g. bulk
  - "cgDIST" emission per gross ton-mile; volume-based cargo e.g. PCTC
  - Can't use the EEOI for this purpose (SEEMP 2 did not collect appropriate data)

# CII – Grades A to E

- **The CII is set with a baseline from the year 2019**
  - This is when the data from SEEMP 2 was collated
  - The CII regulation is reducing over time
  - Reduction factors have been set: 5% from 2019, then 2% a year until 11% in 2026
    - A compliant ship in one year could become non-compliant the year after!
- Individual ships will be required to calculate an “attained CII”
  - This will have to be done every year using the CII calculation
- Five sets of grades have been set from A to E, where A is best, E is worst
- C-rating and above is a clear pass! (See next slide for non-compliance)
- From January 2024 a statement of compliance will be issued

# Non-compliance; consequences

- Non-passing scores:
  - vessels with an **E-rating** in any one year, or
  - ships which get a **D-rating for three years**
- will trigger a requirement for **corrective action**
- non-compliance must be reported to a **Recognised Organisation** (i.e. to Class)
- corrective actions taken must be detailed in the revised SEEMP;
- ship will need to get a C-rating from a **Recognised Organisation** (e.g. a Class Society) in the following calendar year
- **Port Incentives:** IMO suggests ports / authorities give "incentives" so that ships comply



# Non-compliance: sanctions

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- **Flag State:** no specific requirement for a Flag State to enforce compliance
- **Port State Control:** there is no (current) specific PSC sanction for non-compliance
  - Consequence would likely be detention and an inability for ships to trade
  - discussed at IMO and not green-lit; could there be PSC in the future?

  - **AMSA** has indicated no enforcement action… **to begin with**…
  - *"Noting the so-called 'soft' enforcement approach of the short-term measure in the first several years after implementation, AMSA has no plans to take unilateral enforcement action against vessels that arrive in Australian ports with a CII of less than grade C or have not implemented corrective actions within 12 months of being rated E once or D three years in a row.*

    *"Please note that strengthened or enhanced enforcement mechanisms may be considered as part of the review of the short-term measure, which is to be completed by the IMO by 1st January 2026" – AMSA email to SAL of 31 October 2022.*

# CII: market issues

- **Market sanctions**
  - What will charterers do? Will they refuse to charter ships with a rating less than grade C? Possible. Likely? See e.g. zero-carbon shipping group.

- **Slow-down, retro-fit… or scrap & replace?**
  - Fastest, cheapest, easiest counter-measure: slow down. A 10% cut in speed slashes 20% from fuel consumption
  - compliance for existing ships with CII could become costly if energy-saving devices are installed or new fuels have to be used
  - however, there are many processes that can be managed to reduce CII
  - very difficult for ***older ships*** in ***low freight rate environments*** to earn back retrofitting costs, especially for inefficiently designed (but could slow-down instead)
  - age, freight rates, acceptability to charterers, operational cost will be decisive factors in some cases; ***widespread scrapping of older ships is possible*** *(Schroer et al 2022)*

# Shipping industry position on CII

- On 1st January 2023, the CII system enters an initial review period which must complete by 1st January 2026. It will not be clear whether the system is functioning in an accurate and fair manner until then
- The incomplete version of CII that will come into force in 2023 therefore cannot be considered as an adequate and fair basis for enforcement
- CII ratings will be confirmed against annual data returns. In between the annual submissions, it will be impossible to know what a ship's annual rating will be – because of seasonal (winter/summer) variations
- Shipping considers that it is **entirely inappropriate** for Port State Control to detain ships because of non-adherence to CII Implementation Plans or Corrective Action Plans
- Unless a Port State inspection coincides with the end of an annual CII reporting period, or at some point thereafter, it would be impossible for a Port State Controller to fairly judge whether a ship will fully complete the plans or ultimately achieve or exceed a C rating at the end of that annual reporting period.

