School of Mining & Metallurgical Engineering
NTUA
Laboratory of Metallurgy

RawMaterials Hub
Regional Center Greece

CO_2 transformation to synthetic fuels

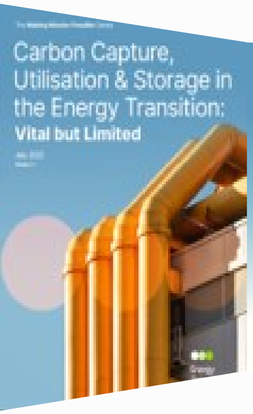
Potential applications in the extractive industry sector

ANTONIS PEPPAS
Assistant Professor

8th Greek Raw Materials Community Dialogue
"Raw Materials: From legacy to an innovative future"

http://research.labmet.ntua.gr/

Energy-intensive industries (EIIs) CO_2 emissions

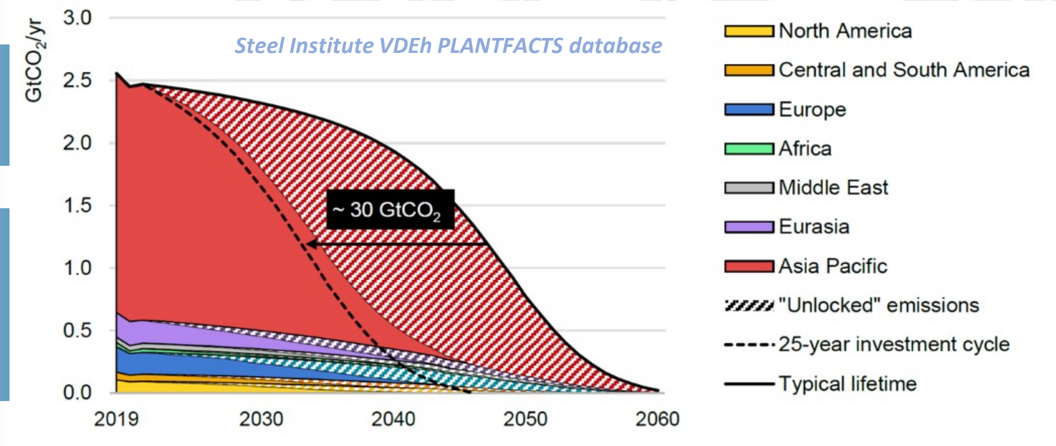


*"To have a 50% chance of limiting global warming to 1.5°C and a 90% chance of keeping below 2°C, the **world must reduce** today's 50 Gt of total annual CO_2-equiv. emissions to around **net-zero by mid-century**, with reductions of around 40% achieved by 2030"*

Energy Transitions Commission – July 2022

1 Primary and **secondary steel** emitted ~2.6 Gt CO_2 in 2020

2 Process and energy emissions from **petrochemicals** accounted for ~1.6 Gt CO_2 in 2020



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Putting CO_2 to Use

Extractive Industries: Creating value from emissions

Tees Valley industrial cluster

58% of the UK's EEIs

Includes steel, ammonia, hydrogen, ethylene, fine chemical and plastics production

- Worth **£2.5 billion** Gross Value Added.
- Responsible for **5.6%** of the **industrial emissions** in the **UK**.

Port Talbot (PT) steelworks emits ~8Mt of CO_2/year (15 - 20% of Wales's CO_2 emissions).

PT steelworks produces carbon dioxide, carbon monoxide and hydrogen.

Suitable for renewables, including option of offshore windfarm and multiple sources of high grade waste heat

Waste heat, renewable energy and carbon dioxide streams at PT steelworks and surrounding area are modelled as part of a project.

If the trials are successful could be replicated to other industries (e.g. cement industry).

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Why Innovate?

CCUS in reaching net-zero

CO_2 **capture capacity**

7–10 $GtCO_2$/year of CO_2 capture capacity will be required by **2050.**

CO_2 **capture capacity**

Of captured CO_2 , around 65% relates to CO_2 from non-fossil fuel sources will need to be stored or used (e.g. cement process emissions).

Remaining CO_2 emissions

The remaining 35% (2.5–4.0 $GtCO_2$/year) would allow **a significant but dramatically reduced scale of fossil fuel use** (e.g. around 10 Mb/d oil, 90% below today's levels).

Carbon capture CCUS projects in Europe

Overview of existing and planned CCUS facilities

AUSTRIA
1. Vienna Green CO_2*

BELGIUM
1. Leilac 1
2. Antwerp@C*
3. Carbon Connect Delta
4. Steelanol
5. C4U
6. North-CCU-Hub
7. Power-to-Methanol Antwerp BV
8. Kairos@C[E]
9. H2BE*

BULGARIA
1. ANRAV[E]

CROATIA
1. Petrokemija Kutina*
2. Bio-Refinery Project*
3. CCGeo[E]

DENMARK
1. Greensand*
2. C4: Carbon Capture Cluster Copenhagen
3. Bifrost*

FINLAND
1. SHARC[E]

FRANCE
1. DMX Demonstration in Dunkirk*
2. Pycasso*
3. K6[E]
4. CalCC[E]
5. **Cryocap**
6. D'Artagnan

GERMANY
1. H2morrow*
2. Leilac 2
3. BlueHyNow*
4. OXYFUEL100 (subproject of Westkuste100)
5. H2GE Rostock*

GREECE
1. Prinos CCS
2. RECODE

ICELAND
1. **Orca**
2. **Silverstone**[E]
3. Coda Terminal[E]

ITALY
1. CCS Ravenna Hub*
2. Cleankerk

THE NETHERLANDS
1. Porthos*
2. Aramis*
3. H2M*
4. H-Vision*
5. Twence*
6. **AVR-Duiven**
7. AZUR*
8. L10 CCS

NORWAY
1. **Sleipner CO_2 Storage***
2. Longship (including Northern Lights)*
3. Barents Blue*
4. Norsk e-fuel
5. Borg CO_2*
6. **Snøhvit CO_2 Storage***
7. Smeaheia*

