Nov 6, 2024

INTRODUCTION TO POWER-TO-X AND SYNTHETIC FUELS: THE PATH TO CLIMATE-NEUTRAL ENERGY SYSTEMS

provadis Hochschule

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The Future of Our Energy

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Chapter 1

INTRODUCTION TO THE POWER TO X LECTURE SERIES

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Prof. Dr. Kirstin Hebenbrock
Provadis Hochschule

ORGANISATIONAL DETAILS

- Welcome – you all registered for todays lecture
- For the future lectures all TEAMS links will be sent a week in advance
- Last call: TEAMS link will be sent briefly (60-90 min) before the lecture, access possible a few minutes before start
- Access via TEAMS or Chrome / Edge Browser

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ORGANISATIONAL DETAILS

- If you want to receive a certificate of participation - there will be a FORMS-link later during the lecture – the certificate will be sent by mail.
- Questions will be collected in the Q&A function and dicussed during the live lecture

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ORGANISATIONAL DETAILS

- There is a QR code for the scientific evaluation of the lectures at the end of each lecture – please take your time to answer

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ORGANISATIONAL DETAILS

- This lecture will be recorded for quality control
- The upload will be a newly recorded version
- The PDF of the slides and the video will be accessible on the project homepage 1-2 weeks after live- session.
- However, some lectures will use the recording of the live session – we will inform you in these cases

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COMPONENTS OF POWER TO X CAPACITY BUILDING

- Preparatory E- learning (available in German Language)

  find link here: Kopernikus-Projekte: P2X: Education and transfer

- 10 lectures

- Summer school in spring 2025- preregistration possible

  find link here: Ringvorlesungen

  E- learning for lectures available Oct 2025

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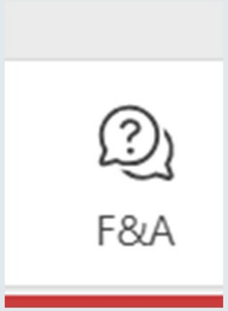
ORGANISATIONAL DETAILS

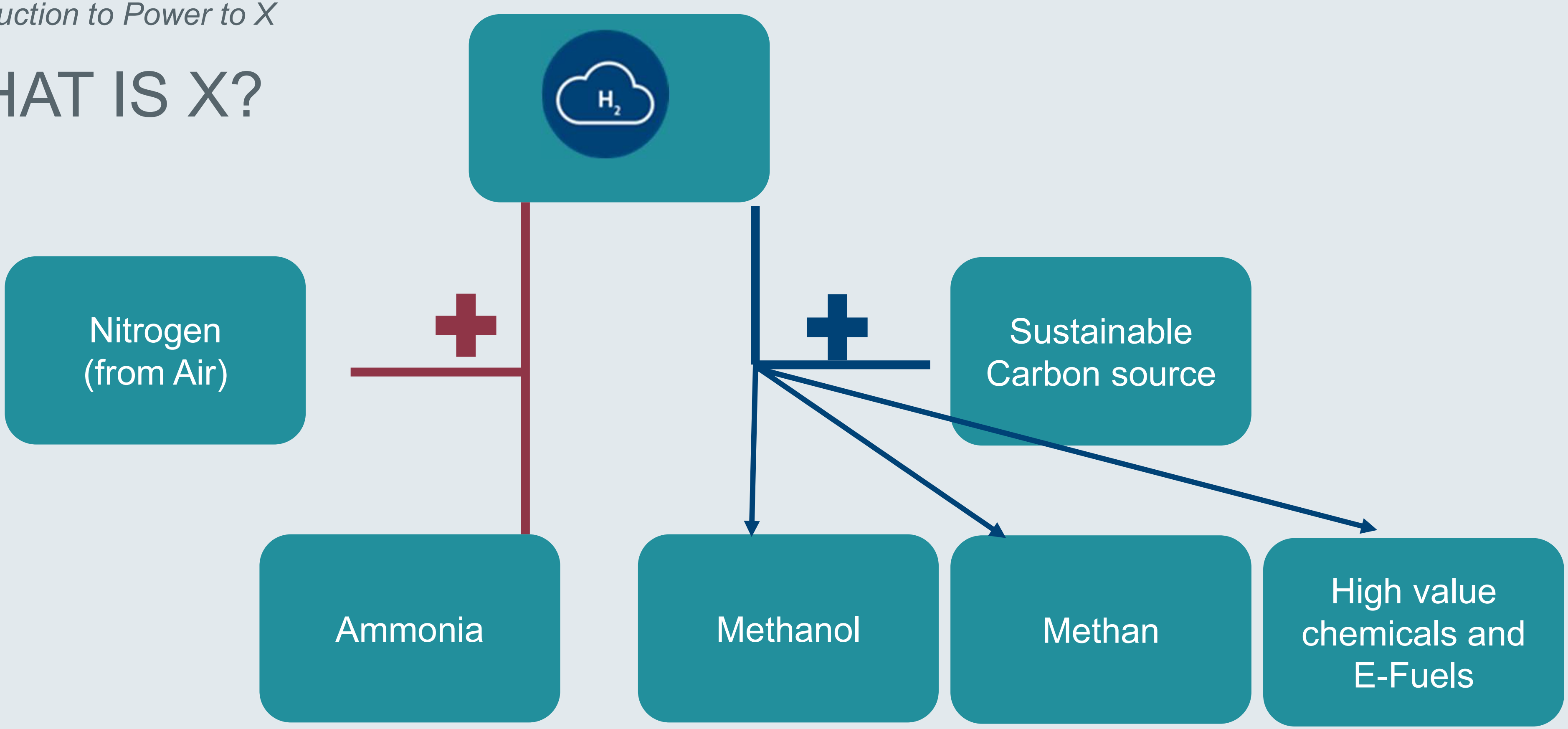
- Any questions concerning organisation?
- please use



- Due to the time delay, we will collect your questions for approximately 2 minutes and return with the answers in about 5 minutes

Introduction to Power to X

WHAT IS X?



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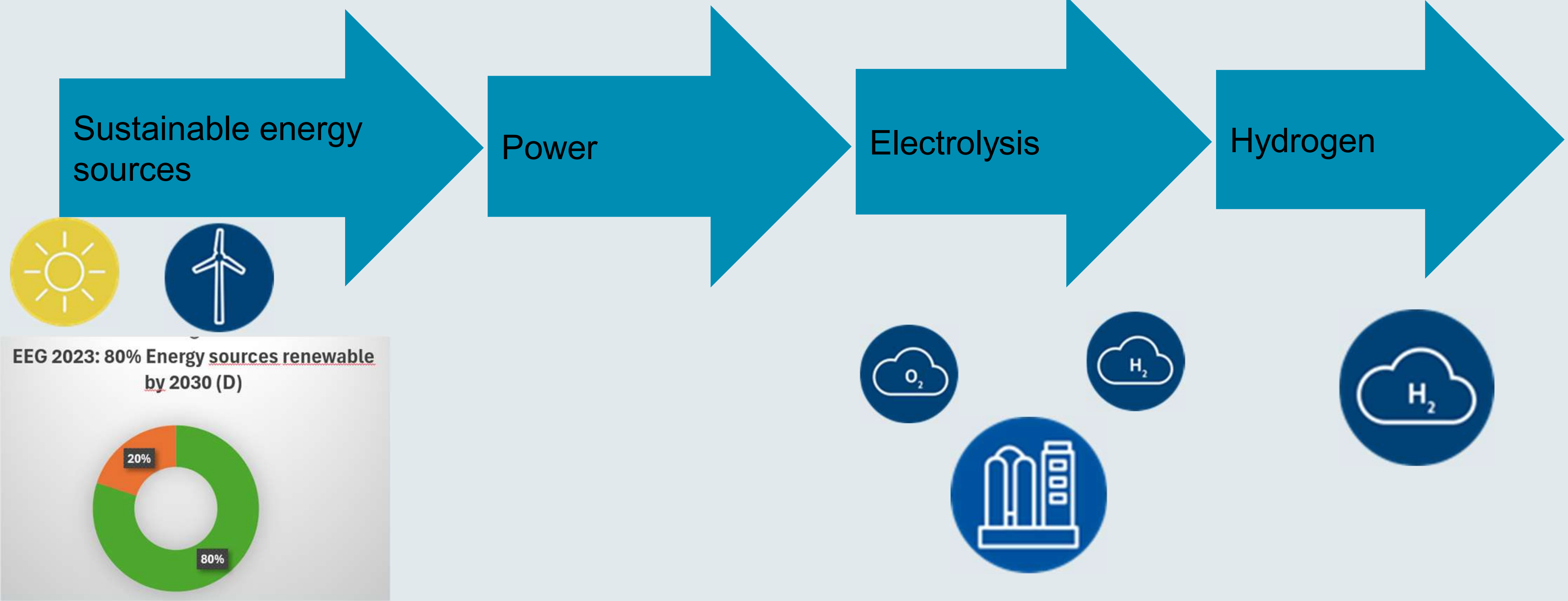
PRODUCTION OF HYDROGEN: ELECTROLYSIS



