Perspectives on powering shipping through sustainable energy

CIMAC 2023 Keynote

Martin Tunér

martin.tuner@energy.lth.se

Lund University

CIMAC Congress 23
Busan, June 12-16, 2023

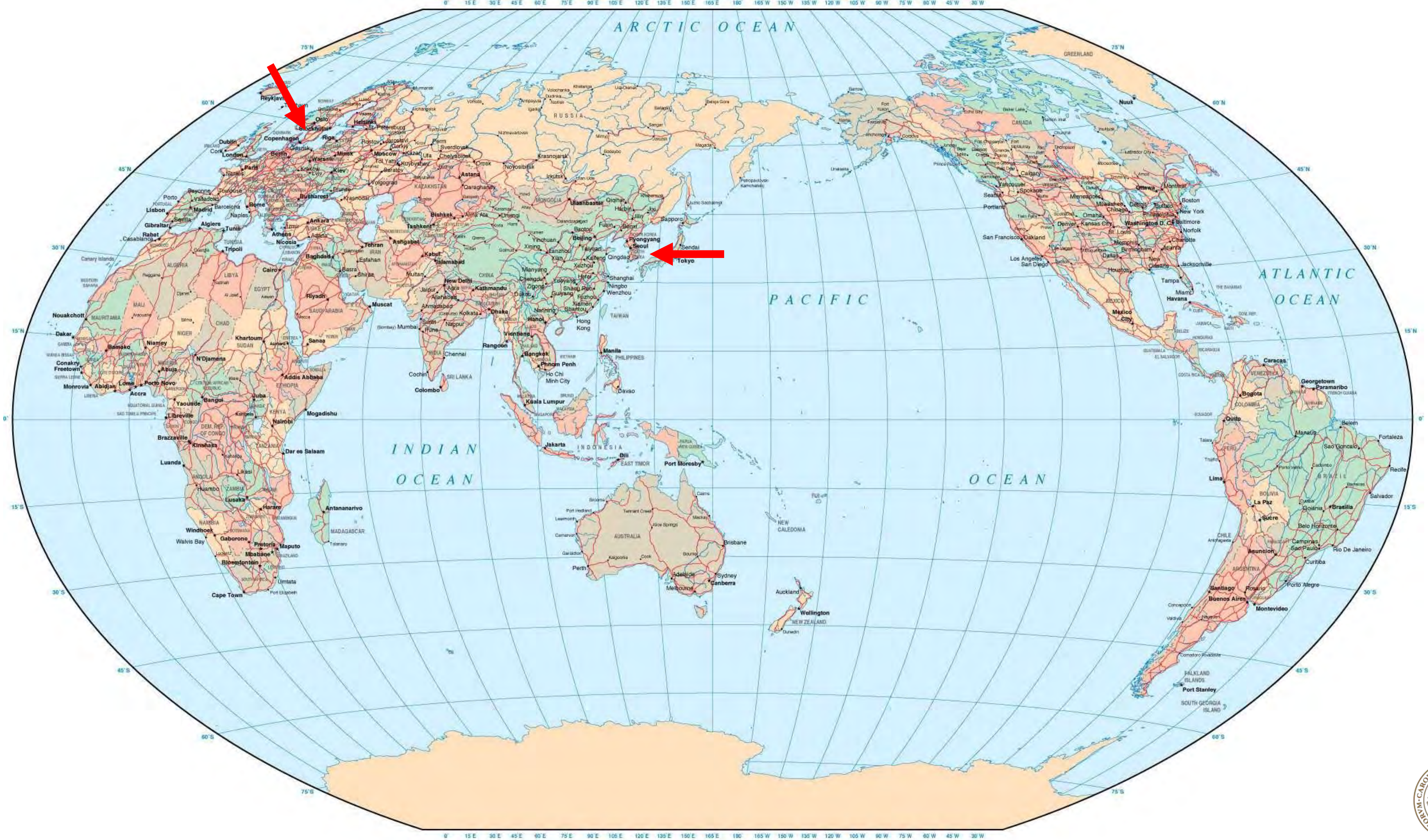
Indeed! Sails have a 6% GHG reduction potential according to OGCI/Concawe

Lund University – a top 100 University

Education, research and collaboration since 1666

45000 students & 8000 staff

works to understand, explain and improve
our world and the human condition



1000 Kilometers Parallel scale at 0 north 0 east

1000 Kilometers Parallel scale at 30 north 0 east

1000 Kilometers Parallel scale at 60 north 0 east

South Korea – a leading country

- World's fastest replacement of light trucks to electric operation
  - Strong economic stimulus
- Largest in the world hydrogen-powered vehicle fleet
  - Long-term and concrete strategy of great relevance to the outside world.
- Second largest in the world battery production
  - Very interesting how the state is now stimulating and part-financing how research and development can be commercialized in the transition to nickel- and cobalt-free batteries and solid state technology.

Source: The Swedish 2030-secretariat

martin.tuner@energy.lth.se

Methanol projects

2010

2020

Methanol engines @ Ghent University

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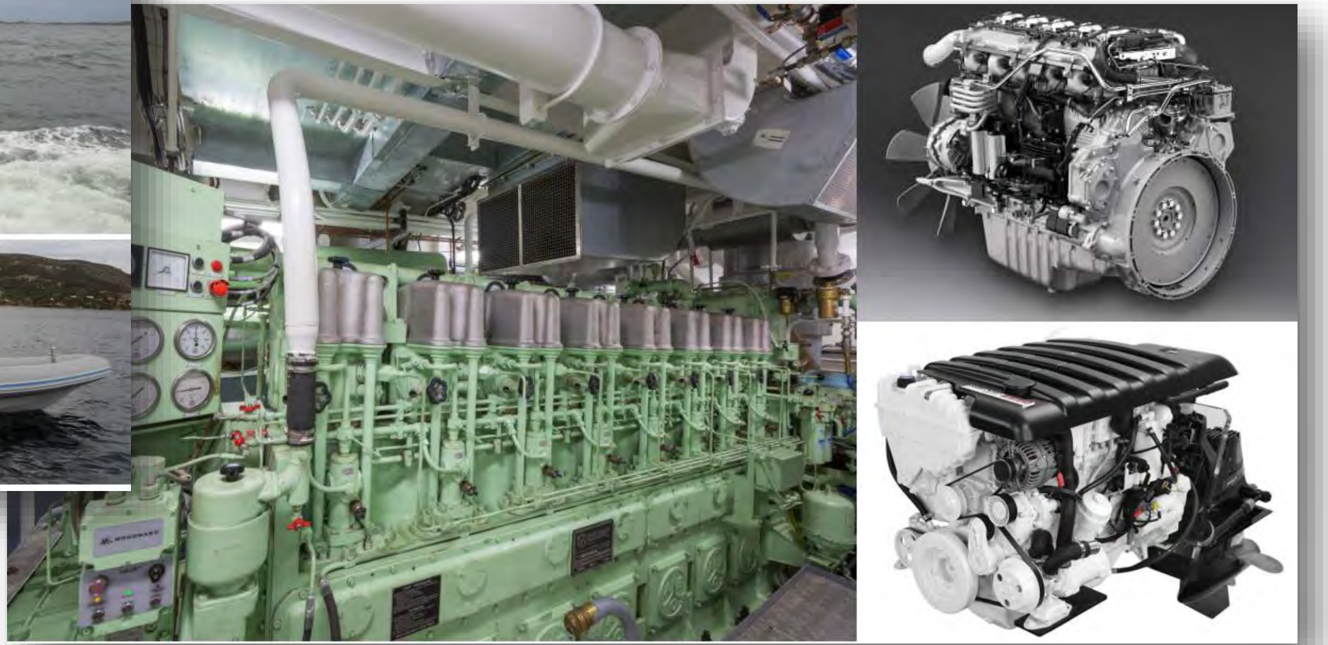
FASTWATER

FAST Track to Clean and Carbon-Neutral WATERborne Transport

June 2020 – May 2024

The project has received funding from the European's Horizon 2020 research and innovation programme (Contract No.:860251)

fastwater.eu



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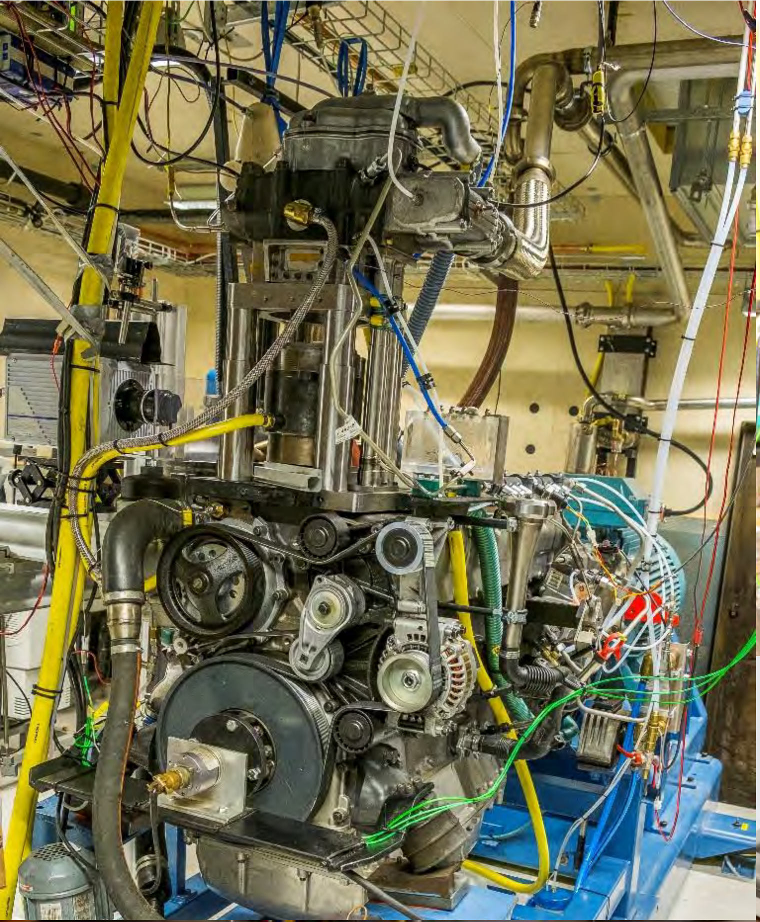
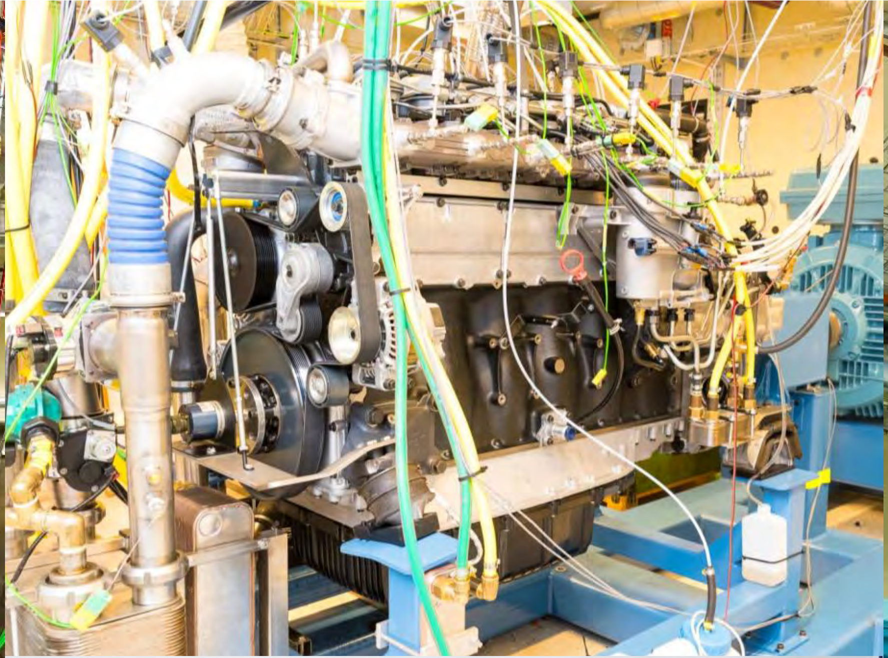
GHENT UNIVERSITY · LUND UNIVERSITY · SSPA · ScandiNAOS AB · Lloyd's Register · Port of Antwerp



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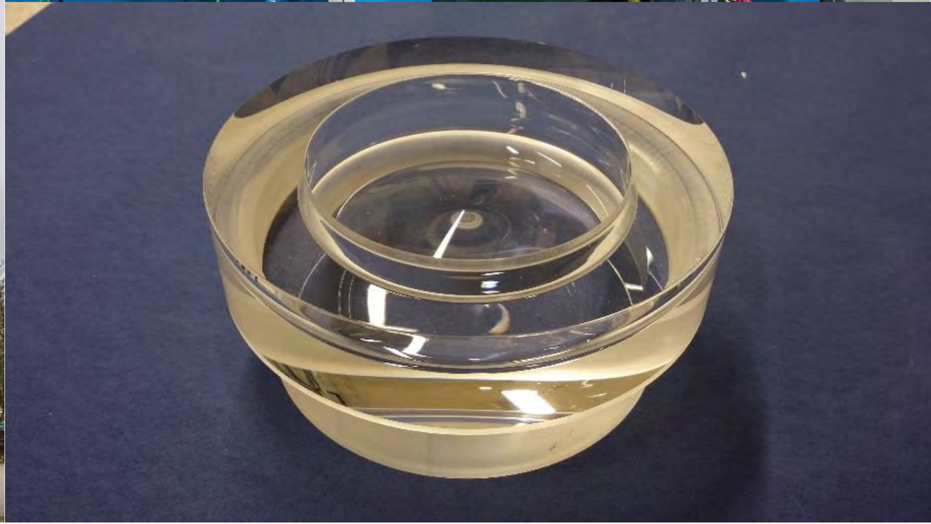

What I will talk about (and not talk about) – "helicopter" perspectives as food for thought

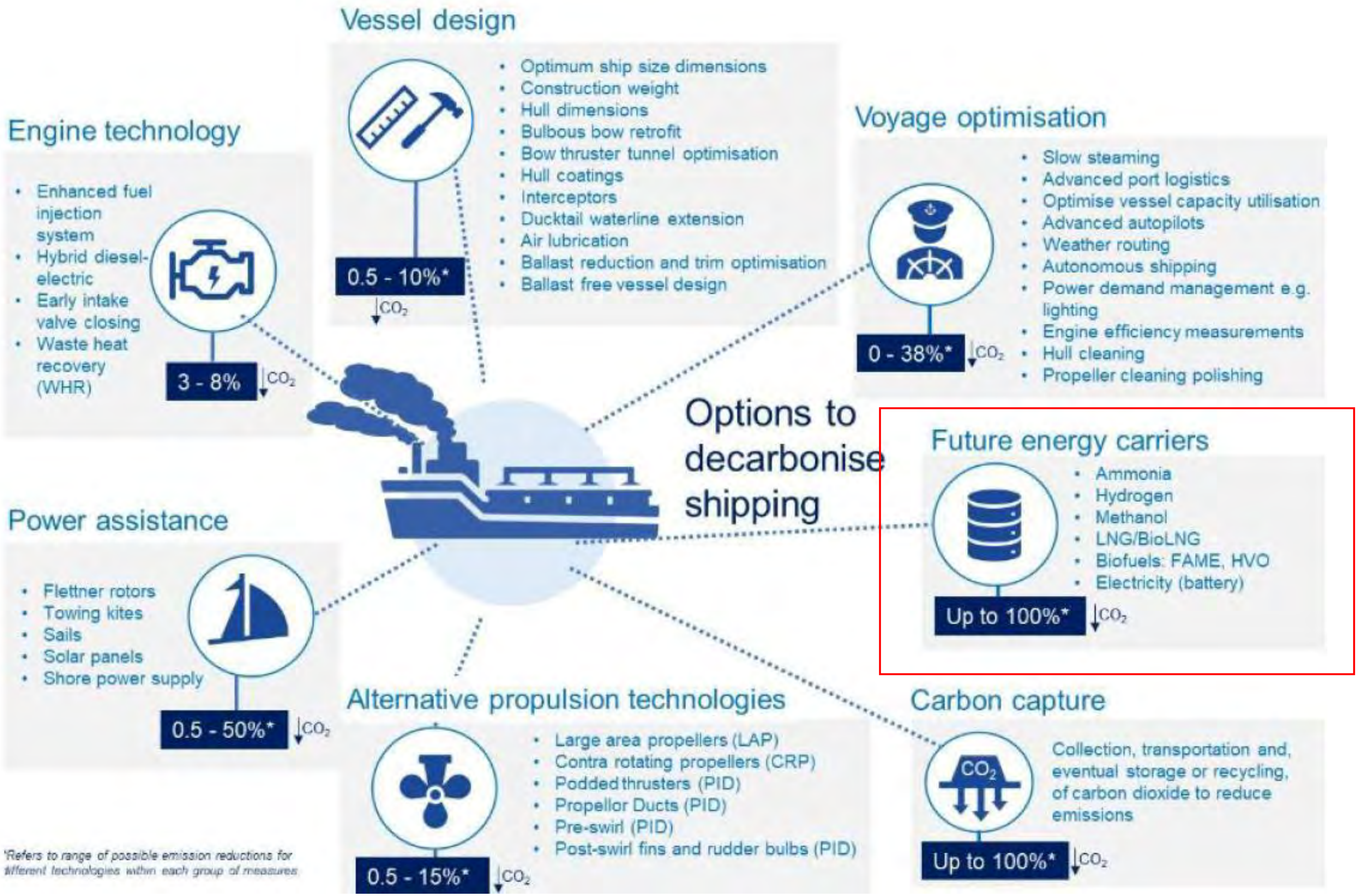

Figure from OGCI and Concawe Maritime Decarbonisation Report (2022)

martin.tuner@energy.lth.se

Overview

- Perspectives on decarbonization
- Scale of the challenge
- Ship sustainable energy options
- Technical aspects
- Costs
- Summary

Perspectives on decarbonization

March 06, 2023 04:43 AM

EU, Germany continue talks on combustion-engine ban

Germany wants the EU to present a proposal allowing combustion engines running on e-fuels to continue to be sold after the cut-off date of 2035.

Bloomberg

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REUTERS

German Chancellor Olaf Scholz and European Commission President Ursula von der Leyen are pictured following a German cabinet meeting in Schloss Meseberg, Germany on March 5.

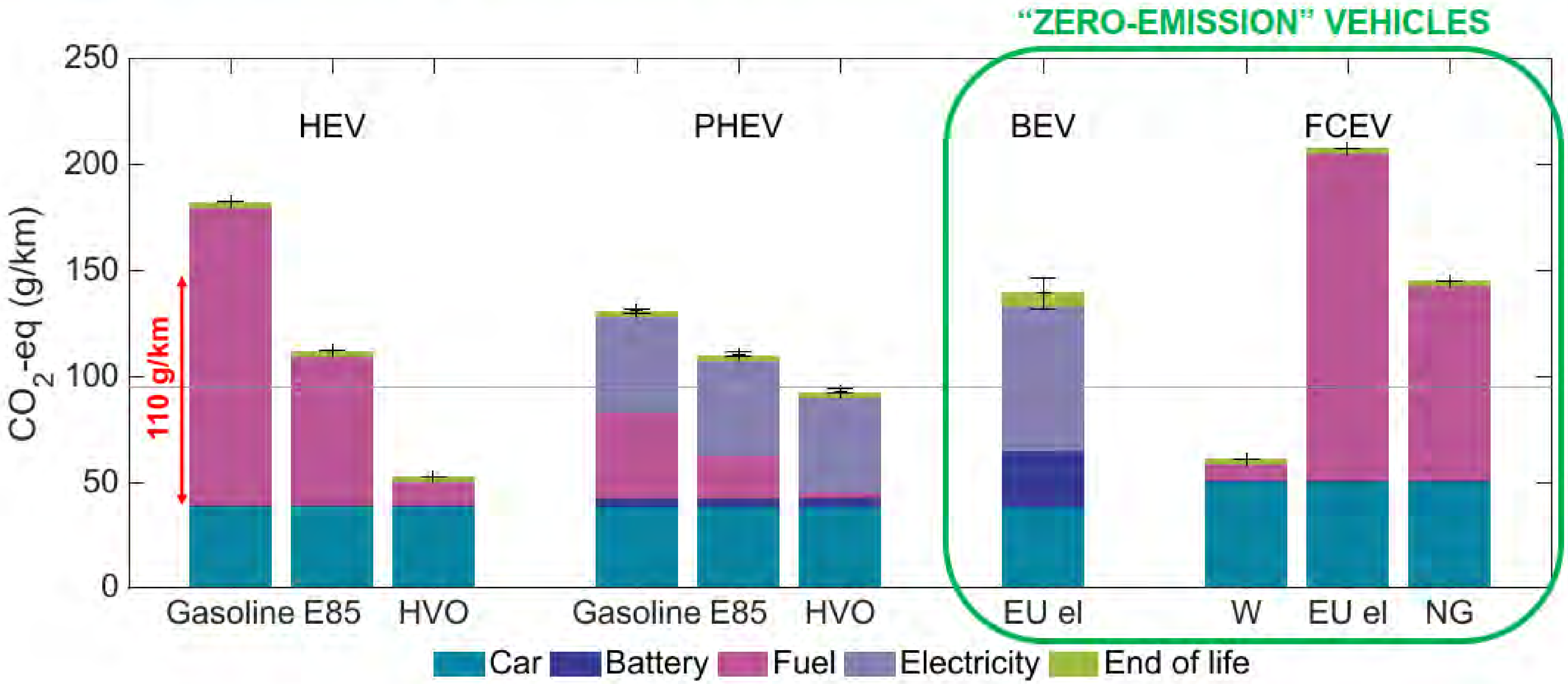
German Chancellor Olaf Scholz said talks were constructive with the European Union in resolving a dispute over plans to ban new combustion-engine cars in the bloc from 2035, after Berlin derailed the effort this past week.

