Carbon4PUR

Turning industrial waste gases into valuable polyurethanes

European research collaboration between steel and chemical industry

Marseille/Fos, 20th March 2019

Dr. Liv Adler
Covestro Deutschland AG

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Port de Marseille Fos

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Universiteit Gent

CHALLENGES:
Saving our fossil resources
Reducing the greenhouse effect

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 768919

Mission

Generate value from the entire carbon from **CO/CO_2-containing waste streams**

Making **carbon productive** and the resulting **PUR products** more **sustainable**

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Carbon4PUR

Turning industrial waste gases (mixed CO/CO_2 streams) into intermediates for polyurethane plastics for rigid foams / building insulation and coatings

Responding to call: H2020-SPIRE-8-2017

Contributing to

- Circular economy
- Industrial symbiosis
- Carbon productivity
- Renewable materials

EC contribution: 7.75 mln. €

Duration: Oct. 2017 – Sept. 2020

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Consortium

Carbon4PUR

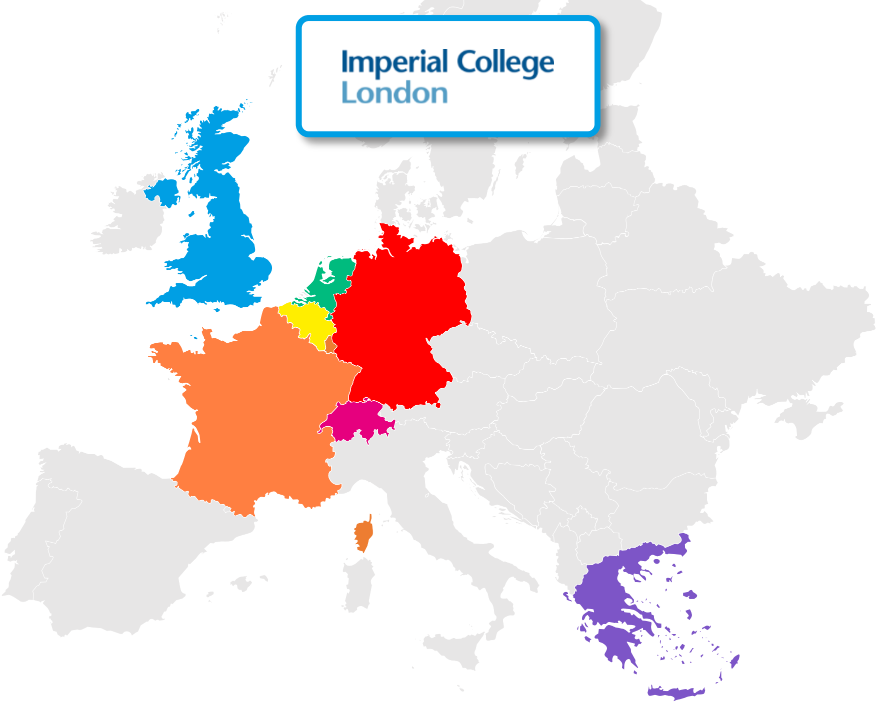
14 Partners from 7 countries – interdisciplinary and across sector

cea
ArcelorMittal
Marseille Fos
Le port euroméditerranéen

RECTICEL
UNIVERSITEIT GENT

Universiteit Leiden
PNO

Imperial College London



covestro
TU berlin
DECHEMA
RWTH AACHEN UNIVERSITY

south pole group

MEGARA RESINS
ANASTASSIOS FANIS S.A.

Leading experts teaming up for an excellent consortium

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Collaboration
Open Innovation

Carbon4PUR

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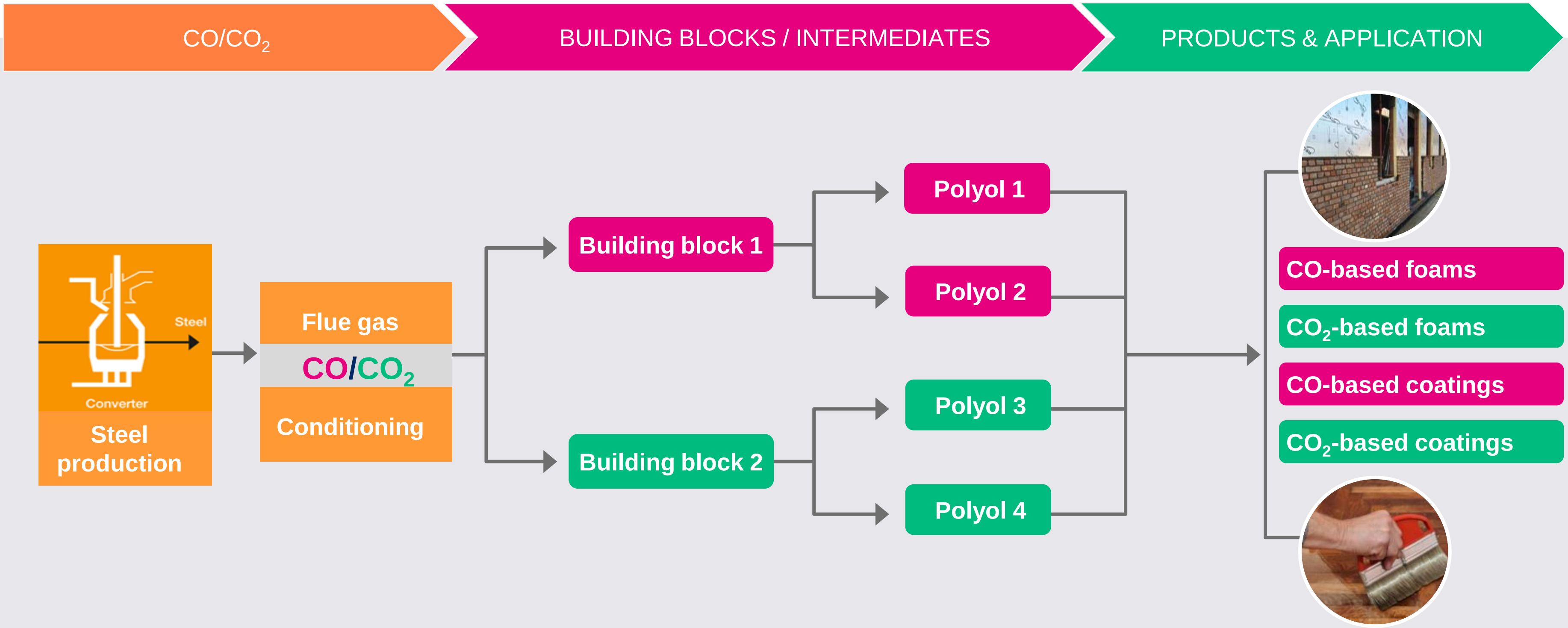
Methodology

