# *Carbon Capture Utilisation :*
# *some CEA on-going works and achievements*

Bedel L, Cantat T, Chaise A, Chappaz A, Cren J,
**Ducros F,** Geffraye G, Mougin J, Nizou S.

## EERA AMPEA virtual workshop on "*Carbon Capture Utilisation and Storage*" March 10-11, 2021

March 10 – 11 : 2021

# International & French national REN contexts

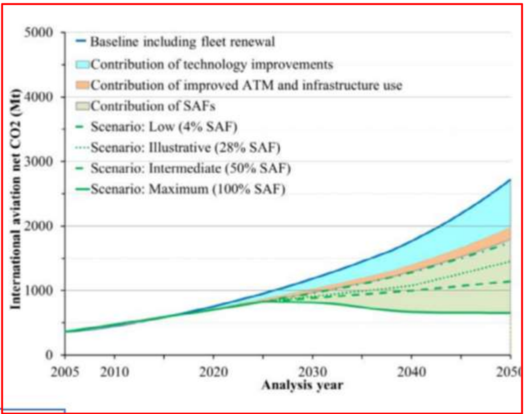
## International

Sustainable Aviation Fuels:
the challenge of decarbonization

David Chiaramonti*

**ScienceDirect**

Energy Procedia 158 (2019) 1202–1207



**RED II :**

- **2030 : biofuels / biogas contribution at least 3,5 % in 2030.**
- **Fuels used in the aviation and maritime sectors can opt in to contribute to the 14% transport target but are not subject to an obligation.**

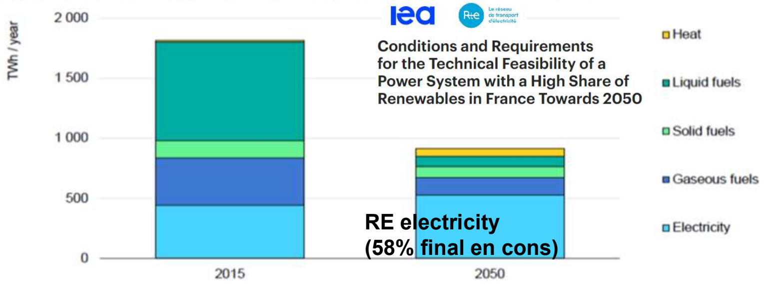
**prognos**

Demand for synthetic liquid energy carriers 2050 in the EU:
up to 2.000 PJ = up to 230 GW installed PtL capacity
(up to 8 GW/a installed capacity from 2020)

➔ Trend towards H2 & *CCU for gas & fuel synthesis*

## French Strategy

**Figure 2.2** Final energy consumption by energy vector, 2015 and 2050

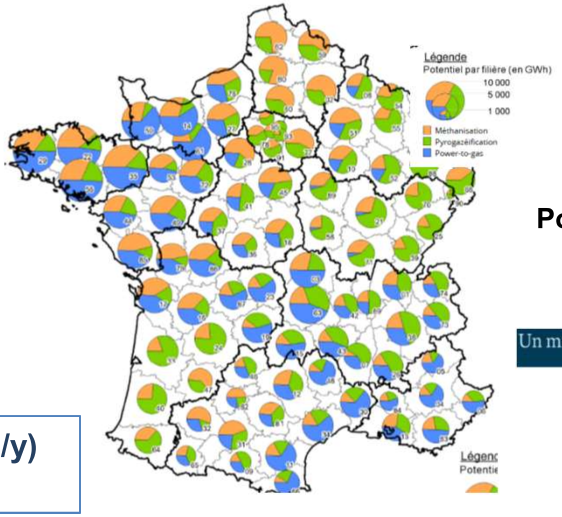


Conditions and Requirements for the Technical Feasibility of a Power System with a High Share of Renewables in France Towards 2050

RE electricity
(58% final en cons)

Note: 2050 levels are projections in the National Low-Carbon Strategy.
Source: RTE analysis based on Direction Générale de l'Energie et du Climat (2020) and PPE 2020.

**Low Carbon Gas (200-300 TWh/y -Incl. $H_2$) & Liquid Fuels (~100TWh/y)**
**Carbon Resources (biomass / CSR / $CO_2$ )**