Scholz met with European Commission President Ursula von der Leyen on the

"The internal combustion engine itself is not the problem, the fossil fuels it runs on are,"

German Transport Minister Volker Wissing

Results with present EU electricity mix (2020)



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Andersson and Börjesson, Applied Energy 289 (2021) 116621

We have to make educated decisions to realize the sustainable world

- We can not allow banning of technologies that can make a difference for the better
- LCA - Life Cycle Assessment - should be used to guide our decisions to avoid dangerous “paper products” and achieve real improvements

martin.tuner@energy.lth.se

Sustainable transportation is critical

In the UN 2030 Agenda for Sustainable Development, sustainable transport is especially related to

- food security (SDG 2)
- health (SDG 3)
- energy (SDG 7)
- economic growth (SDG 8)
- Infrastructure
- cities and human settlements (SDG 11)

The importance of transport for climate action (SDG 13) is further recognized under the UNFCCC since transport and it´s emissions are projected to grow substantially in the years to come.

https://sdgs.un.org/topics/sustainable-transport

martin.tuner@energy.lth.se

New climate report: UN chief demands EU, US set new targets

BY ZIA WEISE AND FEDERICA DI SARIO

MARCH 20, 2023 | 2:11 PM CET | 2 MINUTES READ

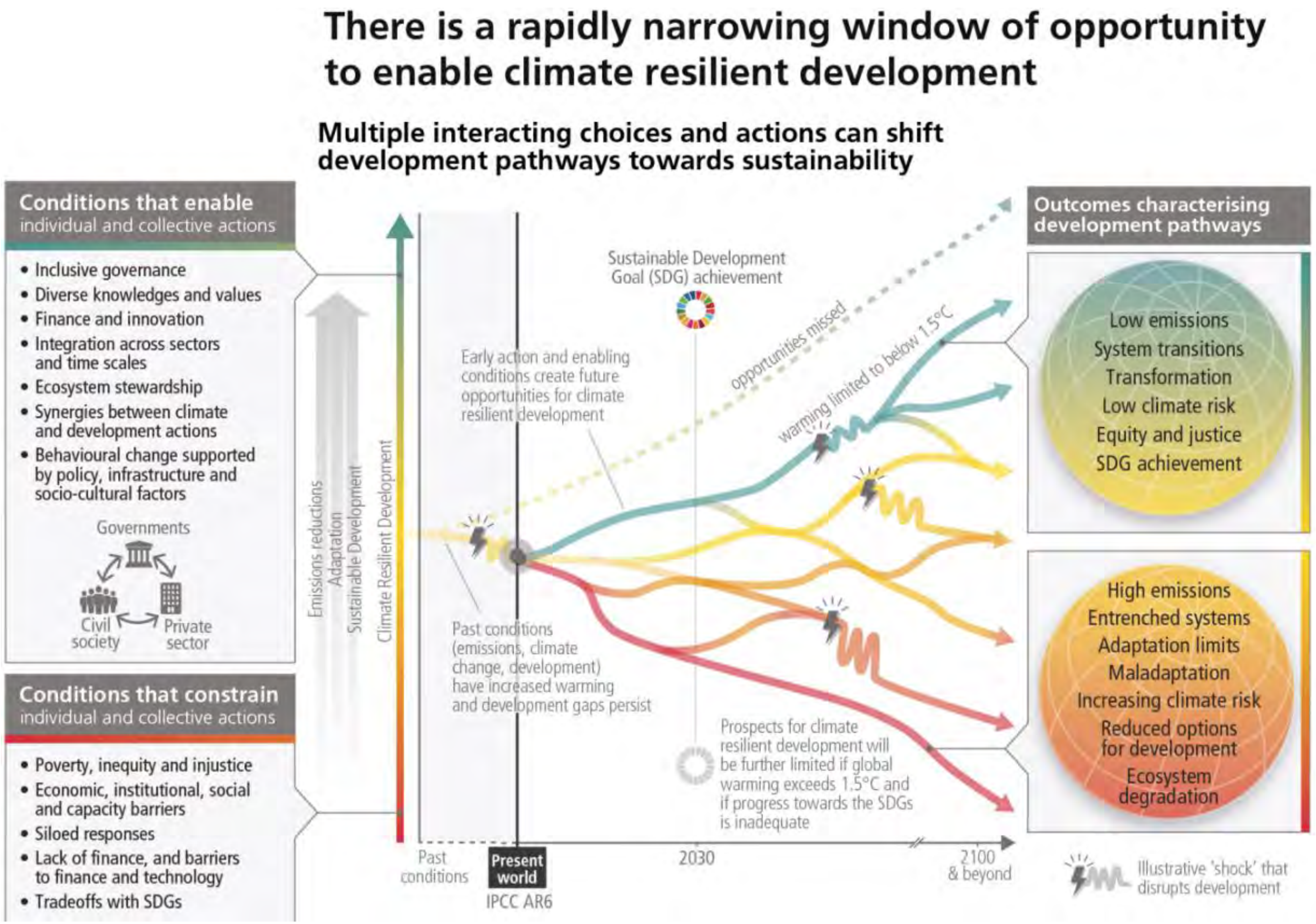
Developed countries should hit net-zero emissions by 2040 to avoid dangerous global warming, António Guterres says.

The U.N. secretary-general on Monday also asked the world's governments to make a series of commitments to accelerate efforts to reduce emissions. Those include a coal phaseout by 2030 for members of the OECD — and by 2040 for all other countries — and halting all new fossil fuel exploration.

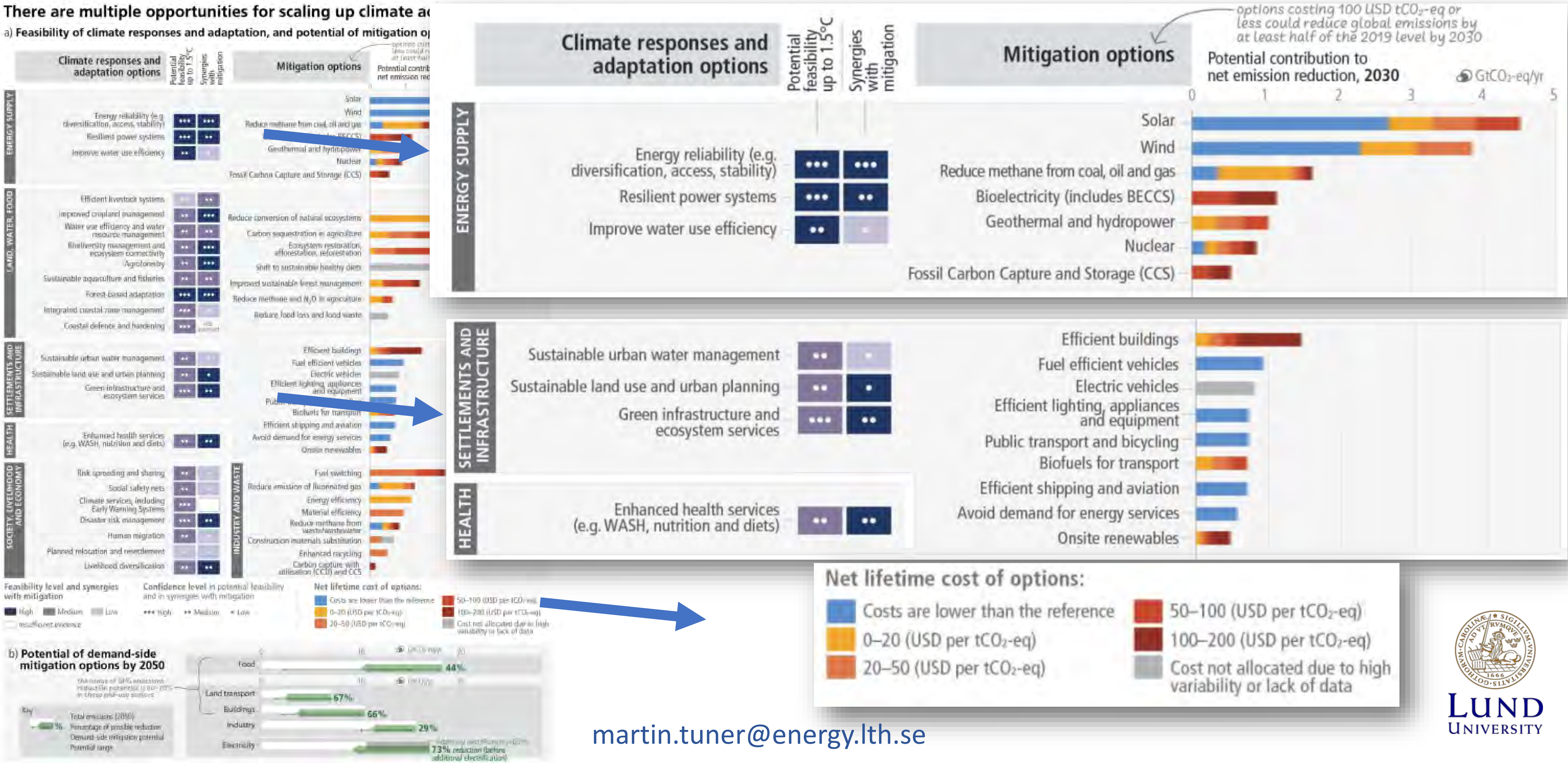
Some EU countries have already pledged to hit net zero before 2050. Germany and Denmark, for example, are aiming for 2045, while Finland has set a 2035 deadline — the bloc's most ambitious target.

martin.tuner@energy.lth.se

The Intergovernmental Panel on Climate Change (IPCC) latest report:



What does IPCC suggest that is related to shipping?



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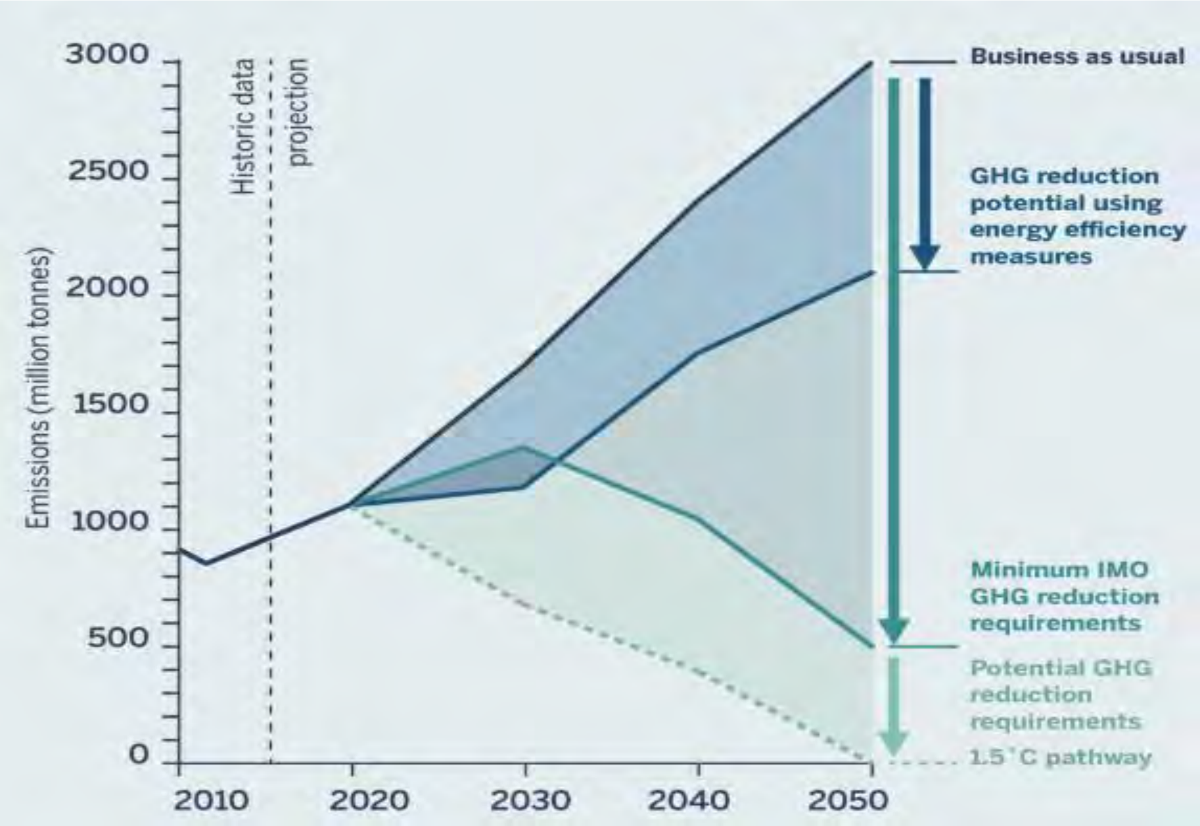
Reduction of GHG	IMO	EU
Base year	2008	1990
2030	40% Intensity	55%
2050	50% Total, 70% Intensity	100% (Net zero GHG)
Before 2100	100%	



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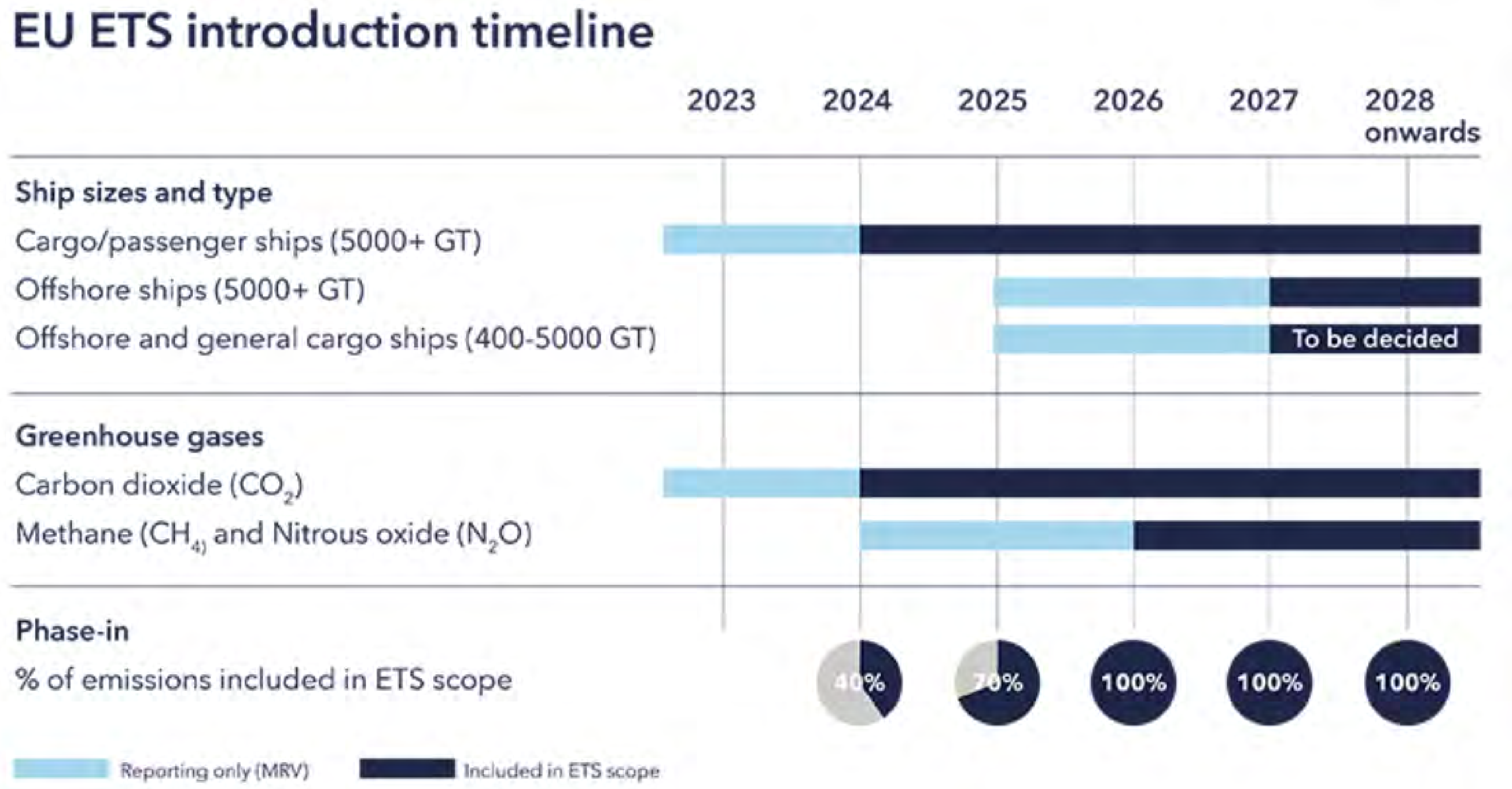
EU Emissions Trading System – includes shipping from 2024



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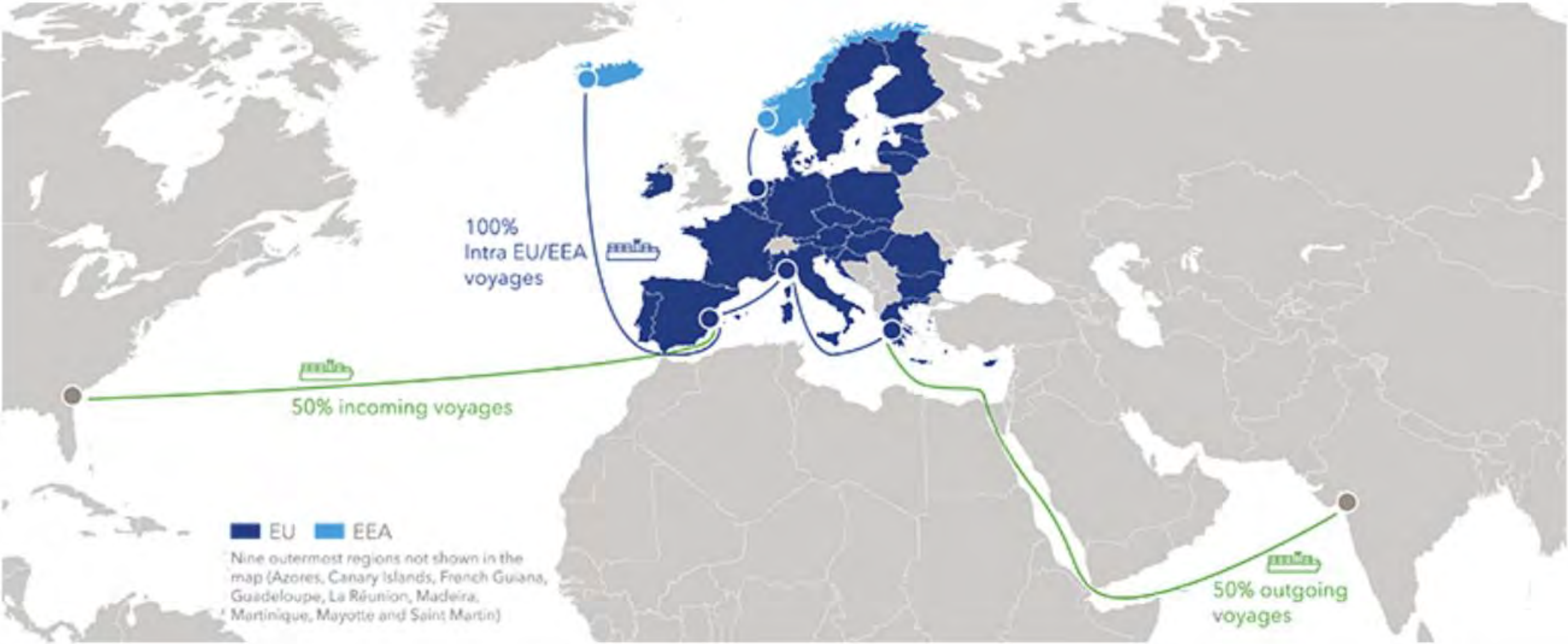

EU ETS based on percentage of emissions on voyages

martin.tuner@energy.lth.se

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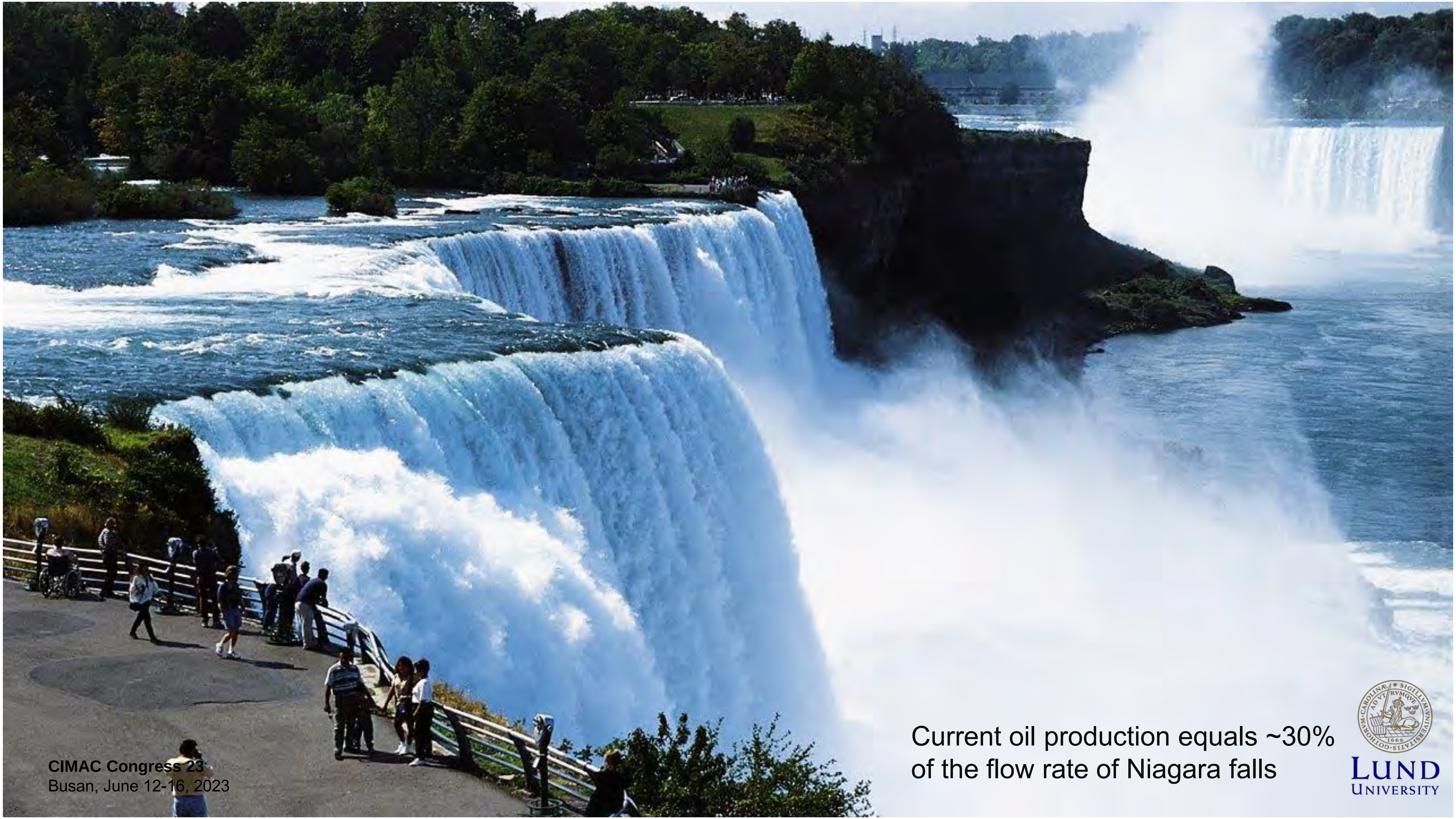
Scale of the challenge

Oil is still the worlds largest energy source

Typically reported production is about 100 million barrels per day. How much is that?

martin.tuner@energy.lth.se



Current oil production equals ~30% of the flow rate of Niagara falls

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5 billion tons of oil – every year!

