

Transport Energy Network

What does the future hold for thermal propulsion systems and fuels?

Philippa Oldham, Gloria Esposito, Penny Atkins
25 July 2019



FUNDING.
EXPERTISE.
COLLABORATION.



Connect
Collaborate
Influence



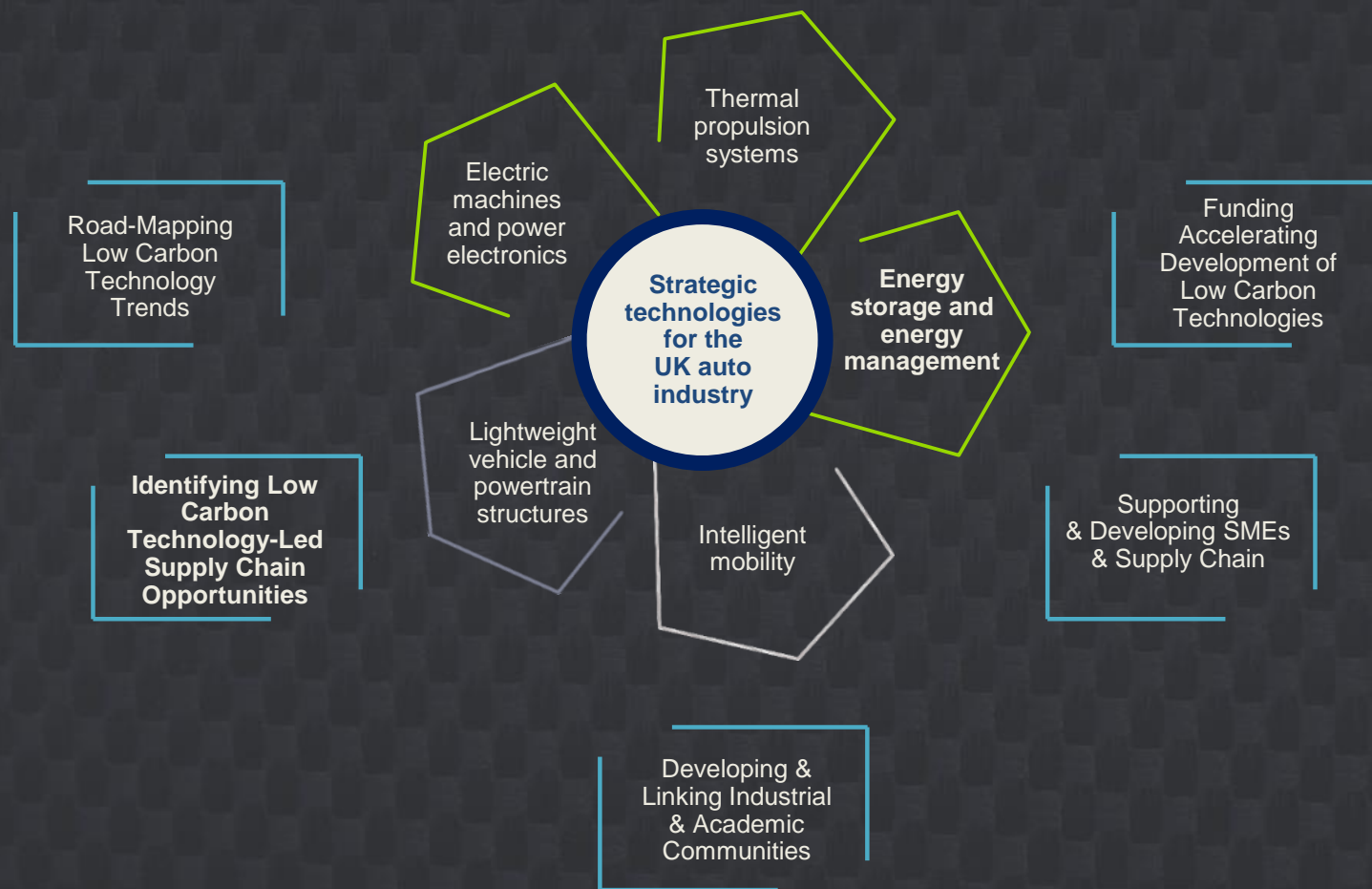
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Advanced Engineering Centre

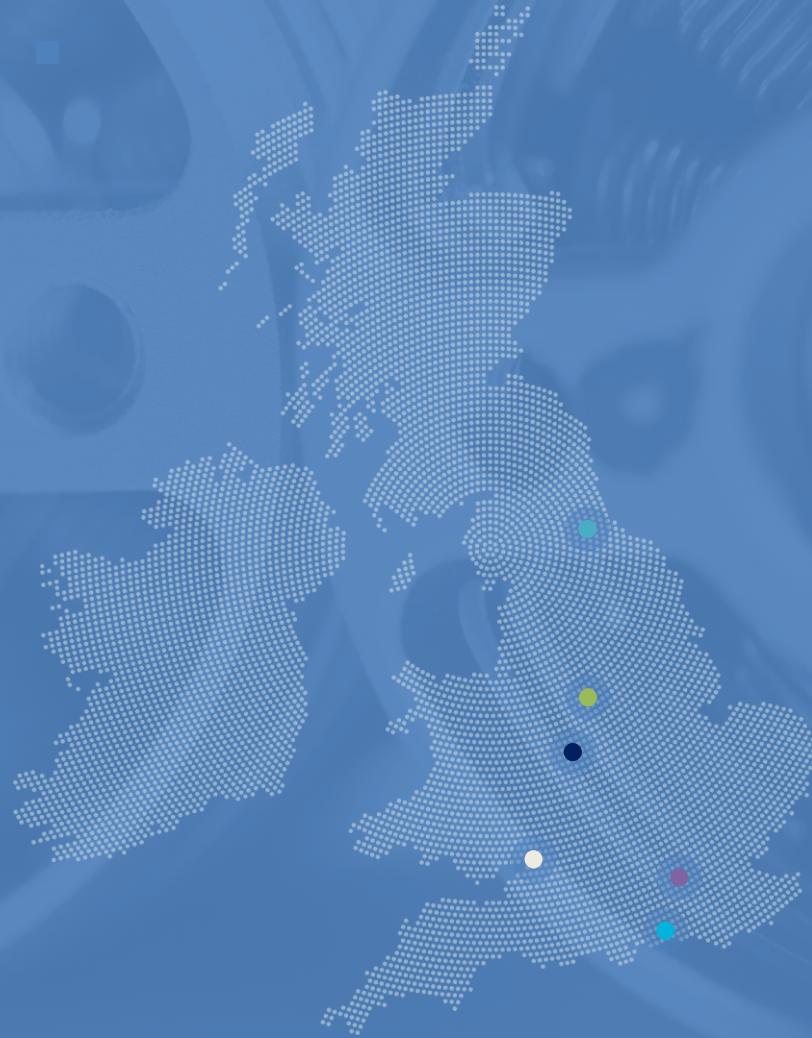
Workshop agenda

- 10.00 - 10.30 Arrival & breakfast
- 10.30 - 11.00 Welcome and Introduction
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- 15.15 - 15.30 Wrap up and close

HELPING THE UK AUTOMOTIVE INDUSTRY CAPITALISE UPON LOW CARBON TECHNOLOGY OPPORTUNITIES



DEVELOPING AND LINKING INDUSTRIAL AND ACADEMIC COMMUNITIES



- ELECTRIC MACHINES SPOKE
Newcastle University
- POWER ELECTRONICS SPOKE
University of Nottingham
- ELECTRICAL ENERGY STORAGE SPOKE
University of Warwick
- TPS SYSTEM EFFICIENCY
University of Bath
- DIGITAL ENGINEERING AND TEST SPOKE
Loughborough University (London)
- TPS THERMAL EFFICIENCY
University of Brighton

Transport Energy Network

Industry need



Policy & Regulation



Research solutions

University of Brighton

Automotive, Heavy Duty & Off-highway

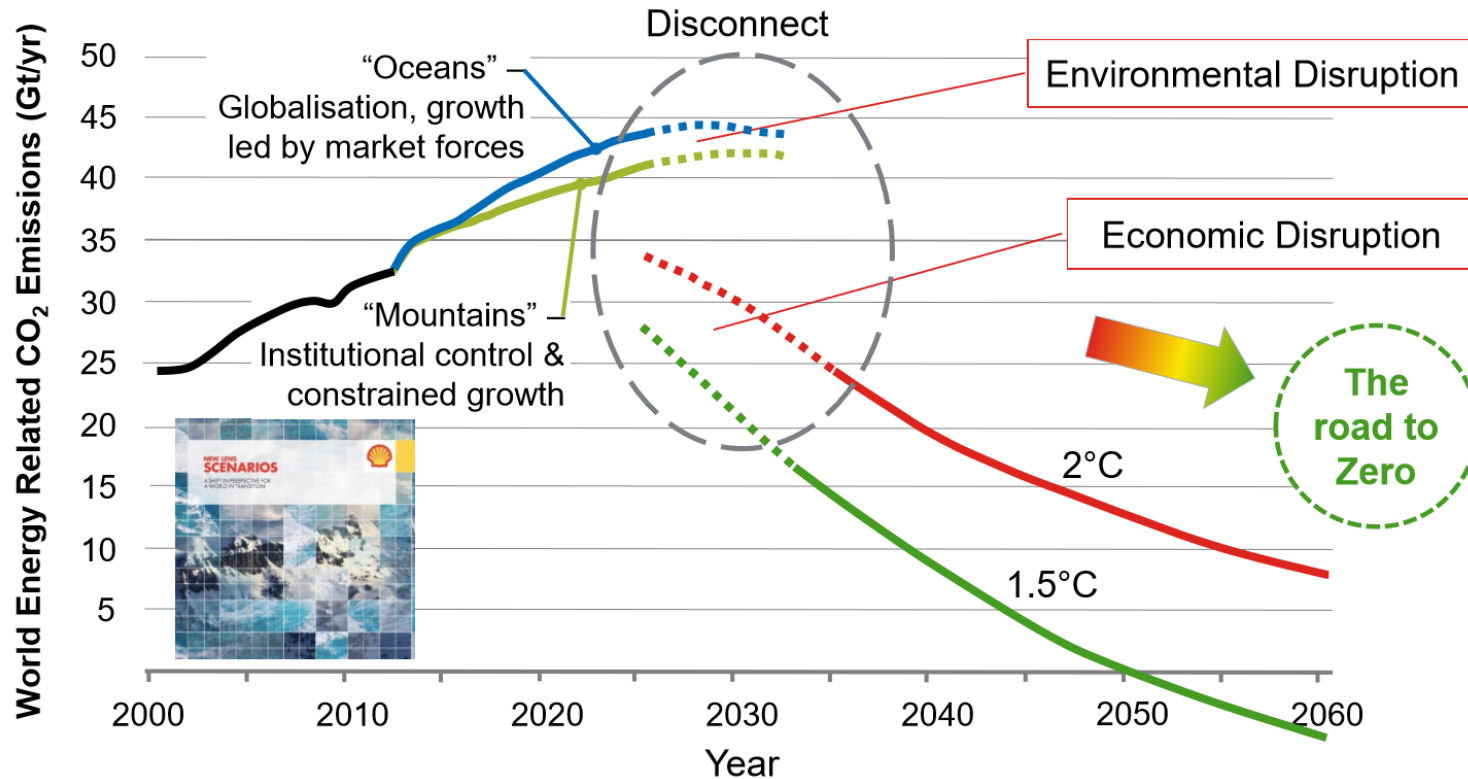


Challenge for all our transport



The need to decarbonise transport is increasingly urgent...

