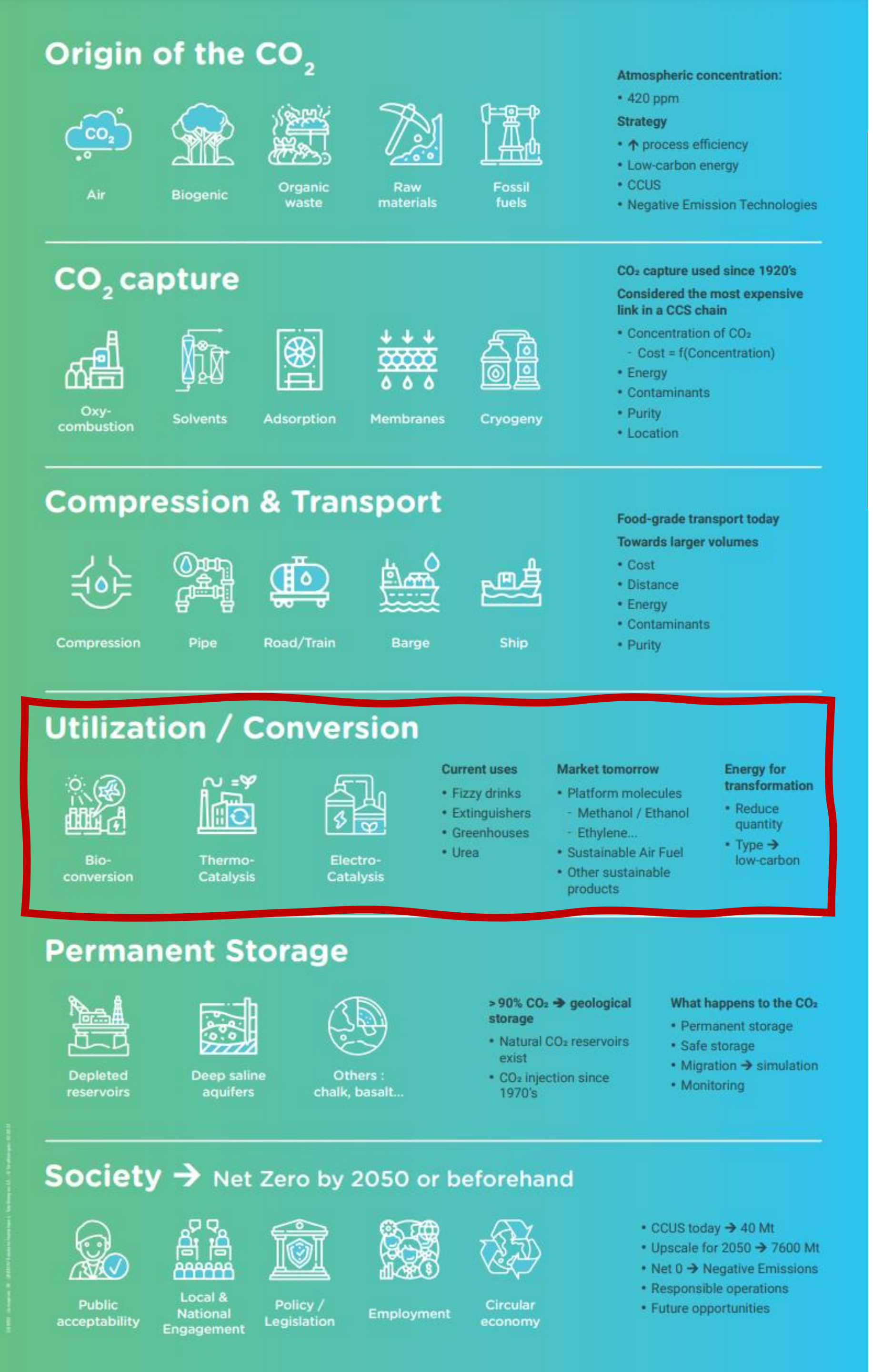


Fondation de la Maison de la Chimie

TotalEnergies

Voies partant du CO_2 : CO_2 fatal et capture à partir de l'air

(Which CO_2, and what routes to sustainable products should we consider ?)

Philip Llewellyn

CCUS R&D Manager

CO_2 & Sustainability Program,
OneTech-TotalEnergies, CSTJF-Pau (France)

Avoid – reduce - compensate

TotalEnergies

- Carbon neutrality by 2050, together with society.
- 10 % of annual R&D budget is dedicated to CCUS
- Store at least 10 millions tonnes of CO_2 per year by 2030

Renewables & low-carbon energy

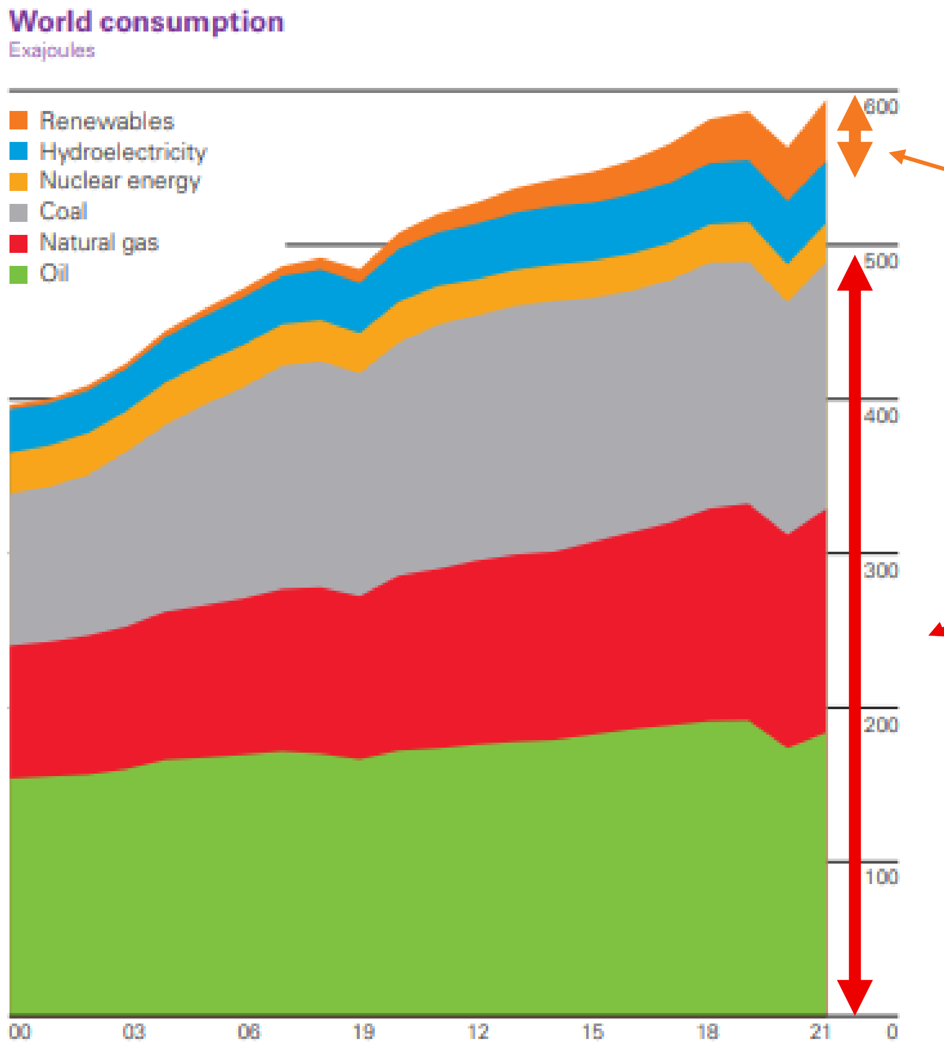
Carbon Capture & Storage (CCS)

NBS & Direct Air Capture

The scale of the challenge ... HC vs renewables !

