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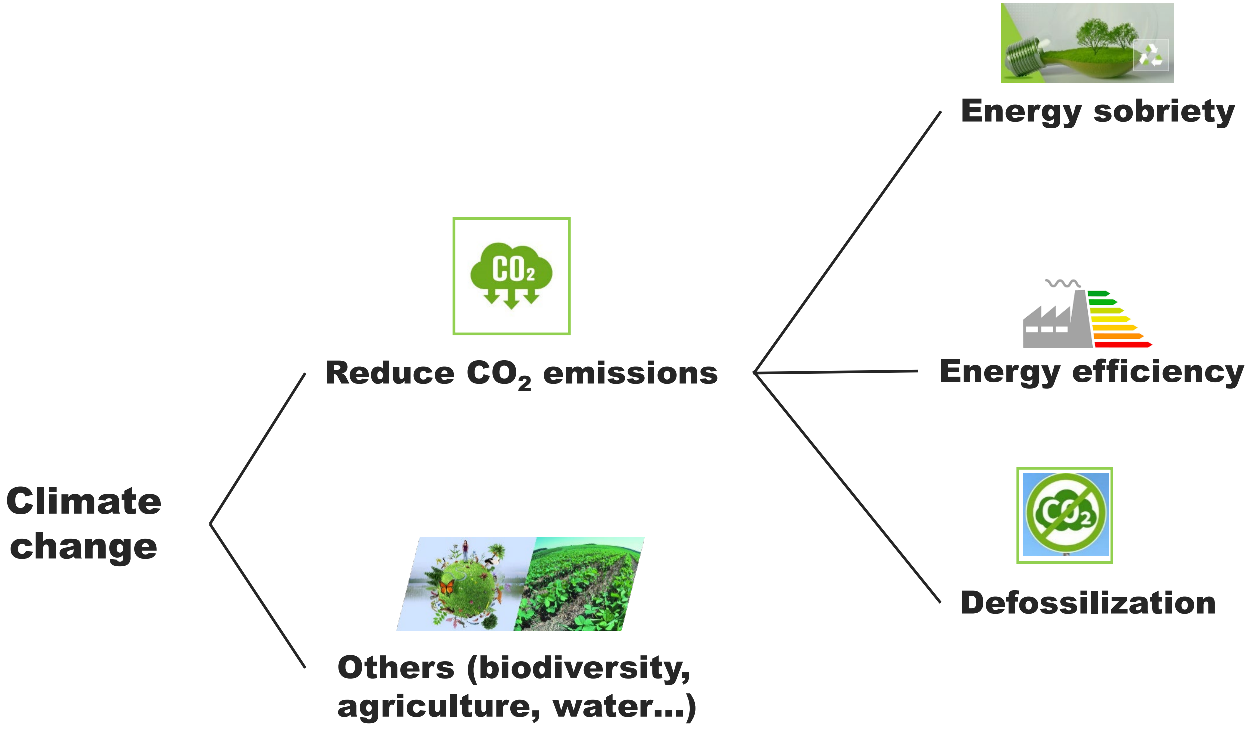
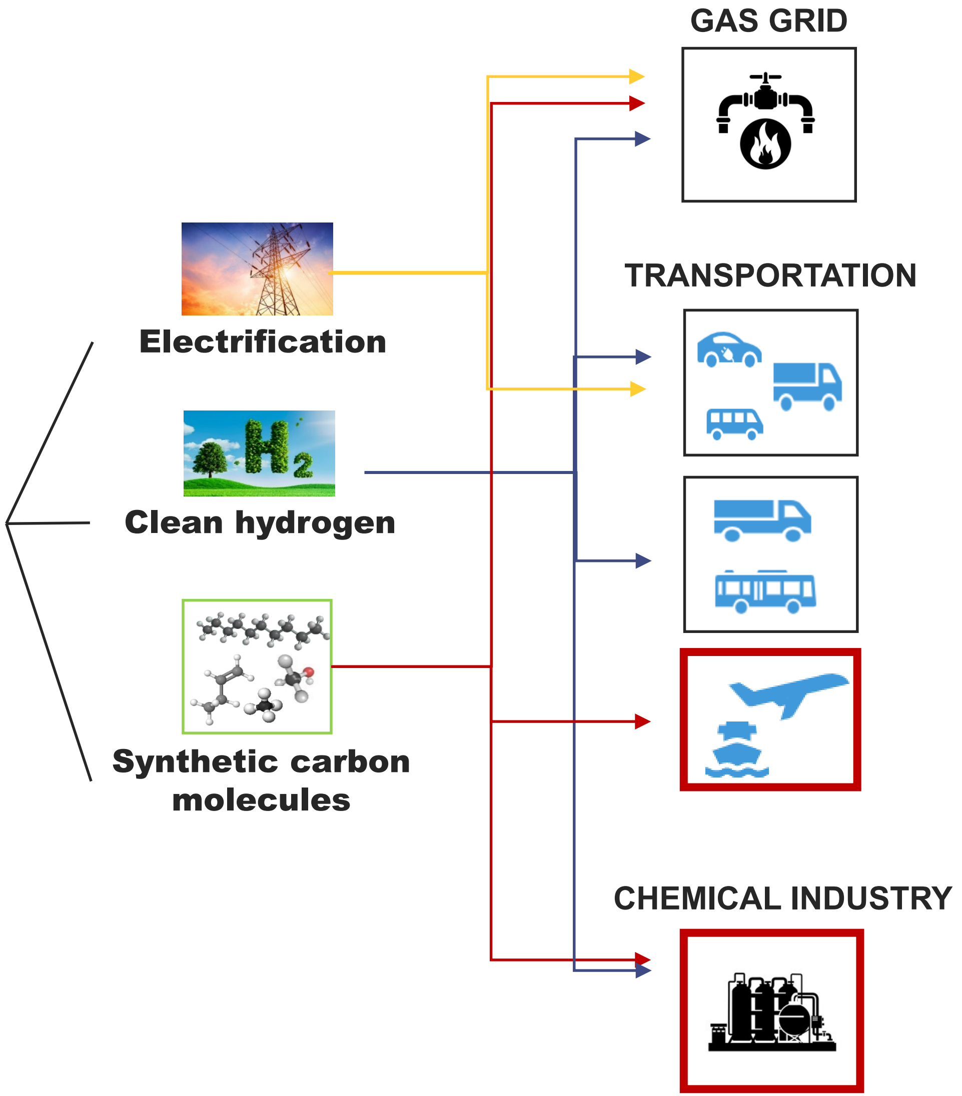
Converting CO_2 emissions into sustainable chemicals and fuels