The Energy/Climate challenge and projected future energy scenarios reveal a significant discontinuity – disruption the likely outcome



- Policymakers in Europe increasingly focused on “Zero” emissions for road transport
- Reducing carbon intensity in other sectors perceived to be more difficult

Source: Shell New Lens Scenarios; Gert Jan Kramer, Utrecht University

The Transport Energy Network aims to accelerate decarbonisation through targeted collaboration between fuels, powertrain and energy systems communities

■ Objectives

- Understand long term R&D priorities for low carbon fuels and clean efficient thermal powertrains
- Enhance collaboration between fuel and thermal powertrain developers
- Develop links to energy systems work and R&D community

■ Scope

- Timescale: Now to 2050, Transport Modes: on road, off highway, marine, rail (consider synergies with aero)
- Liquid and gaseous fuels
- UK focus, but recognising global supply chain

■ Work programme 2019/20

- Four workshops (April, June (x2), November)
- Deliverable report – cross discipline roadmaps

■ Working in collaboration with APC, LowCVP and Automotive Council

Transport Energy Network work programme



Workshop sessions this afternoon aim to generate scenarios for the evolution of propulsion, fuels and energy system and highlight cross disciplinary R&D needs



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Transport Energy Network

Low Carbon Fuels Policy Landscape

Gloria Esposito, Head of Projects, LowCVP
gloria.Esposito@lowcvp.org.uk



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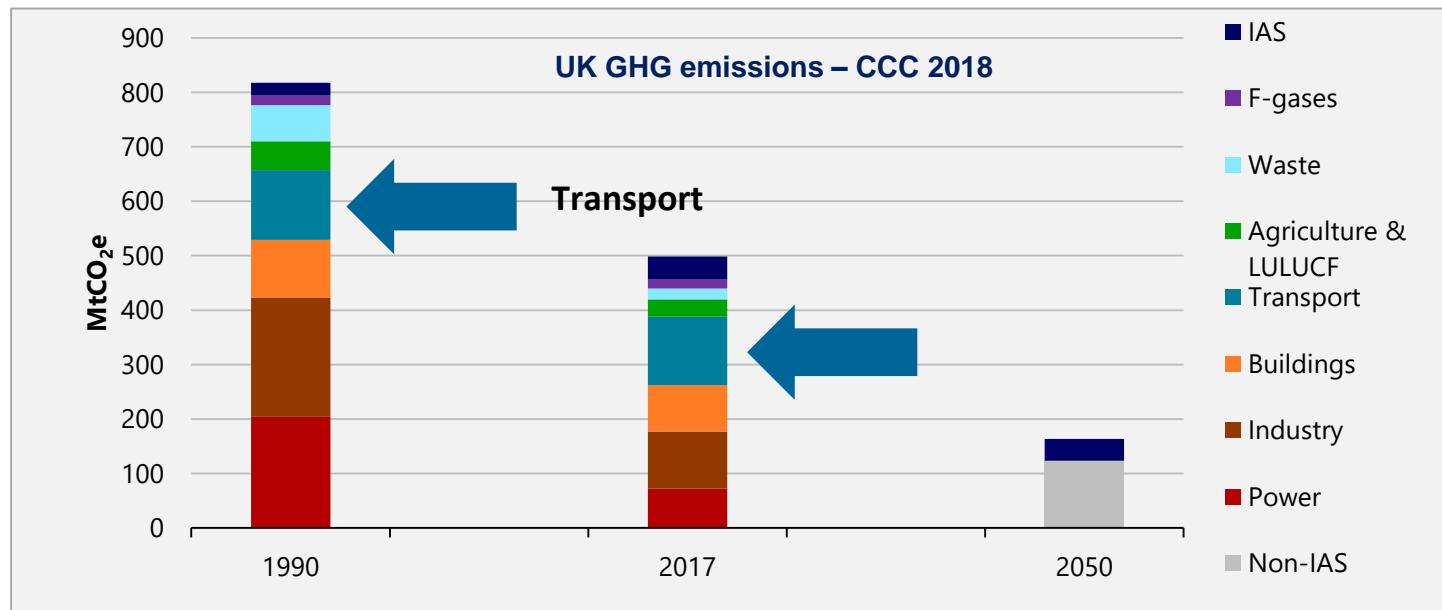
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Advanced Engineering Centre

UK Government has set a long-term vision of 'net' zero emissions by 2050

Transport sector will require low carbon liquid and gaseous fuels alongside electrification over the next two decades to achieve the following:

- Decarbonising road transport today, and while alternatives increase
- Decarbonising aviation, shipping and freight – long distance/high energy demand
- Policy has a critical for stimulating the supply and demand for low carbon fuels, whilst ensuring production is low carbon and sustainable.



Taxonomy of low carbon fuels – current and future

Biofuels

Conventional feedstocks

Food and feed crops, including:



Maize



Sugar cane



Rapeseed oil

Lignocellulosic feedstocks

Non-food or feed feedstocks, including:



Energy crops



Agricultural residues



Biomass fraction of waste

Novel feedstocks

Non-food or feed feedstocks, including:



Algae

A variety of feed-stocks and pathways exist to produce advanced ‘drop-in’ fuels for HDV, aviation and the marine sectors.

Deployment influenced by production cost, resource availability, sustainability, GHG intensity, fiscal incentives

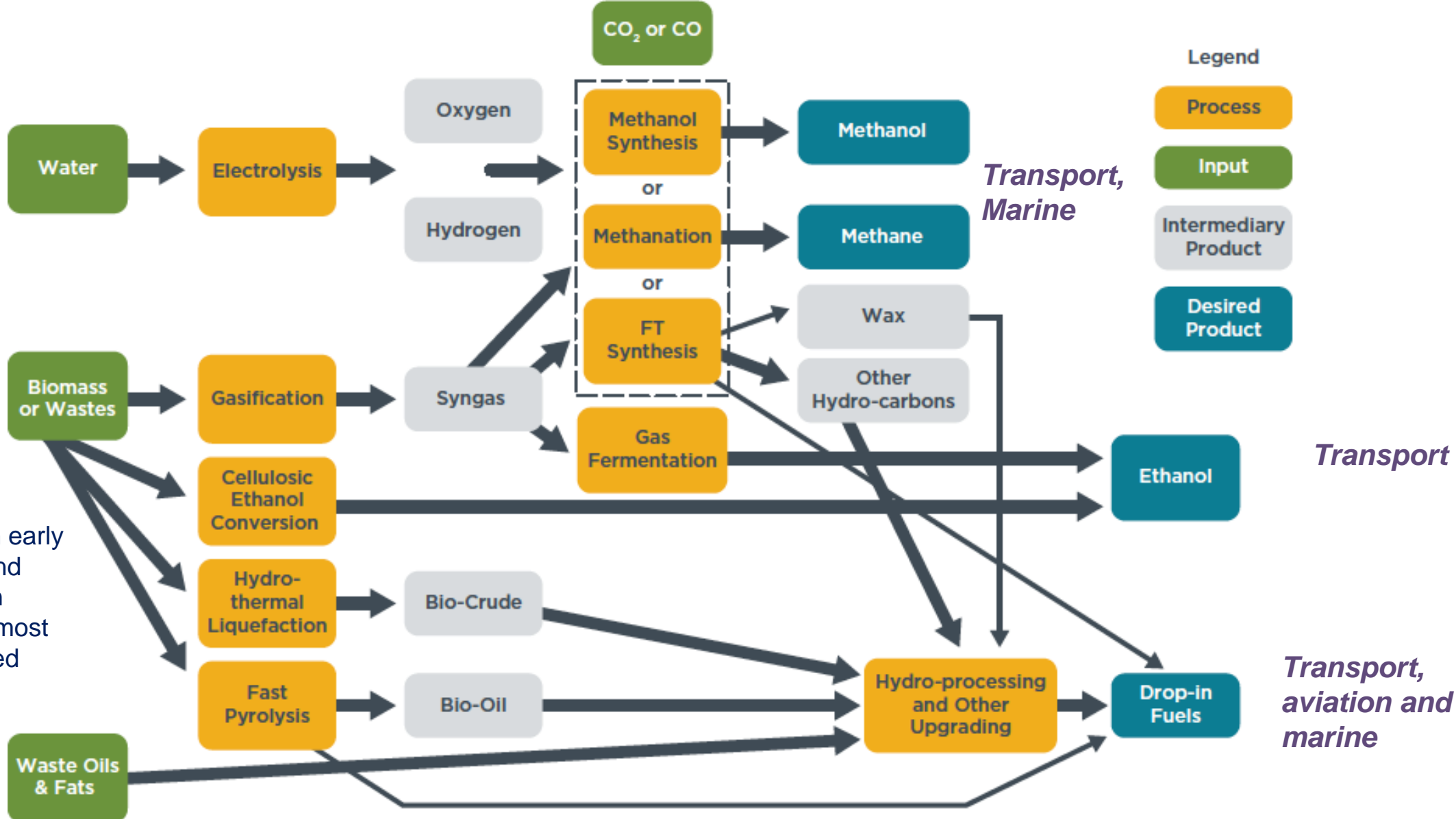
RFNBO

Renewable Fuels of Non-Biological Origin – also called E-fuels, Power to Liquid. Includes hydrogen from electrolysis and synthetic fuels.

Low Carbon Fossil Fuels

Low Carbon Fossil Fuels, also called Recycled Carbon Fuel. Derived from recycled gaseous or solid fossil wastes or from waste fossil gasses that are unavoidable (Feed-stocks could be MSW, end of life plastic, industrial fuel gas)

Pathways for producing advanced fuels



Majority are in early commercial and demonstration stages, HVO most commercialised

European Renewable Energy Directive

RED up to 2020

- 10% of transport fuel in Europe to come from renewable energy sources by 2020.
- Feed-stocks arising from organic waste and residues counted twice.
- Carbon and sustainability criteria for biofuel production pathway
 - GHG emission **>60% savings** compared to fossil equivalent (*lifecycle methodology*)
 - Sustainability 'land-use' criteria – **feedstocks should not be obtained from land of high biodiversity value and high carbon stock**
- Compliance demonstrated through voluntary sustainability scheme certification, independently audited.
- Concerns of indirect land-use change (iLUC) impacts and escalating rainforest deforestation due cultivation of crops for biofuel production – safeguards introduced.



European Renewable Energy Directive

RED II to 2030

- Transport renewable energy target for Europe increased to 14%
- Advanced biofuel target 3.5% by 2030 – double counted
- GHG savings of 65% as from 1st January 2021
- 7% crop-based biofuels cap
- Capped 'high iLUC' biofuels, phased out from 2030
- 1.2x multiplier for aviation and marine
- 'Low iLUC' feed-stocks require evidence via certification

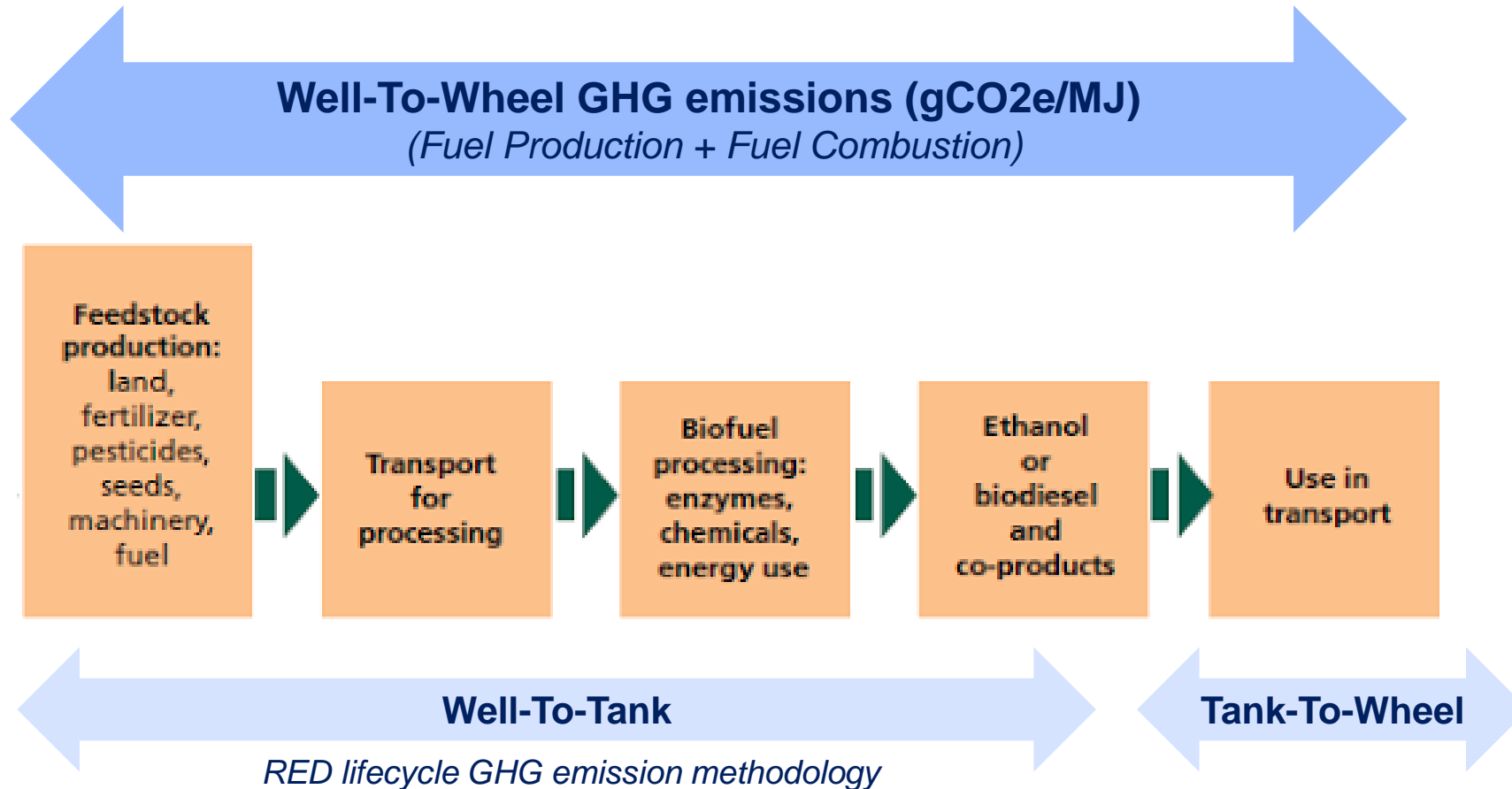
14% total target

Rest can be conventional biofuels (low iLUC), renewable electricity, fuel produced from renewable electricity and fossil waste.