Carbon4PUR



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Ambition

CO/CO_2 → BUILDING BLOCKS / INTERMEDIATES → PRODUCTS & APPLICATION

- **Demonstration** taking into account all variables at the same time:
  - Steel plant flue gases characteristics
  - Material and process parameters
  - End product market requirements

Full value chain

- Small **piloting** of the new process (20t/y)
- **Adaptable** to products for existing large-scale markets

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Methodology

Carbon4PUR

CO/CO_2 | BUILDING BLOCKS / INTERMEDIATES | PRODUCTS & APPLICATION

Steel industry

Steel production | **Flue gas treatment**

ArcelorMittal | UNIVERSITEIT GENT

Chemical – Polyol industry

Catalyst design | **Process design** | **Upscaling**

CAT Catalytic Center | cea | covestro | RWTH AACHEN UNIVERSITY | covestro | RWTH AACHEN UNIVERSITY

Polymer industry

Insulation boards & Coatings

RECTICEL insulation | covestro | MEGARA RESINS

Accompanying

Industrial symbiosis analysis

Marseille Fos | ArcelorMittal | covestro | DECHEMA

LCA and economic analysis

Extended LCA | Economic evaluation | Societal impacts

Universiteit Leiden | south pole

Exploitation – Replication – Dissemination

PNO | RECTICEL insulation | DECHEMA | MEGARA RESINS | Imperial College London | covestro

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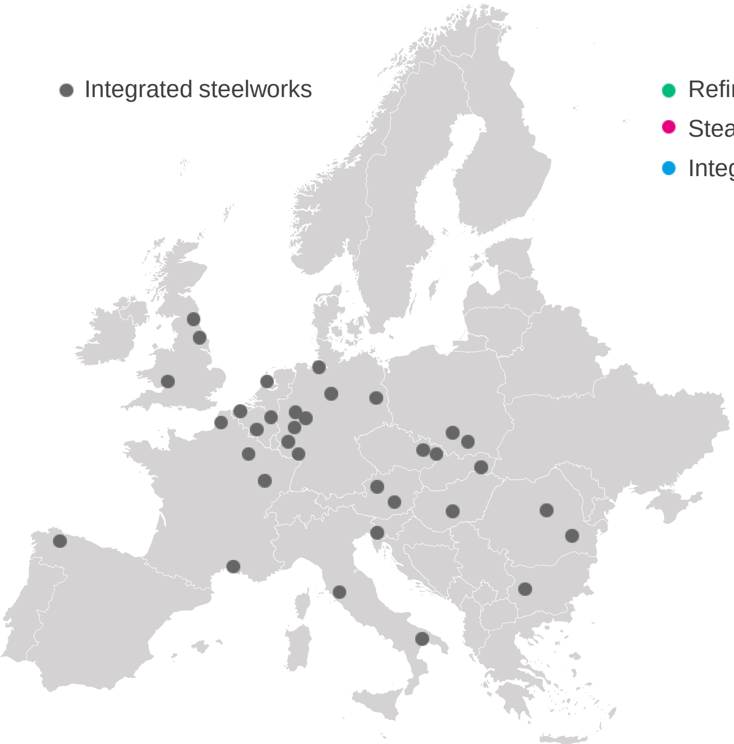
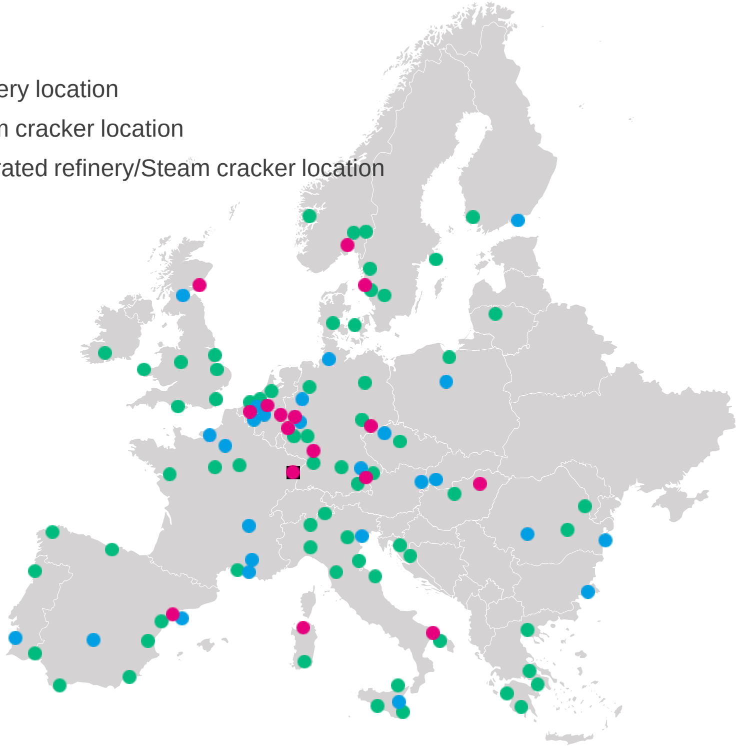
Replication potential