- 100 million barrels crude oil corresponds to about 5.2 billion tons of oil or about 650 000 TWh
- …or an average of 4.6 barrels for every single person on Earth, every year
- Global installed 440 nuclear reactors capacity (2021) is 2653 TWh
- EU total power production is about 2700 TWh

Sources: IEA, World Nuclear Generation and Capacity, Eurostat

In the context of shipping…

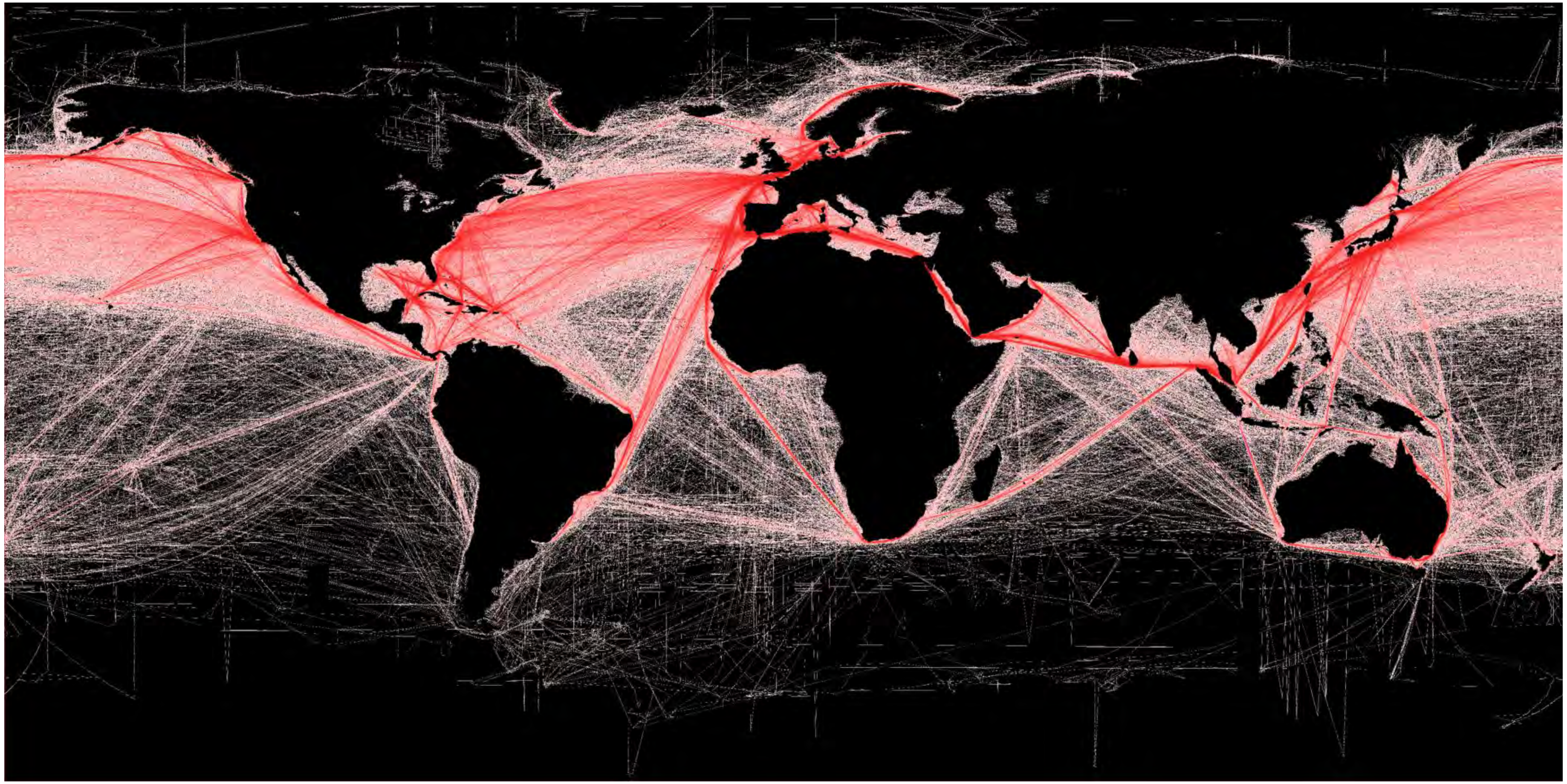


Figure 5.1.1 Goods loaded worldwide

(Billions of tons)

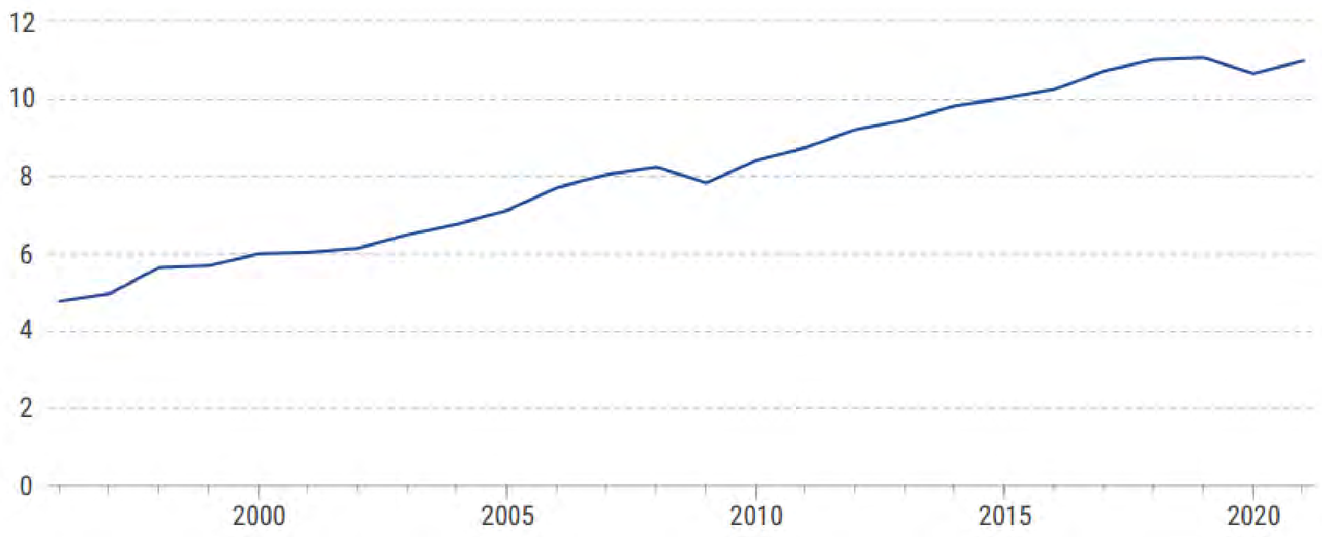
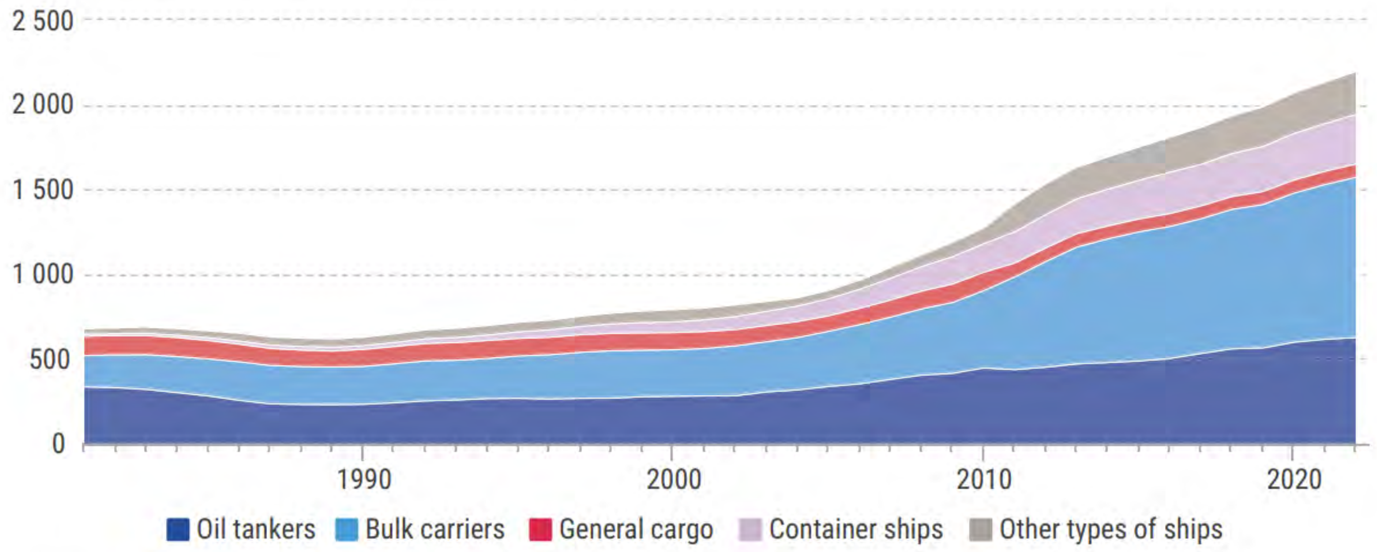


Figure 5.2.1 World fleet by principal vessel type

(Millions of dead-weight tons)

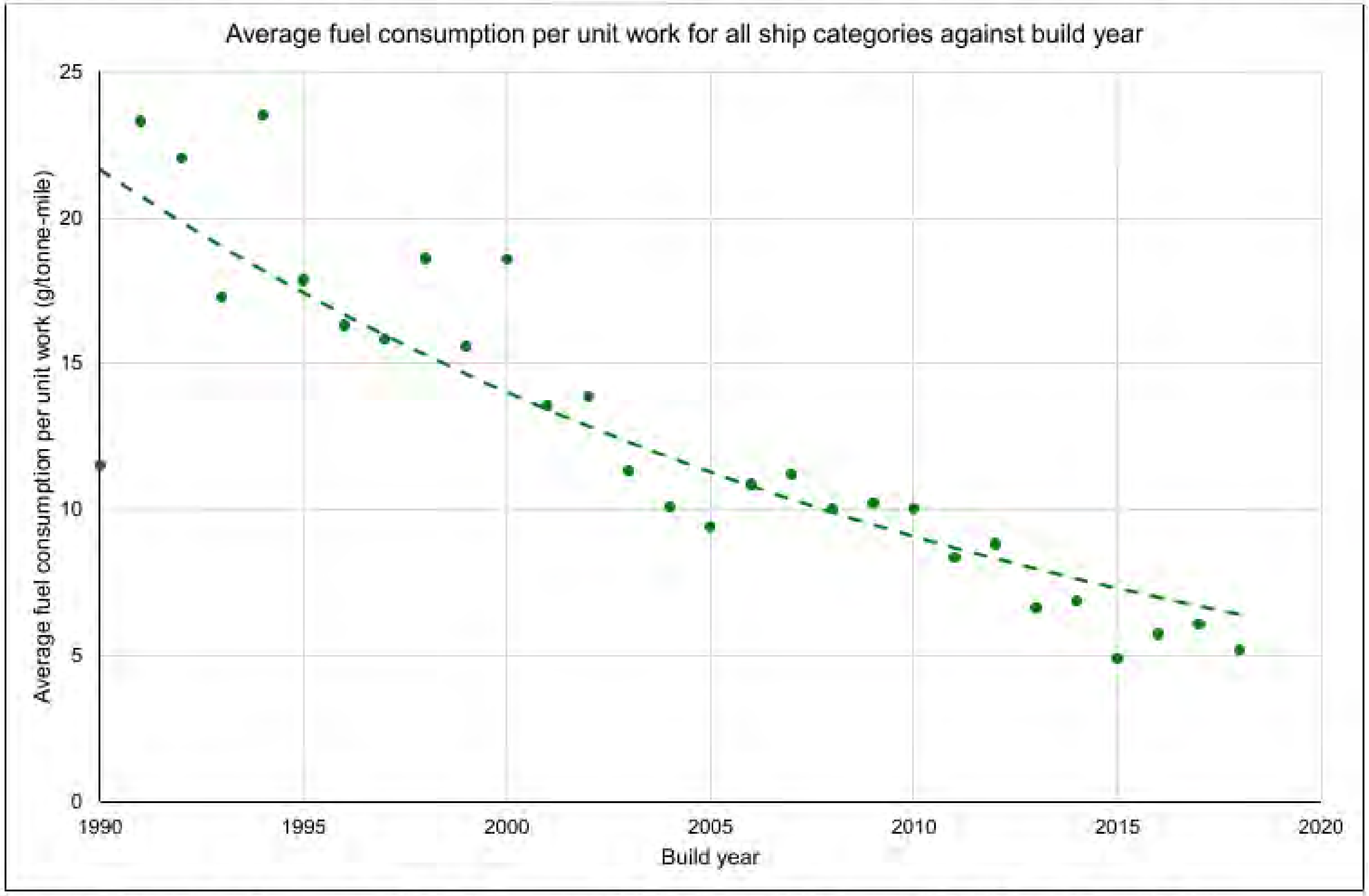


Sources: UNCTADstat (UNCTAD, 2022a); Clarksons Research.

Note: Commercial ships of 100 gt and above. Beginning-of-year figures.

Amazing improvements in shipping efficiency!

Figure 13-4: Overall average fuel consumption per unit work for the fleet in 2019 as a function of build year



Source: Ricardo analysis using EU ship emissions MRV data and Clarksons World Fleet Register data

martin.tuner@energy.lth.se

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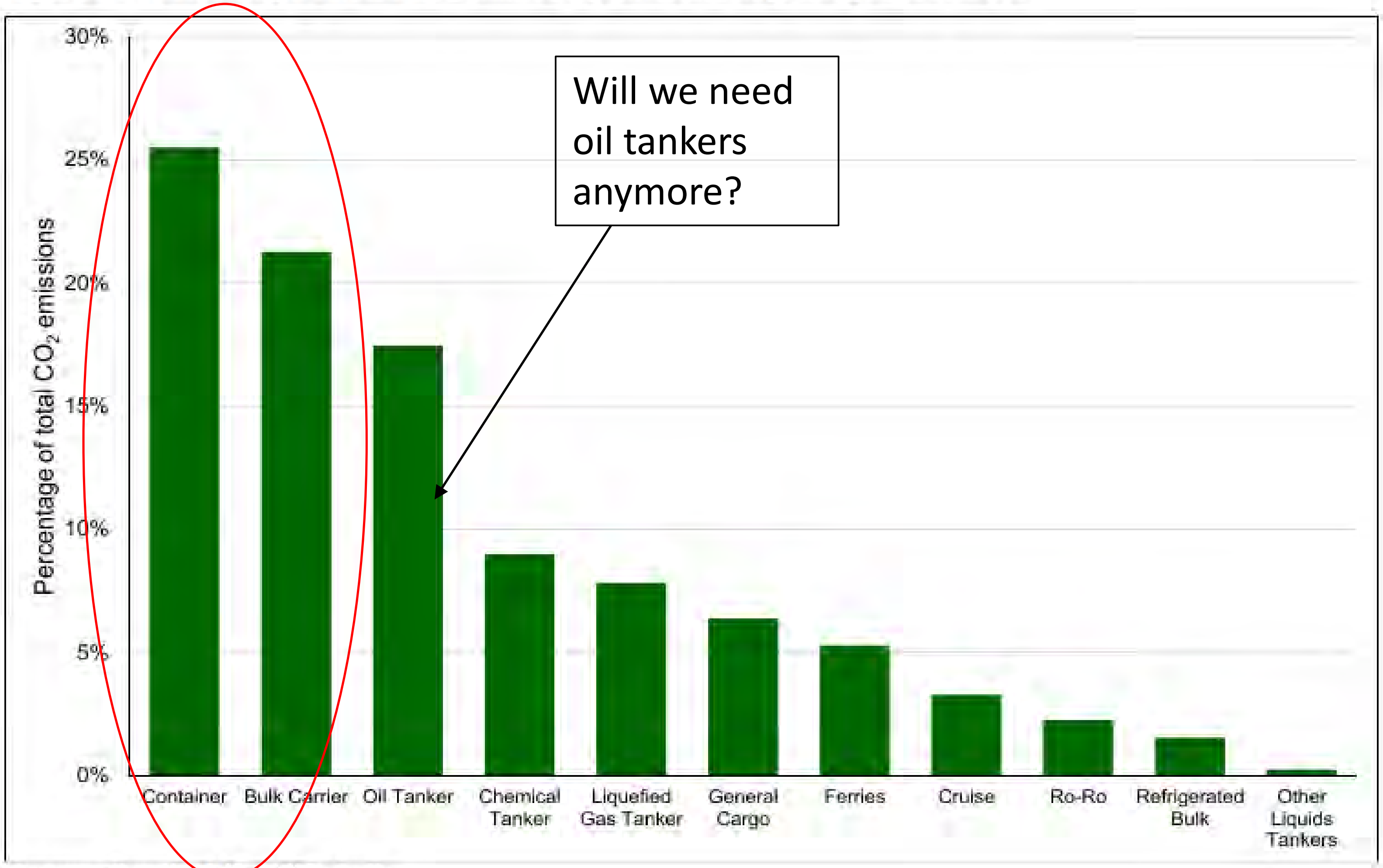
Focusing on the largest ships would make a strong impact

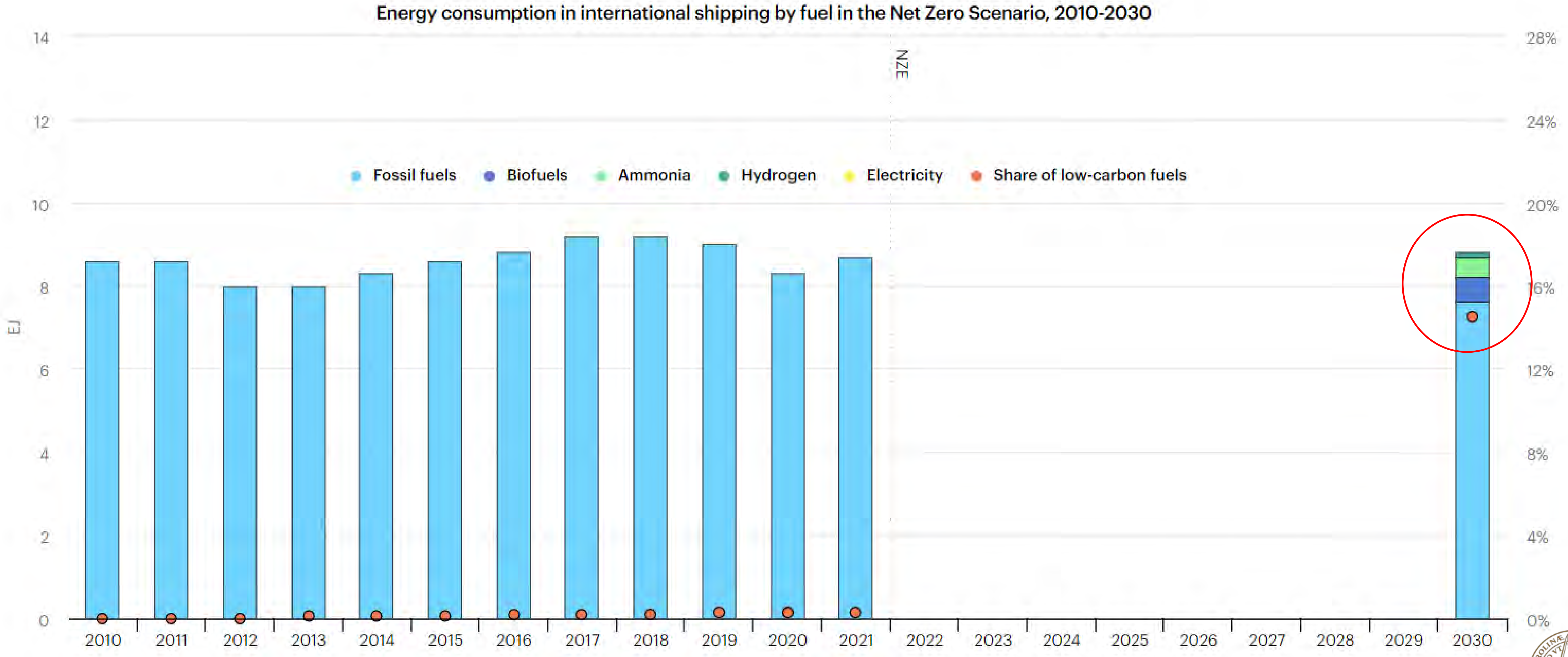
Figure 3-1: Percentage of total CO_2 emitted by different ship categories in 2018