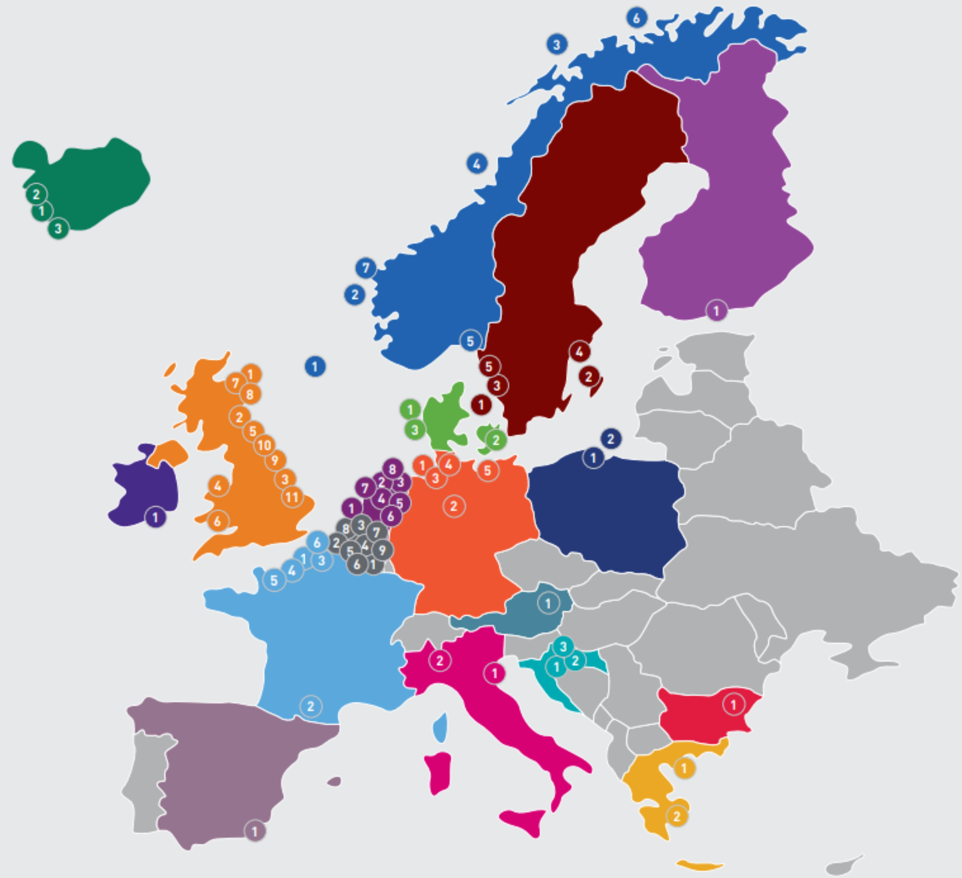
POLAND
1. Poland EU CCS Interconnector
2. Go4ECOPlanet[E]

REPUBLIC OF IRELAND
1. Ervia Cork CCS

SPAIN
1. ECCO2

SWEDEN
1. Preem CCS*
2. Slite CCS
3. CinfraCap
4. BECCS@STHLM[E]
5. Project AIR[E]

UK
1. Acorn*
2. Caledonia Clean Energy
3. Zero Carbon Humber*
4. HyNet*
5. Net Zero Teesside*
6. South Wales Industrial Cluster
7. Peterhead CCS Power Station*
8. Acorn CO_2 SAPLING*
9. Northern Endurance Partnership*
10. H2Teeside*
11. H2H Saltend*



* Project where IOGP Members are involved
[E] EU Innovation Fund (11 selected, **4 awarded**)
Projects listed in **bold** are in operation