Geographical distribution of integrated steelworks and refineries in Europe





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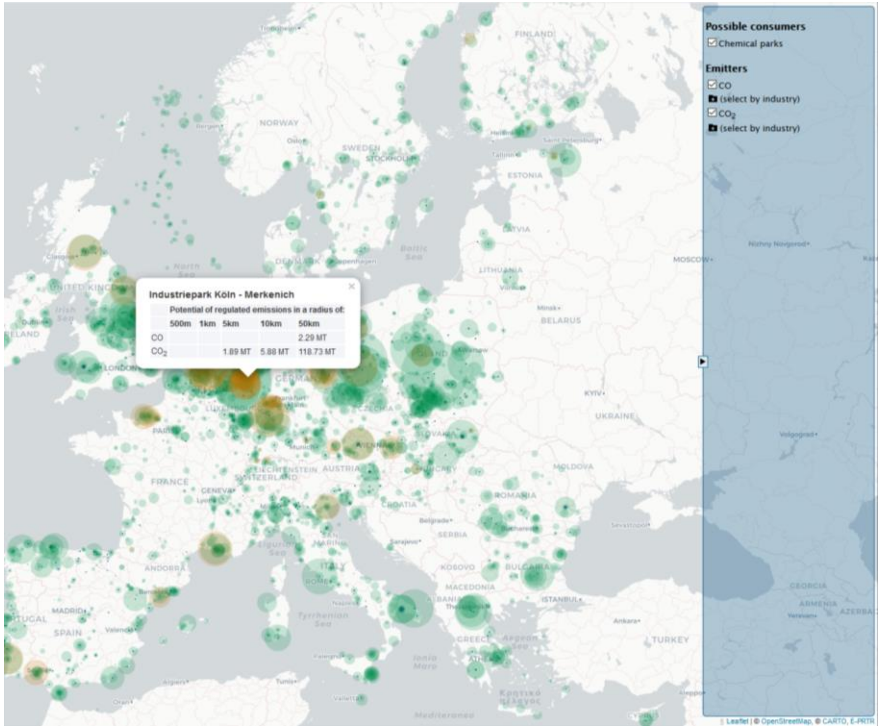
Replication potential

Mapping activities



Modifications to previous mapping of CO/CO_2 availability based on E-PRTR:

- Limited distance to next chemical plant
- Gas composition based on production process for a list of compatible processes

➢ The output will identify the best replication sites for chemical plants in Europe

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CARBON4PUR
Présentation du projet - *Project presentation*

Sylvain PICHON - Energy transition lead - Port of Marseille Fos

Industrial symbiosis

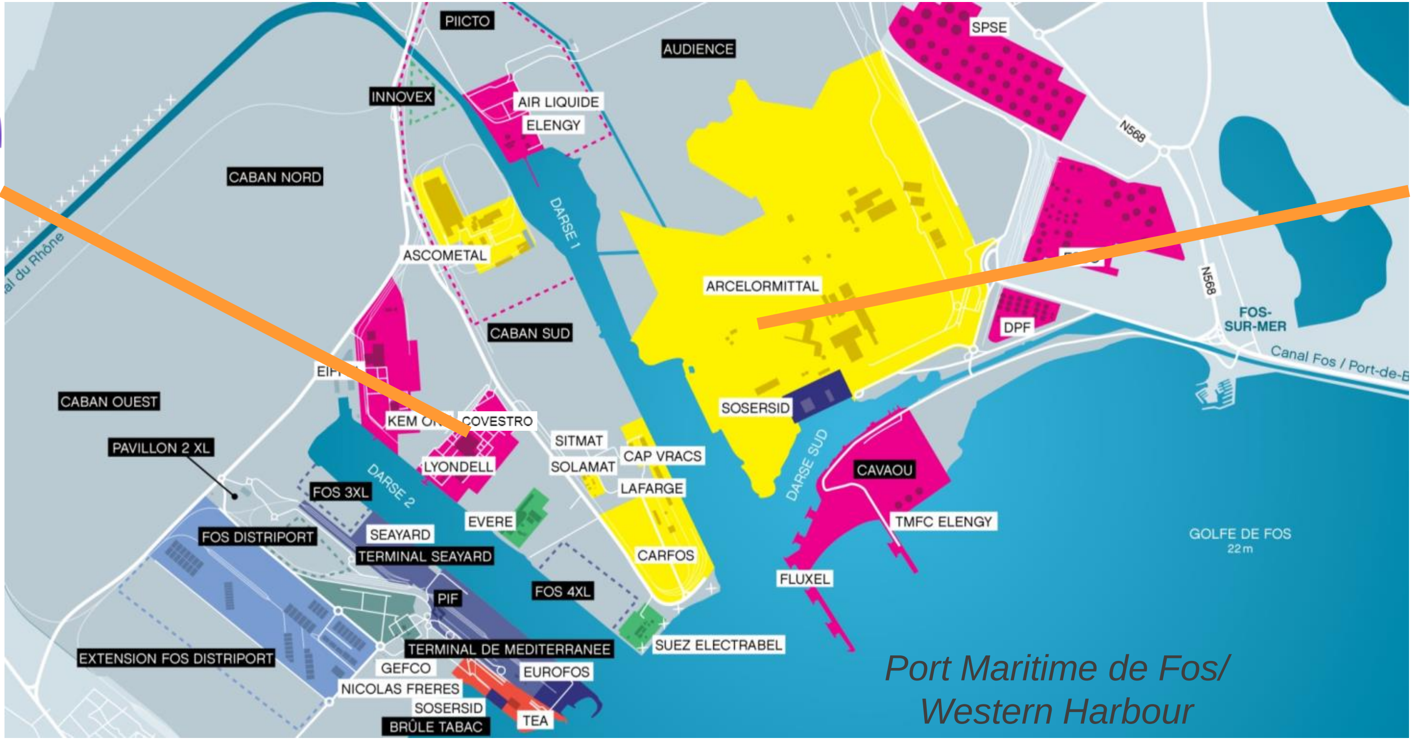

Image-Source:http://www.marseille-port.fr

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WP7 – Objectives > industrial symbiosis preparation

- Evaluation of the technical and economic feasibility of a process implementation in Fos, as prime industrial symbiosis case investigated in Carbon4PUR; this includes feasibility assessment of connecting the infrastructure (distance, potential pipeline length, investments, legal requirement, safety) to lay the foundation for future detailed studies.