bp Statistical Review of World Energy 2022 | 71st edition

TotalEnergies



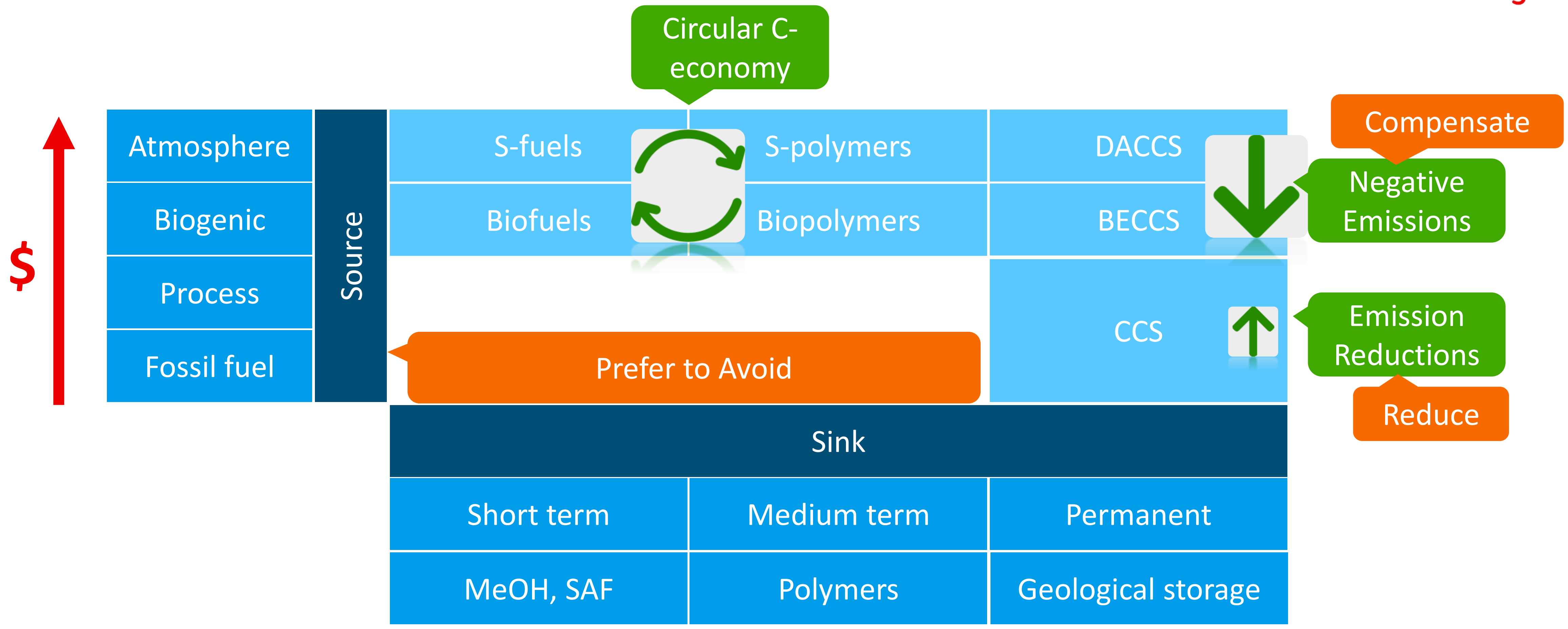
This (renewables) ...

Has to replace

THIS (Fossil hydrocarbons)

$CO_2 + H_2O +$ Renewable Energy → Sustainable HC's

CC(U)S : a case of source to sink matching



Adapted from : http://research.american.edu/carbonremoval/wp-content/uploads/sites/3/2020/12/reduce-remove-recycle_final.pdf

CC(U)S :
a case of *source* to sink matching

Cement
LafargeHolcim, Richmond
Pilot : 1 T CO_2/day

https://www.lafarge.ca/en/project-co2ment

Waste to Energy
Amager Resource Centre
Pilot : 50 kT
Plan for 500 kT

https://www.euractiv.com/section/energy-environment/news/copenhagens-dream-of-being-carbon-neutral-by-2025-go-up-in-smoke/

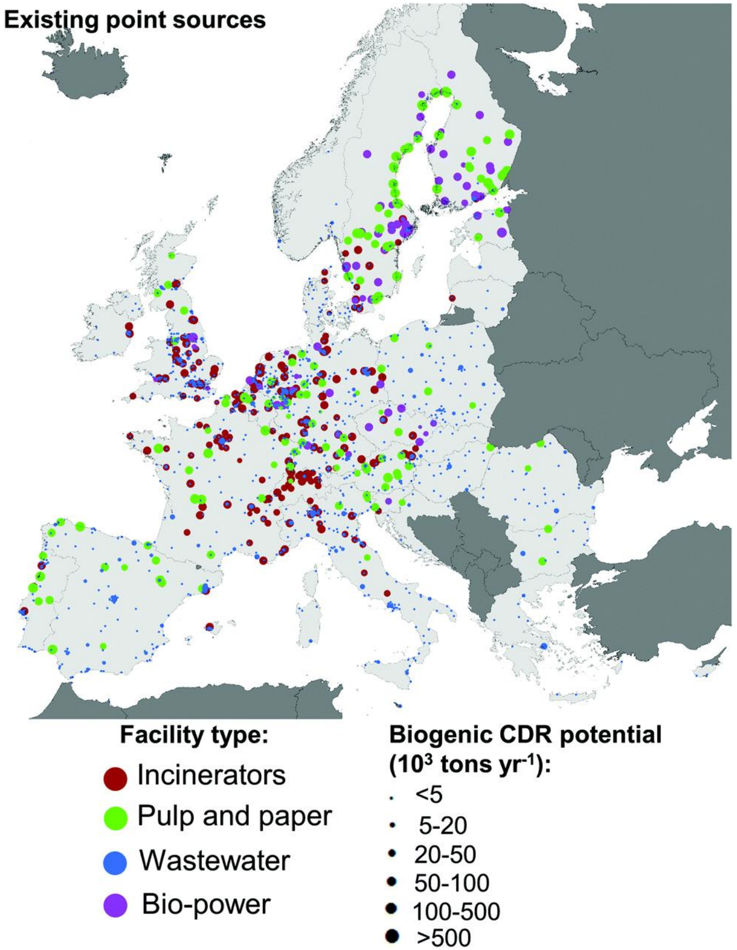
Pulp & Paper
Howe Sound, Port Mellon Mill
Boiler upgrade
1.7 M$
50 kT (-15% CO_2e)

https://www.coastreporter.net/local-news/howe-sound-pulp-and-paper-gets-nearly-17-million-for-emission-reducing-projects-5018434

- Size of the source
- Place of the source
  - Point source
  - More diffuse sources

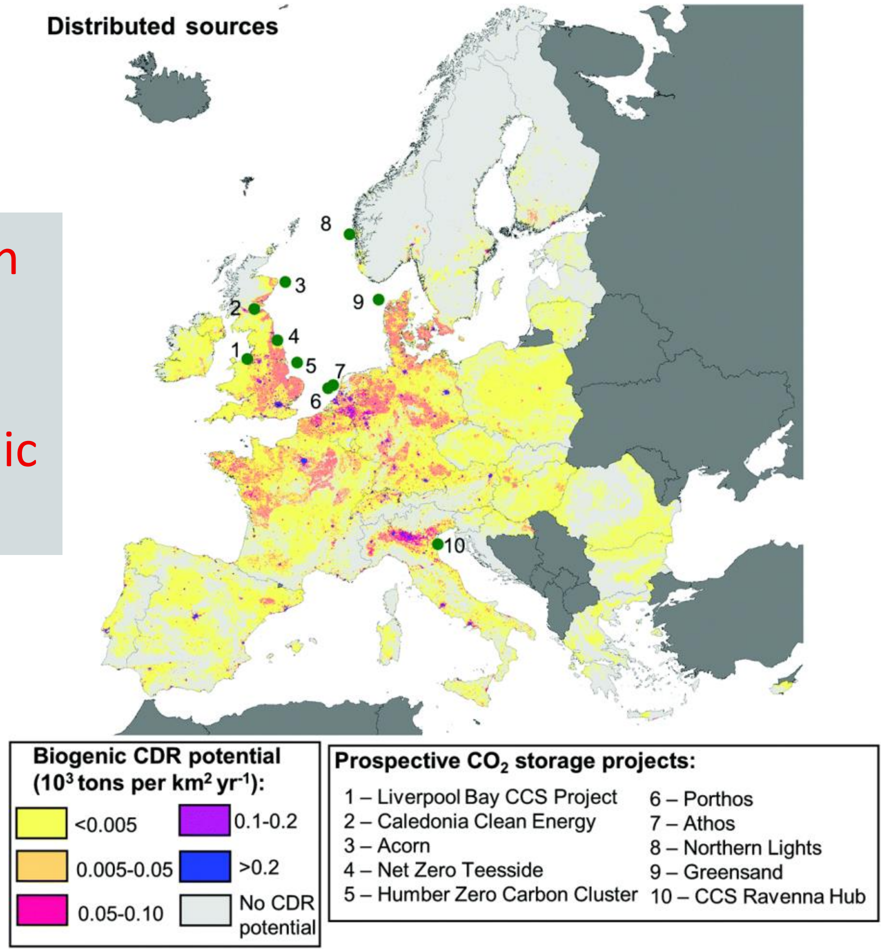
CC(U)S : a case of source to sink matching

Assessment of carbon dioxide removal potential via BECCS in a carbon-neutral Europe
Lorenzo Rosa, Daniel L. Sanchez and Marco Mazzotti, Energy Environ. Sci., 2021, 14, 3086-3097



Geospatial distribution of biogenic carbon dioxide removal potential from existing point sources in Europe in 2018. The figure shows incinerators, pulp and paper, and bio-power facilities emitting more than 0.1 Mtons CO_2 per year,[54] and wastewater treatment plants processing more than 100 000 population equivalent of wastewater per day

5% of 2018 European emissions (~200 MT CO_2 /y), could be mitigated with biogenic CDR from BECCS