Carlotta PANZONE

INSTITUT CARNOT
Energies du futur

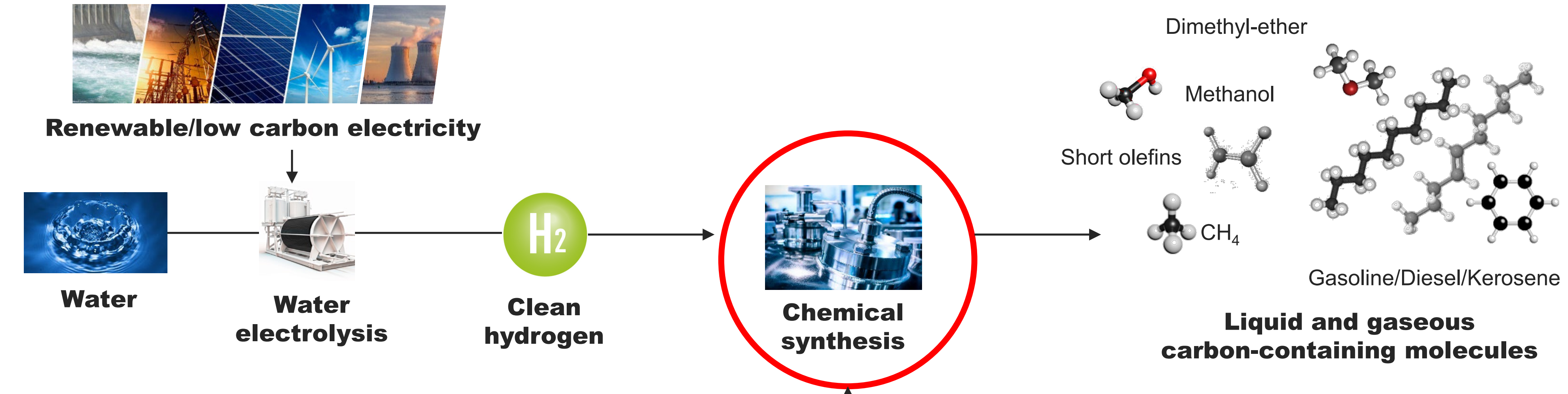
Context: possible solutions for climate change

