# TURNING INDUSTRIAL WASTE GASES INTO VALUABLE POLYURETHANES


25 March 2021

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Carbon4PUR
Covestro Deutschland AG

EUROPEAN RESEARCH COLLABORATION BETWEEN STEEL AND CHEMICAL INDUSTRY

# CHALLENGES:
# Saving our fossil resources
# Reducing the greenhouse effect



These project have received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 768919.

# Solution: Using $CO_2$ instead of oil

A harmful climate gas as useful raw material

$CO_2$ emissions hardly to be completely prevented

BUT:

$CO_2$ is low-energy & sluggish in reaction

Using $CO_2$ is technically very challenging

- ➢ Covestro and its partners have developed a completely new process for the ecologically and economically sensible use of $CO_2$



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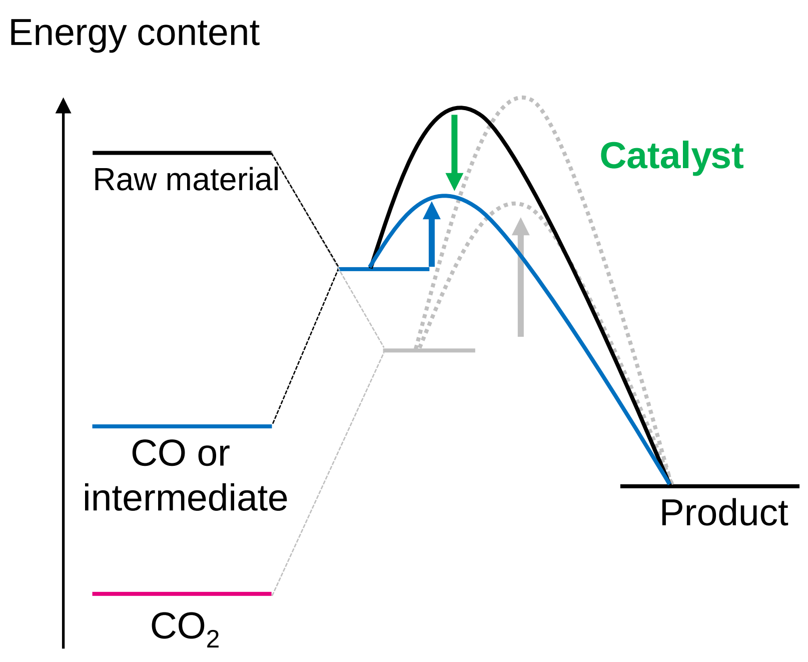
# Scientific breakthrough via catalysis

Hurdle for $CO_2$ use overcome




**Challenge:**

- $CO_2$ activation normally requires a lot of **energy** which is ecologically inefficient

**Solution:**

- Development of an appropriate **catalyst** and process for ecologically and economically efficient reaction
- Start at higher energy level:
  Use **CO from a renewable source**
- Recovered carbon by industrial symbiosis between steel & chemical industry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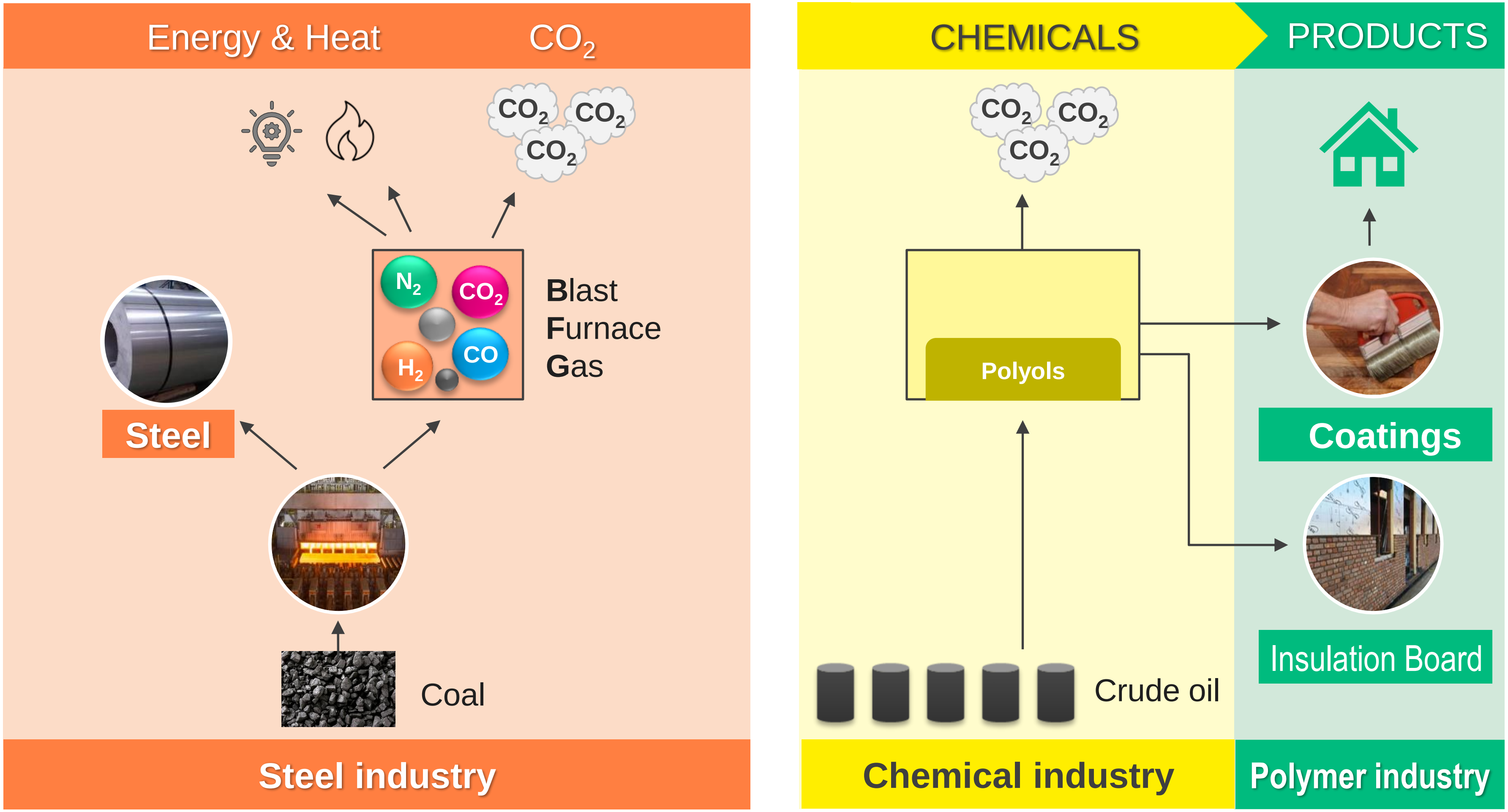
# Conventional Steel & PUR production

