IRENA INNOVATION WEEK 2025

Infrastructure for Sustainable Fuels

Shipping and Aviation

Organised in partnership with

FCA Future Cleantech Architects

13 June 2025 | 11:00-12:30

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Scene Setting

Peter Schniering

Co-founder and CEO
Future Cleantech Architects

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Shipping in a Nutshell

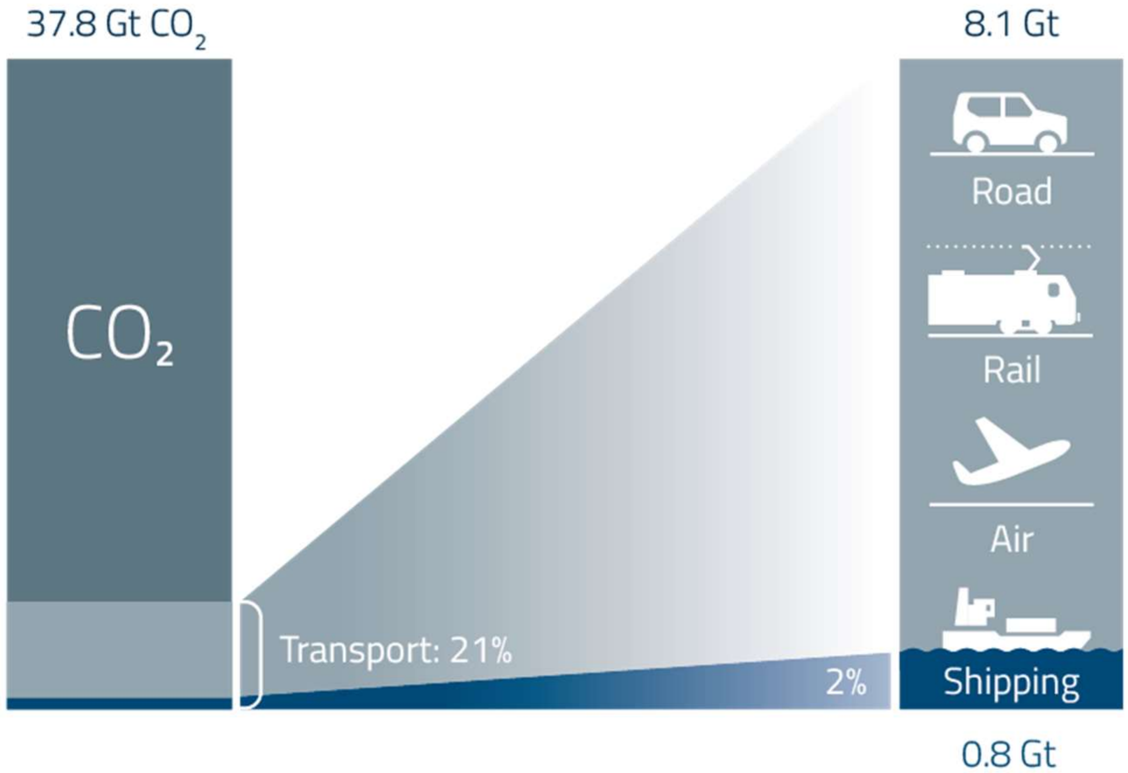
fcarchitects.org

What percentage of international shipping cargo by weight is used for transportation of fossil fuels?

1. 4%
2. 14%
3. 40%

How big is the problem?

Energy-related CO_2 emissions of the shipping sector.



Source: IEA, 2024

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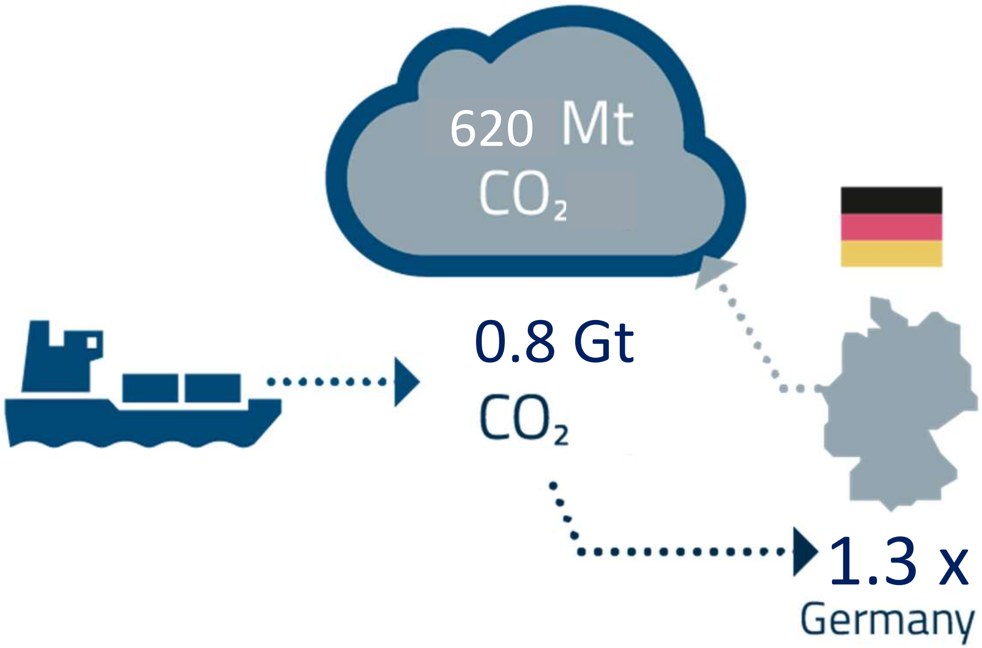
If shipping were a country, its emissions would be 1.3x those of Germany



Source: IEA, 2024

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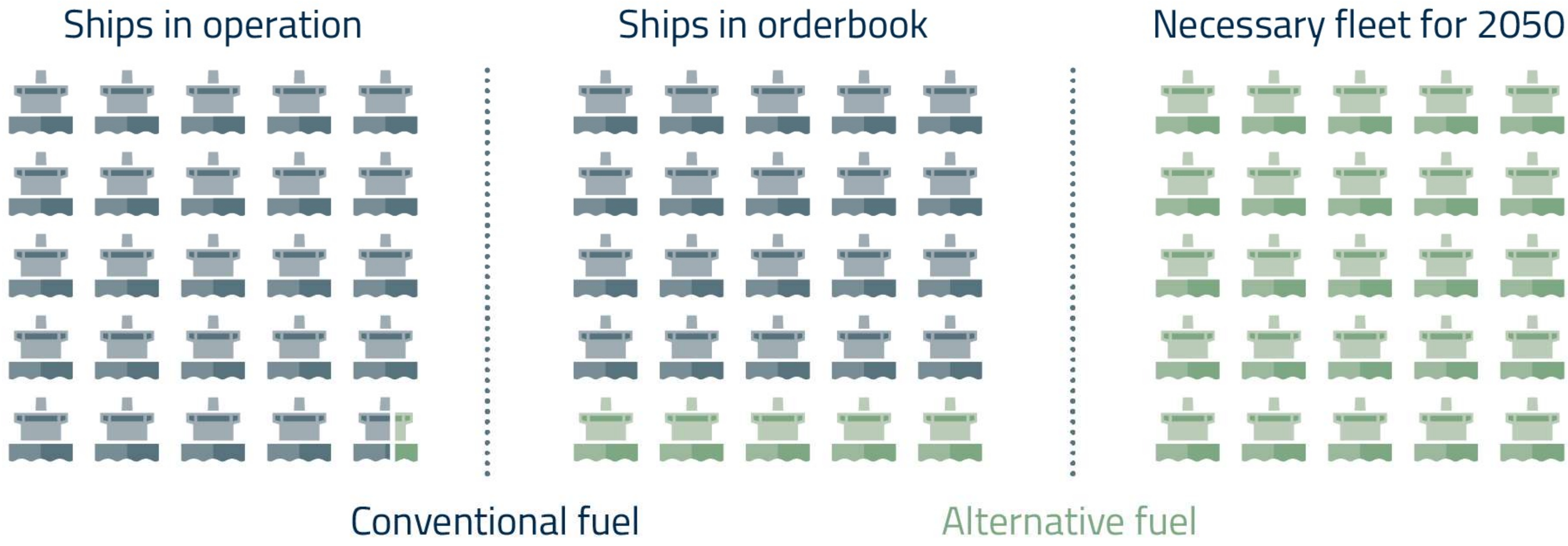
What does the future look like for shipping now? And how it should look like?



Sources: Schafer et al (2018), ICCT (2020), IATA (2022), MPP (2022), Sustainable Aero Lab (2023), Aviation Impact Accelerator (2024)

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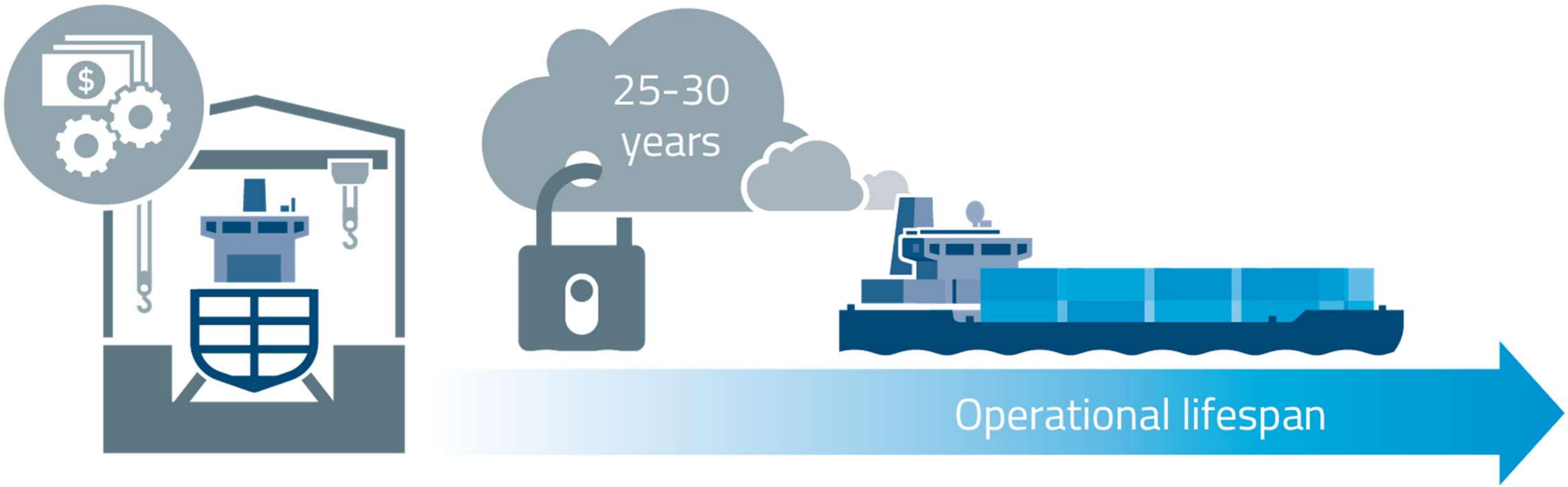
Are we running out of time to transition fleets to sustainable shipping fuels and infrastructure?



