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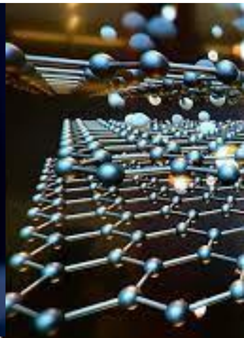
Revolutionising Energy Systems: How Do We Meet Evolving Customer Needs Through Renewables, Hydrogen, CCUS and Electrification

Prof. Lourdes F. Vega
Director, Research and Innovation Center on CO_2 and Hydrogen (RICH Center)
Chemical Engineering Department, Khalifa University, Abu Dhabi, UAE

Abu Dhabi, 12th September 2023



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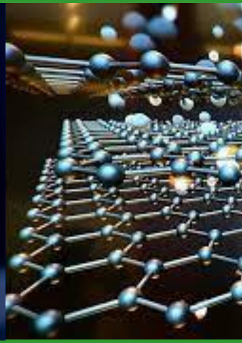

Revolutionising Energy Systems: How Do We Meet Evolving Customer Needs Through Renewables, Hydrogen, CCUS and Electrification

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Khalifa University جامعة خليفة

Research and Innovation Center on CO_2 and Hydrogen (RICH)

Launched in 2019 at KU, it focuses on the **value chain of both, CO_2 and hydrogen**, with the goal to provide innovative solutions for **Sustainable fuels and clean Energy, helping to achieve the Net Zero strategies**

80+ researchers/engineers, including 21 Faculty across colleges, graduate students and researchers.

Close collaboration with industry (oil & gas, power, chemicals, hard-to-abate sectors, water, others), **governmental institutions**, and **international key players**

T1- CO_2 capture & storage

Develop novel materials and highly efficient processes for CO_2 capture, separation and storage

Lead: Ahmed AlHajaj

T2- CO_2 utilization

Advanced materials & processes to convert CO_2 into CO_2-neutral valuable products

Lead: Maryam Khaleel

T3- H_2 production & storage

Establish technologies to efficiently produce and store hydrogen in a low-carbon-footprint economy

Lead: Lourdes Vega

T4- H_2 distribution & utilization

Optimization of materials & processes for H_2 distribution. H_2 applications: e-fuels, ammonia, CHP, etc.

Lead: Dimitri Kyritsis

T5- Sustainable Fuels

Advanced processes and technologies to produce and optimize low-carbon fuels from different sources

Lead: Giovanni Palmisano

T6- Outreach, education, exploitation and dissemination

The RICH team

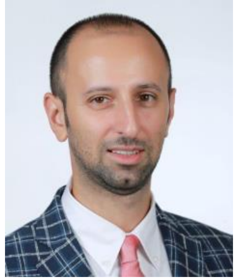
Leadership team


Prof. L. Vega, Director, Lead T3


Dr. A. AlHajaj, Lead T1


Dr. M. Khaleel Lead T2


Prof. D. Kyritsis, Lead T4


Prof. G. Palmisano Deputy Director, Lead T5

21 faculty covering different areas of expertise and technologies.
+70 more scientists: postdocs, graduate students and engineers


Dr. E. Al Shalabi


Prof. R. Nogueira


Dr. J. Rodriguez


Dr. A. Ceriani


Dr. K. Al-Ali


Dr. L. Dumée


Prof. L. Zheng


Prof. A. Almansoori


Dr. W. Alameri


Prof. E. Nashef


Prof. D. Goussis


Dr. A. Decarlis


Dr. H. Taher


Dr. B. Tardy


Dr. S. Sengodan


Dr. S. Mettu

RICH Center @ Khalifa University - Resources

First the excellent team of researchers

RICH Labs
- Advanced Materials Lab
- Photocatalysis and Chemical Reaction Lab
- Biochemical Processes Lab
- Combustion and Chemical Processes Lab
- Supercritical CO_2 Lab
- Computational Lab – Multiscale modeling

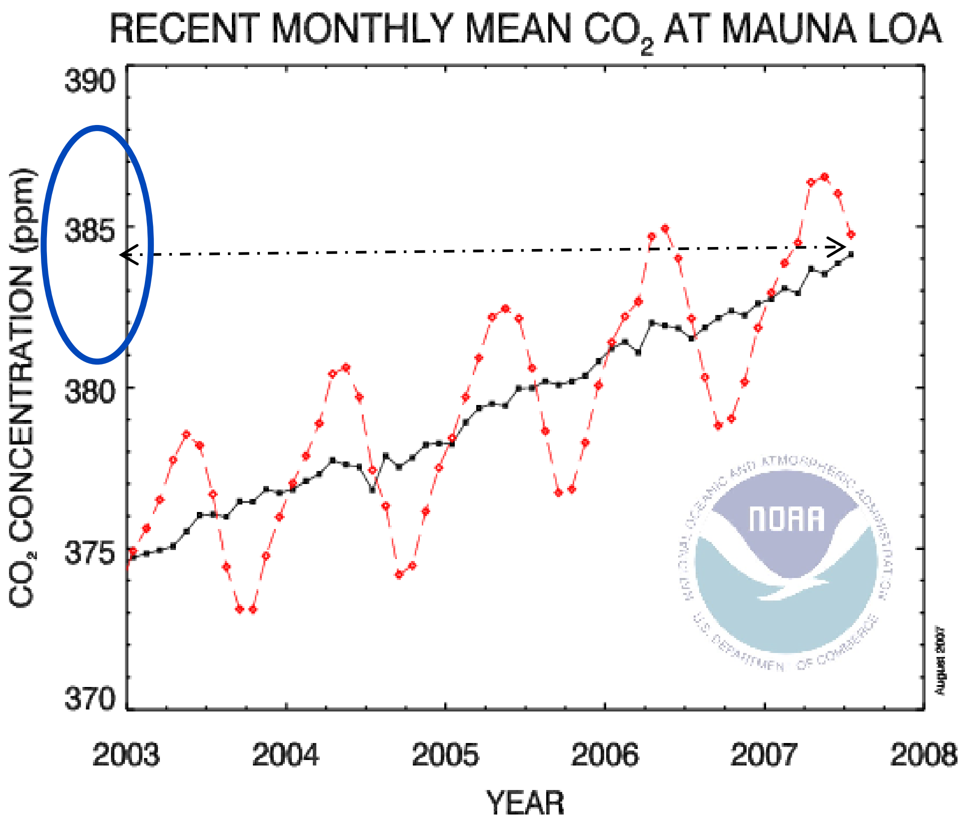
Core laboratories at Khalifa University
- Electron Microscopy facility
- Micro/nanofabrication facility
- Solar and Device Characterization Lab
- Materials testing Lab
- ACBC Lab
  Electrochemistry Lab
- High Performance Computing clusters

Stakeholders and international collaborators

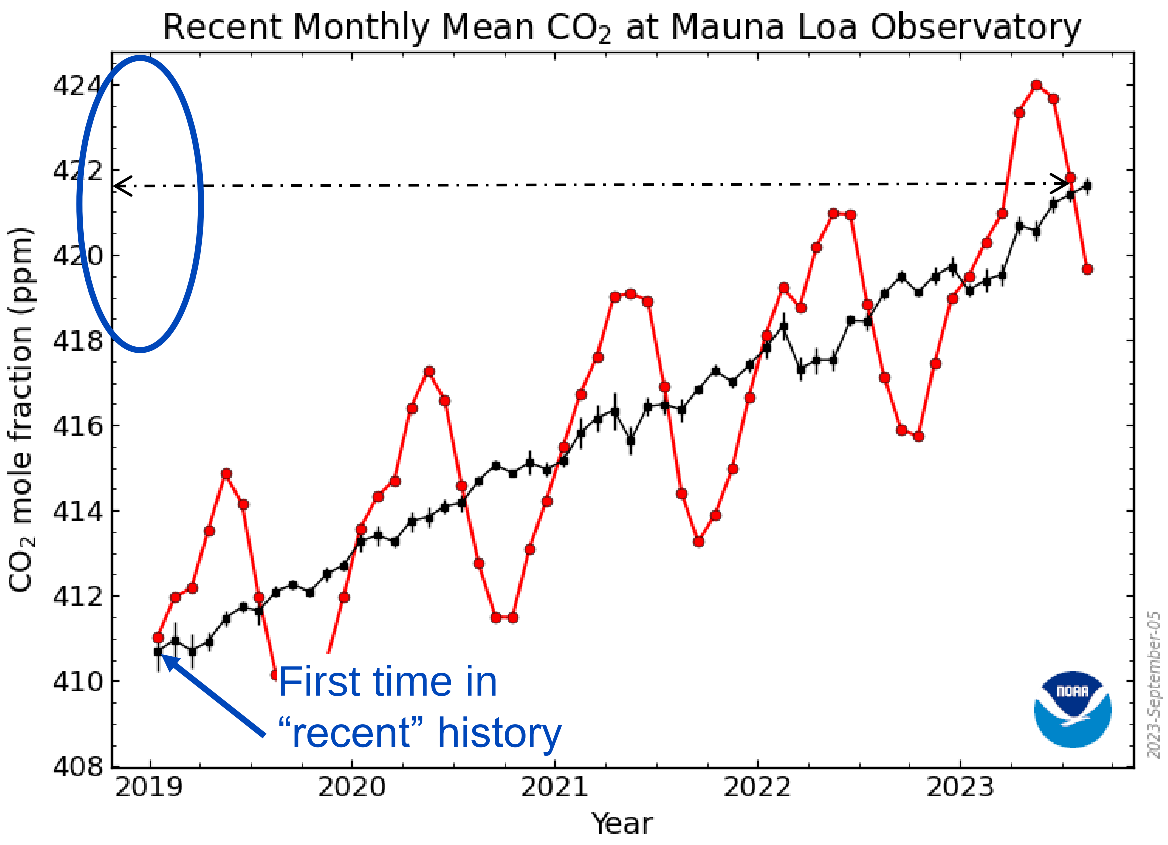
emirates steel, EHA European Hydrogen Association, ieaghg, Air Liquide, IEE Japan, IREC, TU/e Eindhoven University of Technology, Demokritos National Center for Scientific Research, Imperial College London, CSIRO, RTI International, Johns Hopkins University, Texas A&M University, universidade de aveiro, University of Regina, ECN, TNO, Universitat Rovira i Virgili, ADNOC, Masdar A Mubadala Company, ATD, vito, I²CNER, United Arab Emirates Ministry of Energy & Infrastructure

What is the situation today?

August 2023: 419.68 ppm
August 2022: 417.15 ppm
Last updated: Sep 05, 2023



16 years ago (2007)



NOAA NATIONAL CENTERS FOR ENVIRONMENTAL INFORMATION
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
Formerly the National Climatic Data Center (NCDC)... more about NCEI »

https://gml.noaa.gov/ccgg/trends/

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August 2022: 417.15 ppm
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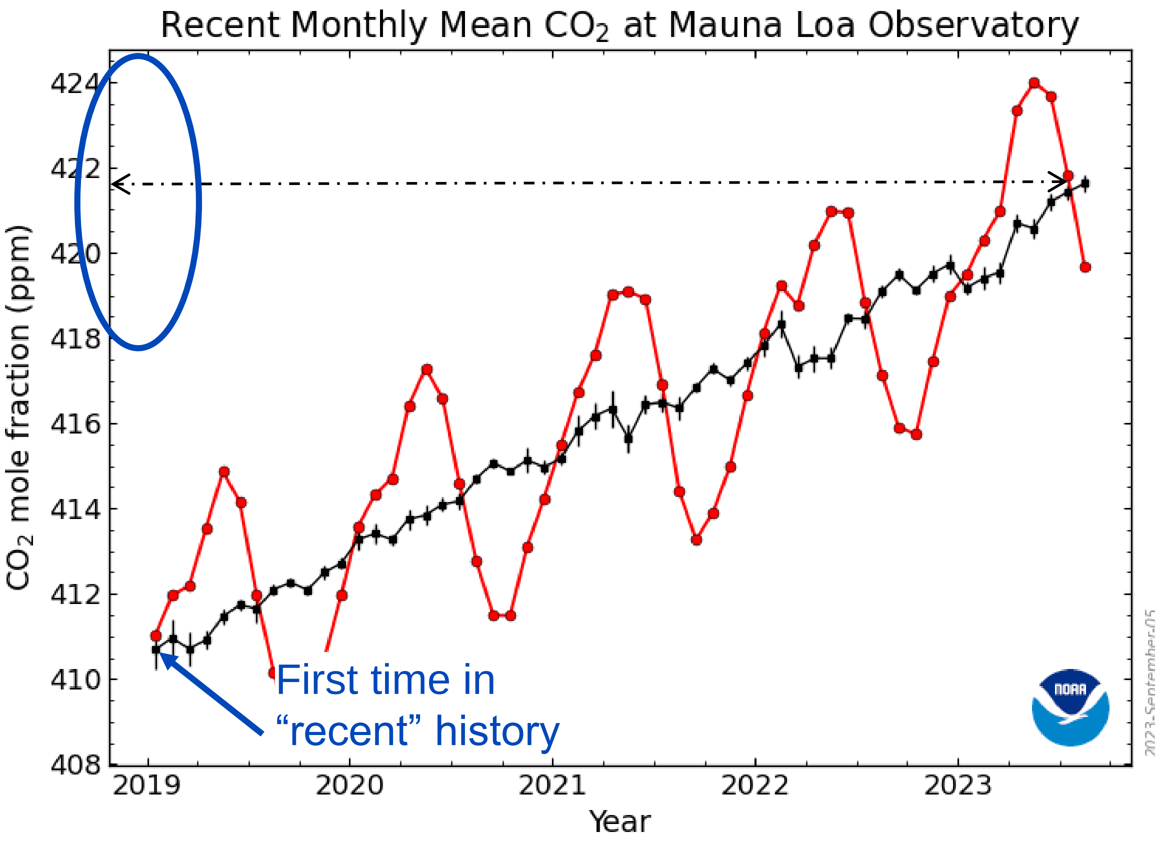
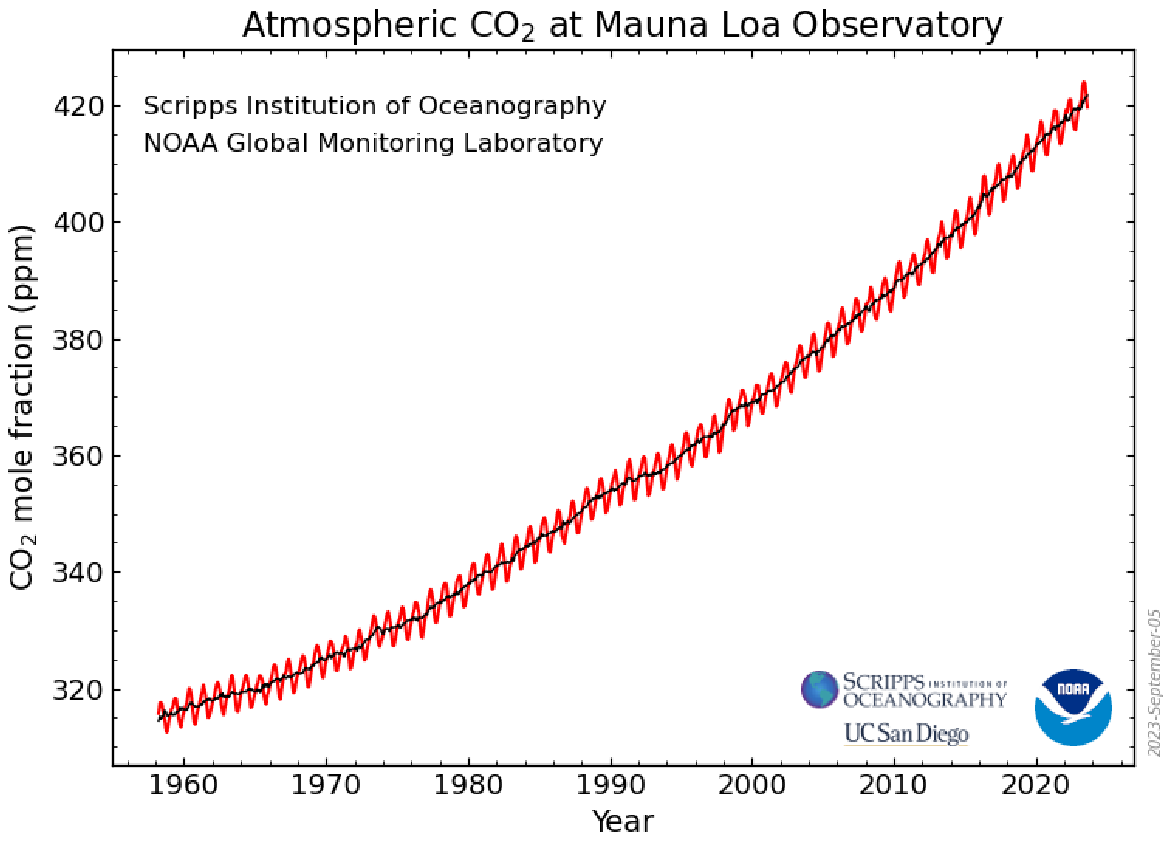
LAST 5 YEARS