Total number of projects: **71**
Around 80 $MtCO_2$/yr stored by 2030

Source: International Association of Oil and & Gas producers

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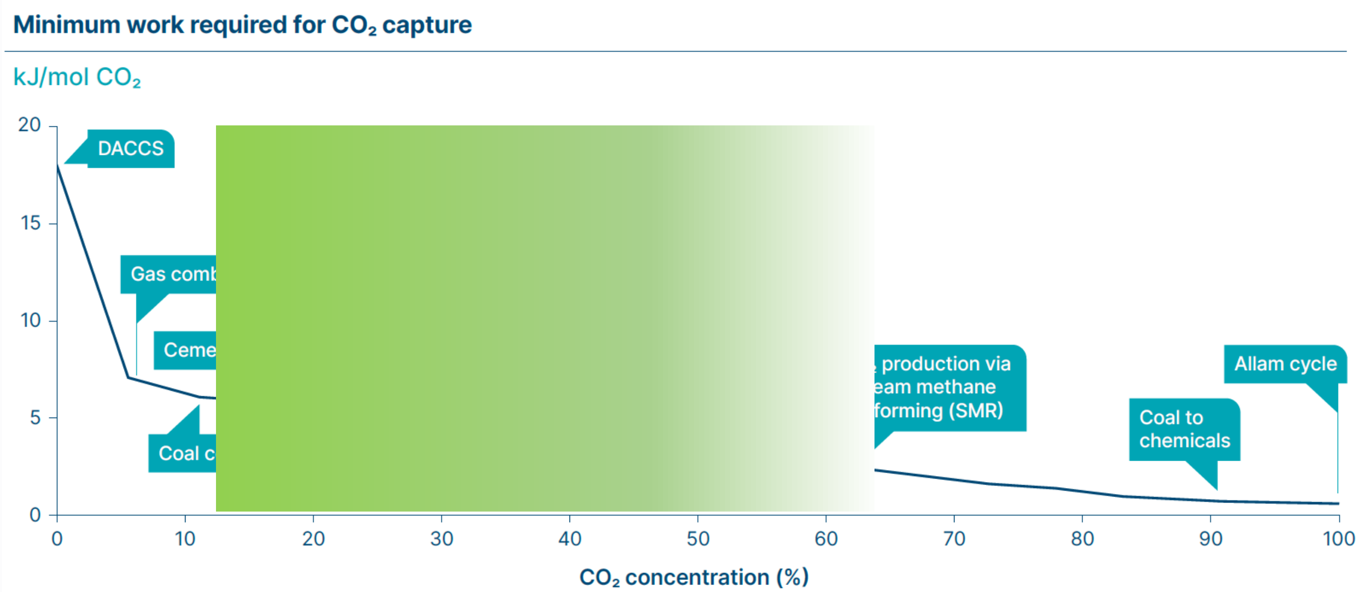
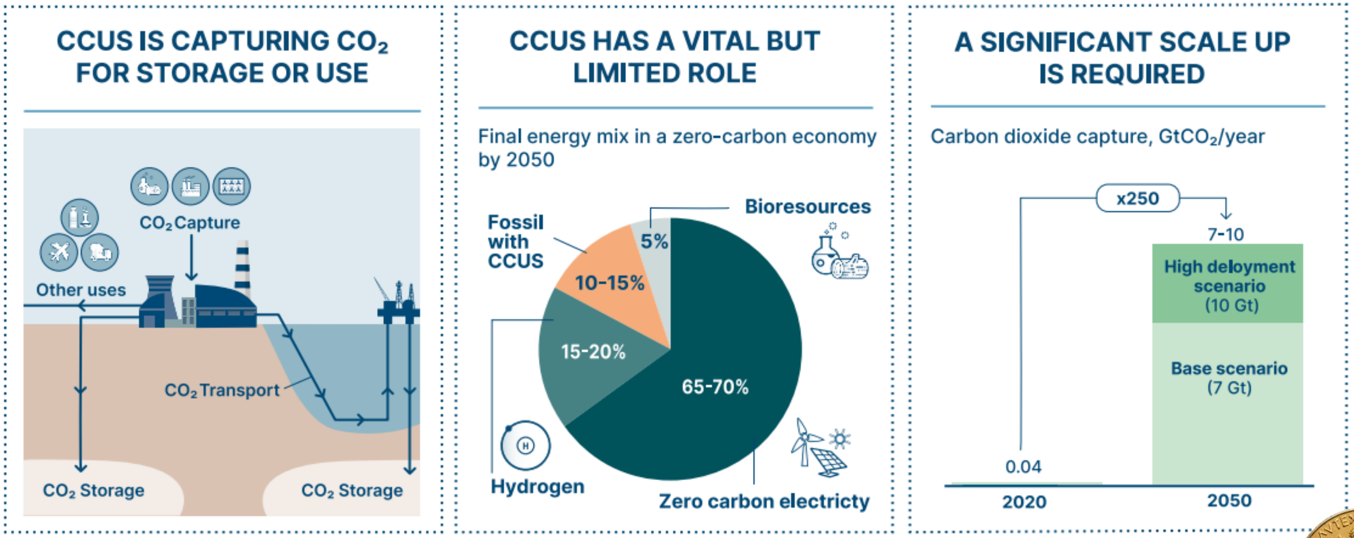
CCUS limitations

Energy intensive process



Finite Storage Capacity



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Underground storage limitations

Porous rock formations called aquifers offer a more expensive and riskier storage option **for a further 5,000 billion tones of CO_2 or 140 years of current emissions.**

Care must be taken around the rate at which the CO_2 is pumped: if done too quickly the **porous rock can fracture and release the gas**.

If you store the CO_2 in liquid form at 100 bar pressure, every cubic meter of storage space will hold 0.6 tonnes of carbon dioxide.

It would require **160 million m^3** of storage **per day** to capture **all CO_2 emissions** across the world.

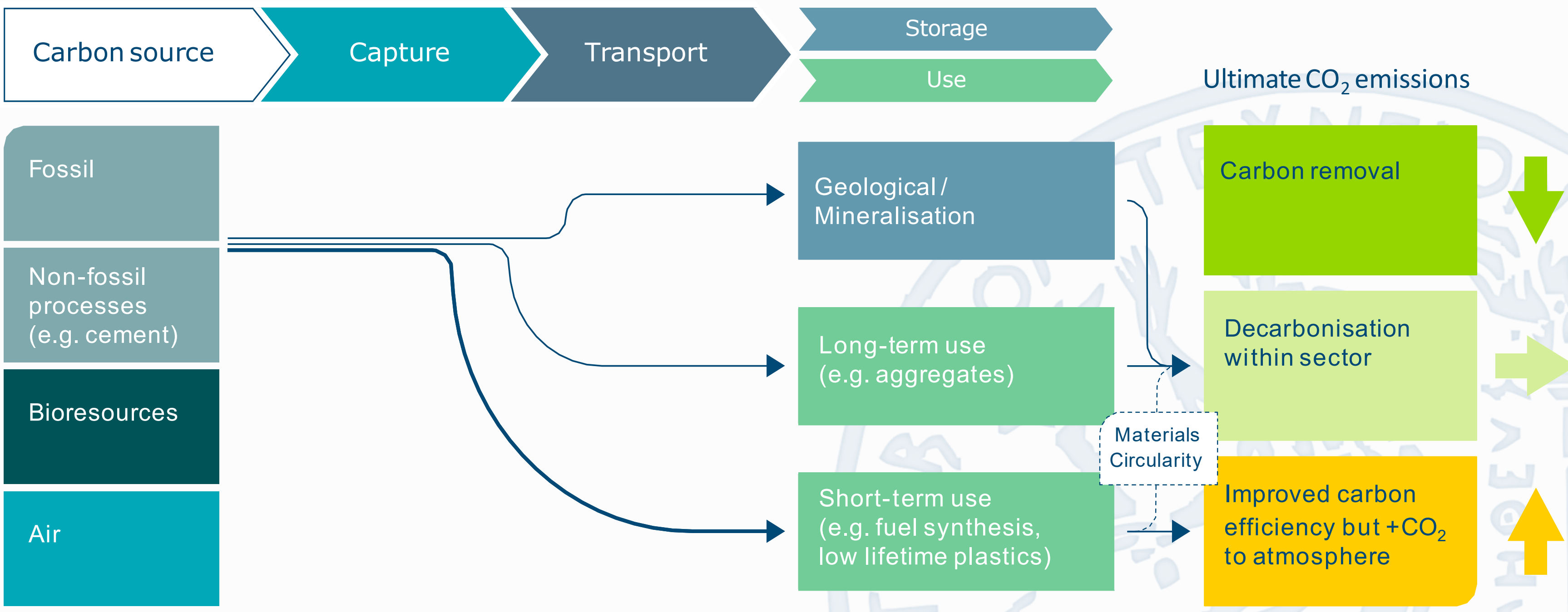
For comparison, today's oil and gas industry extracts liquid fossil fuels at just one fifth of this pump rate with 14 million m^3 of oil and 18 million m^3 of natural gas extracted each day.