Sources: ITF (2021,) ICCT (2020)

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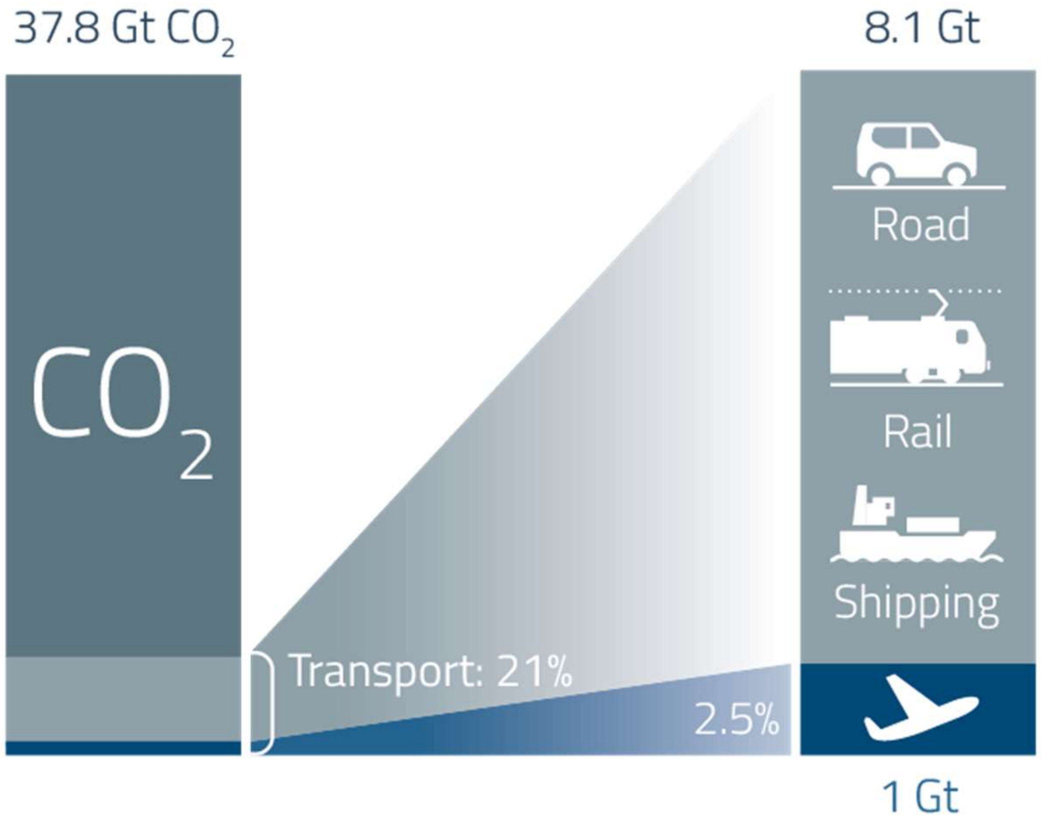
Aviation in a Nutshell
fcarchitects.org

What percentage of the world's population has never flown in an airplane?

1. 8%
2. 48%
3. 80%

How big is the problem?

Energy-related CO_2 emissions of the aviation sector.



Source: IEA, 2024

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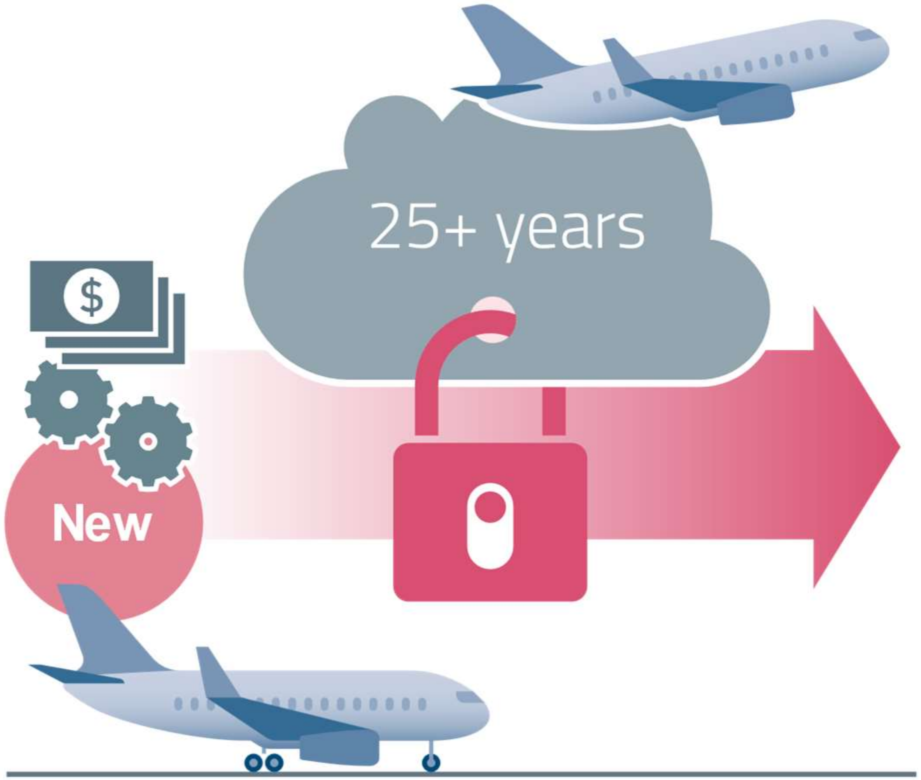
Are we running out of time to transition to sustainable aviation, including infrastructure?



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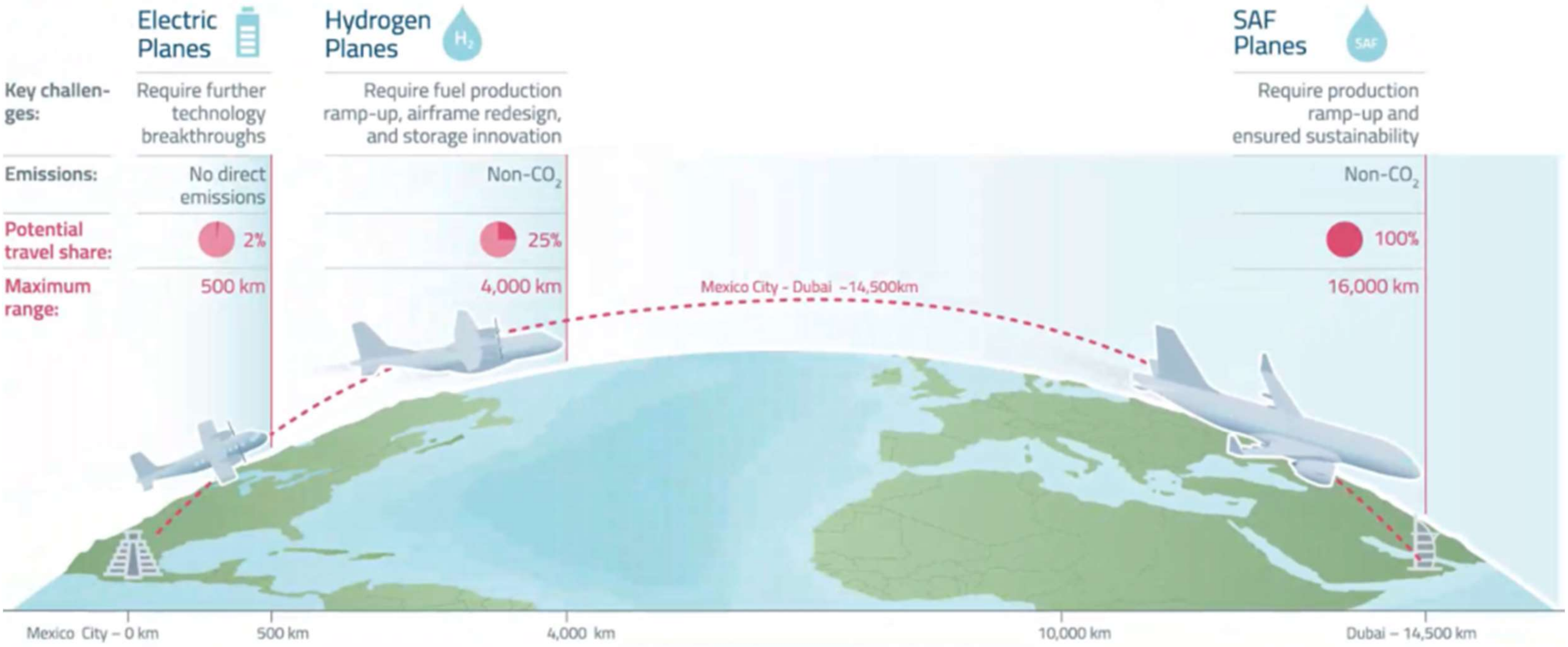
How can we reduce the emissions of this sector?

How can we reduce the emissions of this sector?



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Scene Setting

Arno van den Bos

Analyst - Green Hydrogen Energy and Power-to-X
IRENA

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Main strategies for decarbonising maritime shipping

Source: IRENA 2024 - Decarbonising hard-to-abate sectors with renewables: Perspectives for the G7

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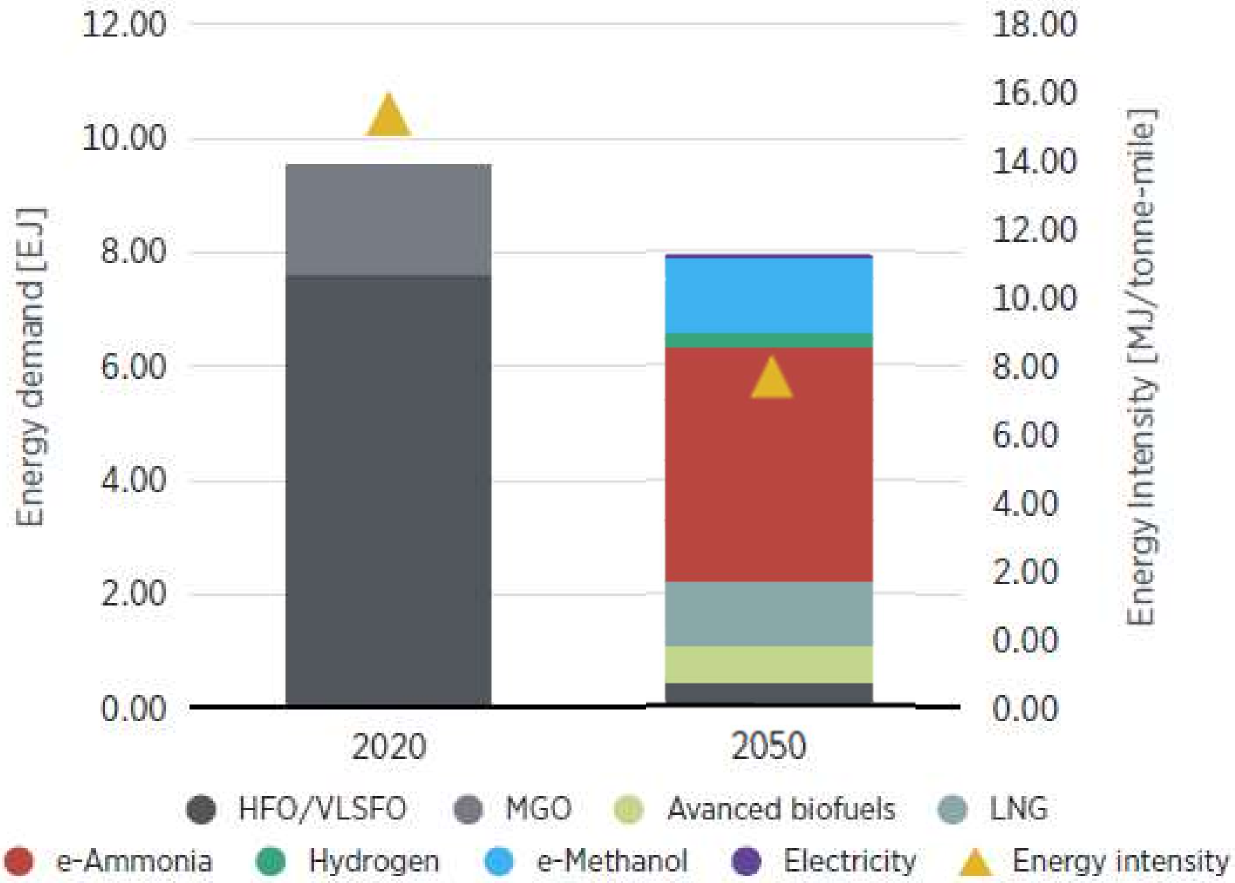
Multiple renewable-based fuels required in 2050