# CII: concept calculation

$$\frac{(\text{Annual fuel consumption} \times \text{C02 emission factor})}{(\text{Annual distance travelled} \times \text{ship capacity})} \times \text{correction factors}$$

**Notes:**

- simplified version of the calculation
- the “C02 emission factor” is based on the type of fuel
- we can ignore the correction factors for the purposes of this presentation

# What *processes* can be improved?

Carbon intensity indicator = (yearly fuel use x $CO_2$ emission factor) / (distance x capacity)

***These process improvements could save 30% to 50%!***

- Optimal trim (ship sails level) (**1%  to 3%)**
- Optimal routing (maximise efficiencies in port calls, use currents and weather advantages; **1% to 5%)**
- Engine de-rating (max speed reduction) (**2% to 10%**)
- Slow-steaming (**10%** drop in speed cuts fuel by **20%**)
- Engine optimisation (**1-4%**)
- Improve auxiliary engine load (reduce no. of auxiliary engines to generate electrical power; auxiliary engines don't have to be functioning all the time; **1% to 5%)**
- Improve hull cleaning (it also provides biosecurity benefits; fuel savings **1% to 5%**))
- Propeller polishing (cavitation damage, fouling); saves main fuel consumption (**3% to 4%)**

Source: GloMeep; misc. List is non-exhaustive. Fuel savings are indicative and vary between sources and  depending upon the exact circumstances of ship operations. Not all processes can be deployed on all ships.

# What *devices* can be used?

Carbon intensity indicator = (yearly fuel use x $CO_2$ emission factor) / (distance x capacity)

***Potentially another 50% of fuel savings here!***

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- Wind assisted propulsion (**e.g. 5% per device**)
- Rudder bulbs **(1.5%)** & Mewis ducts **(7%)**
- Air cavity lubrication (bubble hulls **(10%))**
- Hull-coatings (**8%;** plus biosecurity benefits)
- Propeller optimisation, boss caps and fins **(3%)**
- Inverted bow designs (see e.g. workboats) **(6%)**
- Install (if appropriate) a shaft generator (generates electricity) **(2% to 5%)**
- Install waste heat recovery systems (costs USD$5m-9m; saves on main engine fuel **3-8%**)
- Hull retro-fitting (for ships that spend a lot of time in off-design conditions) re-shaping of bulbous bow, bilge keel optimising etc (**3-7%**)

Source: GloMeep; misc. List is non-exhaustive. Fuel savings are indicative and vary between sources, and depending upon the exact circumstances of ship operations. Not all ships can use all devices.

Pictured: a Mewis duct and a rudder bulb installed on a dry bulker. Credit: Oldendorff Carriers.

# Wind ***Assisted*** Propulsion

Carbon intensity indicator = (yearly fuel use x $CO_2$ emission factor) / (distance x capacity)

- **Hard sails – 5% fuel savings per sail**
  - Telescoping glass fibre reinforced plastic
  - 5% fuel savings per sail
  - “Wind Challenger” approx 100,000 dwt

- **Rotor ‘sails’ - 2–24% fuel savings per sail**
  - Magnus effect - an object spinning in the atmosphere causes application of force side-on to the spinning object
  - This is what happens when you slice your golf ball! You’re not a bad golfer, it’s just physics!

- **Kites - 1–32% fuel savings –**
  - Been around longer, but less popular

*Concerns: rough seas, deployment, port entry / acceptance, and cargo operations*

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*Fuel savings data: “Propulsive power contribution of a kite and a Flettner rotor on selected shipping routes”, Traut et al (2014) ; hard sail data MOL*

# What about fuels?

Carbon intensity indicator = (yearly fuel use x $CO_2$ emission factor) / (distance x capacity)

- **Electrification**
  - Not for bigger cargo ships
  - Could be used for power management
  - Good for near-shore: coastal, ferries, tugs
- **Less carbon-intensive fuels**
  1. LNG
  2. Methanol
  - Biofuels
    (from waste materials; drop-in;
    not examined here;
- **Carbon free fuels!**
  3. Ammonia
  4. Hydrogen

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# Battery electric small craft

- **Tugs**
  - PoAL's "Sparky"; 2022 delivery
  - 70 bollard pull; Damen Tugs design
  - 80 battery racks; 2,240 batteries; 2,784 kWh of power; diesel backup
  - 4 ship movements per full charge
  - NZ$12m operating savings over 25 years
- **Ferries** (many examples around the world)
  - Danish inter-island car/pax ferry "Ellen" sailed 50nm (96km) on a single charge
  - Euro 21.3m cost
- **Coastal ships**
  - Yara Birkeland - box feeder, Norway
  - Asahi bunker tankers (Japan) on order
- **662 battery vessels (in operation & on order)**

Pictured: Sparky. Photo: PoAL. Battery ship stats – DNV.