Iceland, €22 per metric tonne

Putting CO_2 to Use

Extractive Industries: Extend CO_2 lifetime as feedstock

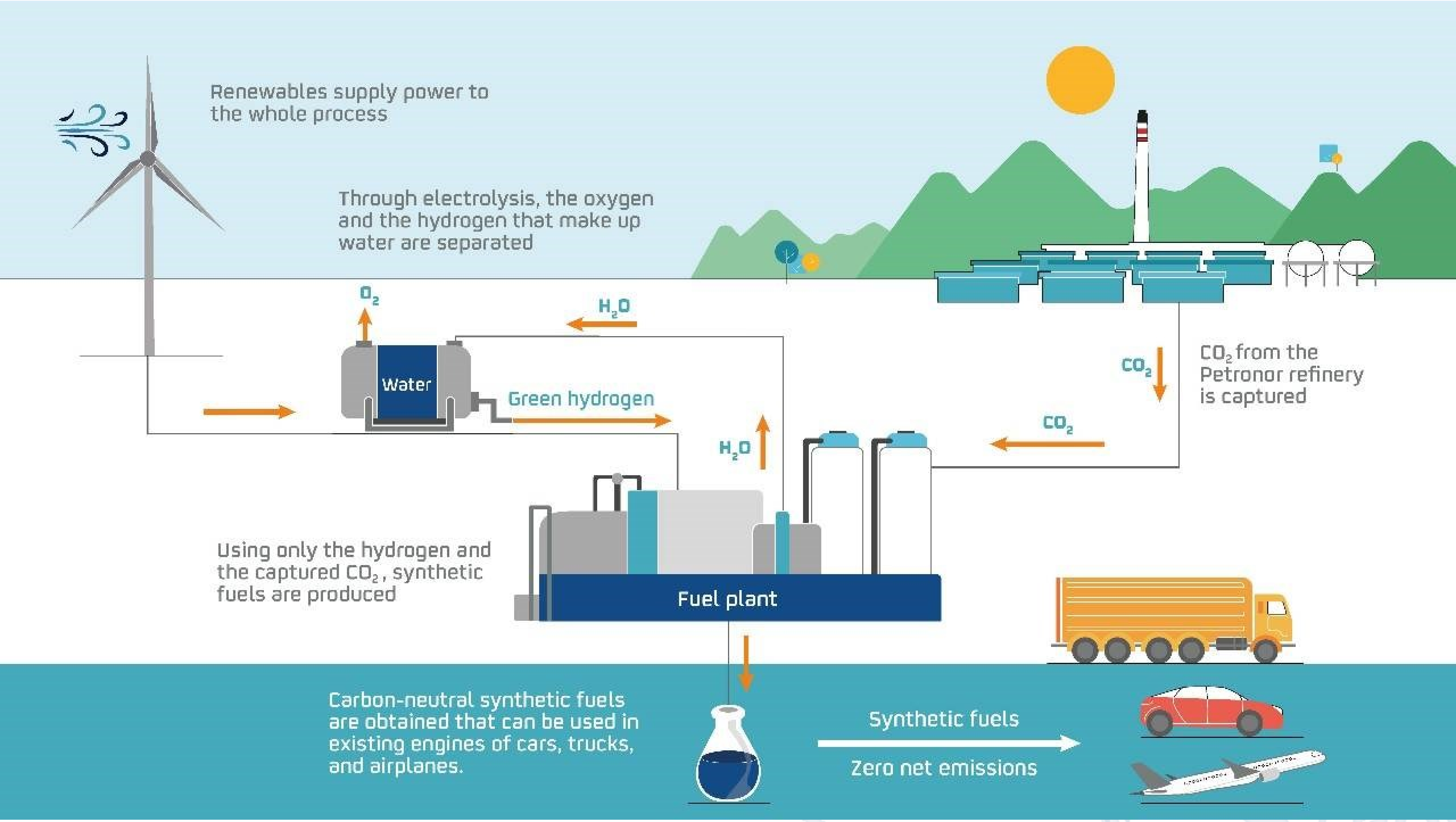
Ultimate emissions of CO_2 from fossil combustion & industrial process



SOURCE: SYSTEMIQ for the ETC (2022)

Co-funded by the European Union

Putting CO_2 to Use, Power-to-X



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Putting CO_2 to Use, Power-to-X