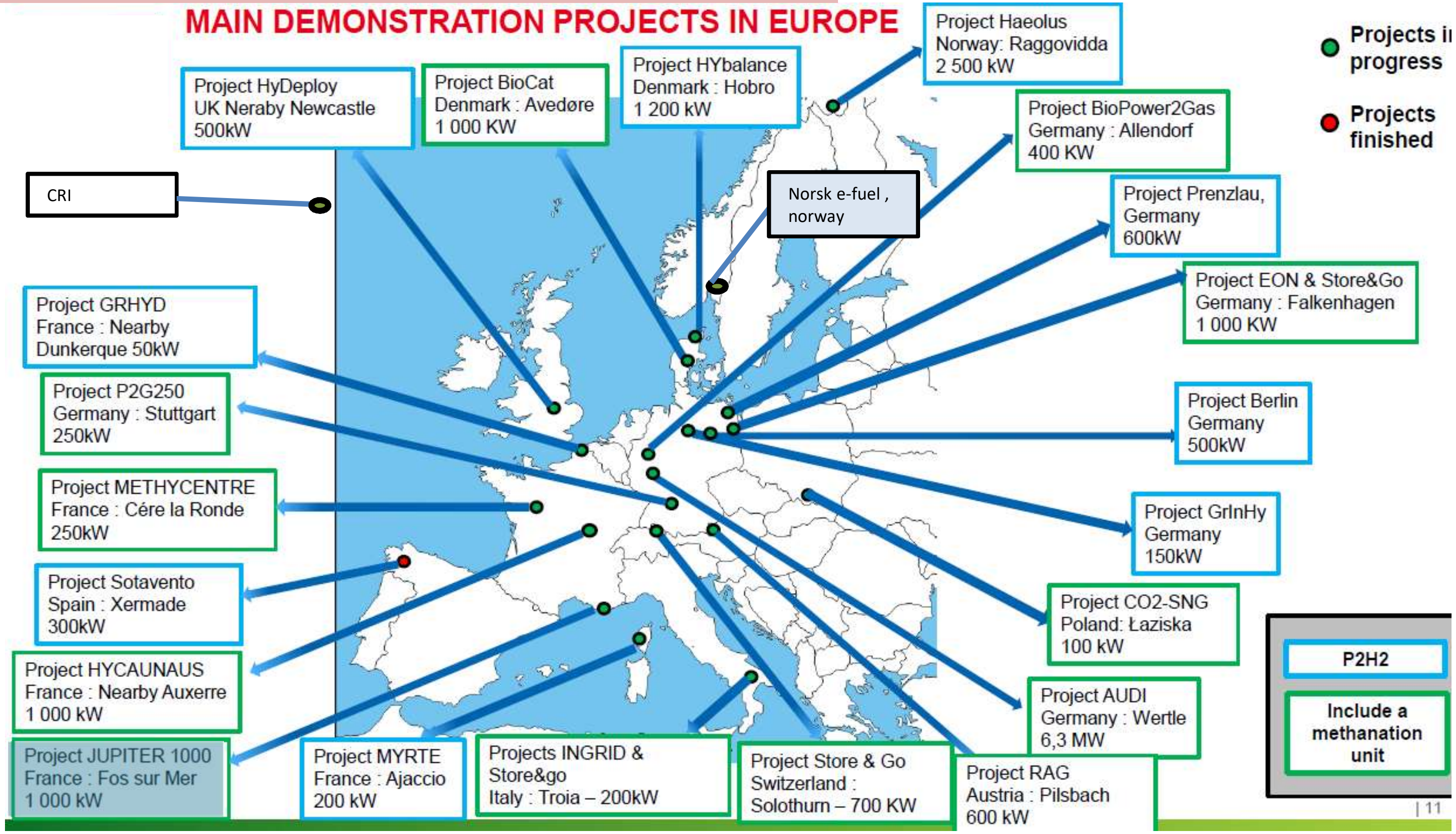
**Potential RE Gas**

Un mix de gaz 100 % renouvelable en 2050 ?

SYNTHÈSE DE L'ÉTUDE

# Demonstrators in Europe

➔ Trend is started



## MAIN DEMONSTRATION PROJECTS IN EUROPE

● Projects i progress

🔴 Projects finished

CRI

Norsk e-fuel , norway

Project HyDeploy
UK Neraby Newcastle
500kW

Project BioCat
Denmark : Avedøre
1 000 KW

Project HYbalance
Denmark : Hobro
1 200 kW

Project Haeolus
Norway: Raggovidda
2 500 kW

Project BioPower2Gas
Germany : Allendorf
400 KW

Project Prenzlau,
Germany
600kW

Project EON & Store&Go
Germany : Falkenhagen
1 000 KW

Project Berlin
Germany
500kW

Project GrInHy
Germany
150kW

Project CO2-SNG
Poland: Łaziska
100 kW

Project AUDI
Germany : Wertle
6,3 MW

Project RAG
Austria : Pilsbach
600 kW

Project Store & Go
Switzerland :
Solothurn – 700 KW

Projects INGRID &
Store&go
Italy : Troia – 200kW

Project MYRTE
France : Ajaccio
200 kW

Project JUPITER 1000
France : Fos sur Mer
1 000 kW

Project HYCAUNAUS
France : Nearby Auxerre
1 000 kW

Project Sotavento
Spain : Xermade
300kW

Project METHYCENTRE
France : Cére la Ronde
250kW

Project P2G250
Germany : Stuttgart
250kW

Project GRHYD
France : Nearby
Dunkerque 50kW

P2H2

Include a methanation unit

| 11

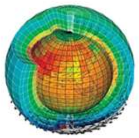
# A structuring program ⇔ Circular Carbon Economy Research Program

**Lead : Thibault Cantat**

A Carbon Circular Economy is based on:

a collection of technologies able to convert $CO_2$ and its derivatives into useful products, from low-carbon energies (incl. nuclear and renewables), to achieve carbon neutrality with a positive environmental and societal impact.