Based on fossil resources and emitting $CO_2$





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# Conventional Steel & PUR production

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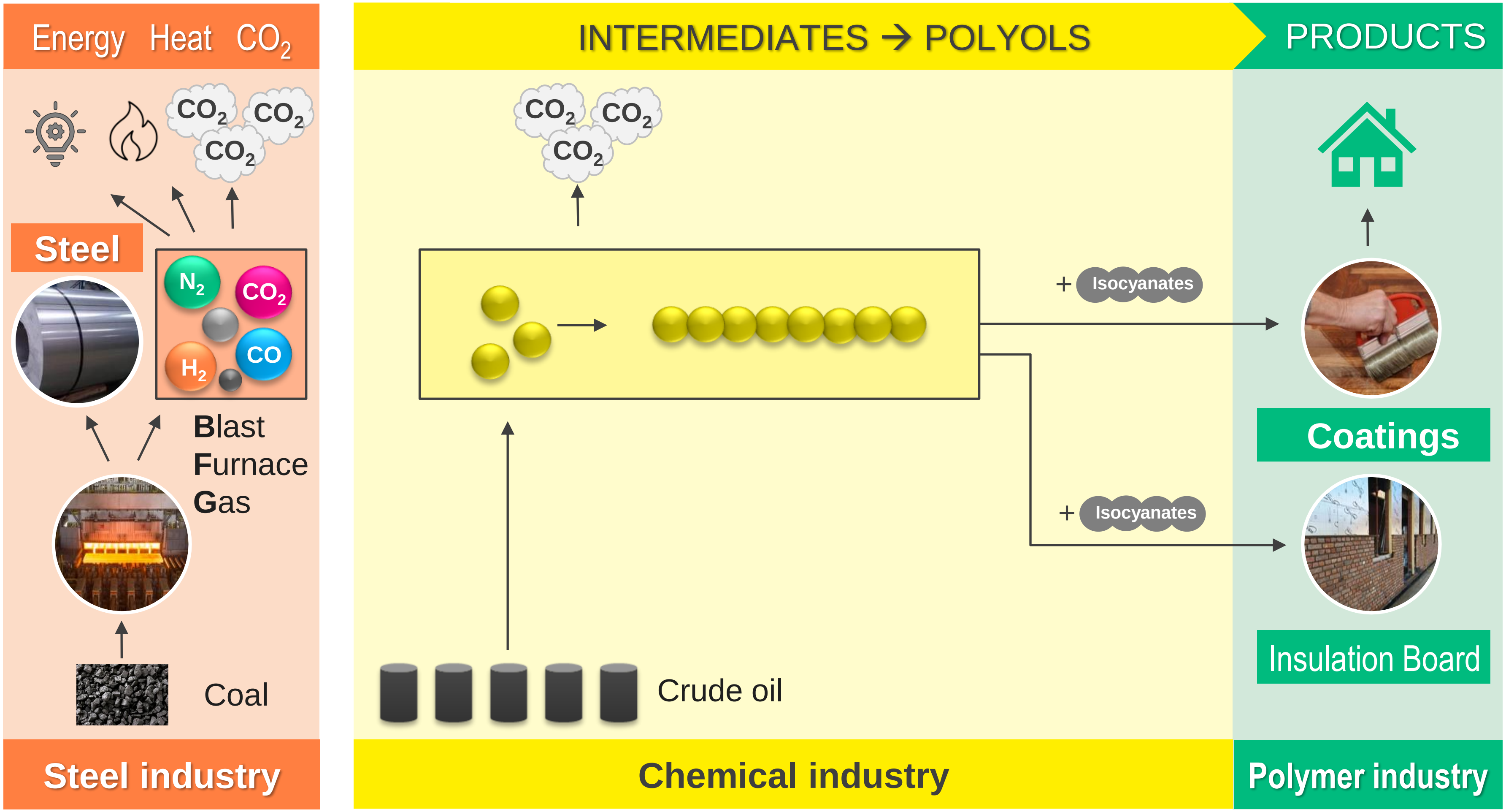