LAST 63 YEARS



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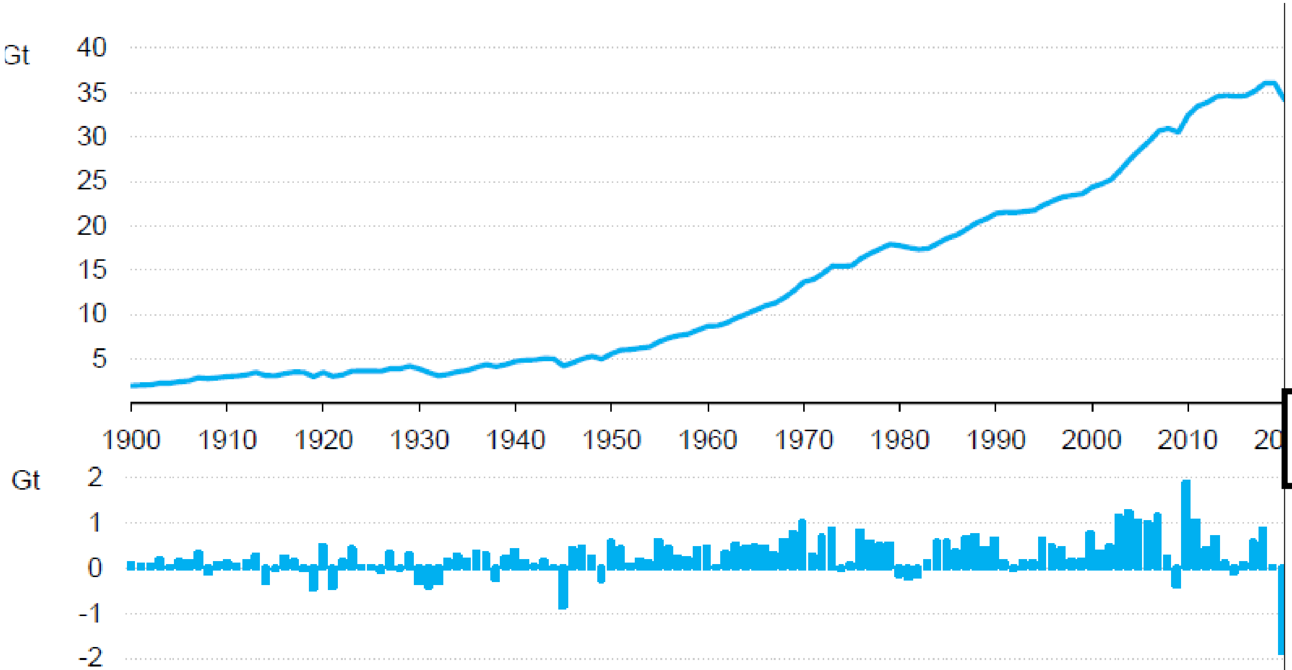
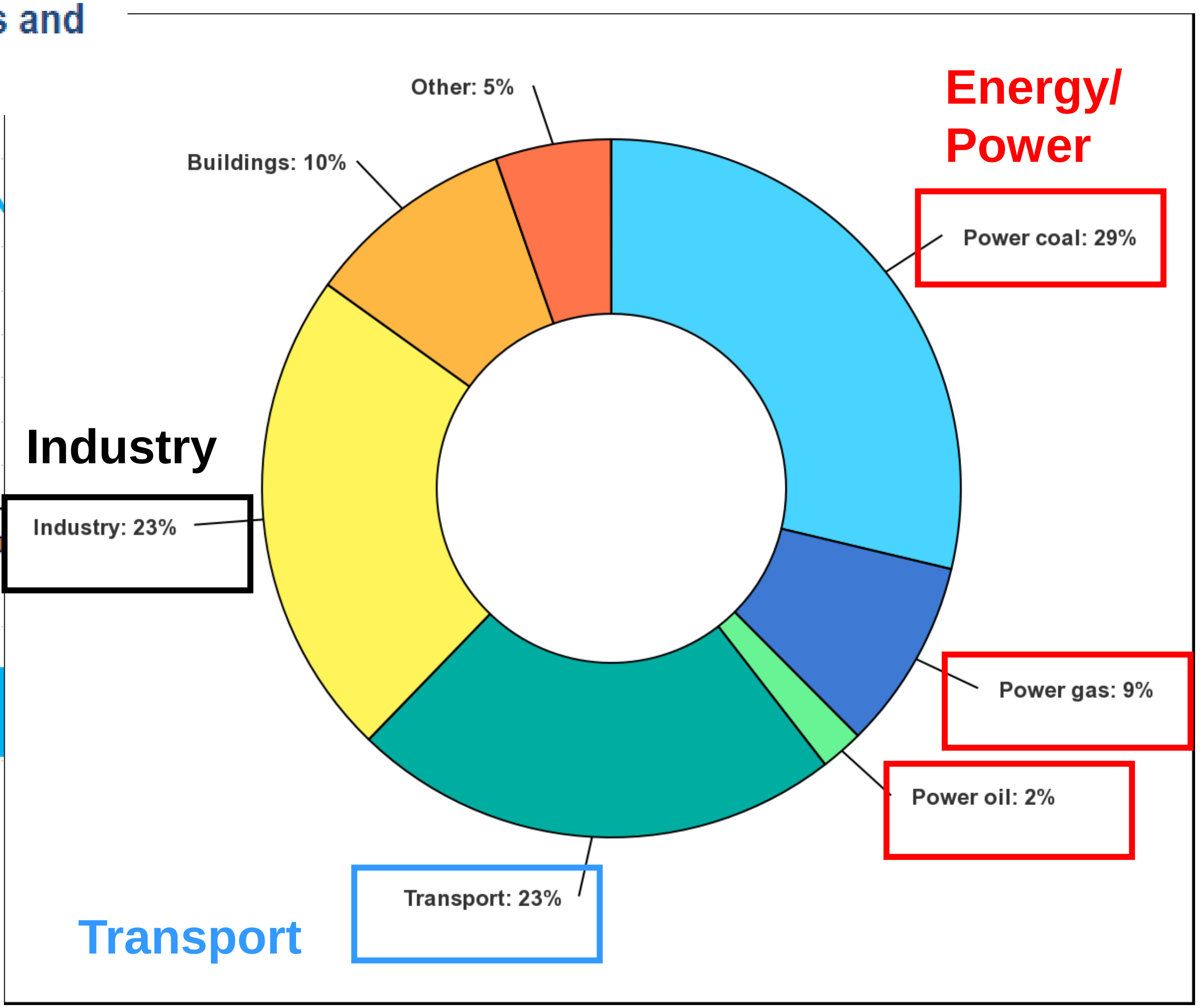
Where are these emissions coming from?

Total CO2 emissions from energy combustion and industrial processes and their annual change, 1900-2021



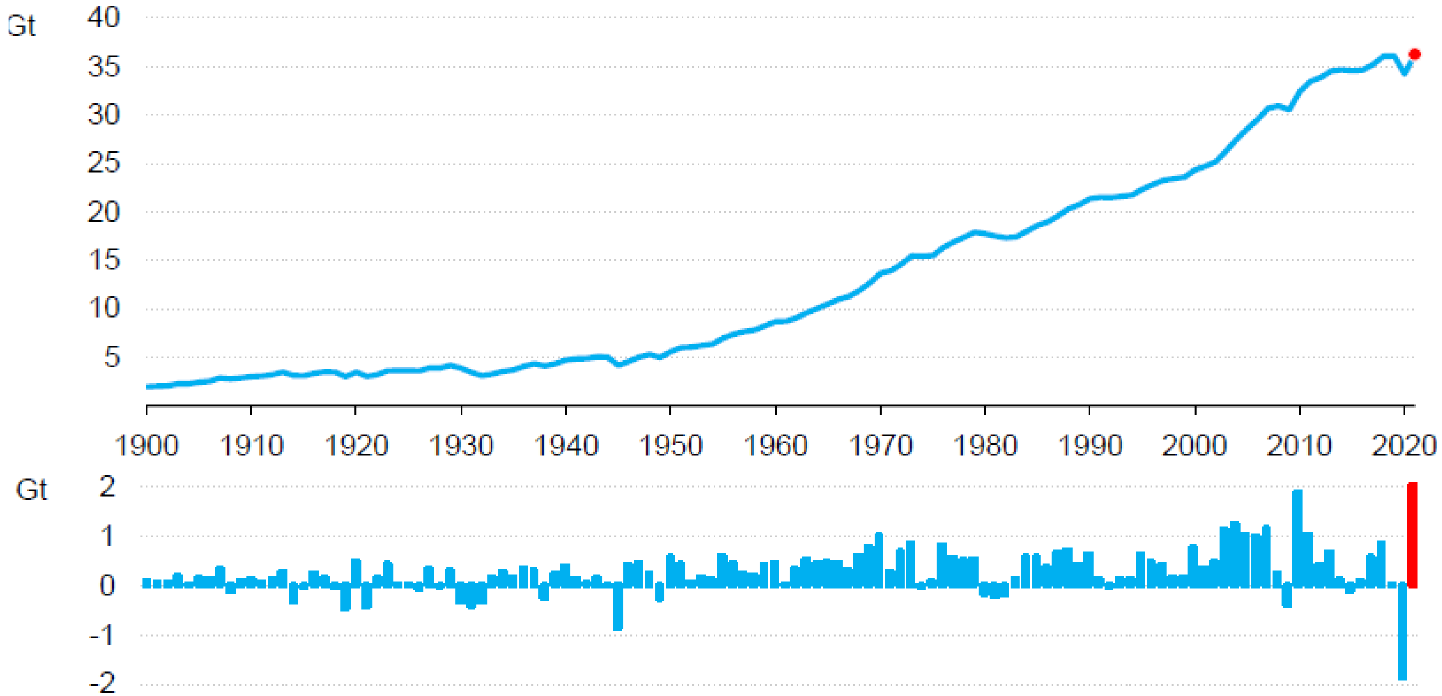


Energy-related CO_2 emissions grew to 36.3 Gt in 2021 – highest ever

Source: Global Energy Review: CO2 Emissions in 2021, IEA

Where are emissions coming from?