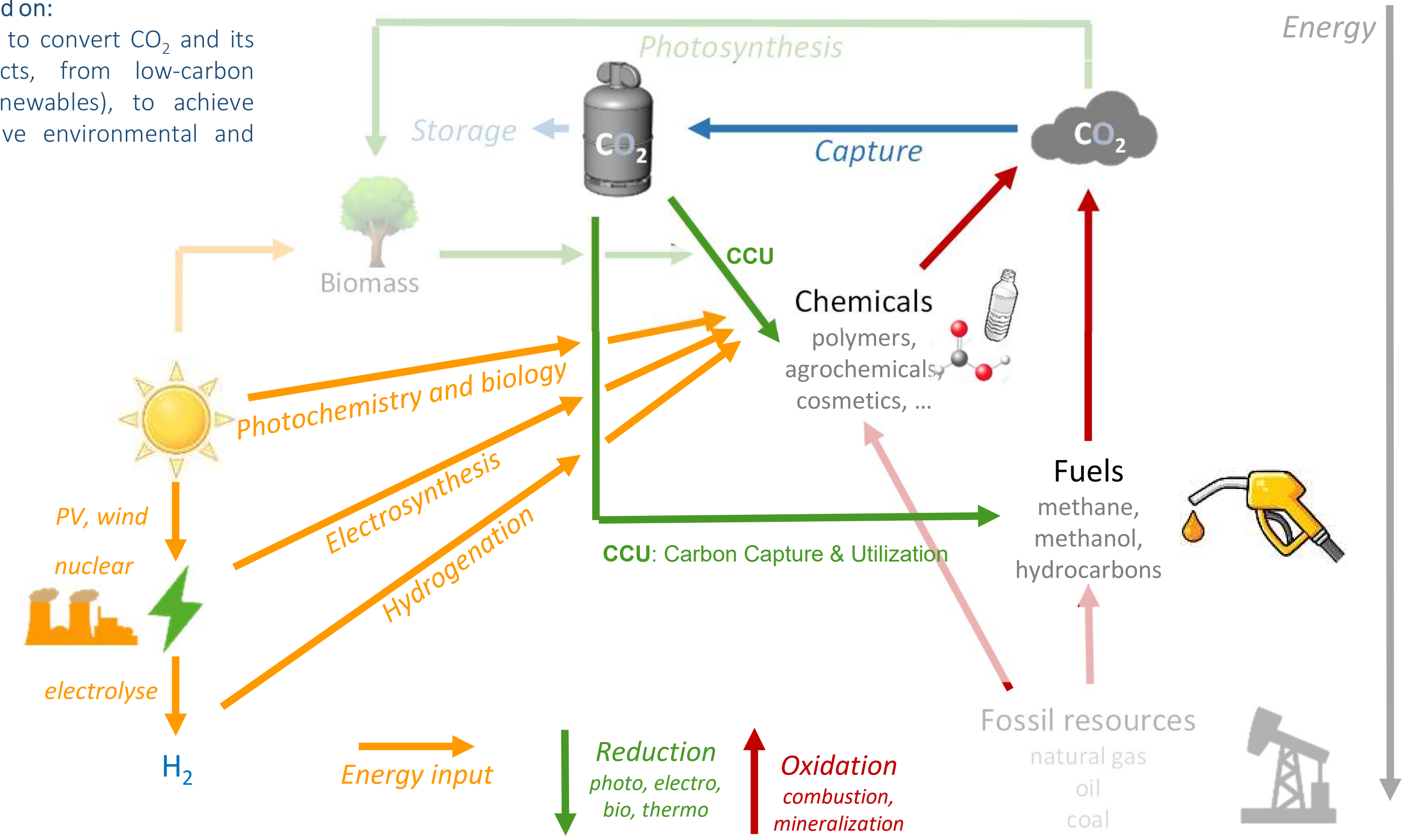
**Cross-cutting challenges**



**Impact analysis of soils and climate**

**Multicriterai Life Cycle Analyses**

**Sustainability of resources**



Photosynthesis

Storage

$CO_2$

Capture

$CO_2$

Energy

Biomass

**CCU**

Chemicals

polymers,
agrochemicals,
cosmetics, …

Photochemistry and biology

Electrosynthesis

Hydrogenation

PV, wind

nuclear

electrolyse

$H_2$

Fuels

methane,
methanol,
hydrocarbons

**CCU**: Carbon Capture & Utilization

Fossil resources

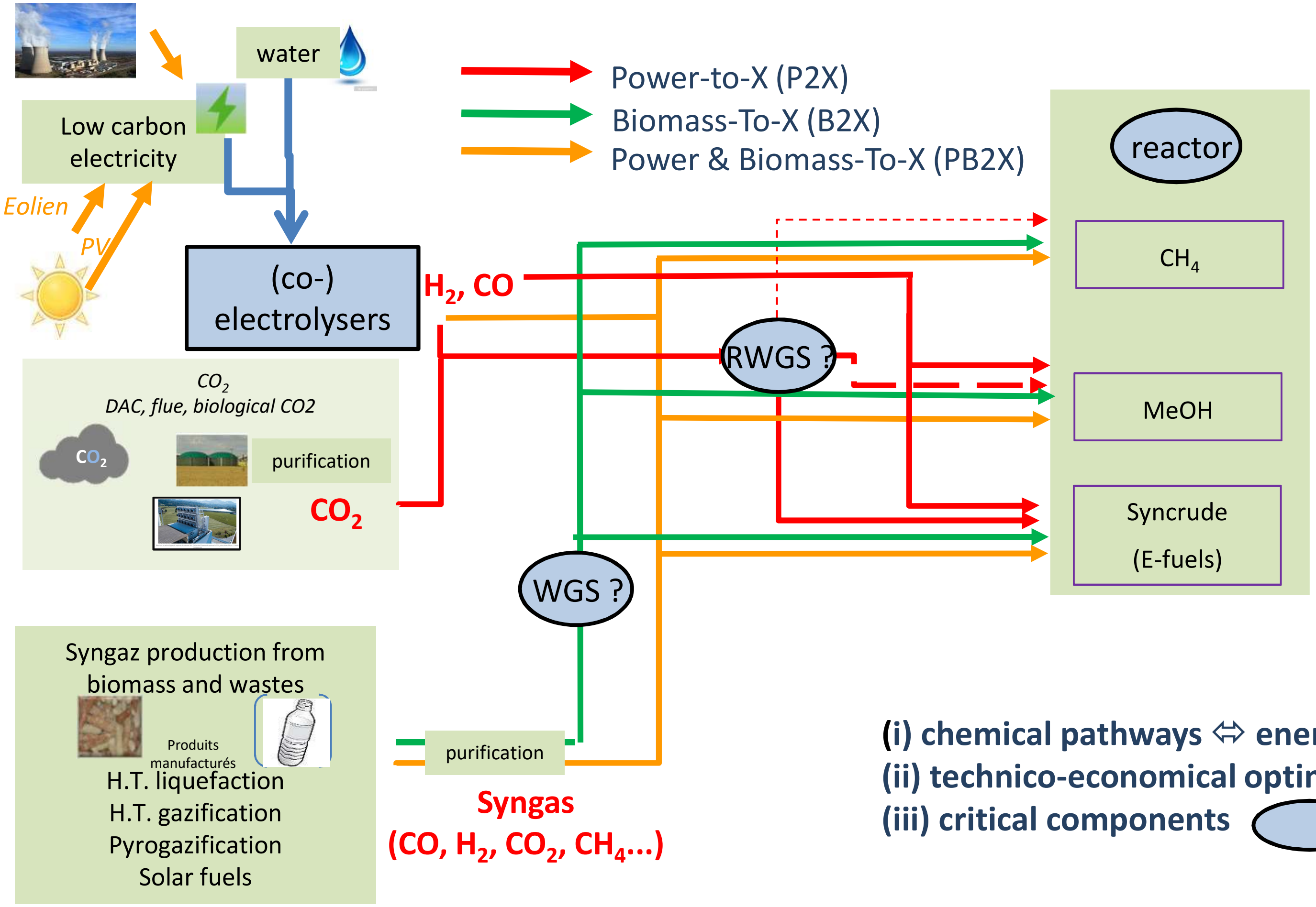
natural gas
oil
coal

Energy input

Reduction
photo, electro,
bio, thermo

Oxidation
combustion,
mineralization

# Electro-thermo-catalytic conversion to molecules of interests



water

Low carbon electricity

Eolien

PV

(co-) electrolysers

$H_2$, CO

Power-to-X (P2X)

Biomass-To-X (B2X)

Power & Biomass-To-X (PB2X)

$CO_2$

*DAC, flue, biological CO2*

$CO_2$

purification

$CO_2$

RWGS ?

WGS ?

reactor

$CH_4$

MeOH

Syncrude

(E-fuels)

Syngaz production from biomass and wastes