Source: Fourth IMO GHG study

IEA: Scaling up low-carbon fuels is the key to decarbonising international shipping

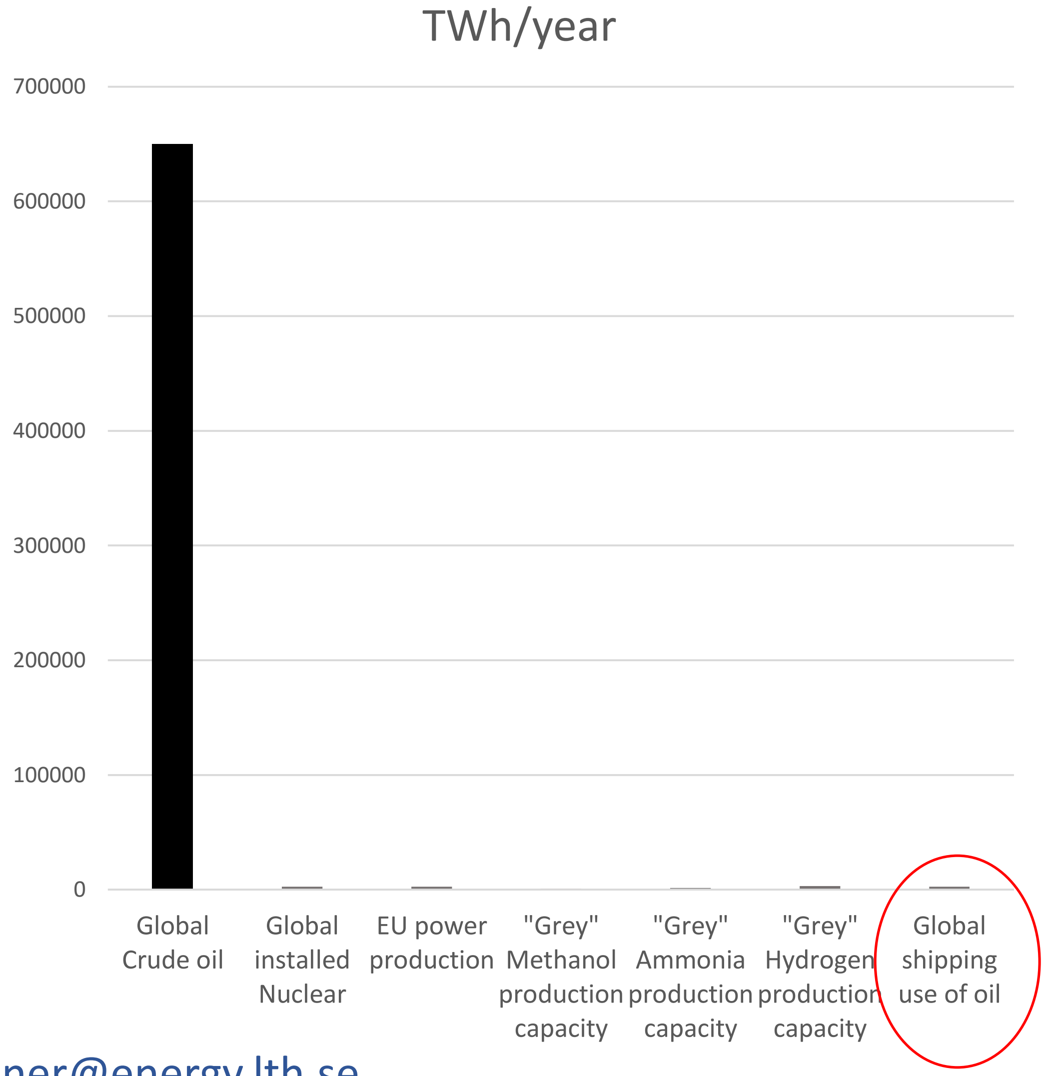
"By 2030, low-carbon fuels represent about 15% of total energy demand in the Net Zero Scenario"



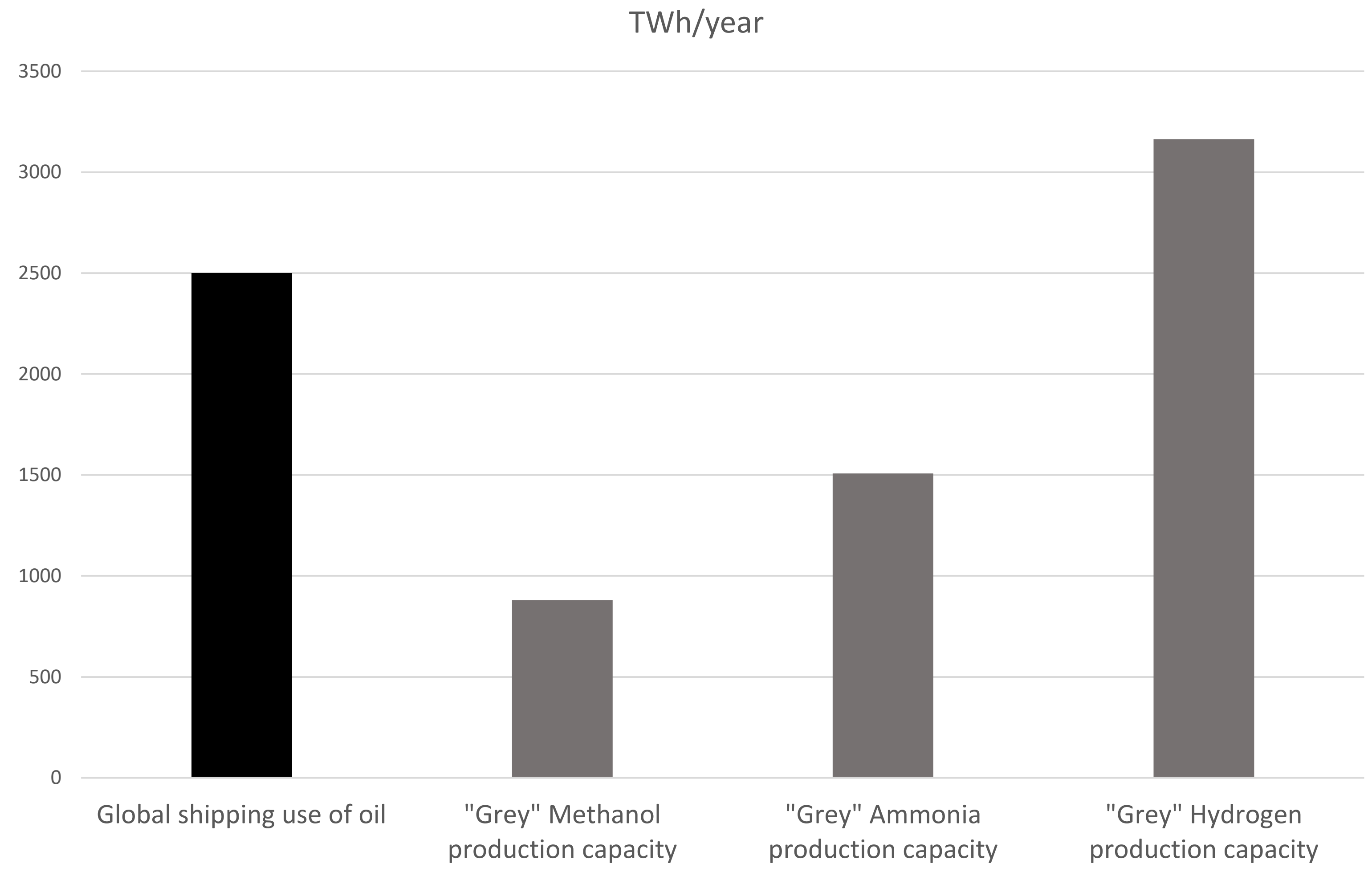
So hydrogen, methanol and ammonia are often mentioned. How much do we have today?

Production capacities

- Methanol 160 million ton
- Ammonia 240 million ton
- Hydrogen 95 million ton



Compared to global shipping needs



Sources: IEA

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Ship sustainable energy options

Fuel *Pathway*	GHG reduction potential(%)*	TRL for trans-oceanic	Compatibility
HFO *(low sulphur)*	-	9	-
MDO	-	9	-
LNG *Global average*	10	9	Requires gas/dual fuel engine and associated cryogenic storage.
BioLNG *Liquid manure***	72	9	Same requirements as for LNG.
LPG *Natural gas (propane)*	20	9	Requires LPG/dual fuel engine.
Methanol (Grey) *Natural gas*	(emissions > HFO)	9	Not drop-in. Compatible with internal combustion engines.
Methanol (Green) *Synthetic (renewable)*	95	7	
Ammonia (Grey) *Natural gas*	(emissions > HFO)	7	Not drop-in. Compatible with engines under development (spark ignition with a hydrogen blend, or dual-fuel with pilot diesel). Safety and toxicity concerns.
Ammonia (Blue) *Natural gas + CCS*	85	4/5/6	
Ammonia (Green) *Renewable electrolysis*	75	3/4/5	
Hydrogen (Grey) *Natural gas*	(emissions > HFO)	7	Not drop-in. Compatible with internal combustion engines (spark ignition & dual-fuel) but requires development and a supporting fuel.
Hydrogen (Blue) *Natural gas + CCS*	84	4/5/6	
Hydrogen (Green) *Renewable electrolysis*	75	3/4/5	
FAME *e.g. Waste cooking oil*	73	9	Drop-in (blended only < 20% FAME)
HVO *e.g. Waste cooking oil*	77	9	Drop-in (blended and neat)
Batteries	66%	4/5/6	Not compatible with ICE. Require their own storage systems and equipment. Weight and size challenges.

Attractive **Moderate** **Unfavourable**

Technological, Operational and Energy Pathways for Maritime Transport to Reduce Emissions Towards 2050
Ref: ED 13389 | Final Report | Issue number 6 | Date 31/01/2022

Bio-LNG

Works with the already implemented LNG carriers!

martin.tuner@energy.lth.se

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Biomethane production

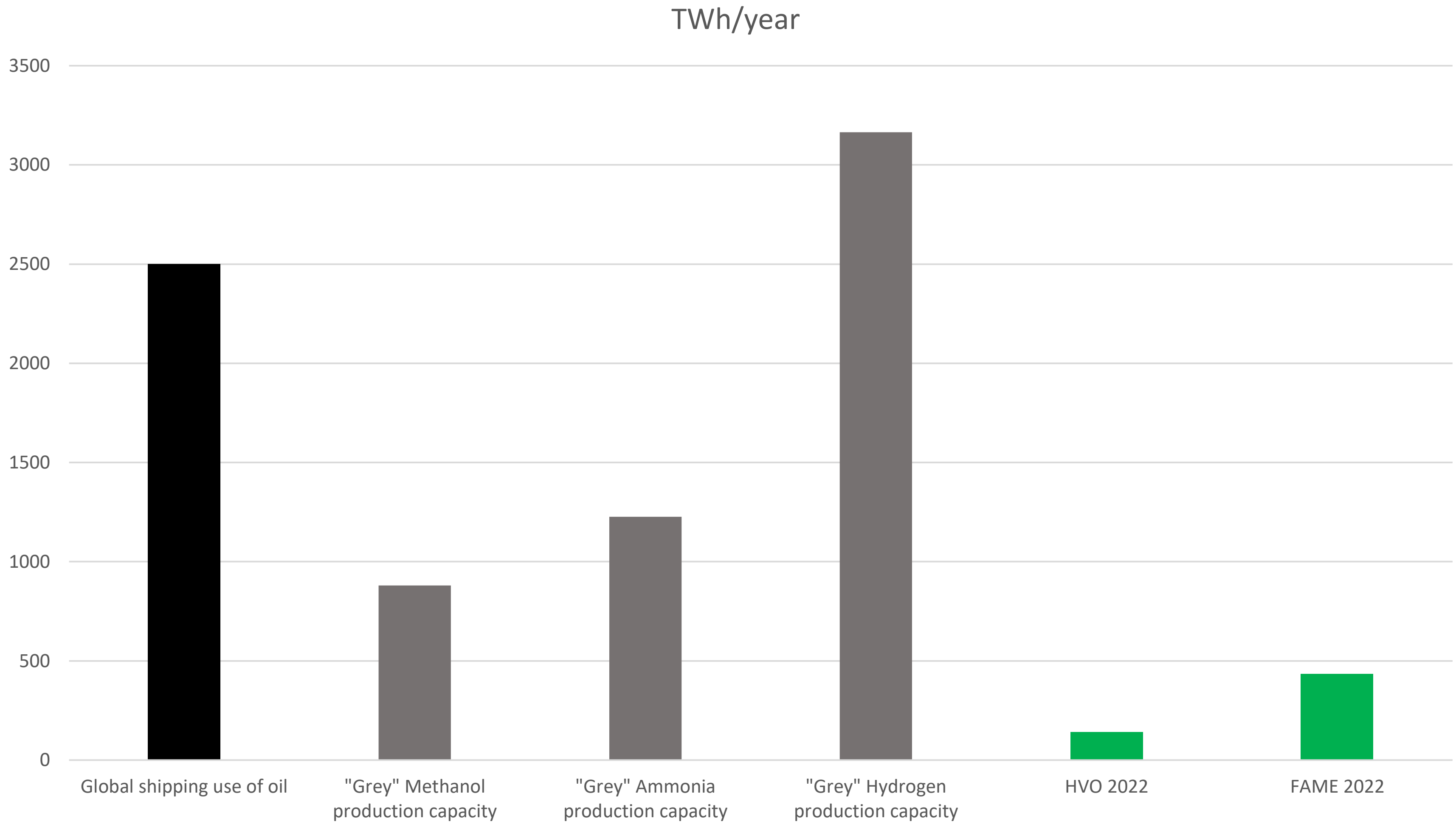
Gas for Climate projects that biomethane production will ramp up to 1170 TWh in 2050, from 20 TWh in 2020. 50% of that biomethane will be used as bio-LNG for the heavy-duty transport sector. That is about 40 Mtons of bio-LNG per year.

FAME & HVO

Great when you want to avoid ship modifications!

But aviation might pay more…

Compared to global shipping needs



Sources: IEA

martin.tuner@energy.lth.se

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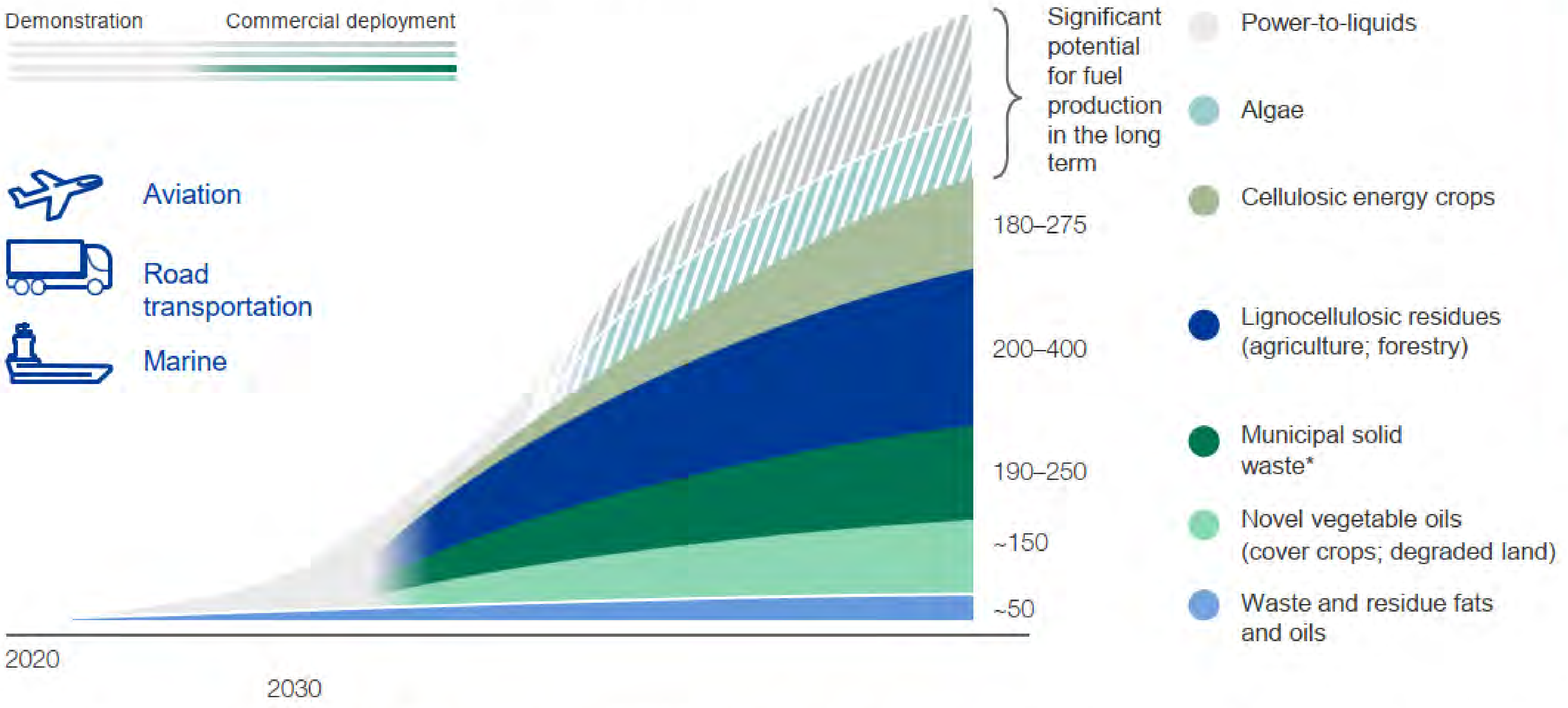
Unlocking new raw material pools with innovation to accelerate emission reductions in transportation

Global raw material potential for renewable fuels (Mtoe)

Long-term fuel potential (Mtoe)



Renewable raw materials hold significant potential to accelerate the reduction of CO_2 emissions, in particular in the transportation sector.

Regulators hold the key to enable a broad renewable raw material pool to unlock the full emission reduction potential in transport and beyond.

Source: Neste analysis based on WEF Clean Skies for Tomorrow and other sources. Biomass potential converted to fuel potential, using around 85% conversion efficiency (weight-based) for fats and oils and novel vegetable oils; around 25% efficiency for lignocellulosic biomass and municipal solid waste.