Total CO2 emissions from energy combustion and industrial processes and their annual change, 1900-2021



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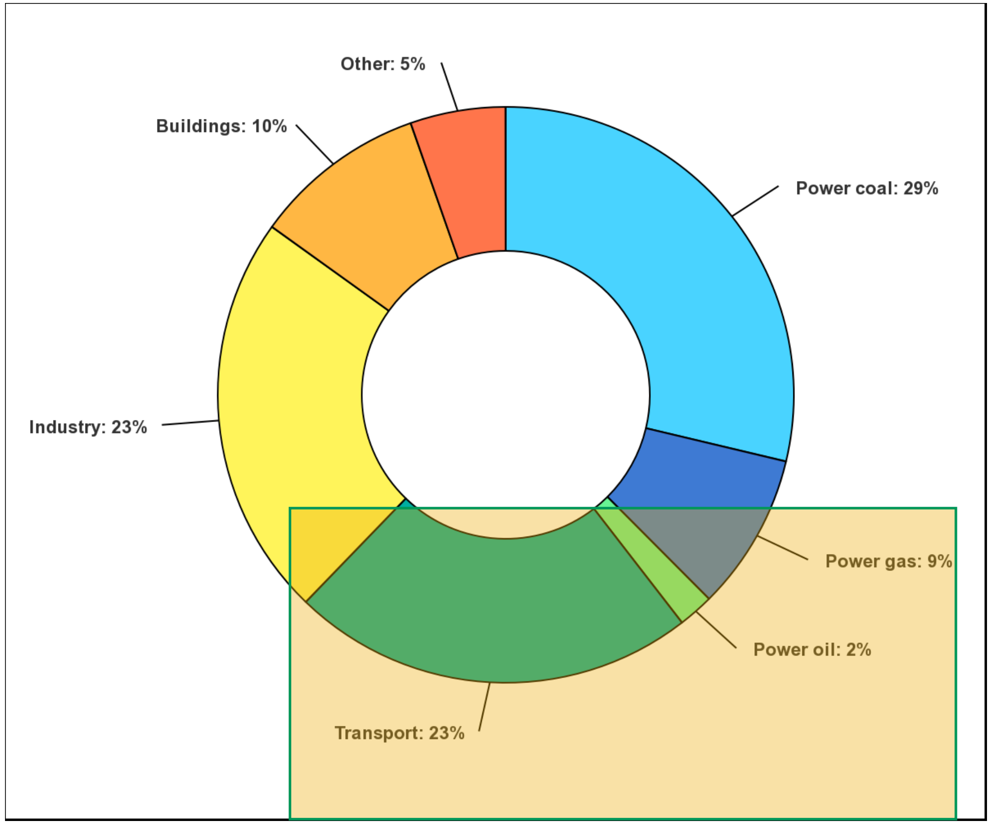
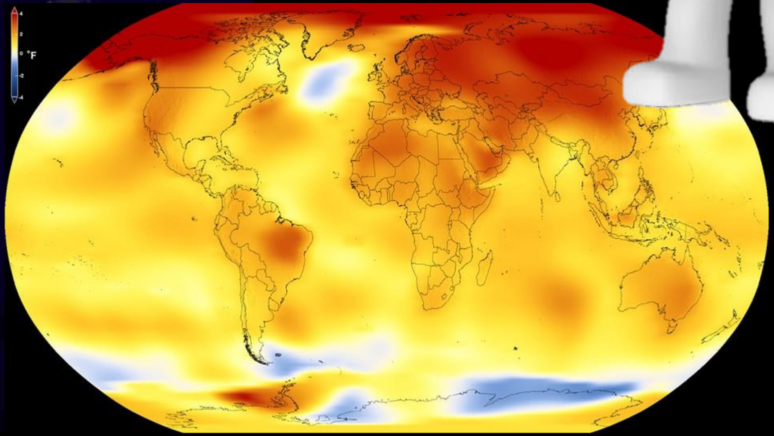


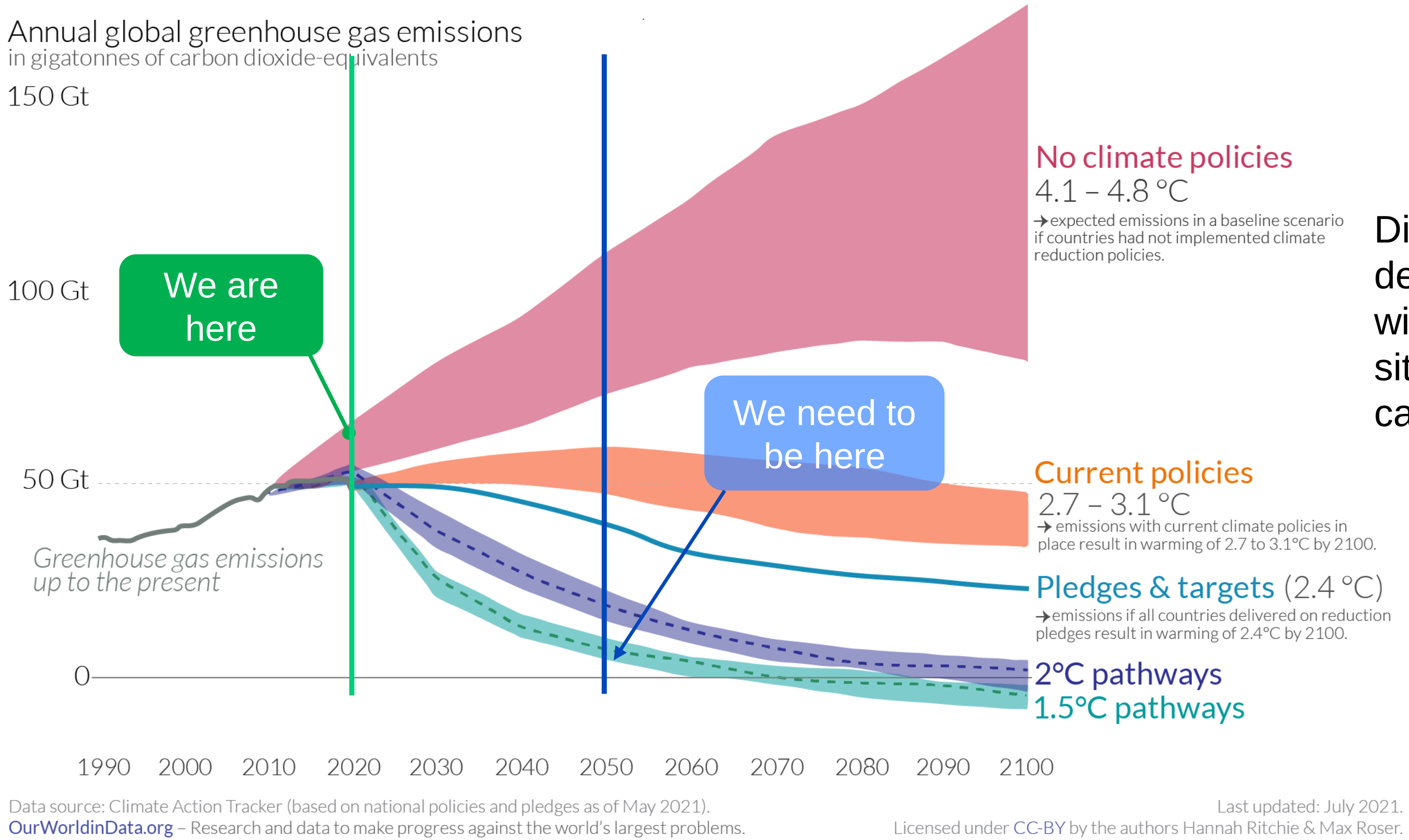
Related to Oil & Gas

Source: Global Energy Review: CO2 Emissions in 2021, IAE

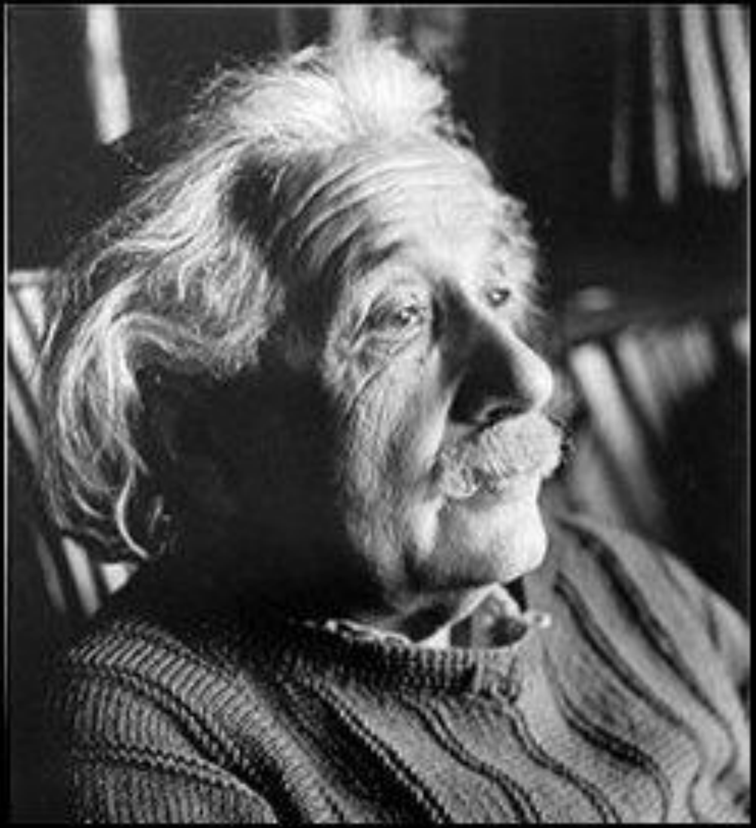
A planet in search for sustainable (secure and affordable) energy



The energy transition and greenhouse gases emissions



Different scenarios, depending on the actions, will lead us to different situations, some of them catastrophic.

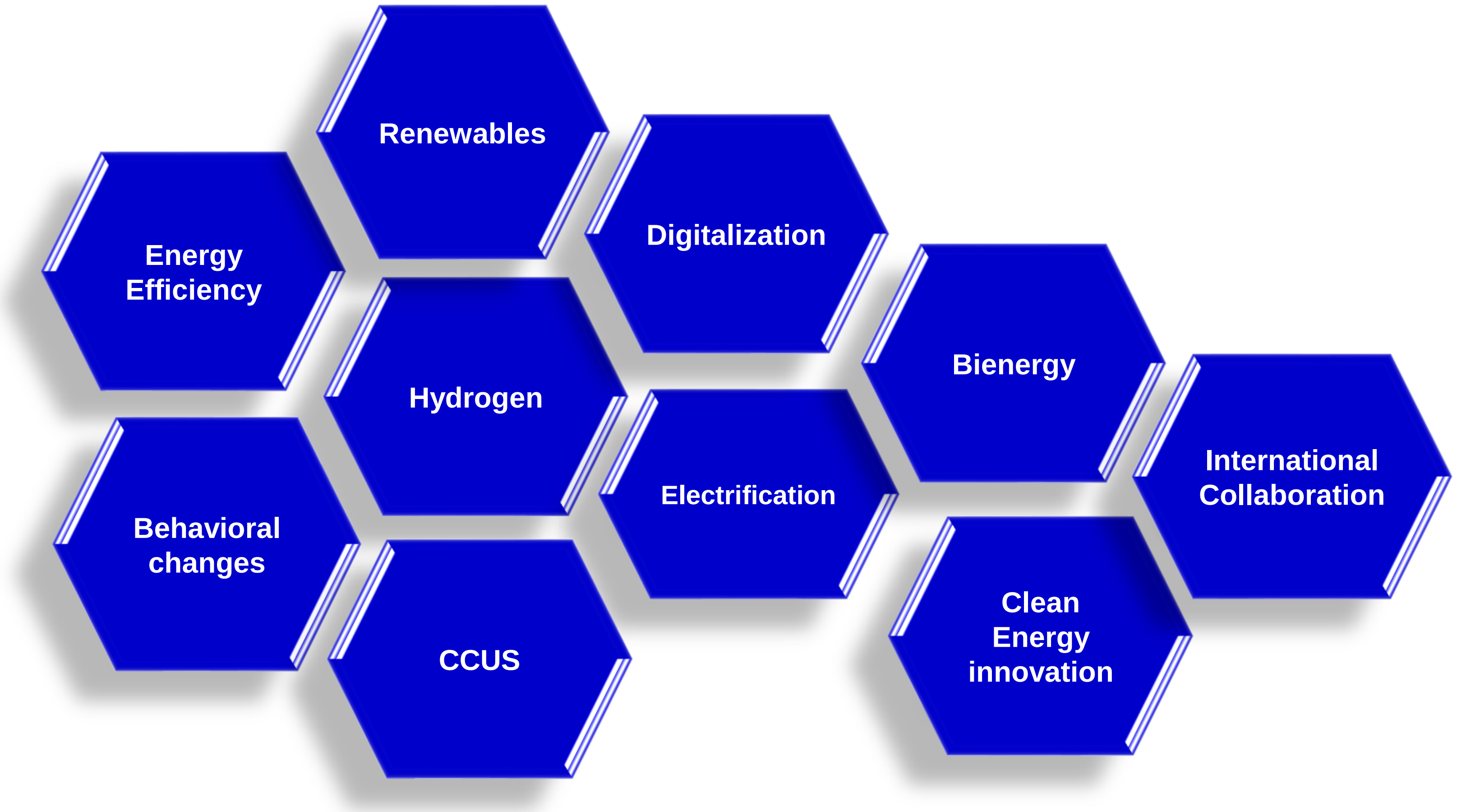


« Those who have the privilege to know have the duty to act. »

~ Albert Einstein (1879-1955)

WHAT CAN WE DO?