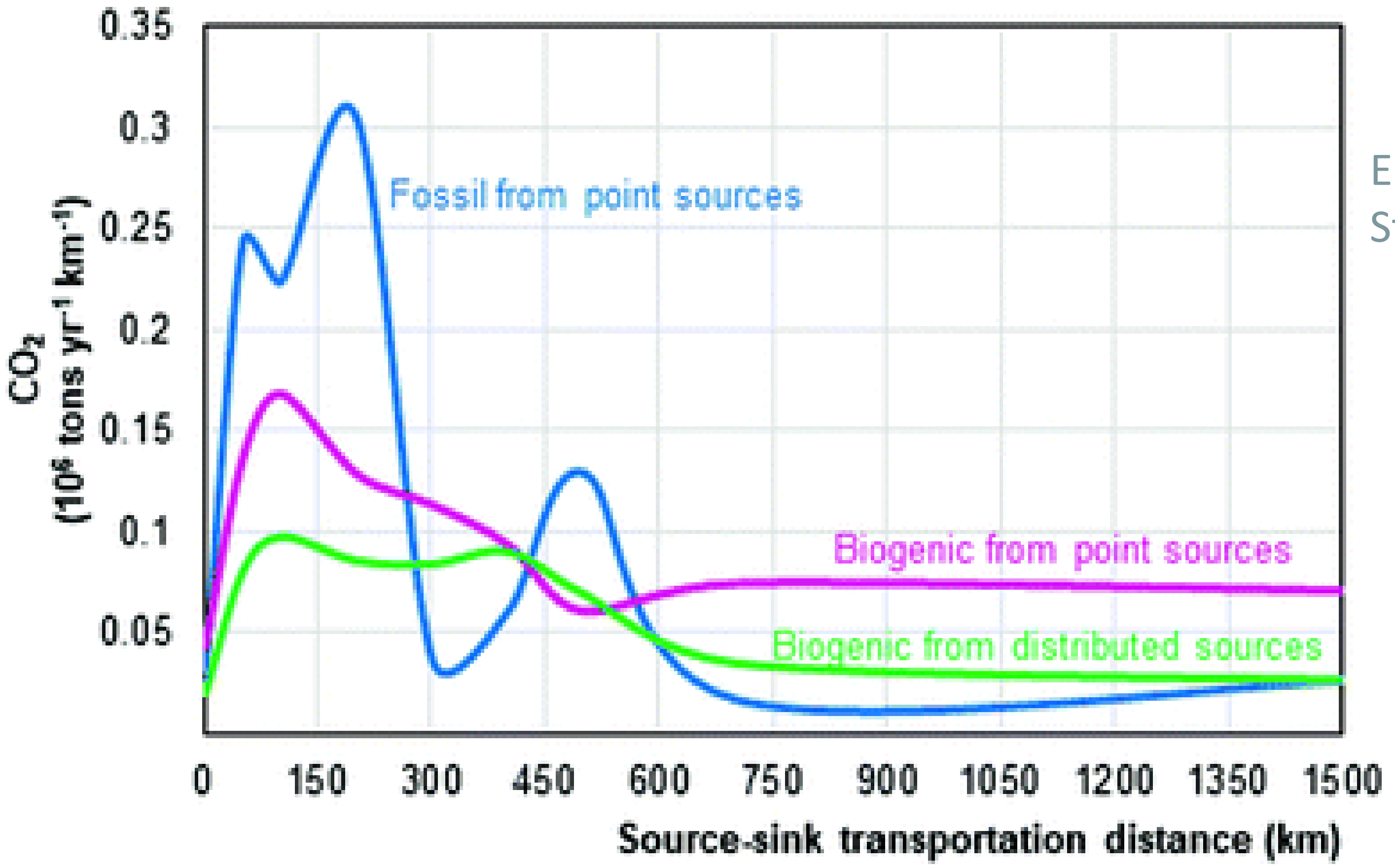


Geospatial distribution of biogenic carbon dioxide removal potential from distributed sources of biogenic CO_2 in Europe. Distributed sources of biogenic CO_2 are livestock manure, household organic food waste, and crop residues. The figure shows location and name of ten prospective carbon storage sites that are planned or in start-up phase in Europe.

CC(U)S : a case of source to sink matching

… one can argue that ‘transport’ is a deciding factor …

Assessment of carbon dioxide removal potential via BECCS in a carbon-neutral Europe
Lorenzo Rosa, Daniel L. Sanchez and Marco Mazzotti, Energy Environ. Sci., 2021, 14, 3086-3097



Emission-based distribution of source–sink (North Sea Storage) transport amount and distance of European CO_2.

For longer transort distances, maybe geological storage is not the best option

➔ Bioenergy / Bioproducts

CC(U)S : a case of
<u>*source*</u> to sink matching

- Air : the most abundant & dilute source of CO_2

- Advantage : not site specific
  - control transport

- Disadvantage : energy requirement (and type)

https://climeworks.com/roadmap/orca

Orca
4000 T/y
Start Nov 2021

Mammouth
38 000 T/y

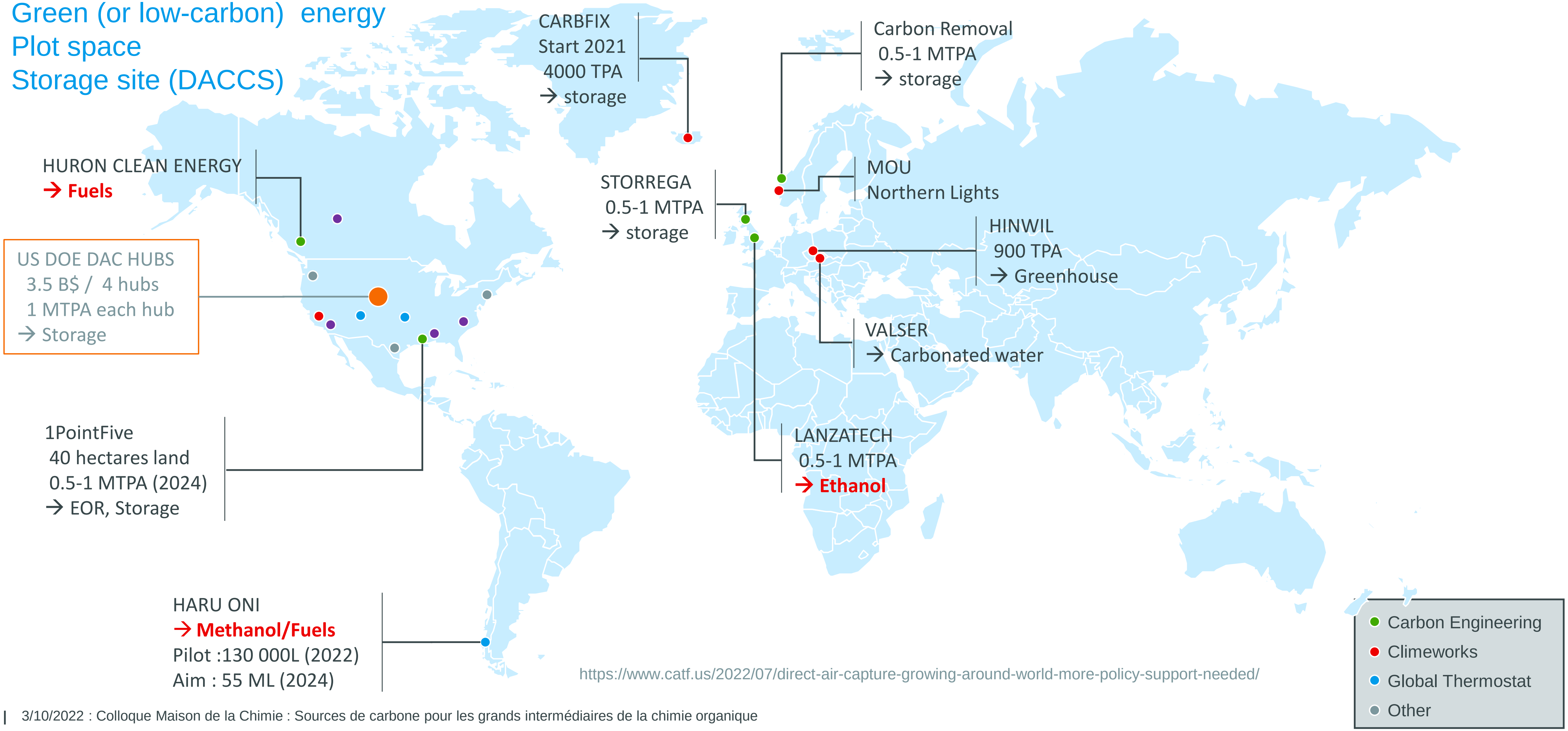
Haru Oni, Chile
350 T/y MeOH
130,000 L gasoline /y

https://www.hifglobal.com/haru-oni

Some worldwide DAC ‘projects’ today …

Integration levers:

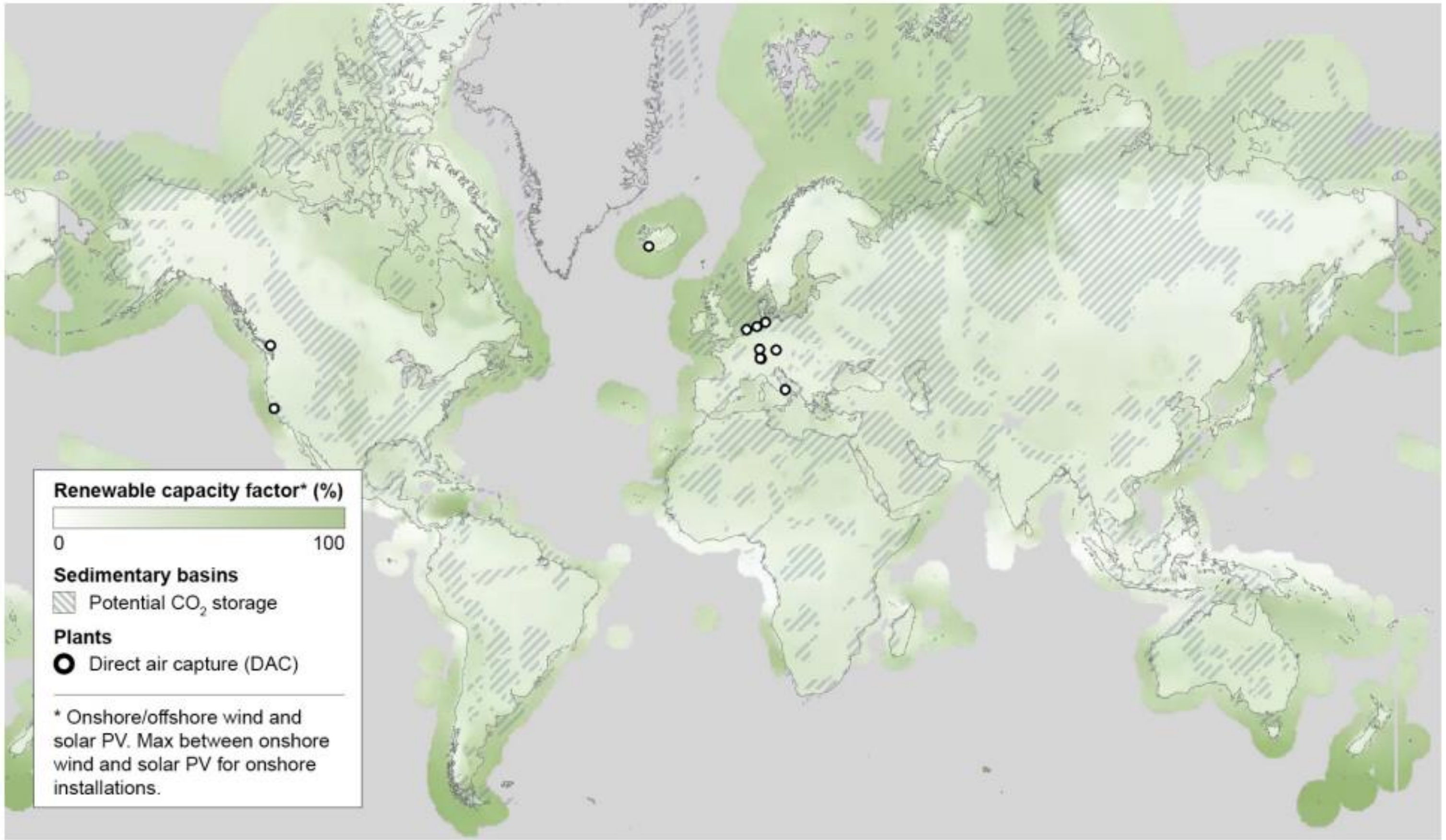
- Green (or low-carbon) energy
- Plot space
- Storage site (DACCS)



https://www.catf.us/2022/07/direct-air-capture-growing-around-world-more-policy-support-needed/

What energy should we use for DAC ?

Map of renewable energy source potential and geological storage



Notes: This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area.

IEA / Direct Air Capture, A key technology for net zero
https://iea.blob.core.windows.net/assets/78633715-15c0-44e1-81df-41123c556d57/DirectAirCapture_Akeytechnologyfornetzero.pdf

Renewable energy considered :
- Wind
- Solar

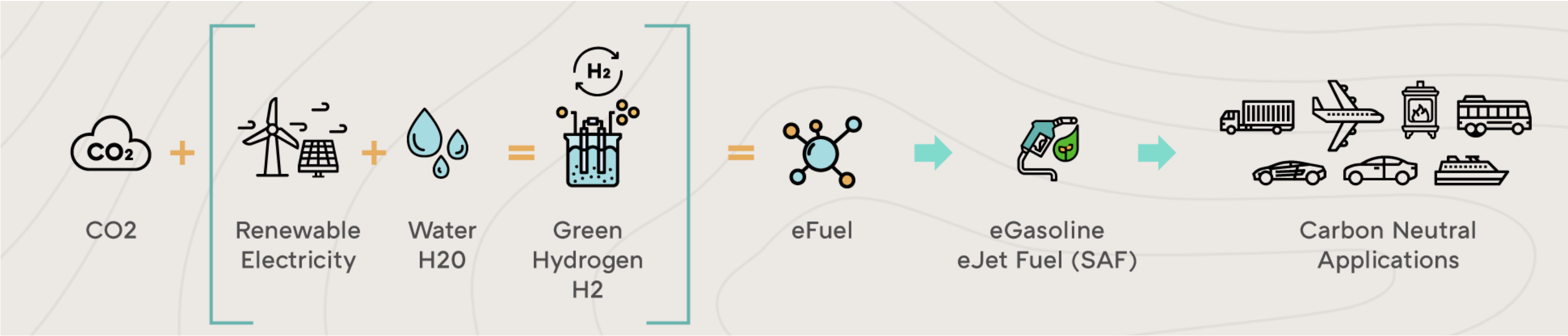
Should also consider at least :
- Geothermal
- Hydro

Haru Oni :

e-H_2 + $CO_{2(air)}$ → MeOH → gasoline

Magallanes Region, Chile

- Siemens Gamesa wind turbine → 3.4 MW
- H_2O Electyrolysis → Silyzer 200 PEM
- DAC → Global Thermostat
- MeOH synthesis → MAN / Johnson Matthey
  → 750 000 L/y (2022)
- MTG (ExxonMobil) → 130,000 liters per year