*80% organic waste, with 20% non-reusable, non-separable plastic waste

NESTE

Methanol

Simple molecule that can be produced in many ways!

martin.tuner@energy.lth.se

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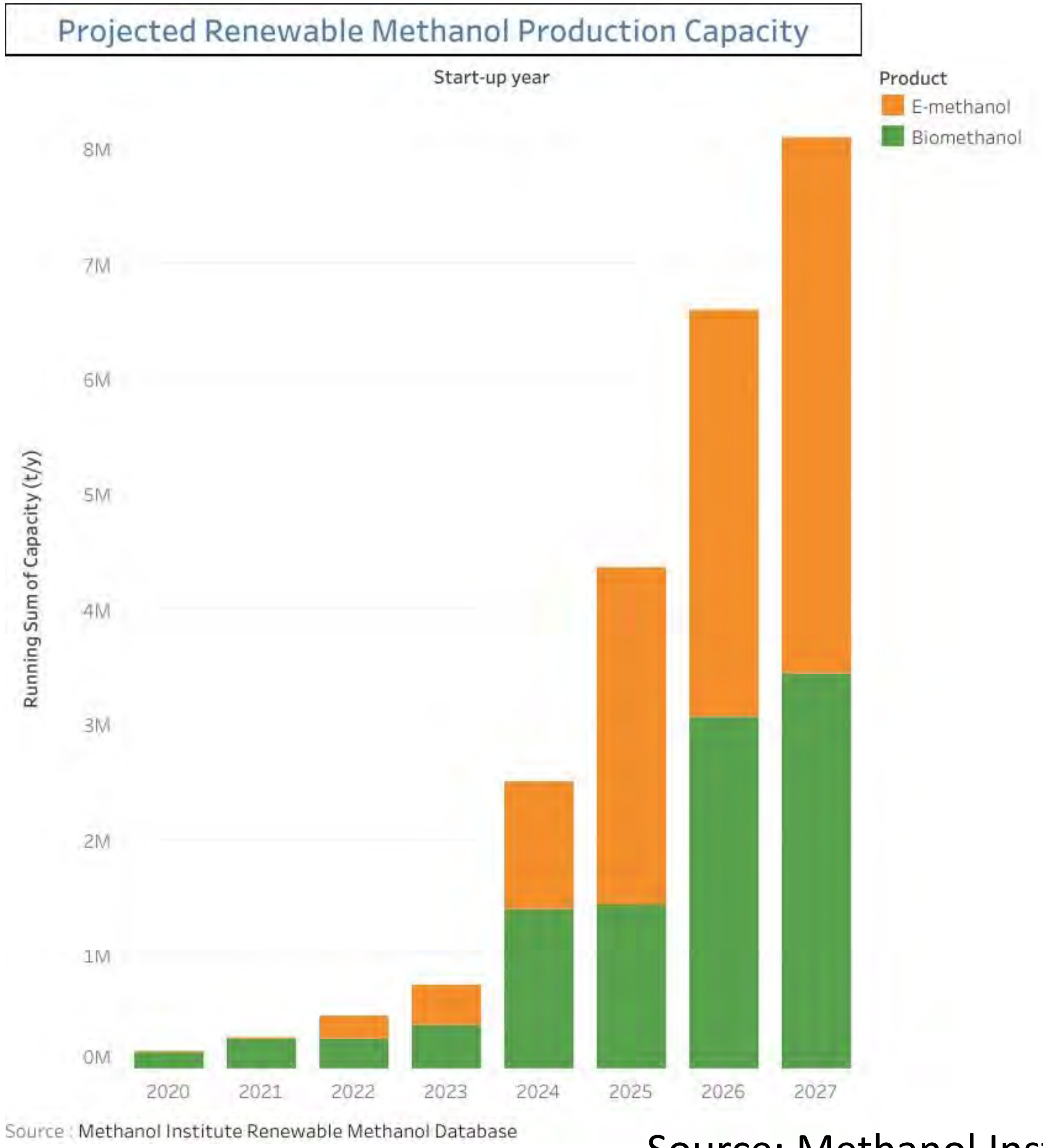

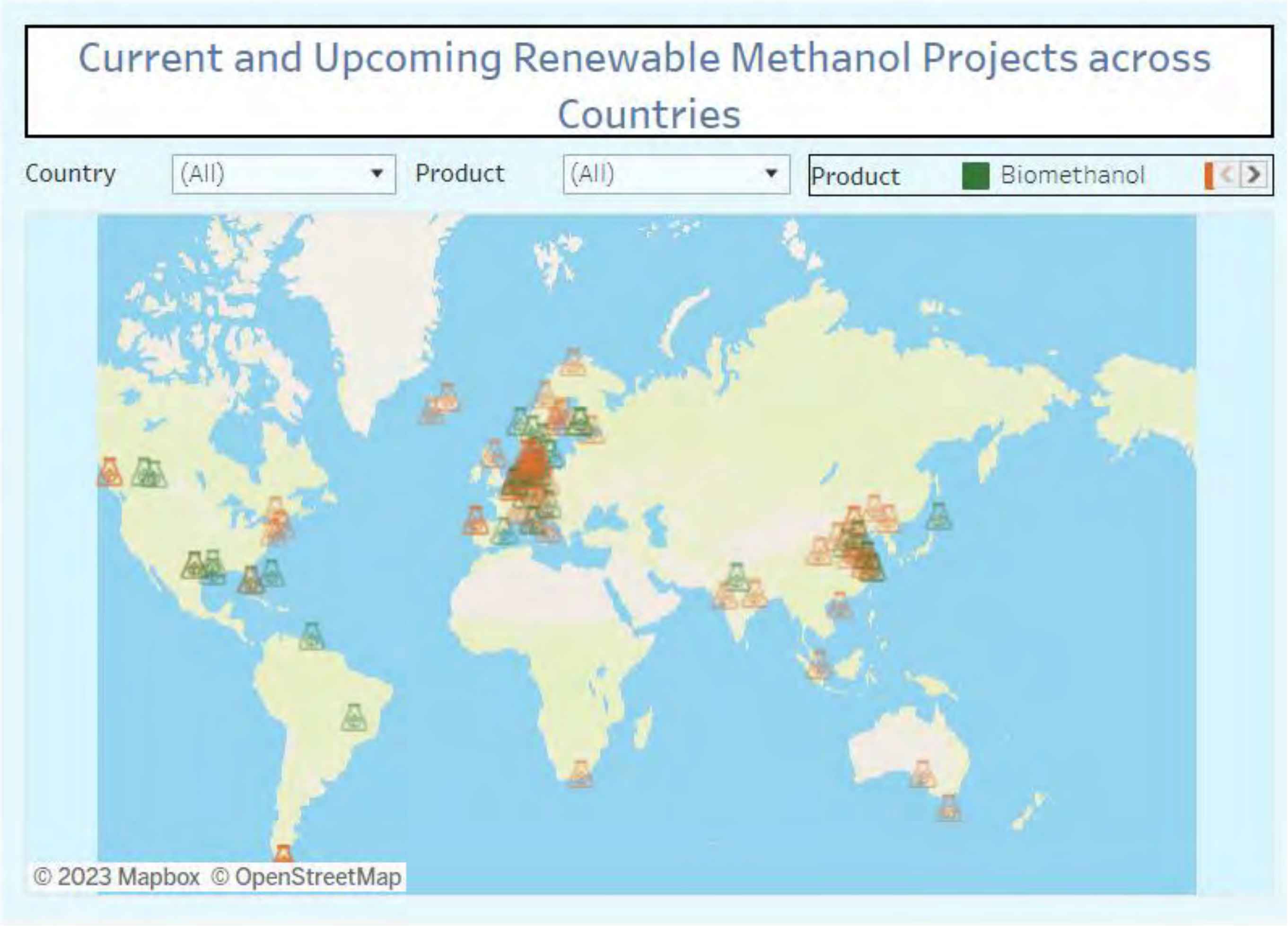

Source: Methanol Institute – data from dec 2022

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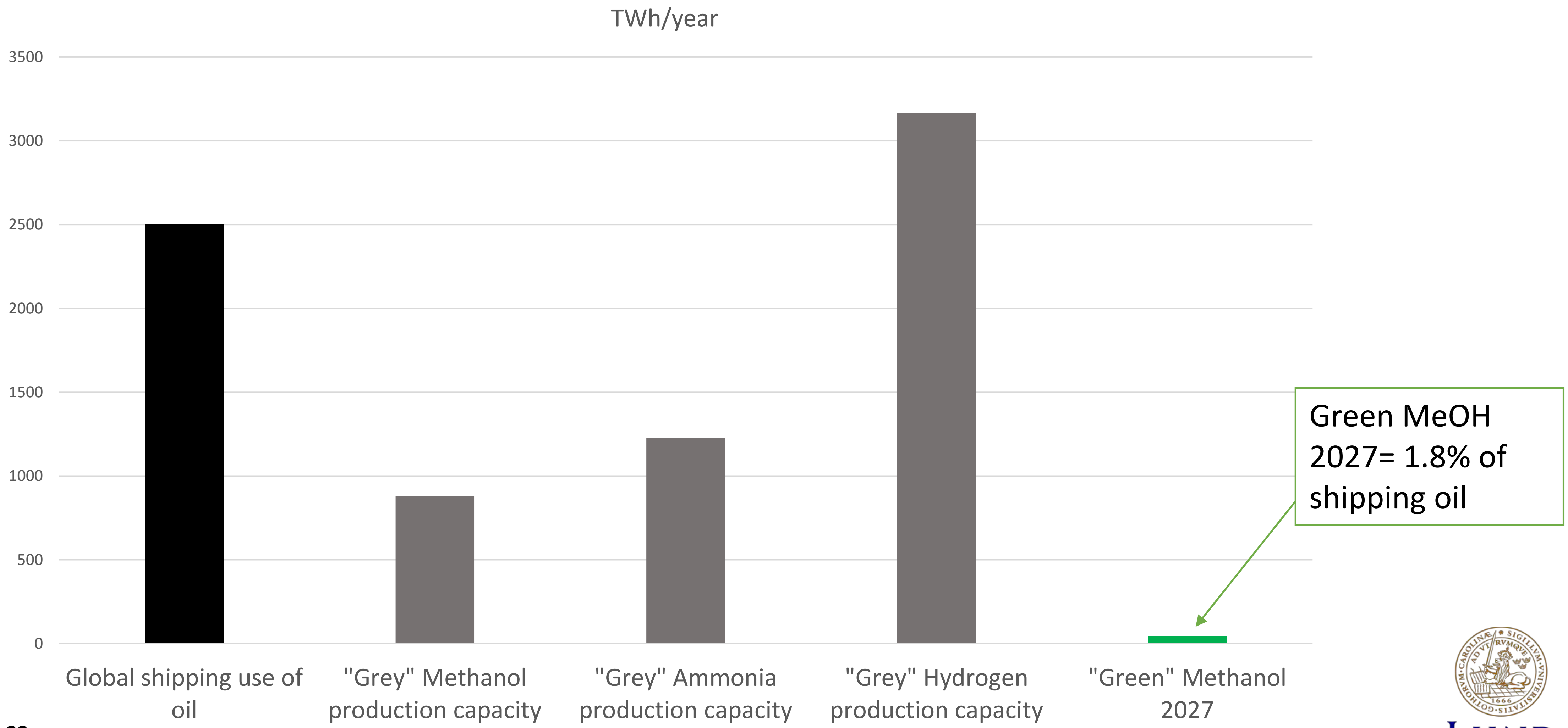
Promising curve! How much is it?



Sources: IEA, Methanol Institute

martin.tuner@energy.lth.se

Ammonia

Removing carbon from the equation helps a lot!

Unlikely fuel for road transportation – opportunity for shipping

martin.tuner@energy.lth.se

AMMONIA TRANSITION STRATEGY / SEPTEMBER 2022: By 2030, the shipping sector alone has the potential to make or break the demand for near-zeroemissions ammonia.

The International Maritime Organization (IMO) will be instrumental in delivering the following policy milestones across international shipping jurisdictions:

- **Certify ammonia as a shipping fuel, standardise handling and trading protocols** to facilitate its adoption, and establish safety regulations to mitigate perceived risks posed by the toxicity of ammonia.
- **Develop a comprehensive decarbonisation strategy, sending unambiguous signals of sector transformation.** The 50% emissions reduction ambition by 2050 should be increased to net zero by 2050, and an aggressive 2030 target of 5%–15% of deep-sea shipping to be powered by zero-emissions fuels should be set and these targets should be made enforceable.
- **Boost stringency on technical efficiency standards, for example EEDI**[xxii] (Energy Efficiency Design Index for new-build ships) and **EEXI**[xxiii]**/CII**[xxiv] (Energy Efficiency Existing Ship Index and Carbon Intensity Indicator for existing ships), in alignment with net-zero targets.
- **Implement market-based mechanisms (MBMs) to close the competitiveness gap between zero-emissions fuels and conventional fuels** through mechanisms like contracts for difference (CfDs) or subsidies. Closing the competitiveness gap through a carbon price to reach full decarbonisation for this sector is estimated at \$50–\$100/t CO_2 by 2030, increasing to \$191–\$400/t CO_2 by 2050.[xxv] Even more recent studies envision carbon prices up to \$650/t CO_2 by 2050.[xxvi]

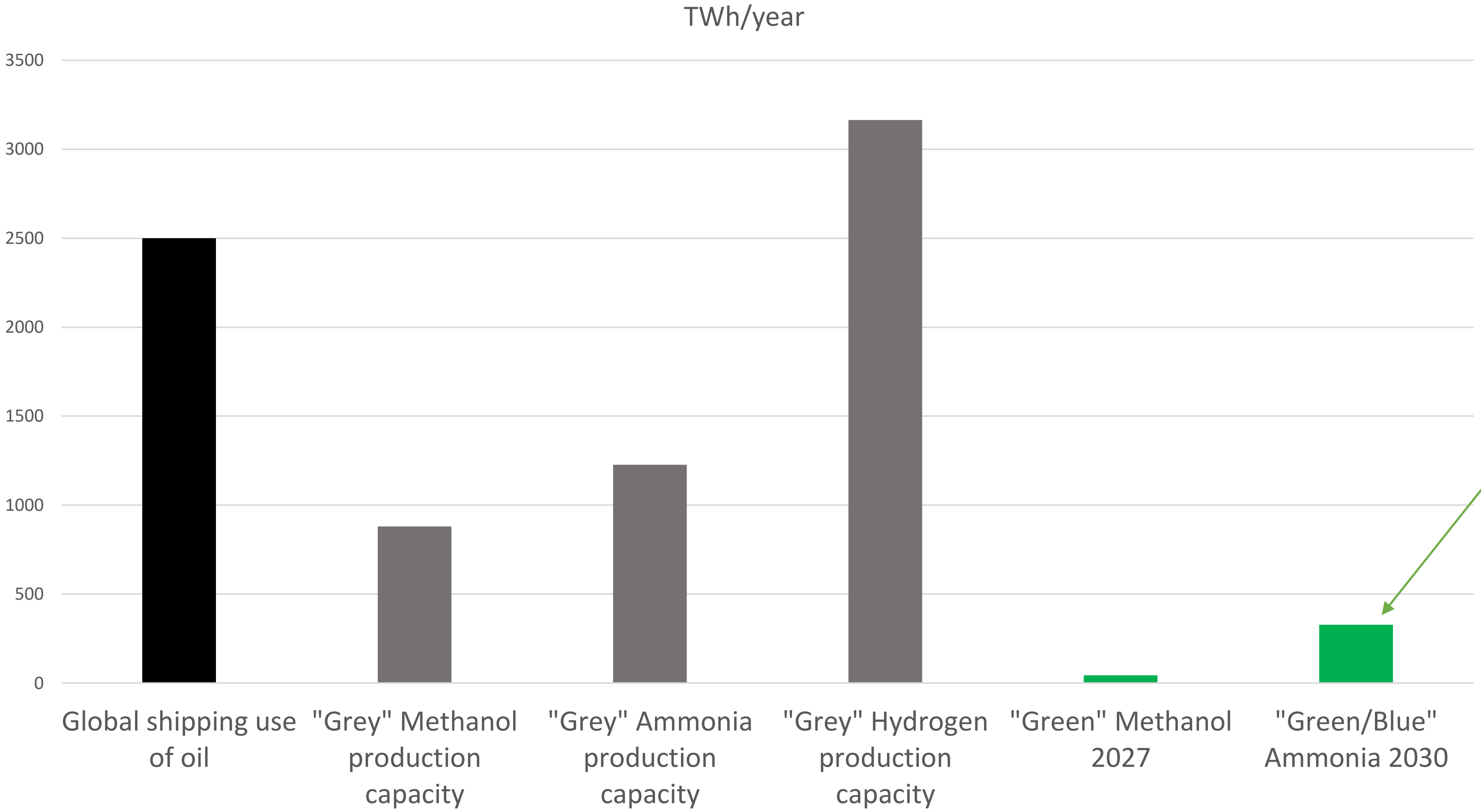
The **implementation of voluntary mechanisms,** such as the establishment of green shipping corridors and information programmes disclosing environmentally related data, will be key in order to accelerate action amongst sector stakeholders.

Pioneering large-scale green ammonia project gets world's first clean hydrogen certificate

German certification body TÜV Rheinland gives stamp of approval to planned facility in Oman, which will have 300MW of electrolysers powered by 500MW of solar

20 April 2022 17:44 GMT   *UPDATED 20 April 2022 18:32 GMT*

How much are the estimates for ammonia?



Green/Blue Ammonia / Hydrogen 2030 = 13% of shipping oil

Sources: IEA, Methanol Institute, Hydrogen Council, and many more.

Hydrogen

Most scenarios show a strong dependence on E-fuels – depending on hydrogen!

martin.tuner@energy.lth.se

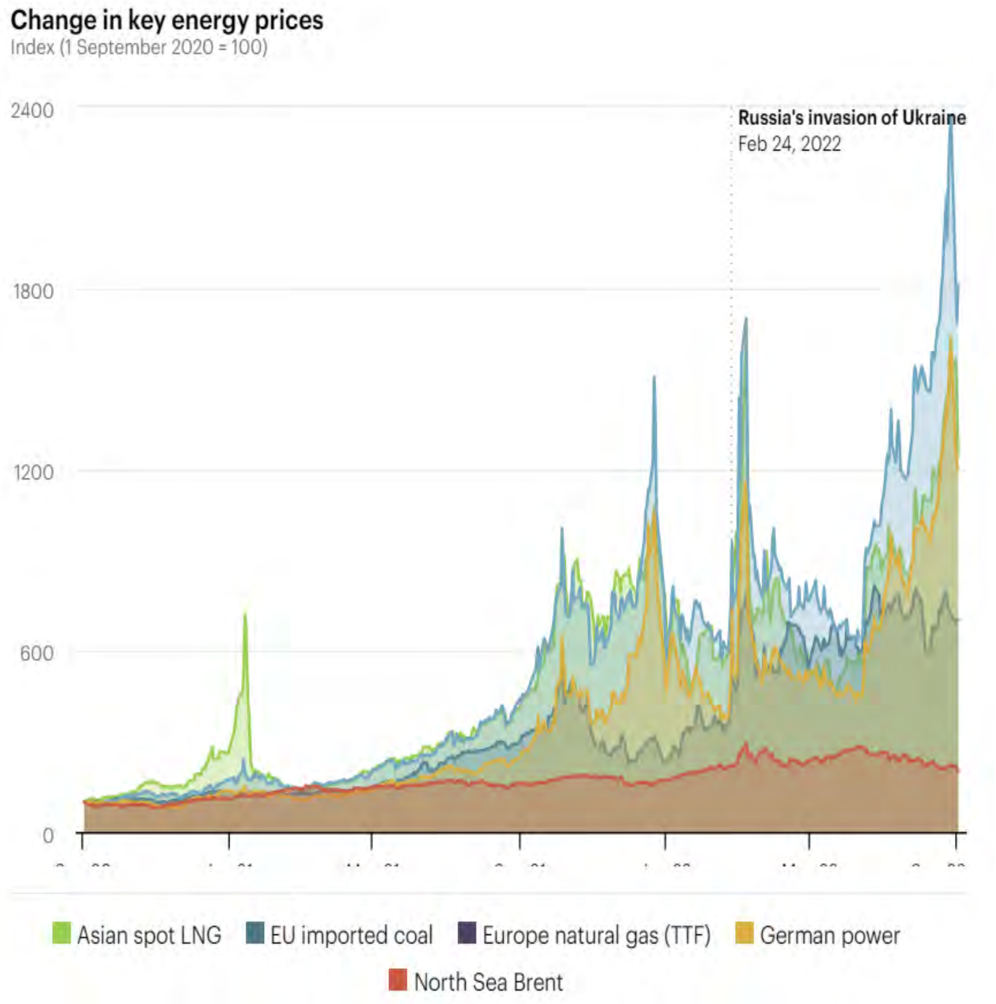

WAR!

Replacing fossil Natural gas

EU dependence on NG is to be quickly eradicated:

- EUs RePower package increase ambitions radically regarding H2.
- Goal to produce 10 M ton within EU and import 10 M ton by 2030 https://ec.europa.eu/commission/presscorner/detail/en/IP_22_3131

USA enters the H2 ”race” through IRA (Inflation Reduction Act), heaviliy subsidicing green H2 https://www.energypolicy.columbia.edu/the-battle-for-the-us-hydrogen-production-tax-credits/



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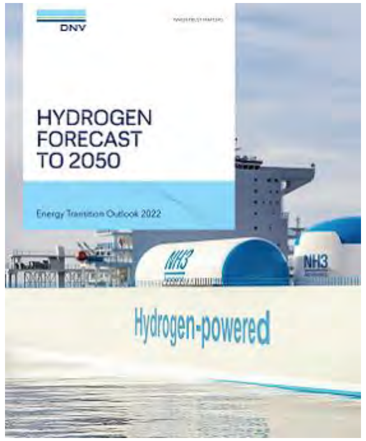
Hydrogen forecast to 2050

Amount of hydrogen in the energy mix will be only 0.5% in 2030 and 5% in 2050.

Electrolysers – will be the dominant form of production accounting for 72% output

This will require a surplus of renewable energy, to power an electrolyser capacity of 3,100 gigawatts. This is more than twice the total installed generation capacity of solar and wind today.