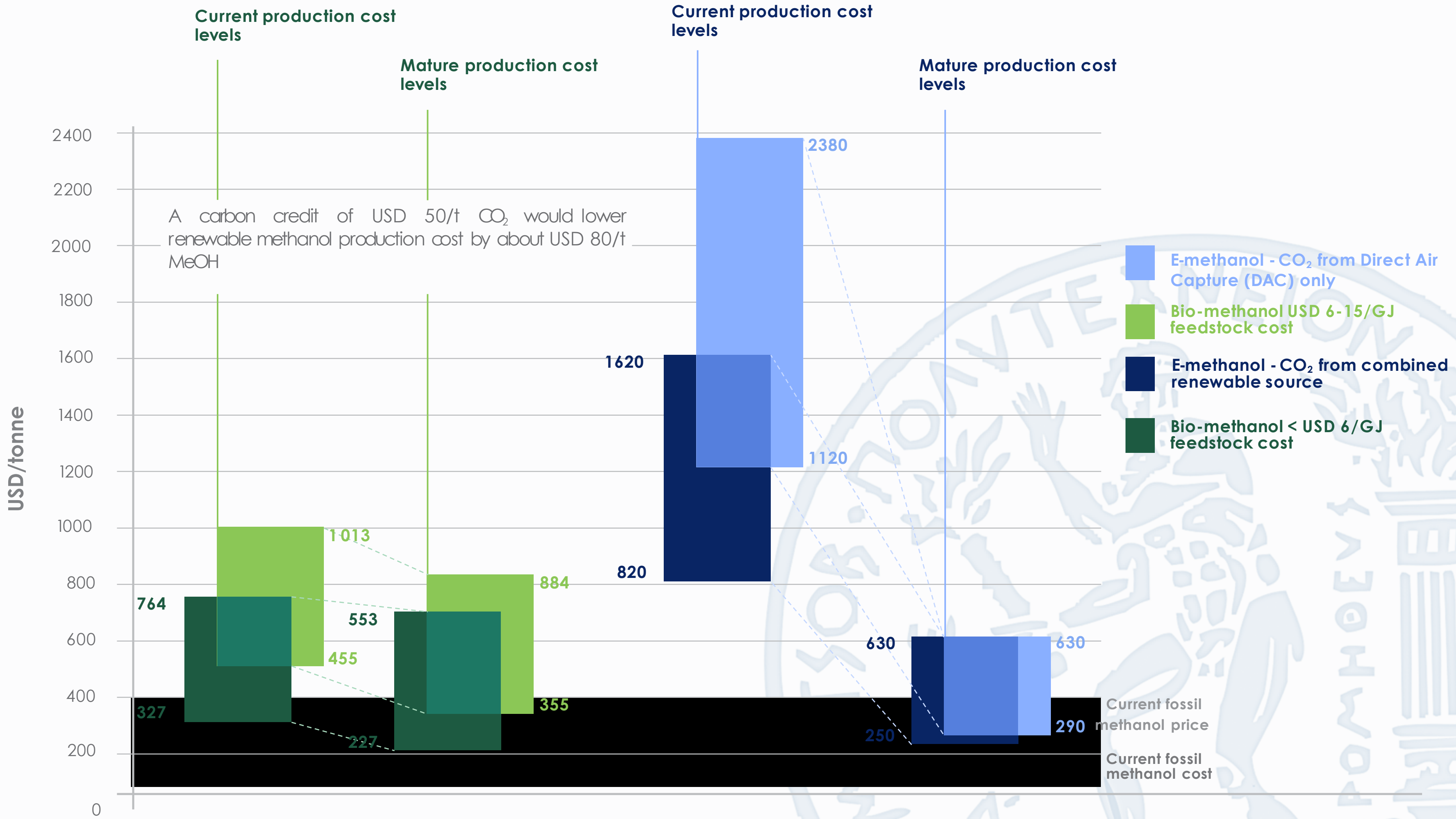
01 — Decarbonising transportation is considered crucial for a sustainability transition of the European wider energy system.

02 — Within the EU the transport sector accounted for almost 1/4 of greenhouse gas emissions.

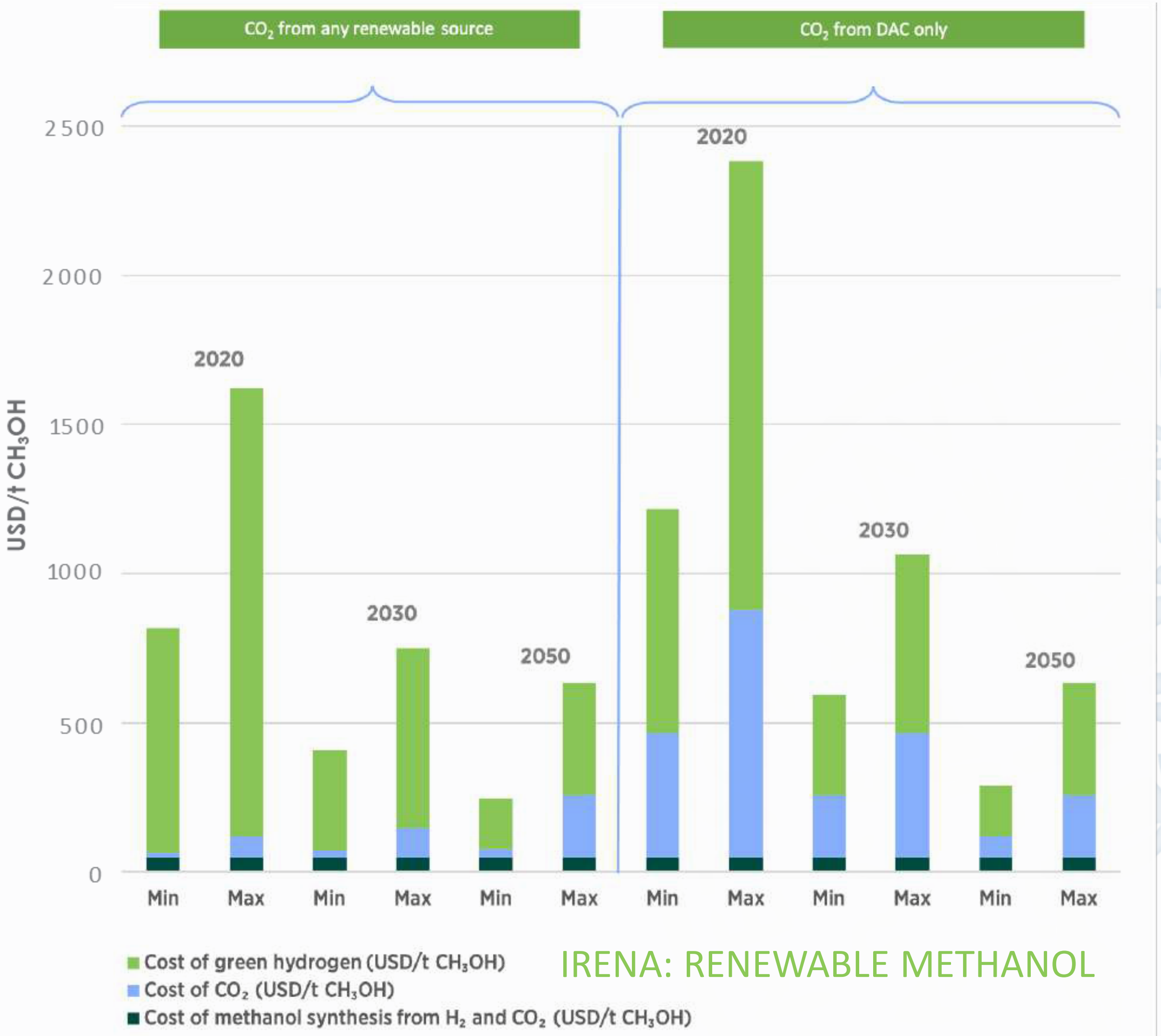
03 — A promising solution is the use of synthetic fuels, such as hydrogen generated via electrolysis (PtG-hydrogen), biomass-to-liquid fuels (BtL) and power-to-liquid fuels (PtL).