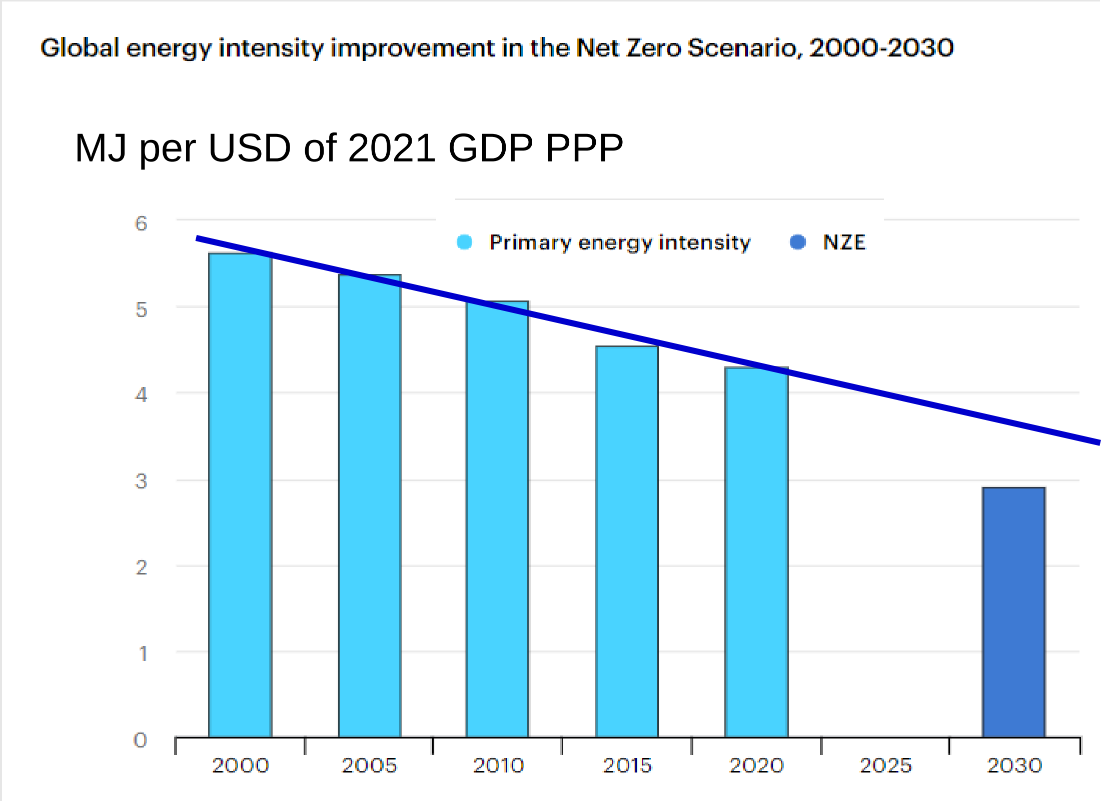
Tracking clean energy processes



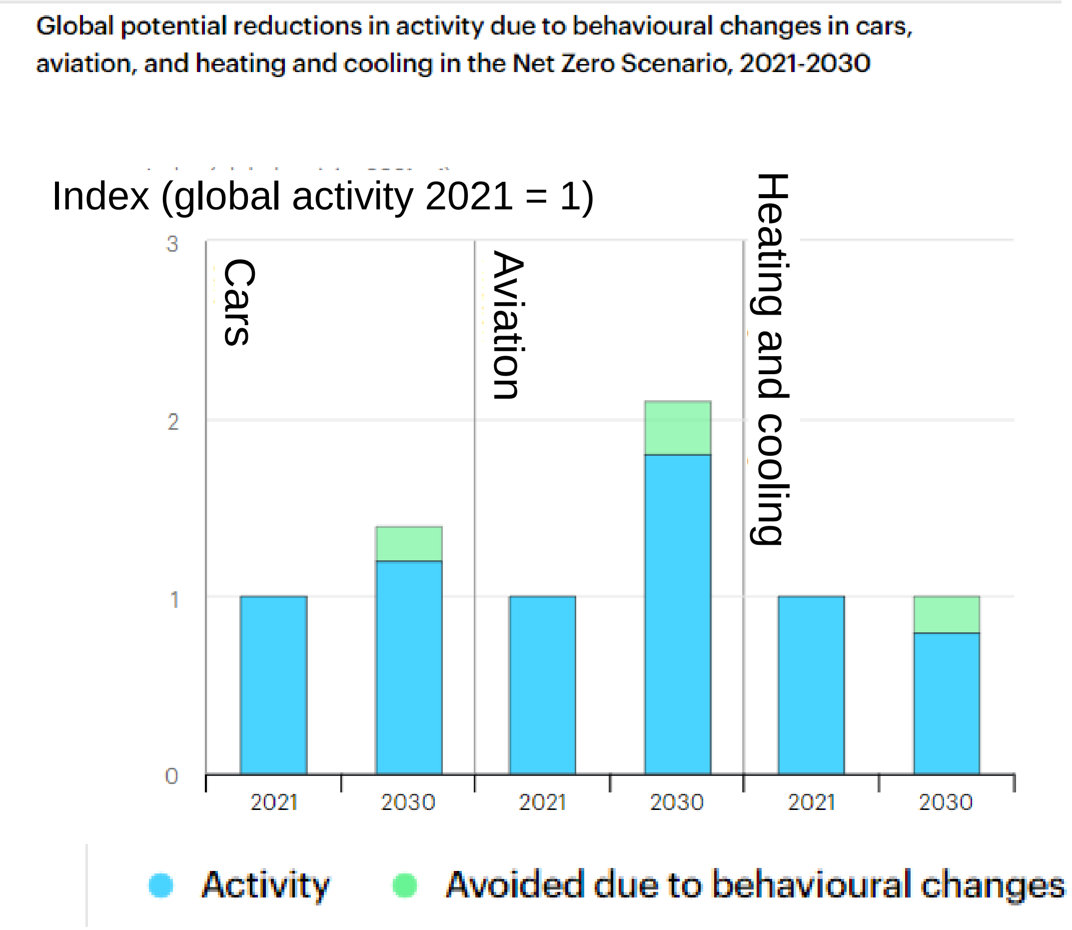
IEA (2022), Energy System Overview, IEA, Paris https://www.iea.org/reports/energy-system-overview, License: CC BY 4.0

Contributions to the clean energy revolution

Energy efficiency



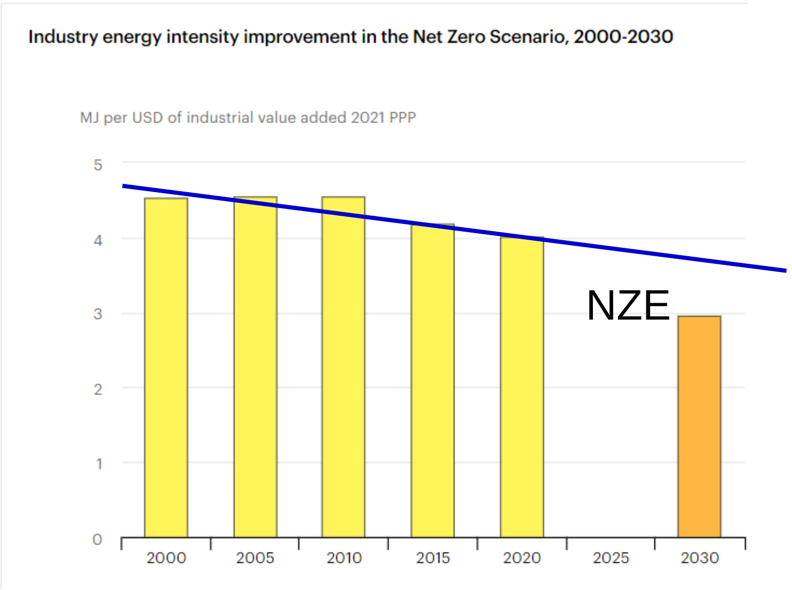
Behavioral changes



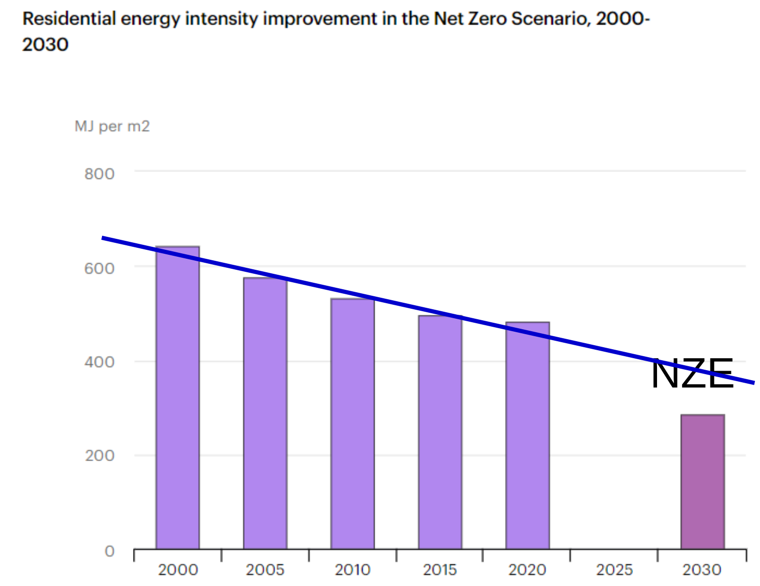
https://www.iea.org/reports/energy-system-overview

Energy intensity in different sectors

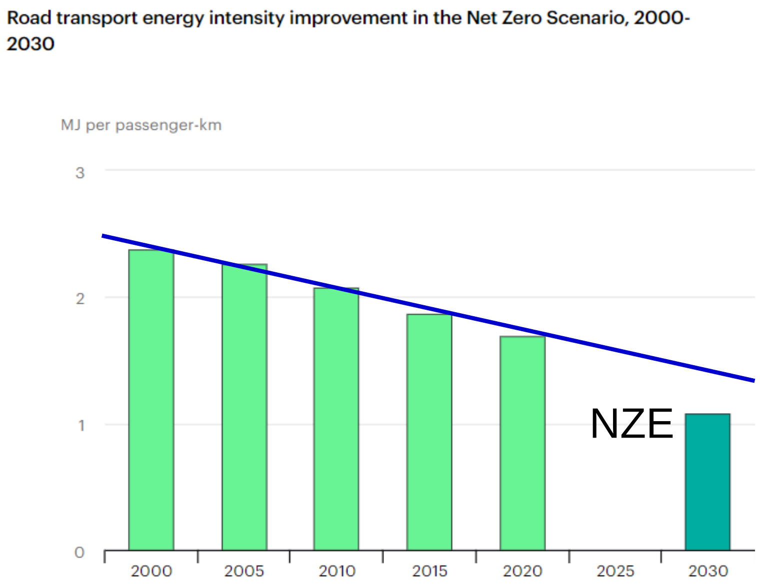
Industry



Residential



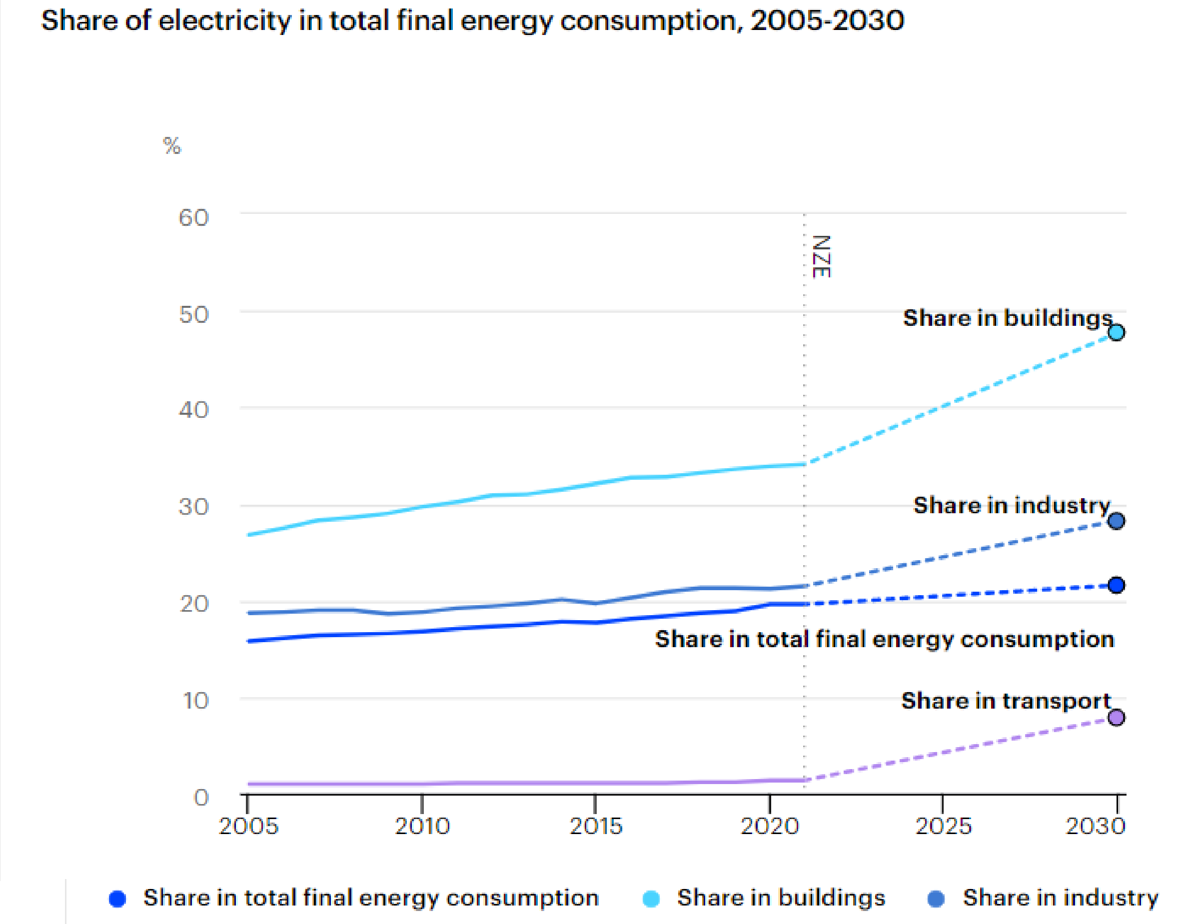
Road transportation



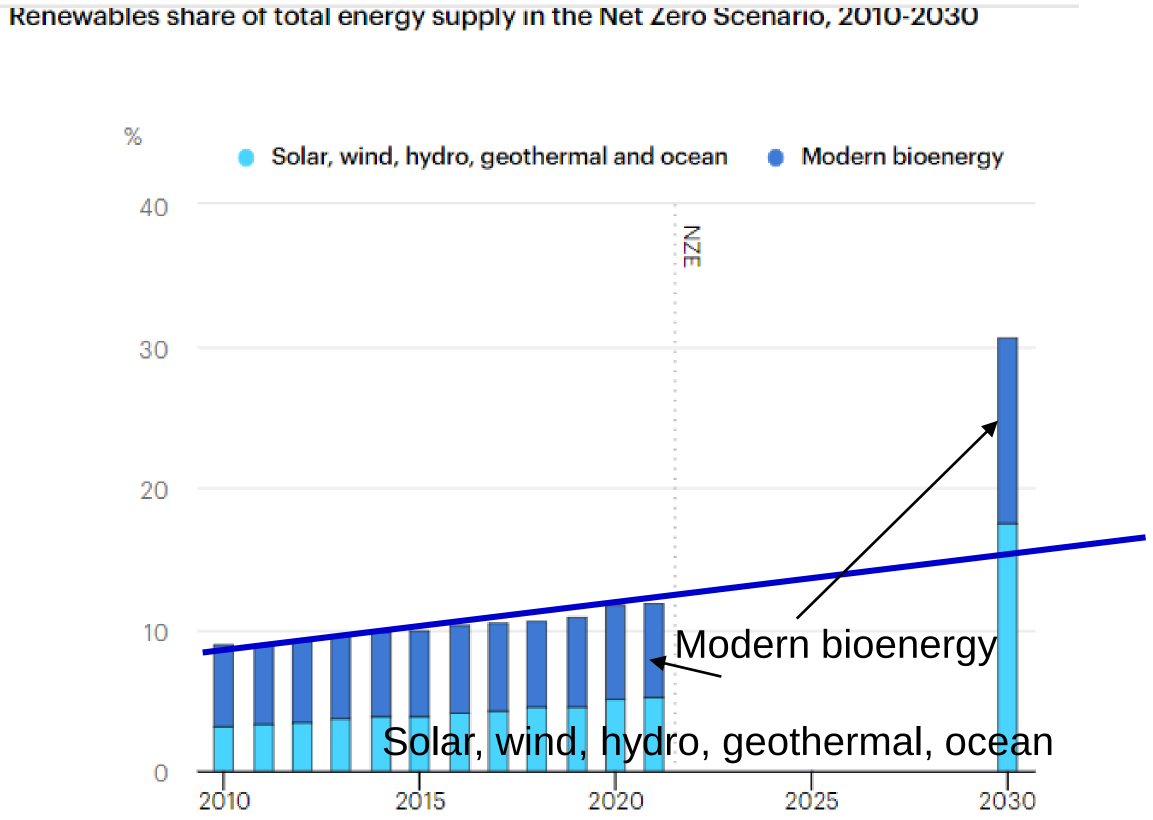
IEA (2022), Energy System Overview, IEA, Paris https://www.iea.org/reports/energy-system-overview, License: CC BY 4.0