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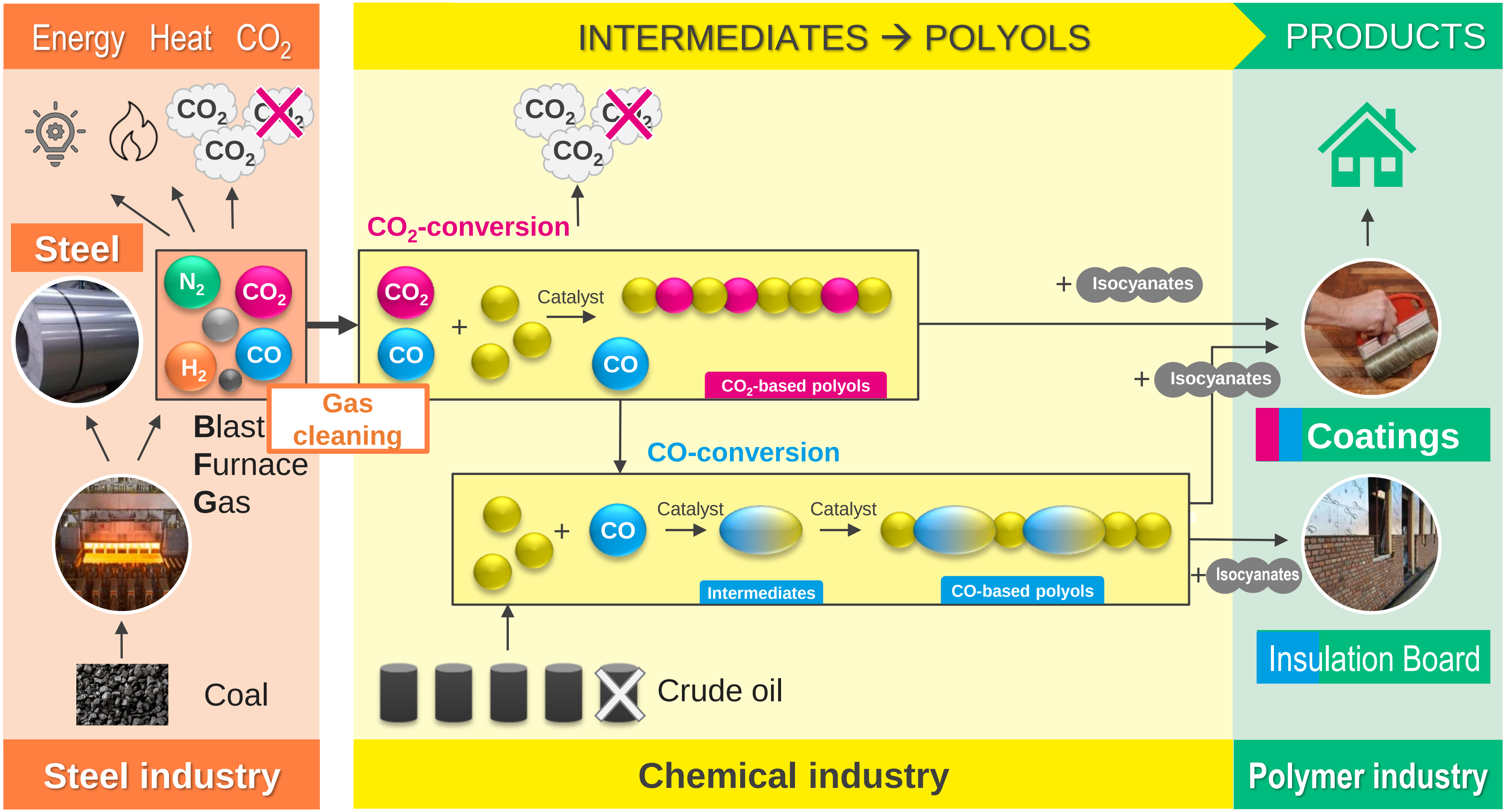
# Carbon4PUR CO/$CO_2$ technology

Recycling of CO and $CO_2$ reduces emissions and need for fossil resources



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# Collaboration along the Value Chain

14 Partners from 7 countries, supported by the EU with 7.8 m€, 10/2017 – 03/2021

| CO/$CO_2$ | INTERMEDIATES & POLYOLS PRODUCTION | PRODUCTS & APPLICATION |
|---|---|---|

## Steel industry

**Steel production** | **Steel mill gas treatment**

ArcelorMittal
GHENT UNIVERSITY

## Chemical – Polyol industry

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

cea
CAT Catalytic Center
covestro
AVT
RWTH AACHEN UNIVERSITY

## Polymer industry

**Insulation boards & Coatings**

RECTICEL The passion for comfort
covestro
MEGARA RESINS

## Accompanying

### Industrial symbiosis analysis

Marseille Fos Le port euroméditerranéen
ArcelorMittal
covestro
DECHEMA

### LCA, economic & social analysis - Acceptance

Universiteit Leiden The Netherlands
Technische Universität Berlin
RWTH AACHEN UNIVERSITY
south pole

### Exploitation – Dissemination

PNO
DECHEMA
Imperial College London
RECTICEL
MEGARA RESINS
covestro



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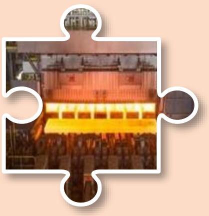
SPIRE PROJECT

Carbon4PUR

# Pieces of a big puzzle

All work packages in parallel to accelerate the overall project

| $CO/CO_2$ | INTERMEDIATES & POLYOLS PRODUCTION | PRODUCTS & APPLICATION |
|---|---|---|
| **Steel industry** | **Chemical – Polyol industry** | **Polymer industry** |
| **Steel production**, **Steel mill gas treatment** | **Catalyst design**, **Process design**, **Upscaling** | **Insulation boards & Coatings** |






## Accompanying

| Industrial symbiosis analysis | LCA, economic & social analysis - Acceptance | Exploitation – Dissemination |
|---|---|---|