04 — Following the Hydrogen Roadmap Europe, the ambitious deployment of green and low-carbon hydrogen can translate to a €130 bn industry for EU fuel and equipment companies by 2030 that could reach €820 bn by 2050.

Putting CO_2 to Use, Power-to-X



Putting CO_2 to Use, Power-to-X



Note: *CAPEX and OPEX for the production of hydrogen and CO_2 are already included in the respective cost of hydrogen and CO_2.*

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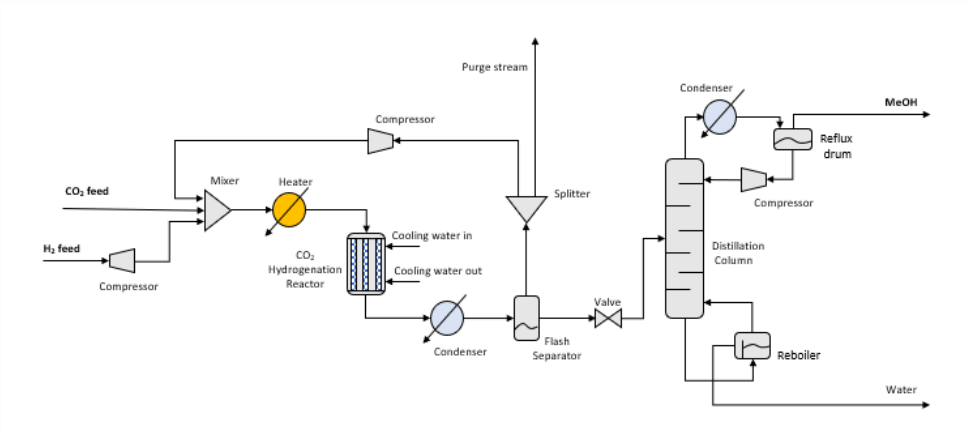
Putting CO_2 to Use, Power-to-X

- The **world's first commercial scale CO_2-to-methanol plant** has started production in Anyang, Henan Province, China.
- 110,000 tonnes of methanol per year.
- The new facility can capture 160,000 tonnes of carbon dioxide emissions a year, which is equivalent to taking more than 60,000 cars off the road.
- The entire unit weighs around 84 tonnes or the weight of a fully-loaded Boeing 737.

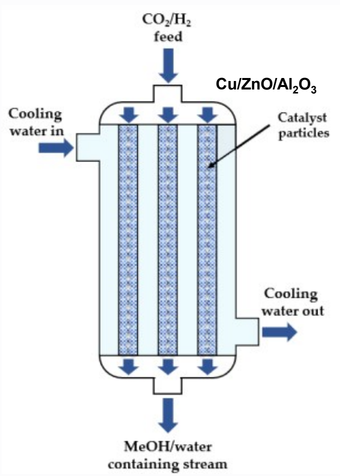
Putting CO_2 to Use, Power-to-X

CO_2 to Methanol transformation Unit Modelling & Design



EAF off gases analysis	
Temperature	56.6 °C
O_2	20.78%
CO	56 ppm (70 mg/Nm^3)
CO_2	0.36%
NO	2 ppm (2.68 mg/Nm^3)
NO_2	0.1 ppm (0.21 mg/Nm^3)
NO_x	2.1 ppm (2.88 mg/Nm^3)
SO_2	0 ppm

- Carbon Conversion efficiency > 85%
- MeOH production efficiency > 45%



Multi-tubular catalytic Lurgi reactor

Components	Temperature (°C)	Pressure (bar)
CO_2 to MeOH transformation system		
CO_2 Hydrogenation Reactor	220-300	40-100
Flash Separator	~30	40-100
Distillation Column	~30	1-1.5
Reboiler	~110	1-1.5
Reflux Drum	~64	1-1.5