Electrification, renewables

Electrification



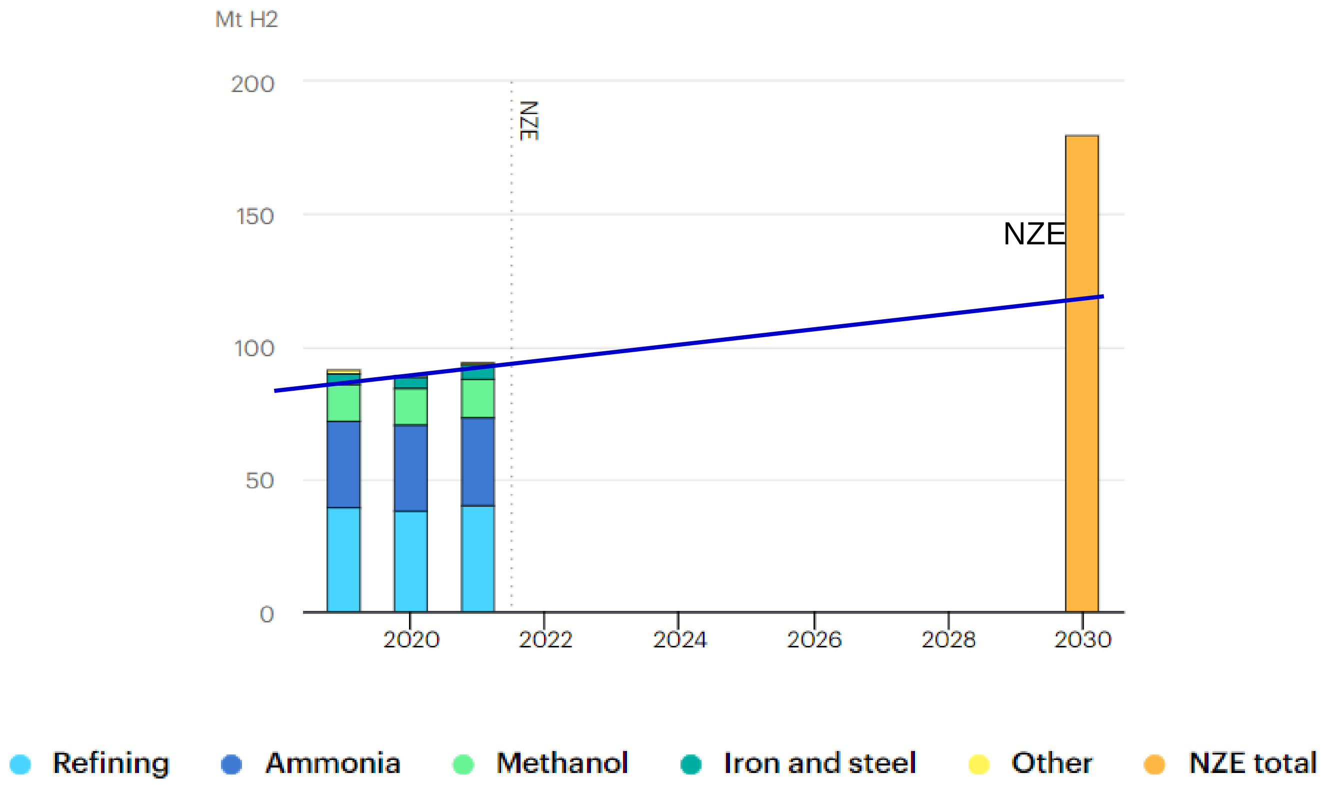
Renewables



Hydrogen and CCUS

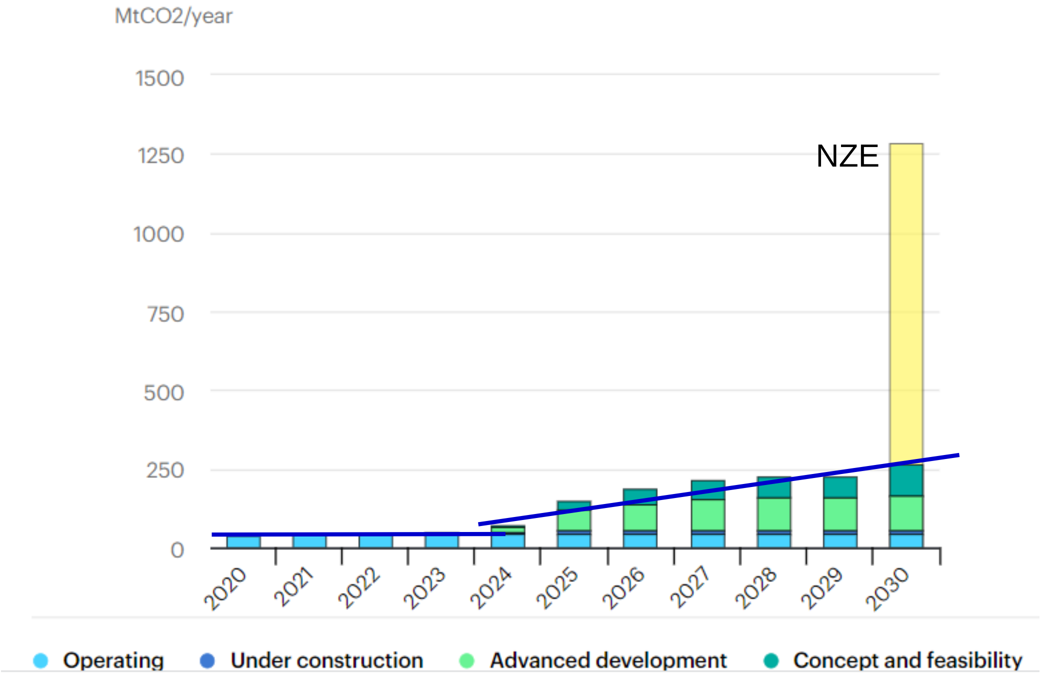
Hydrogen

Global hydrogen demand by sector in the Net Zero Scenario, 2019-2030



Carbon Capture Utilization and Storage

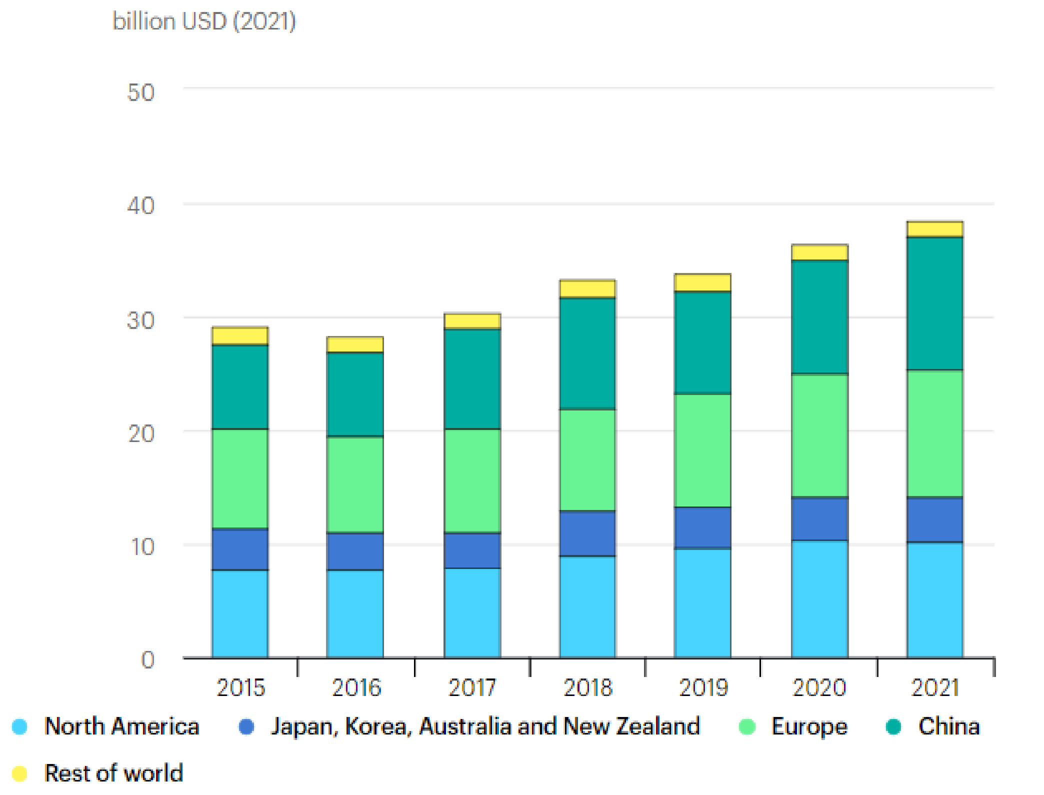
Capacity of large-scale CO2 capture projects, current and planned vs. the Net Zero Scenario, 2020-2030