WHY DO WE DO WE WANT TO CONVERT „POWER“ INTO „X“

- "Power-to-X, and especially hydrogen, will play a key role in providing flexibility where and when it is needed.
- Infrastructure planning 2050
- Source: Aktualisierung des integrierten nationalen Energie- und Klimaplans.pdf

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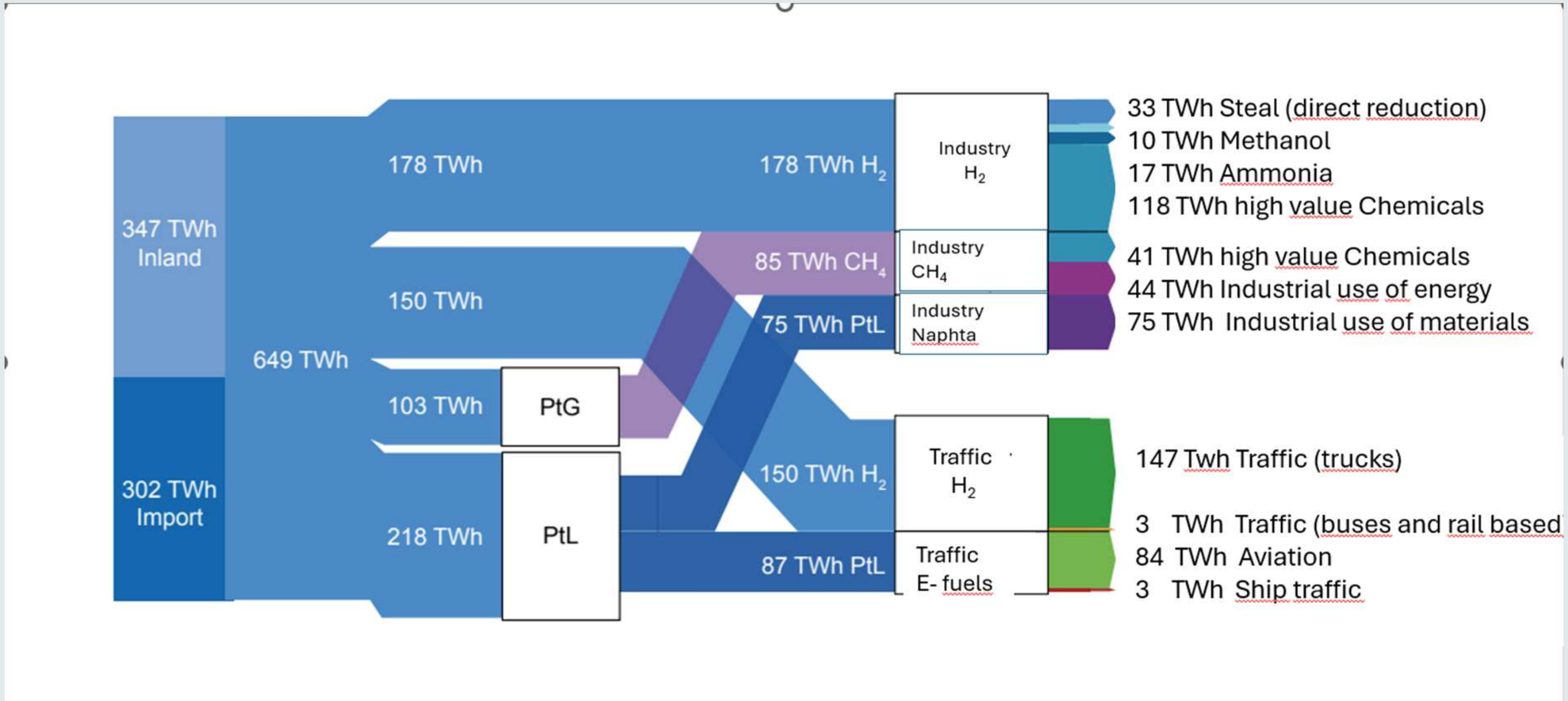
WHY DO WE DO WE WANT TO CONVERT „POWER“ INTO „X“

- The “**ENERGIEWENDE**” energy transition aims to reduce greenhouse gas emissions, increase energy efficiency, and create a more sustainable energy system
- To find **new technical solutions** for our commitment to replace fossil fuels and nuclear power to renewable energy sources like wind, solar and biomass.

POSSIBLE USE OF HYDROGEN AND „X“ IN 2050



- Basis scenario of the Kopernikus Project Roadmap 4, Phase II

Link: 221025_DEC_P2X4_V08_Web.pdf

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WHAT ARE THE ADVANTAGES / DISADVANTAGES OF CONVERTING „POWER“ INTO „X“

Pro

Energy Storage enabled for surplus energy from intermittently producing sources (solar / wind)

Versatility in Use for various applications, including electricity generation, heating, transportation fuel, and industrial use

Grid Stability: Mitigation of the effects of fluctuating renewable energy inputs and reduction of the need for fossil-fuel-based backup power.

Decarbonization: “X” Production with renewable power, hydrogen and sustainable carbon source helps reduce greenhouse gas emissions in hard-to-decarbonize industries.

WHAT ARE THE ADVANTAGES / DISADVANTAGES OF CONVERTING „POWER“ INTO „X“

Con

Energy Efficiency Loss: Energy conversion involves energy losses. (electrolysis efficiency 65-85%*) further conversion steps reduce efficiency even more.

High Costs: P2X, especially electrolysis and carbon capture for synthetic methane production, is currently expensive, compared with direct electric usage or fossil fuels.

Infrastructure Needs: Hydrogen is highly flammable and difficult to store. Up to now storing and transporting hydrogen requires pressurized tanks and specialized infrastructure.

Water Demand: Hydrogen is produced from water – resources are limited in arid regions.

Methane Leakage: Methane is a potent greenhouse gas. Leaks (up to 25%*) during storage and transport reduce the climate benefits.

*FAZ NR 176, Page N1 Juli 31, 2024

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WHAT DO WE ADRESS IN THE LECTURE SERIES

Synthetic Fuels: the path to climate-neutral energy system

Where are we now – what are the advantages of each method.

Power

Sun

Biomass

To

Liquid

SAF
Sustainable (Aviation)
Fuels

Prof. Dr. Manshausen
Provadis Hochschule

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WHAT DO WE ADRESS IN THE LECTURE SERIES

Nov. 13

Fire and Ice: Hydrogen and carbon dioxide as key components at the intersection of energy and chemistry.

-Hydrogen obtained from the electrolysis of water

- Catalytic conversion with CO_2 to products like fuels, Kerosene

Prof. Dr. Walter Leitner
Max Planck Institute for chemical energy conversion

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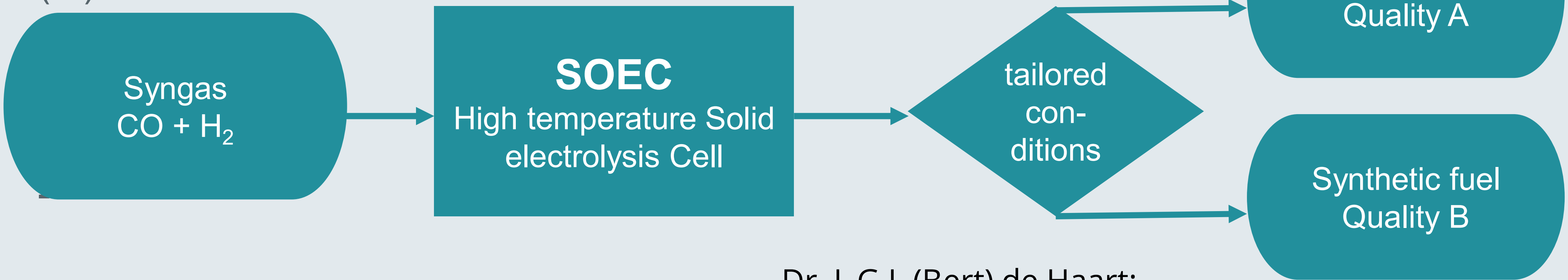
WHAT DO WE ADRESS IN THE LECTURE SERIES

Nov 20

Power-to-X and electrolysis - Turning Steam into Rocket Fuel

(M)



Dr. L.G.J. (Bert) de Haart;
Forschungszentrum Jülich / RWTH Aachen

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WHAT DO WE ADRESS IN THE LECTURE SERIES

Nov 27

Are e-fuels a beneficial alternative to conventional fuels?