- To develop a best practice case for industrial symbiosis for replications or learnings for other industrial sites and CO2/CO recycling projects in Europe

- To assess the potential for replication of the investigated case to other sites in Europe via mapping of sources and industrial infrastructures and identification of preferable locations which would offer promising conditions for industrial symbiosis

Expectations and added value of Carbon4PUR

- **To anticipate and implement a mix of industrial waste gases and CO_2 recycling solutions** on the industrial port zone (>12MT CO_2 emission) in addition to current experimentations : Jupiter 1000 (methanation), VASCO (algae bioremediation),
- **To develop industrial symbiosis** profitable to our actual and future industrial customers,
- **To create sustainability, acceptance** towards industrial developments and commercial attractiveness, in an increasing carbon price context,
- **To market the port of Marseille Fos as a “port of the future”** deeply involved in the ecology and energy transition
- **Green port in a blue economy**

Port of Marseille main role in the project

WP7 Lead beneficiary "Industrial symbiosis preparation"

Partners = ICL, DECHEMA, ARCELOR MITTAL, COVESTRO, PNO

The Port of Marseille role will be mainly to facilitate the connection between Arcelor Mittal and Covestro, taking part of the development of an industrial symbiosis within the industrial port zone.

The main tasks to carry out will be :

- **Task 7.1 Definition of gas specifications**
- **Task 7.2: Definition of the future activity size**,
- **Task 7.3: Concept for gas treatment on site before transport**
- **Task 7.4 Evaluation of the technical and economic feasibility of a gas pipeline in Fos**
- **Task 7.5: Mapping of industrial sites for CO/CO_2 recycling**
- **Task 7.6: Replication of Carbon4PUR to other industrial sites**

To reach some of these tasks the PICCTO association support will be need

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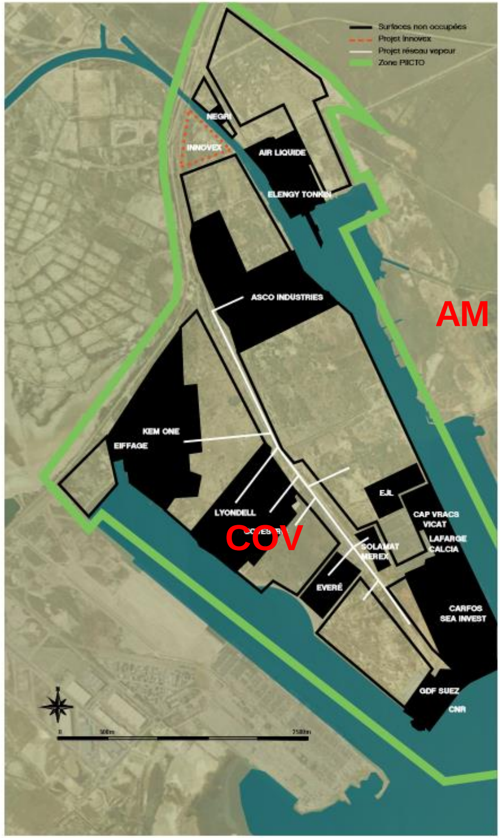
Présentation du projet - *Project presentation*

Jean-Philippe GENDARME *– President of PIICTO*

PIICTO

Platform for Industry and Innovation at Caban Tonkin

A Cutting Edge Industrial Port Zone



Key Figures:

- 1,200 ha site located in the industrial port area of Fos
- 3,000 jobs
- 17 plants
- 5 million tons of maritime throughput
- More than 600 ha still to commercialize

A Multimodal Platform and Diverse Energy Hub:

- Electricity (225 kV)
- Natural Gas and Frigories (2 LNG Terminal)
- Coal, Biomass
- Wind and Solar Power
- Hydrogen, Ethylene, Propylene, Nitrogen, etc.

The PIICTO Association

A collective dynamic that unites diverse economic and institutional stakeholders and is in accord with local and regional economic development policies

Governance:

- President: Jean-Philippe Gendarme (Kem One)
- Vice President: Christine Cabau-Woehrel (GPMM)
- Vice President: Mathieu Stortz (Elengy)
- Treasurer: Corinne Ramombordes (Solamat Merex)
- Secretary: Patrick Grimaldi (Kem One)

Two main objectives: **1:** Strengthen industrial competitiveness
2: Enhance economic appeal of port area

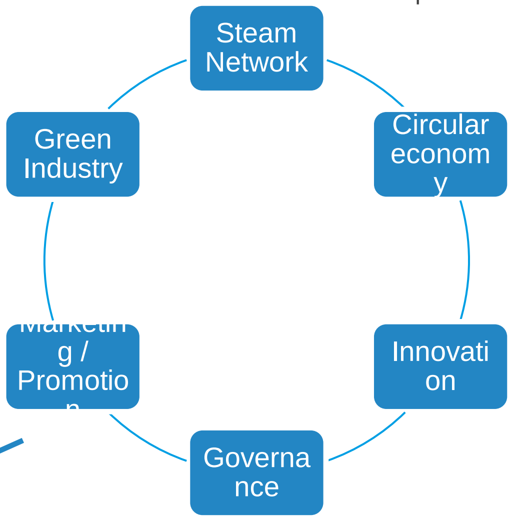
Tools:

- Industrial ecosystem: exchange of material and energy flows, cooperation between actors, mutualized services and facilities, etc.
- Innovation: energy transition, green industry, pilot projects, etc.

6 Operational Working Groups and several projects already launched or implemented

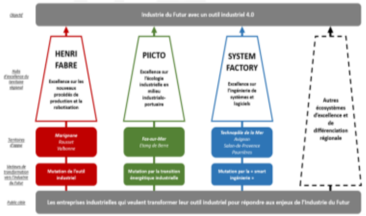
A Circular Economy creating synergies between industries (valorization of ferrous metals, recovery of sludge, etc.)
Steam network projects, a strategic investment in the port area to create synergies between consumers and producers on the platform

Multi-Platform Approach: A metropolitan-scale approach to industrial innovation including Berre, La Mède, and PIICTO tackling major issues such as microalgae, bio-plastics, and biofuels. Launching of *Provence Industry'Nov* industrial innovation hub.