1.7% limit on waste oil and fats

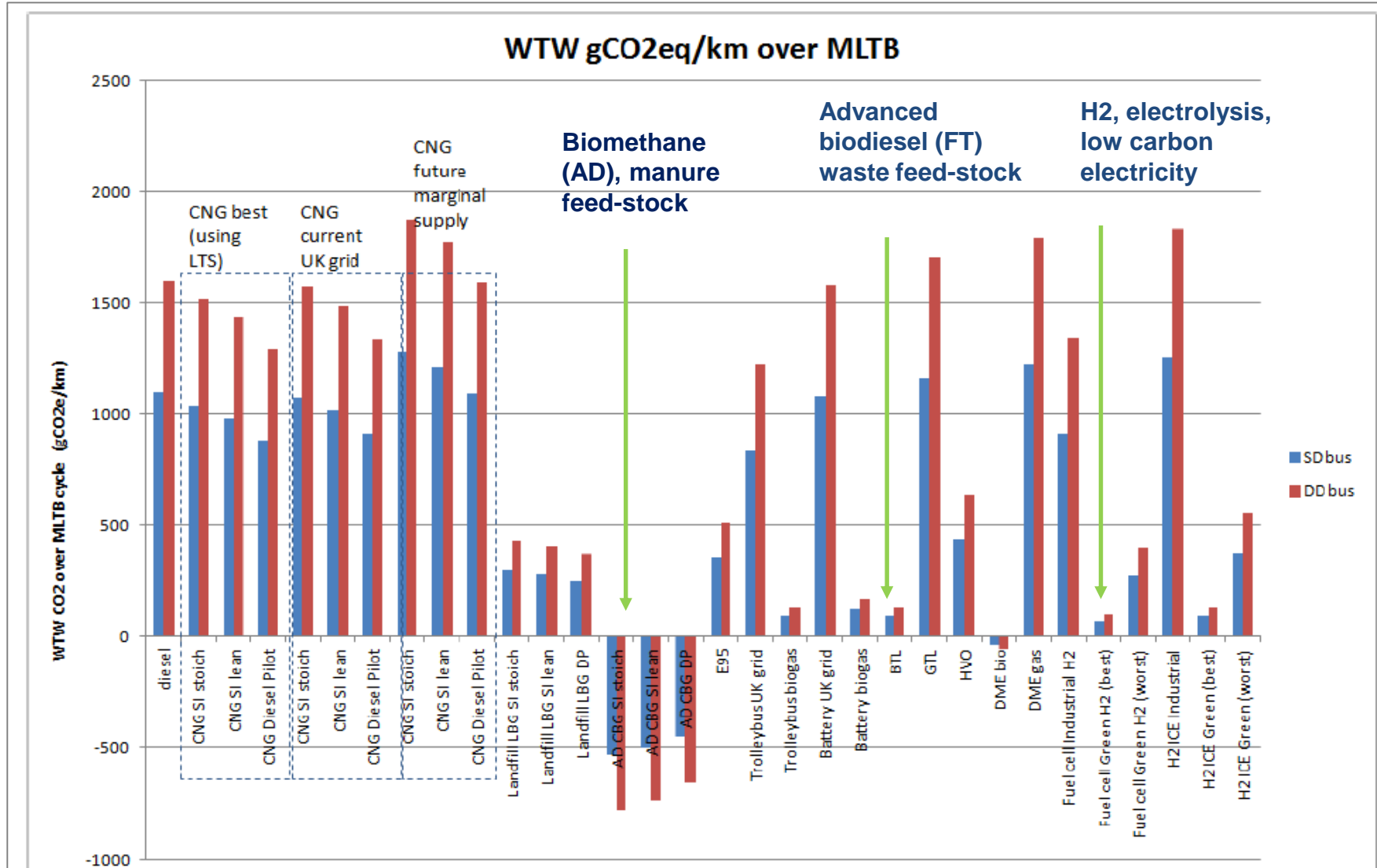
3.5% minimum must be advanced biofuels

Lifecycle GHG Emissions – where are the boundaries?



Paramount to take into account the WTW GHG emissions in the quest for a 'net' zero carbon future. Efficiency of the fuel production pathway and availability of low carbon electricity will be influential.

Fuel production pathway can have a significant influence of WTW GHG emissions



LowCVP – Low Carbon Bus Roadmap (Ricardo 2013)

International GHG emission reduction - aviation and marine sectors

Aviation



Three routes

- Improving airplane efficiency
- **Sustainable fuels** - drop-in liquid fuels, bio-kerosene and e-fuels. UK Roadmap created.

GHG emission and sustainability criteria introduced

- ICAO Carbon Offsetting and Reduction Scheme (CORSIA)

Voluntary from 2020, mandatory from 2027



International Shipping

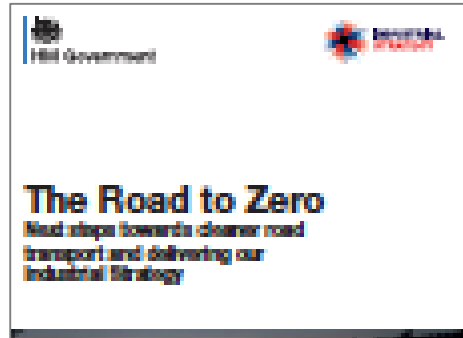


- IMO 'Initial Plan' for 50% GHG emission reduction by 2050 based on 2008, but little policy as yet.
- Early opportunities for alternative fuels – LNG, hydrogen, biodiesel



Hydrogen in Norway

UK GHG Emission Reduction Transport Policies



Renewable Transport Fuel Obligation – 10yrs of GHG savings

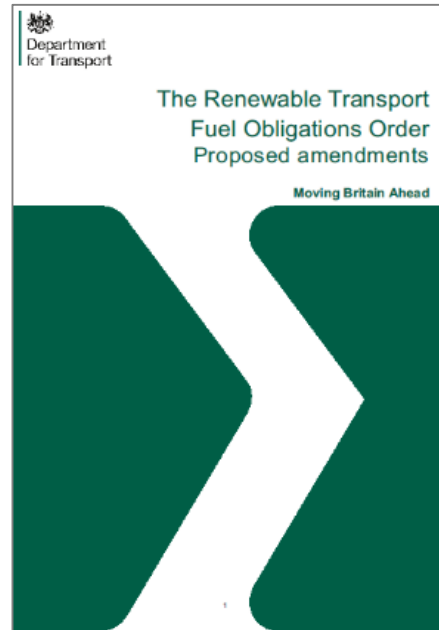
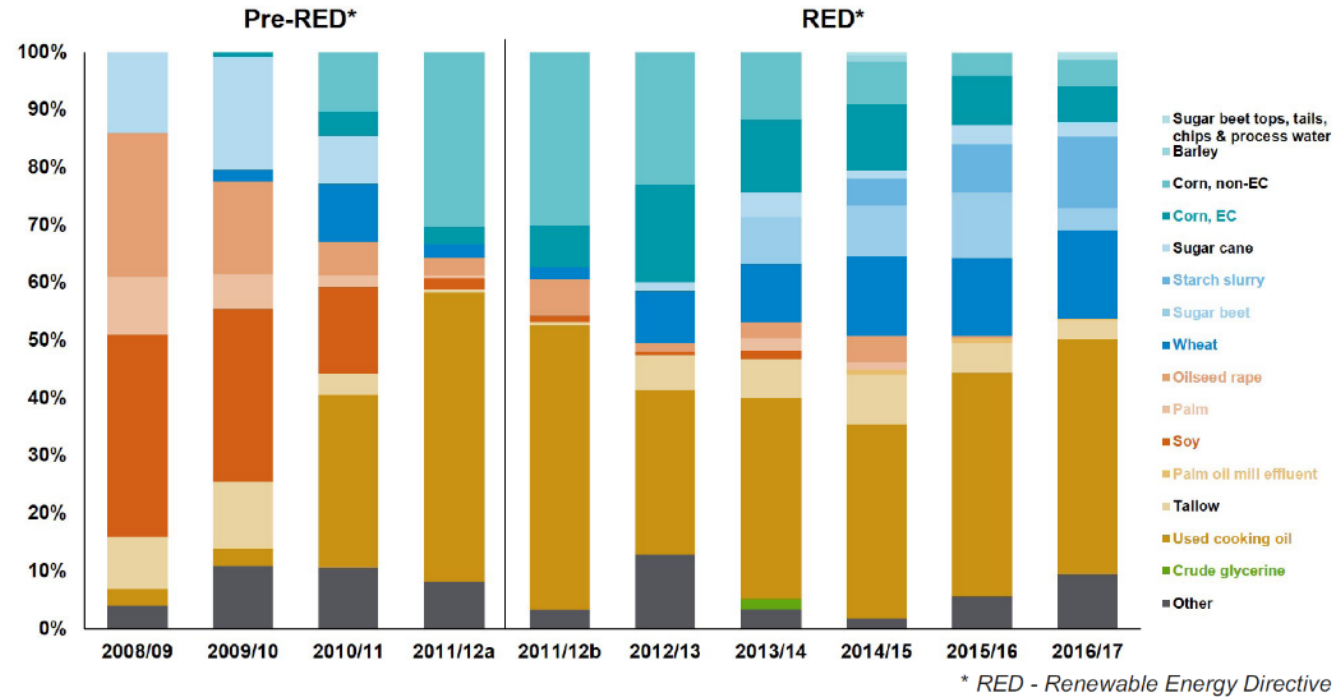


Figure 9: Supply of biofuels to the UK by feedstock, 2008/09 to 2016/17



2018 - Biodiesel produced from waste oils, bioethanol from wheat

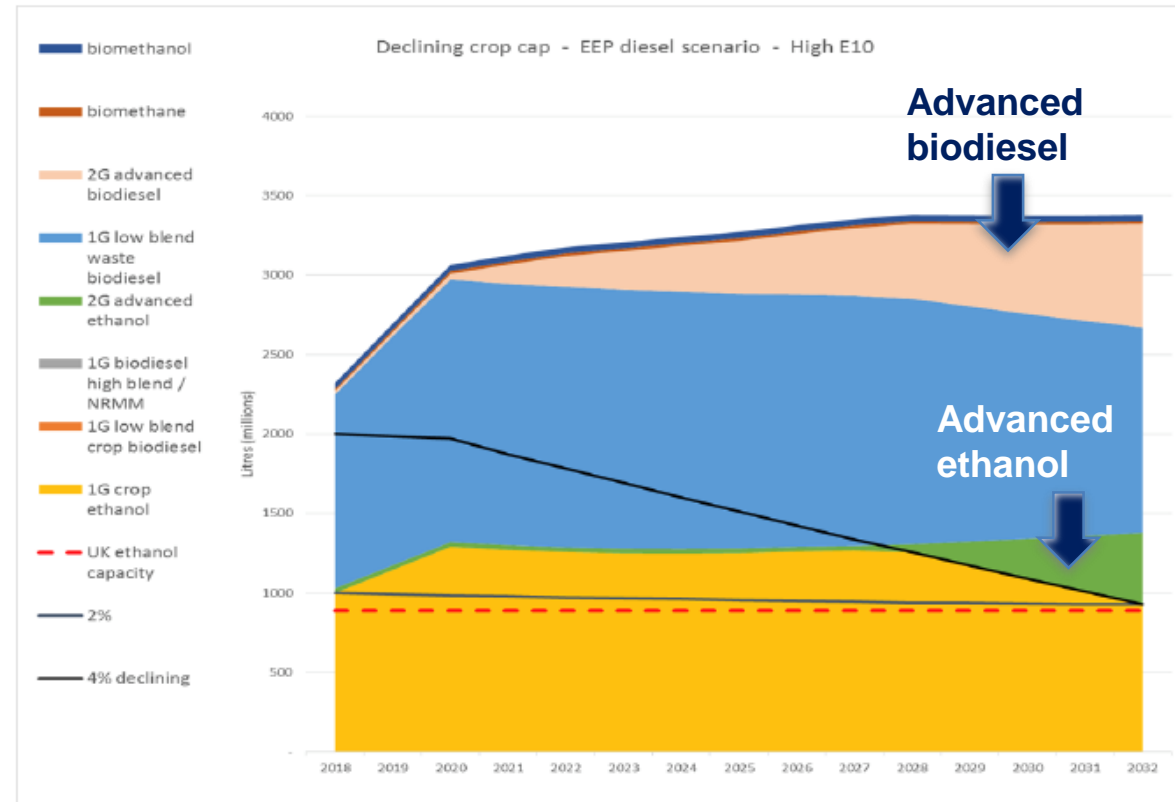
Average GHG savings 78%

98% certified by a voluntary sustainability scheme

- Legal obligation for UK fuel supplies to supply sustainable renewable fuel – sets mandates
- Incentivises renewable fuel supply through market traded certificates (RFTCs), doubled counted for waste feed-stocks
- Bio-ethanol (E5) and Biodiesel (B7) – 4.6% by volume, (clearly will not meet 2020 target!)
- High blend biodiesel and biomethane use in trucks and buses.