- environmental impact?
- economic feasibility?
- technological readiness?

Questions to be adressed

- ➢ high production costs,
- ➢ energy-intensive manufacturing processes,
- ➢ need for substantial renewable energy inputs

Prof. Dr. Ralf Ehret
Provadis Hochschule

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WHAT DO WE ADRESS IN THE LECTURE SERIES

Dec 4

Flexible Load Operation of industrial plants for the integration of renewable energies (M)

Dr. Eike Cramer;
RWTH Aachen
Kopernikus Synergie

WHAT DO WE ADRESS IN THE LECTURE SERIES

Dec 12

Infrastructure, networks and availability of resources

transport and storage infrastructure of green hydrogen
system-analytical and economic aspects

four energy vectors:

- Gaseous Hydrogen
- Liquid Hydrogen
- Ammonia
- LOHC Liquid organic hydrogen carriers

Frank Graf/ Deutscher Vereins des Gas- und Wasserfaches e.V. (DVGW)-Ebi, Dorothea Müschenborn/Max-Planck-Institut für Chemische Energiekonversion; **TransHyDE**

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WHAT DO WE ADRESS IN THE LECTURE SERIES

Jan 15

Hydrogen and Power-to-X in the future German energy system (M)

- Energy grids,
- Energy storage

Dr. Franz Bauer
OTH Regensburg
Forschungsstelle für Energienetze und Energiespeicher (FENES)

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WHAT DO WE ADRESS IN THE LECTURE SERIES

Jan 22

Towards a sustainable Power-to-X economy – the role of international trade and reliable frameworks

- Hydrogen trade
- trade (certification system for imported products)
  environmental, economic, social and governance impacts
- Chile emerging as a key player

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Ulrike Hinz/WWF, Heino von Meyer/PtX Hub, Veronica Vukasovic/GIZ PtX Hub Chile, Urugay

WHAT DO WE ADRESS IN THE LECTURE SERIES

Jan 29

Microreactors and organic electrosynthesis (M)

- **High value chemicals**
- microreactor technology and their potential to be coupled to electrolysis
- Organic electrosynthesis- direct use of electrons as chemical reactants
- Examples for industrial processes

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Dr. Peter Holtappels
KIT

WHAT DO WE ADRESS IN THE LECTURE SERIES

Feb 5

Power-to-X: Impact on society/acceptance

- acceptance factors
- criteria for a socially acceptable hydrogen ramp-up

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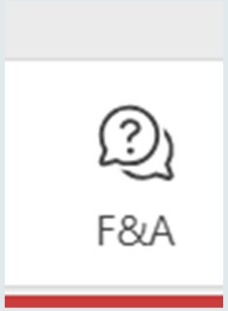
Irina Rau, Jan Hildebrand
IZES

INTRODUCTION

- Any questions concerning introduction?
- please use



- Due to the time delay, we will collect your questions for approximately 2 minutes and return with the answers in about 5 minutes

Chapter 2

SYNTHETIC FUELS:
THE PATH TO CLIMATE-NEUTRAL ENERGY SYSTEMS

PROF. DR. PETER MANSHAUSEN

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EUROPEAN GREEN DEAL

The EU aims to be climate-neutral by 2050 – an economy with net-zero greenhouse gas emissions. This objective is at the heart of the European Green Deal, and is a legally binding target thanks to the European Climate Law.

GLOBAL CO_2 EMISSIONS FROM TRANSPORT

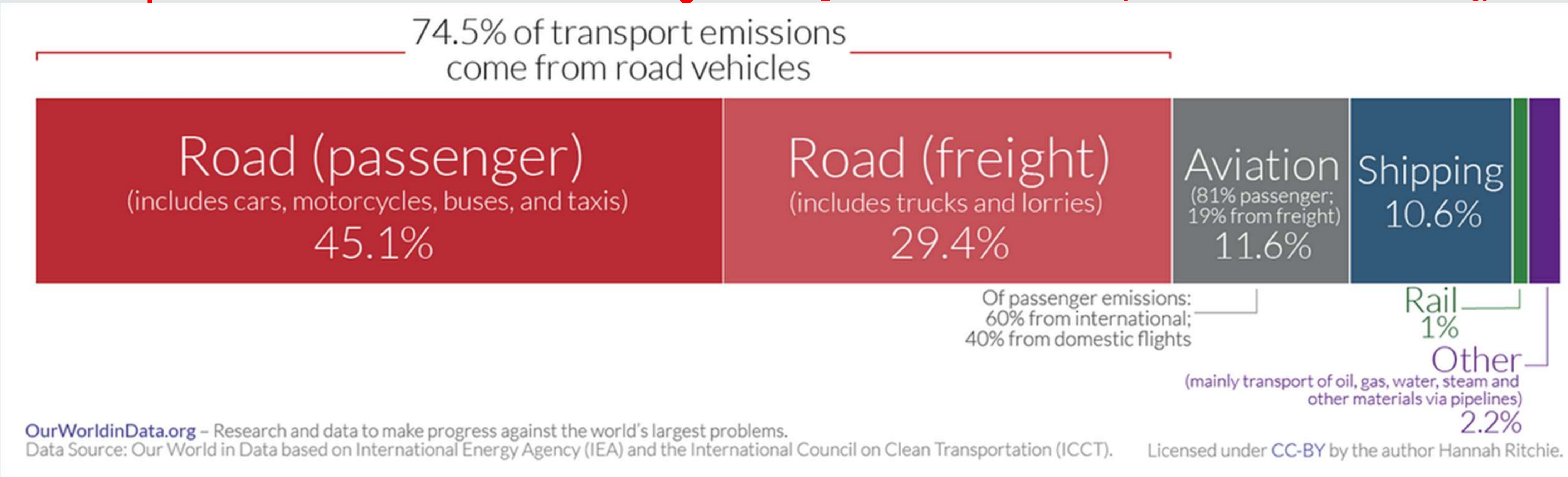
Transport accounts for around one-fifth of global CO_2 emissions … if we only consider CO_2 emissions from energy

The International Energy Agency (IEA) expects global transport (measured in passenger kilometers) to double, car ownership rates to increase by 60%, and demand for passenger and freight aviation to triple by 2070

https://ourworldindata.org/co2-emissions-from-transport

GLOBAL CO_2 EMISSIONS FROM TRANSPORT

Transport accounts for around one-fifth of global CO_2 emissions … if we only consider CO_2 emissions from energy