Fostering dynamic innovation (INNOVEX)
4 Key Areas: Energy Storage / Circular Economy / Smart Grid / Safety
+ 60M€ private investments for industrial demonstrators

Marketing and building of a Plug & Play approach
PIICTO is one of the major pillars of both the Industry of the Future and the Energy of Tomorrow economic development plans developed by the PACA region. PIICTO's innovative projects are generating more interest in international partnerships



PIICTO Today

A dynamic industrial ecosystem featuring:

- **Key synergies between industrial plants** already implemented or in the process of being implemented (exchanges of material or energy flows, cooperation between actors, mutualized services or facilities, etc.)
- **An array of industrial opportunities including:**
  - Over €300 million in cumulative potential investment
  - Current and future creation of hundreds of jobs
  - Systematic search for potential integrations and synergies with existing industry members on the platform

And an innovative platform with:

- **Pioneering projects:**
  - ~60M€ already engaged
  - More than 20 projects in progress (from start-ups to large corporations)
- **A Commitment to the energy and environmental transition:**
  - Power-to-Gas – Power-to-Power – Power-to-Liquids – Solar Energy – Wind Power – etc.
  - Recycling of CO_2 and waste flows: microalgae, sludge, biofuels, etc.

For more information, feel free to contact:

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Website: www.piicto.fr

Methodology

Carbon4PUR

CO/CO_2	BUILDING BLOCKS / INTERMEDIATES	PRODUCTS & APPLICATION
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Steel industry

Steel production

ArcelorMittal

Flue gas treatment

UNIVERSITEIT GENT

Chemical – Polyol industry

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Upscaling

covestro, RWTH AACHEN UNIVERSITY

Polymer industry

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LCA and economic analysis

Extended LCA	Economic evaluation	Societal impacts
Universiteit Leiden	TU berlin	south pole

Exploitation – Replication – Dissemination

PNO, RECTICEL insulation, DECHEMA, MEGARA RESINS, Imperial College London, covestro

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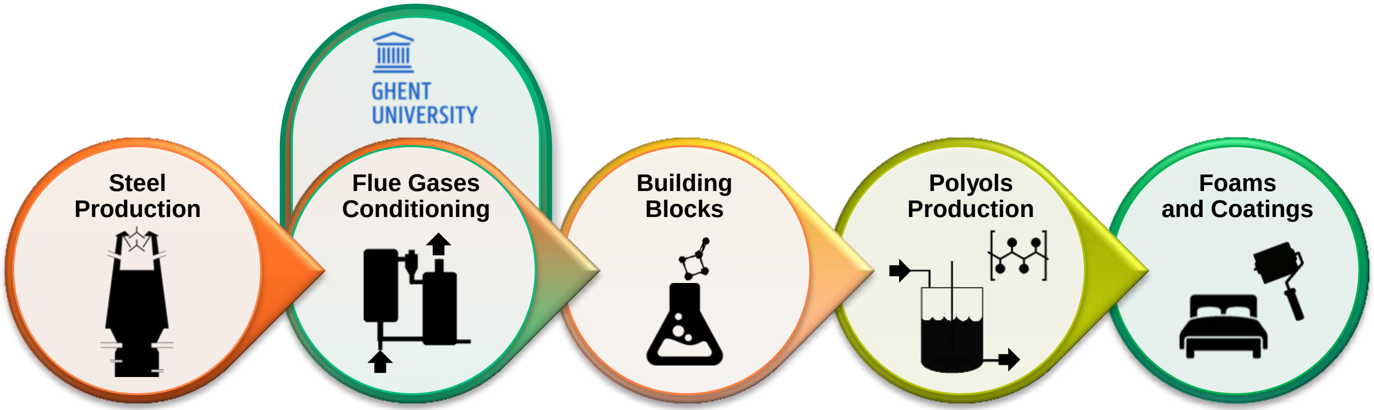
How is UGent involved in Carbon4PUR?



Overview of our work
Aims, Objectives & Partners

Aim

Reduce H_2 concentration in steel mill flue gas stream to less than 0.1% by volume

Objectives

Analyze, select, pretreat, and sample industrial flue gases from a steel mill for conditioning

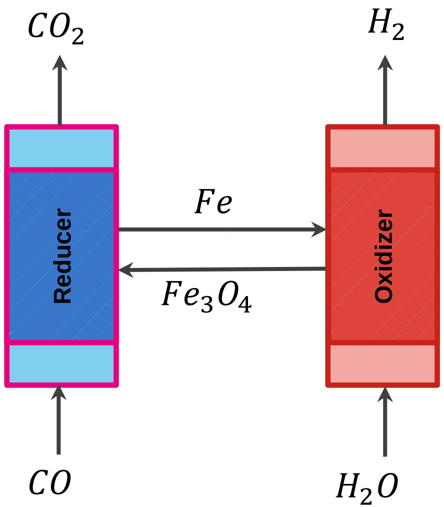
Develop an economical chemical process to reduce H_2 content in a CO/CO_2-rich waste stream

Chemical Looping

Chemical intermediates are used in a reaction-regeneration to

1) Decompose one target reaction into two or more sub-reactions.