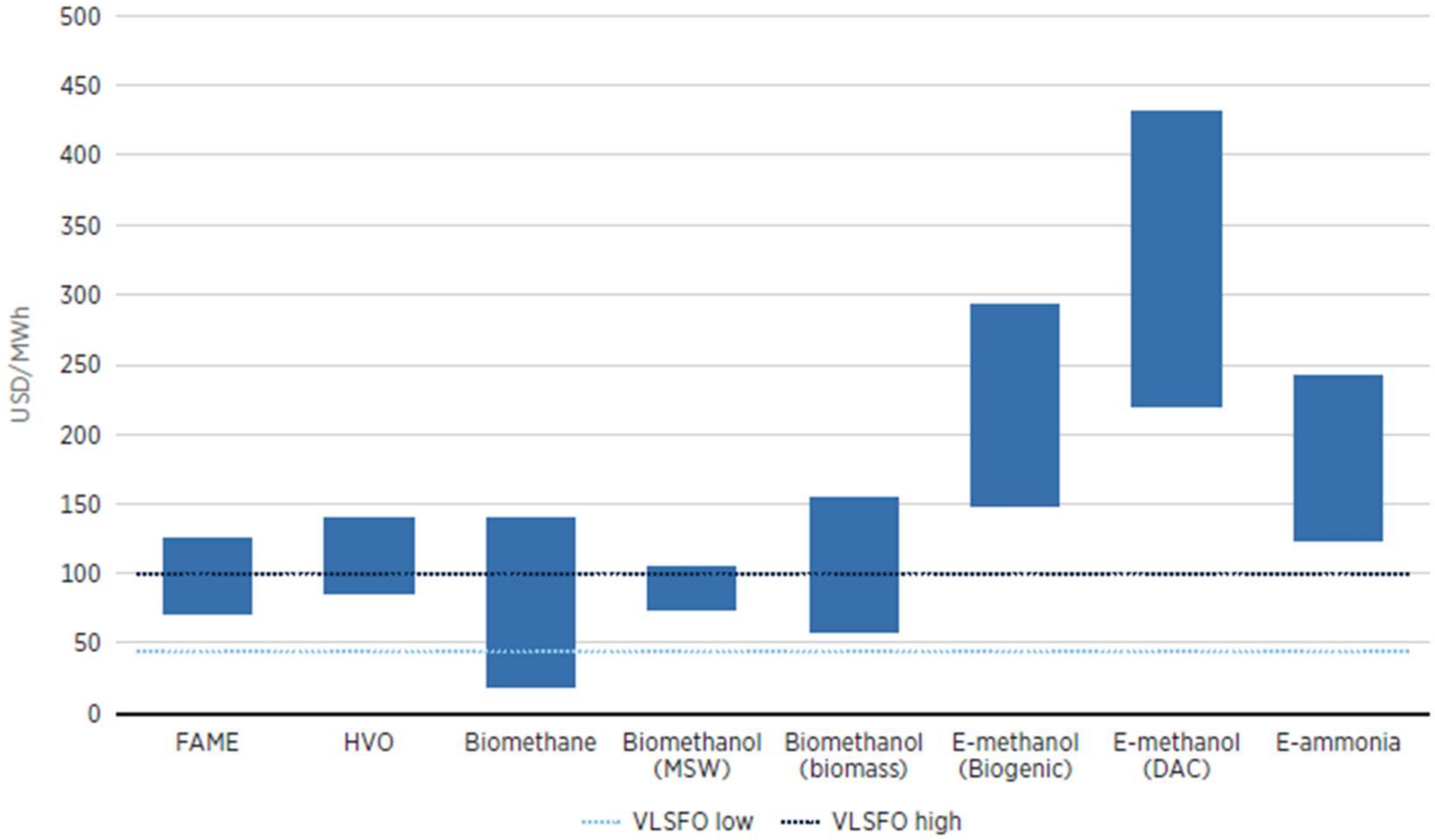
2050 fuel mix for shipping sector (IRENA 1.5C scenario)



Source: IRENA World Energy Transition Outlook 1.5 C scenario

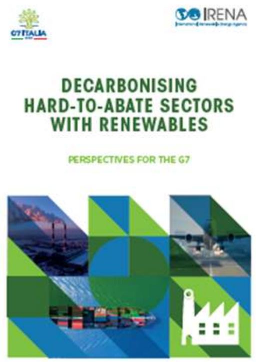
- In **2050**, maritime transport will require **46 Mton of green hydrogen** for use as synthetic fuels
- ~ 50% for **ammonia**, and ~ 20% for **methanol**
- **Methanol** requires sustainable sources of carbon.
- **Ammonia** requires development of engines and solving safety issues (toxicity)

Cost comparison of renewable marine fuels



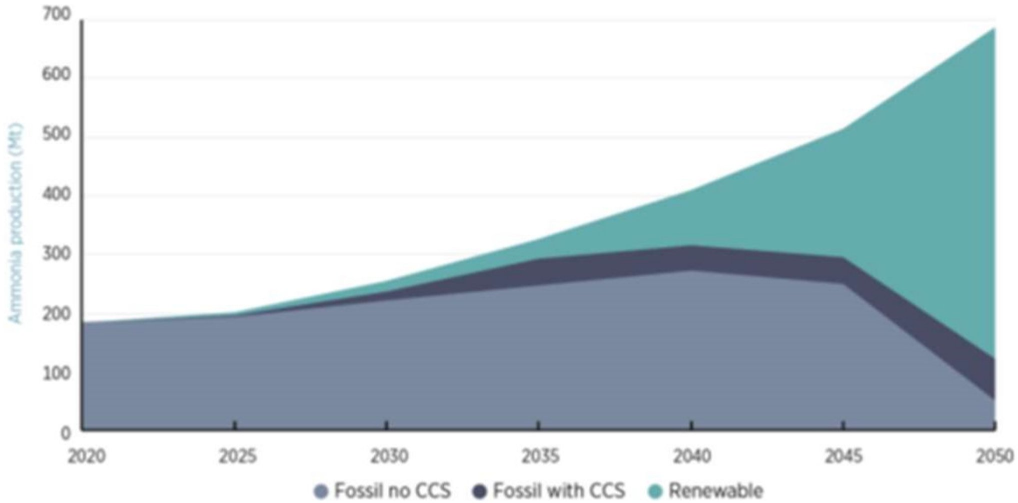
Source: (IRENA, 2018, 2021a; IRENA and AEA, 2022; IRENA and Methanol Institute, 2021; Ship & Bunker, 2024).

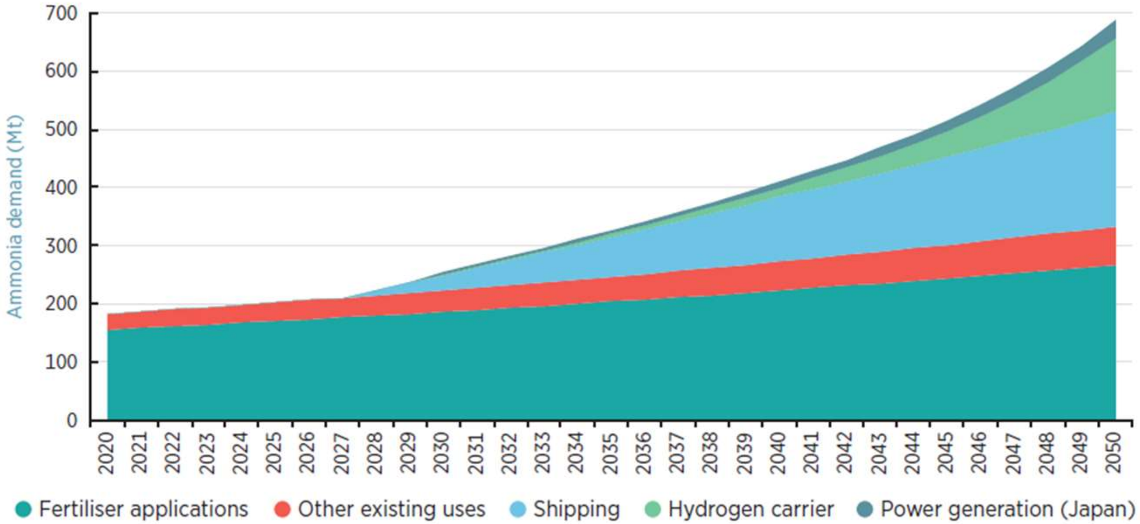
Note: Renewable fuel costs are production costs. VLSFO shows the highest and lowest spot prices registered between March 2021 and March 2024.



Ammonia as early market opportunity for green hydrogen use

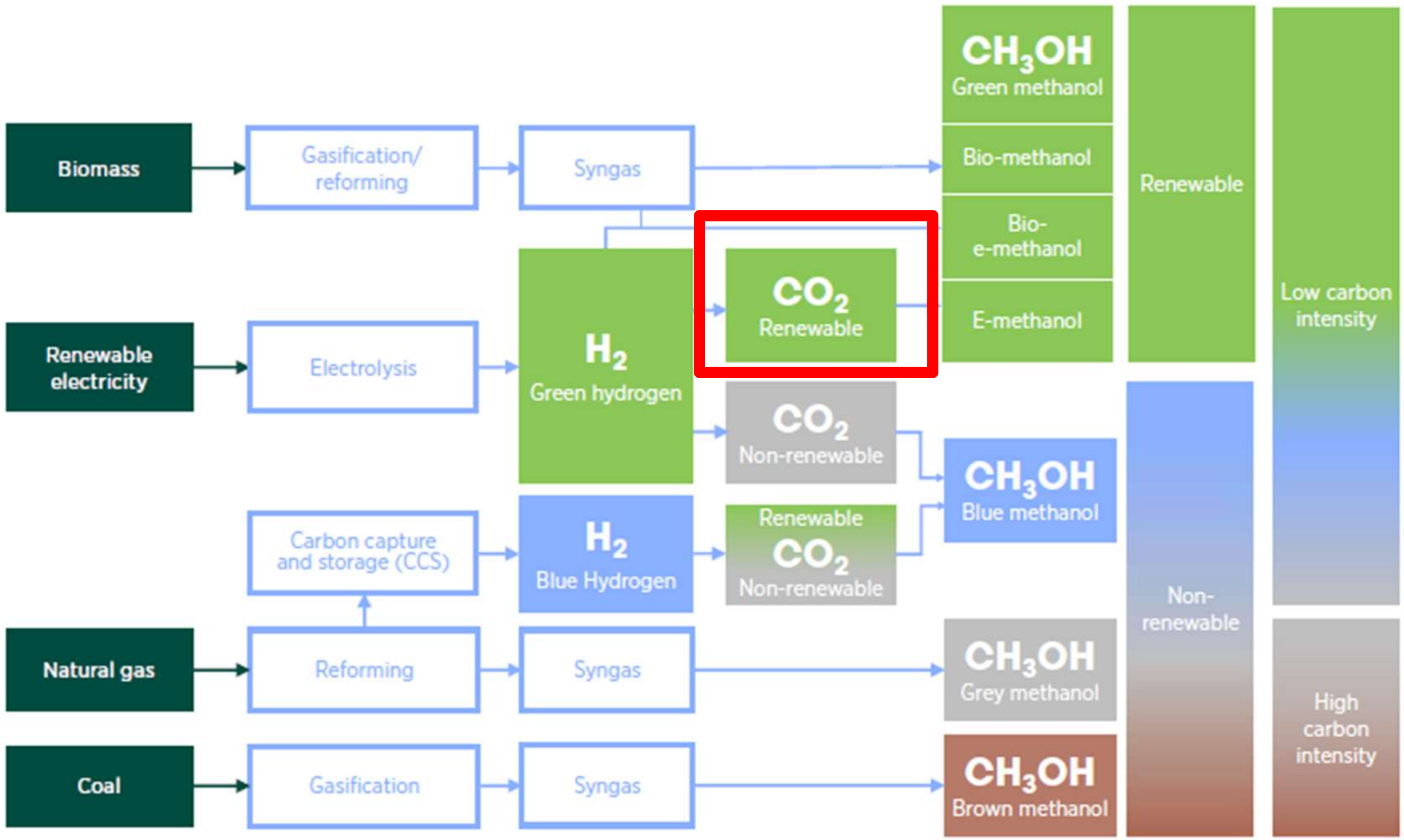
Expected ammonia production and demand capacity up to 2050 for the 1.5° C scenario