Produits manufacturés

H.T. liquefaction

H.T. gazification

Pyrogazification

Solar fuels

purification

**Syngas**

**(CO, $H_2$, $CO_2$, $CH_4$...)**

**(i) chemical pathways ⇔ energy, C budgets, related costs**

**(ii) technico-economical optimal operations**

**(iii) critical components**

# Assessment of different & complementary conversion chains

## P2X, B2X & PB2X Assessment on methane (possible on other molecules)

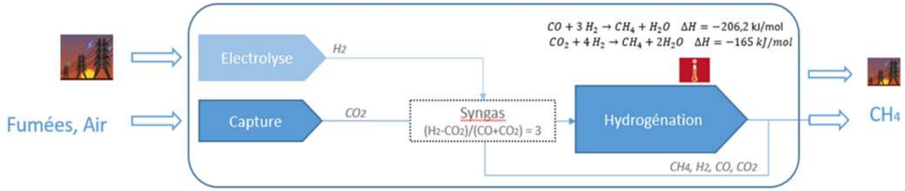
## The system

**System size (25 MW LHV $CH_4$) : 2500 Nm3/h x 8 000 h/y**

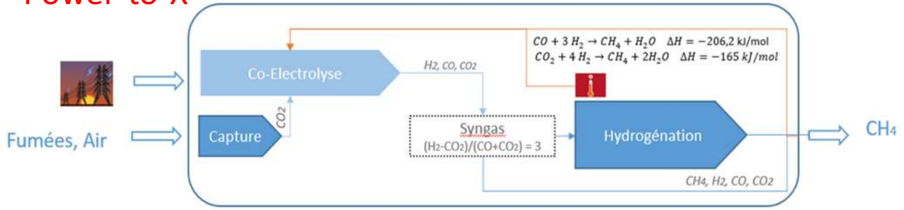
## Hypotheses

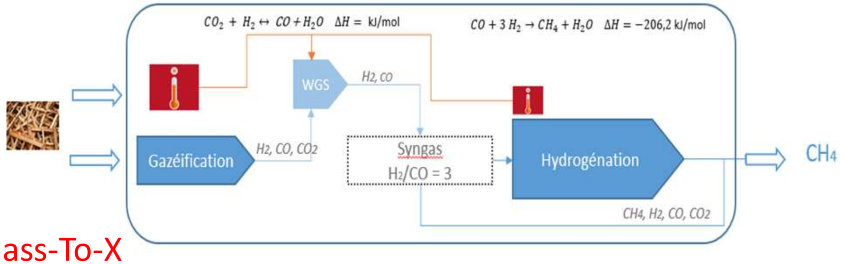
- ✓ **Electricity cost 55€/$MWh_{LHV}$, carbon footprint at 52 $kg_{CO2é}$/Mwhe**
- ✓ **Biomass (30% moisture content, residues & wastes) 20 €/$MWh_{LHV}$, carbon footprint 7 $kg_{CO2é}$/MWhe ;**
- ✓ **Natural gas at 20€/$MWh_{LHV}$, carbon footprint 360 $kg_{CO2é}$/MWht.**
- ✓ **Building & services 12% of installed materials, indirect costs 14%. OPEX 5,5%, depreciation period 25 years, discount rate 8%,**