Key enablers to revolutionizing the energy systems

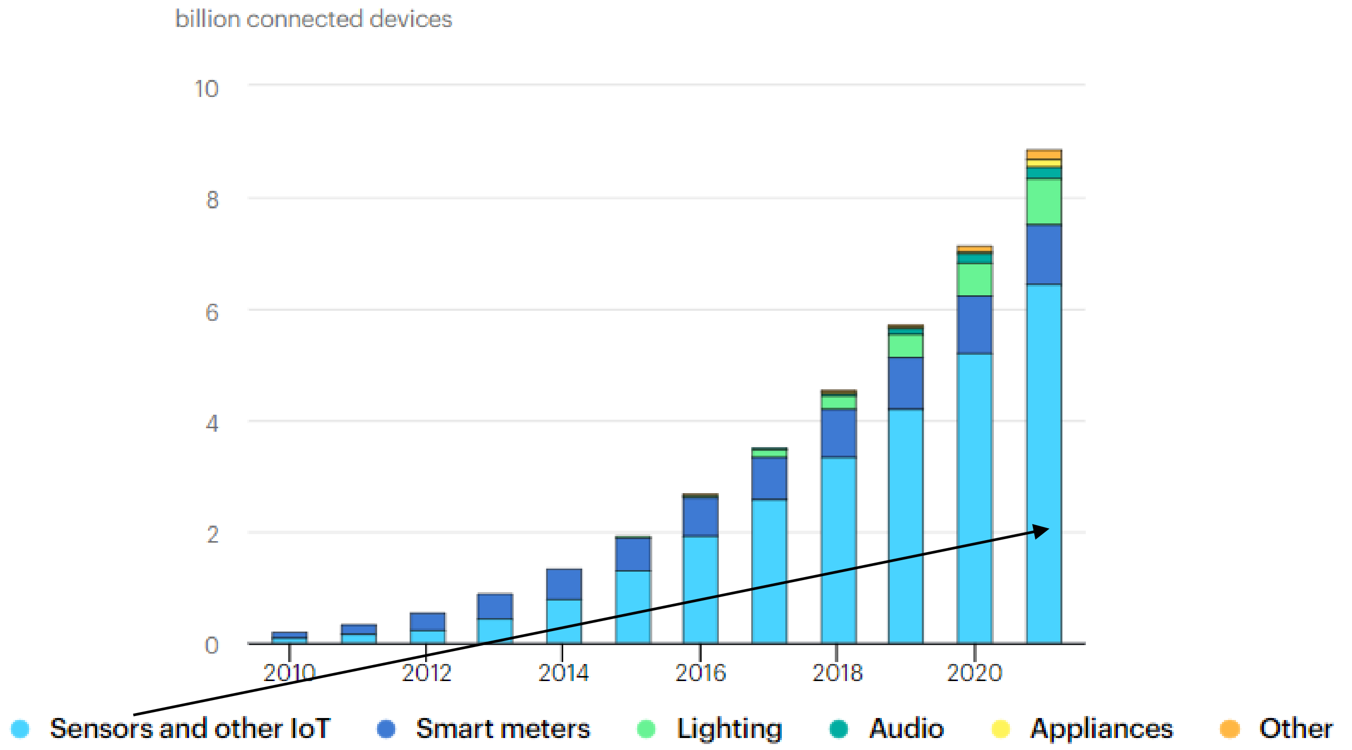
Clean Energy Innovation

Spending on energy R&D by governments, 2015-2021



Digitalization

Global stock of digitally enabled automated devices, 2010-2021



Tracking clean energy processes

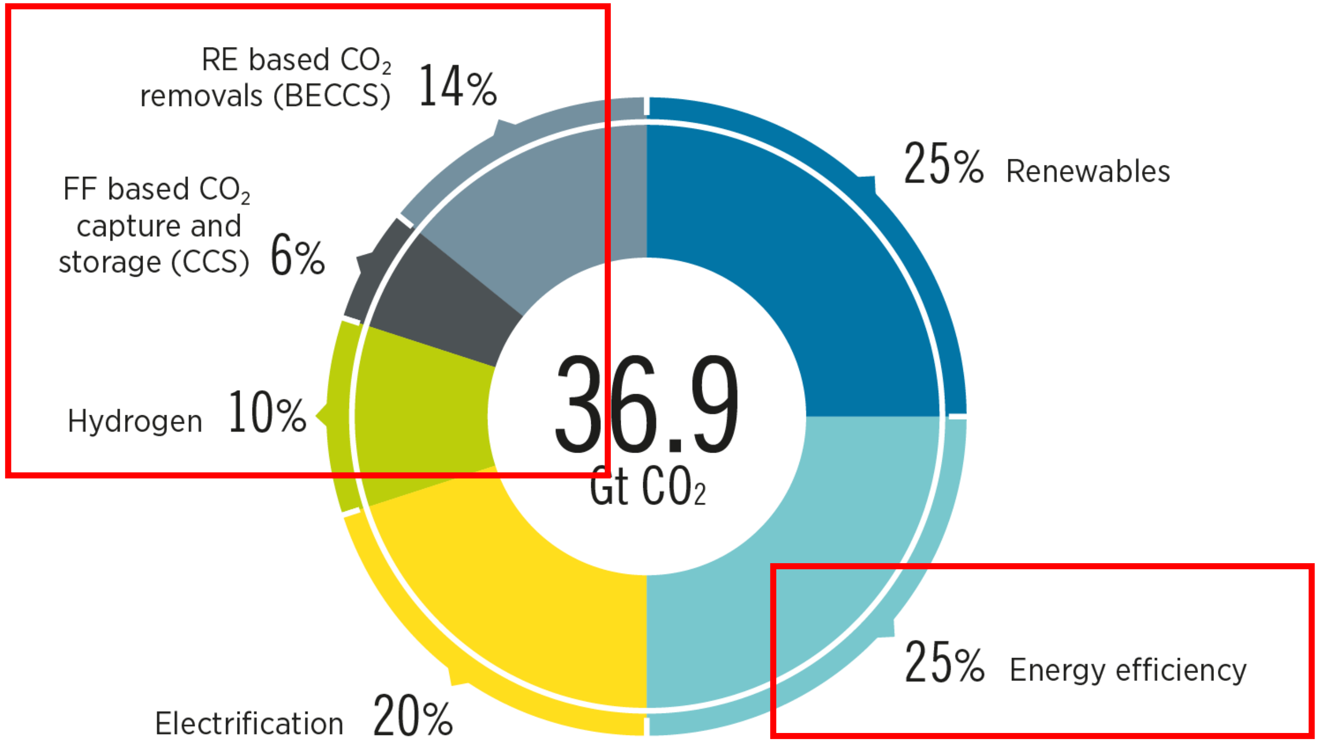
- ✗ Energy efficiency
- ✗ Behavioral Changes
- ! Electrification
- ! Renewables
- ! Bioenergy
- ! Hydrogen
- ✗ Carbon Capture, Utilization and Storage
- ! Clean Energy Innovation
- ! International Collaboration
- ! Digitalization

- ✗ Not on track
- ! More efforts needed
- ✓ On track

IEA (2022), Energy System Overview, IEA, Paris https://www.iea.org/reports/energy-system-overview, *License: CC BY 4.0*

Technological avenues for the energy transition

Reducing emissions by 2050 through six technological avenues



90% of all decarbonisation in 2050 will involve **renewable energy** through direct supply of **low-cost power, efficiency, electrification, bioenergy with CCS and green hydrogen**.

30% from CCUS and hydrogen

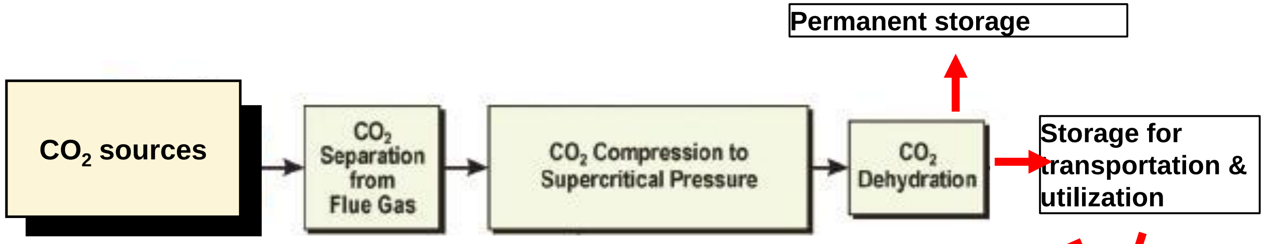
Achieving the 2050 target depends on sufficient action by **2030. Radical action** is needed to change the current trajectory.

This will require **political will** and well-targeted **policy packages**.

Game changes in technology are also needed.

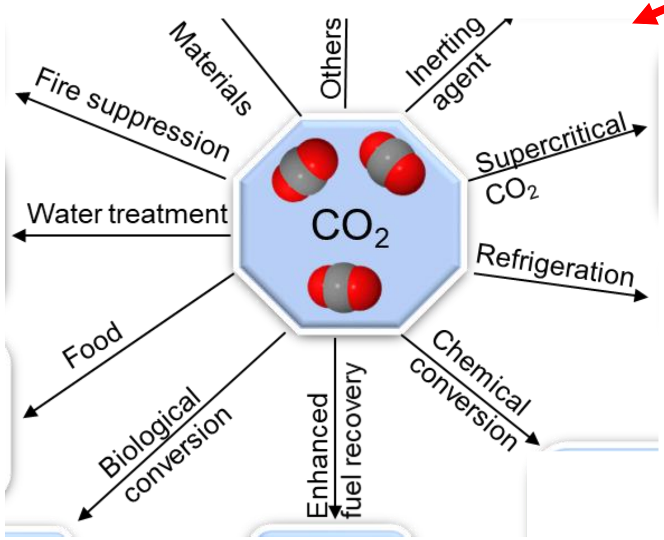
https://www.irena.org/Publications/2022/Mar/World-Energy-Transitions-Outlook-2022

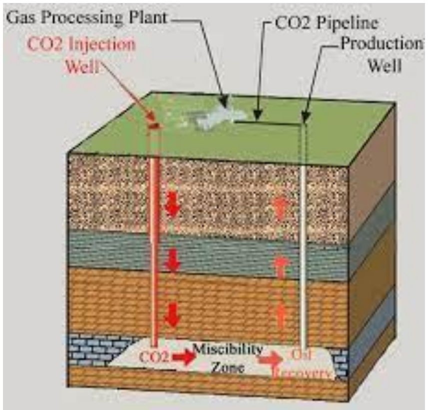
CCUS – concept and implementation

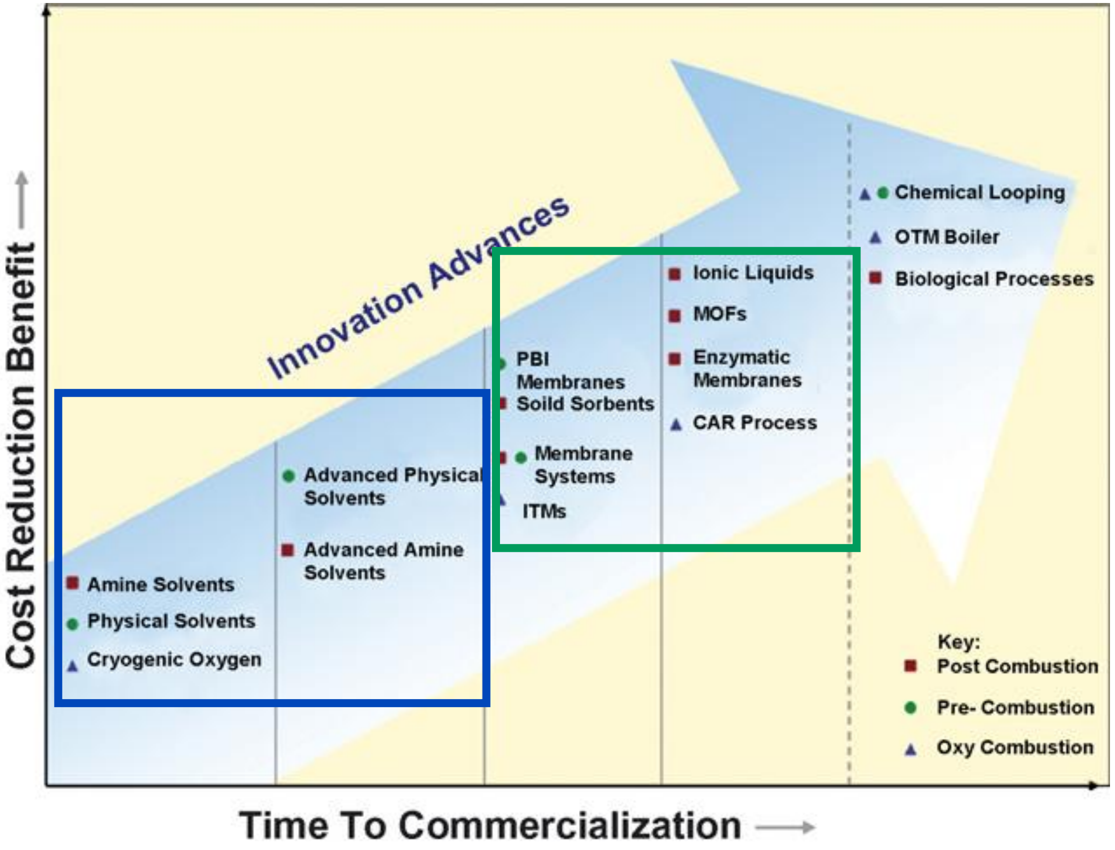


CO_2 Utilization

EOR







Figueroa et al., (2008) Int. J. Greenh. Gas Control, 2(1), 9-20.

How big are the utilization opportunities?

The numbers on CO2:

- **36.3 Gt emitted in 2021**
- **230 Mt used in all applications**

What it is the role of hydrogen?

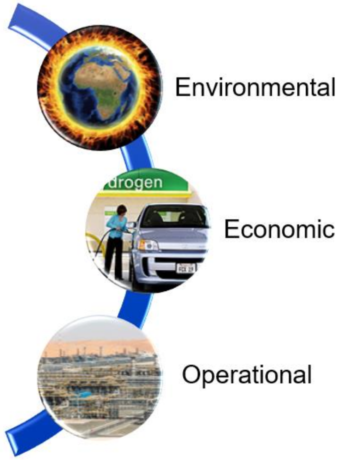
- Hydrogen is not a primary source of energy (like the sun or the wind), but an **energy vector** -> manufactured **capable of storing energy** that can later be released and can also be used for other applications (mobility, industry, production of heat and electricity, etc.).
- Hydrogen can help tackling various critical energy challenges while also strengthening energy security providing a smooth transition to a more sustainable energy economy and achieving the net zero goal.

How H_2 can help?

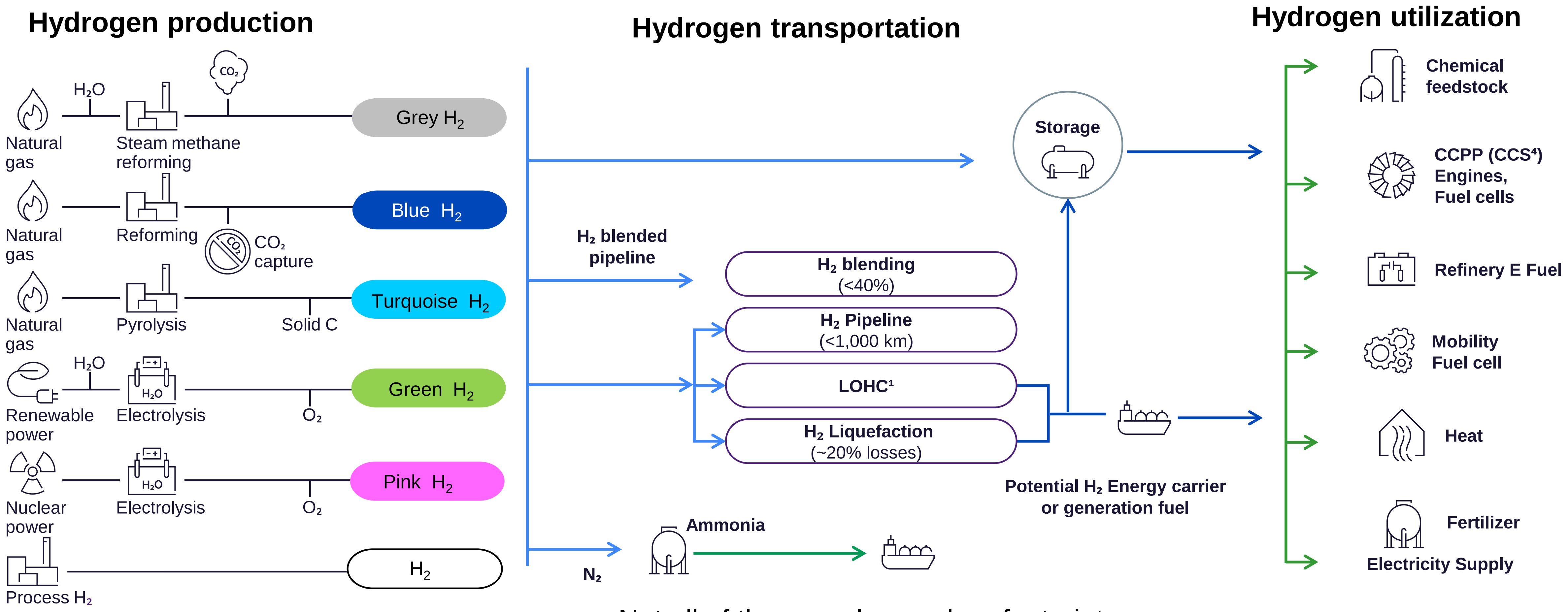
- H2 can be produced by using the excess of Renewable Energy and producing Energy when needed – excellent long term Energy storage
- H_2 be used as a zero-emission fuel for transportation: trains, buses, trucks, automobiles and ships.
- H_2 can be a **feedstock** for various industries including chemistry, refining and **steelmaking**.
- H_2 can provide a source of energy and heat for buildings (CHP)

How is it produced?

- Most of the hydrogen produced today (98-95%) is from SMR, with the corresponding CO_2 footprint
- Considerable efforts are made in recent years to find alternative routes to produce green hydrogen, mainly by water (H_2O) splitting and to a lesser extent, by hydrogen sulfide (H_2S) splitting combined with renewable energies.