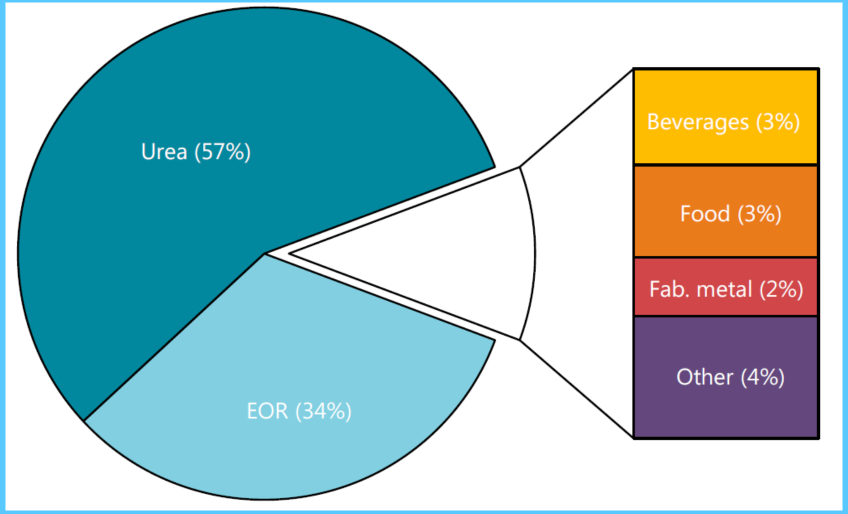


Phase 2++

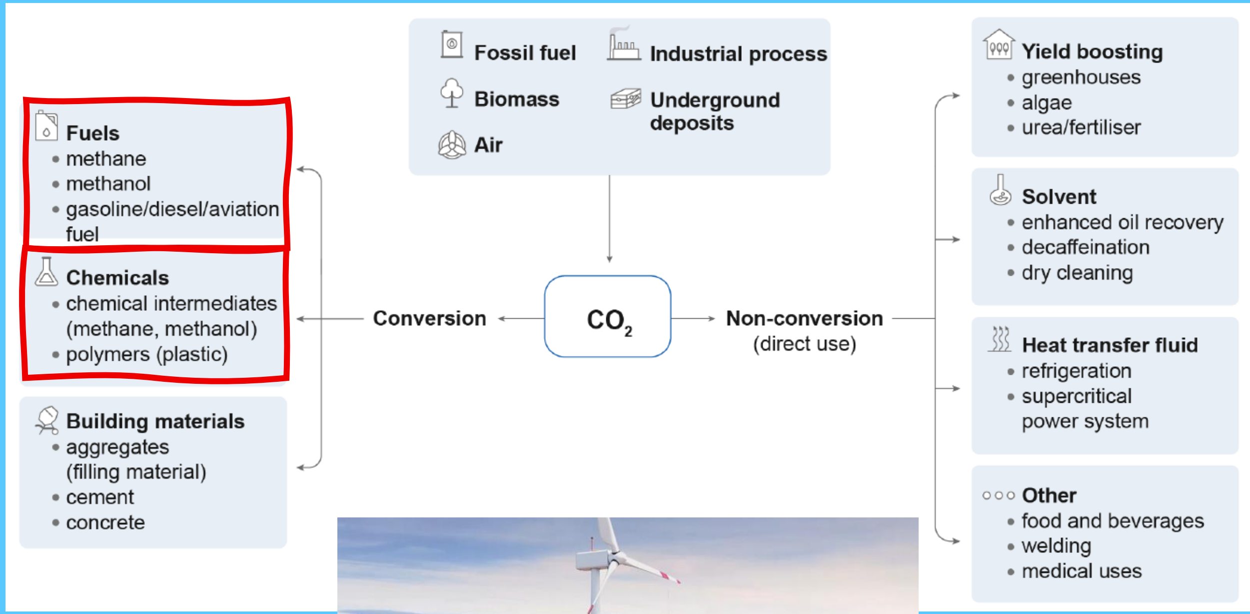
- Wind Farm → 280 MW → 2,5 GW
- 55 million liters e-gasoline per year by 2024 and over 550 million liters per year by 2026
- Ship transport (MeOH powered ?) to Europe → One container has a loading capacity of 25,000 – 30,000 liters.

(https://www.haruoni.com/#/en)

CC(U)S : a case of source to *sink* matching



https://www.iea.org/reports/putting-co2-to-use

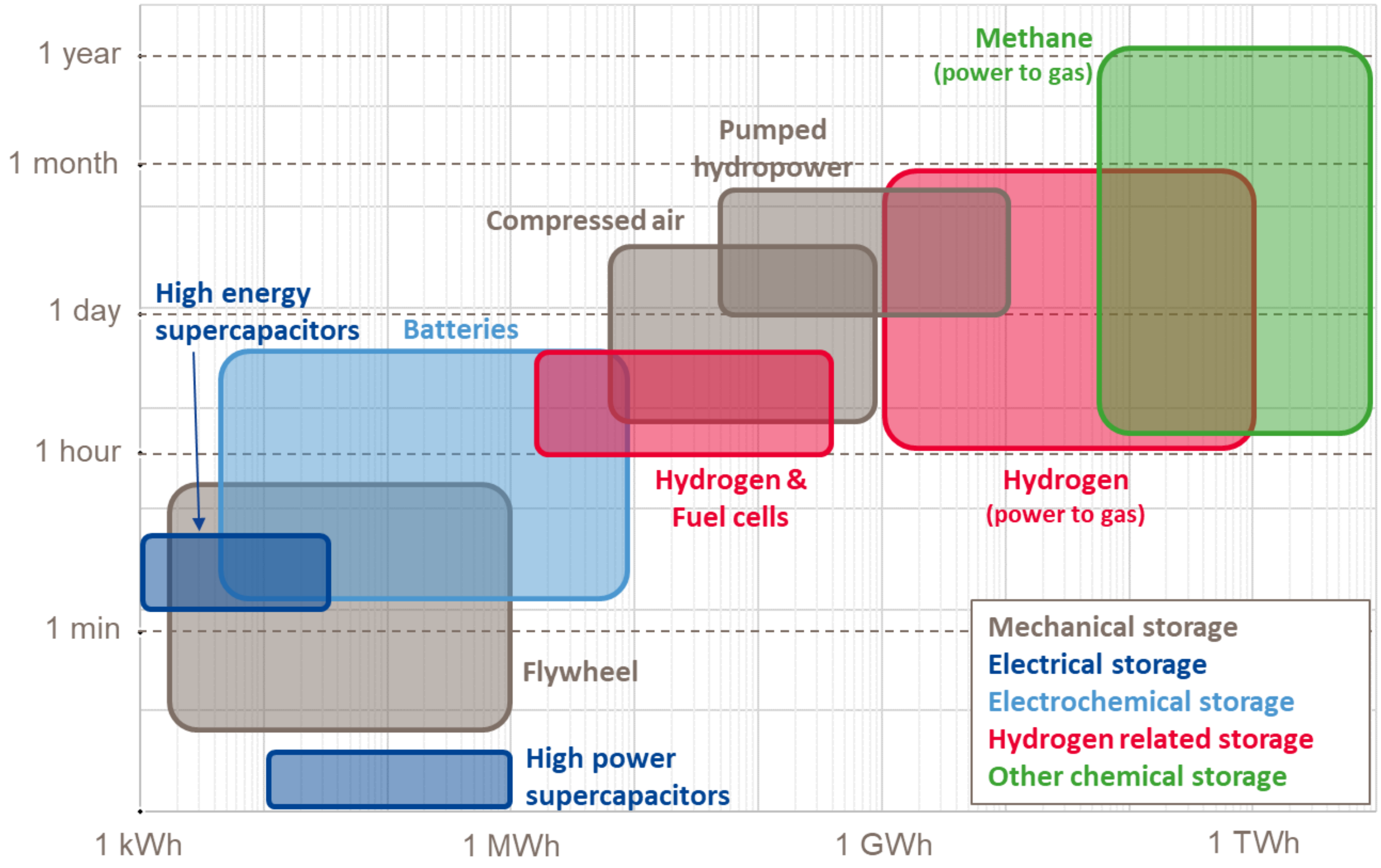


- Market for the sink
- Today use ~230 Mt(CO_2)/y
  - 130 Mt/y → urea
  - Others : EOR, food & drinks, metal, fire extinguishers, greenhouses.
- Future
  - CO_2 to energy
  - CO_2 to sustainable products

Should we consider CO_2 to chemical energy as a long-term energy storage solution vs batteries for ex.

TotalEnergies

Size and time scales of energy options



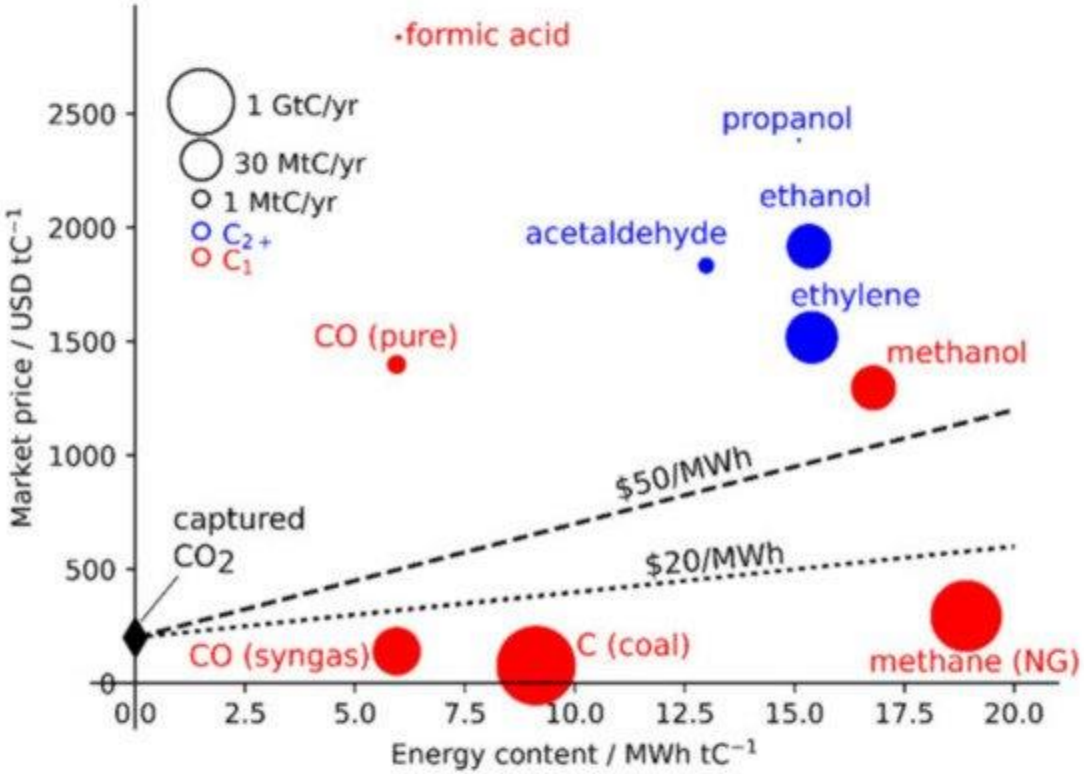
What are the best energy vectors ?

CH_4, or other chemicals from CO_2 capture : Ethanol, methanol, C_2H_4

What is the best energy source to convert CO_2 : heat, H_2, e^- ?

Quid : integration, intermittency …

What should we transform CO_2 into ?
What is the market need ? … and future market ?