*Work and results from E. Le Goff and G. Boissonnet*

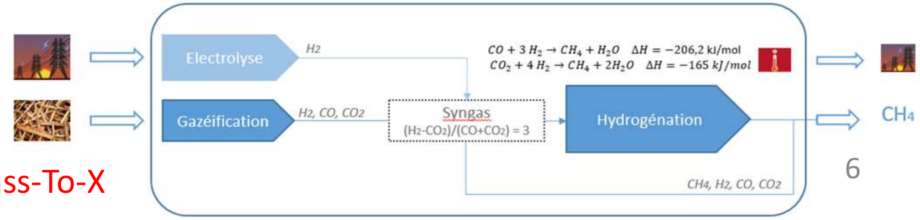


Power-to-X





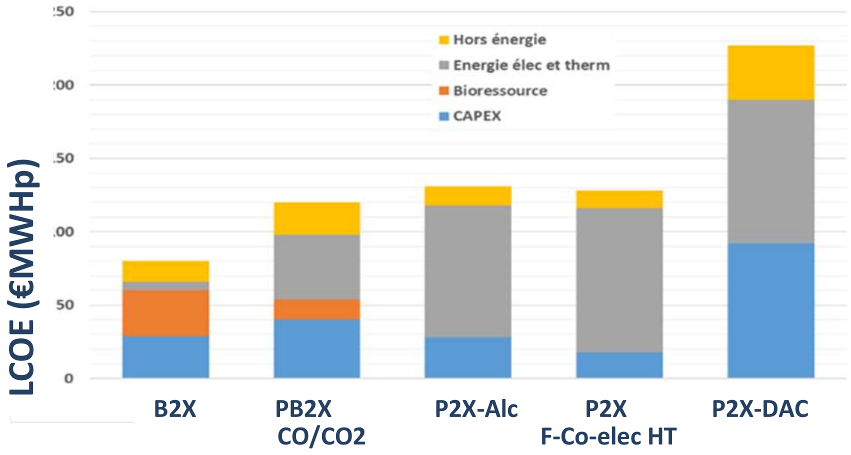
Biomass-To-X

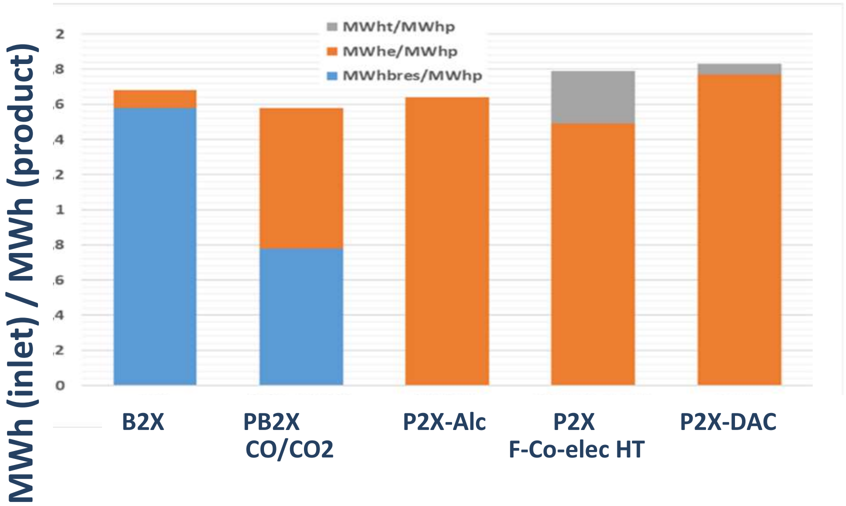


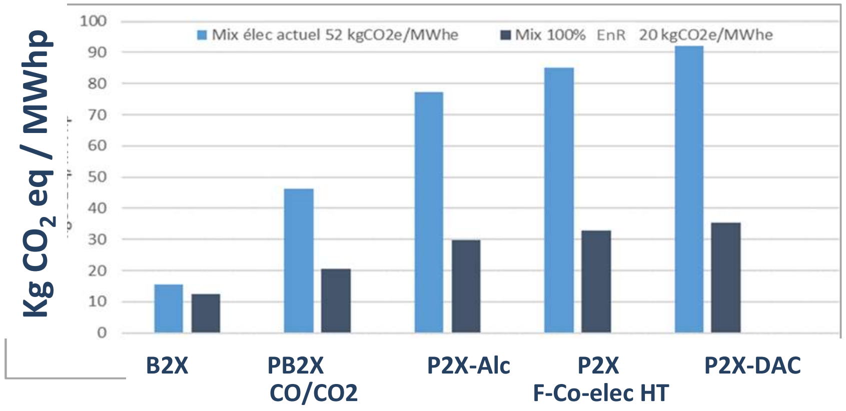
Power & Biomass-To-X

# Assessment of different & complementary conversion chains

Assessment on methane (possible on other molecules)







Biomass and $CO_2$ ➔ 2 carbon resources
Complementary conversion chains (P2X, B2X & PB2X systems)

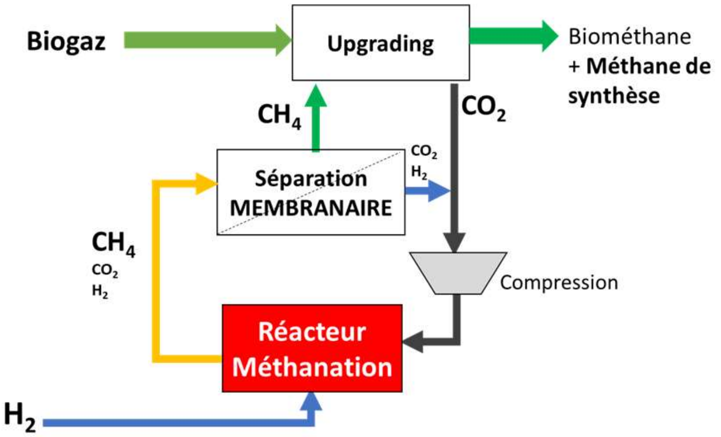
*Work and results from E. Le Goff and G. Boissonnet*