# Liquefied natural gas

- 1,061 LNG ships or LNG-ready ships in operation or on order
- August 2022: 147 ports around the globe can bunker LNG; this figure is likely to reach 200 by 2024
- About 372.3 million tonnes of LNG internationally traded (2021)
- LNG tanks on ships have to be about 2.5x to 3x bigger than HFO because of the lower energy content


*The "Jacques Saade", a 23,000 TEU LNG-powered boxship delivered in 2020. Photo: CMA CGM. Data sources: SEA LNG, Clarkson Research, DNV, IGU*

# LNG key points

- Natural gas is 95%+ methane ($CH_4$)
- Cooled to −162 °C (−260 °F); cryogenic
- Compresses from gas to liquid by 600 times
- Odorless, colorless, non-toxic, non-corrosive
- Virtually no SOx, Particulates; little NOX
- About 20%-25% less carbon than HFO; cannot get us to GHG zero
- Methane is a potent greenhouse gas itself and breaks down into $CO_2$ after 10 years in the air
- Widely traded, available, handled
- High knowledge of how to safely handle

# Methanol ($CH_3OH$)

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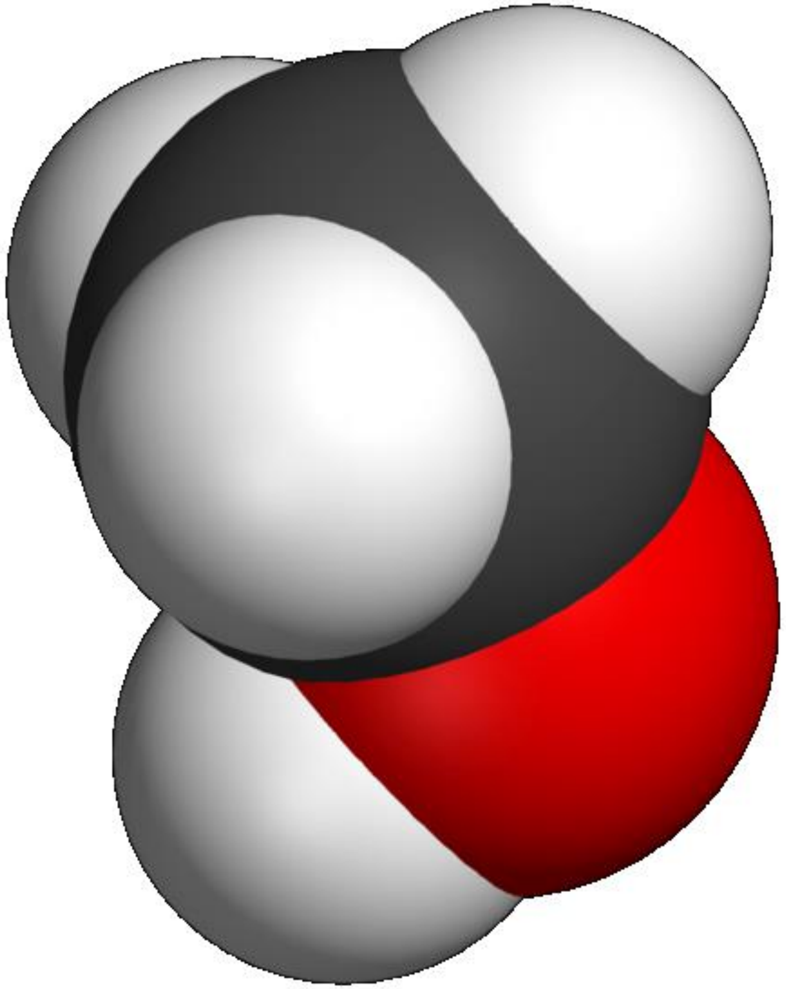