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ArcelorMittal

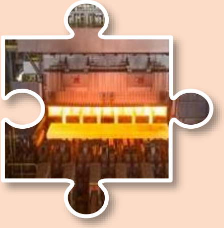
# STEEL PRODUCTION

## Eric de Coninck

**$CO/CO_2$**

Steel production

Steel mill gas treatment



**INTERMEDIATES & POLYOLS PRODUCTION**

Catalyst design

Process design

Upscaling

**PRODUCTS & APPLICATION**

Insulation boards & Coatings

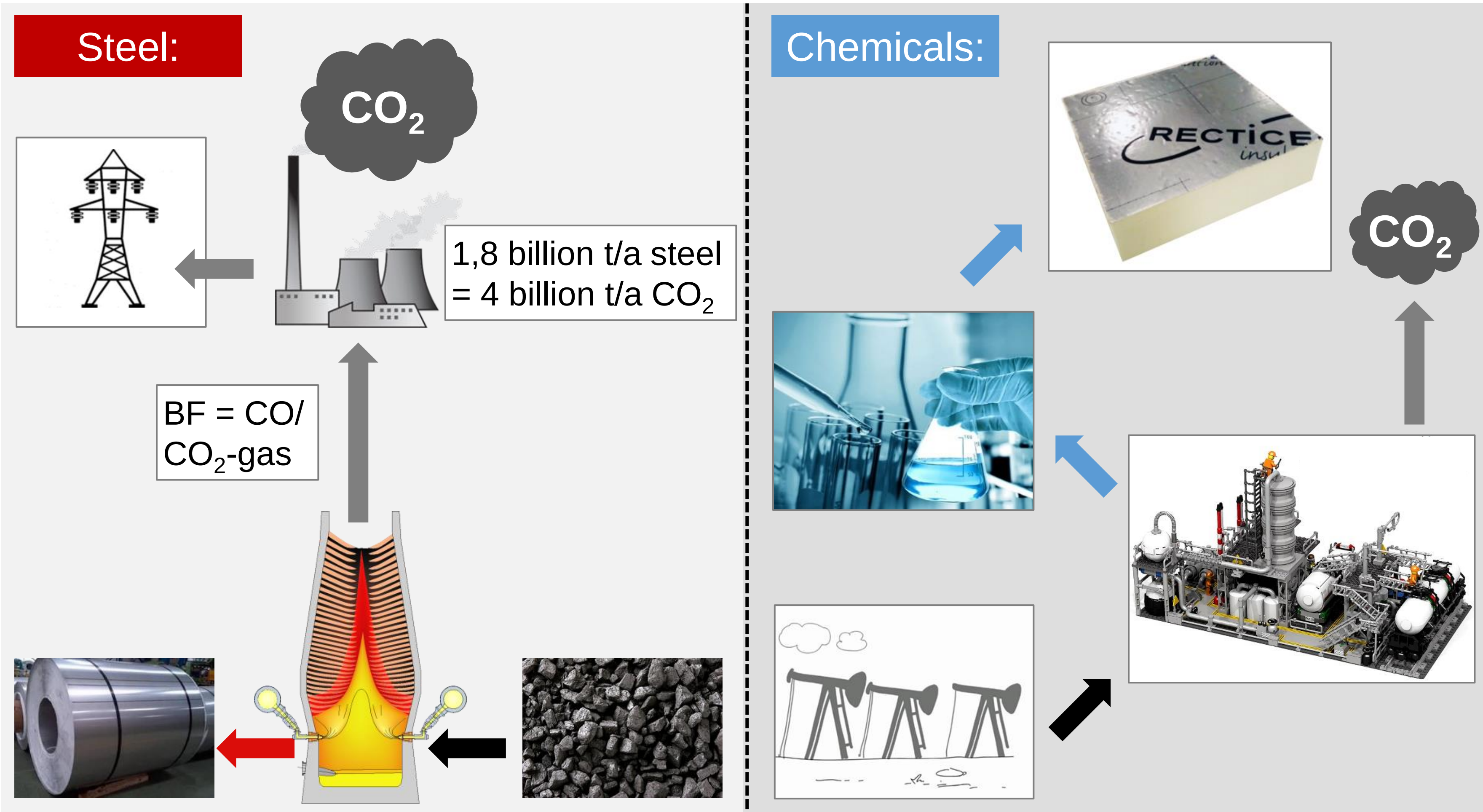
**ACCOMPANYING**

Industrial symbiosis analysis

LCA, economic & social analysis – Acceptance

Exploitation – Dissemination

# Current situation of production





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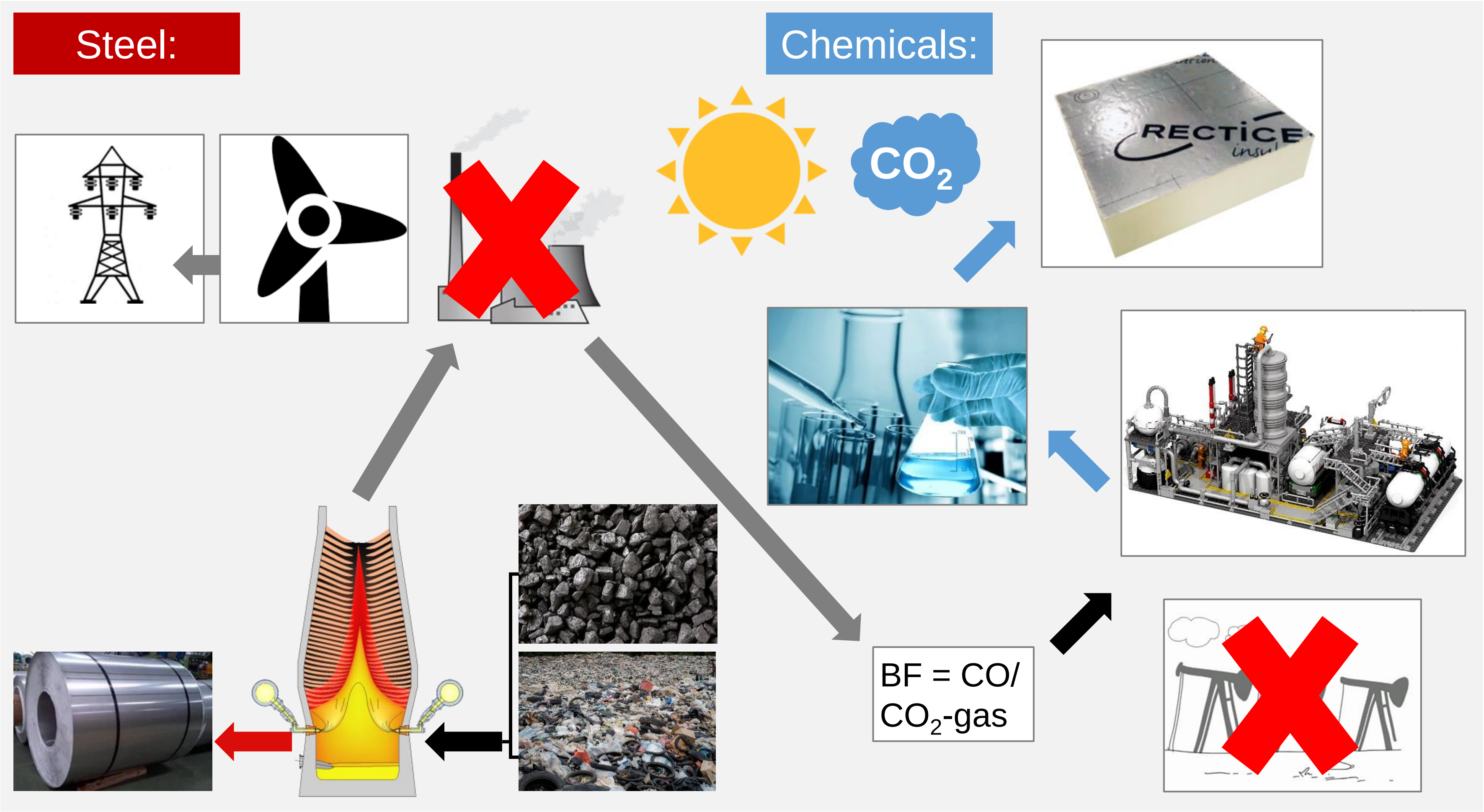
# New situation of production = CCU