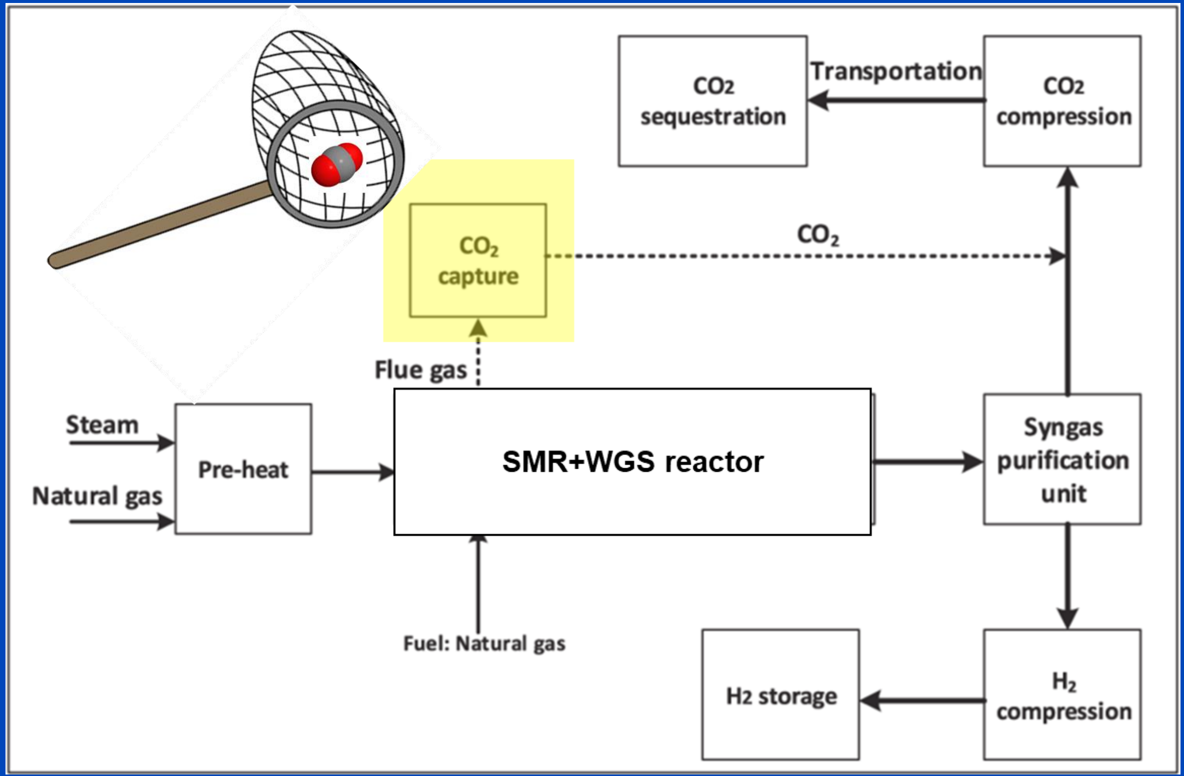


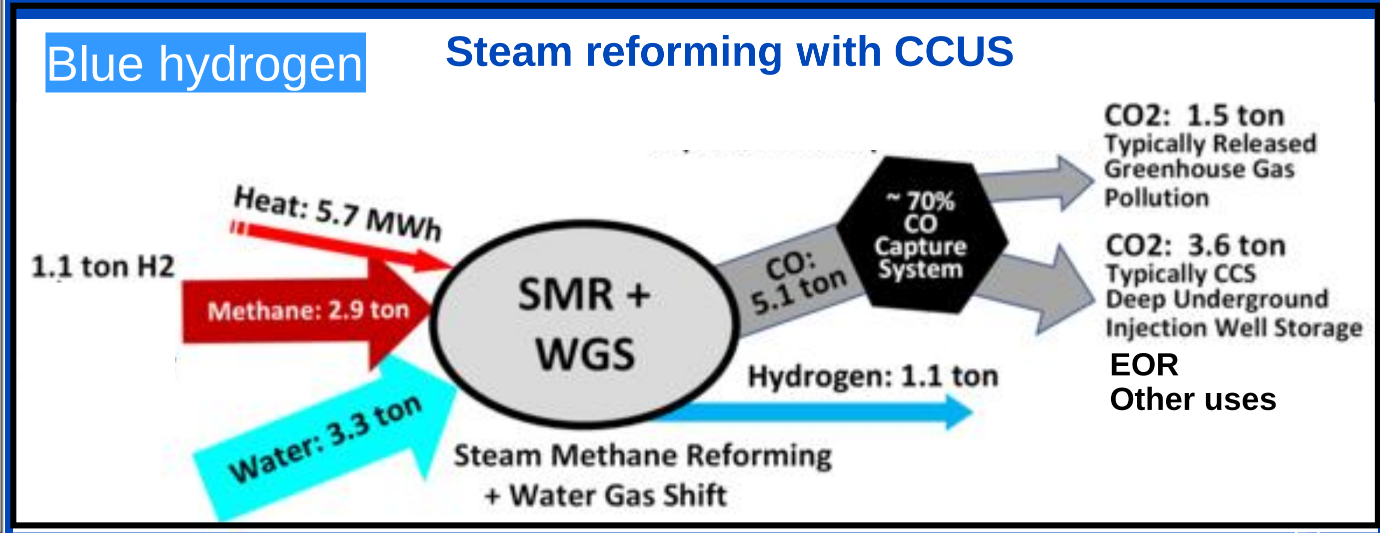
The hydrogen value chain



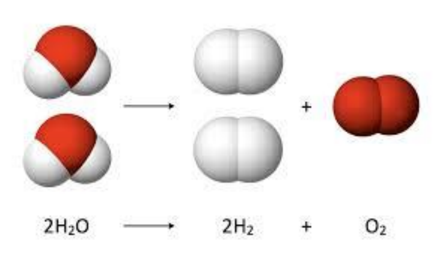
Not all of them are low-carbon footprint
Not all of them are mature technologies
Not all of them are used at large scale

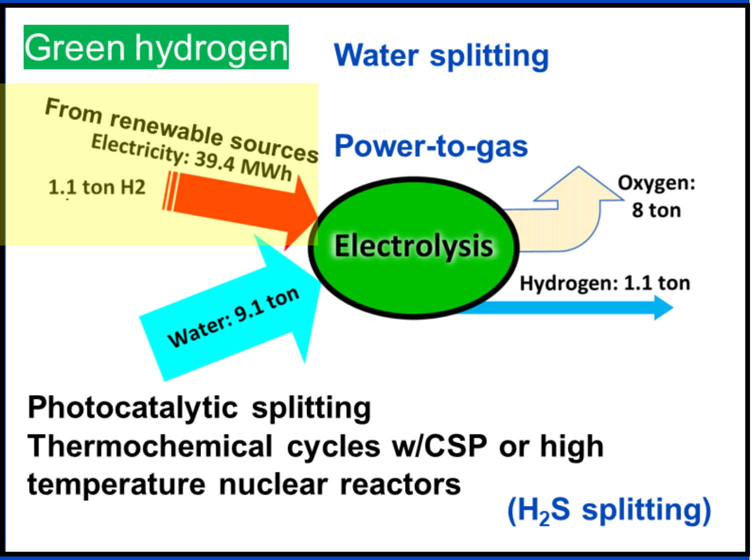
Blue hydrogen

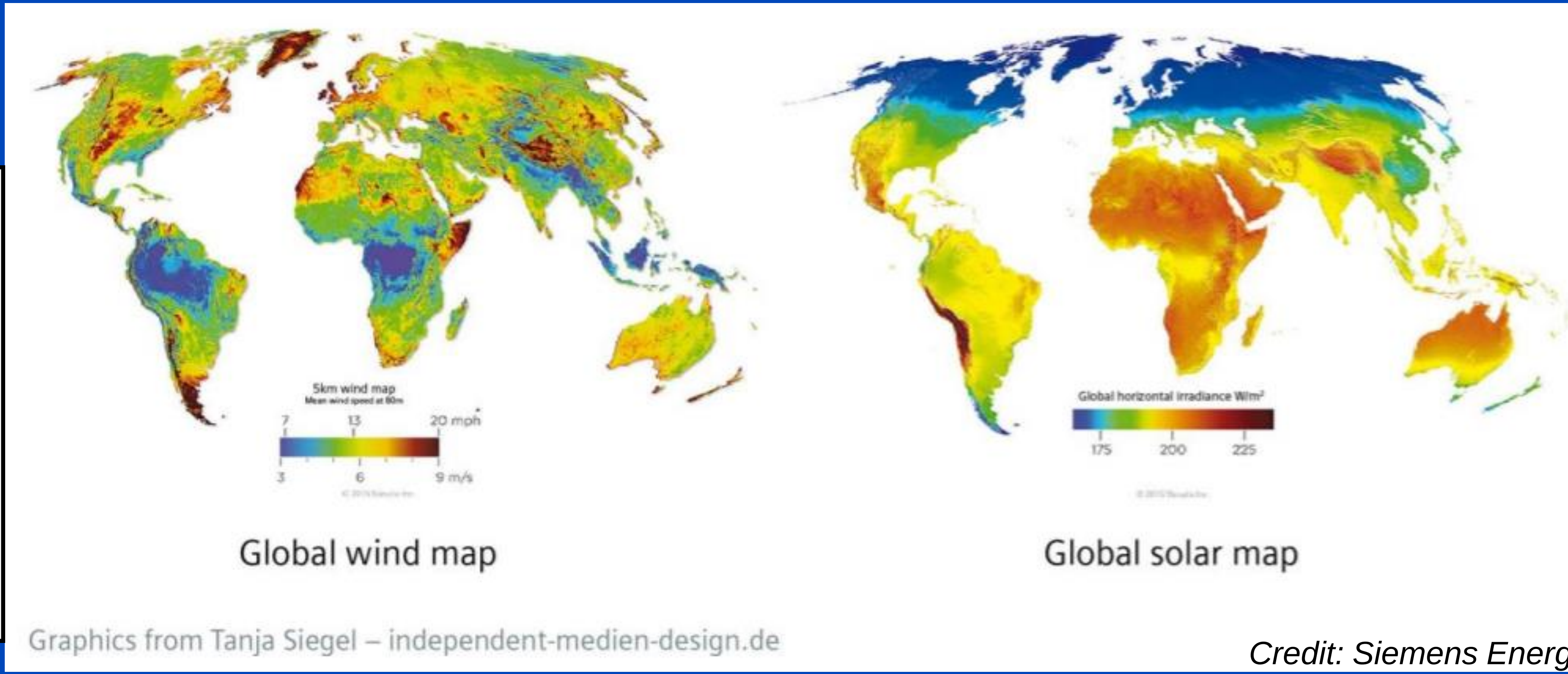




Green hydrogen







Credit: Siemens Energ

Opportunities ahead - green hydrogen in the GCC

Renewable energy

Lowest cost solar electricity in the world

800MW solar PV plant - Maktoum Solar Park (Dubai- DEWA III) 2.99 $ct/kWh

300MW Sakaka project (KSA) 2.34 $ct/kWh

CSP with integrated thermal storage can be used to produce nighttime solar electricity, complementing daytime solar PV

Fresh water ← Desalination

Hydrogen sulfide

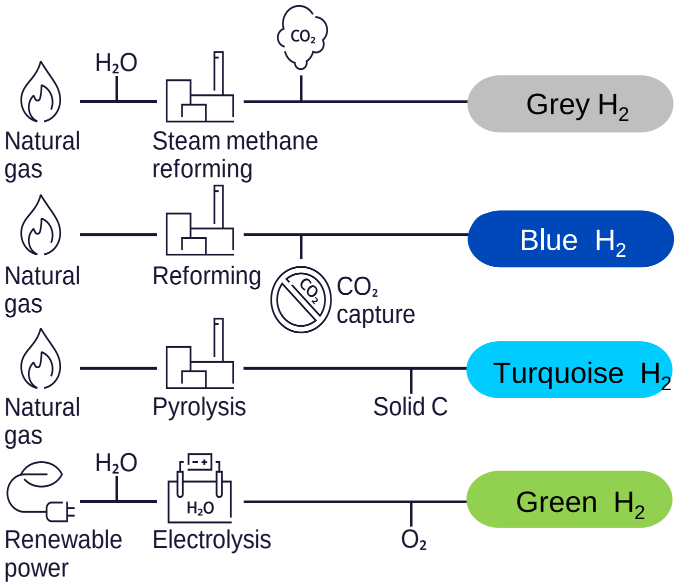
Electrolysers – efficiency and cost

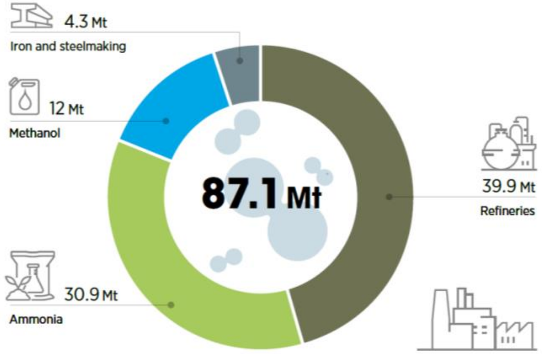
Is H_2 the "new oil"? Using 20% of the UAE's land surface for solar plants producing green hydrogen for export would suffice to match its current oil & gas revenue. (F. Wouters & A. van Wijk, 2020)

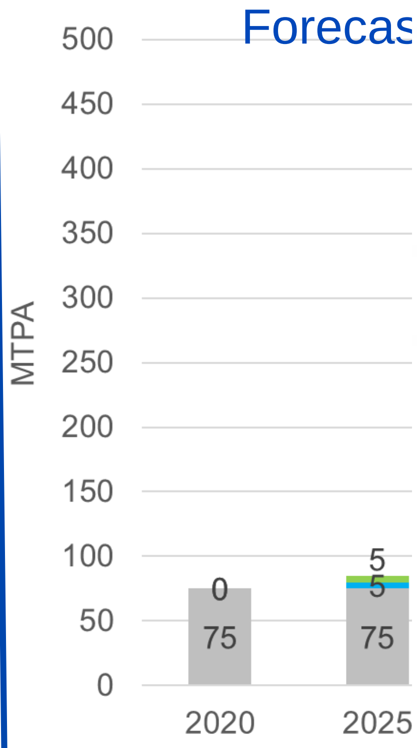
There are challenges to be solved, and some more **research/ demonstration/ industrial projects are needed to fully deploy hydrogen opportunities in different industrial sectors**