3100 GW corresponds 27 000 TWh/year (assuming 100% availability)

Five bottlenecks holding up green hydrogen in Europe

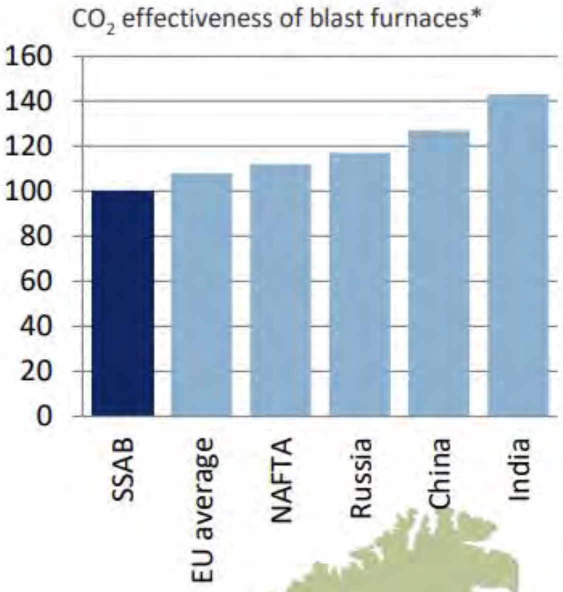
Demand is not the problem, rather:

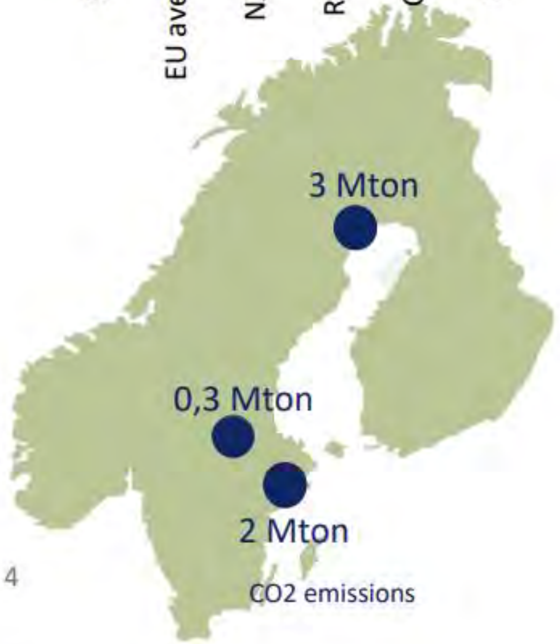
- Permitting
  - “It needs to take two years maximum to get all the permitting done.”
- Value chains
  - “we must build value chains that have secured unrestricted access to those core components and raw materials”
- Skills
  - The renewables industry needs to recruit and train one million people by 2030 - it can take up to 15 years
- Regulation
  - “We are now leaving the industry in limbo with no rules,” Paquet said. “We know that financial investment decisions have already been postponed. It needs to start now.”
- Level playing field
  - “Let’s be clear: it’s about sustainable manufacturing, social standards, environmental standards,” “We need to make sure the same rules apply also to the global competition.”

François Paquet, Renewable Hydrogen Coalition (RHC), October 2022

HYBRIT
FOSSIL-FREE STEEL

The dilemma



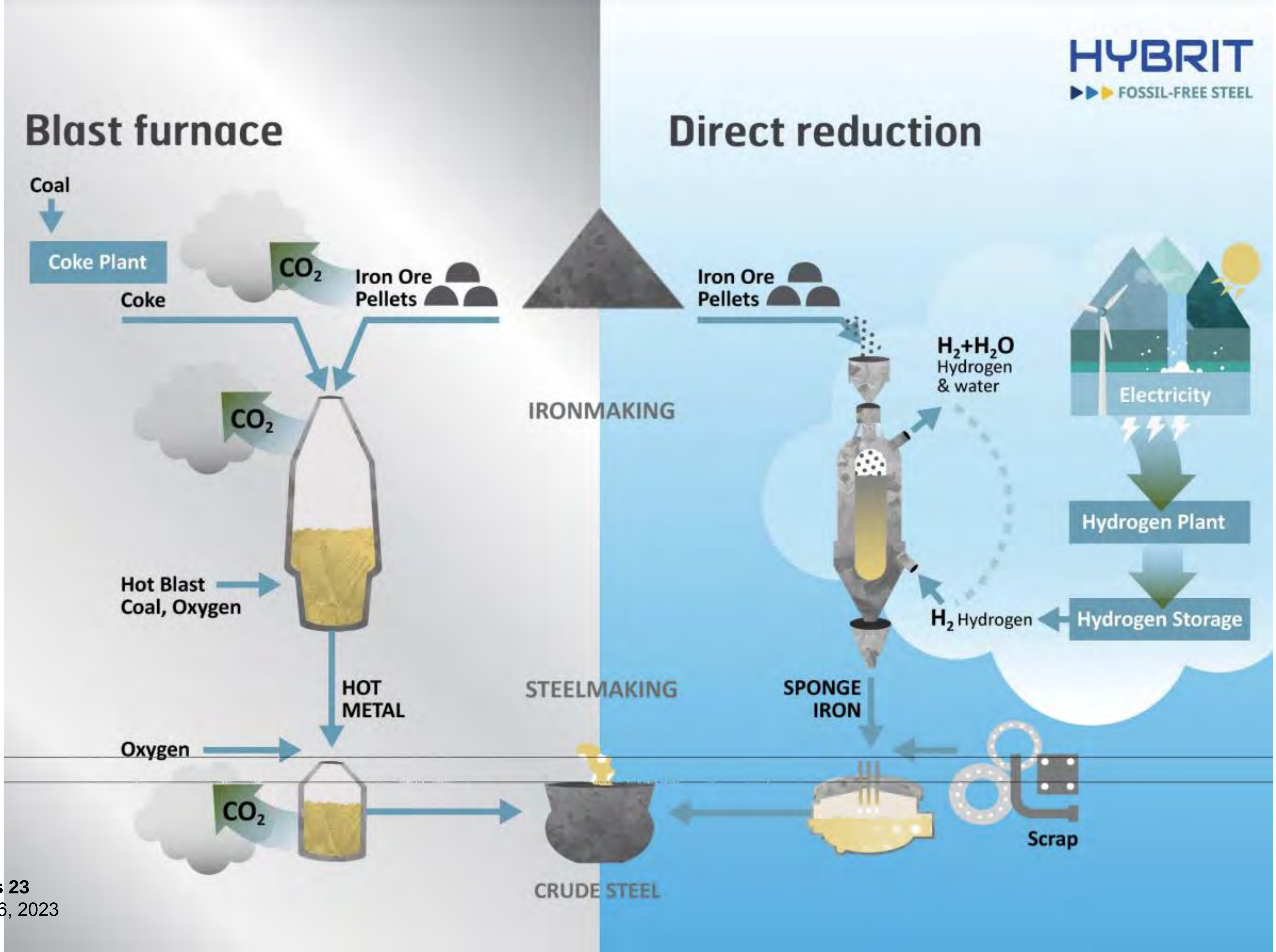


- Close to theoretical minimum of CO_2-emission in today's blast furnace technology

- Considerable CO2-emissions:
  - Sweden's two single largest emission sites
  - Ca 10% of Sweden's total emission
  - Ca 30% of ETS system in Sweden

Source: Stahl-Zentrum. *The indexed carbon efficiency in ironmaking based on coal consumed 2012

A joint venture between SSAB, LKAB and Vattenfall


HYBRIT
FOSSIL-FREE STEEL
Blast furnace
Direct reduction
Coal
Coke Plant
Coke
CO_2
Iron Ore Pellets
CO_2
Hot Blast Coal, Oxygen
HOT METAL
Oxygen
CO_2
IRONMAKING
STEELMAKING
CRUDE STEEL
Iron Ore Pellets
H_2+H_2O Hydrogen & water
Electricity
Hydrogen Plant
H_2 Hydrogen
Hydrogen Storage
SPONGE IRON
Scrap

Total steel production in Sweden
would need an estimated 70 TWh electricity by 2045!

Similar to the electricity consumption of Belgium

Sources: HYBRIT, LKAB, H2 Greensteel, Eurostat

martin.tuner@energy.lth.se

Hydrogen leaks impact climate

H2 does not directly trap heat.

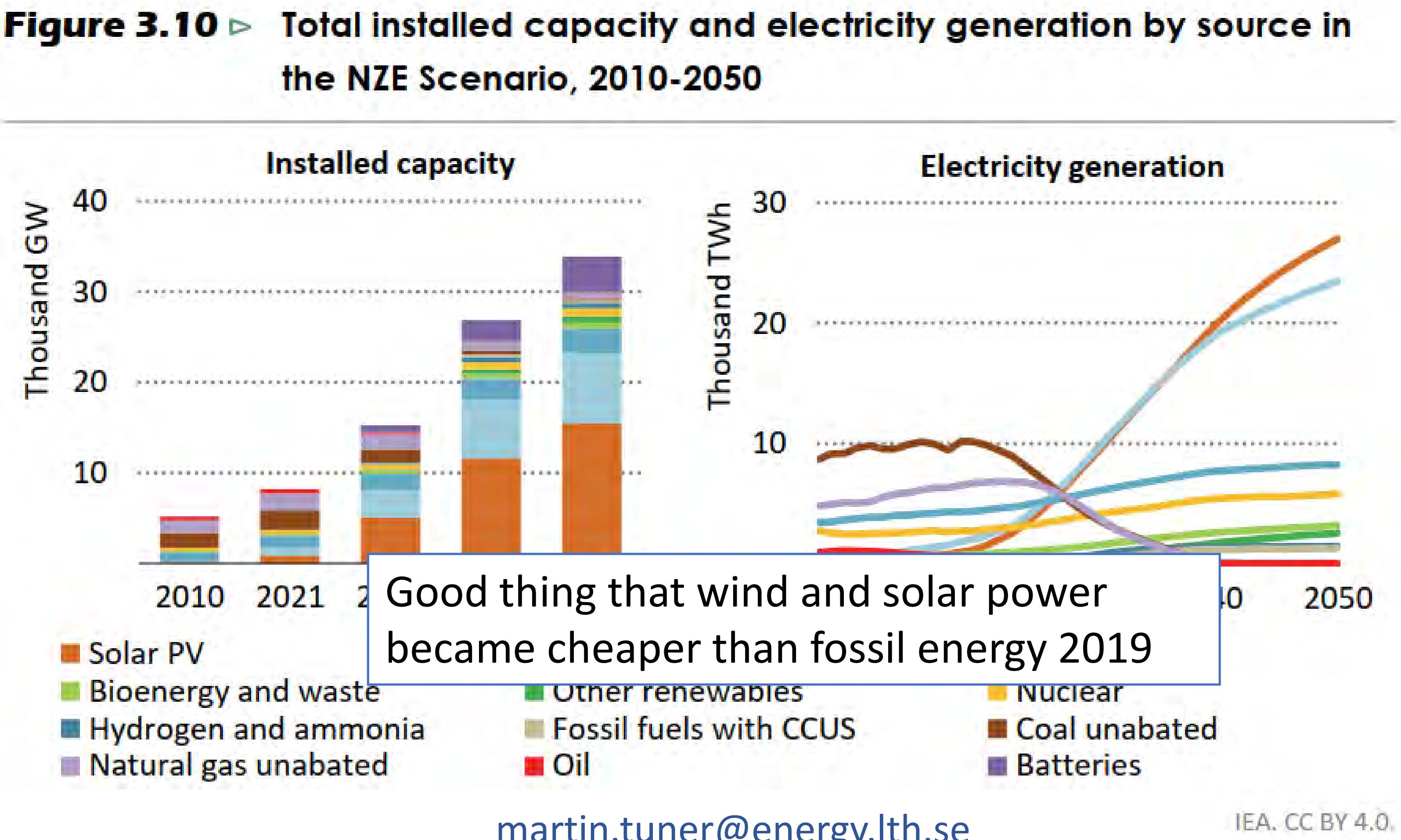
H2 has an indirect global warming effect by extending the lifetime of GHGs (Derwent et al. 2020)

A high-risk scenario could potentially lead to a 5.6 percent economy-wide leakage (IEA 2021)

martin.tuner@energy.lth.se

Electricity

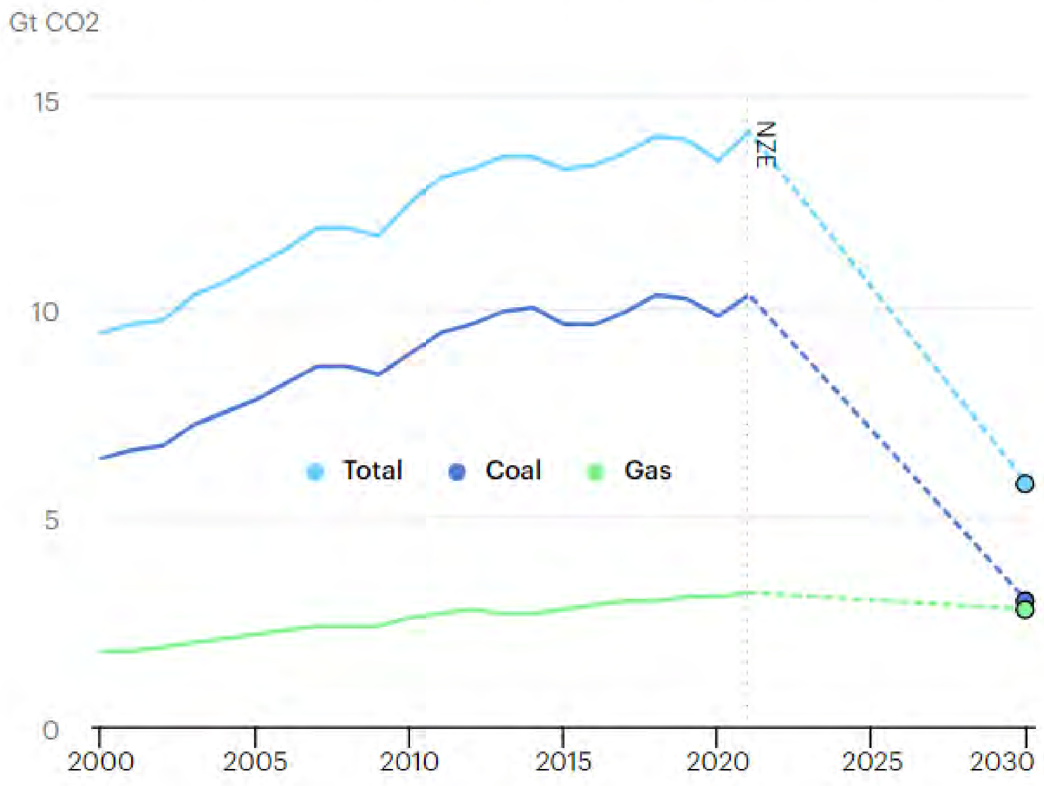
Huge dependency on low cost sustainable electricity!



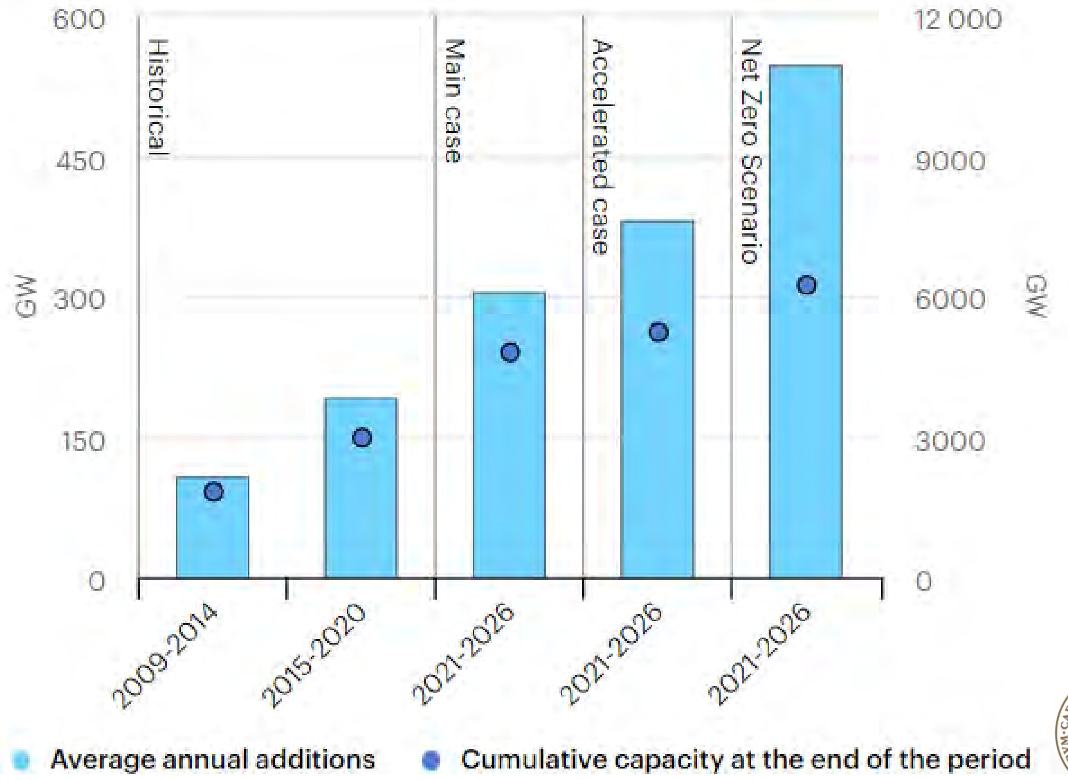
Good thing that wind and solar power became cheaper than fossil energy 2019

Renewable electricity capacity additions trend is not on track to meet the IEA Net Zero by 2050 Scenario

Power sector CO2 emissions in the Net Zero Scenario, 2000-2030



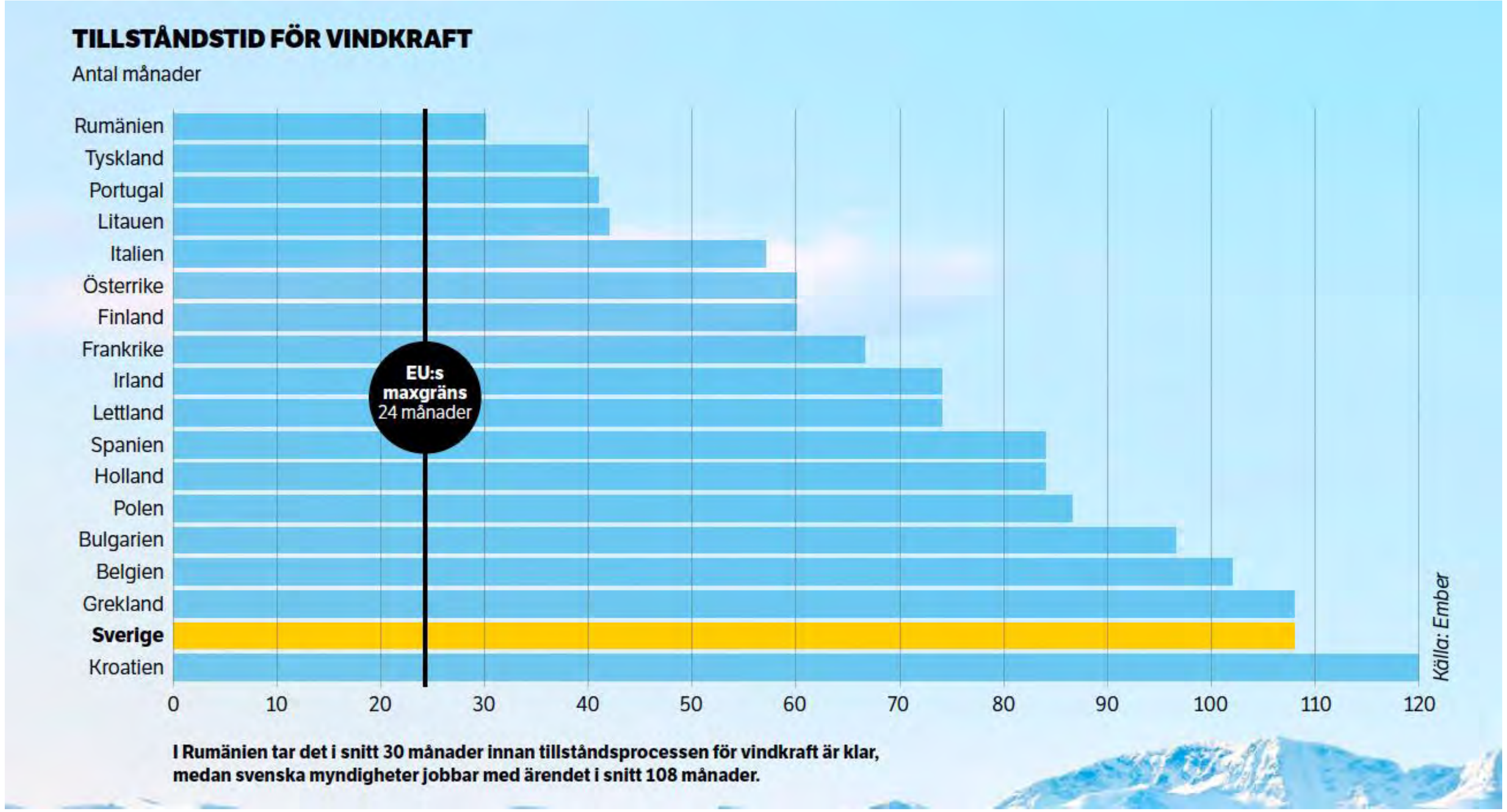
Average annual renewable capacity additions and cumulative installed capacity, historical, forecasts and IEA Net Zero Scenario, 2009-2026



martin.tuner@energy.lth.se

Bottlenecks for clean electricity

- Grid: Limited transmission capacity is a huge bottleneck
- Skills shortage (installation etc)
- Permitting



martin.tuner@energy.lth.se

Dubbed ‘the Tesla of the seas’ this fully-electrified, fully-autonomous cargo ship is already making waves. The Yara Birkeland has a 7MWh battery, charged by Norwegian hydro power. She can carry a little over 100 containers. The ship cost about 25 million dollars, about three times a “conventional ship price”, but will nonetheless cut OPEX for Yara by 90%.