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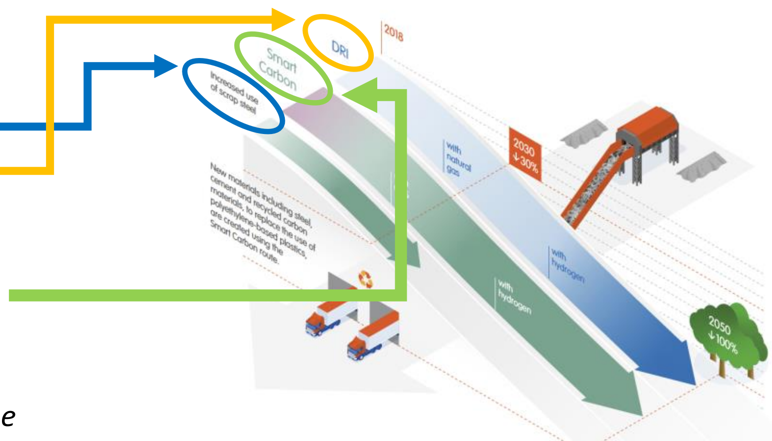
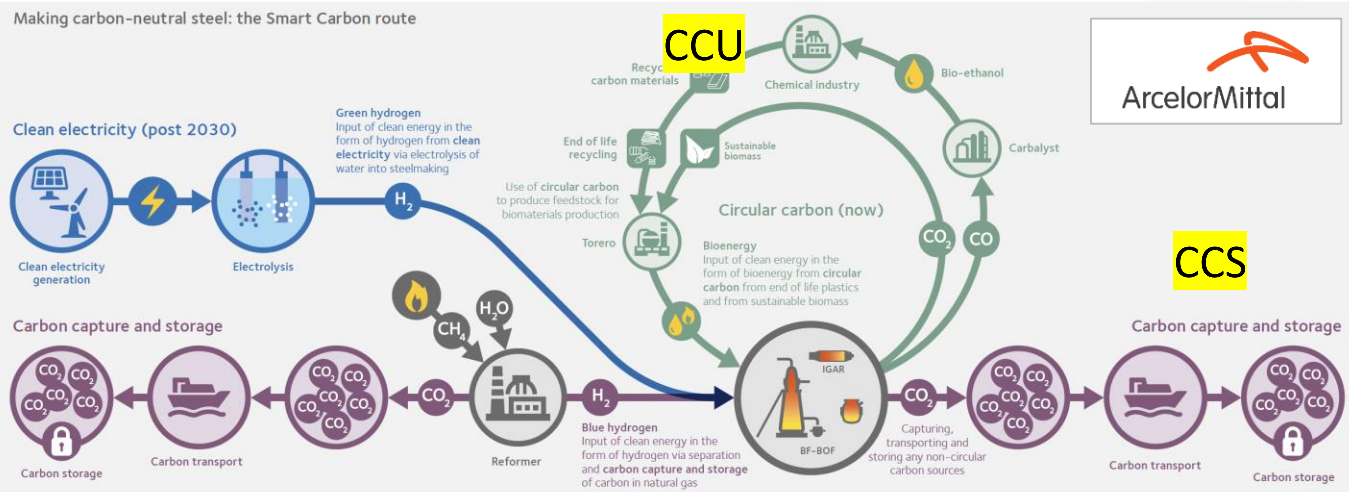
# AM decarbonation plan:
# -30 % by 2030, carbon neutrality by 2050

SEVERAL MEASURES TO BE DEVELOPED:
- Energy efficiency and recovery
- Maximum use of affordable renewables (scrap melting) and C-free hydrogen (DRI)
- Use of biomass
- Use of circular carbon products (e.g. waste plastics)
- Re-use of carbon emissions (CCU)
- Storage of carbon emissions (CCS)