RTFO beyond 2020, supporting advanced fuels

- 2018 DfT introduced their 15yr policy framework – taking into account REDII
- Increased renewable energy target to 14% by 2032.
- New ‘development fuels’ sub target**
 - RFNBOs, aviation fuel, advanced biofuels made from waste feed-stocks, substitutes for natural gas by gasification or pyrolysis
 - 0.1% in 2020 to 2.8% in 2032.
 - 2x RTFCs
 - GHG threshold >70% savings
- Sets a crop cap, tightening over time.
- Considering low carbon fossil fuels



Department for Transport have a 15 yr policy framework for low carbon fuels

Clean Maritime Plan quote – ‘Government will consult in 2020 on how the Renewable Transport Fuel Obligation could be used to encourage the uptake of low carbon fuels in maritime’

Looking ahead – wider sustainability impacts and lifecycle GHG metrics must be taken into account when developing future fuels

Emphasis on land-use sustainability criteria in regulations for biofuels, however new feed-stocks and production pathways require evaluation of potential environmental and societal risks.

Use of feed-stocks such as MSW could undermine recycling

Re-use or recycling is nearly always the best use for a resource from an LCA perspective

Increase reliance on fossil fuels (LCFF)

LCFFs could perpetuate fossil fuel supply chains and prevent progress towards GHG reduction goals

Generate more waste

Using wastes for transport fuel production may increase the value of that waste and incentivise increased production and/or discourage efficiency improvements

Cause other environmental issues

Air quality or water consumption



Voluntary certification for advanced fuels will become increasingly important and require broader range of criteria.

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Transport Energy Network work programme



Transport Energy Network Workshop 1 output – Discussions covered transport decarbonisation landscape, collaboration and technology

■ Landscape

- Potential for loss of powertrain engineering skills
- Role of government - Carbon pricing to encourage uptake of low carbon technology, support to resolve chicken and egg dilemma?
- Importance of LCA

■ Collaboration

- Fuel and engine development separate – both working towards a fixed spec
- Balance cost/GHG of fuel production (variation in spec/impurities) vs effect on powertrain performance – match applications to fuels, considering whole supply chain cost
- Global vs local specification and supply chain

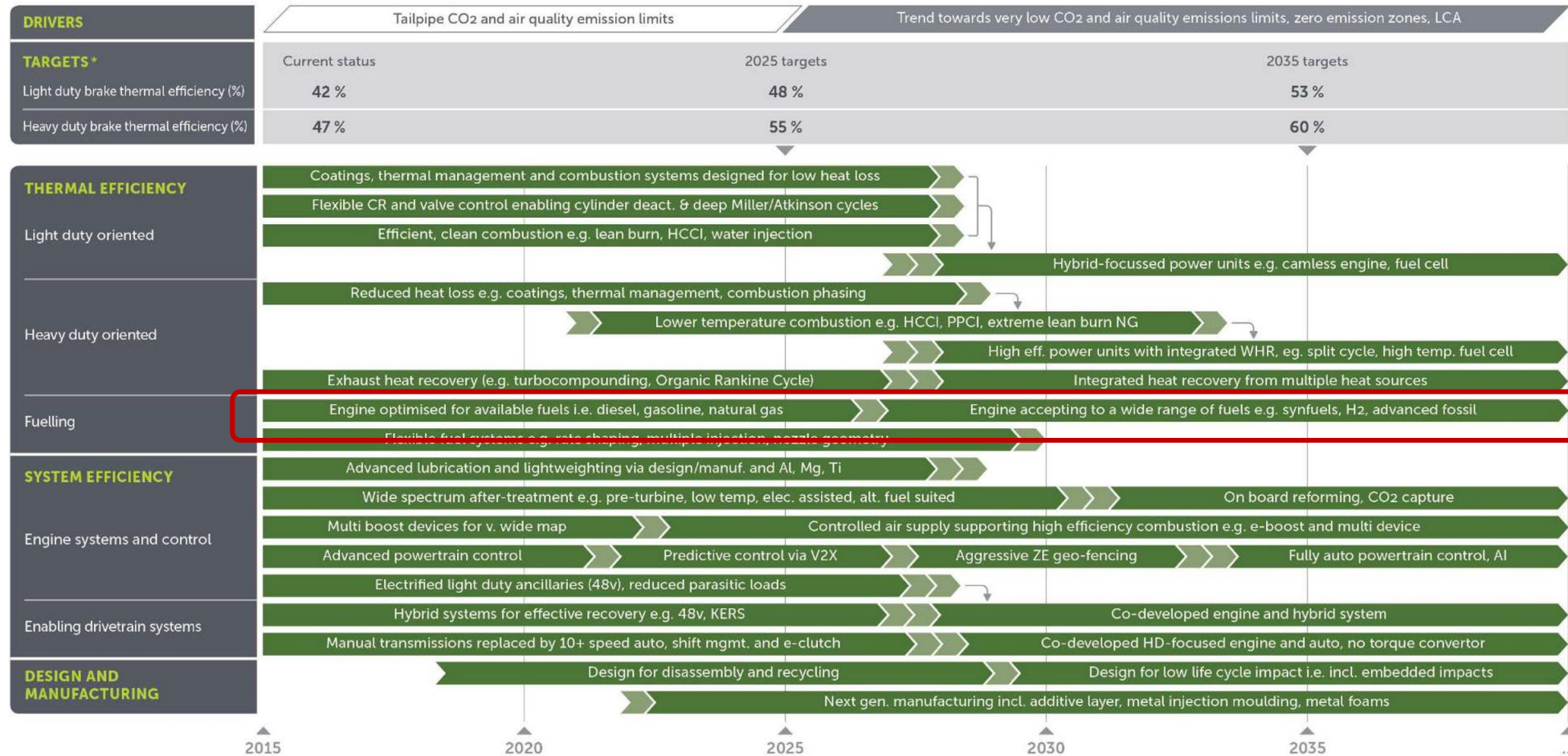
■ Technology

- View that engine is flexible, whereas fuel production more difficult – tolerant engine
- Map effect of fuel chemistry on engine performance – is there a sweet spot balancing fuel spec range and WTW GHG/cost
- Role for smart technology – communicate what fuel is in use and adjust calibration

This workshop aims to develop insight for cross discipline roadmaps – building on Advanced Propulsion Centre propulsion system roadmaps..

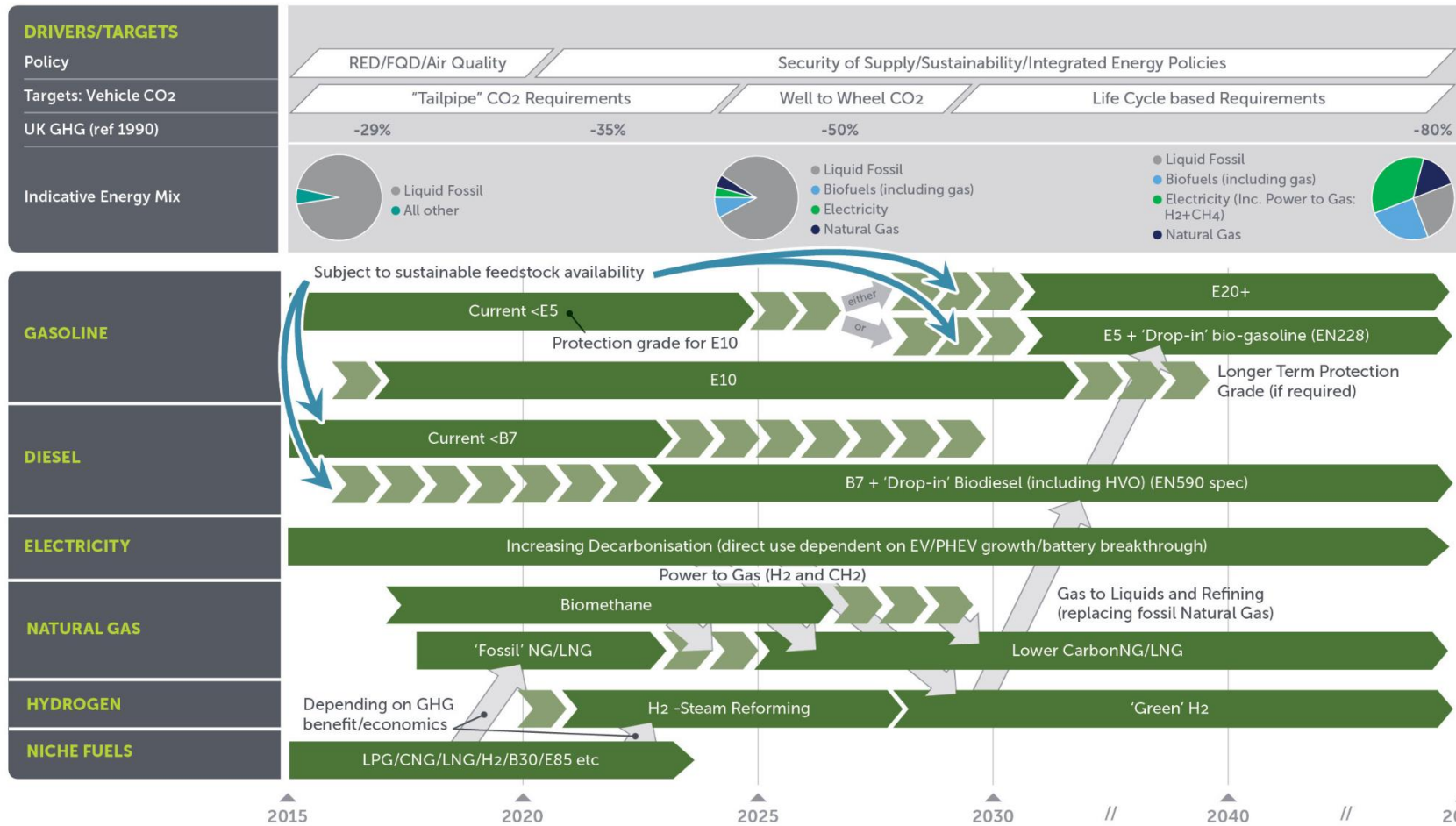
TECHNOLOGY ROADMAP 2017: THERMAL PROPULSION SYSTEMS

Roadmap developed by the Automotive Council and the Advanced Propulsion Centre



.. and Automotive Council Energy Roadmaps developed in 2015

TECHNOLOGY ROADMAP 2015: ENERGY AND FUELS ROADMAP



Introduction → Mainstream → Phasing out

Workshop sessions this afternoon aim to generate scenarios for the evolution of propulsion, fuels and energy system and highlight cross disciplinary R&D needs



The “Three Horizon” model used in business planning is often used to develop more robust longer term roadmaps

Horizon 1

- Short term evolution or iterations from existing knowledge
- The “first steps” in technology development
- Relatively low risk and based on existing knowledge

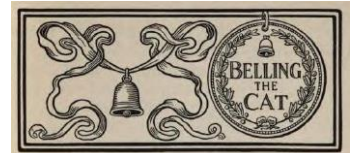
Horizon 2

- Links short term (Horizon 1) & long term vision (Horizon 3)
- Provides a Logical route to technology development
- Often the most important part of the roadmapping process

Horizon 3

- The longer term future vision or “ideal” future position
- Meets longer term regulatory and consumer/economic demands
- Assumes step change in technology capability

Aesops Fable
“Belling the Cat”



Its not just the solution - its how to get there that's important



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Session 1 – Scenarios for net zero at 2050

- In groups, consider different sectors:
 - Pass car
 - HD
 - Off highway
 - Marine
 - Aviation
- Consider different ways of achieving net zero in 2050
- Consider 2 time periods: 2020 – 2030, 2030 - 2050
- Record your ideas on the flip charts

Session 2 – Enablers for these scenarios

- In groups, consider enablers for the selected scenarios
- You could consider
 - Vehicle technology
 - Infrastructure
 - Policy
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Department
for Transport

Advanced Biofuels Programme

Aysha Ahmed
Head of the Advanced Biofuels Programme



Demand pull (RTFO)