Main particulars

- LOA 80 m
- Beam 15 m

Depth 12 m

- Draught (full) 6 m
- Eco speed 6-7 knots
- Max speed 15 knots

Capacity

- Cargo capacity 120 TEU
- Deadweight 3,200 tons

Propulsion

- Azipull pods 2 x 900 kW
- Tunnel thrusters 2 x 700 kW

Batteries

- Capacity 6.8 MWh

martin.tuner@energy.lth.se

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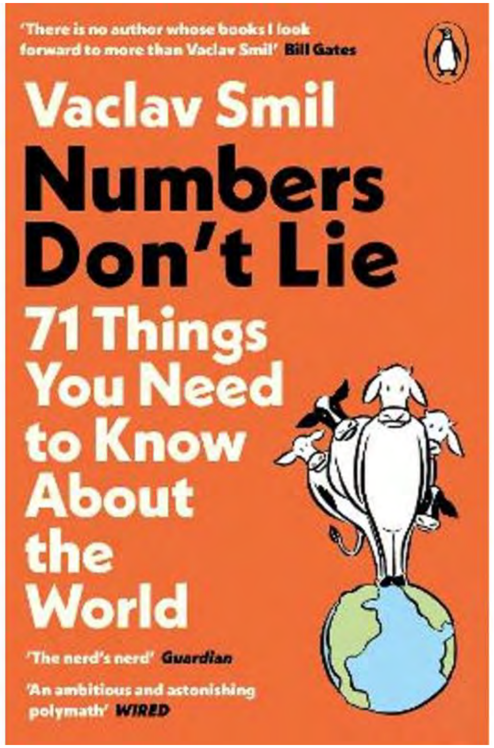
Today's state-of-the-art diesel container vessels thus carry 150 times as many boxes (> 18 000) over distances 400 times as long at speeds three to four times as fast as the pioneering electric ship can handle.



On a 31-day trip these big ships burns 4,650 metric tons of fuel, each ton packing 42 gigajoules.

That's an energy density of about **11,700 watt-hours per kilogram, versus 300 Wh/kg** for today's lithium-ion batteries, a nearly 40-fold difference.

The total fuel demand for the trip is about 195 terajoules, or 54 gigawatt-hours. Large diesels (and those in the ships are the largest we have) are about 50 percent efficient, hence their useful propulsive energy demand is about 27 GWh. To match that demand, large electric motors operating at 90 percent efficiency would need about 30 GWh of electricity.

Load the ship with today's best commercial Li-ion batteries (300 Wh/kg) and still it would have to carry about **100,000 metric tons** of them to go nonstop from Asia to Europe in 31 days.

Those batteries alone would take up about 40 percent of maximum cargo capacity, an economically ruinous proposition, never mind the difficulties involved in charging and operating the ship.

And even if we push batteries to an energy density of 500 Wh/kg sooner than might be expected, an 18,000-TEU vessel would still need nearly 60,000 metric tons of them for a long intercontinental voyage at a relatively slow speed.

To have an electric ship whose batteries and motors weighed no more than the fuel (about 5,000 metric tons) and the diesel engine (about 2,000 metric tons) - we would **need batteries with an energy density more than 10 times as high as today's best Li-ion units.**

That's a tall order indeed: In the past 70 years the energy density of the best commercial batteries hasn't even quadrupled.

Not easy to find energy dense battery materials even just for cars

Table 2: Current global supply and economically exploitable reserve of critical metals for battery production, together with the quantities required for 30% and 100% of passenger car and light commercial vehicle production [33].

		Lithium	Cobalt	Nickel
Current global supply	tonnes	77,000	140,000	2,700,000
Total land reserves	tonnes	17,000,000	7,000,000	89,000,000
Required for 30% of automotive production, using NMC 811	tonnes	154,845	131,130	1,046,250
Proportion of current supply	%	201%	94%	39%
Time to deplete current reserves	years	110	53	85
Required for 100% of automotive production, using NMC 811	tonnes	516,098	437,056	3,487,151
Proportion of current supply	%	670%	312%	129%
Time to deplete current reserves	years	33	16	26

With NMC 811 …

- NMC 811 is the next generation Li-ion battery (available after 2025)
- Uses 8 parts nickel per part manganese and cobalt ("8-1-1")
    - *So, much less cobalt*
- Today's Li-ion batteries use NMC 111 chemistry

Muelaner JE. Unsettled Technology Domains for Pathways to Automotive Decarbonization. SAE EDGE Report EPR2020014, 2020. doi: 10.4271/ EPR2020014.

Nuclear

A focus in the previous Collin Trust keynote by Roland Clift, Emeritus Professor, University of Surrey, UK

DOE and ABS Launch New Studies on Nuclear Energy for Commercial Ships

NS Savannah operated in the 1960s as the US's first demonstration of nuclear power on a merchant ship (Nuclear Regulatory Commission photo)

PUBLISHED AUG 17, 2022 6:17 PM BY THE MARITIME EXECUTIVE

The U.S. Department of Energy has awarded ABS a contract to research barriers to the adoption of advanced nuclear propulsion on commercial vessels.

The $800,000 research project, which was awarded by the DOE's Office of Nuclear Energy last year, is now being formally contracted through its U.S. Industry Opportunities for Advanced Nuclear Technology Development funding opportunity.

According to ABS, the scope of the research project will address the challenges of adopting new reactor technology in commercial maritime applications. ABS will develop models of different advanced reactor technologies for maritime applications and develop an industry advisory on the commercial use of modern nuclear power.

WORLD NUCLEAR ASSOCIATION

Home / Information Library / Non-power Nuclear Applications / Transport / Nuclear-Powered Ships

Nuclear-Powered Ships

(Updated February 2023)

- **Nuclear power is particularly suitable for vessels which need to be at sea for long periods without refuelling, or for powerful submarine propulsion.**
- **Over 160 ships are powered by more than 200 small nuclear reactors.**
- **Most are submarines, but they range from icebreakers to aircraft carriers.**
- **In future, constraints on fossil fuel use in transport may bring marine nuclear propulsion into more widespread use. So far, exaggerated fears about safety have caused political restriction on port access.**

In 2021 it was suggested that modular molten salt reactors of about 100 MWt would be particularly suitable for marine propulsion due to ambient operating pressure and low-enriched fuel. Shipping company X-Press Feeders has invested in UK-based Core Power, which is promoting modular molten salt reactors for marine propulsion. Since 2020 Core Power has been involved with Southern Company and Terrapower in the USA developing the molten chloride fast reactor as a marine MSR which would never require refuelling during its operational life.

In June 2021 Samsung Heavy Industries (SHI) announced that it would partner with Korea Atomic Energy Research Institute (KAERI) to develop compact molten salt reactors to power ships as well as market offshore power plants. In January 2023 SHI completed a conceptual design for the CMSR Power Barge – a floating nuclear power plant based on compact molten salt reactors. The design of between 200 MWe and 800 MWe, developed by Danish company Seaborg Technologies, would have an operational lifetime of 24 years. SHI plans to commercialize the CMSR Power Barge by 2028.

Apart from naval use, where frequency of refuelling is a major consideration, nuclear power seems most immediately promising for the following:

- Large bulk carriers that go back and forth constantly on few routes between dedicated ports – *e.g.* China to South America and NW Australia. They could be powered by a reactor delivering 100 MW thrust.
- Cruise liners, which have demand curves like a small town. A 70 MWe unit could give base-load and charge batteries, with a smaller diesel unit supplying the peaks. (The largest afloat today – *Oasis* class, with 100,000 t displacement – has about 60 MW shaft power derived from almost 100 MW total power plant.)
- Nuclear tugs, to take conventional ships across oceans.
- Some kinds of bulk shipping, where speed may be essential.

While…

- Today Nuclear accounts for about 10% of produced electricity
- Electricity demand expected to triple
- Muellner et al. Energy Policy (2021)
  - Economically viable Uranium 235 resources ~8 million ton
  - Current consumption ~60 000 ton
  - Thus with tenfold increase in Nuclear, uranium 235 will last ~15-20 years
- Mark Z. Jacobson at Stanford reports:
  - Planning to operation times (planning-permits–construction) for all reactors ever built range from 10-19 years, Average today is around 15-16 years.
- Starting today 2023 + 15 years = 2038

martin.tuner@energy.lth.se

Scenarios presented by the OGCI and Concawe Maritime Decarbonisation Report (2022)

OGCI and Concawe Maritime Decarbonisation Report (2022)

- 3 main scenarios
  - Early pursuit of zero carbon fuels
  - Moderate uptake of interim and drop-in fuels
  - initial maximisation of vessel decarbonisation measures (includes CCS)
- All scenarios meet IMO 2050 WTW
  - CO2 reduction vs 2020: 79%, 81% and 101%

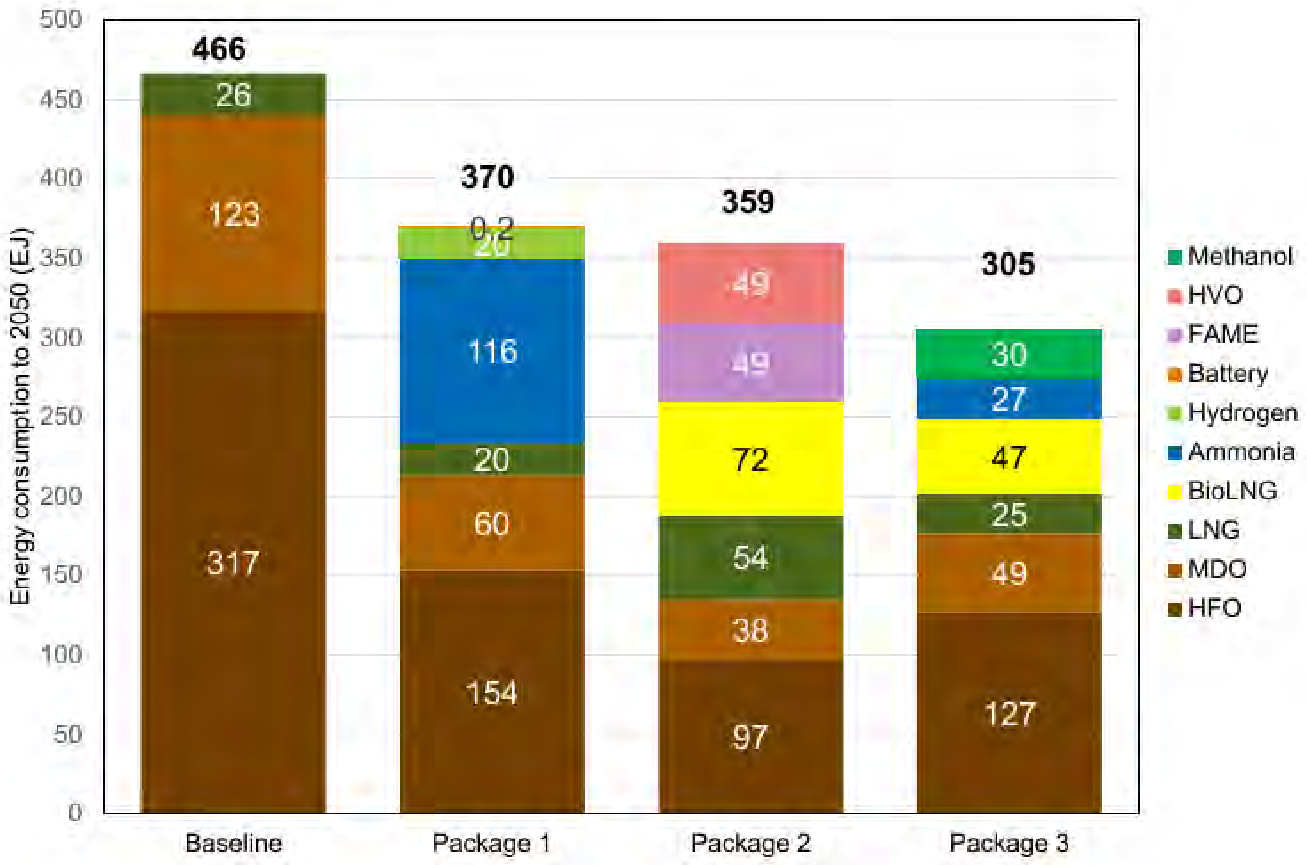
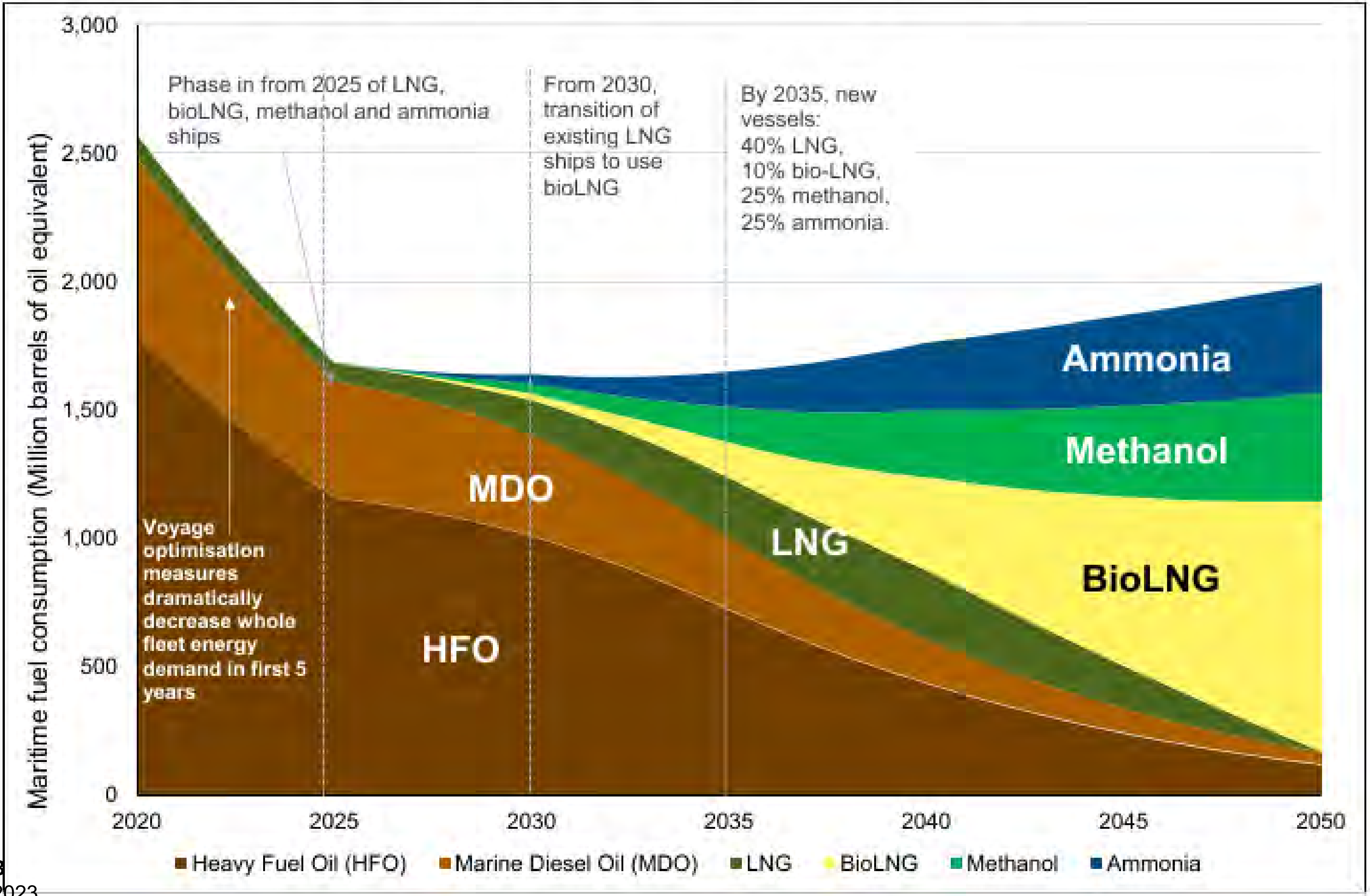


Figure 7-6: Fuel consumption to 2050 under the central scenario for package 3



OGCI and Concawe Maritime Decarbonisation Report (2022)

Technical aspects

WE ARE FUEL AGNOSTIC - DEVELOPMENT CONTINUES FOR ENERGY AND MARINE CUSTOMERS

BioLNG

or Synthetic methane

Can readily be used with equipment made for fossil LNG and blended in all ratios

Verified: 2003

Cryogenic LNG operations are well-known (IGF code of safety for ships since 2016)

MeOH

Green Methanol

A methanol conversion package for the engine is required.
Stena Germanica started operation on Methanol in March 2015

Verified: 2015
Ready for serial production: 2023

Non-pressurised tanks
Toxic, local emissions (NOx)

NH_3

Green Ammonia

Combustion concepts to maximise engine performance and related safety technologies are currently being investigated
70% Ammonia blend on typical marine engine load achieved already

Indicative: 2021
Tech concept ready: 2023

Non-cryogenic but toxic
Rules & regulations develops
Local (NOx) and GHG emissions (N2O)

H_2

Green Hydrogen

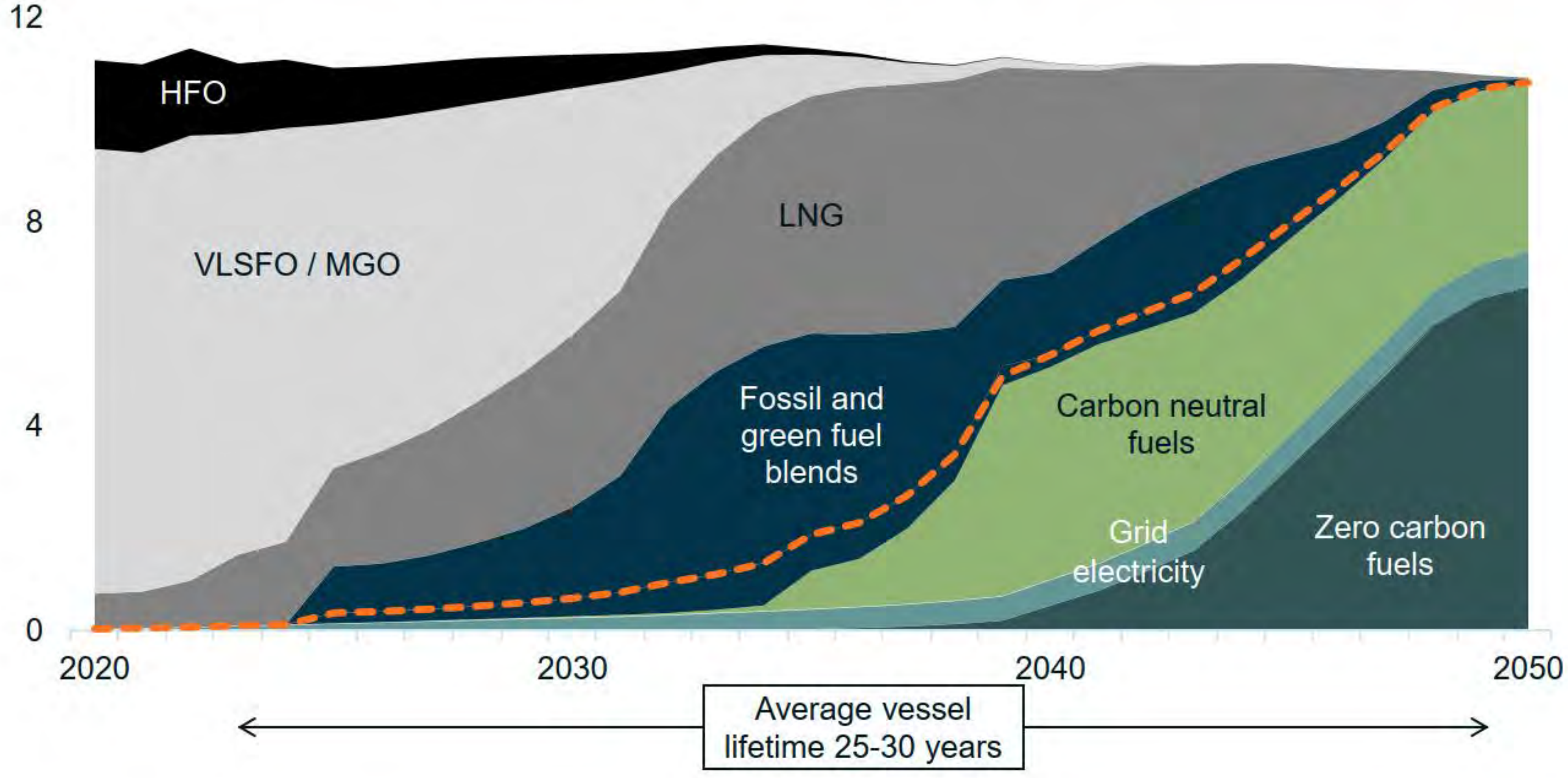
Our gas engines are already able to blend up to 25%-vol hydrogen in LNG, and combustion concepts under work for 100% hydrogen.
Pure Hydrogen operation achieved already

Indicative: 2021
Tech concept ready 2025

Storage of LH2 at -253 °C
Local emissions (NOx)

Shipping have to invest in fuel flexibility to avoid risk of stranded assets

Distribution of fuel types for Decarbonisation 2050 (1.5ºC scenario), EJ



Source: DNV Maritime Forecast 2050 model, Wärtsilä internal estimates

Carbon neutral and zero carbon fuels in maritime

- By 2050, 60-100% fleet will use a **different fuel compared to today**
- Shipping is moving to a **multi-fuel model**; LNG is considered as the bridge fuel
- **Drop-in fuels will play a key role in the short term**, as they can be used in varying blending fractions with no or minimal modifications to engines and fuel systems;
- The path to decarbonised shipping may appear like a long winding road and yet it is **less than one vessel lifetime away**

Future for global shipping?