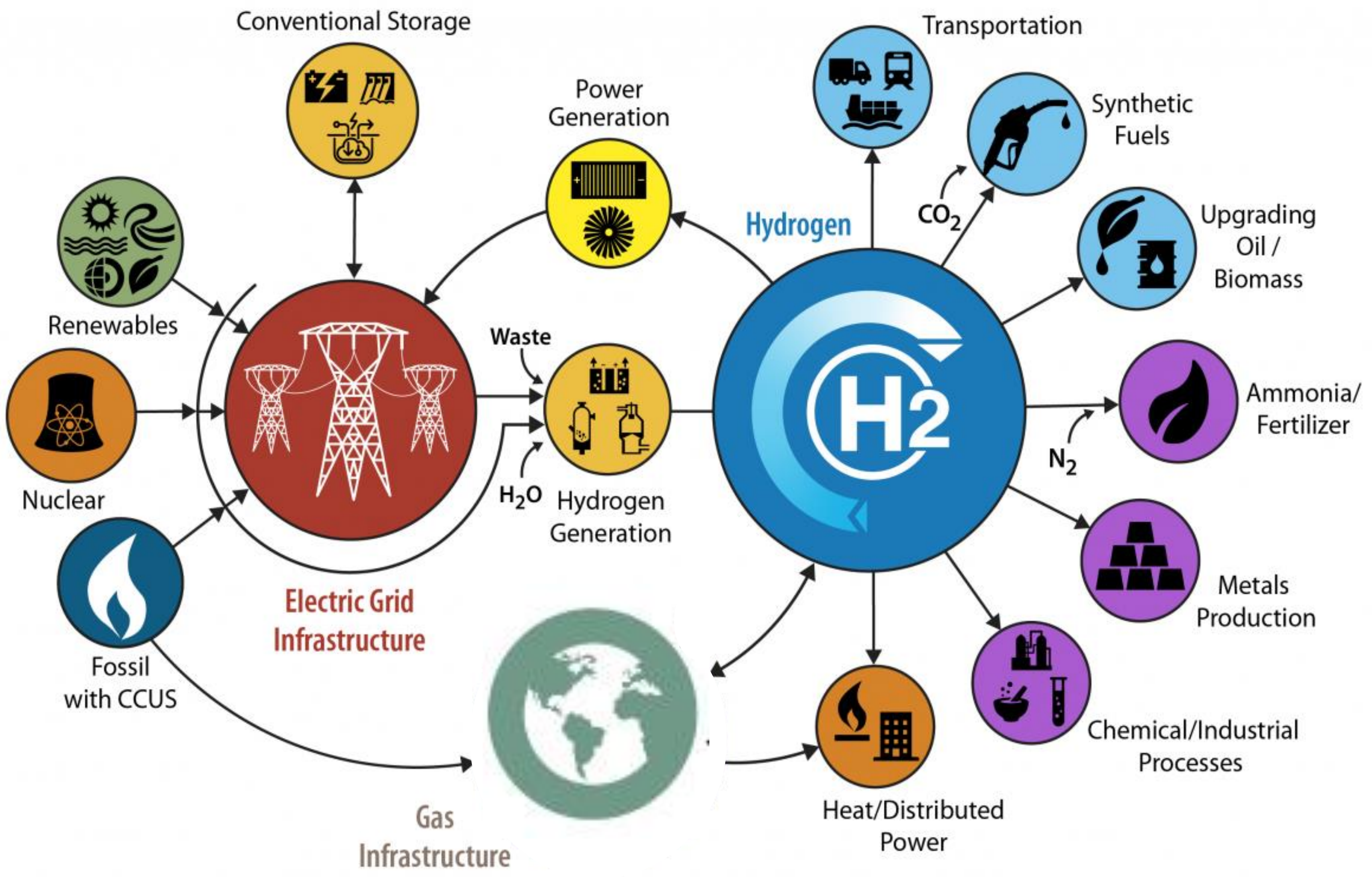
The hydrogen economy – concept and implementation

Hydrogen production technologies





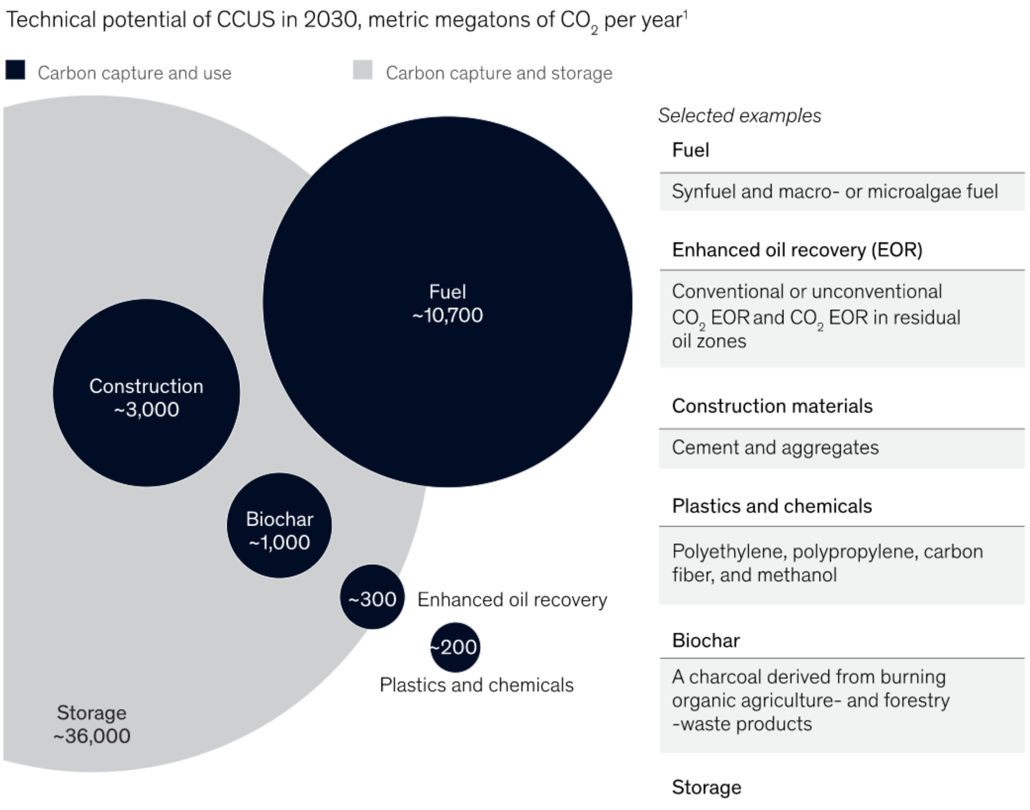




Predictions strongly dependent on the use of hydrogen in transport, heat production and industrial uses.

Key strategic areas of focus

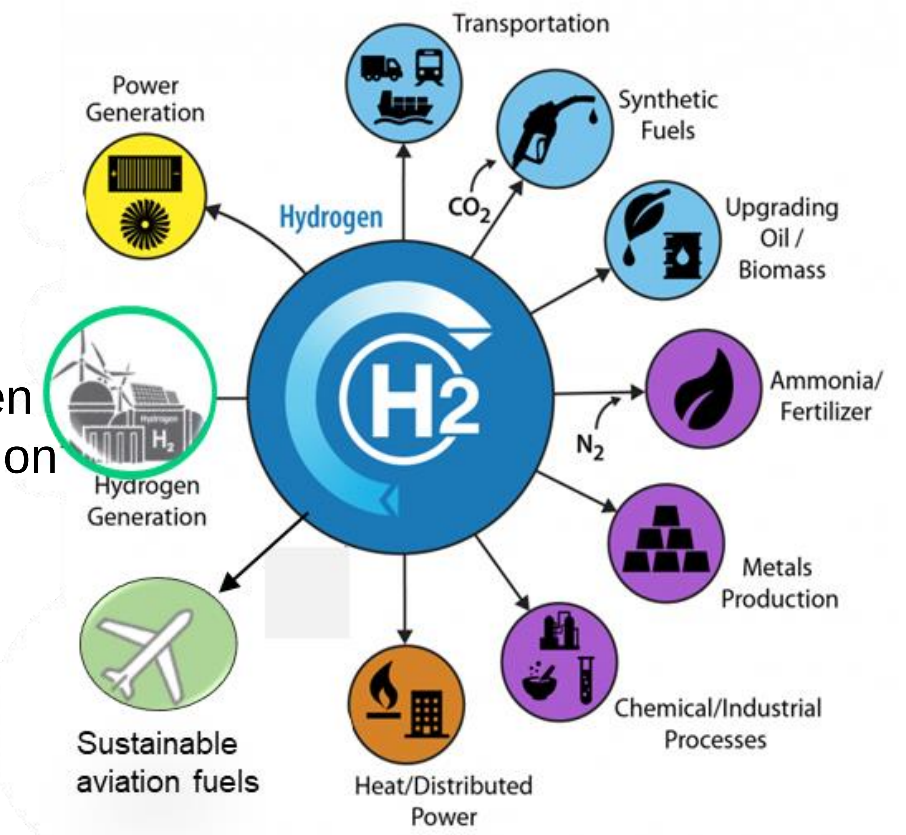
Driving CO_2 emissions to zero (and beyond) with carbon capture, use, and st…



CCUS

From McKinsey's report

Low-C hydrogen production



Hydrogen and Power-to-X

Final remarks

- New times, new challenges, new businesses opportunities
- A combination of different approaches is needed: renewables (with energy storage), electrification, Energy efficiency, alternative sources of Energy, CCUS, hydrogen
- CCUS is in all agendas as a needed technology to decarbonize the society in order to reach net zero emissions – it is part of the solution.
- Hydrogen is not the solution to achieving net-zero but will also play a key role as part of the solution.
- Research and Innovation in these areas is still needed to find efficient and environmental friendly solutions.
- A combination of **fundamental science** with **technology development** and **implementation**, together with the joint efforts of administrations, governments and companies are needed to reach the net zero goals
- **Collaborations between academia and industry**, and **among different companies and sectors,** and with the **governmental institutions** are more needed than ever to speed up the pathway to decarbonization – investments are needed (no free ride) but business opportunities are ahead.

The future is here

"Water will one day be employed as fuel, that hydrogen and oxygen which constitute it, used singly or together, will furnish an, of an inexhaustible source of heat and light intensity of which coal is not capable."

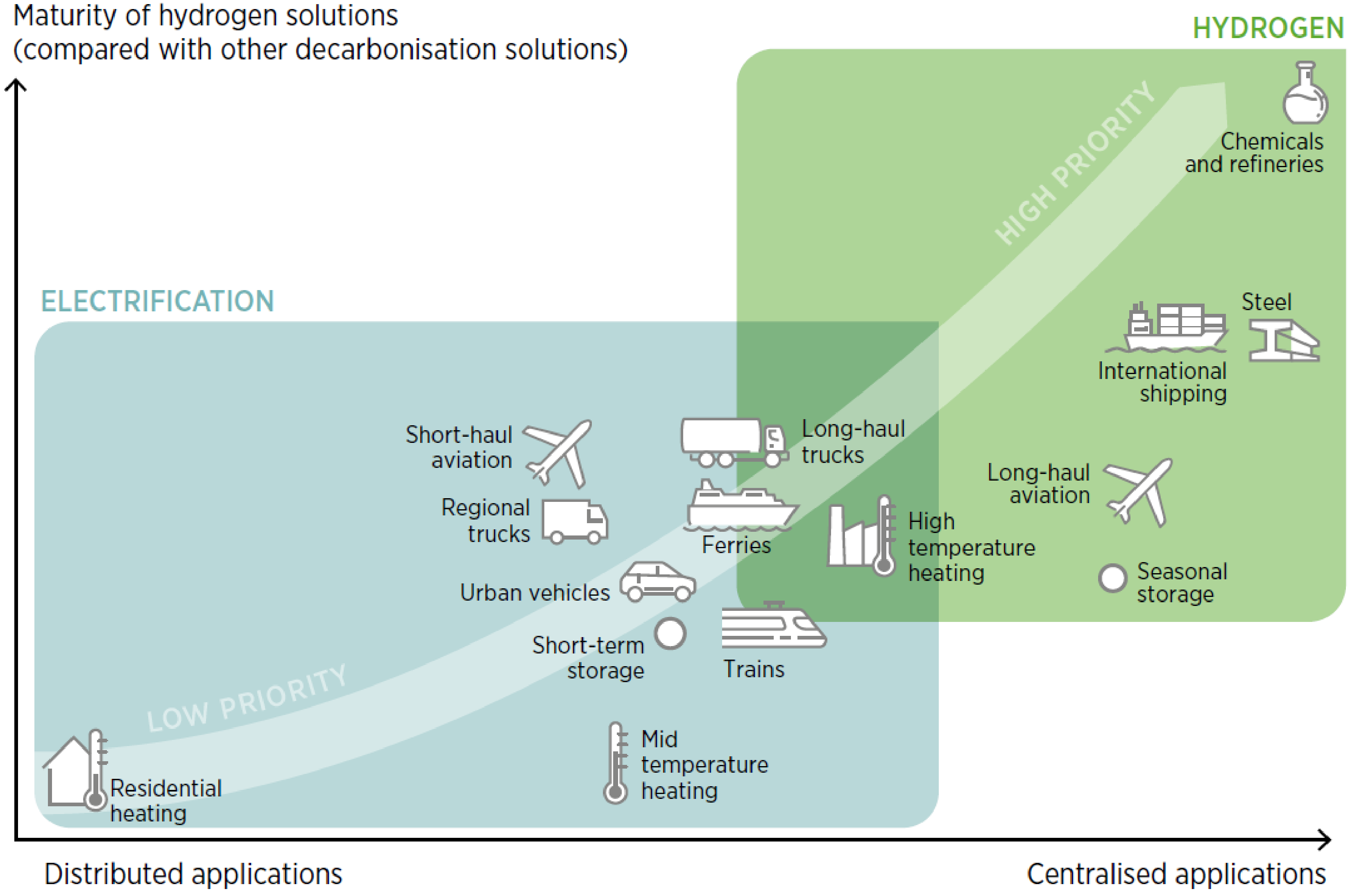
The Mysterious Island,
Jules Verne, 1874

Thank you very much for the invitation.

Lourdes.vega@ku.ac.ae

https://www.ku.ac.ae/rich

Maturity of hydrogen solutions



Policymakers should identify priorities for **indirect electrification using green** hydrogen with a focus on **hard-to-abate sectors** and devise strategies for its deployment.

Source: IRENA 2022