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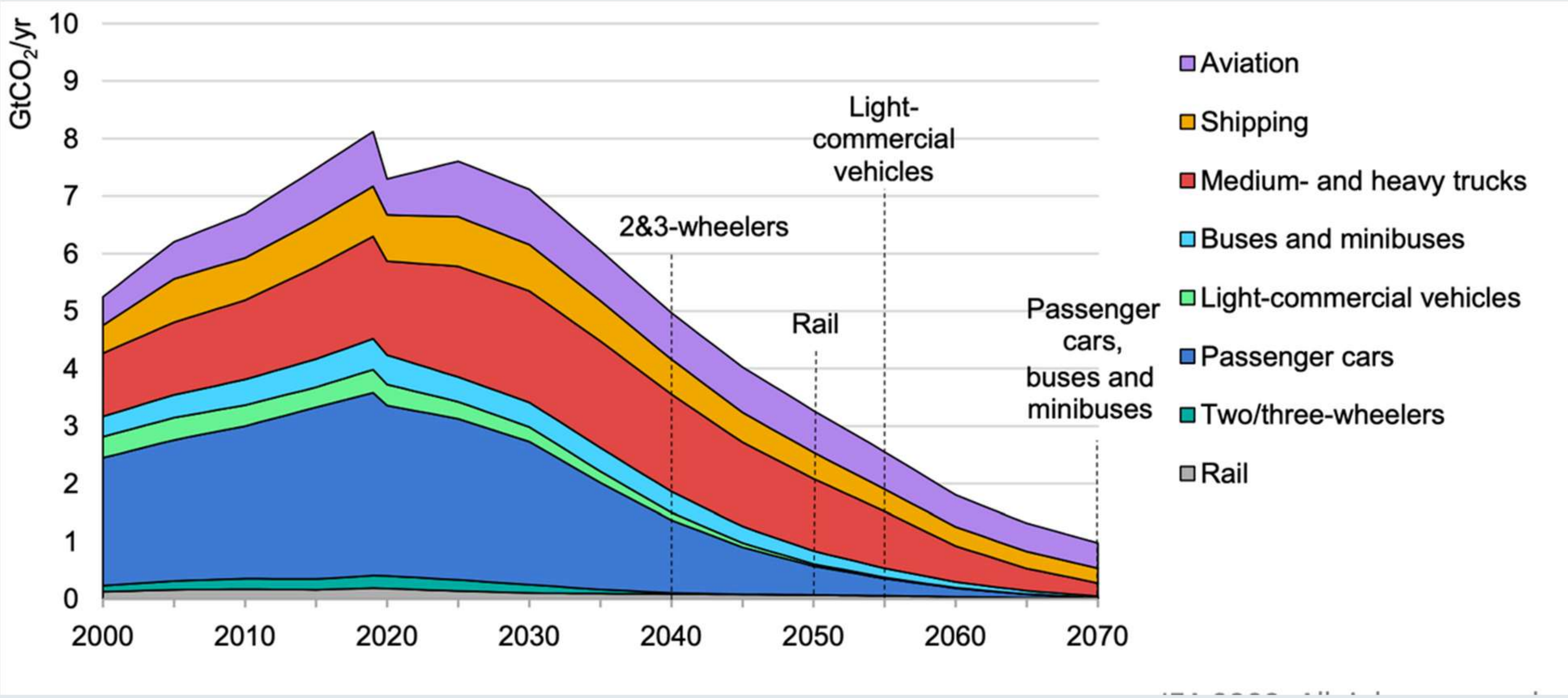
https://ourworldindata.org/co2-emissions-from-transport

GLOBAL CO_2 EMISSIONS BY TRANSPORT MODE – REDUCTION SCENARIOS



Dotted lines indicate the year in which various transport modes have largely stopped consuming fossil fuels

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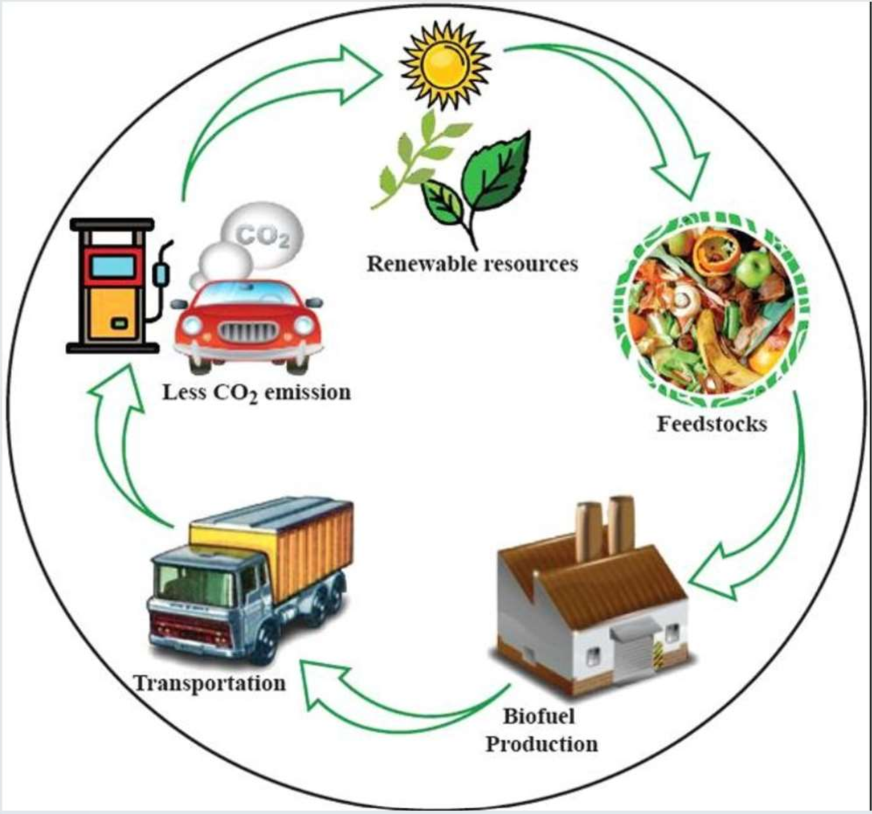
IEA (2020), Energy Technology Perspectives 2020, IEA, Paris
Hannah Ritchie (2020) - "Cars, planes, trains: where do CO_2 emissions from transport come from?" Published online at OurWorldinData.org. Retrieved from: 'https://ourworldindata.org/co2-emissions-from-transport' [Online Resource]

CLIMA-NEUTRAL (SUSTAINABLE) FUELS CAN BE A SOLUTION



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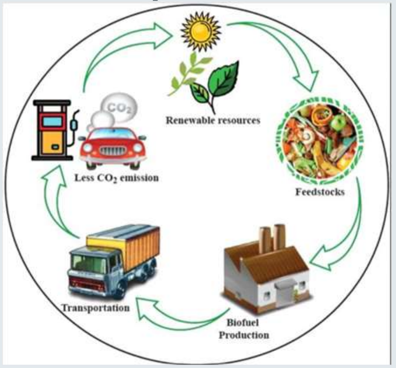
HOW TO PRODUCE CLIMA-NEUTRAL (SUSTAINABLE) FUELS



- Biofuel – conversion of biomass, generated by photosynthesis

  produced from energy plants (e.g. 1st, 1.5 generation bio-ethanol, or biodiesel) or from agricultural, domestic or industrial biowaste (e.g. 2nd, 3rd generation bioethanol, “Fischer-Tropsch-fuels”, and others.

- Hydrogen Fuel - directly transformed into electricity in “Fuel Cells”

  produced by natural gas reforming (a thermal process “blue Hydrogen”), electrolysis (“green Hydrogen”) as well as solar-driven and biological processes.

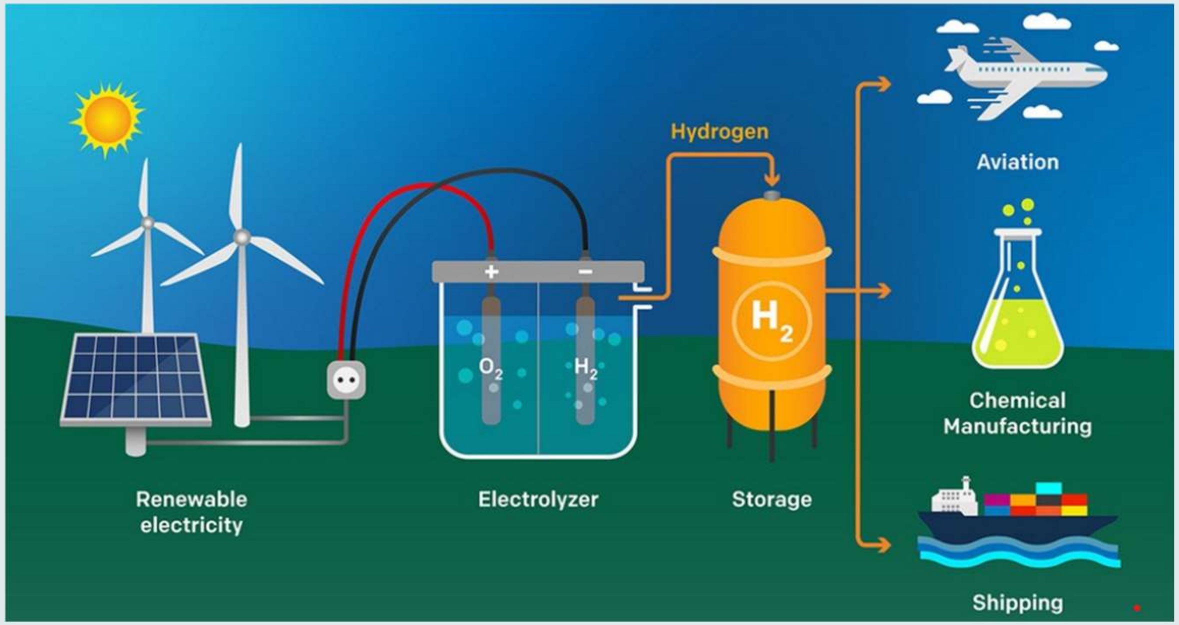
HOW TO PRODUCE CLIMA-NEUTRAL (SUSTAINABLE) FUELS