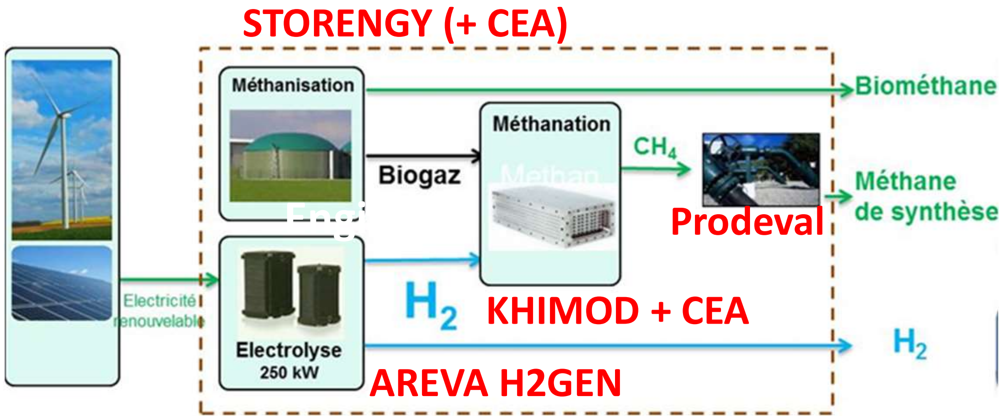
# An example of PB2X conversion

**METHYCENTRE demonstrator**

$CO_2$ from methanisation (Biomass)

- 250 kW electrolysis
- 22,5 $Nm^3/h$ de synthetic $CH_4$
- Distribution network injection





**Issues**

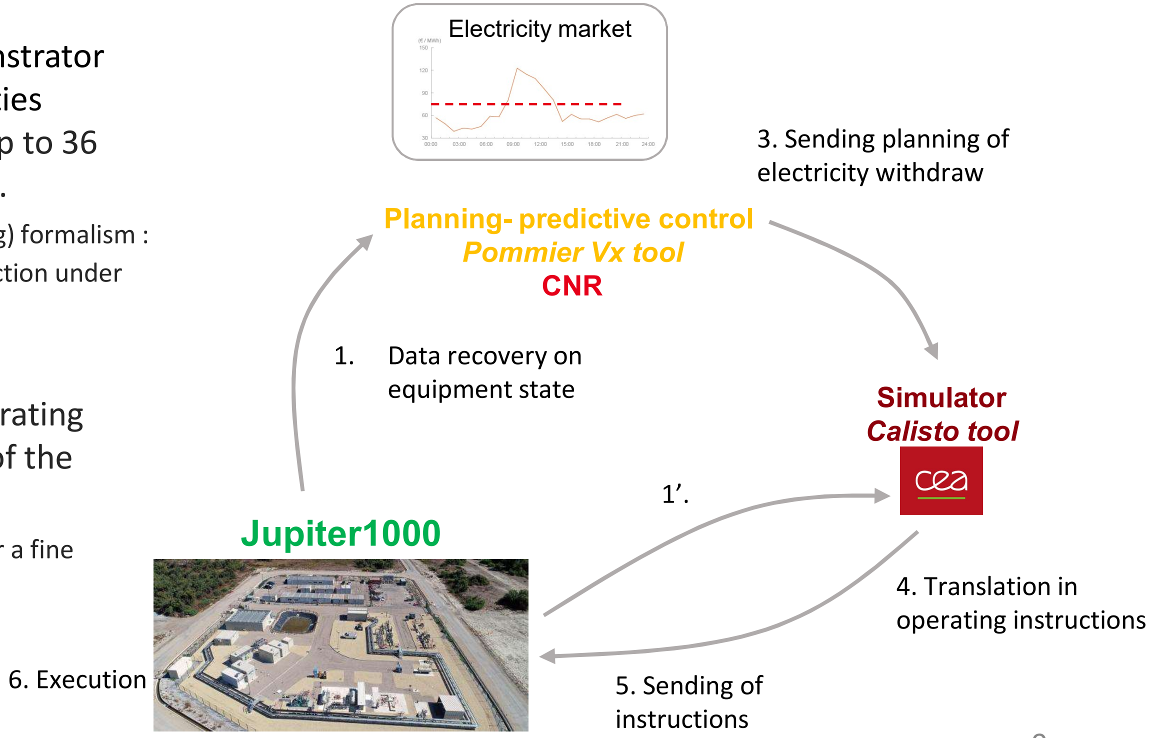
- Inlet composition at reactor inlet (real gas effect)
- Coupling reactor/separation/recycling
- Process Optimisation

# Numerical tools to optimize the system operation with anticipation capability

**Objective:** developing a smart energy management system in order to optimize the operation of **the Power-to-Gas demonstrator Jupiter 1000** according to economical criteria (price of electricity and gas).

- **First tool** to plan the operation of the demonstrator according to predictive economic opportunities (withdraw electricity, inject $H_2$ and syngas) up to 36 hours before, with a time step of 30 minutes.
  - Use of MILP (Mixed Integer Linear Programming) formalism : efficient solvers that minimize an objective function under linear constraints

- **Second tool:** to translate the planning in operating instructions according to the effective state of the equipment with a finer time step of 5 min.
  - Use of non linear models of the components for a fine modeling



Electricity market

**Planning- predictive control**
***Pommier Vx tool***
**CNR**

3. Sending planning of electricity withdraw

1. Data recovery on equipment state

**Simulator**
***Calisto tool***

1'.