*Pictured: a model of a molecule of methanol; black = carbon; grey, hydrogen; red, oxygen*

- The simplest form of alcohol (wood alcohol)
- Six atoms: One carbon, four hydrogen, one oxygen atom
- Major ship orders – Maersk, Berge, Höegh Autoliners, Stena Bulk, CMA CGM, Waterfront Shipping (aims for 60% of its fleet) and more
- China Merchants Energy Shipping & Cosco Bulk have reportedly decided on methanol as their future fuel
- 66 ships in operation or in order (mostly on order; was 26 in mid-2021 (source: DNV
- Extensive industry research into bunkering, testing e.g. Alfa Laval
- Methanol bunkering has been carried out around the world Korea, Singapore etc

# Methanol – key points

- Combustion: requires pilot ignition with fuel oil
  - Necessitates two sets of fuel lines and different fuel tanks; research underway to solve
- Much lower gravimetric & volumetric energy than HFO
  - So requires bigger tanks (2.5 x than HFO) or more frequent bunkering (similar to LNG)
- Methanol propulsion adds 11%-12% to cost of a new ship
  - But much less costly to build and operate than LNG-propelled (adds 22% more)
  - Methanol Capex (engine, tanks, pipes etc) 1/3 that of additional cost of LNG
- Non-cyrogenic, it's a basic chemical commodity, widely traded, stored, handled

# Methanol - safety

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- Low flashpoint fuel (burns at 11 Celsius) and broadly flammable; burns with a near-invisible flame in daylight; HFO has a flashpoint of 50 degrees Celsius
- **Toxicity:** very much dependent on species and size; unfortunately, humans are particularly sensitive to methanol
    - Low exposure to humans via ingestion, inhalation, or skin contact can result in medical issues (irritated tissues, shortness of breath, nausea, headache, blindness, vomiting, diarrhea, death)
- Offsetting toxicity - lots of safety knowledge in how to handle and use
- ***Stena Germanica*** (a ferry) recorded thousands of hours of safe operations
- The IMO approved methanol as a safe fuel in MSC.1/Circ.1621, the Interim Guidelines for the Safety of Ships Using Methyl/Ethyl Alcohol as Fuel (2020)

# Methanol - production

- Can be produced from a range of feedstocks
  - Natural gas, coal
  - Black liquor (waste by-product of converting pulp into paper); forest residues
  - agricultural wastes
  - C02 can be captured from industrial sources

- **Worldwide supply** - more than 90 methanol plants, with a combined production capacity of about 110 million tons (Mt); Energy content is equivalent to approximately 55 Mt of oil; green methanol supply is limited

- **Infrastructure:** much existing infrastructure can be repurposed
  - methanol is compatible with stainless steel
  - However, it can be corrosive to coatings, pipes, seals
  - bunkering to be developed

*(Source: "Alternative fuels for containerships," DNV, v2 accessed 25-11-2022).*

# Methanol – a green(er) fuel

- **Sox:** 95-98% less than heavy fuel oil
- **NOx: 25-80%**% less than HFO
- **Particulate matter:** 95% less than HFO
- **Carbon dioxide:** it's complicated
  - 5% to 10% less for non-green methanol; up to 80% less for green methanol
  - Production from natural gas, coal can result in worse green house gas emissions than heavy fuel oil combustion; manufacture with renewable energy from biomass, waste leads to considerably less carbon dioxide emissions
  - manufacture from **biological-origin CO2;** electrolysis of water produces hydrogen
  - potential for carbon offsetting (planting forests, mango groves, kelp, peat bogs etc)
  - ***onboard carbon capture and storage – could make methanol carbon-negative***
- **Marine environmental safety**
  - mixes with seawater but does not persist; generally degrades and / or evaporates
  - does not bio-accumulate; generally low toxicity to marine organisms

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# Ammonia ($NH_3$): not ready

- Carbon free… but manufactured using a dirty process; can in theory be made with renewable energy, hydrogen (via electrolysis) and nitrogen (using an air separation system)