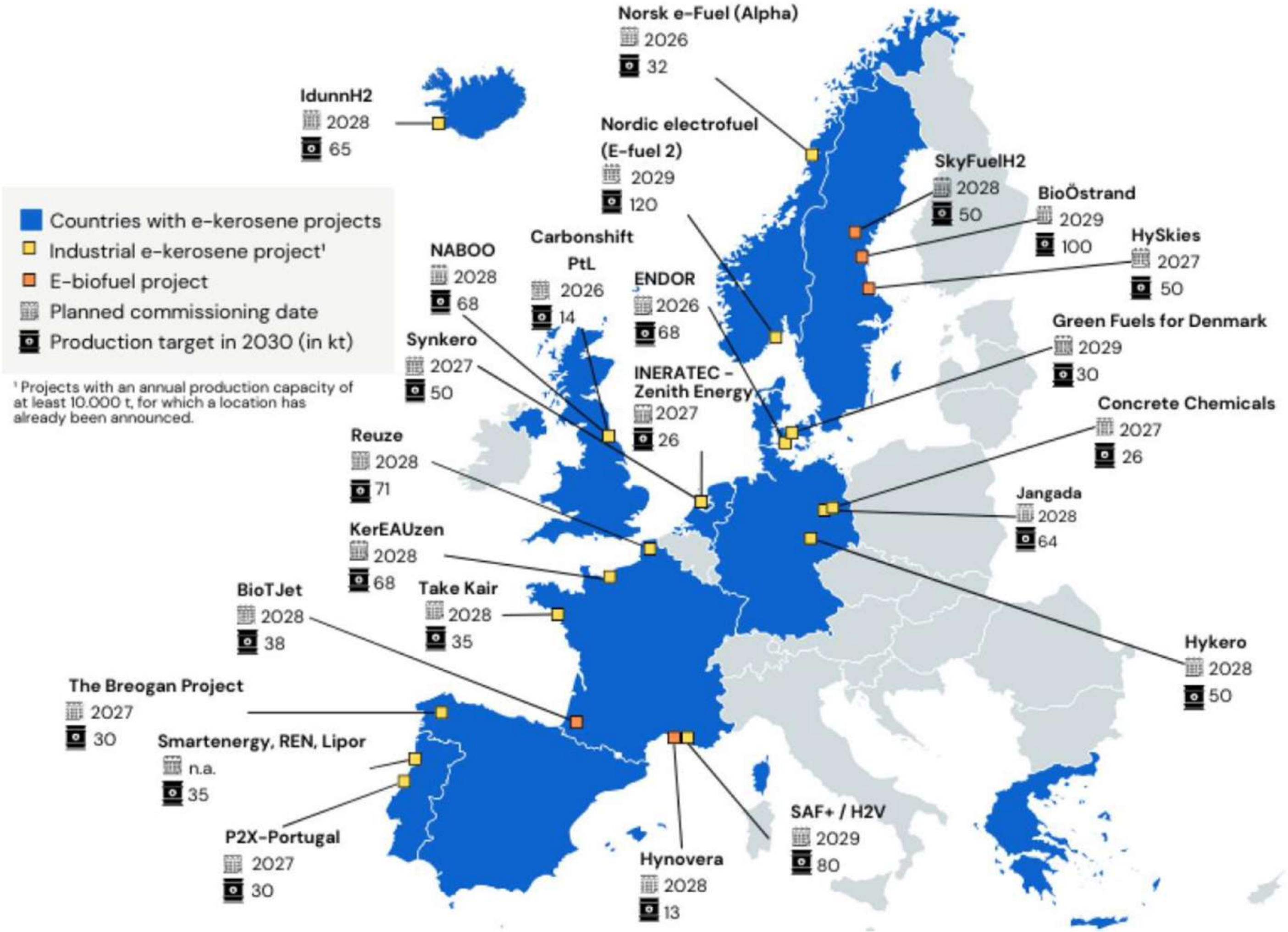
- Developers have announced a pipeline of 180 Mton of annual low-carbon ammonia production plants that could be built by 2035 (BNEF 2024)
- This is equivalent to today's ammonia production capacity

Methanol production pathways



Source: IRENA, 2021. Innovation Outlook – Renewable Methanol. Available from: https://www.irena.org/publications/2021/Jan/Innovation-Outlook-Renewable-Methanol

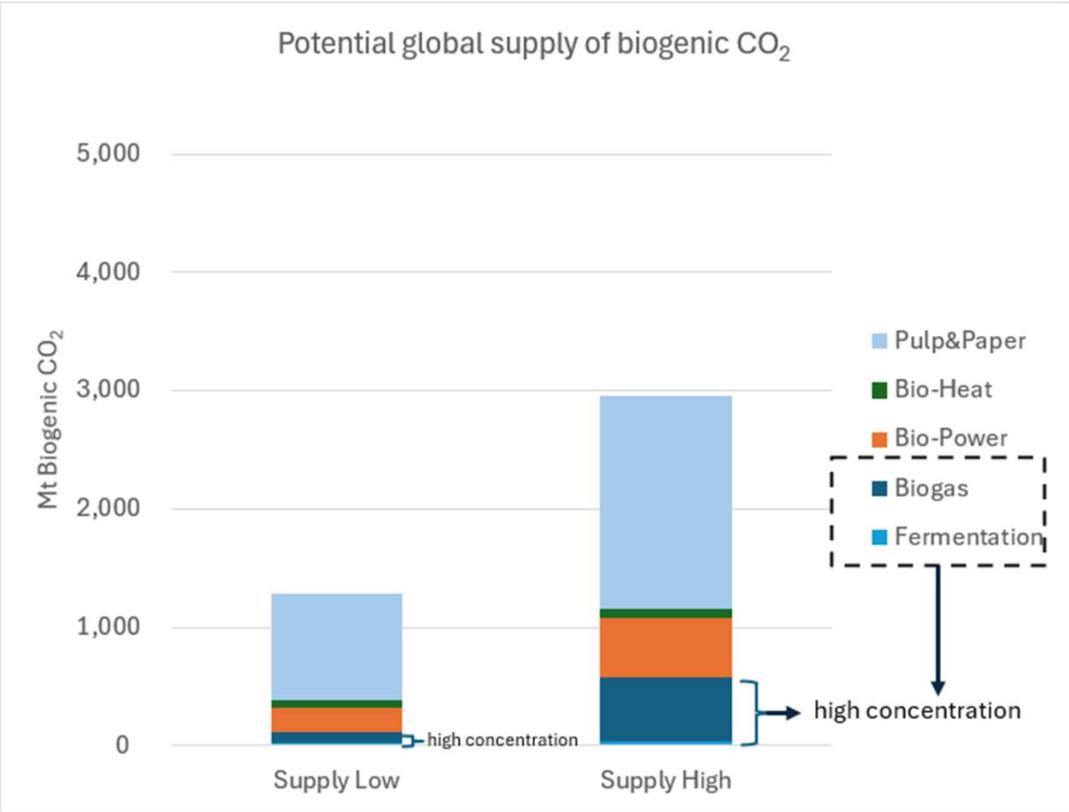
Renewable sources of CO_2

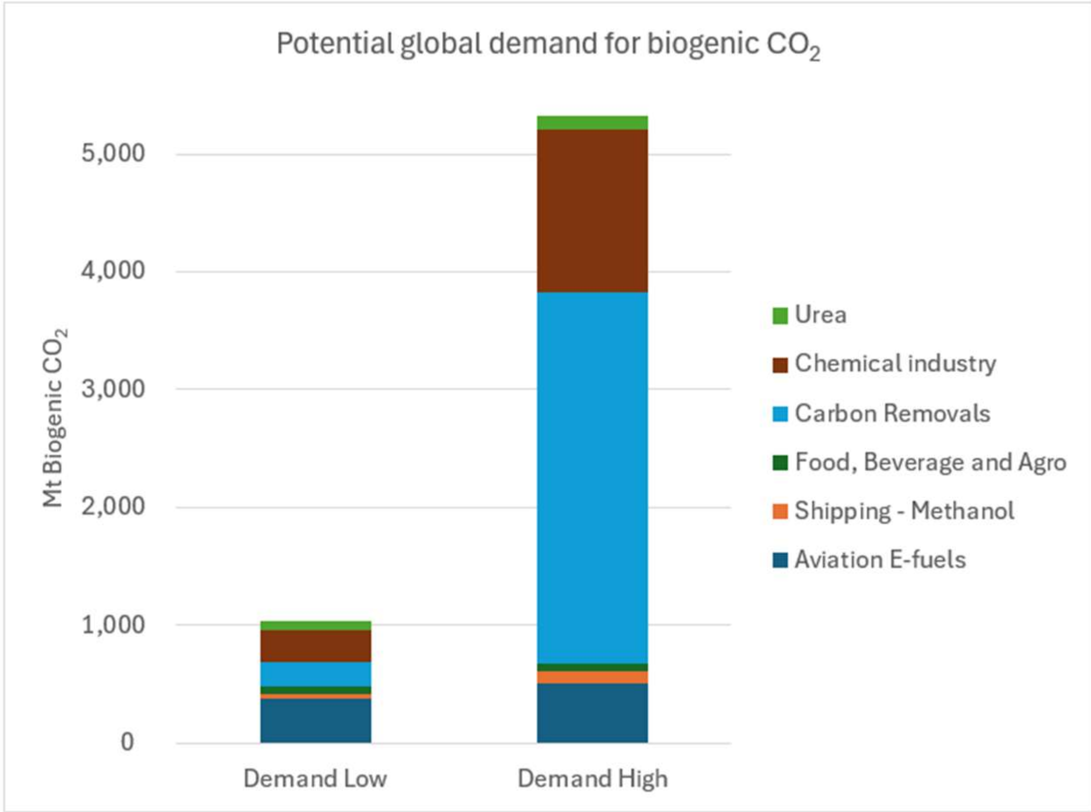


ALL of these 45 e-SAF projects in Europe are proposing to use biogenic CO_2.
Zero DAC
Zero fossil CO2