**Jupiter1000**

4. Translation in operating instructions

5. Sending of instructions

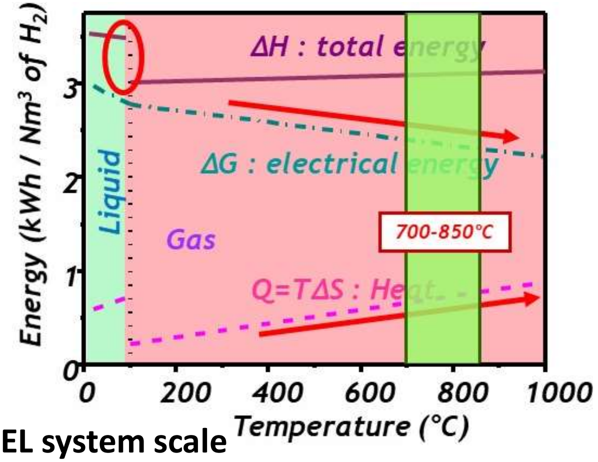
6. Execution

# Hydrogen production with low C footprint: interest of Solid Oxide Electrolysis (SOEL)

**HIGH EFFICIENCY TECHNOLOGY**

$H_2O_g \rightarrow H_{2g} + ½\ O_{2g}$

$\Delta H = \Delta G + T\Delta S$ ~ constant

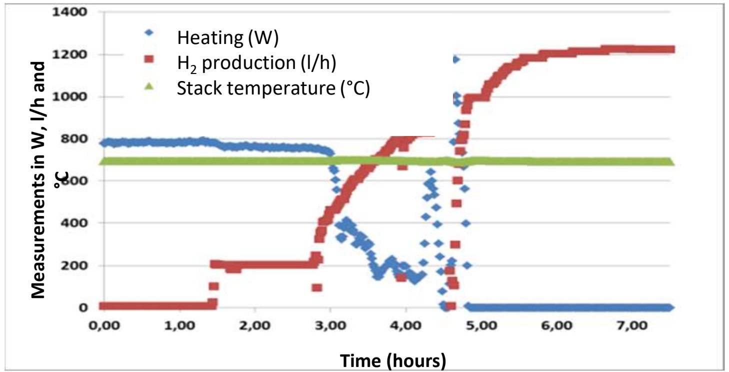


- The hotter the electrolysis operation, the lower the electricity demand:
  - High T: energy = 70% electricity, 30% heat
  - Low T: energy = 85% electricity / 15% heat
- **Main advantage of SOEL with T range = 700-850°C**

**Direct consequence on efficiency:**

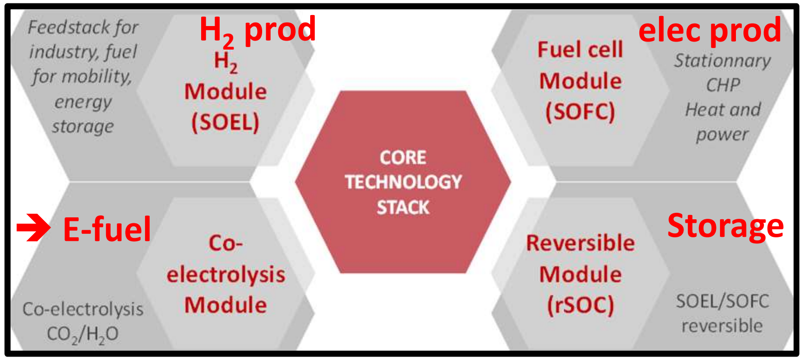
- water electrolysis: $\eta_{LHV}$ = 60-70%
- steam electrolysis:
  - $\eta_{LHV}$ > 85% if steam not generated with electricity ( heat source ~150°C is sufficient )
  - Nota: If steam generated electrically $\eta_{LHV}$ ~ 76% LHV

**… at the SOEL system scale**



*Source: A. Chatroux, et al., ECS Transactions, 68 (1) (2015) 3519-3526*
*J. Mougin, 12th European SOFC&SOE Forum 5-8 July 2016, Luzern, A0605 (2016)*

**FLEXIBILITY OF USE :** Same core technology for several applications



**$H_2$ prod**

*Feedstack for industry, fuel for mobility, energy storage*

$H_2$ Module (SOEL)

**elec prod**

Fuel cell Module (SOFC)

*Stationnary CHP Heat and power*

CORE TECHNOLOGY STACK

**➔ E-fuel**

Co-electrolysis Module

Co-electrolysis $CO_2/H_2O$

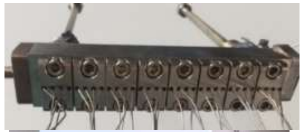
**Storage**

Reversible Module (rSOC)

SOEL/SOFC reversible

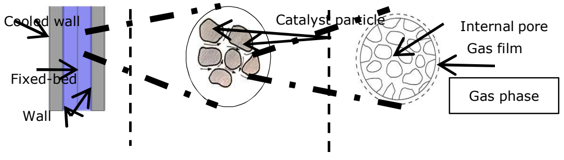
# Catalytic fixed bed reactors for methane and e-fuels

Catalyst Selection



Highly instrumented HX reactor

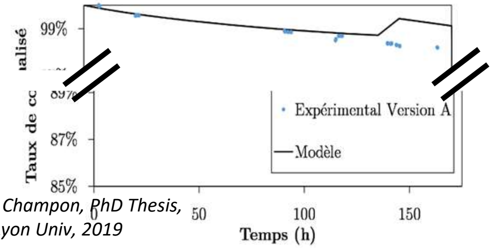
Design tools and detailed analysis



Reactor definition-demonstrators/ upscaling

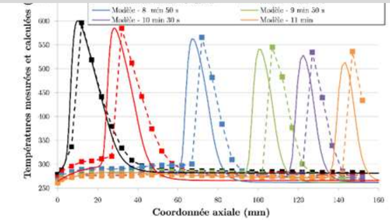
## Research

Model and experimetal counterpart for catalysts ageing



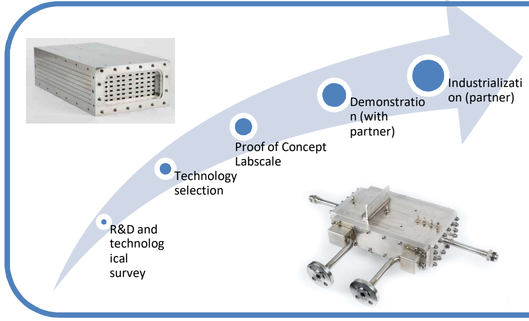
*I Champon, PhD Thesis, Lyon Univ, 2019*

Reactor shut-down : 280-260°C, VVH 15600 h-1, H2/CO2 ratio 4, P = 2.5 bar [25]