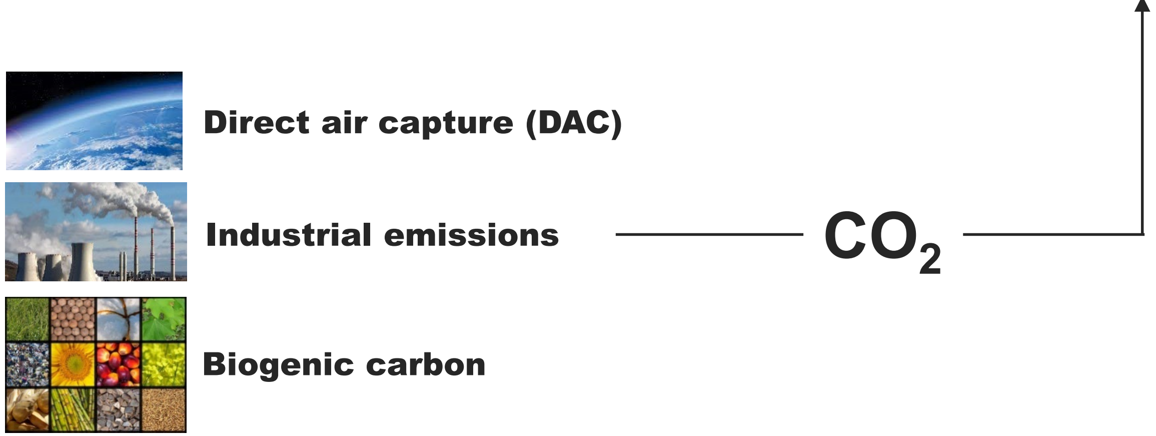




Carbon molecules will be needed in sectors where we don't have other choice ➔ **non-fossil sources of carbon molecules**

The concept of Power-to-X and CCU





1. **Power-to-X (PtX)** ➔ Support to the intermittency of renewable electric grids
2. **Power & Biomass-to-X (P&BtX)** ➔ Maximise the use of C in biomass-derived syngas
3. **Carbon Capture and Utilization - CCU, Circular Carbon Economy** ➔ Avoiding the massive use of fossil fuels, valorisation of the carbon already existing on Earth

Our work: the synthesis of carbon-containing molecules from CO_2

Clean hydrogen

Chemical synthesis

Carbon-containing molecules

CO_2

Reactor design

Adaptability

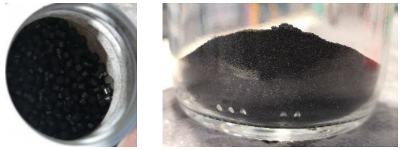
Flexibility

Up and down scalability

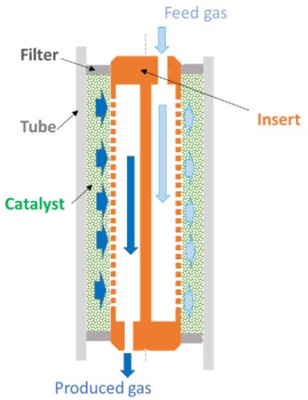
Catalytic reactions

Catalyst synthesis

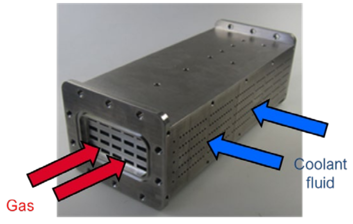
(Fe, Ni, Cu…)



ORTHORADIAL REACTOR



MILLI-STRUCTURED REACTOR



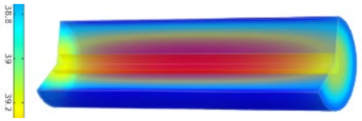
Cross flow configuration

From idea to industrialization

Illustration : Milli-structured reactor industrialised for methanation reaction

Experimental benches
& Analytical platform

Reactor modelling
& simulation tools



Idea
R&D and tech. survey

Technology selection

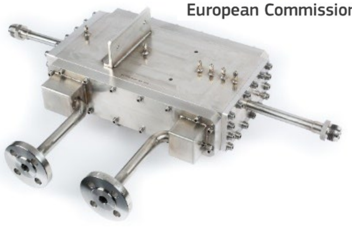
Millistructured reactor

Proof of Concept labscale

Demonstration

Demonstration projects

Jupiter 1000
GRTgaz
STORE&GO
European Commission
MÉTHYCENTRE
storengy



Industrialization

KHIMOD
ALCEN

The synthesis of carbon-containing molecules from CO_2

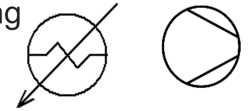
Current state-of the-art

INDIRECT PATHWAY (2-steps)