- ▶ Policy certainty to drive investment
- ▶ Create a UK market for low carbon transport fuels
- ▶ Focus on to key fuels

Supply push (advanced competitions)

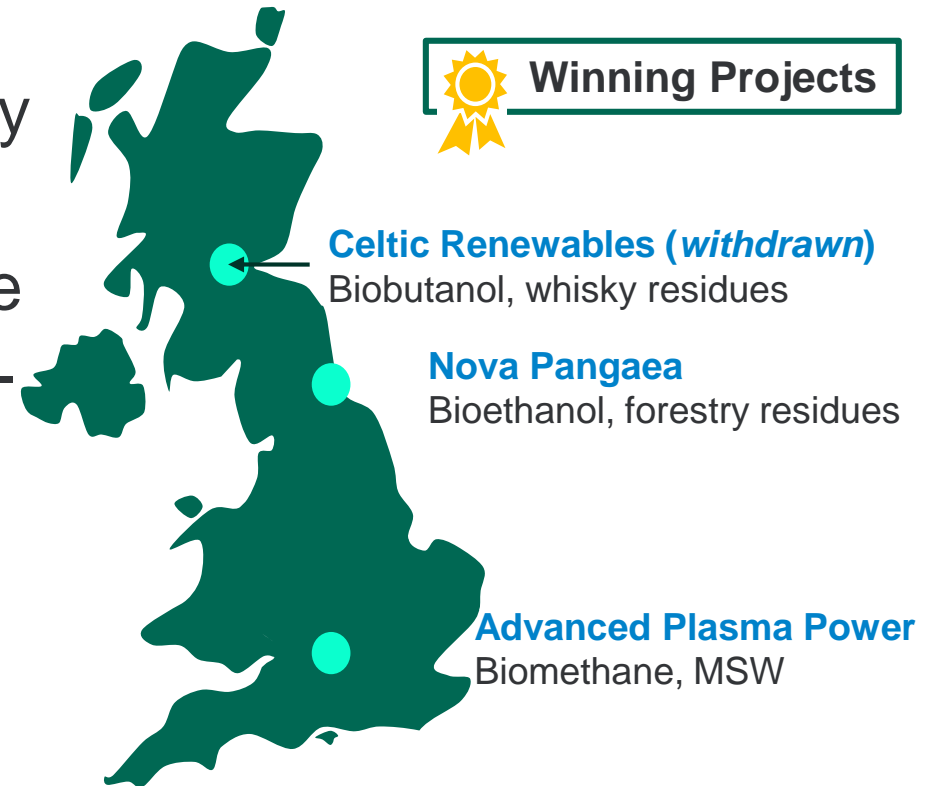


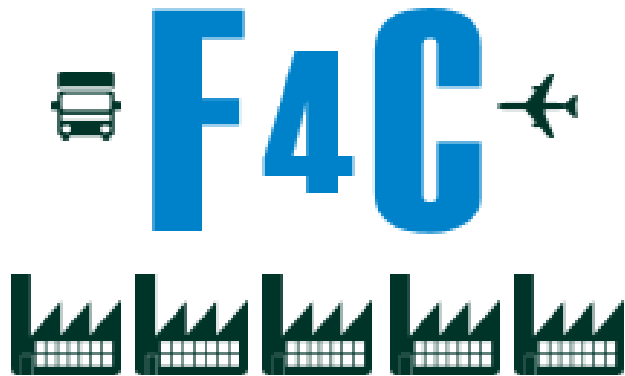
- ▶ Enable investment through capital support
- ▶ Facilitate research and development
- ▶ Build UK production capacity to satisfy domestic demand





- ▶ Launched 2014
- ▶ Kick-start a domestic industry
- ▶ Advanced technologies
- ▶ £25m capital grants available
- ▶ Leverage substantial private-sector funding
- ▶ Designed to demonstrate technical and commercial viability





Targeting strategically important
fuels

- ▶ £22m competition
- ▶ Aviation and freight sectors
- ▶ Expect up to 4 plants
- ▶ £2m project development funding
- ▶ Aligns with development fuels sub-target under RTFO



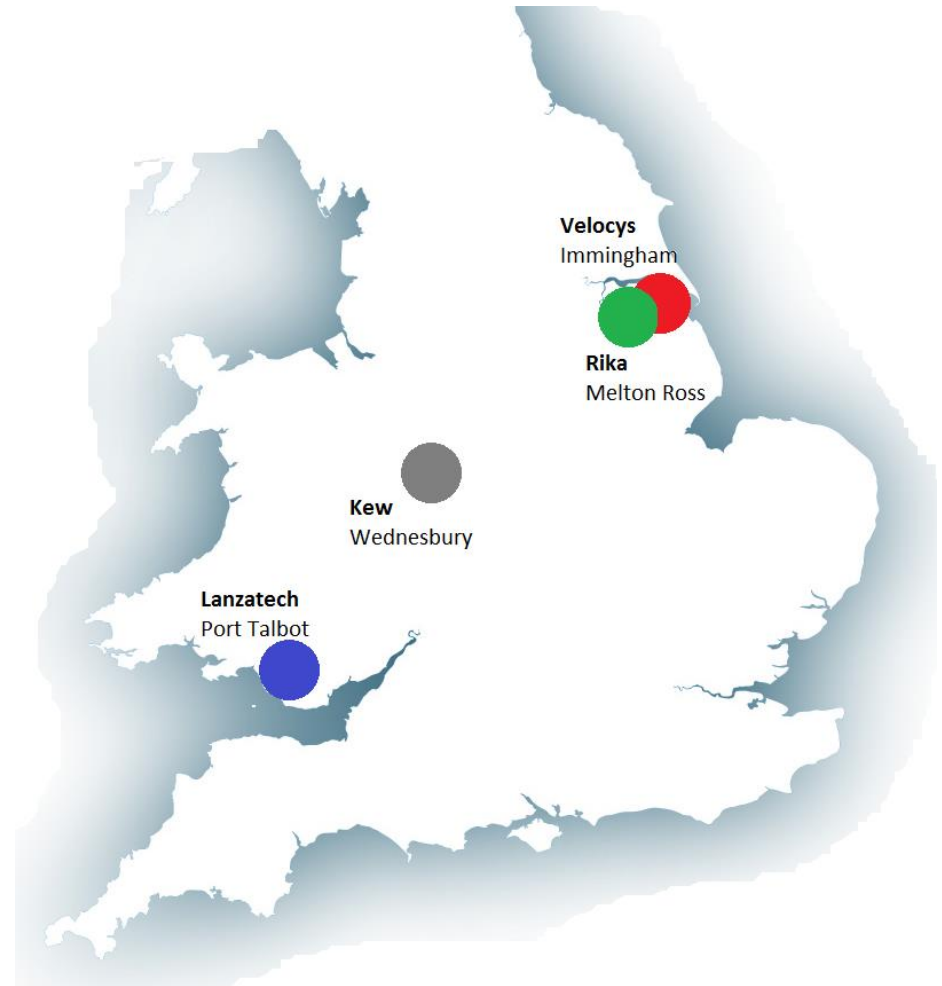


Company	Detail
Rika Biogas Technologies	Large step-up in scale for use of wet straw for production of liquefied natural gas at existing anaerobic digestion facility.
Johnson Matthey	Demonstration of Fischer-Tropsch (FT) commercial length reactor for diesel and jet fuel utilising gasification using waste wood and municipal waste.
Standard Gas	Demonstration of methane production from pyrolysis technology, currently at pilot stage in the UK using RDF and waste wood.
LanzaTech	Large scale demonstration / first-of-a-kind commercial plant for production of jet fuel from ethanal.
Progressive Energy	Commercial scale-up of the current APP demo plant using municipal waste and waste wood funded under the DfT's ABDC.
Kew Projects	Demonstration of FT diesel production using gasification, using waste wood as a feedstock (potentially RDF).
Velocys Technologies	Demonstration of FT jet fuel production from post recycling municipal waste gasification.





Company
Rika Biogas Technologies
LanzaJet
Kew Projects
Altalto





- ▶ Applied to F4C
- ▶ Investment is high risk
- ▶ Must allow some flex in project timelines
- ▶ Need to address barriers
 - Low oil prices (although recent increase saw an increase in interest level)
 - Technical challenges of converting waste to fuel
 - Engine manufacturers reluctant to use products in their equipment
 - Investment. Investment community uncomfortable with the risk profile; how can we engage the O&G majors?
 - Lack of demonstrable successful operation of the technology
 - Scale-up
 - Lack of wider understanding of different technologies, and where the risks arise and how they can be controlled





Modal strategies are developing

The Road to Zero

Next steps towards cleaner road transport and delivering our Industrial Strategy



HM Government

Aviation 2050

The future of UK aviation

A consultation

Cm9714 December 2018



maritime 2050 NAVIGATING THE FUTURE

MARITIME 2050 Navigating the Future





- ▶ Continue to support
 - ▶ Support mechanisms?
- ▶ Synthetic fuels
- ▶ Aviation
- ▶ Research





Thank you

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“Powering Ships of the Future”

‘Transport Energy Network’

**Richard Bucknall
University College London**

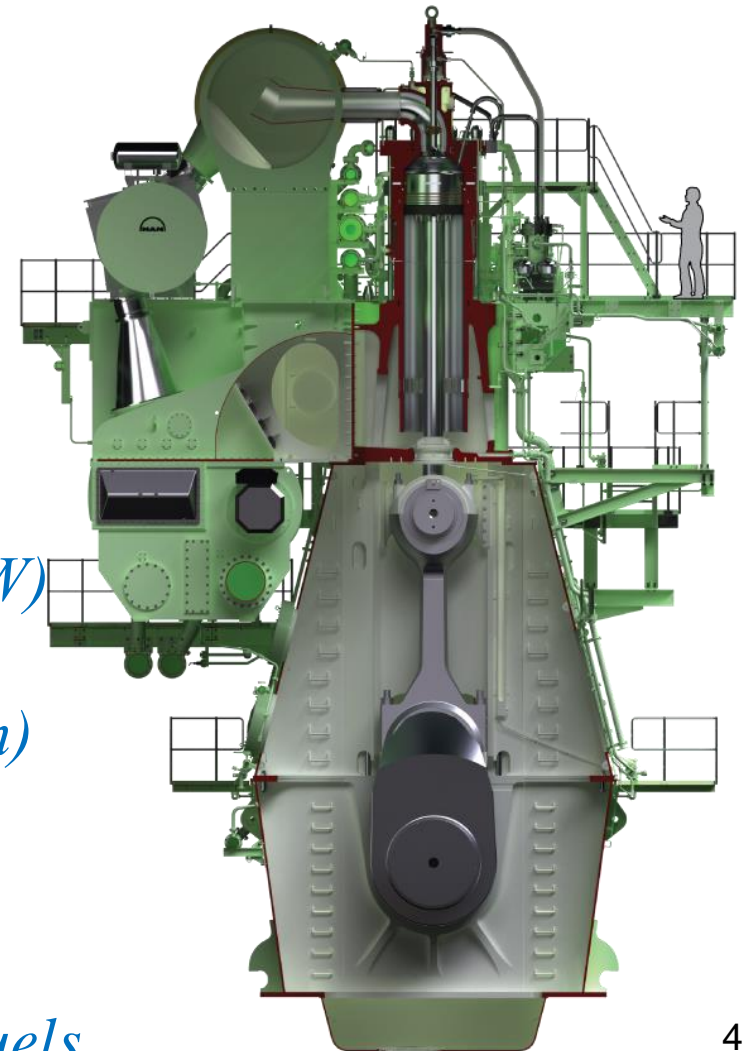
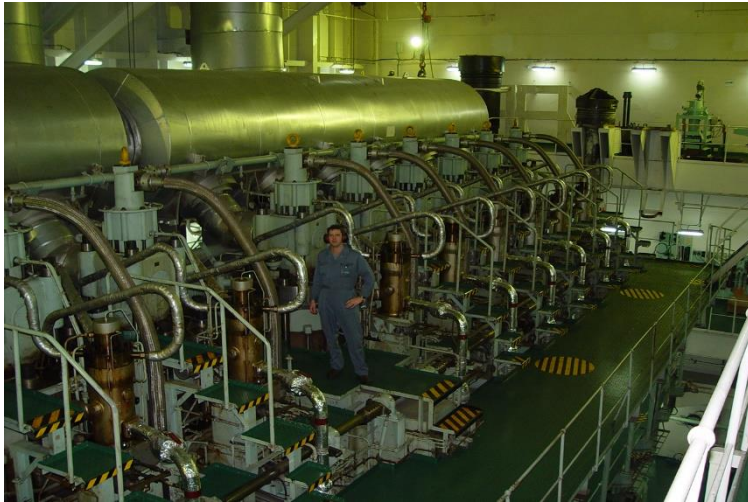
There are different types of ship some big...