Source: T&E 2024

Biogenic carbon availability is not guaranteed and requires a strategy





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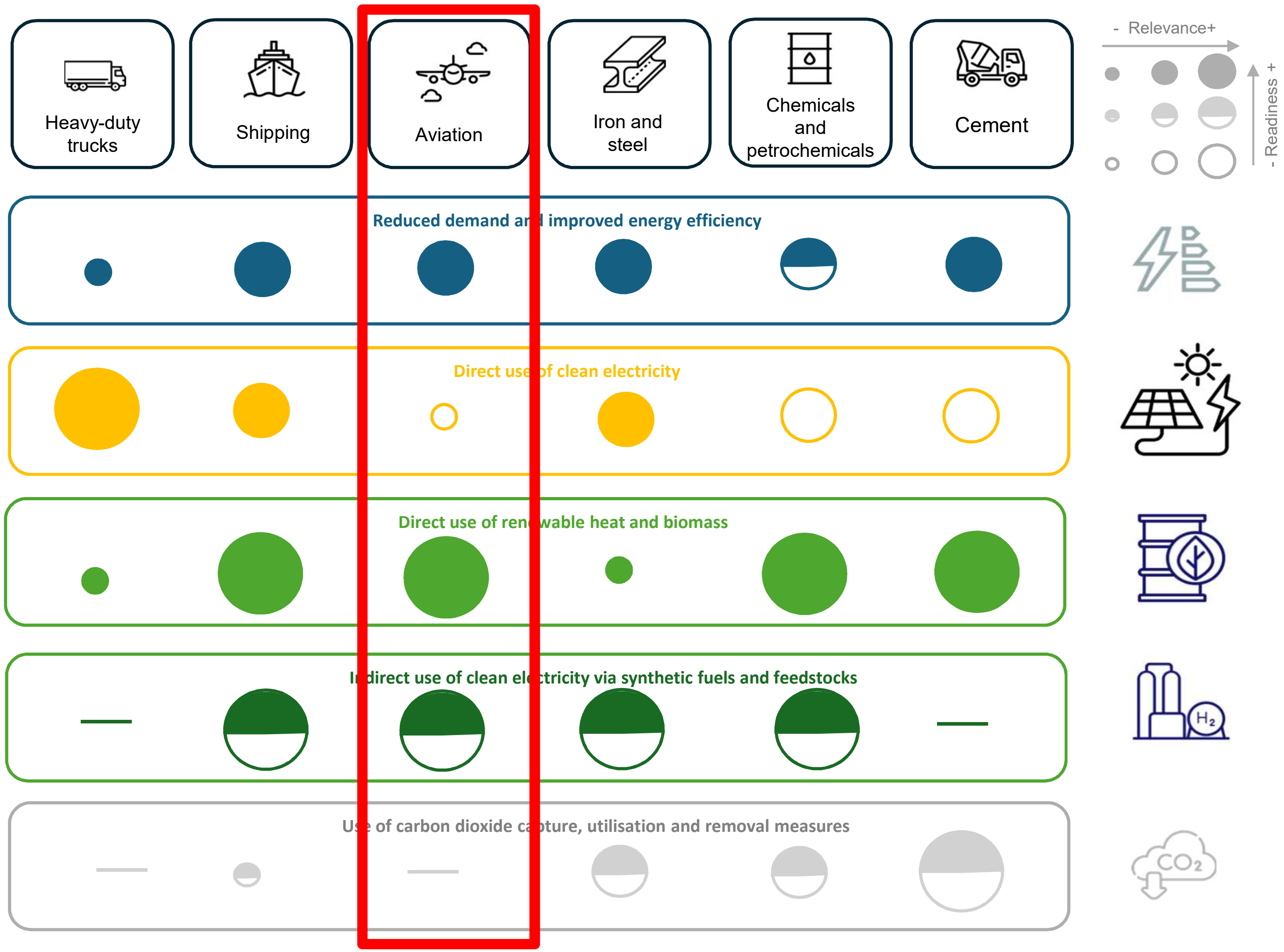
Decarbonisation pathways and infrastructure needs - Aviation



Source: IRENA 2024 - Decarbonising hard-to-abate sectors with renewables: Perspectives for the G7

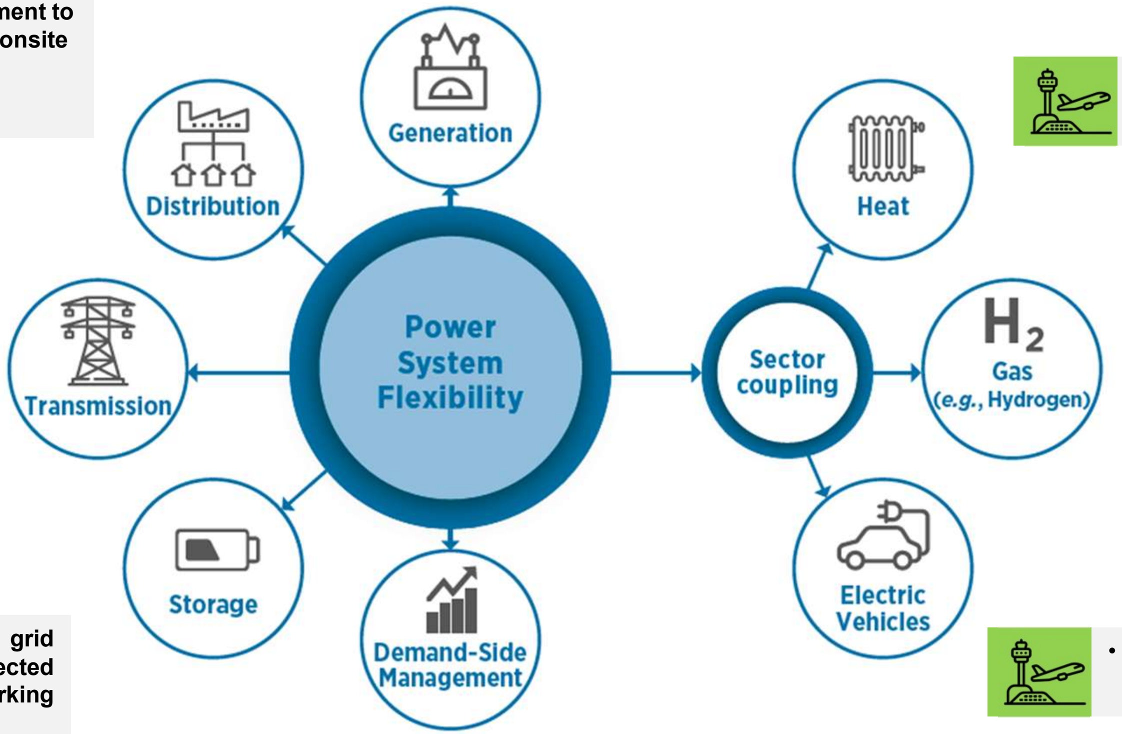
Airports can play an important role in integrating more renewables into energy systems

Energy system flexibility enablers

- Onsite renewable power generation with solar PV

- Connection reinforcement to enable electrification, onsite generation, flexibility services.

- Deployment of heat pumps in airport facilities



- Demand response / grid services from connected EVs in airport parking facilities.

- Electrification of ground operation vehicles.

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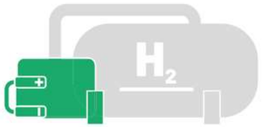
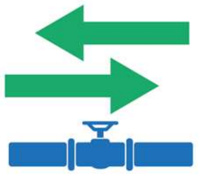
IRENA (2018), Power system flexibility for the energy transition – Part I: Overview for policy-makers

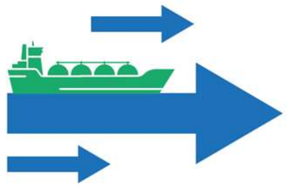
About a quarter of the global hydrogen demand could be internationally traded, about half overseas



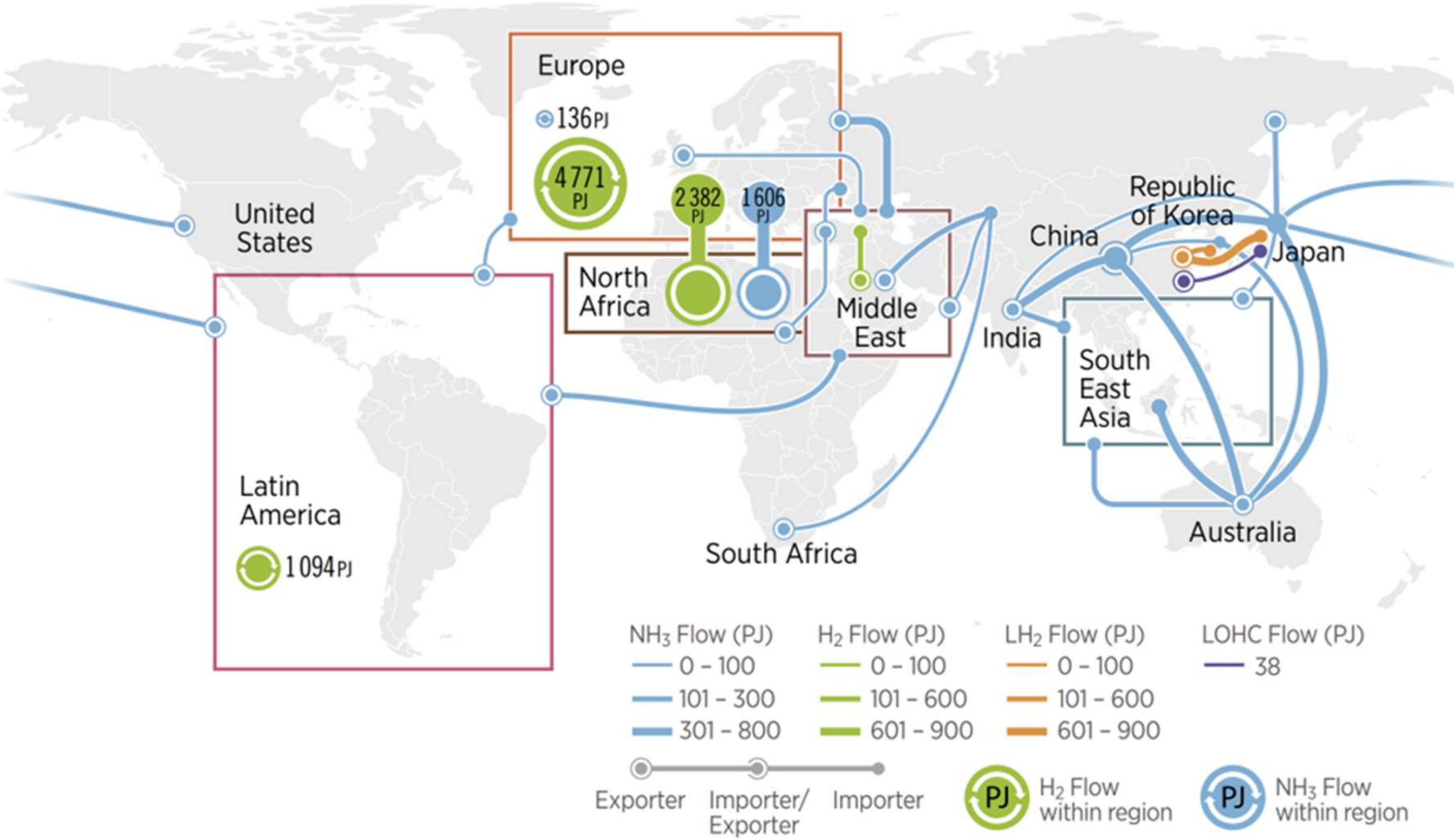
By 2050, international trade could satisfy about ¼ of the total global hydrogen demand in IRENA's 1.5°C scenario.



55% of this hydrogen would be traded via pipelines.



45% of this hydrogen would be shipped, predominantly as ammonia.



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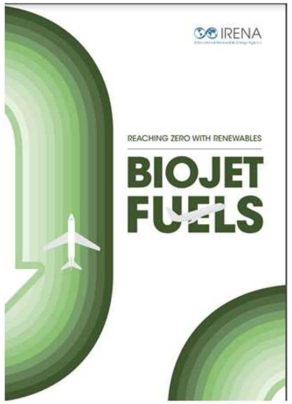
Source: IRENA, 2022. Global hydrogen trade to meet the 1.5C goal. Part I: Trade outlook for 2050 and way forward.

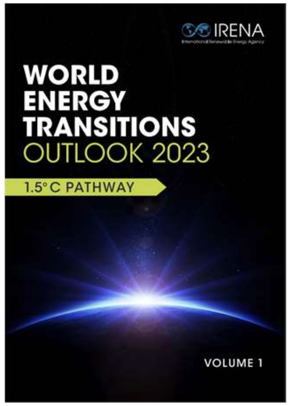
Some of IRENA’s work on renewable solutions for the aviation sector



This report provides a comprehensive analysis of biojet fuels as a decarbonisation option for the aviation sector with a focus of reaching zero in time to fulfil the Paris Agreement.

Citation: IRENA (2021), Reaching Zero with Renewables: Biojet fuels, International Renewable Energy Agency, Abu Dhabi.

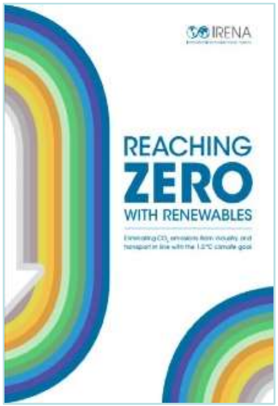
Download report here



This first volume of the 2023 Outlook provides an overview of progress by tracking implementation and gaps across all energy sectors and identifies priority areas and actions based on available technologies that must be realised by 2030 to achieve net zero emissions by mid-century.