- Energy content of 19 MJ/kg and 12 ML/L (half and one third of HFO, respectively) – it’s got the energy

- Research project – “Viking Energy”
  - to be powered by a 2MW ammonia fuel cell 2024
  - aims for a 3,000 hours of operation
  - a further fuel cell testing programme by Wartsila
- Mass produced – about 235m tonnes worldwide
- Global infrastructure exists (storage, pipes, not bunkering)
- Liquid at normal temperature and 17 bar
  - Easily stored and handled;  great handling knowledge
- Does not burn easily – boon and curse
  - Ignition research projects underway worldwide
- Colourless, smelly, highly toxic - tissue irritation, burning of tissues, blindness, convulsions, death

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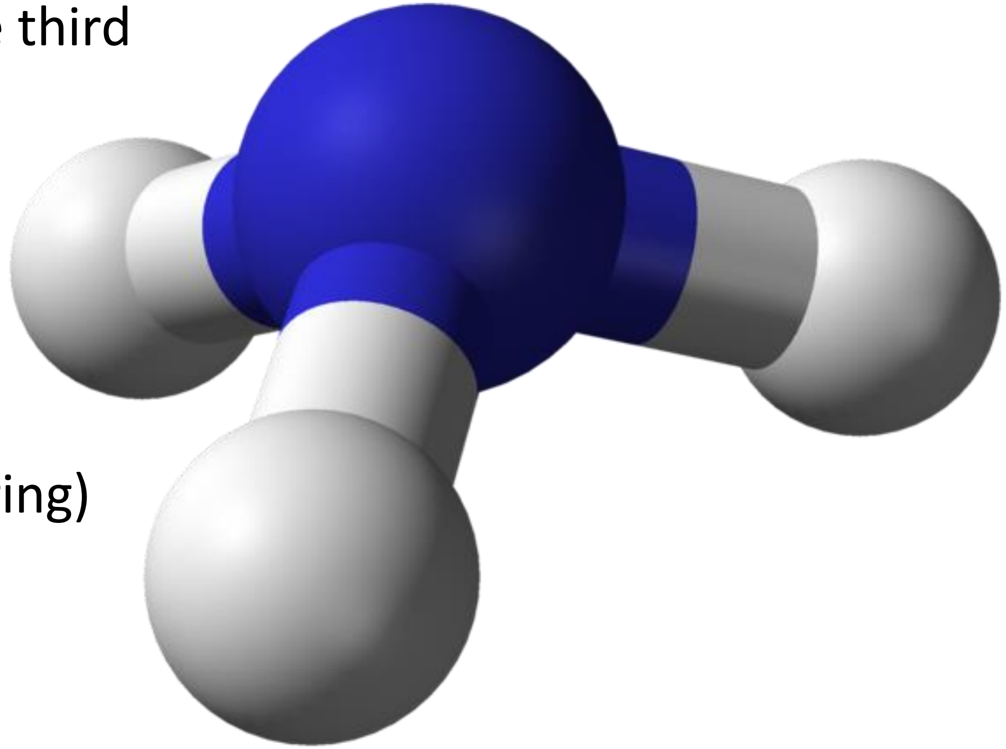

*Pictured: an ammonia molecule (NH3). Public domain by Benjah-bmm27.*

# Hydrogen ($H_2$): not ready

- High energy content by weight but low by volume (120 MJ/kg vs 8 MJ / Litre)
- Cleanest fuel – no SOx, NOx, PM, CO2
- Currently created from fossil fuels – releases 6.6-9.3 tonnes of C02 per tonne hydrogen (steam methane reforming); but can be cleanly produced in theory (with renewable energy and electrolysis); 90 million tonnes per year produced
- 15 hydrogen ships in operation / on order (DNV); experimental small craft; plus one hydrogen carrier – *Susio Frontier* (2020)
- Future Proof Shipping (Europe) plans to retrofit an inland river ship; will take up 2 x FEU spaces
- Problems with hydrogen for shipping
  - explosive and flammable
  - temperature near absolute zero
  - embrittlement
  - colourless, odourless, burns invisibly
  - asyphxiation risk if it displaces oxygen (inert gas asphyxiation)
  - major energy losses if transformed into ammonia
    - liquefaction, changing to NH3, changing back to H2, combustion etc