- Gas-to-Liquid (produce liquid fuels, which are more readily transported than methane)
- Power-to-Liquid – uses (green) Electricity to produce sustainable fuels which are Hydrocarbons of various compositions. The production of these sustainable fuels then needs several steps

Power-to-Liquid (PtL) step 1: H_2-generation

- Power-to-Liquid (PtL) is an innovative and emerging technology that addresses the dual challenges of **reducing carbon emissions** and **creating sustainable fuels**. PtL involves the conversion of renewable electricity into liquid hydrocarbons, which can be used as **synthetic fuels** or **chemical feedstocks**. The process begins with electrolysis, where water is split into hydrogen and oxygen using renewable electricity.

Biofuels are then made by combining Hydrogen with Carbondioxide (or Carbonmonoxide)



Picture: https://www.linkedin.com/pulse/largest-green-hydrogen-projects-world-futurefuels/

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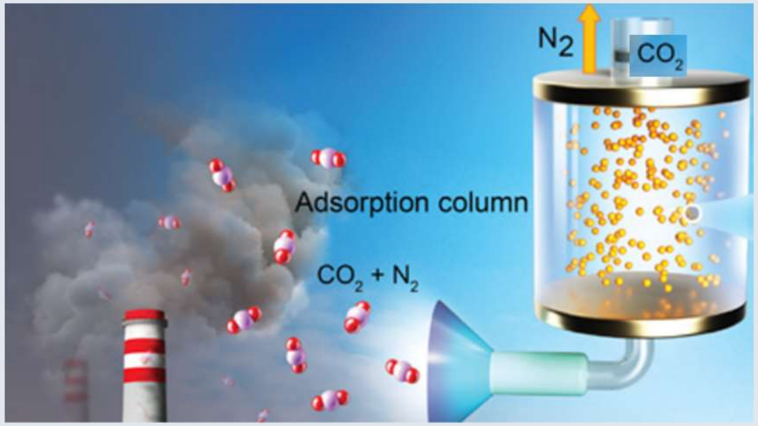
Power-to-Liquid (PtL) step 2: CO_2 capture & purification, N_2 separation

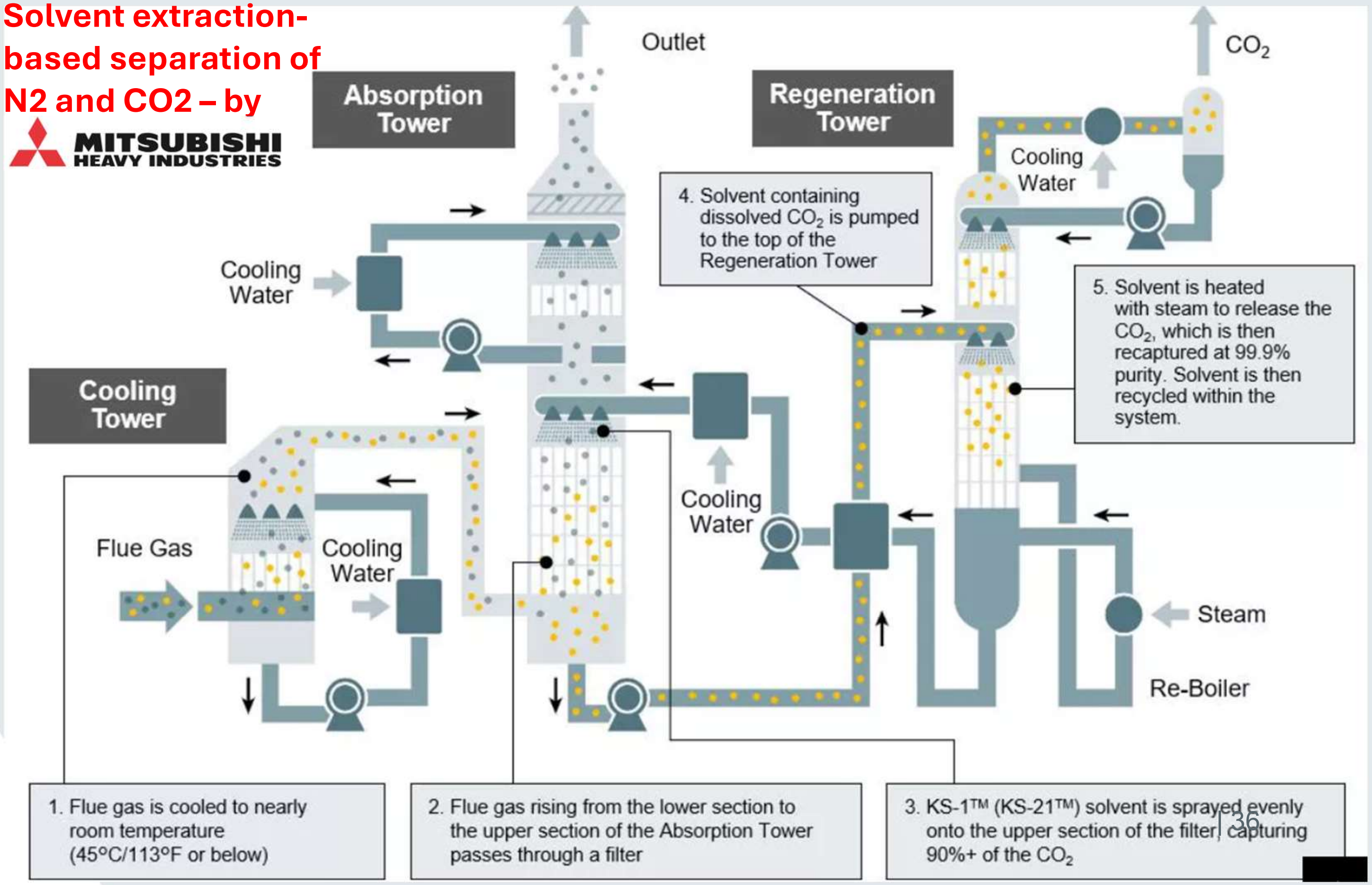
Membrane based separation of N2 and CO2



https://news.berkeley.edu/2022/08/04/a-simple-cheap-material-for-carbon-capture-perhaps-from-tailpipes/

Solvent extraction-based separation of N2 and CO2 – by

MITSUBISHI HEAVY INDUSTRIES



https://www.mhi.com/products/engineering/co2plants_process.html

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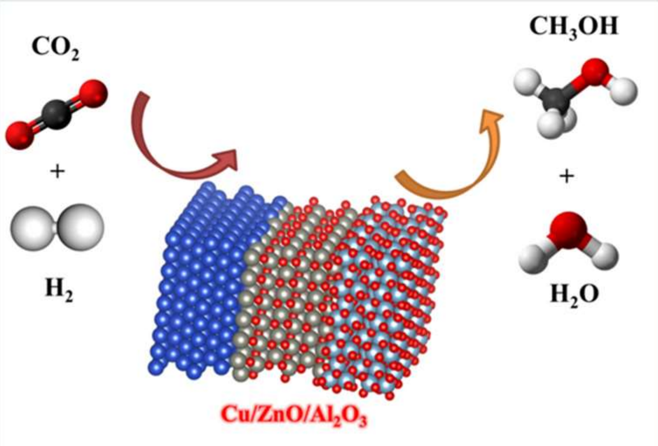
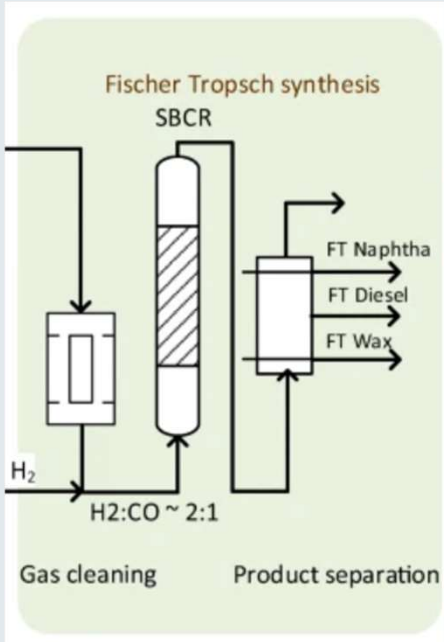
Power-to-Liquid (PtL) step 3 reaction of H_2 and CO_2