Zhenyu Jin et al., Sustainability 2022

METHANOLICS ANONYMOUS

Maersk can't find enough green fuel to power its carbon-neutral ships

On Jan. 10, Maersk confirmed that it had ordered four more carbon-neutral container ships, on top of the eight green ships it had already ordered from South Korean shipwright Hyundai Heavy Industries. The ships, which can either run on fossil fuels or a low-carbon fuel called green methanol, are set to be delivered starting in 2024.

The trouble is, Maersk isn't sure if it can find enough green methanol to fuel its new green ships. Maersk will need over 450,000 tons of green methanol a year to run the 12 low-carbon ships it has on order. The current global output is 100 million metric tons per year.

"I'm still optimistic that we will get at least some of these big ships operating on green methanol in 2024," Morten Bo Christiansen, head of decarbonization strategy at Maersk, said at a Dec. 8 press conference. "2025 is looking a lot better. Will we get it for the maiden journey for the first ship? I cannot promise you that."

Maersk secures green e-methanol for the world's first container vessel operating on carbon neutral fuel

19 August 2021

Denmark Europe Decarbonisation Sustainability Share

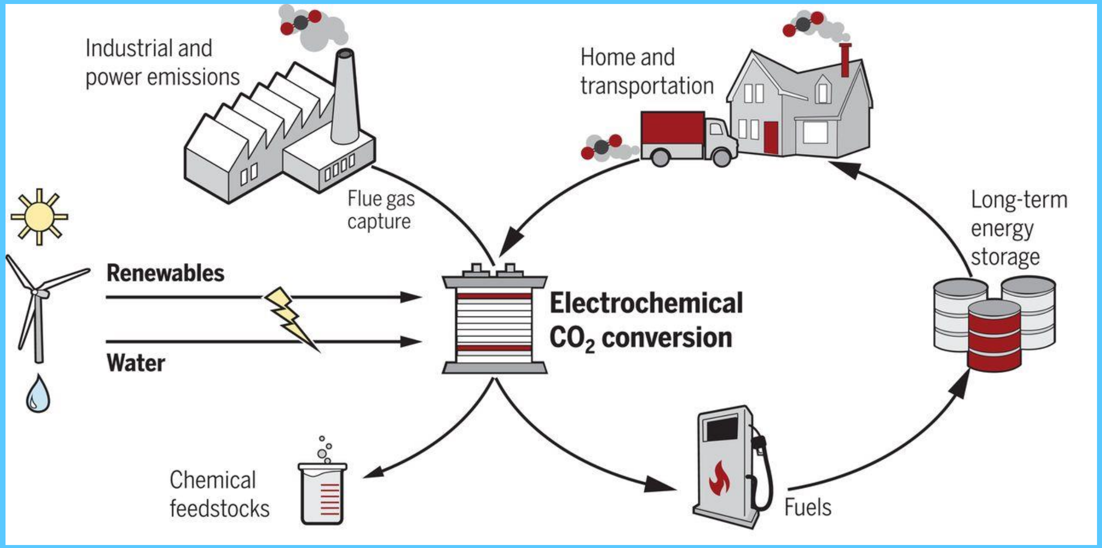
European Energy will establish a new e-methanol facility in Denmark and provide renewable energy to fuel it.

Copenhagen: A.P. Moller - Maersk has identified its partners to produce green fuel for its first vessel to operate on carbon neutral methanol: REintegrate, a subsidiary of the Danish renewable energy company European Energy.

REintegrate and European Energy will establish a new Danish facility to produce the approx. 10.000 tonnes of carbon neutral e-methanol that Maersk's first vessel with the ability to operate on green e-methanol will consume annually. Maersk will work closely with REintegrate and European Energy on the development of the facility.

> "This type of partnership could become a blueprint for how to scale green fuel production through collaboration with partners across the industry ecosystem, and it will provide us with valuable experiences as we are progressing on our journey to decarbonise our customers' supply chains. Sourcing the fuels of the future is a significant challenge, and we need to be able to scale production in time.
>
> Henriette Hallberg Thygesen,
> CEO of Fleet & Strategic Brands, A.P. Moller - Maersk

Projects @ CCU R&D



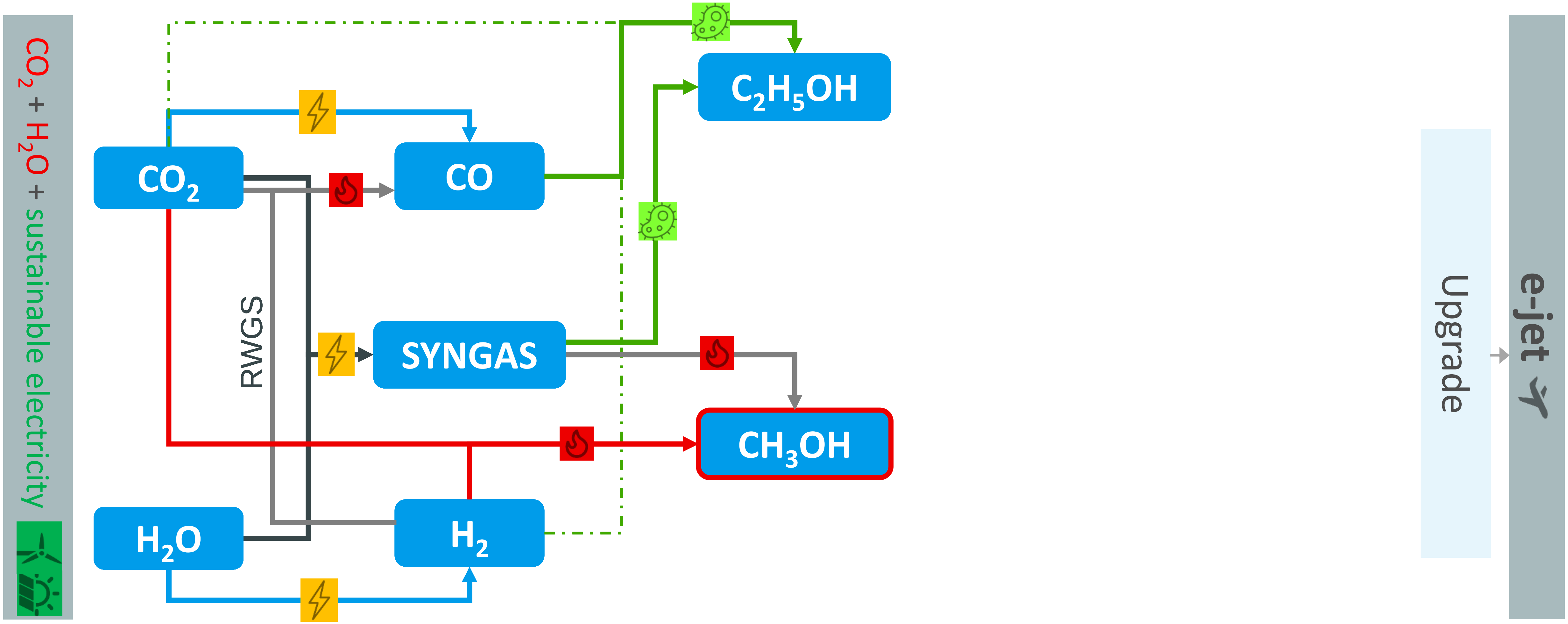
De Luna *et al.*, *Science* **364**, 350 (2019)

- Pathways to sustainable air fuel

- Choices made by our program
  - Methanol
  - Ethylene
  - Direct conversion to liquid hydrocarbons

Various pathways from CO_2 to sustainable molecules

Type of Energy : Electrochemical Thermochemical Biochemical



Sustainable methanol

Catalysts for CH_3OH

Winner: 2022 Environment, Sustainability and Energy Division Horizon Prize: John Jeyes Award

ETH Zürich, TotalEnergies, Institute of Chemical Research of Catalonia and Paul Scherrer Institute, the Sustainable Methanol team are being recognised for the discovery, fundamental understanding, and technical development of a novel catalytic technology for the recycling of carbon dioxide to produce sustainable methanol.