*https://corporate.arcelormittal.com/sustainability/climate-action-in-europe*




Smart Carbon Usage



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GHENT UNIVERSITY

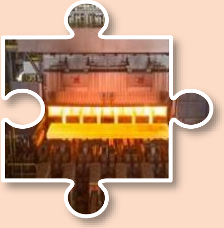
# STEEL MILL GAS TREATMENT

Mark Saeys

**$CO/CO_2$**

Steel production

Steel mill gas treatment



**INTERMEDIATES & POLYOLS PRODUCTION**

Catalyst design

Process design

Upscaling

**PRODUCTS & APPLICATION**

Insulation boards & Coatings

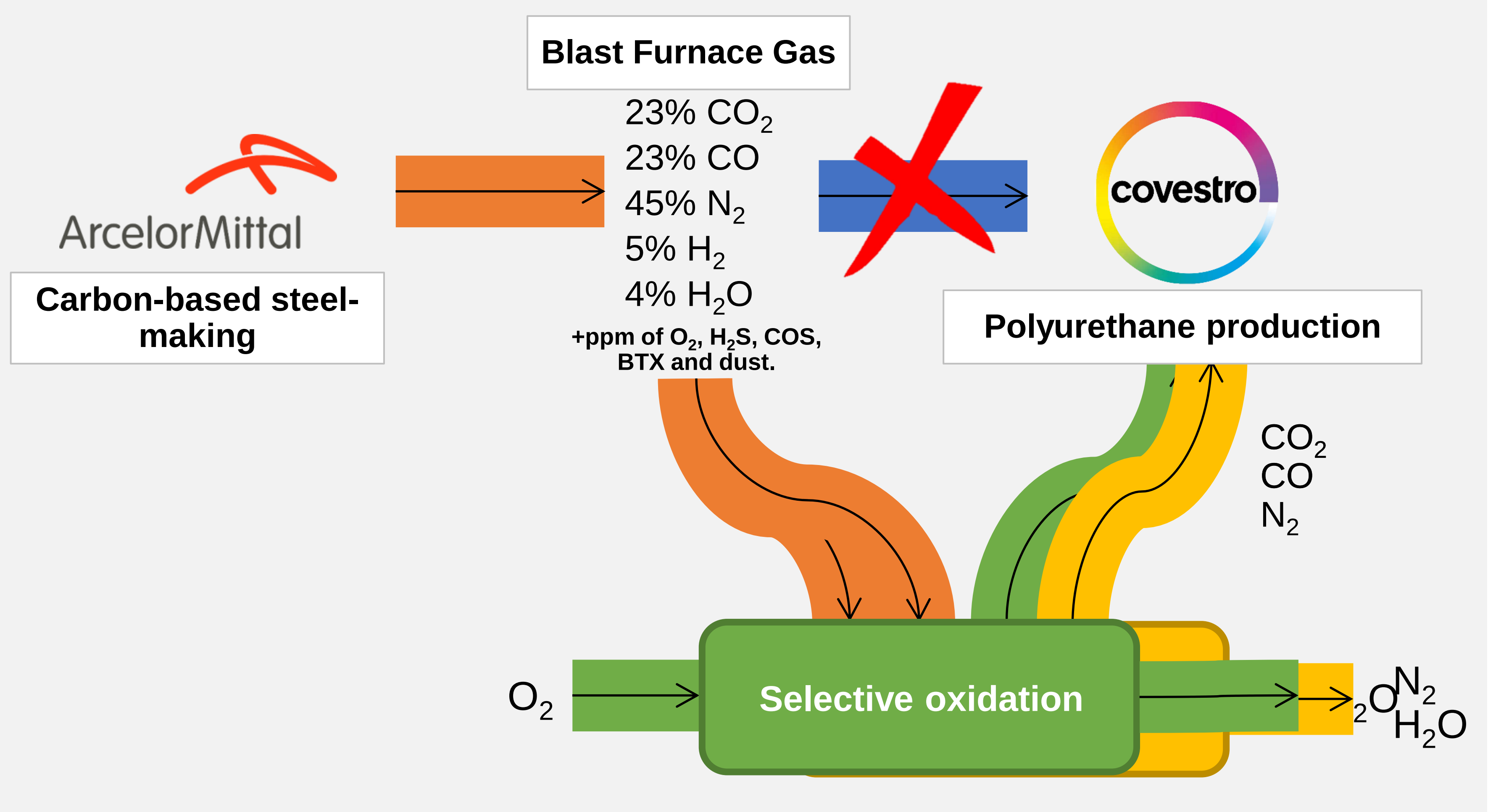
**ACCOMPANYING**

Industrial symbiosis analysis

LCA, economic & social analysis – Acceptance

Exploitation – Dissemination

# Gas conditioning technologies developed in Carbon4PUR



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# Gas conditioning technologies developed in Carbon4PUR

**Selective oxidation**

**Proposed Solution (TRL1-2)**
Thermodynamics
Stoichiometry
Potential routes

**(TRL3-4) Lab Studies**
Rates
Selectivity
Deactivation

***model* BFG (TRL 4)**
Stability 24h+

***model* BFG + impurities (TRL 4-5)**
Stability for 75h+

***real* BFG (TRL 5-6)**
Pilot-testing at AM Gent
Stability for 5h+

1 2 3 4

$$CO + 1/2O_2 \leftrightharpoons CO_2$$

$\Delta G_{298K}$=-257 kJ/mol CO & $\Delta H_{298K}$=-283 kJ/mol CO

$$H_2 + 1/2O_2 \leftrightharpoons H_2O$$

$\Delta G_{298K}$=-229 kJ/mol $H_2$ & $\Delta H_{298K}$=-242 kJ/mol $H_2$

$$CO_2 + H_2 \leftrightharpoons CO + H_2O$$

$\Delta G_{298K}$=+29 kJ/mol & $\Delta H_{298K}$=+41 kJ/mol


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# Gas conditioning technologies developed in Carbon4PUR