First commercial steam-iron process (Howard Lane, 1904)



Reducer: $Fe_3O_4 + 4\,CO \rightarrow 3\,Fe + 4\,CO_2$

Oxidizer: $3\,Fe + 4\,H_2O \rightarrow 4\,H_2 + Fe_3O_4$

et reaction: $CO + H_2O \rightarrow CO_2 + H_2$

ooping medium: $Fe_3O_4 \leftrightarrow Fe$

Benefits:

1) WGSR equilibrium avoided
2) Combined gas separation

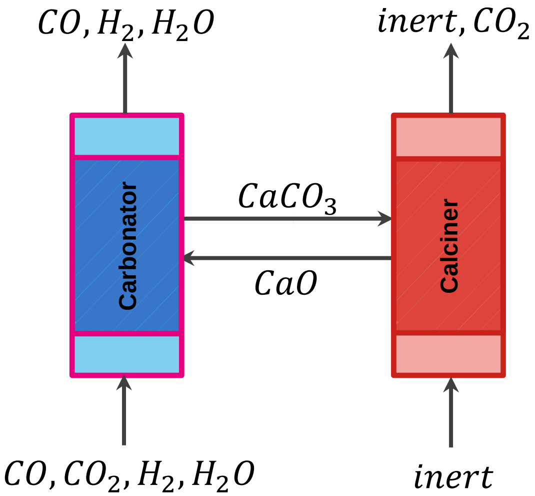
R. W. Breault (2018) *Handbook of Chemical Looping Technology*. Morgantown, WV: Wiley-VCH.
L. S. Fan (2010) *Chemical Looping Systems for Fossil Energy Conversions*. Hoboken, NJ: American Institute of Chemical Engineers.

Chemical Looping

Chemical intermediates are used in a reaction-regeneration cycle to:

2) Separate gases.

The CO2 Acceptor Gasification Process (G. P. Curran et al., 1967)



Carbonator: $CaO + CO_2 \rightarrow CaCO_3$

Calciner: $CaCO_3 \rightarrow CaO + CO_2$

Looping medium: $CaO \leftrightarrow CaCO_3$

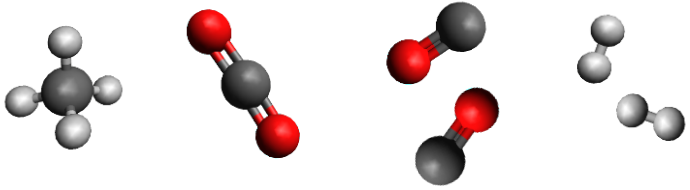
Benefits:

1) High temperature sorbents
2) High ability of regeneration

R. W. Breault (2018) *Handbook of Chemical Looping Technology*. Morgantown, WV: Wiley-VCH.
F. Schora (1967) *Advances in Chemistry*. Washington, DC: American Chemical Society.

Dry Reforming of Methane

$$CH_4 + CO_2 \rightarrow 2\,CO + 2\,H_2$$



Reduces greenhouse gases

Produces valuable chemicals

Currently, there are no commercial processes

Thermodynamic limitations.

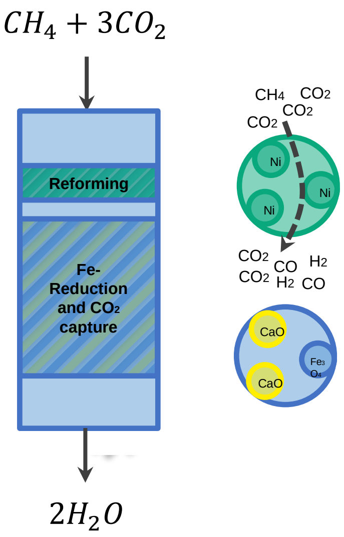
Deactivation of the catalysts due to carbon formation

Disadvantageous spent material disposal

Arora and Prasad, *RSC Adv., 2016, 6*, 108668-108688.

Super-Dry Reforming of Methane

$$CH_4 + \ 3\ CO_2 \ \rightarrow 4\ CO + 2\ H_2O$$



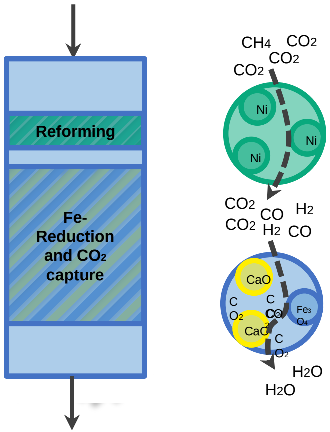
Reforming: $CH_4 + CO_2 \ \rightarrow 2CO + \ 2H_2$

Buelens, Galvita et al., *Science,* 2016, *354* (6311).

Super-Dry Reforming of Methane

$$CH_4 + 3\,CO_2 \rightarrow 4\,CO + 2\,H_2O$$

$CH_4 + 3CO_2$



$2H_2O$

Reforming: $$CH_4 + CO_2 \rightarrow 2CO + 2H_2$$

Reduction:

$$\tfrac{1}{2}\,Fe_3O_4 + 2\,CO \rightarrow \tfrac{3}{2}\,Fe + 2\,CO_2$$

$$\tfrac{1}{2}\,Fe_3O_4 + 2\,H_2 \rightarrow \tfrac{3}{2}\,Fe + 2\,H_2O$$

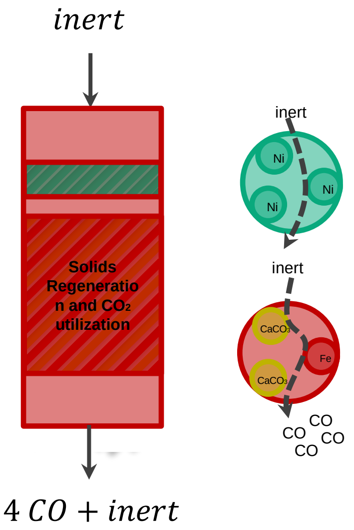
CO_2 capture: $$4\,CaO + 4\,CO_2 \rightarrow 4\,CaCO_3$$

$$\boldsymbol{CH_4 + 3\,CO_2 + Fe_3O_4 + 4\,CaO \rightarrow 3\,Fe + 4\,CaCO_3 + 2\,H_2O}$$

Buelens, Galvita et al., *Science,* 2016, *354* (6311).

Super-Dry Reforming of Methane

$$CH_4 + \ 3\, CO_2 \ \rightarrow 4\, CO + 2\, H_2O$$



CO2 release: $4\, CaCO_3 \ \rightarrow 4\, CO_2 + 4\, CaO$

Oxidation: $3\, Fe + \ 4\, CO_2 \ \rightarrow \ Fe_3O_4 + 4\, CO$

$$\boldsymbol{inert + 3\, Fe + 4\, CaCO_3 \rightarrow 4CO + Fe_3O_4 + 4\, CaO + inert}$$

Buelens, Galvita et al., *Science,* 2016, *354* (6311).