> "The discovery offers a technically viable solution for recycling carbon dioxide to produce methanol as a key chemical and energy carrier in a sustainable manner."
>
> Javier Pérez-Ramírez

CO_2 thermocatalytic conversion to platform molecules

→ getting some energy back into “C” ➔ e-methanol

TotalEnergies

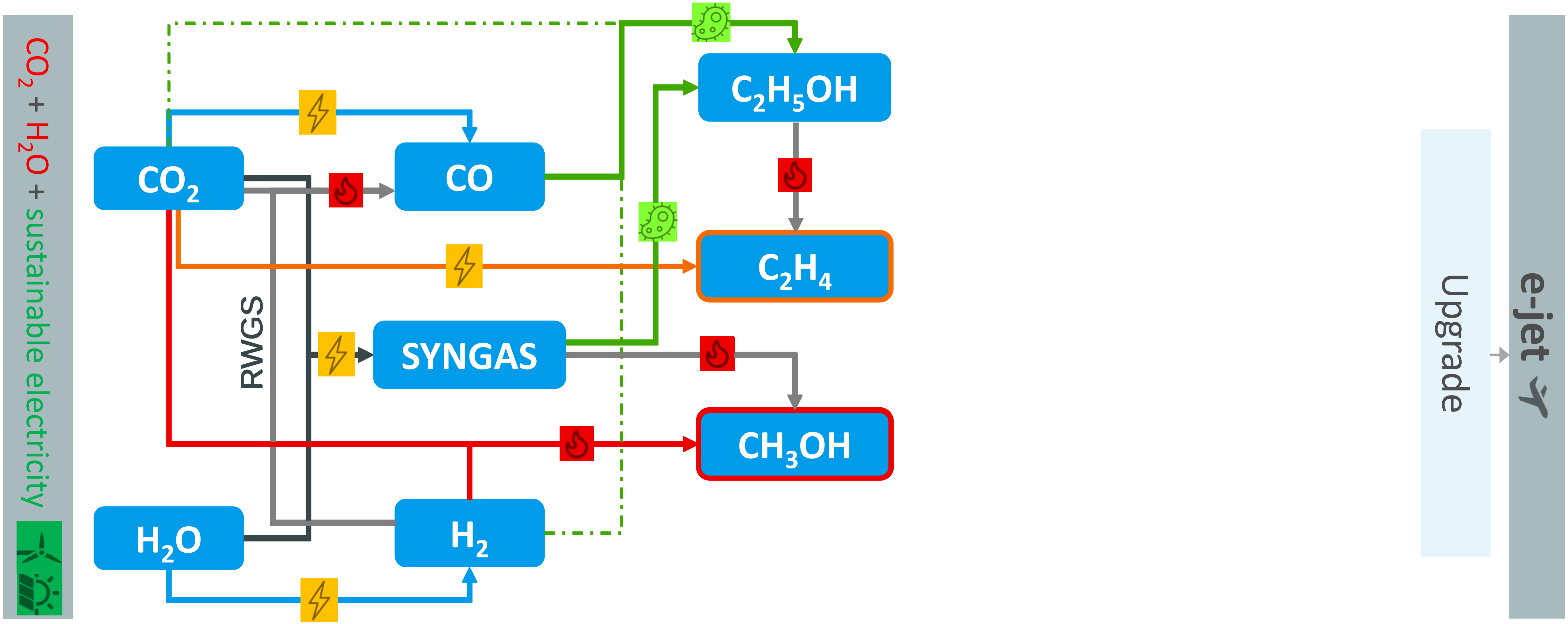
Integration of green H_2 for CH_3OH production

- 1 MWe electrolyser,
- 21 L catalyst reactor,
- 0.6 CO_2 t/d converted,
- 240-360 kg H_2/d used,

  ➔ 0.4 MeOH t/d

Various pathways from CO_2 to sustainable molecules

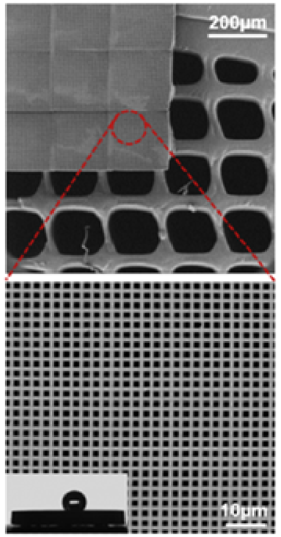
Type of Energy : Electrochemical Thermochemical Biochemical

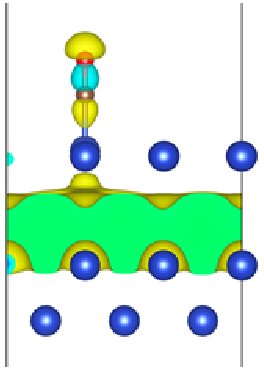


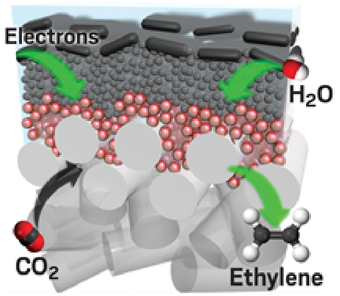
CO_2 electrocatalytic conversion to platform molecules

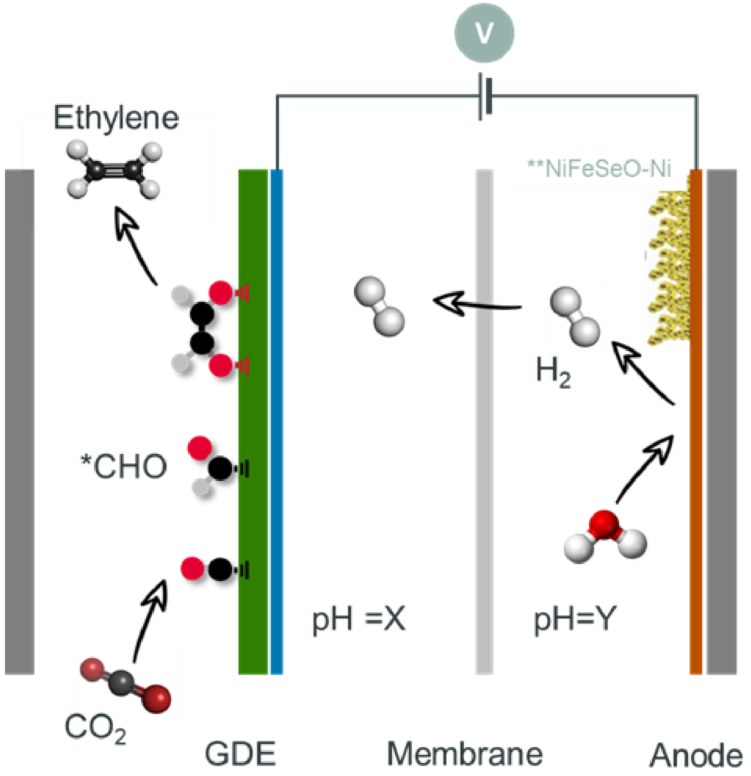
→ getting some energy back into "C" ➔ e-ethylene

TotalEnergies









- New 'Cu-based' catalysts
- Reaction mechanisms
  - Gas diffusion electrode (GDE)
  - Membrane
  - Anode
- GDE construction
- Device development

UNIVERSITY OF TORONTO

COLLÈGE DE FRANCE 1530

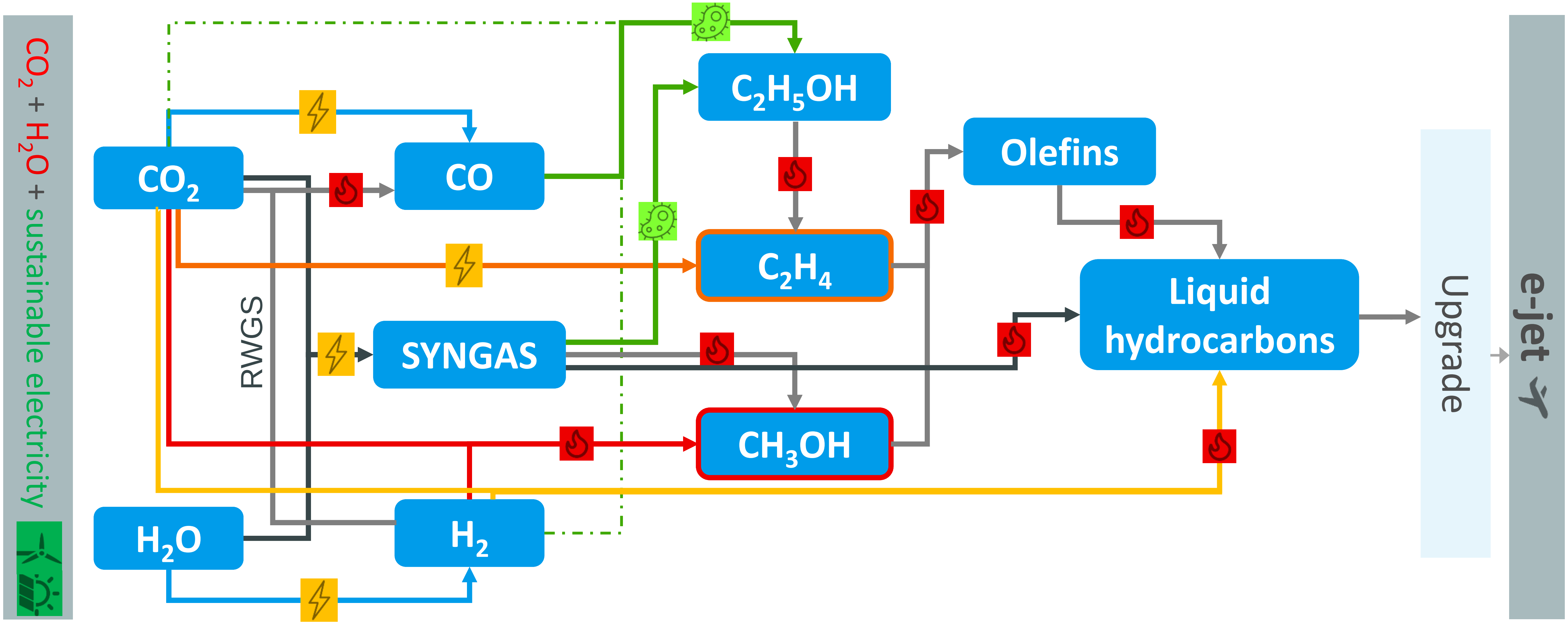
Lawrence Livermore National Laboratory

Electro-catalysis of CO_2 to C_2H_4

* Ma et al., Nature Catalysis 3, (2020) 478–487
** Peugeot et al., Joule 5, (2021) 1-20
*** Dinh et al., Science, 18 (2018) 783-787