Citation: IRENA (2023), World Energy Transitions Outlook 2023: 1.5°C Pathway, Volume 1, International Renewable Energy Agency, Abu Dhabi.

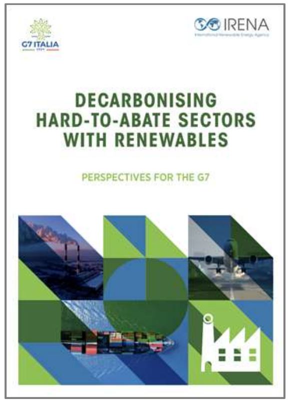
Download report here



A comprehensive study of deep decarbonisation options for hard to abate sectors, focused on reaching zero into time to fulfil the Paris Agreement and hold the line on rising global temperatures.

Citation: IRENA (2020), Reaching zero with renewables: Eliminating CO2 emissions from industry and transport in line with the 1.5C climate goal,

Download report here



This report – prepared in support of Italy’s presidency of the G7 – elaborates on the technological pathways and systemic innovations needed to decarbonise five hard to abate sectors: iron and steel, chemicals and petrochemicals, road freight transport, shipping and aviation. It aims to provide actionable recommendations that the G7 can follow to accelerate global efforts to decarbonise these sectors.

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Presentation

Zhang Chang

Chief Engineer- Hydrogen Energy Technology
Department Huaneng Clean Energy Research Institute

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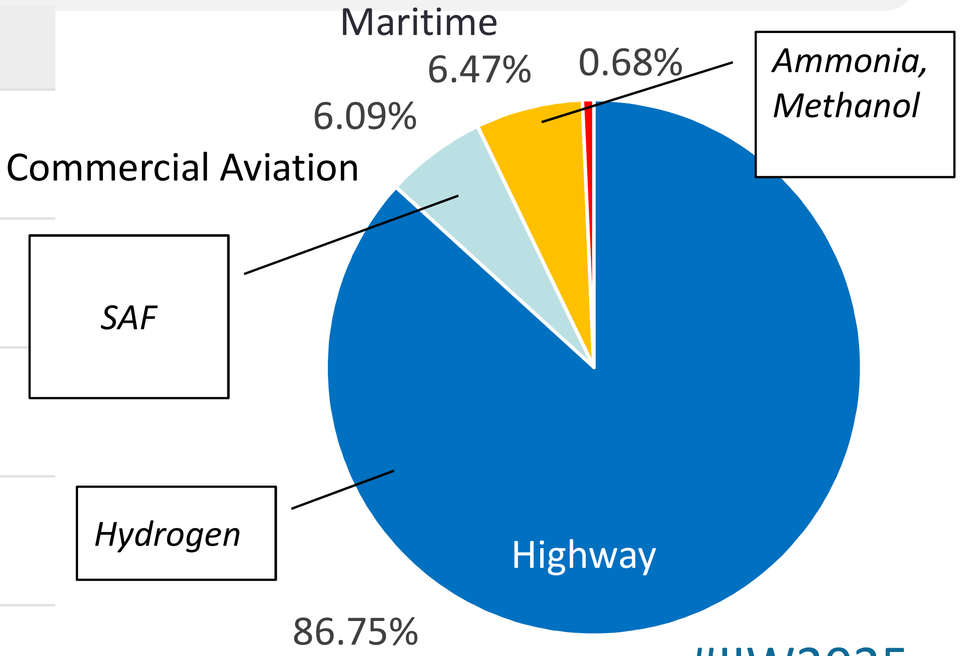
CONTENTS

01 Expected Application Space of Sustainable Fuels in China

Current Carbon Emissions

The transportation sector accounts for approximately 10% of China's total carbon emissions. In addition to electrification, low-carbon fuels represent an effective solution for carbon reduction in transportation, particularly in the shipping sector where electrification remains challenging.

Sector	Share	Major Sources
Power & Heat Generation	44%	Coal power (>70%), heating
Industry & Manufacturing	28%	Steel, cement, chemicals
Transportation	10%	Road freight (52%), aviation/shipping
Building Operations	9%	HVAC systems, residential electricity
Agriculture & Others	9%	Farming, waste management



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Source：IEA，CEADs， Solar Energy Journal, 1003-0417(2025)02-05-11

02 Relevant Policy Planning

Nationwide pilot of E10 ethanol gasoline

2019

Implementation Plan for Expanding Biofuel Ethanol Production

2019

Revised Renewable Energy Law mandates waste-oil biodiesel

Mandates waste-oil biodiesel (B5/B10) in Shanghai, Hainan, etc

positioning sustainable fuels as key to energy transition

2020

Dual Carbon Goals set carbon peaking by 2030 and neutrality by 2060

2021-2025

14th Five-Year Plan prioritizes biofuel and green hydrogen

prioritizes biofuel, green hydrogen, and other non-fossil fuels

2022

Medium-Long Term Hydrogen Plan targets green hydrogen capacity

Targets 100k-200k tons/year green hydrogen capacity by 2025, focusing on renewable-powered electrolysis

2022

Technology Roadmap advances CO_2-to-SAF technologies

Advances CO_2-to-SAF (Sustainable Aviation Fuel) technologies

2022

14th Five-Year Plan for Green Aviation Development

Mandates >20,000 tons/year SAF consumption by 2025, with commercial flight trials

2023

Air China operates first international flight using China-made SAF

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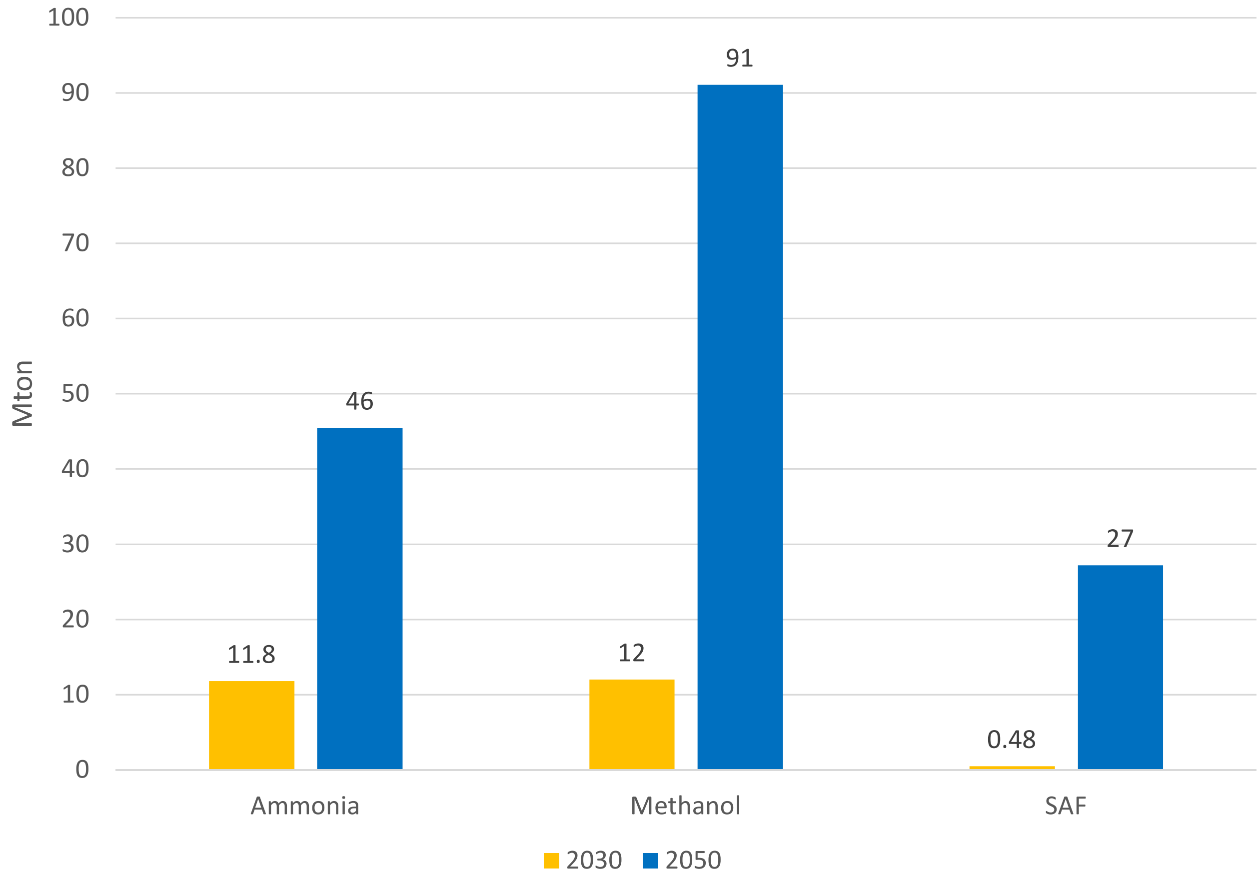
02 Demand and Prospects



Ammonia: The main expected demand is in the industrial sector, corresponding to green hydrogen demand of 2.1 million tons / 8.2 million tons respectively.

Methanol:

Industrial sector (chemical raw material): 11.4 million tons / 57.1 million tons;
Transportation sector (marine fuel): 610,000 tons / 34 million tons;
Corresponding green hydrogen demand: 2.32 million tons / 18.4 million tons.

SAF: Estimated based on China's policies and global forecast data.

Source：CWHP, Guosen Securities

02 Typical Projects

Project Name	Scale	Features	Status
1. Green Hydrogen Production & Utilization			
Zhangjiakou Renewable Hydrogen Project	(10,000 t/yr)	(Wind-PV powered electrolysis)	(Operational since 2022; fueled Beijing Winter Olympics transport)
Ningxia Baofeng Solar-to-Hydrogen Project	(20,000 t/yr)	(World's largest integrated solar-to-hydrogen plant, supplies green H_2 for coal-chemicals)	(Phase I: 16,000 t/yr operational in 2023)
2. Biofuel Commercialization			
Sinopec Bio-jet Fuel Demonstration	(50,000 t/yr)	(Waste cooking oil to SAF conversion)	(1st plant operational 2022; 1st passenger flight with SAF in 2023)
Zhejiang Biodiesel Industrial Base	(300,000 t/yr)	(Food waste oil to biodiesel)	(Mandatory B5/B10 blend for ships since 2021)
3. Power-to-Fuel (PtX) Initiatives			
Jilin Wind-PV-Storage & Power-to-Gas	(120 million m^3/yr)	(Green H_2 + CO_2 → synthetic methane)	(Tech validation completed 2023; integrated into gas grid)
DICP CO_2-to-Jet Fuel Pilot	(1,000+ t/yr)	(Direct CO_2 hydrogenation to jet fuel)	(10,000 t/yr process package designed in 2024)
4. Hydrogen Fuel Cell Transport			
Guangdong-Hong Kong-Macao Hydrogen Corridor	(30+ H_2 stations; 5,000 FCVs)	(Multi-scenario: trucks, buses, ships)	(Covering 9 cities by 2024; cumulatively reduced 180k t CO_2)
Chengdu-Chongqing H_2 Logistics Network	(1,200 H_2-fueled heavy trucks)	(Full-chain demo from H_2 production to end-use)	(500 trucks deployed in 2023; 300km/trip range)

03 Green hydrogen supply is crucial for sustainable fuel production projects

Importance of Supply

The stable supply of green hydrogen as a basic raw material is crucial for the development of the entire industry. The low- carbon synthesis fuel process is the core link in achieving green and low- carbon fuels. The storage and transportation of synthesis fuels are relatively mature.

Technology Breakthrough Directions

Analysis of the breakthrough directions for green hydrogen production technology, such as reducing costs and improving efficiency, is provided to ensure the quality and market circulation of green fuels and promote the sustainable development of the industry.

03 Key Green Hydrogen Technologies

Electrolysis of Water for Hydrogen Production

Electrolysis of water is the only commercialized method for producing green hydrogen from renewable energy. The cost is significantly affected by energy consumption and equipment investment.