...and some smaller...

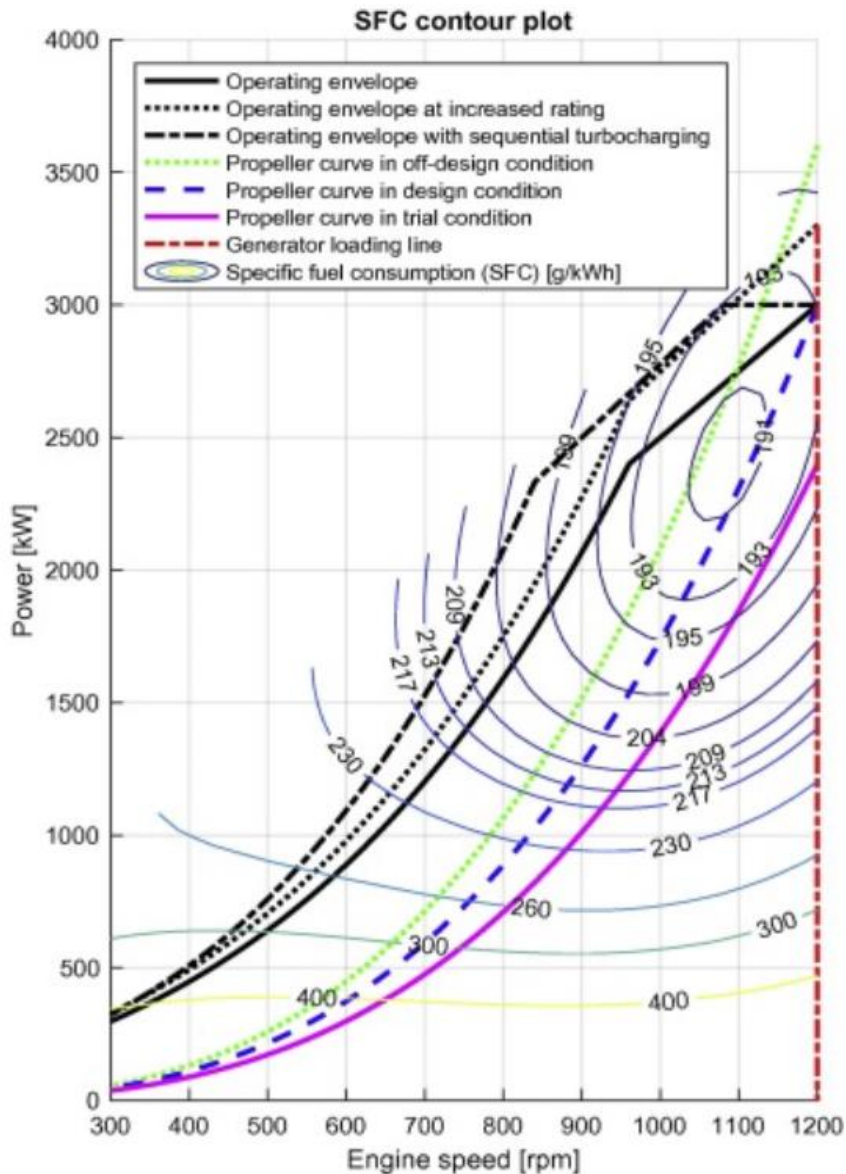


There are about 100,000 ships in the world: Large ships use 2-stroke main engines...



- Match propeller speed ≈ 80 rpm (80MW)*
- Reliable and low maintenance*
- Fuel efficient $\approx 50\%$ to 55% (170g/kWh)*
- EGWHR for electrical power*
- JWWHR for generating fresh water*
- Reversible*
- Use HFO; IFO; MDO; (L)NG; other fuels*

but 4-stroke engines too...



Propulsion engines:

- *mechanical indirect drive*
- *electrical drive*

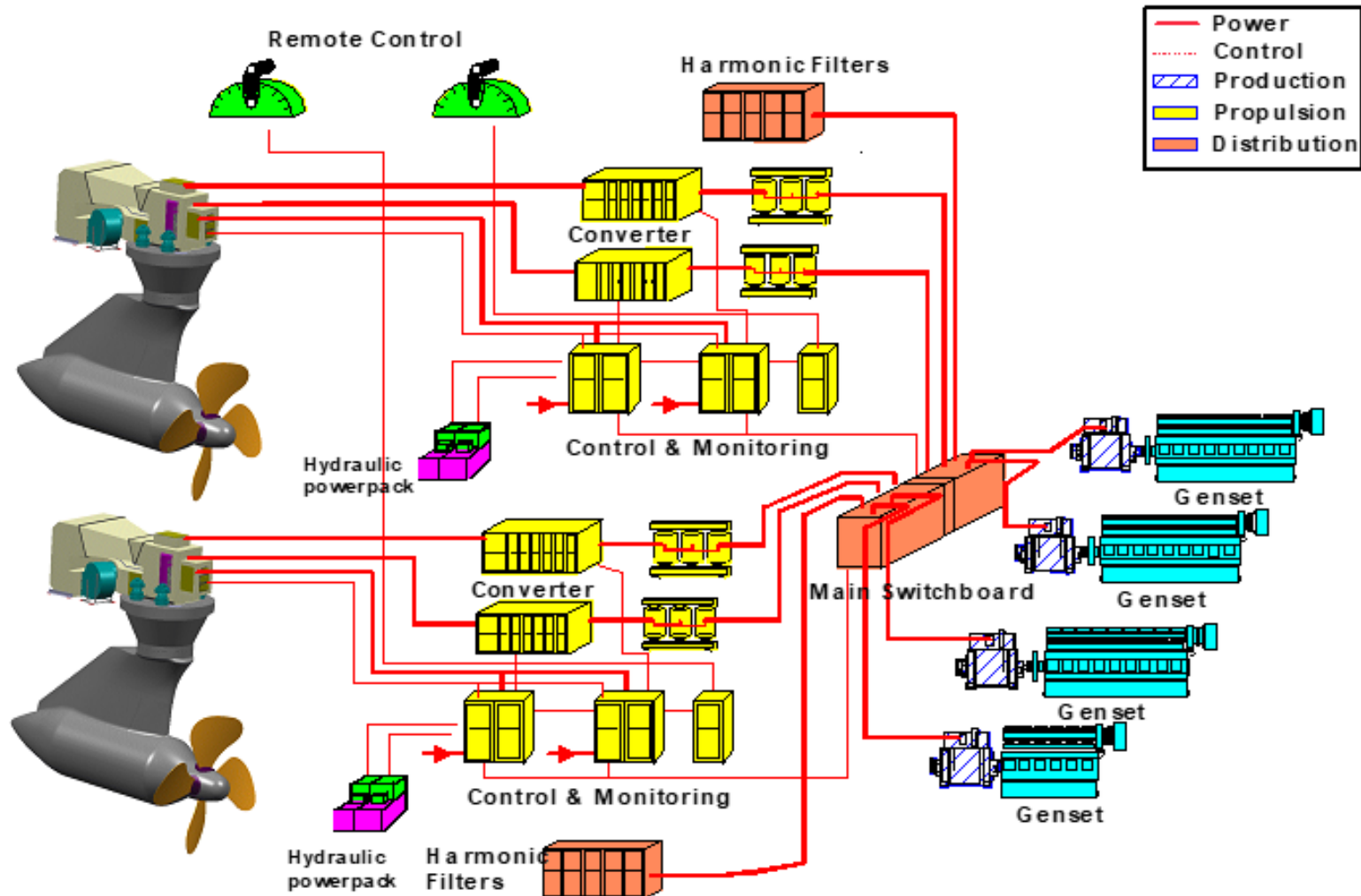
Electrical generation:

- *directly connected*

Fuel:

- *marine diesel oil*
- *(L)NG*

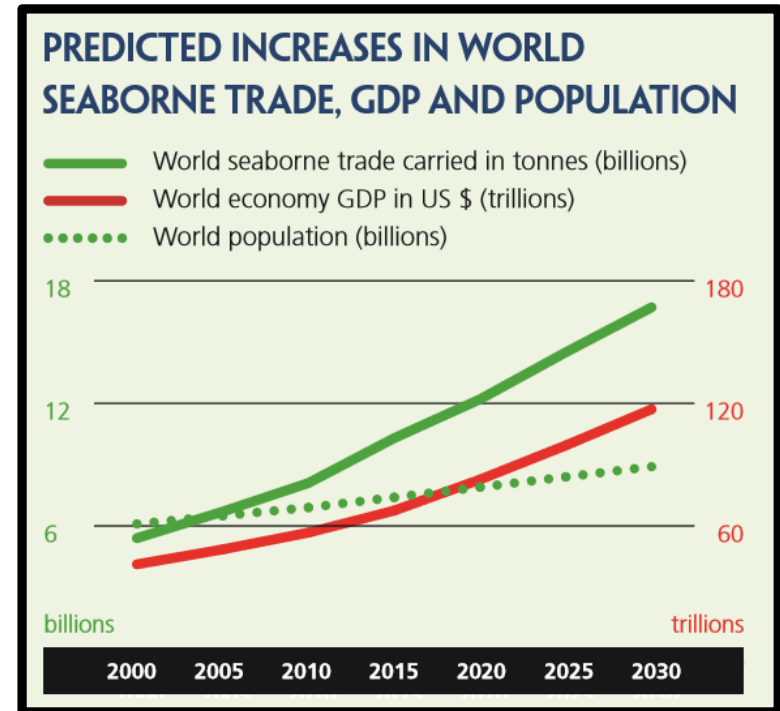
Including in large electrical propulsion plant...



Ships use a variety of fuel oils...

- **MGO (Marine gas oil including LS)** – Distillate fuel
- **MDO (Marine diesel oil)** – Blend of heavy gas oil and very small amounts of black refinery feed stocks having higher viscosity.
- **IFO 180 (Intermediate fuel oil)** Blend of gas oil and heavy fuel oil having a maximum viscosity of 180 Centistokes/50⁰ C.
- **LS 180** – Low-sulphur intermediate fuel oil with a maximum viscosity of 180 Centistokes/50⁰ C
- **HFO (Heavy fuel oil)** – Pure or nearly pure residual oil.

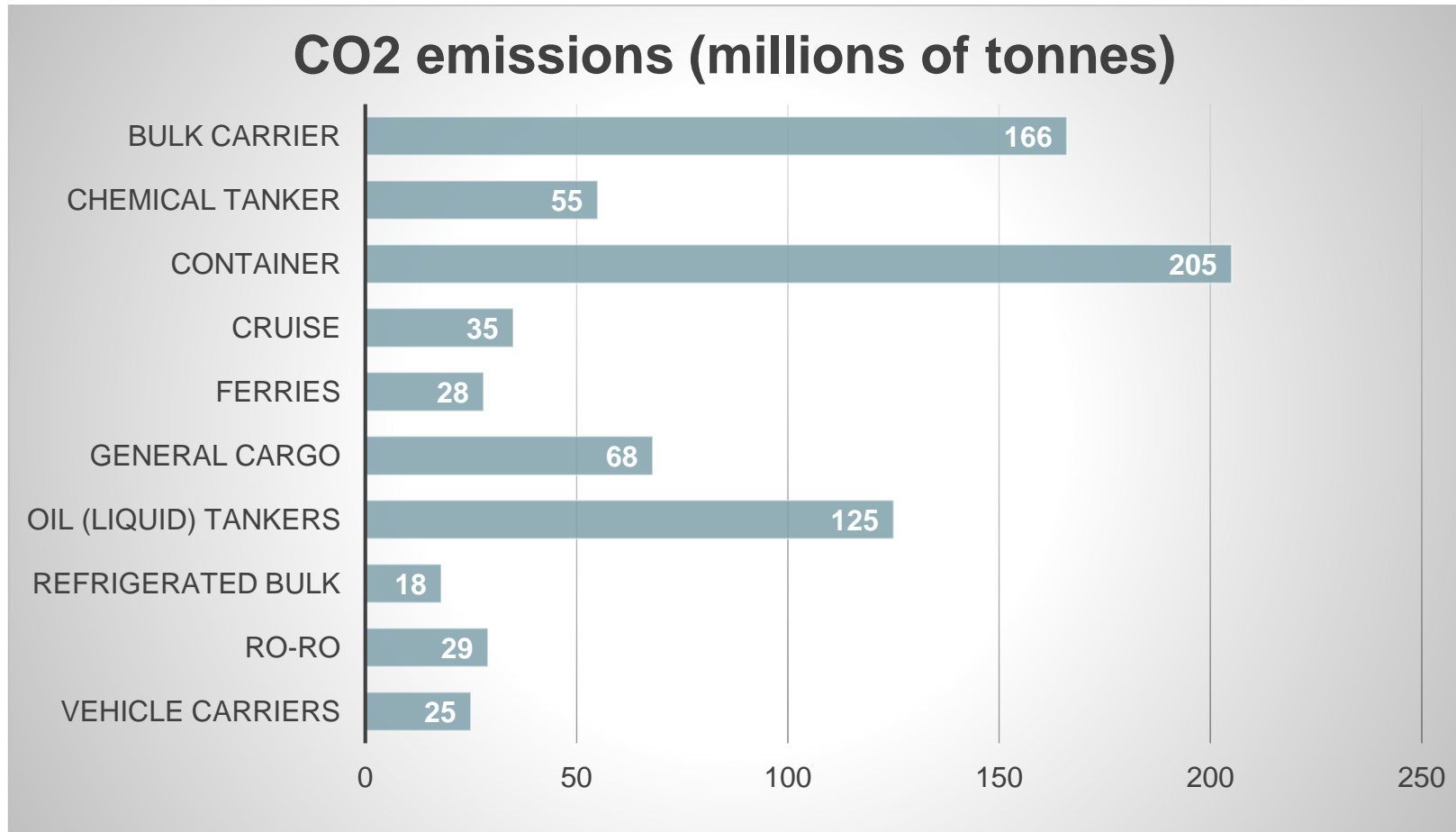
So the problem is GHG...