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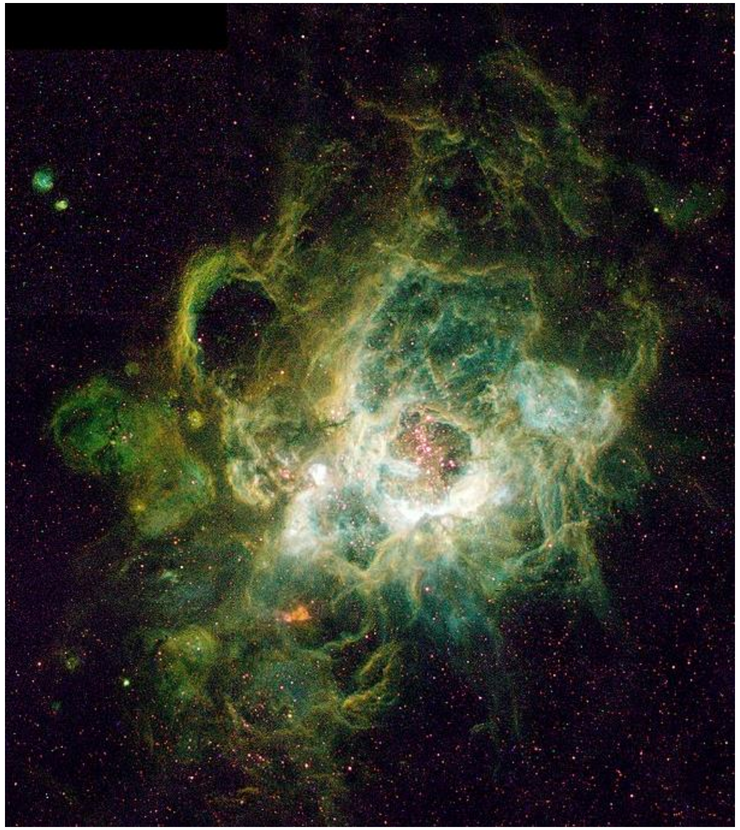

Pictured: a hydrogen gas cloud inside the Triangulum Galaxy. Photo credit: NASA.

# The Future (according to DNV)

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- IMO GHG strategy / regulations are forecast to have a *“significant impact on design and operations of all ships”*
- More orders for alternative-fuelled and bigger ships
- Fossil LNG to dominate; but ammonia & hydrogen fuel technologies to start appearing in eight years
- Short-sea shipping will mature the zero $CO_2$ tech
- An increased focus on safety will be necessary – toxicity of methanol, ammonia, & “extreme” flammability of hydrogen
- Increased interest in onboard carbon capture & storage
- Fossil fuels (incl LNG) to be in rapid decline by 2050
- DNV modelled 24 different scenarios

***Source: DNV***

# Appendix: Approximate energy content

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| Fuel (by alpha-order) | Gravimetric density; (Gross heating value); *Energy by mass MJ/kg* | Volumetric density; (Gross heating value); *Energy by volume; MJ/Litre* |
|---|---|---|
| Ammonia ($NH_3$) | 18.6 - 22.5 | 11.5 |
| Biodiesel (FAME) | 38 | 33 |
| Biodiesel (HVO) | 40 - 43 | 33-35 |
| ***Heavy Fuel Oil*** | ***39 - 42*** | ***33.4*** |
| Hydrogen (liquid) | 120-142 | 8.5-10 |
| Liquefied Natural Gas (mostly methane: CH4) | 48 - 55 | 22 |
| Methanol ($CH_3OH$) | 19.9 | 15.8 |

*Note: figures will vary by temperature, pressure etc; values can differ greatly between sources. Beware that some sources give density in different units – metric, British Imperial, US customary etc and also in different scales e.g. kg, m3, litres etc. Many sources disagree on the values. Fuels may be mixed e.g. IFO 380 is mostly HFO with a small volume of distillate. Sources: Statista; Engineering ToolBox; SEA-LNG; International Bioenergy Association; misc other*


That's all Folks!