- Hydrogen is then combined with carbon dioxide, captured from industrial processes or directly from the atmosphere, through a series of chemical reactions such as **Methanol Synthesis** or **Fischer-Tropsch Synthesis**



Methanol Synthesis



$$2H_2 + CO \rightarrow (CH_2) + H_2O$$

$$(2n+1)\,H_2 + nCO \rightarrow C_nH_{2n+2} + nH_2O$$

$$(2n)\,H_2 + nCO \rightarrow C_nH_{2n} + nH_2O$$

Fischer-Tropsch Synthesis

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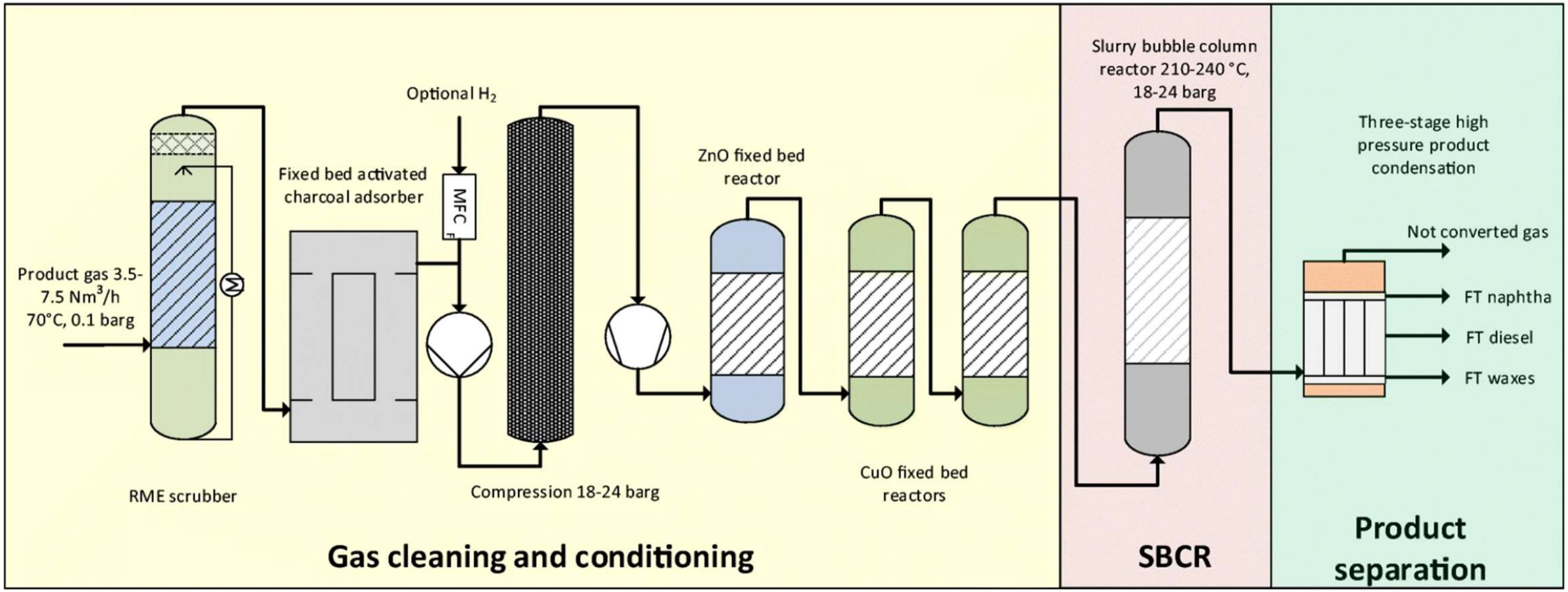
https://link.springer.com/article/10.1007/s13399-019-00459-5
https://www.researchgate.net/publication/374927377_Hydrogen_Spillover_Mechanisms_on_CuZnO-Based_Catalysts_for_CO2_Hydrogenation_to_Methanol?_tp=eyJjb250ZXh0Ijp7ImZpcnN0UGFnZSI6Il9kaXJlY3QiLCJwYWdlIjoiX2RpcmVjdCJ9fQ

Power-to-Liquid (PtL) step 3 – Fischer-Tropsch

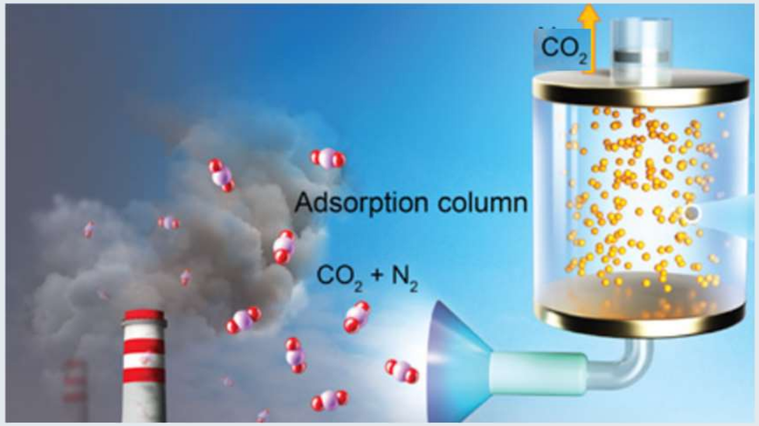


The result is a range of liquid hydrocarbons, including synthetic diesel, kerosene, and methanol, which can be used in existing internal combustion engines, aviation, and chemical industries.

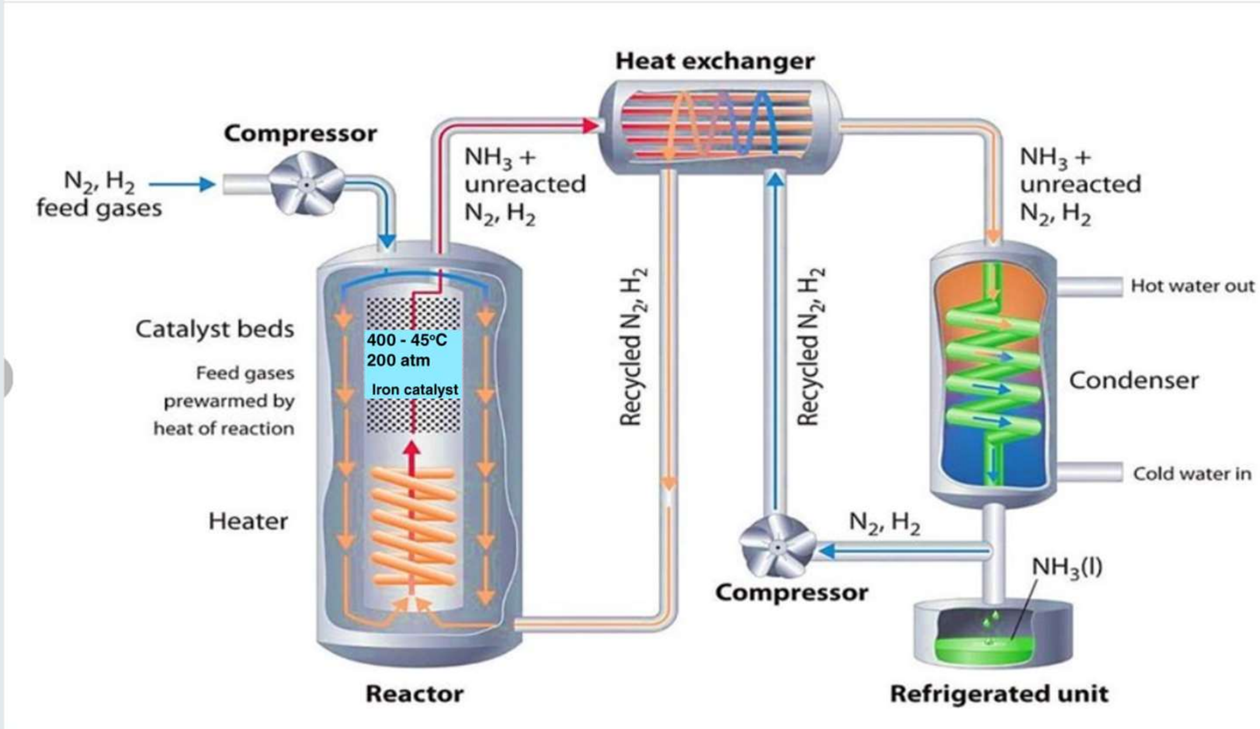
https://link.springer.com/article/10.1007/s13399-019-00459-5