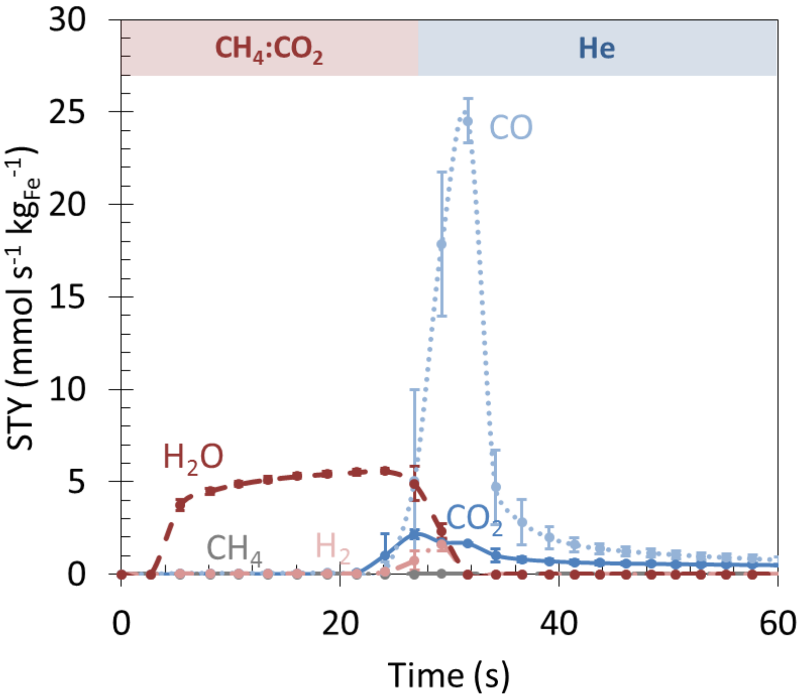
Super-Dry Reforming of Methane

Single fixed bed

T = 1023 K

CH_4:CO_2 = 1:3

25 cycles



Buelens, Galvita et al., *Science,* 2016, *354* (6311).

Super-Dry Reforming of Methane

Super-Dry Reforming of Methane	Conventional Dry Reforming of Methane
$CH_4 + 3\ CO_2 \rightarrow 4\ CO + 2\ H_2O$	$CH_4 + CO_2 \rightarrow 2\ CO + 2\ H_2$
$\Delta H^o_{298K} = 110\ kJ\ mol^{-1}{}_{CO_2}$	$\Delta H^o_{298K} = 250\ kJ\ mol^{-1}{}_{CO_2}$
Water-gas shift reaction avoided.	Limited by the water-gas shift reaction.
Carbon deposition avoided.	Carbon deposition causes deactivation.
Allows use of Ni-based catalyst at 750 °C.	Requires noble metal catalyst to mitigate carbon formation between 800 to 1000 °C.
Reduces separation costs.	Separation of gases is required.
Flexible process where process variables, reactor configurations and materials can be fine-tuned.	Process limited by the water-gas shift reaction.

Buelens, Galvita et al., *Science,* 2016, *354* (6311).