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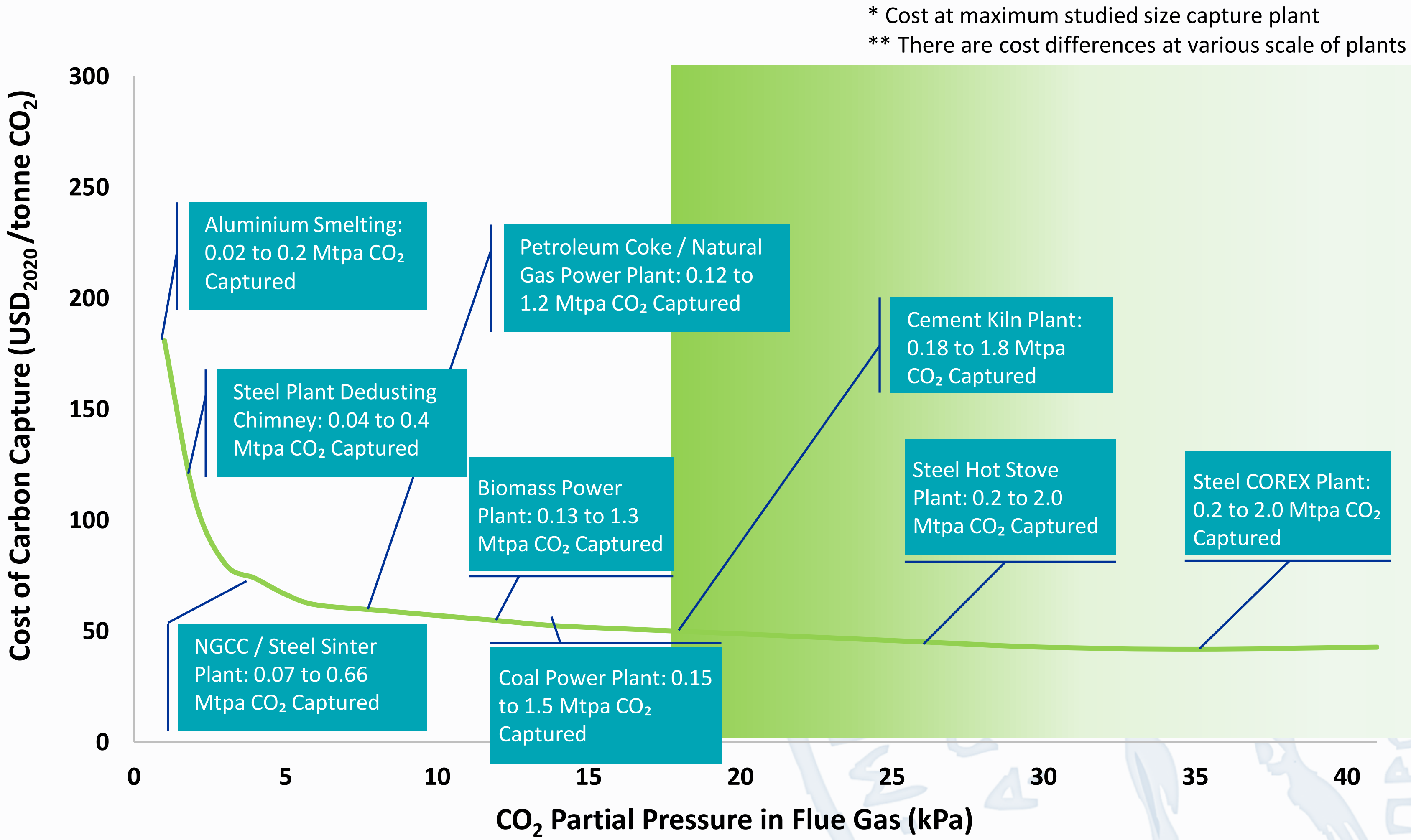
Project: 101058696-HEPHAESTUS
HORIZON-CL4-2021-TWIN-TRANSITION-01

Optimising Carbon Capture Cost for Extractive Industries



a Living Lab

integrating renewables (solar & wind),

H_2 production, use and storage facilities

for decarbonisation technologies

adapting AI and deep reinforced model training

targeting to advanced monitoring and hardware control

Intelligent BMS
and monitoring system
adapting system requirements

Prototype H_2 burner with a
condensing boiler (60 kWth)

Energy storage capacity*: 1MWh

*Equivalent Electrical Energy ready to be delivered to the building through the Fuel Cell (Hydrogen storage at 200bar)

Intelligent Safety and
Protection System

User friendly and fully automated
Energy Management and Monitoring System

40 kW CHP for residential
applications (PEM Fuel Cell)

Enhancing cooperation and future perspectives

- ✓ The developed RES-H_2 hybrid energy system can be used as a full-scale research, development and testing facility of:
  - H_2 production, storage and consumption technologies
  - Energy management systems
- ✓ Existing demonstration site presents a great opportunity to attract interested parties for direct knowledge exchange, consultancy and joint initiatives
- ✓ Contribute to standardization activities at system level for residential buildings or districts of buildings

Public awareness

- ✓ TV documentaries broadcasted to more than 130 countries in 10 languages (Euronews, RAI, TV5 and others)
- ✓ More than 25 articles published in Newspapers and Social Magazines
- ✓ Educational visits for students (more than 2000 students already hosted on site)
- ✓ Wide interest from Scientific, Governmental and investors representatives

NTUA School of Mining & Metallurgical Engineering

Sustainable Energy Solutions Living Lab

Milestones achieved

2024

Integration of a **containirised continuous plant for CO_2 capture and synthetic fuel production**

2020

Policy recommendations published by European Union for applying a common methodology **in accordance with Directive 2014/94/EU**


Bundesministerium für Wirtschaft und Klimaschutz

Energiekostenvergleich für Personenkraftwagen in €/100 km

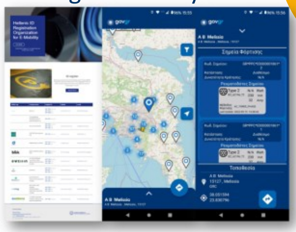
Super (E5)	10,52	13,23
Super E10 (E10)	10,19	12,83
Diesel (B7)	8,32	9,21
Strom	7,88	8,04
Erdgas H (CNG)	6,19	7,33
Autogas (LPG)	8,10	-
Wasserstoff (H2)	-	10,81

Der Energiekostenvergleich beinhaltet die Gegenüberstellung der Kosten verschiedener Energieträger für Personenkraftwagen bezogen auf dieselbe Maßeinheit gemäß § 3 Absatz 4 des Energieverbrauchskennzeichnungsgesetzes. Der Energiekostenvergleich wird vierteljährlich aktualisiert und ersetzt nicht die Auszeichnung der Kraftstoffpreise an der Tankstelle nach der Preisangabenverordnung (PAngV). Wenn für eine Fahrzeugsegment-Gruppe keine entsprechenden Daten verfügbar sind, wird in dem dafür vorgesehenen Feld ein Minuszeichen gesetzt.