Power-to-Liquid (PtL) option 2: Ammonia (NH_4) synthesis Haber-Bosch process

Membrane based separation of N2 and CO2



https://news.berkeley.edu/2022/08/04/a-simple-cheap-material-for-carbon-capture-perhaps-from-tailpipes/



Ammonia is an energy carrier which is much easier to transport, than Hydrogen

https://www.mhi.com/products/engineering/co2plants_process.html

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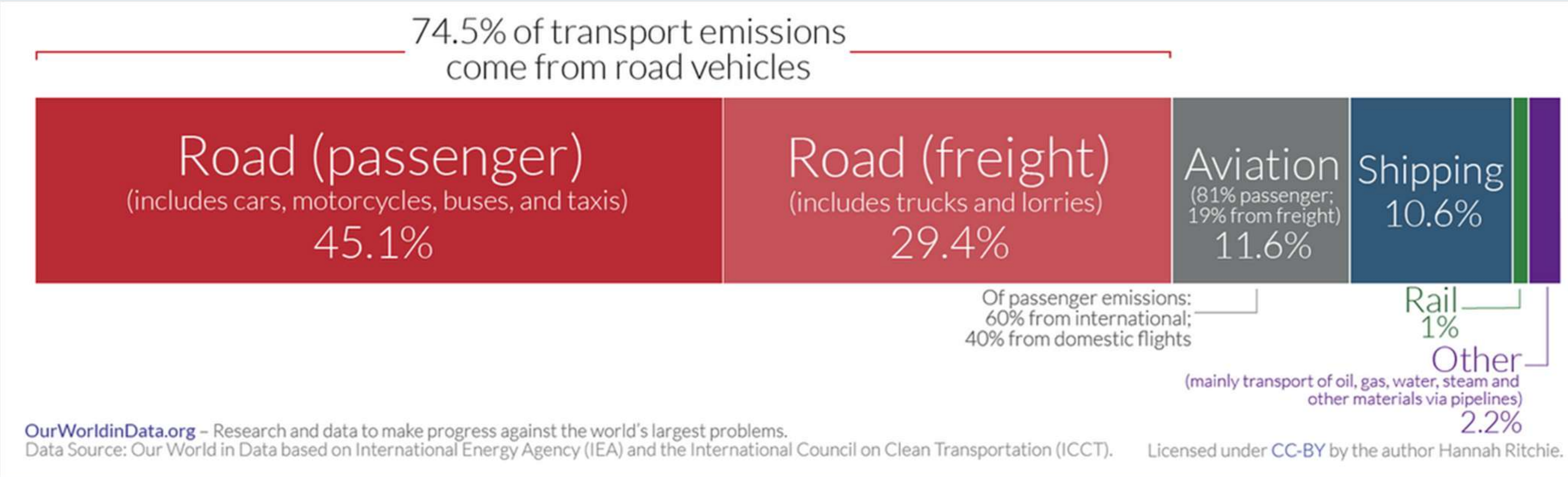
GLOBAL CO_2 EMISSIONS FROM TRANSPORT

Transformation of aviation is one of the most challenging task on our way to sustainability

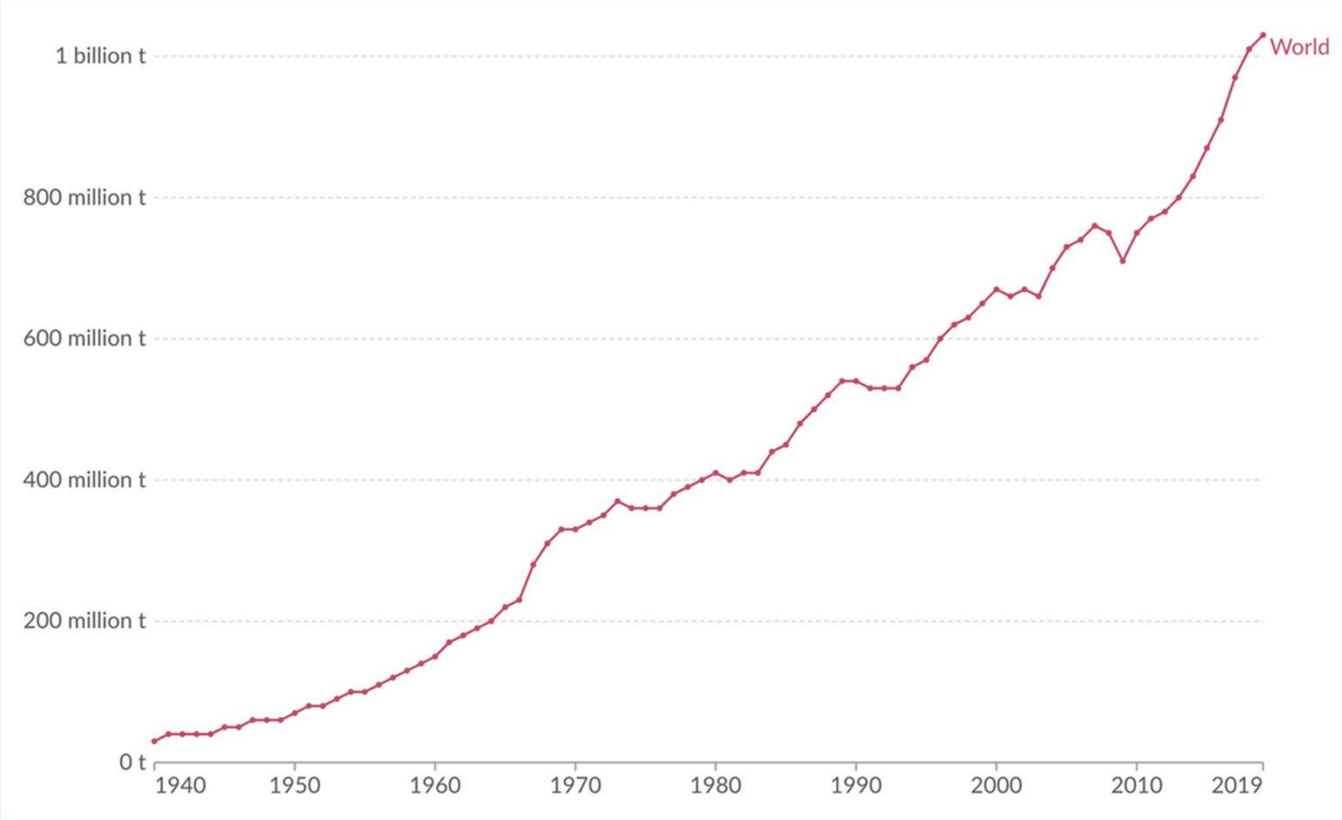


Production of Sustainable Aviation Fuels (SAF) is one important key driver for a “greener” transportation future