Carbon4PUR

CCU Portfolio at UGent

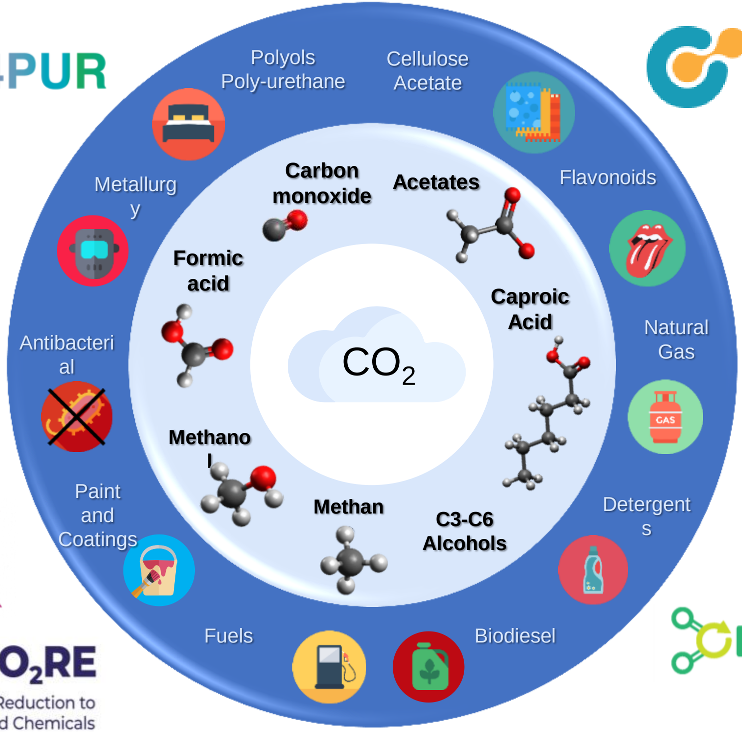
Carbon4PUR

Super-Dry Reforming

CO2PERATE

ENERGY X

CATCO$_2$RE
Catalytic CO_2 Reduction to Solar Fuels and Chemicals



Project EnOp
- Improving our lives -

capaa

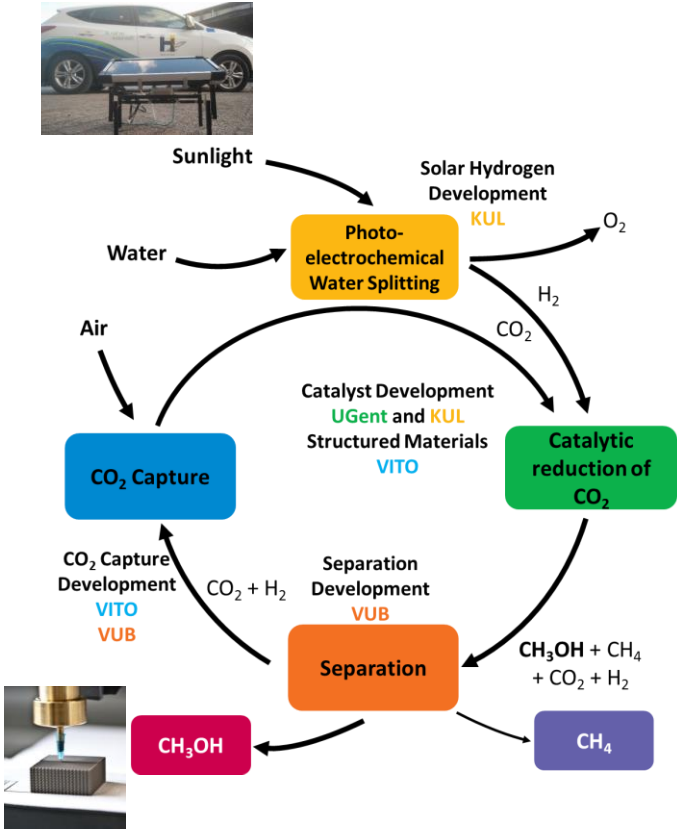
BIOCON-CO_2

CATCO$_2$RE

Catalytic CO_2 Reduction to Solar Fuels and Chemicals

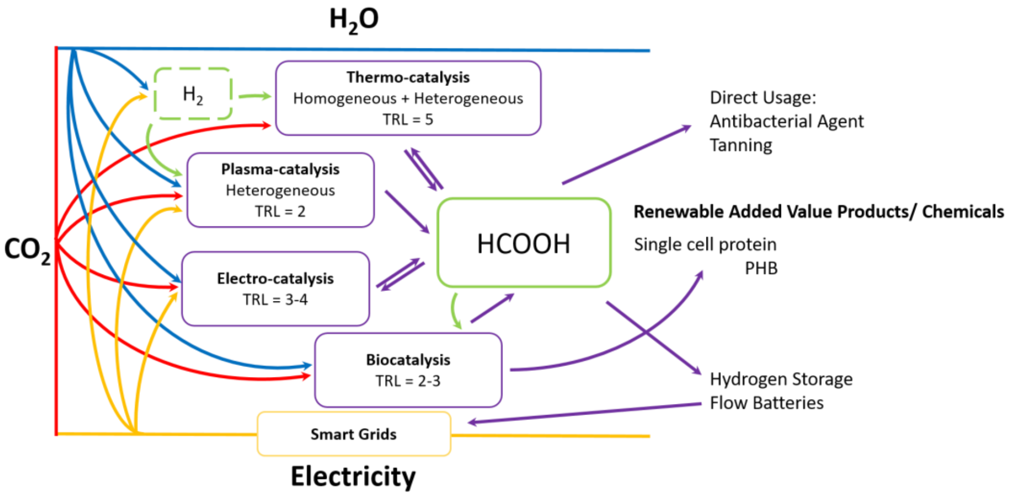
Carbon4PUR

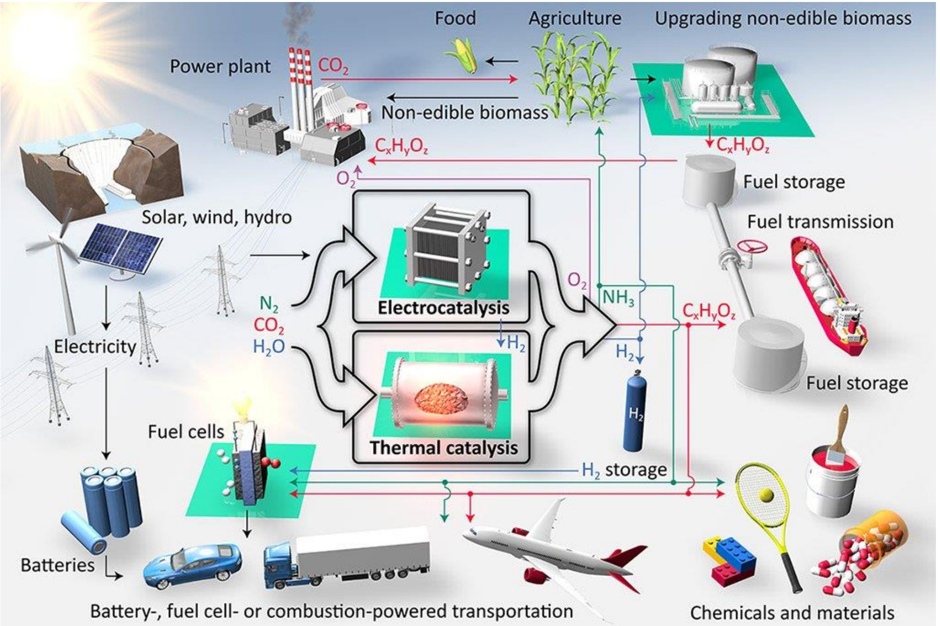
Investigate conversion of CO_2 to solar fuels (methane and methanol), integrating new developments in the production of solar hydrogen, with the design and synthesis of selective catalysts active at milder reaction conditions, and effective CO_2 capture and separation technologies.



GHENT UNIVERSITY KU LEUVEN VUB vito

Develop new technologies for the conversion of CO_2 to value-added chemicals using catalysis and renewable energy; benchmark, compare and develop the various technologies starting with Formic Acid




Food
Agriculture
Upgrading non-edible biomass
Power plant
CO_2
Non-edible biomass
$C_xH_yO_z$
O_2
Fuel storage
Fuel transmission
Solar, wind, hydro
Electricity
N_2
CO_2
H_2O
Electrocatalysis
Thermal catalysis
NH_3
H_2
Fuel storage
Fuel cells
H_2 storage
Batteries
Battery-, fuel cell- or combustion-powered transportation
Chemicals and materials

Thank you!

... You for your attention

… The EC for funding

… The Port for today‘s organisation

… and all collaboration partners

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