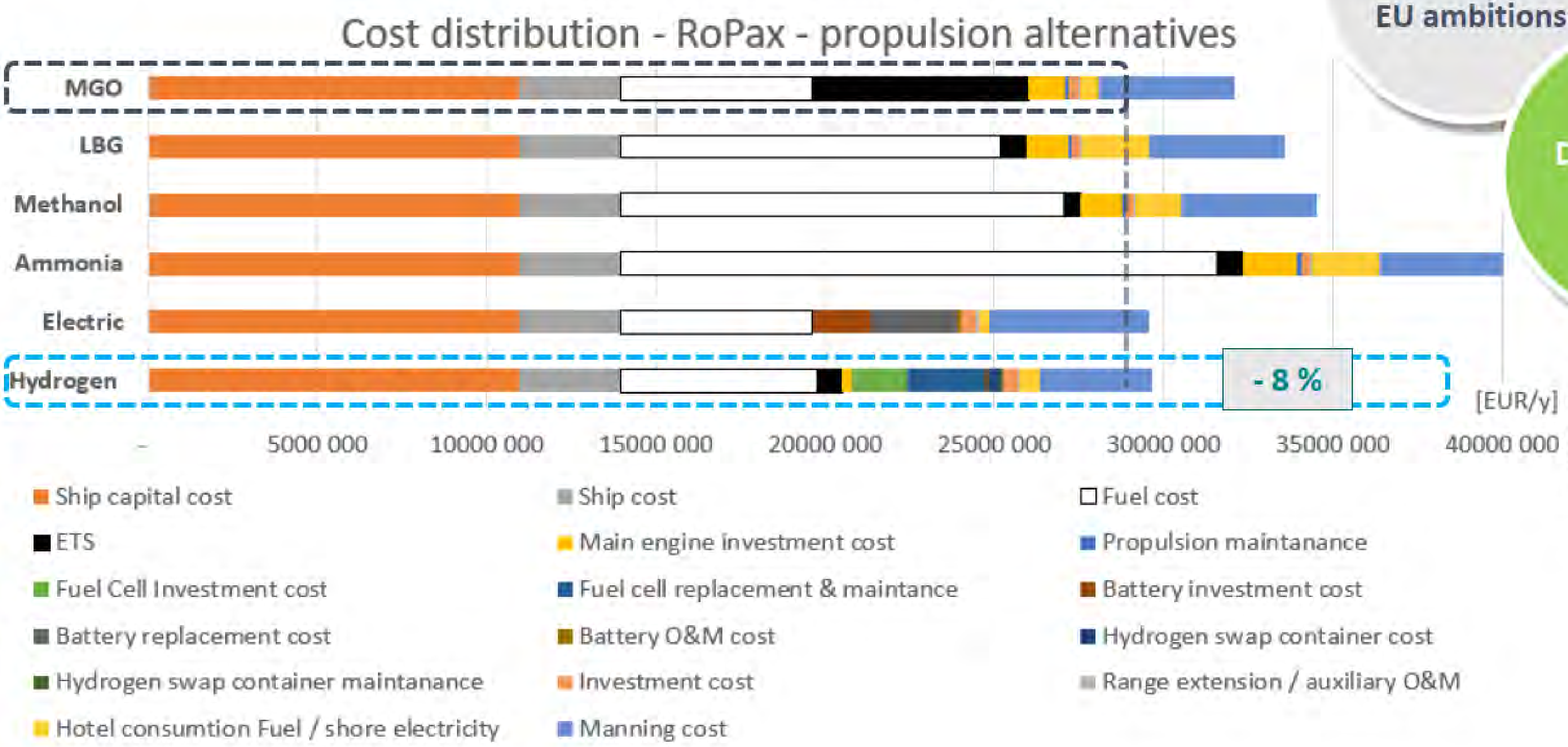
- Energy losses over propeller is 20-40%
- Cable ferries offer higher efficiency and "autonomous drive"

martin.tuner@energy.lth.se

Costs

HOPE - Hydrogen fuel cells solutions in shipping – a Nordic perspective

Cost for marine hydrogen fuel cell solutions and assessment of emission impacts of potential uptake in Nordic fleet



Preliminary data

Hydrogen costs more in line with EU ambitions

Decreased fuel cell costs

Increased ETS (100 EUR/ton => 200 EUR/ton

ivl Swedish Environmental Research Institute

Results. Total cost of ownership (TCO) in M€/yr. Large ferries. Base case.

Costs include: fuel production, fuel infrastructure, annuitized investments in propulsion technologies, energy storage onboard, and eventual reduced income due to less cargo space.

Color coding: within each fuel category (biofuels, electrofuels) and utilisation rate to highlight the cheapest option (9 blocks).

Results

- Biofuels generally the lowest TCO.
- Methanol shows lowest cost within all fuel categories (similar to DME, ammonia, HVO).
- ICE always lower TCO than fuel cells (but similar, or the opposite, for long distance).
- BE lower TCO than all electrofuel options and almost all FC options.
- BE not an option for the other ship categories.

Acronyms used:
MGO= Marine gas oil (low sulpur bunker oil)
DME= Dimethyleter (from gasification of wood)
LMG= Liquefied methane gas (from gasification of wood)
LBG= Liquefied biogas (from digestion of household waste)
HVO= Hydrotreated vegetable oil
LH2= liquefied hydrogen
ICE= Internal combustion engine propulsion
FC= fuel cell propulsion
BE= battery electric propulsion

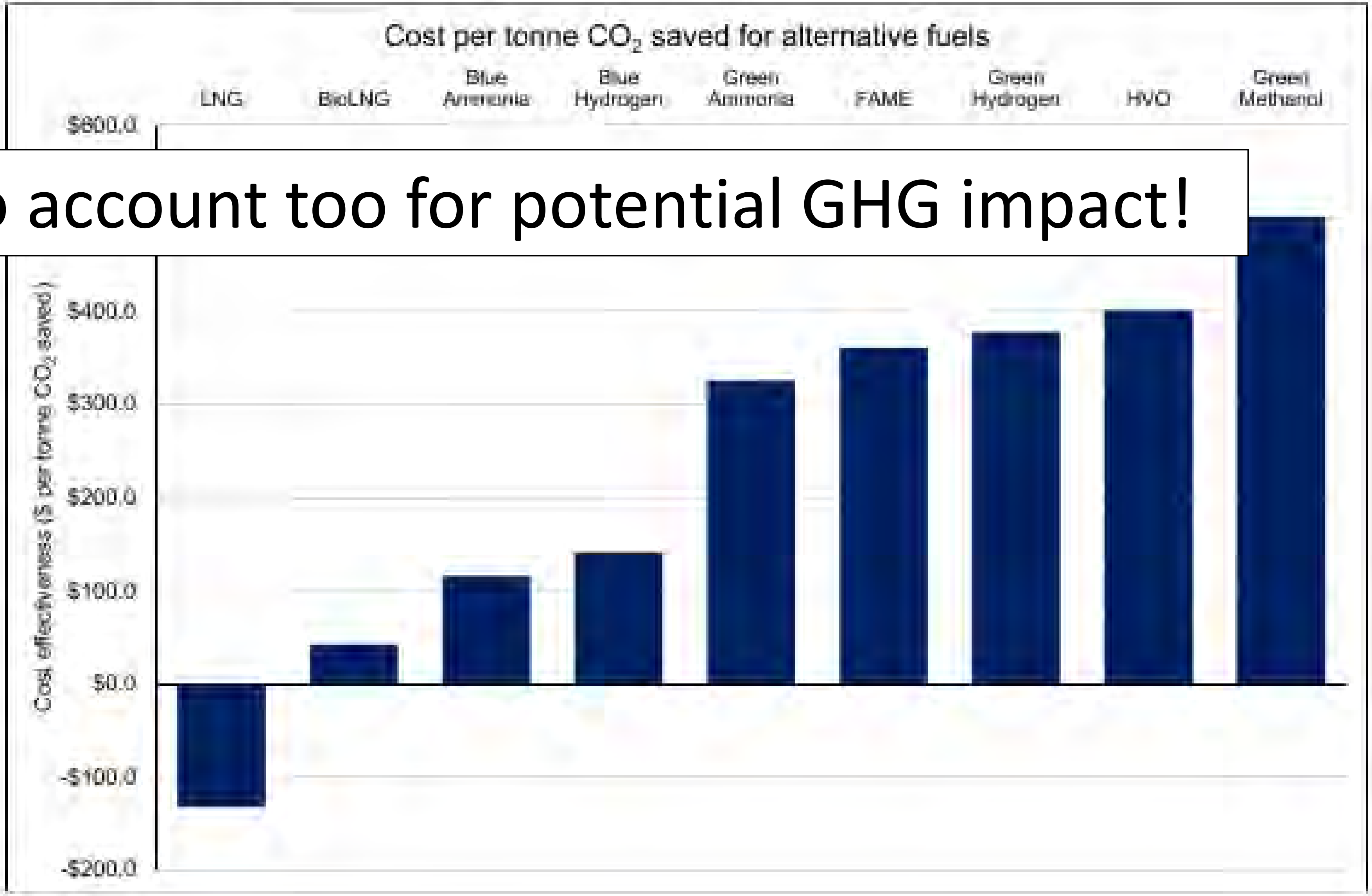
Utilisation/trip		Short			Medium			Long		
Propulsion		ICE	FC	BE	ICE	FC	BE	ICE	FC	BE
MGO		0.9			1.7			2.4		
Biofuels	Biomethanol	2.0	4.2		3.9	5.7		5.7	7.2	
	BioDME	2.3			4.2			6.2		
	Biodiesel	2.7			5.2			7.6		
	BioLMG	3.0	4.9		5.4	6.8		7.8	8.7	
	BioLBG	2.8	4.8		5.1	6.6		7.4	8.4	
	HVO	2.4			4.6			6.8		
Bio-electrofuels	E-biomethanol	2.6	4.7		4.9	6.6		7.3	8.5	
	E-bioDME	2.9			5.4			7.9		
	E-biodiesel	3.2			6.2			9.2		
	E-bioLMG	3.6	5.4		6.6	7.8		9.6	10.2	
	E-bioLBG	3.6	5.3		6.5	7.7		9.5	10.1	
Electrofuels	E-methanol	3.3	5.3		6.5	7.8		9.7	10.3	
	E-DME	3.7			7.0			10.3		
	E-diesel	4.3			8.4			12.5		
	E-LMG	4.3	5.9		8.0	8.9		11.8	11.9	
	Ammonia	3.7	5.5		6.9	8.0		10.2	10.6	
LH_2		4.7	5.3		8.8	8.6		13.0	11.9	
Electricity				2.8			5.5			8.3

Low TCO M€/year

High TCO M€/year

Korberg AD, Brynolf S, Grahn M, Skov IR (2021). Techno-economic assessment of advanced fuels and propulsion systems in future fossil-free ships. Renewable and Sustainable Energy Reviews 142: 110861

Figure 5-6: Cost-effectiveness ranking for alternative fuels



Needs to account too for potential GHG impact!

OGCI and Concawe Maritime Decarbonisation Report (2022)

Cost-benefit analysis

- The potential of ammonia and hydrogen to decarbonize shipping becomes quite obvious from the analysis undertaken in this research. Their life-cycle GHG emissions are far less than the ones generated from the use of MDO with the relevant external cost from their use also being minimal in comparison to conventional options.
- High total expenditure for their employment also becomes apparent underlining the urgent need to put a cost on GHG emissions to level the playing field for the employment of alternative fuels and accelerate the energy transition of the sector according to the 'polluter pays' principe.

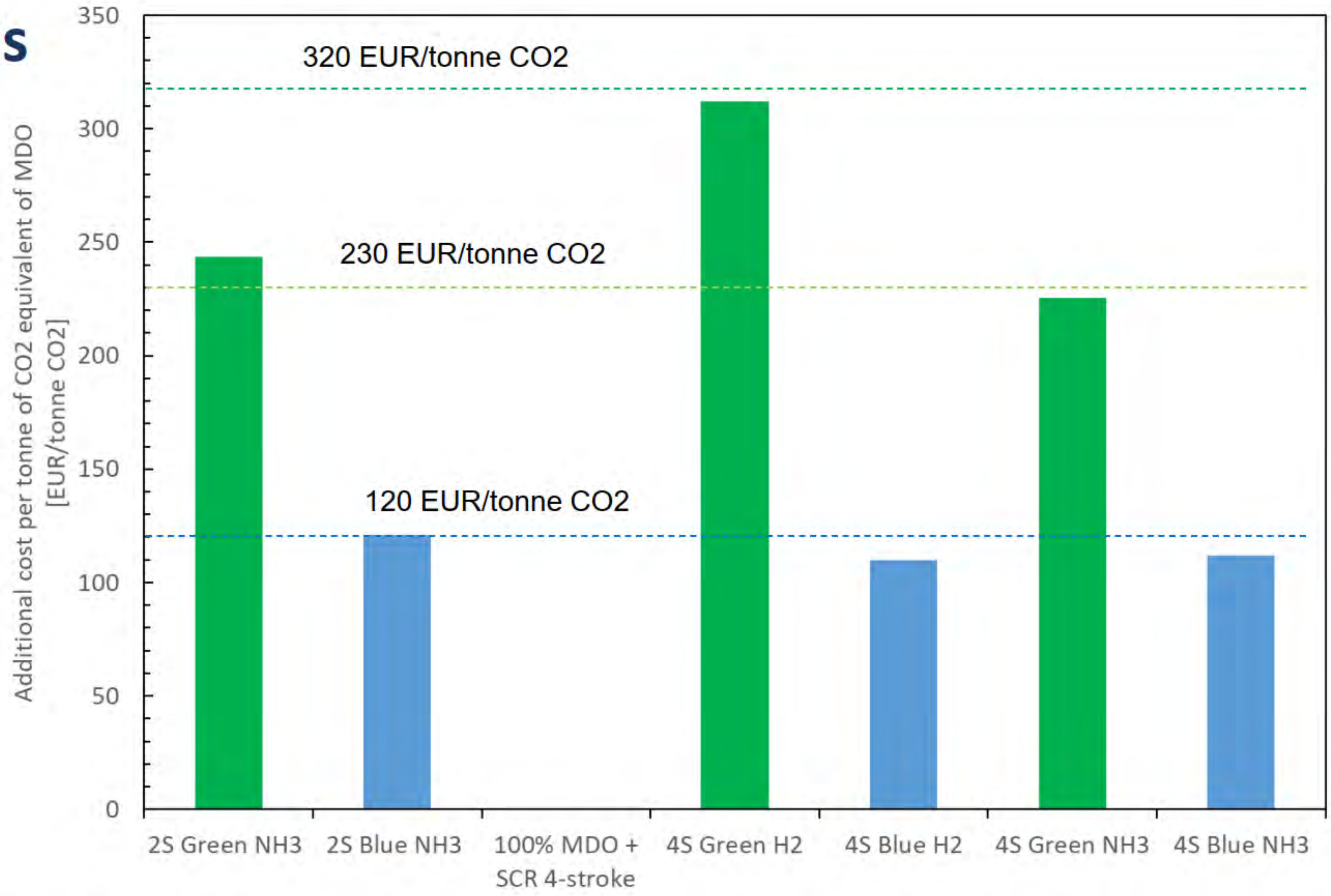
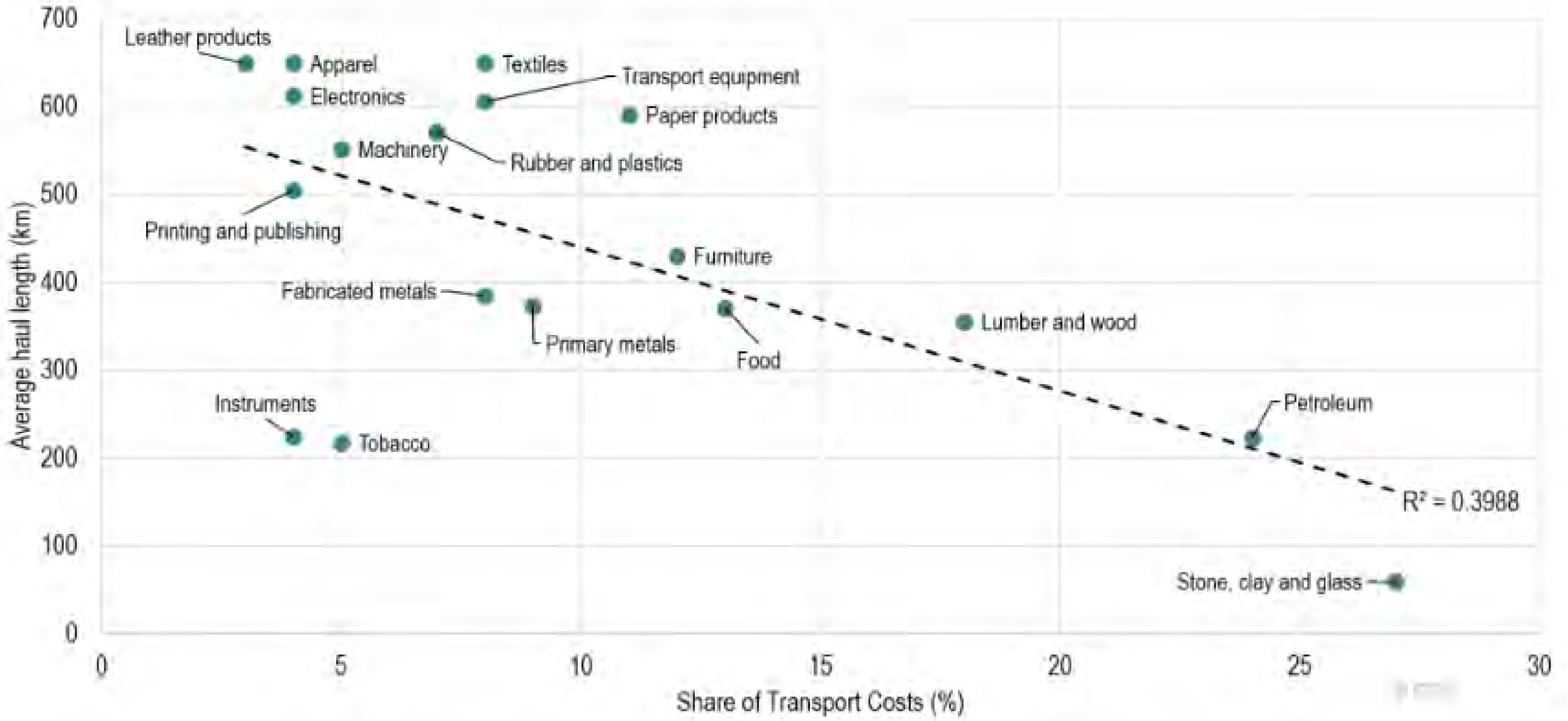


Figure 4: Additional costs per tonne of CO2 equivalent of MDO (€/tonne CO2)

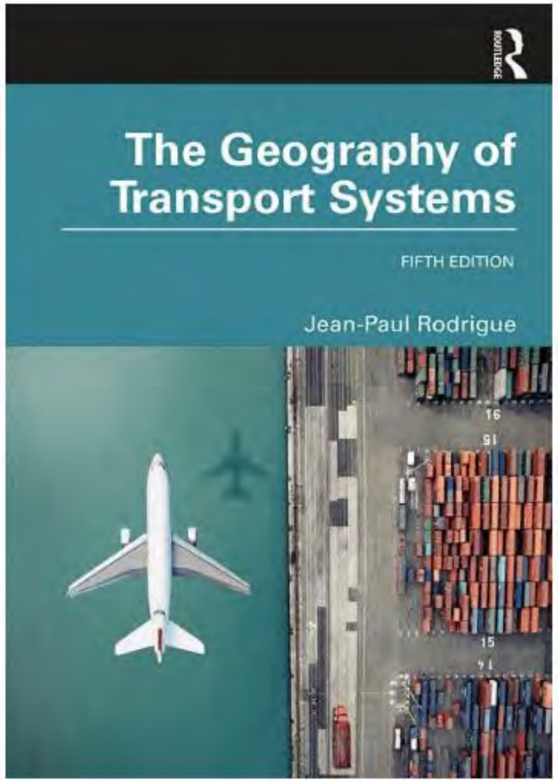
Anastasia Christodoulou, Tuan Dong, Alessandro Schönborn

WMU WORLD MARITIME UNIVERSITY

Sustainable transport: Added costs for end consumers small – but huge for operators and investors



Share of Transport Costs in Product Prices and Average Haul Length



The Geography of Transport Systems

FIFTH EDITION

Jean-Paul Rodrigue (2020), New York: Routledge, 456 pages. ISBN 978-0-367-36463-2

Do I believe global shipping will meet the sustainability goals?

Are we on track?

- Maybe
  - So many positive actions
  - In several sectors planned or commissioned facilities would meet the needs
  - Still insufficient evidence on commitment to scale up production of sustainable energy sources
  - Dangerously slow permit processes

Is there potential?

- Yes
  - Needed technologies largely in place – better ones are coming
  - Several investigations outlines plans based on realistic assessment of available and complementing resources: bio + e-fuels + electric
  - Life cycle assessment and cost-benefit analysis paves for better decisions
  - Multiple paths must be pursued immediately – the challenge is HUGE

martin.tuner@energy.lth.se

Enough food for thought?

martin.tuner@energy.lth.se

Now…

That was only 3% of global GHG

- We need to be careful with Earth´s resources
- Sustainable shipping needs to collaborate with the other sectors for sharing resources for the greater good
- Market models need development for responsible sustainability with a clear link to end consumers costs
- Global agreements and policing are needed on a lot of topics:
  - If we walk together we walk faster to the same place
  - Prevent new problems from new solutions
- Our goals for 2030, 2050 and after that, depends on that we start today!

Listen to the IPCC!

martin.tuner@energy.lth.se

Action – what you can do now!

- Go and convince your politician – there is need for fast track permit processes and long term sustainable financing and costing schemes
- Invest in sustainable energy – many options are relevant and will be good investments

Then you have done a lot to secure a future

for your children and grandchildren!

martin.tuner@energy.lth.se

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