Source: shipping-world-trade-and-the-reduction-of-co2-emissions. (UNFCCC)

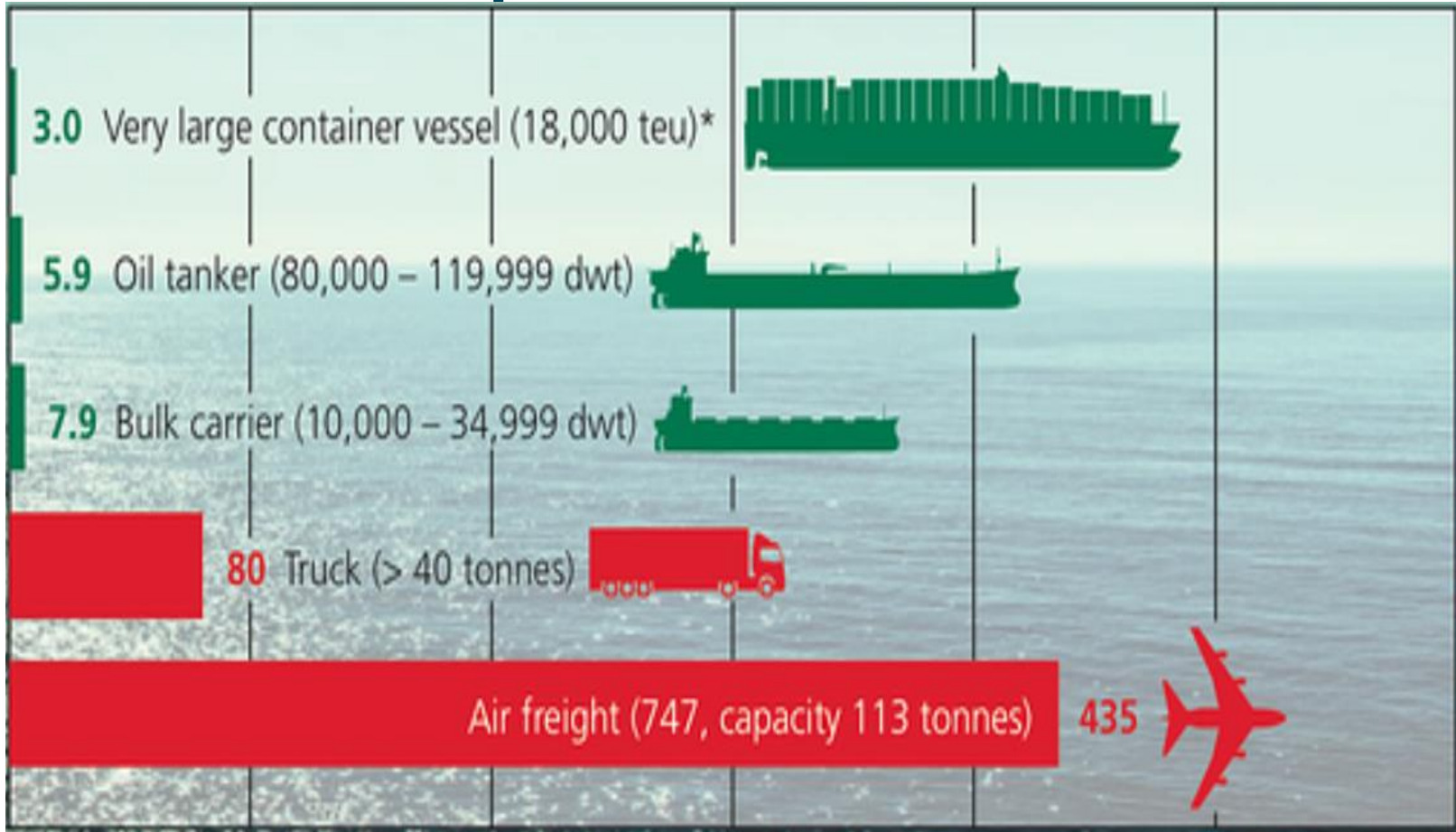
- Transport is the largest sectoral emitter of CO₂
- Global shipping:-
 - Emits ≈ 1 billion tonnes of anthropogenic GHG annually
 - accounts for nearly 2.5% of global emissions
 - emissions potentially increase up to 250% by 2050

From all the different ship types...



Data Source: IMO 3rd GHG Study

...even though ships CO2 emissions are modest in comparison...






Source: IMO 3rd GHG Study

...but there is also human health.

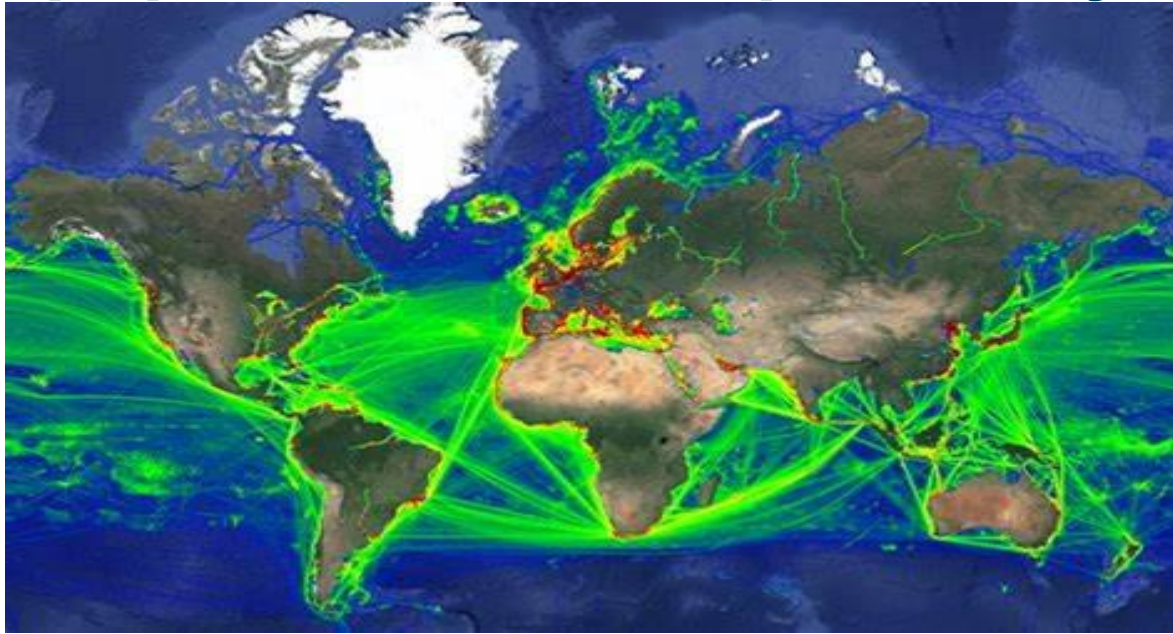
The *Danish Centre for Energy, Environment and Health (CEEH)* found “that European ship emissions were responsible for around 50,000 premature deaths every year”.

...and it isn't just NOx.

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Exhaust Gas Components	Why Bad?	Primary: Engine-Internal Solutions	Secondary: Off-Engine Solutions	Fuel Solutions
Nitrogen Oxides NOx  NO NO ₂	Ground ozone formation Respiratory issues Acid rain	Reduce temperature during the combustion process Exhaust Gas Recirculation (EGR)	Aftertreatment technology (e.g. SCR)	Natural Gas
Sulfur Oxides (SOx) 	Respiratory issues Acid rain	Fuel injection control	Aftertreatment technology (e.g. Scrubbers)	Natural Gas, Low Sulfur Fuels, Bio-Fuels
Particulate Matter (PM) 	Air pollution Respiratory and heart issues	Fuel injection control	Aftertreatment technology (e.g. DPF)	Natural Gas, Low Sulfur Fuels, Bio-Fuels
Hydrocarbons (HC)	Volatile Organic Compounds (VOCs)	Fuel injection control and engine maintenance	Oxidation Catalyst	Natural Gas
Carbon Monoxide (CO)	Toxic Ground ozone formation	Fuel injection control Low load avoidance	Oxidation Catalyst	Natural Gas
Carbon Dioxide (CO₂)	Greenhouse Gas/ Global warming	Various measures reducing total fuel consumption per ton-mile		

Coastal populations are impacted by ships...



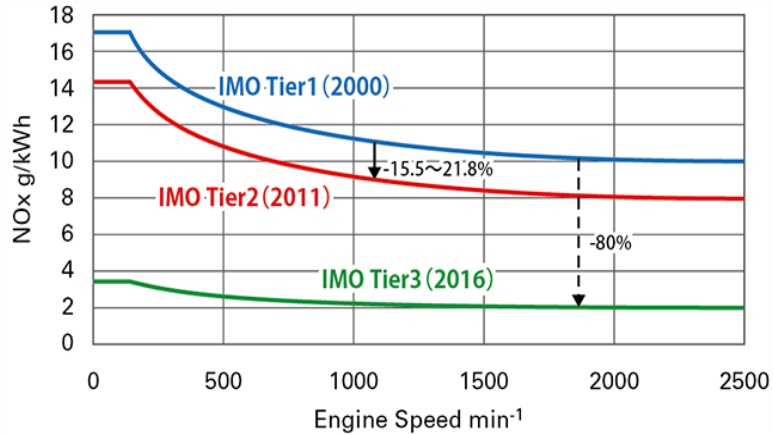
World shipping routes and coastal density

Source: marinetraffic.com

World Coastal populations...

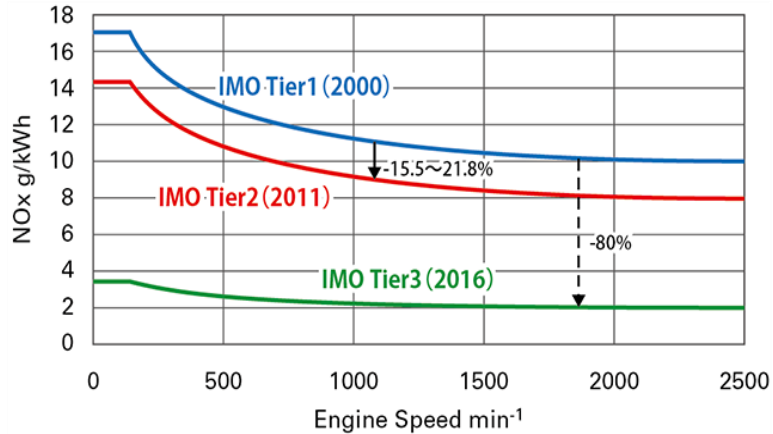
- 75% of mega-cities are by the sea.
- 40% of population lives within 40 km of the sea.
- 80% of population lives within 60 km of the sea.

So the IMO regulated...



First came NOx...

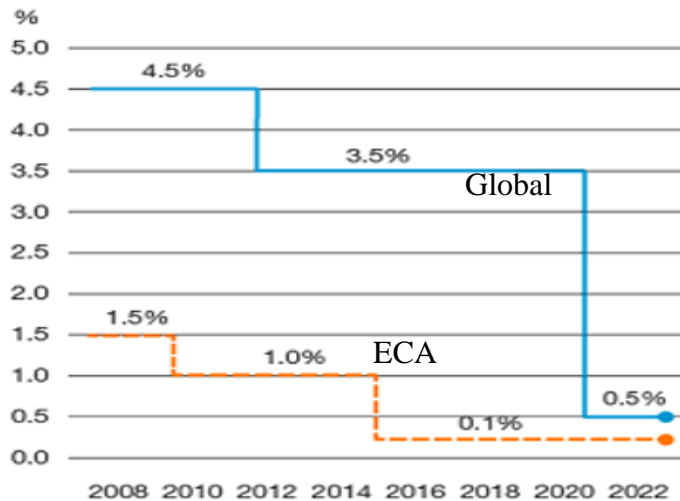
So the IMO regulated...