H_2 → CO_2 → **Reverse Water-Gas Shift (RWGS)** → **syngas + H_2O** → **Fischer-Tropsch synthesis (FT)** → **Liquid and gaseous carbon-containing molecules**

RWGS
Ni, Fe, Cu
400-800°C
R&D

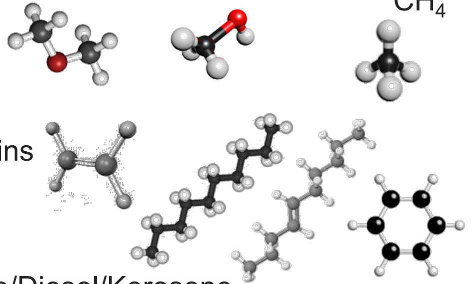
Cooling



Compression

sasol VELOCYS PetroSA

FT
Ru, Co, Fe
180-250°C
20-30 bars
industrialized



Indirect pathway

- Demonstration plants (Vázquez, F. V., et al. (2018). *Journal of CO2 Utilization*, *28*, 235-246. https://doi.org/10.1016/j.jcou.2018.09.026, https://www.sunfire.de/en/e-fuel, https://www.audi-mediacenter.com/en/press-releases/audi-steps-up-research-into-synthetic-fuels-9546)
- Estimated energy efficiency $\eta = 67\%$ (König, D.H., et al. (2015). Energy 91)

The synthesis of carbon-containing molecules from CO_2

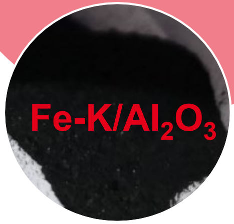
Our proposition

DIRECT PATHWAY (1-step)

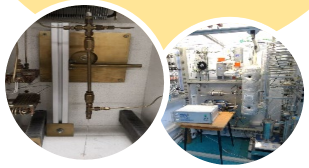
- Intermediate cooling and compression avoided: ↑ **energy efficiency**
- RWGS equilibrium shifted towards **higher CO_2 conversion**
- Low-maturity process → potential new market

Direct CO_2 conversion into short olefins

Catalyst development



Reaction kinetics and mechanism study in fixed-bed reactor at lab-scale

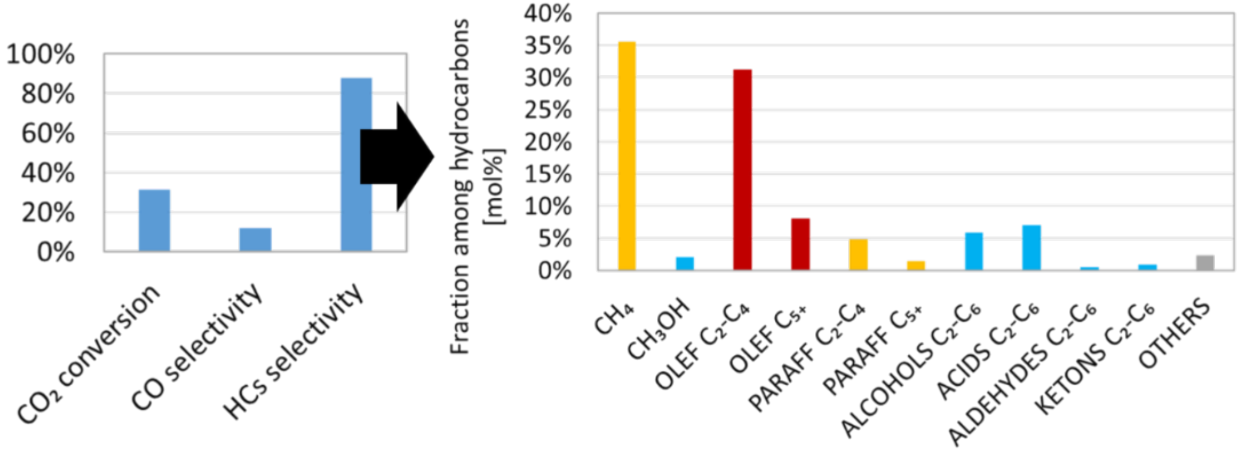


Reactor modelling and understanding of physical phenomena

COMSOL MULTIPHYSICS®

FIRSTS RESULTS OF CATALYSIS

C. Panzone thesis, 2021



Results of a run in reference conditions (2000 Nml/g/h, 15 bar, 300°C, H_2/CO_2=3).