*Rasmey Try, PhD Thesis, Université de Lyon, 2015*

## Indus



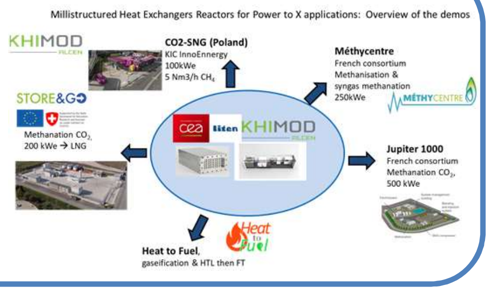
R&D and technological survey

Technology selection

Proof of Concept Labscale

Demonstration (with partner)

Industrialization (partner)



Millistructured Heat Exchangers Reactors for Power to X applications: Overview of the demos

**CO2-SNG (Poland)**
KIC InnoEnnergy
100kWe
5 Nm3/h $CH_4$

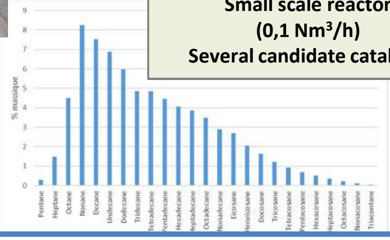
**Méthycentre**
French consortium
Methanisation & syngas methanation
250kWe

Methanation $CO_2$,
200 kWe → LNG

**Jupiter 1000**
French consortium
Methanation $CO_2$,
500 kWe

**Heat to Fuel**,
gaseification & HTL then FT

## P-t-L



**Prototype**
**Small scale reactor**
**(0,1 $Nm^3/h$)**
**Several candidate catalysts**

Test & modeling

**Demo scale reactor**
**(1,5 Nm3/h)**
**To be implemented in Vienna**

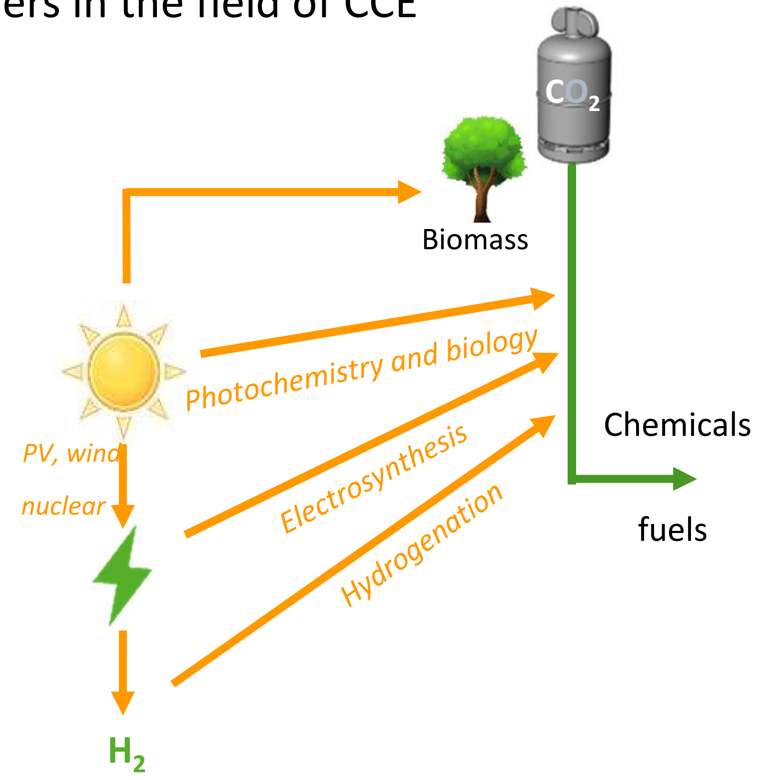
# The CCE Focus

CEA has hired (2020) about 20 PhD/Postdoc researchers in the field of CCE

4 Clusters :

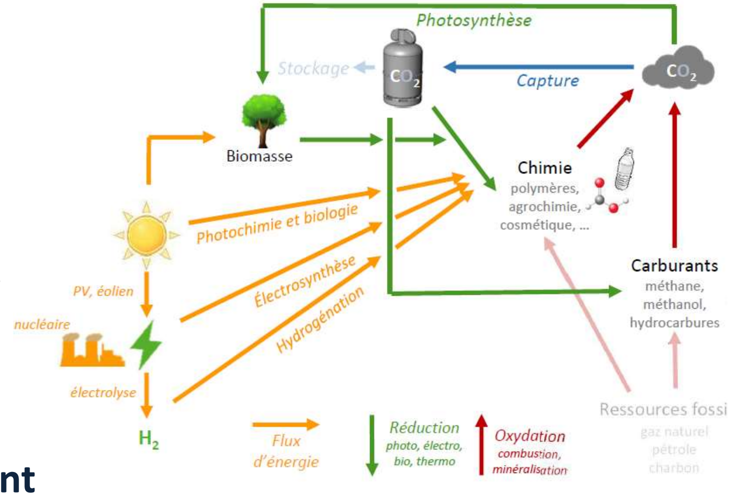
- Solar Fuels
- New approaches for 3G Biofuels
- Electro and photo catalytic materials
- Thermo chemical conversions towards fuels and chemicals (*)

(*) : a dedicated PhD towards “climate impact of technological developments for carbon neutrality”



# Conclusions

**CEA has launched a structuring « Carbon Circular Economy" program**



- **From fundamental research up to demonstrators (TRL 6~7)**
- **Electro-thermo-catalytic conversion of basic resources ($CO_2$ carbon loaded wastes, water, power) to molecules of interests**
- **System scale :**
  **various chemical pathways could be considered**
  **technico-economical optimal operational management**
- **Component scale :**
  - **Electrolysis**
  - **Catalytic conversion**