Hydrogen Production System Control

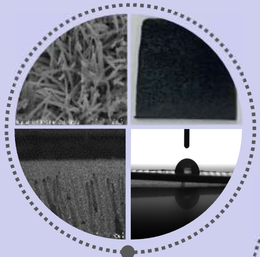
Due to the instability of renewable energy power generation, the hydrogen production process is dynamic and requires advanced control technologies and strategies.

Capacity Planning and Management

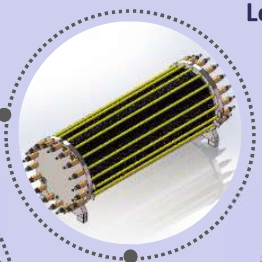
The economic viability of green hydrogen- based fuel projects is a key factor for sustainable development.

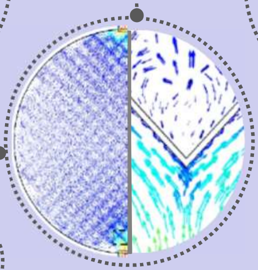
03 Key Green Hydrogen Technologies of Huaneng

1 New Material
Electrode
Diaphragm

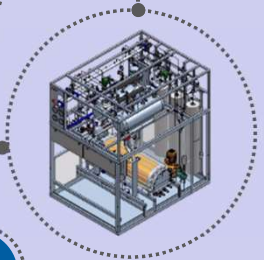


3 Electrolyzer
High-performance
Scaling-up
Lowcost





2 Electrolyzer Design
Configuration design
Flow field optimization



4 System Integration
Dynamic control
Intelligent

Hydrogen Electric Coupling

5 Dynamic power response

Demonstration Project

7 Construction of hydrogen production station
Integrated hydrogen supply chain

6 H_2 application
Chemical
Transportation

8 Consultation
Planning consultation
Comprehensive evaluation

Key technology of green hydrogen production

- Developed key materials of electrocatalysts & seperator.
- Electrolyzer design & assembly.
- Control optimization & integration of hydrogen production system with equipment level and station level.

Technology & demonstration of hydrogen industry chain

- Dynamic coupling with renewable energy
- Hydrogen application in transportation & chemical industry, etc.
- Project planning & demonstration of hydrogen industry chain.

03 Future Development Directions

Global Energy Transition Trends

The global trend of energy structure transformation towards green and low-carbon is emphasized. The important role of green fuels in reducing carbon emissions and ensuring energy security is highlighted as an unstoppable force.

Future of China's Green Hydrogen-based Fuel Industry

With the support of policies, technological innovation, and market demand, China's green hydrogen- based fuel industry is expected to have a broad development space. It will make an important contribution to achieving carbon neutrality and optimizing the energy structure.

03 The key focus for future development is cost reduction and green certification

Cost Reduction

The high cost of green fuels compared to traditional fuels currently makes them less competitive in the market. Reducing costs is essential for the commercialization and large-scale development of green fuels to enhance their market competitiveness.

Certification System

The certification system is crucial for regulating the green fuel market. Establishing unified certification standards and procedures ensures the quality of green fuels, protects consumer rights, and promotes the healthy and orderly development of the market.

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Panel discussion

Moderator

Peter Schniering

Future Cleantech Architects

Panellists

Arno van den Bos

IRENA

Ralph-Uwe Dietrich

German Aerospace Center (DLR)

Pierpaolo Cazzola

European Transport and Energy Research Centre

Santiago Haya-Leiva

European Union Aviation Safety Agency (EASA)

Zhang Chang

Huaneng Clean Energy Research Institute

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Slides for discussion

Dr. Ralph-Uwe Dietrich

Manager Techno Economic Assessment
German Aerospace Center (DLR)

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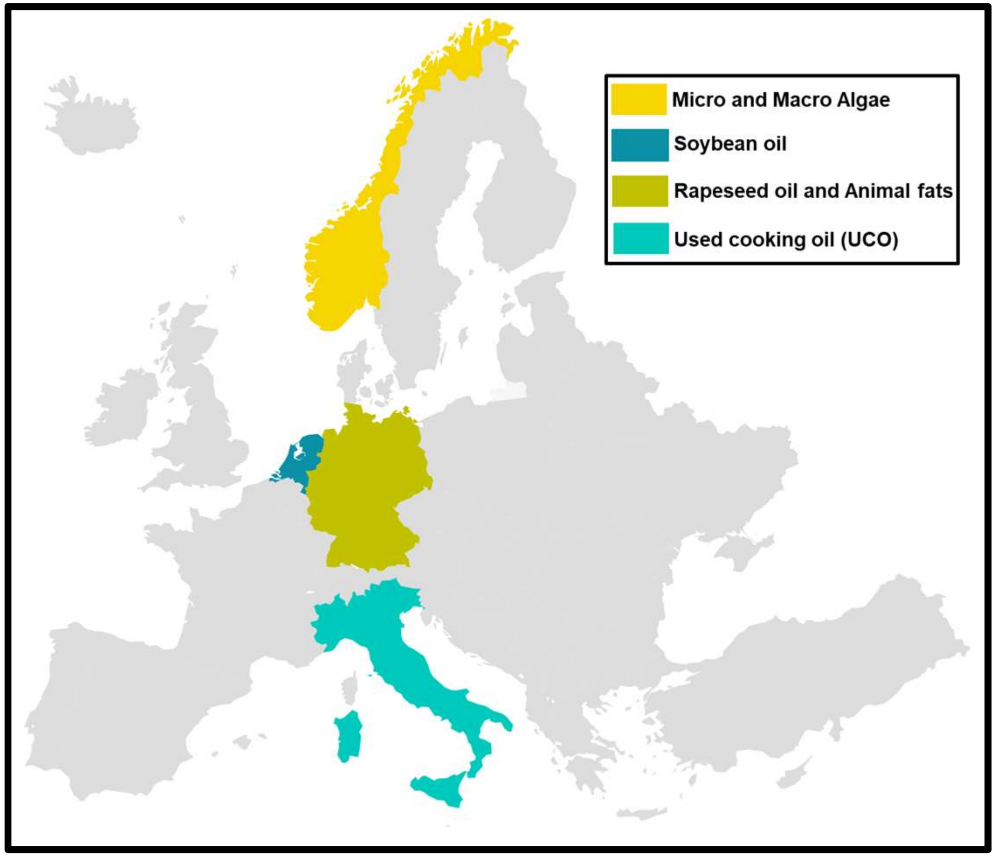
Only certified SAF applicable: 1. HEFA kerosene

Currently HEFA kerosene preferred
 - Low conversion costs
 - Inexpensive feedstocks

Open socio-economical questions
 - Food vs. fuel vs. road transport
 - Reliability / sustainability of import
 - Cost vs. environmental impact
 - EU-wide feedstock collection and certification mechanism?

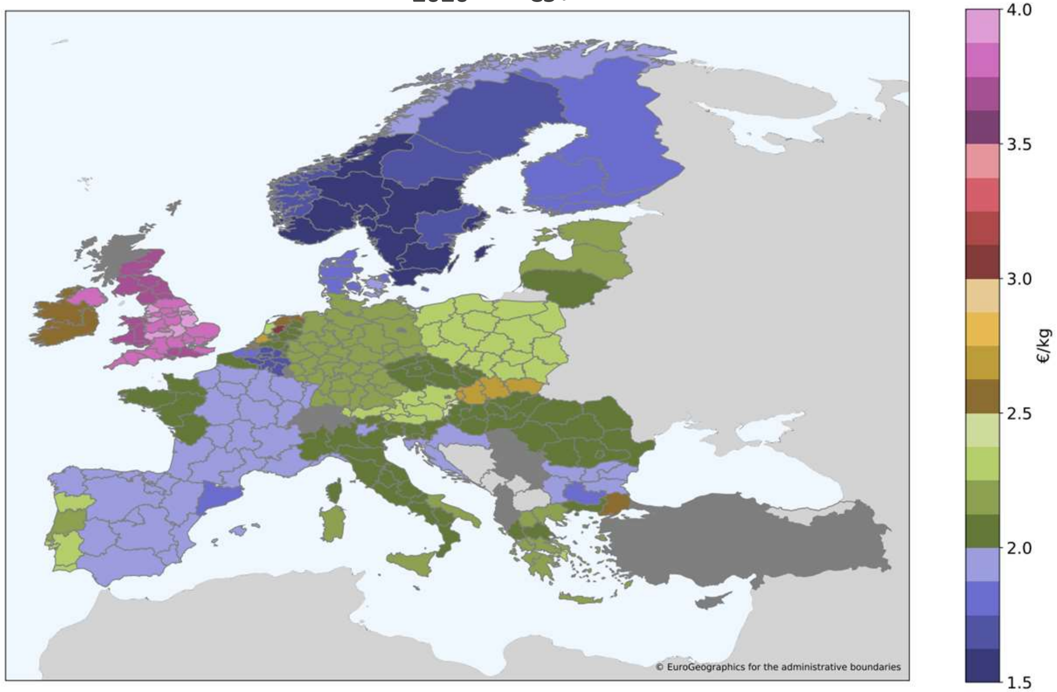
Possible European HEFA Feedstock favorites (not completed yet)



Only certified SAF applicable: 2. FT-SPK from woody biomass

Extensive investigation @ Habermeyer et. al (2023) Sustainable aviation fuel from forestry residue and hydrogen. A techno-economic and environmental analysis for an immediate deployment of the PBtL process in Europe. Sustainable Energy and Fuels, doi: 10.1039/d3se00358b.

Net production cost [$€_{2020}/kg_{C5+}$]:



Net Production cost

+ Abundant cheap woody biomass and low carbon electricity in Scandinavia

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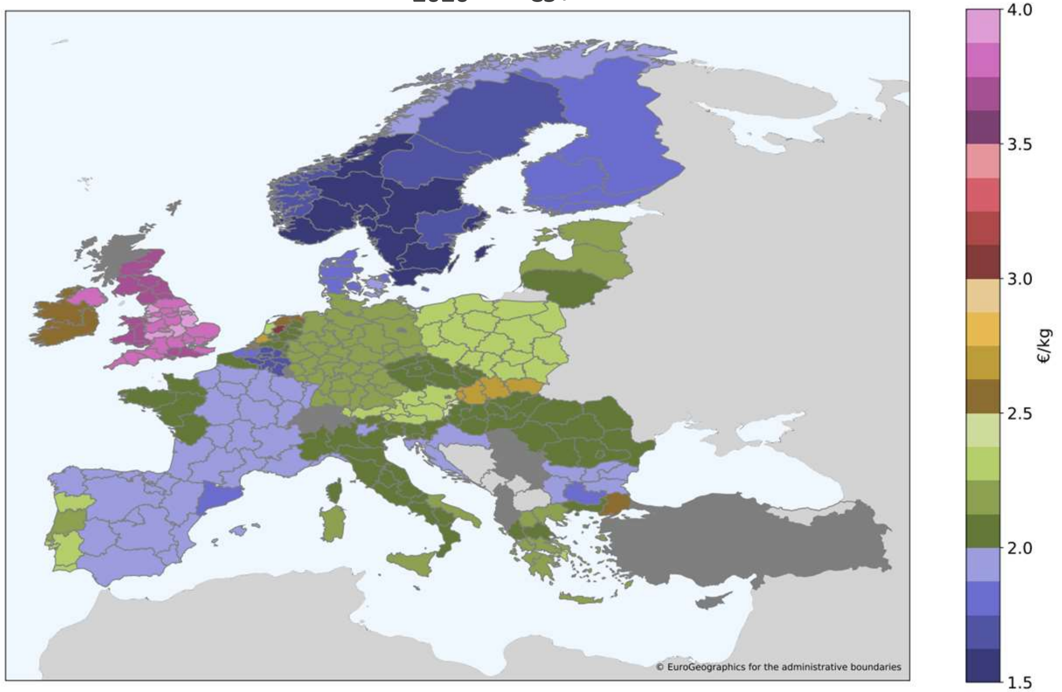
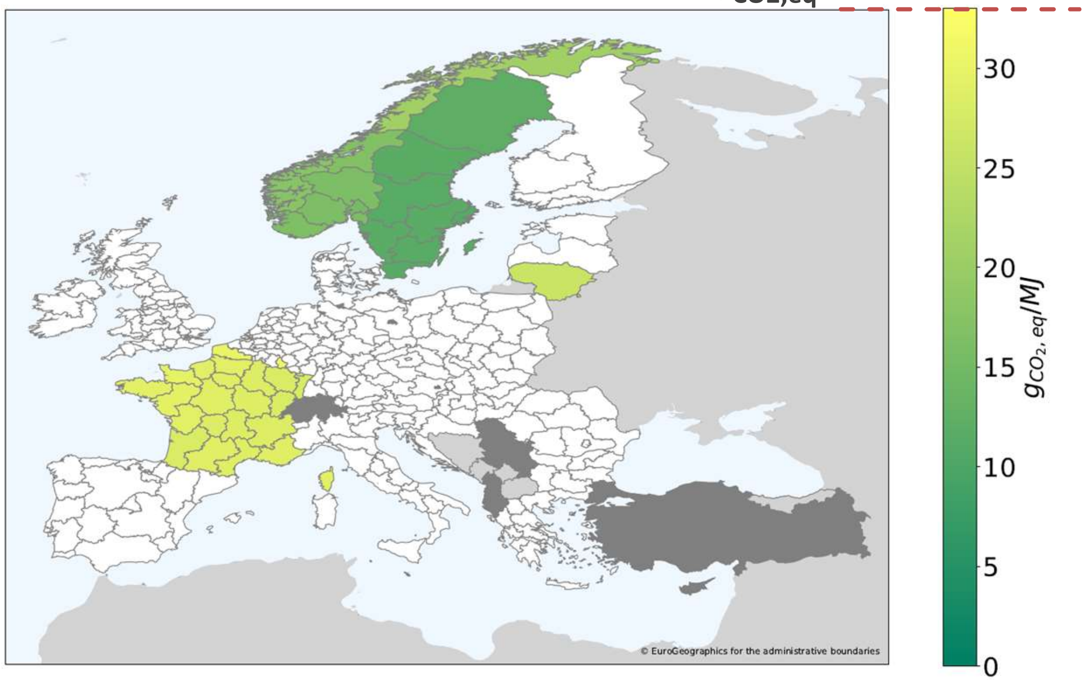