Various pathways from CO_2 to sustainable molecules

Type of Energy : Electrochemical Thermochemical Biochemical

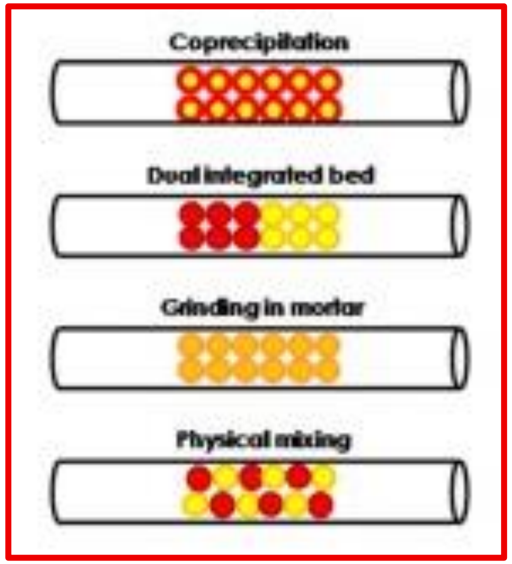


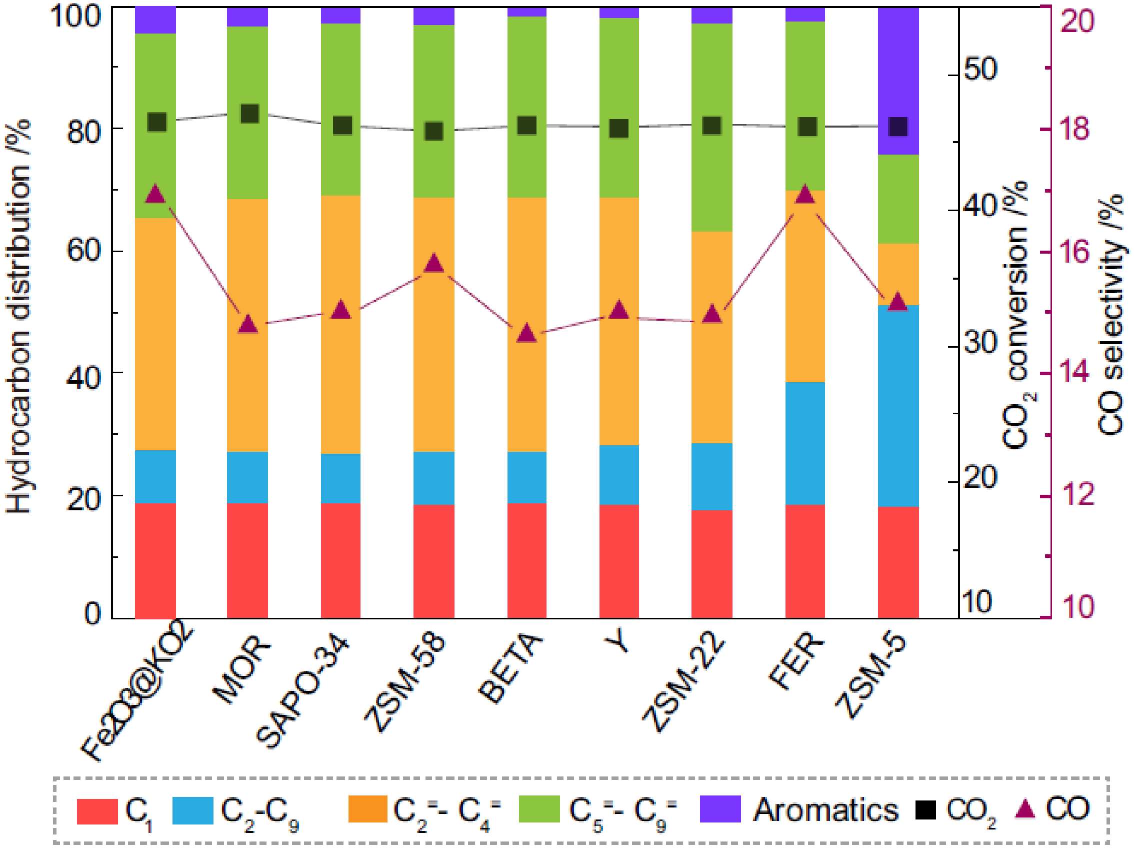
CO_2 to hydrocarbons with dual bed Fe_2O_3@KO_2 & zeolites

Catalytic performance of the Fe_2O_3@KO_2/zeolite bifunctional material catalyzed hydrogenation of CO_2 process

TotalEnergies

Direct conversion of CO_2 to liquid HC's

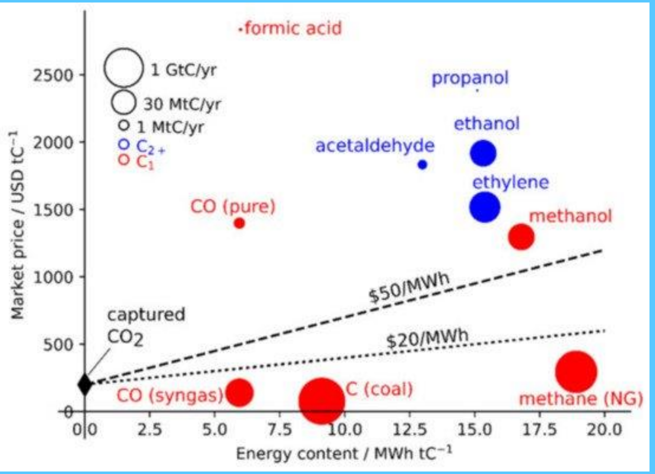




جامعة الملك عبدالله
للعلوم والتقنية
King Abdullah University of
Science and Technology

Adrian Ramirez et al., Nature Comm, 2021, 12:5914

We find that the different zeolite topologies can be classified into four distinct groups in terms of selectivity:
(i) light olefins (MOR, SAPO-34, ZSM-58, BETA, Y), (ii) paraffins (FER),
(iii) long (olefinic) hydrocarbons (ZSM-22), and (iv) aromatics (ZMS-5)3.



TotalEnergies

Final thoughts

- A question of source to sink matching with some key parameters
  - Quantity & origin of the CO_2
    - Point source
    - Diffuse source / DAC
  - Market need and price for sink
    - Energy vector
    - Sustainable products
  - Energy requirement and type for CO_2 transformation
    - Electrification
    - Process Integration
  - Transport will be one decision factor in CCS *vs* CDU

Want to know more about GHGT mitigation

TotalEnergies

Steering Committee

The GHGT-16 Conference series is organised by the Steering Committee; a group made up from members of the host organisation (Club CO2) with support from the GHGT conference guardians (IEAGHG). The Steering Committee is chaired jointly by Philip Llewellyn of TotalEnergies and Tim Dixon of IEAGHG, and under their leadership the committee arrange the conference assisted by the Technical Programme Committee (TPC) to formulate the technical programme content, and overall structure of the event.

The Greenhouse Gas Control Technologies (GHGT) conference series was formed in 1997 following the merger of the earlier series of ICCDR and the Greenhouse Gas: Mitigation options conference.

ieaghg

The IEA Greenhouse Gas R&D Programme (IEAGHG) is the guardian of the conference series. The GHGT conferences are held every two years in IEAGHG's member countries. The conference series rotates between North America, Europe and Asia.

The GHGT conference series is established as the principal international conference on greenhouse gas mitigation technologies, focussing on Carbon Capture, Utilisation and Storage.

Each conference will be a forum for technical discussions related to the field of greenhouse gas control technology.

https://ghgt.info/

Technical Programme Committee

The Technical Programme Committee (TPC) has the overall responsibility to agree the themes and subthemes of the conference. Once abstracts are submitted and reviewed by the Expert Review Panel, the TPC then select the most relevant fitting abstracts for the oral presentations and allocate them to the appropriate oral technical session, the remaining abstracts are assigned to poster sessions.

Authors are then notified by the Secretariat that their abstract has been selected for an oral or poster session and given a deadline date to prepare and submit the full paper of their work. Providing this work is presented by themselves or a co-author at the GHGT-16 conference, the full paper will be published post conference in the GHGT-16 proceedings on SSRN.

ghgt-16

16TH GREENHOUSE GAS CONTROL TECHNOLOGIES CONFERENCE

23 - 27 OCTOBER 2022

Hosted by Club CO2 With ADEME brgm ifp Energies nouvelles TotalEnergies