Weitere Informationen finden Sie unter www.bmwk.de/Pkw-Energiekostenvergleich.

Stand: Juni 2022

Hellenic AFI ID registration system

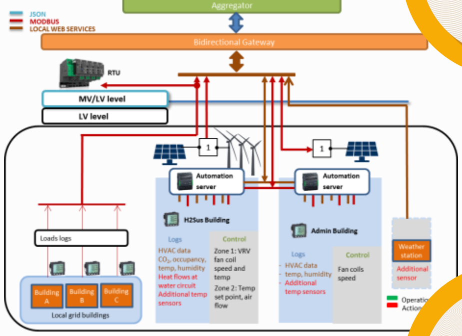


2016

Advanced monitoring and hardware control through **AI and deep reinforced model training**

2014

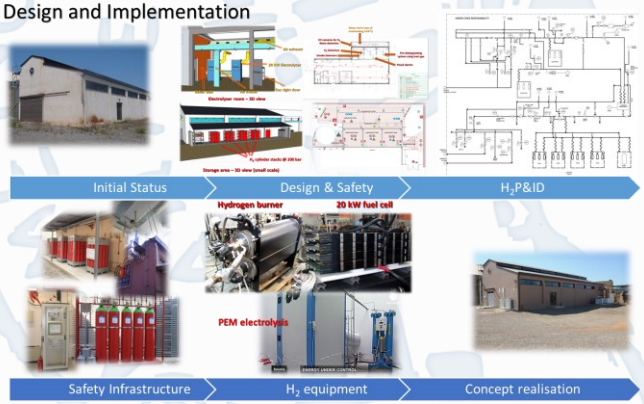
MV/LV microgrid deployment,
1400Ah OPC battery bank



2010

Integrated decarbonised hybrid energy system utilising green H_2 (55kg@200bar), zero emissions H_2 burner

Design and Implementation



2006

Decarbonised energy systems conceptualisation & design

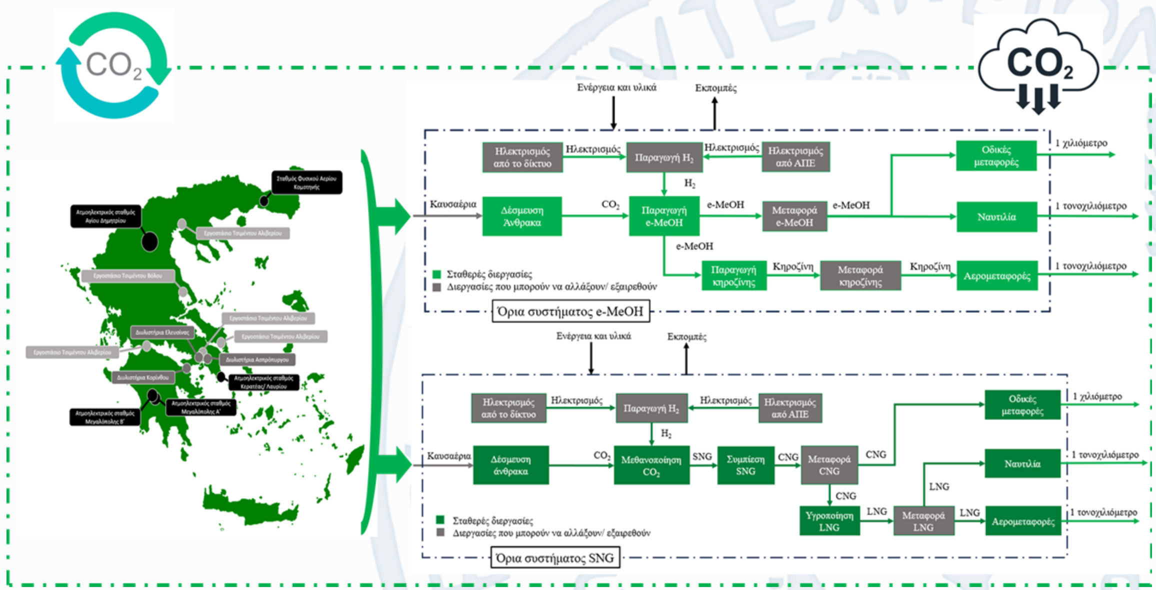
Our Vision

Extractive Industries:
Transition to sustainable Systems

Putting CO_2 to Use, Power-to-X

Improve the maritime industry's environmental impact.

The program will focus on several key areas: developing alternatives to traditional fuels, improving energy efficiency in ships and ports, using new digital technologies to better manage operations, and encouraging recycling and the use of biofuels. Through this program, we aim to make shipping more sustainable and efficient.



Life cycle assessment &
prefeasibility analysis
for utilising SNG and e-MOH

Greece 2.0 NATIONAL RECOVERY AND RESILIENCE PLAN
Funded by the European Union NextGenerationEU
ΕΠΑνΕΚ 2014-2020 ΕΣΠΑ 2014-2020
Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης
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Co-funded by the European Union

School of Mining & Metallurgical Engineering
Laboratory of Metallurgy

Research Unit: Raw Materials Exploitation & Sustainable Energy Solutions

EU Transparency Register: 512032248325-80

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YouTube Our activities:

- Laboratory profile
- [Scandium extraction from residues, Euronews broadcast]
- [Hydrogen based hybrid systems, Euronews broadcast, 3rd part of the video]
- [Innovative construction materials]
- [Efficient HVAC for improved indoor environment]
- [Smart Grid Demonstration]
- [Spin off, Ecosystem for upscaling and testing multifunctional lightweight concrete]