First came NOx...



Then came SOx...

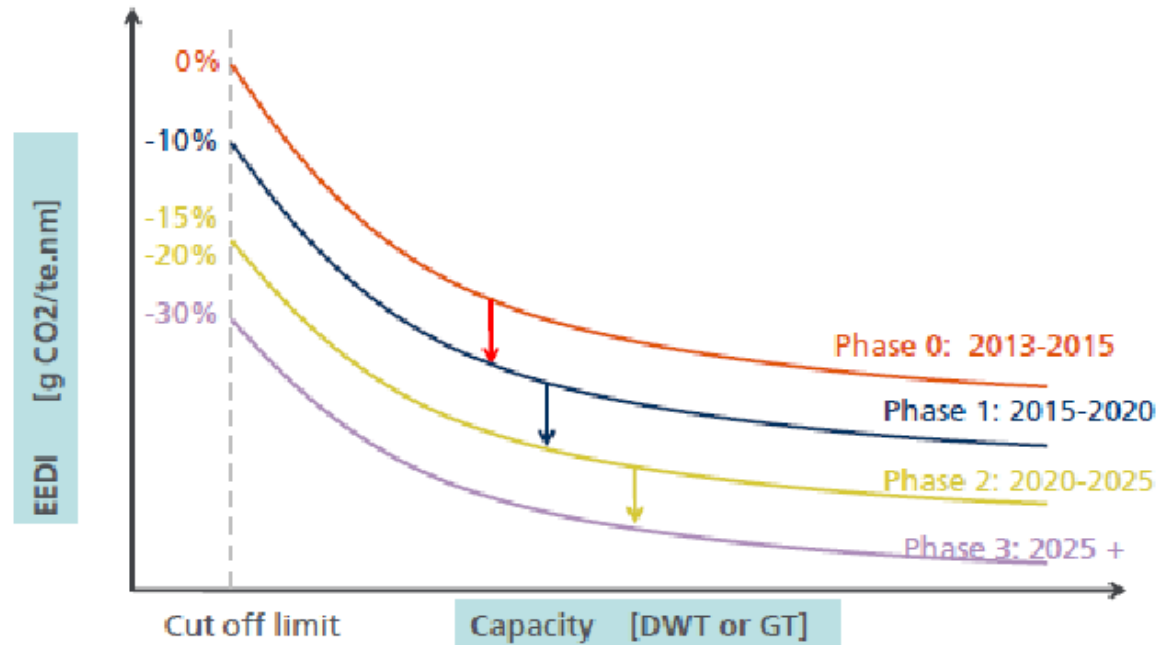


But also came CO₂ via a complicated calculation...

$$EEDI_{simplified} = \frac{\left(\prod_{j=1}^M f_j\right) \left(\sum_{i=1}^{nME} P_{ME(i)} \cdot C_{FME(i)} \cdot SFC_{ME(i)}\right) + (P_{AE} \cdot C_{FAE} \cdot SFC_{AE})}{f_i \cdot Capacity \cdot V_{ref} \cdot f_w}$$

C_{FME}	Non-dimensional conversion factor between fuel consumption measured in grammes and CO ₂ emission also measured in grammes
FC_{ME}	The certified specific fuel consumption, measured in g/kWh, of the main engines.
P_{AE}	The required auxiliary engine power to supply normal maximum sea load including necessary power for propulsion machinery/systems and accommodation.
C_{FAE}	Non-dimensional conversion factor between fuel consumption measured in g and CO ₂ emission also measured in g based Where:
f_j	Correction factor to account for ship specific design elements.
P_{ME}	75% of the rated installed power (MCR) for each main engine after deducting any installed shaft generator on carbon content for the auxiliary engines.
SFC_{AE}	The certified specific fuel consumption, measured in g/kWh, of the auxiliary engines.
f_i	The capacity factor for any technical/regulatory limitation on capacity.
Capacity	The amount of cargo being transported.
V_{ref}	The ship speed, measured in knots, on deep water in the condition corresponding to the Capacity.
f_w	A non-dimensional coefficient indicating the decrease of speed in representative sea conditions of wave height, wave frequency and wind speed.

So let's make it easier to understand...



$$EEDI_{simplified} = \frac{Engine\ Power \times SFC \times Cf}{Cargo \times Speed} \quad \frac{grammes\ of\ CO_2}{cargo_{tonne} \times mile}$$

But soon it was realised EEDI wasn't enough...

$$EEDI = \frac{(\prod_{j=1}^M f_j)}{(\sum_{i=1}^n ME_i)}$$



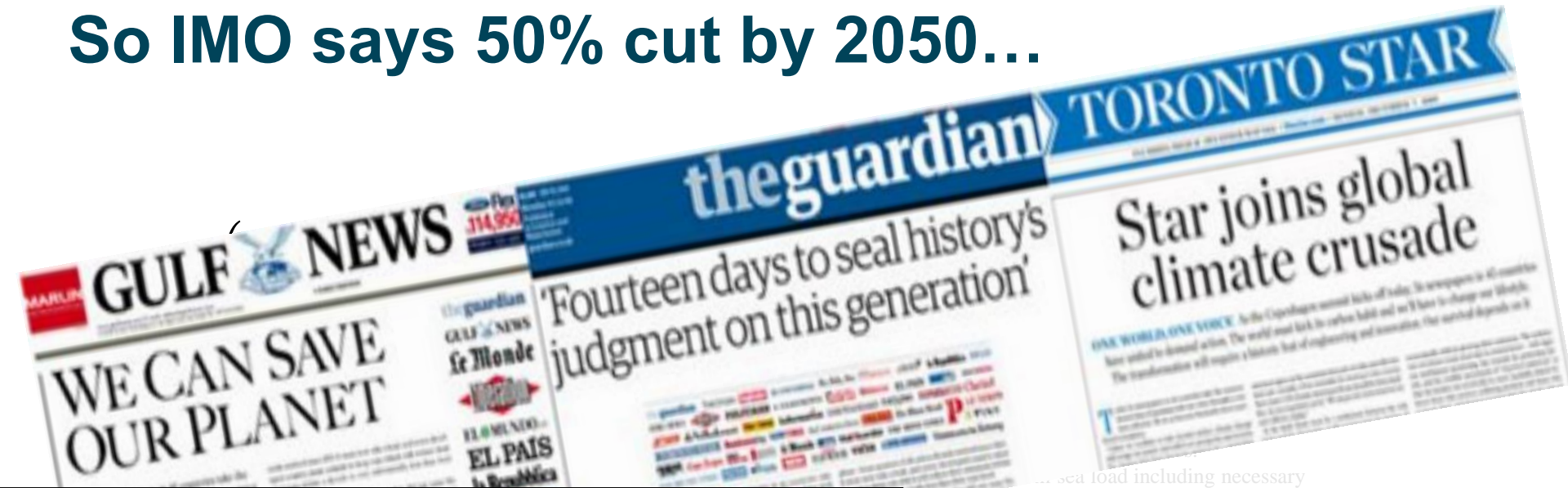
f_j
 P_A
 SF
 f_i
 Cap
 V_{ref}
 f_w

...water in the condition corresponding to the Capacity.
 ...indicating the decrease of speed in representative sea conditions of wave height, wave frequency and wind speed.

...carbon content for the auxiliary engines.

$$EEDI_{simplified} = \frac{Engine\ Power \times SFC \times Cf}{Cargo \times Speed} \quad \frac{grammes\ of\ CO_2}{cargo_{tonne} \times mile}$$

So IMO says 50% cut by 2050...



**INTERNATIONAL
MARITIME
ORGANIZATION**

... sea load including necessary
consumption measured in g and CO₂ emission
sign elements.
... main engine after deducting any installed shaft
... ed in g/kWh, of the auxiliary engines.

GHG emissions from international shipping to peak and decline

to peak GHG emissions from international shipping as soon as possible and to reduce the total annual GHG emissions by at least **50%** by 2050 compared to 2008 whilst pursuing efforts towards phasing them out as called for in the Vision as a point on a pathway of CO₂ emissions reduction consistent with the Paris Agreement temperature goals.

So IMO says 50% cut by 2050...

News story

Ambitious targets to cut shipping emissions

Clean maritime plan setting maritime zero-emission travel strategy released.

Published 11 July 2019

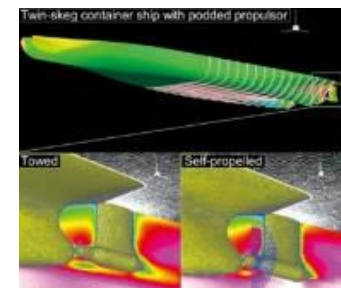
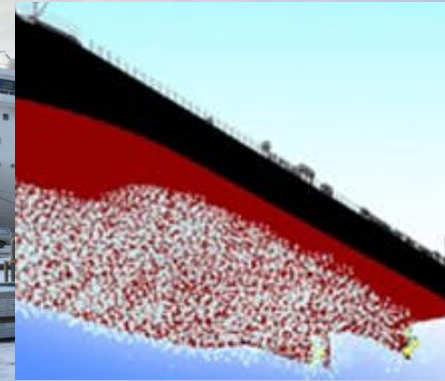
From: [Department for Transport](#) and [Nusrat Ghani MP](#)



to peak GHG
to reduce the
to 2008 whilst
Vision as a point on a pathway of CO₂ emissions reduction consistent with the Paris Agreement temperature goals.

ne
ossible and
compared
for in the

Tough to do... but lots of ideas to improve efficiency and reduce emissions...



And alternative fuels too... such as LNG



And some new propulsion systems (hybrid)...



Which need large batteries...



Of course LNG was not too hard a step to make...

- Experience of LNGCs since 1960's
- Used in boilers and dual-fuel engines

Benefits...

- $\approx 25\%$ reduction in CO_2
- No SO_x emissions
- Low NO_x due to lean burn
- Low particulates
- Available across the world
- Cheap

But it won't achieve a 50% cut... So what else...????

Low carbon fuels that must be...

- Compatible with the diesel engine
- (Reasonable) Cost
- Wide availability
- High energy density (volume)
- Bunkering (*and de-bunkering*)
- Storage systems onboard
- Onboard fuel processing plant
- Compliant (environmental, toxicity, fire, etc.)
- Safe (SOLAS, etc)

...Perhaps methanol?

- Positives...
 - Compatible with ICEs and fuel cells
 - It is available as biofuel
 - It can be synthesized from and CO_2 and Hydrogen
 - Liquid fuel = more simpler storage
 - Experience of methanol handling at sea
- Negatives...
 - Low energy content of 19.7 MJ/kg
 - Methanol is hygroscopic
 - Formation of acidic products during combustion potential cause of damage to valves
 - Some health impact

Methanol ships



... or perhaps Hydrogen?

- Positives...
 - Renewables to produce electrolysed hydrogen to be utilised in fuel cells or ICEs
 - Offers the best energy-to-weight storage ratio of all fuels
 - Potential fuel for fuel cells and ICEs
 - Only emission is (potentially) water
- Negatives...
 - Difficult and costly to produce, transport, and store.
 - Compressed hydrogen has a very low energy density by volume
 - Liquid hydrogen requires cryogenic storage at very low temperatures (-253°C or 20K) and is costly.

Hydrogen ships



...or perhaps ammonia

- Positives...
 - No carbon atoms
 - Previously used as a fuel
 - Use in ICEs and potentially fuel cells
 - Experience at sea
- Negatives...
 - Gas fuel with potential storage problems
 - Corrosive and toxic
 - Low energy content at 22.5 MJ/kg

Ammonia ships



...or perhaps bio-fuels

- Positives...
 - Marine fuel supply is already contaminated by first-generation biofuels; carefully managed on board ships.
 - Biofuels are potential alternatives to conventional fuels.
 - Synthetic fuels based on higher alcohols and new types of algae and other microorganisms appear attractive.
- Negatives...
 - Volumes (supply) in competing markets
 - Storage and handling of these fuels, and their impact on health, safety and the environment.

Biofuels



Or maybe battery ships?



Zemship,
96 kW PEMFC with battery



Viking Lady,
320 kW MCFC with DE and battery



Mariella,
30 kW HT-PEMFC with DE



Forester, 2009-2017 (phase1), 2017-2022 (phase2)
100 kW SOFC with DE and battery

We just don't know...but possibly autonomous too... (ref Vara Birkeland)



Thanks for listening.



Various Reports from
EPSRC funded projects
etc.

Media Centre / Press Releases / News: New UK centre for maritime innovation and technology established



News: New UK centre for maritime innovation and technology established

Press Releases Published: 11th July 2019

<https://marri-uk.org/About-Us>