Grid-supported FT-SPK SAF GWP 2020 [$g_{CO2,eq}/MJ$]:

RED II 65% limit



Net Production cost	Greenhouse Gas Abatement
+ Abundant cheap woody biomass and low carbon electricity in Scandinavia	– High carbon footprint of electricity prevents power-based SAF production in most European countries

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Slides for discussion

Santiago Haya-Leiva
International Cooperation Officer - Sustainability
International Cooperation - EU Neighbourhood & Asia Section
European Union Aviation Safety Agency (EASA)

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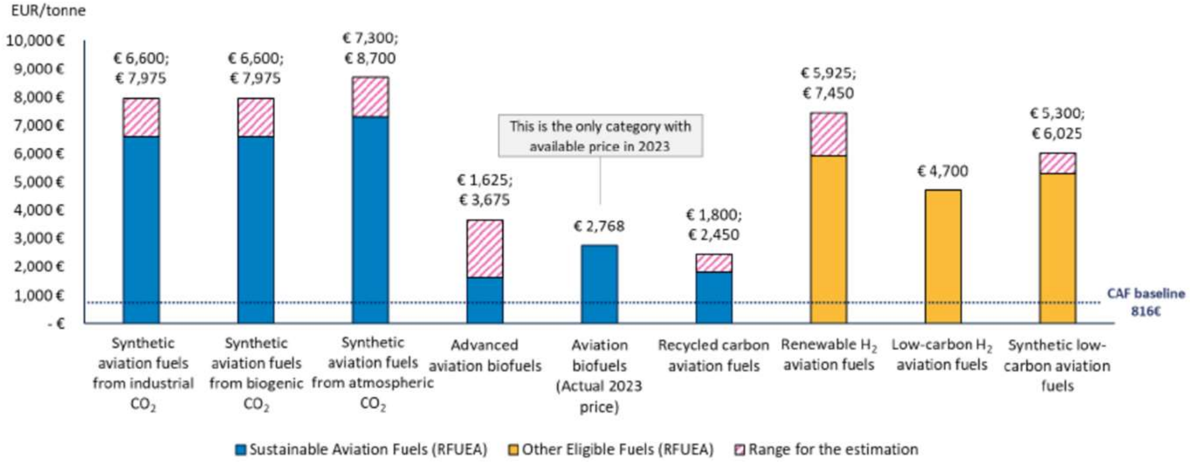
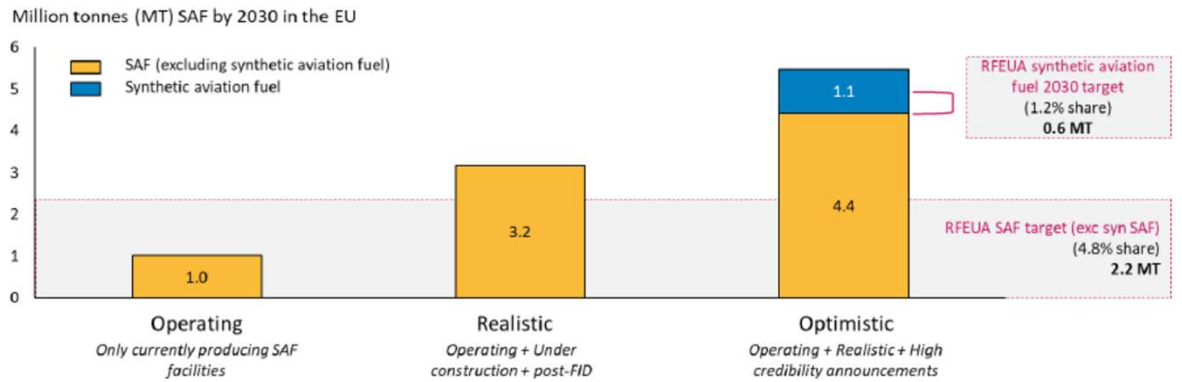
SAF Challenges – Affordability and Availability

- High environmental value but no ecomic drive
  - High CAPEX, high financial risks
  - Complex value chain and infrastructure
  - Stringent certification/approval specs.
- Multiple pathways, combination of feedstocks and technologies, different challenges, industry profiles, TRL,…
- Policy intervention to create or incentivise a market - EU example:
  - Refuel EU Aviation enabling SAF production
  - Additional challenges for e-SAF





Sources:
https://www.easa.europa.eu/en/domains/environment/refueleu-aviation/eu-saf-market-report

Typical SAF value chain

Feedstock → Crude production → Refining → Blending → Distribution logistics → Airports (logistics, infrastructure) → Consumer

Infrastructure Needs

Policies and Standards (regulation)	Certification bodies[1]	Technology developer	Investors / financing institutions	Trade / Supply	SAF associations, e.g. buying, representative

ASTM INTERNATIONAL

European Commission | Renewable Energy Directive (RED II)

ISCC International Sustainability & Carbon Certification

RSB

SABA SUSTAINABLE AVIATION BUYERS ALLIANCE

CORSIA

Sustainable Aviation Fuel Users Group

ETS

[1] sustainability certification schemes (SCS) and standards

Sustainable Aviation Fuels

ASTM certification for SAF

Technical certification assuring that the **chemical properties** of the fuel are adequate and compliant with the use as jet fuel.

ASTM D1655: key specification for JetA/A-1.

ASTM D7566: quality standard required for each SAF production pathway, defining which feedstock must be used, the associated process and the properties and the output of each pathway.

ASTM D4054: the process for approval of new SAF production pathways.

ASTM INTERNATIONAL

Sustainability certification for SAF

Certification about **compliance towards sustainable criteria** according to specific sustainability programs (e.g., CORSIA).

Key sustainable criteria for SAF production:

- Sustainable feedstock availability
- Direct / Indirect Land Use Change
- GHG Emissions
- Labour / Human rights
- Food security
- Traceability.

CORSIA

RSB CERTIFIED

ISCC International Sustainability & Carbon Certification

ASTM D7566 and D1655 – Allowed SAF production pathways

Specifications and Requirements for Sustainable Aviation Fuel in Aviation Turbine Fuels

	Exemplary feedstock	Group	ASTM qualified conversion process (D7566, D1655)	Max. blend	Chemical composition	Technology used	ASTM
1	**Fatty acids or fatty acid esters** (from virgin or used fats and oils)	HEFA & Co-Processing	**HEFA-SPK**: Synthesized paraffinic kerosene from hydroprocessed esters and fatty acids	50%	Paraffins, no aromatics	Hydroprocessing for HEFA	D7566
2	**Fatty acids or fatty acid esters** (co-processed with fossil petroleum)	HEFA & Co-Processing	**Co-processed HEFA**: Co-hydroprocessing of esters and fatty acids in a conventional petroleum refinery	5%	Paraffins and aromatics contained in the jet fuels	Co-hydroprocessing	D1655
3	**Algae**	HEFA & Co-Processing	**HC-HEFA-SPK**: Synthesized paraffinic kerosene from hydrocarbon - hydroprocessed esters and fatty acids	10%	Paraffins, no aromatics	Hydroprocessing for HEFA	D7566
4	**Hydrocarbons** derived from **triglycerides or their derivates**	HEFA & Co-Processing	**Co-fractionation** using maximum 24% of bio-material, with result of maximum 10% bio-share in the jet fuel.	10%	Paraffins and aromatics contained in the jet fuels	Hydroprocessing for HEFA	D1655
5	**Syngas** (via gasification or from H_2/CO_2)	Fischer-Tropsch	**FT-SPK**: Fischer-Tropsch hydro-processed synthetic paraffinic kerosene	50%	Paraffins, no aromatics	Fischer-Tropsch synthesis	D7566
6	**Syngas** (via gasification or from H_2/CO_2)	Fischer-Tropsch	**FT-SKA**: Synth. kerosene with aromatics derived by alkylation of light aromatics from non-petr. sources	50%	Paraffins and aromatics	Fischer-Tropsch synthesis	D7566
7	**FT hydrocarbons** (co-processed with fossil petroleum)	Fischer-Tropsch	**Co-processed FT**: Co-hydroprocessing of Fischer-Tropsch hydrocarbons in a conventional petroleum refinery	5%	Paraffins and aromatics contained in the jet fuels	Co-hydroprocessing	D1655
8	**C2-C5 Alcohols** (various feedstocks)	Oligomerisation	**ATJ-SKA**: Alcohol to jet synthetic paraffinic kerosene with aromatics (Pure SAFSM)	50%	Paraffins and aromatics	Fermentation to alcohol, dehydration and oligorimerisation	D7566
9	**Ethanol, Iso/n-butanol, Isobutene** (from crops, 2G biomass, H_2/CO_2)	Oligomerisation	**ATJ-SPK**: Alcohol to jet synthetic paraffinic kerosene	50%	Paraffins, no aromatics	Fermentation to alcohol, dehydration and oligorimerisation	D7566
10	**Sugars** (from crops or 2G biomass)	Oligomerisation	**SIP**: Synthesised iso-paraffins from hydroprocessed fermented sugars	10%	Paraffins, no aromatics	Fermentation	D7566
11	**Fatty acids or fatty acid esters** (from virgin or used fats and oils)	other	**CHJ**: Catalytic hydrothermolysis jet fuel	50%	Paraffins and aromatics	Hydrothermal synthesis	D7566

Source: ASTM

Other process in the pipeline for ASTM approval: **Methanol-to-Jet**, **Synthesised Aromatic Kerosene** (Virent), **Integrated Hydropyrolysis and -conversion IH2** (Shell), **Pyrolysis of non-recyclable plastics** (OMV), **Coprocessing** of **pyrolysis oil**, **certification for flying with 100% SAF.**

IRENA INNOVATION WEEK 2025

Closing Remarks

Peter Schniering

Co-founder and CEO
Future Cleantech Architects

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INNOVATION WEEK 2025

Renewables and Digitalisation for a Sustainable Energy Future

Thank you!

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