https://ourworldindata.org/co2-emissions-from-transport

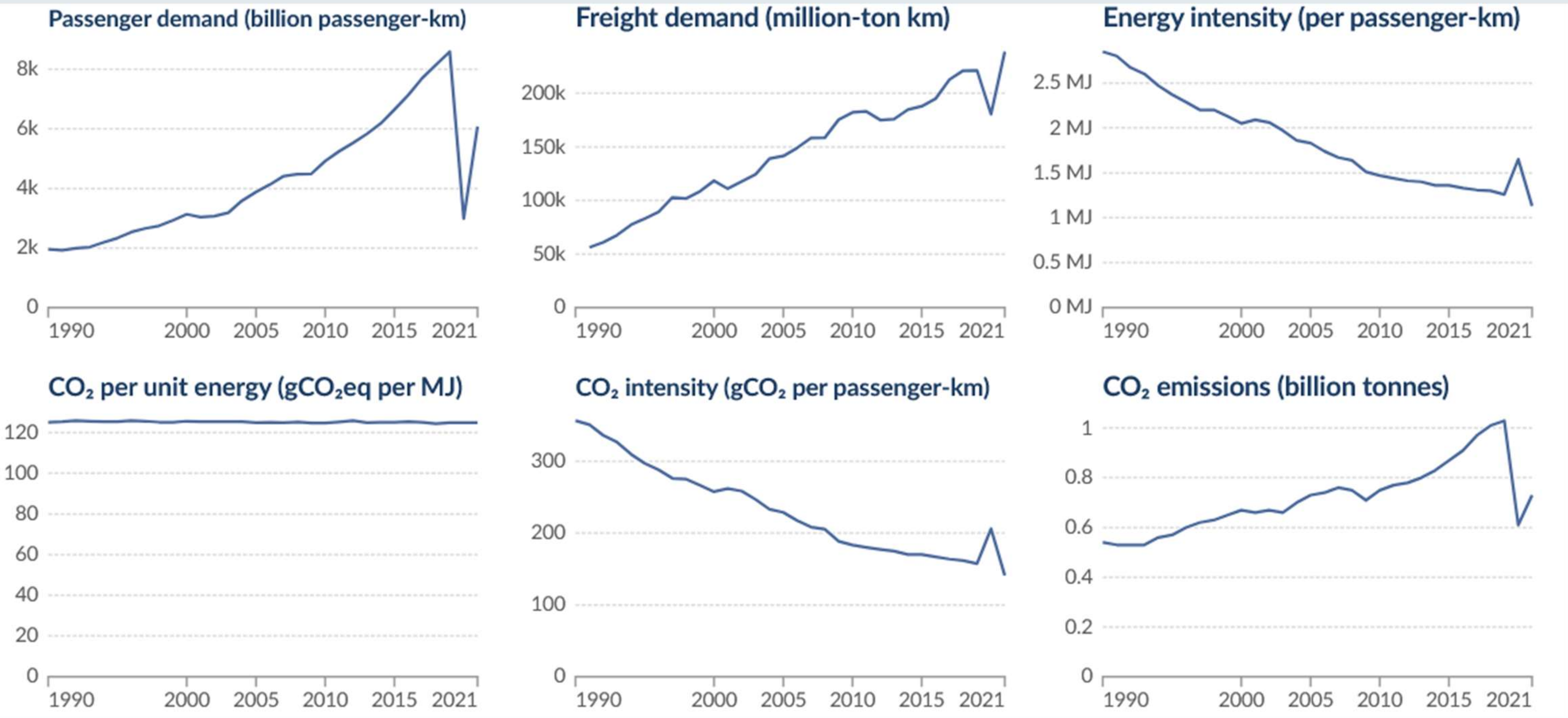
GLOBAL CO_2 EMISSION FOM AVIATION (1940-2019)

Global CO_2 emissions from aviation have quadrupled since the 1960s. Nowadays Aviation accounts for 2.5% of global CO_2 emissions.



Data source: Pre-1990 data from Lee et al. (2021); 1990 onwards from Bergero et al. (2023)

GLOBAL AVIATION DEMAND, ENERGY EFFICIENCY AND CO_2 EMISSIONS, 1990 TO 2021



Bergero et al. (2023). Pathways to net-zero emissions from aviation

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THESE FIGURES ILLUSTRATE THE IMPORTANCE OF SUSTAINABLE AVIATION FUELS

HOW TO PRODUCE SUSTAINABLE AVIATION FUELS (SAF)

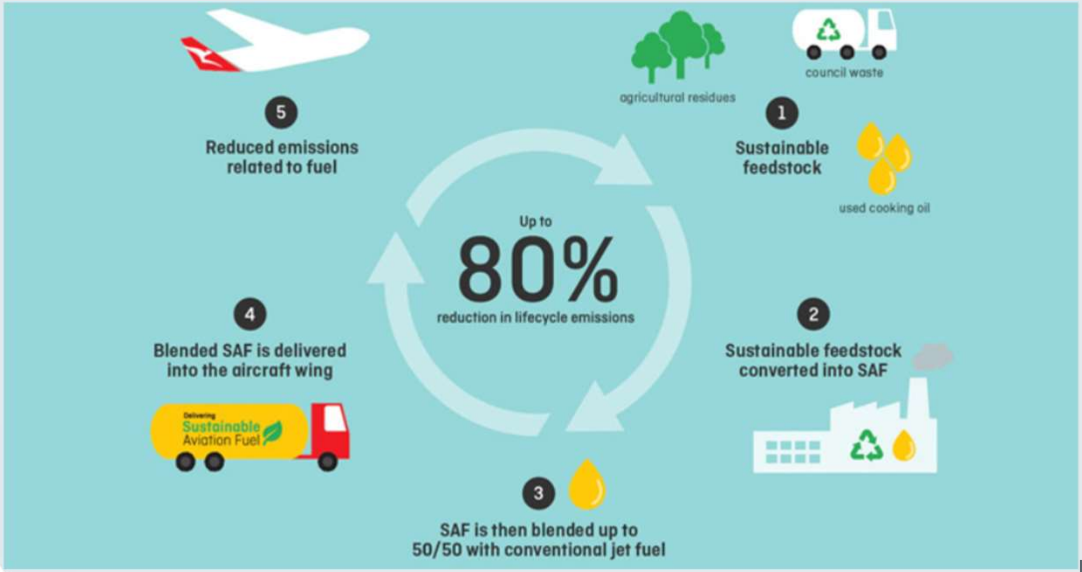
SAF can be produced from non-petroleum-based renewable feedstocks including, but not limited to, the food and yard waste portion of municipal solid waste, woody biomass, fats/greases/oils, and other feedstocks. Several technologies are applied:

- **Hydroprocessed Esters and Fatty Acids** (HEFA-SPK - 4.2 million *tonnes* by 2025)
- Fischer-Tropsch Synthetic Paraffinic Kerosene (FT-SPK),
- Synthesized Iso-paraffin from Hydro-processed Fermented Sugar (HFS-SIP),
- Alcohol to Jet Synthetic Paraffinic Kerosene (ATJ-SPK),
- Catalytic Hydrothermolysis Synthesized Kerosene (CHJ),
- Hydroprocessed Hydrocarbons (HC-HEFA-SPK from Algae),
- Fischer Tropsch Synthetic Kerosene with Aromatics (FT-SKA),

AVIATION FUELS (KEROSENES) HAVE VERY MUCH RESTRICTIVE SPECIFICATIONS

Sustainable Kerosene replacements in aviation fuels are difficult to obtain and they need approval according to ASTM D7655 and DEF-STAN 91-91. Standard alternatives do not comply with these specifications.
In 2009 first sustainable aviation fuels had been developed, receiving an approval from authorities to be used in Kerosene-blends with up to 50% SPK

SAF is priced at approximately **2400 USD per tonne**, which is 2.5x the price of conventional jet fuel. This disparity is largely attributed to SAF's small production runs.
By 2050, the average cost is estimated at **$760-$900 per tonne SAF**



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Die Zukunft unserer Energie

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MAJOR INDUSTRIAL MANUFACTURERS OF SAF

Aemetis, Inc., Alder Fuels, Fulcrum BioEnergy Inc., Gevo Inc., LanzaJet, Neste, Northwest Advanced Bio-Fuels, LLC, Preem AB, Red Rock Biofuels, Shell PLC, SkyNRG BV, World Energy, and others

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SUSTAINABLE FUELS AND FUEL-EFFICIENCY PLAY AN IMPORTANT ROLE TO BECOME CLIMATE-NEUTRAL BY 2050

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PARTICIPATION CERTIFICATE

.

Participation Certificate Request

BEGLEITFORSCHUNG P2X-RINGVORLESUNG

Your opinion is important - We look forward to your participation!

Ihre Meinung ist wichtig - Wir freuen uns über Ihre Teilnahme!

Foto von Firmbee.com auf Unsplash

SCAN ME

www.soscisurvey.de/P2X-Ringvorlesung/

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IZES Institut für ZukunftsEnergie- und Stoffstromsysteme

THANK YOU FOR YOUR PARTICIPATION – SEE YOU NEXT WEEK

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