Energy efficiency of non-optimized process
$\eta = 66\%$

Improvement directions

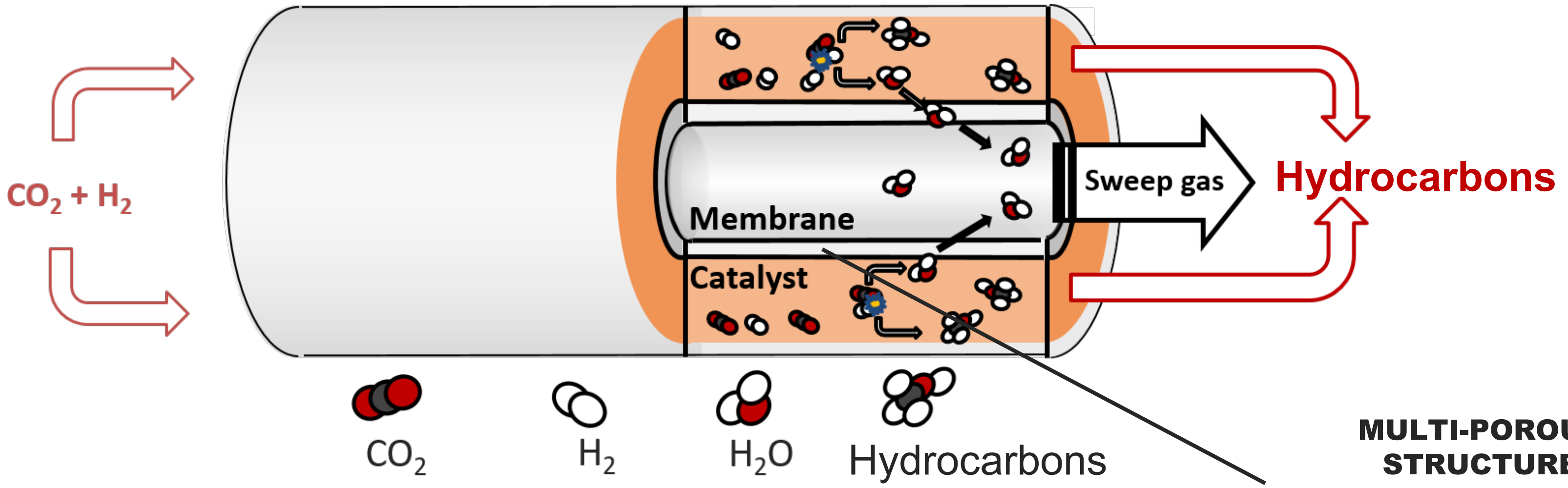
+ Catalyst synthesis improvement
+ Novel reactor technology
+ Water removal

Direct CO_2 conversion into short olefins– membrane reactor

Water removal via a permselective membrane (Le Chatelier's principle)

$$CO_2 + H_2 \leftrightarrow CO + \cancel{H_2O}$$

$$CO + 2H_2 \rightarrow \frac{1}{n} C_nH_{2n} + \cancel{H_2O}$$

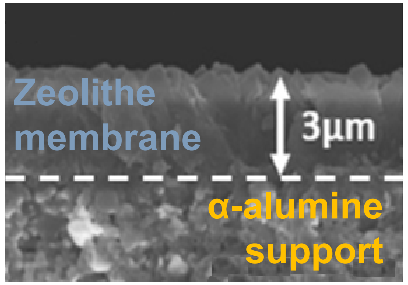


V. Gautier thesis, ongoing

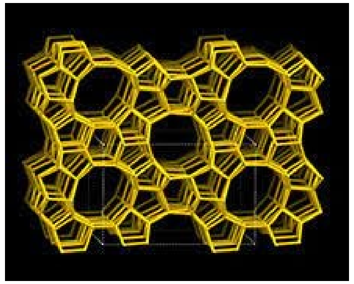
MULTI-POROUS STRUCTURE

Molecules separation

Mechanical resistance



EXAMPLE OF ZEOLITHE STRUCTURE (ZSM-5)



Objective: Up to **32%** energy saving

Conclusions

- **Reactor design and optimisation**
  - Adaptability and flexibility
  - Scalability
  - System integration (heat valorisation/energy efficiency)

- Objective: **industrial technological transfer**
  - R&D study
  - Global process study
  - Technical-economical analysis
  - Life cycle analysis

- **Focus: conversion of CO_2 to short olefins**
  - Low TRL process ➔ high potential of improvement and **energy efficiency increase**
  - Green economy transition **game changer**

Thank’s for your attention