**Chemical Looping**

**The challenge:**
**$CaO_{(s)} + CO_{2\,(g)} \leftrightarrow CaCO_{3\,(s)}$**

**Limited by the $CO_2$ partial pressure**

**Possibilities:**

- **Use an inert gas.**

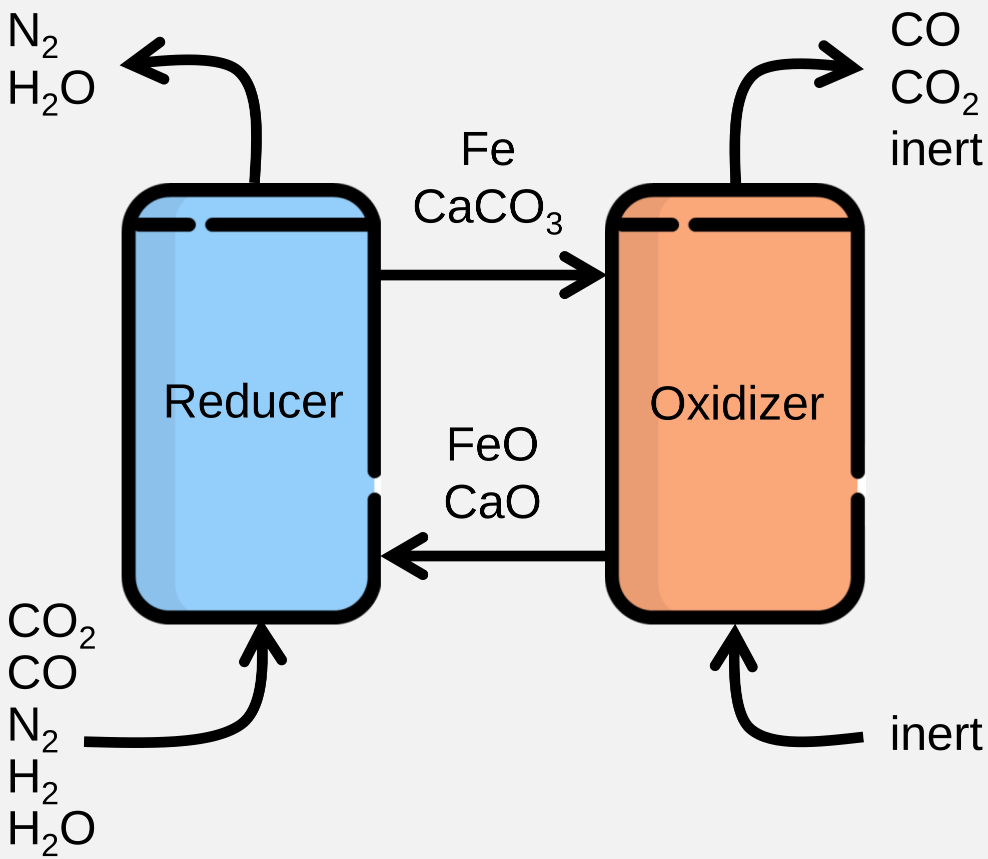
**→ dilutes the product stream**

- **Thermal swing.**

**→ evaluated experimentally.**

- **Pressure swing.**

**→ evaluated through modeling.**



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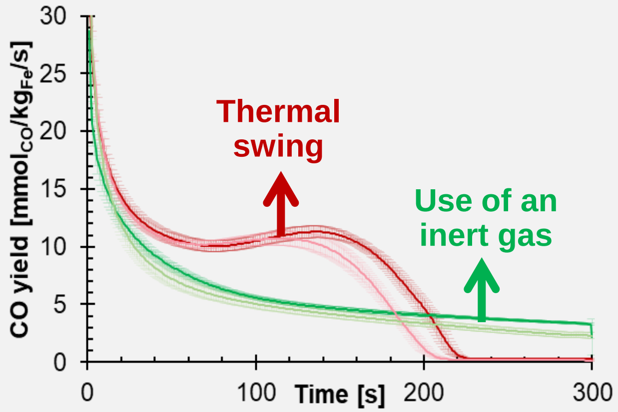
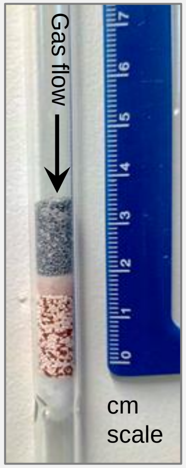
# Gas conditioning technologies developed in Carbon4PUR

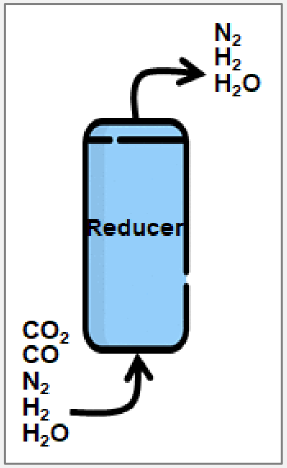
THERMAL SWING

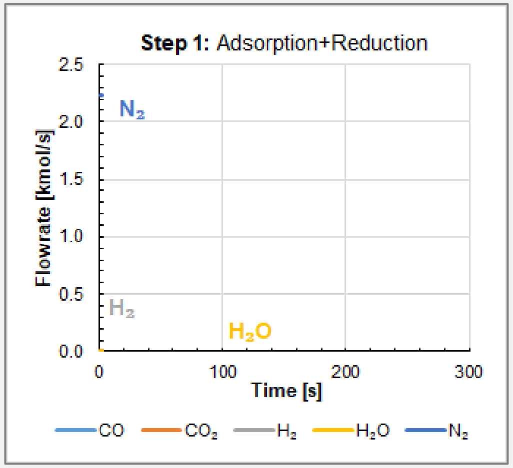
**Chemical Looping**

PRESSURE SWING




- Demonstrated at lab scale (TRL 3).
- Swinging the solids' temperature leads to longer cycles.

- Only exists in the computer.
- Potentially requires shorter cycles at slightly lower temperatures.



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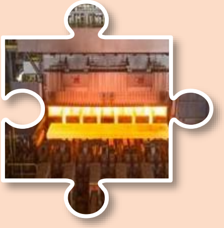
# CATALYST & PROCESS DESIGN – UPSCALING

Martin Machat

| CO/$CO_2$ | | INTERMEDIATES & POLYOLS PRODUCTION | | | PRODUCTS & APPLICATION |
|---|---|---|---|---|---|
| Steel production | Steel mill gas treatment | Catalyst design | Process design | Upscaling | Insulation boards & Coatings |



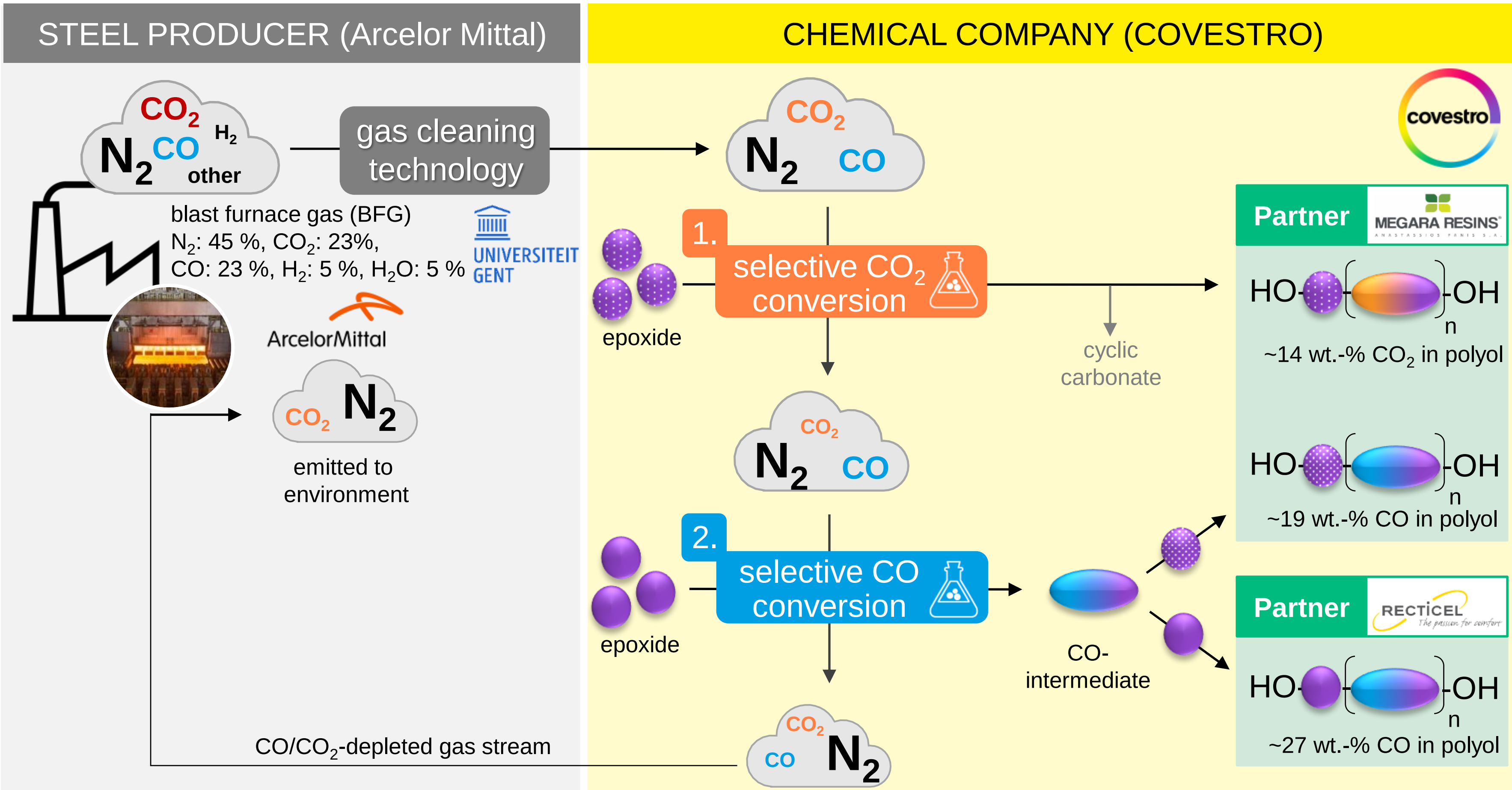



**ACCOMPANYING**

| Industrial symbiosis analysis | LCA, economic & social analysis – Acceptance | Exploitation – Dissemination |
|---|---|---|

# Carbon4PUR process overview

Utilizing $CO/CO_2$-containing steel mill gas for selective chemical transformations




➢ Four different process scenarios determined for in-depth TEA and LCA analysis



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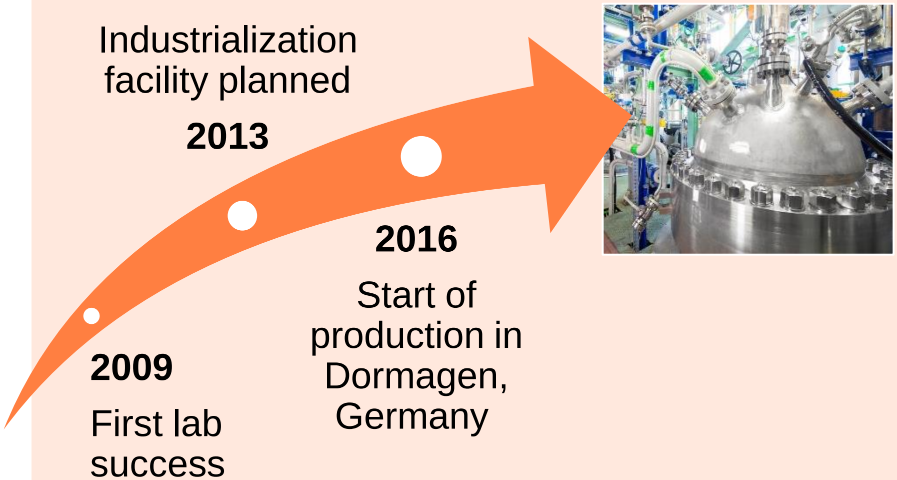
# $CO_2$ and CO conversion technologies

Combining two technologies of different technological readiness levels

## 1. $CO_2$ conversion technology

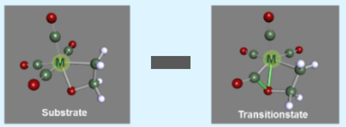



- Up to **~20 wt.-% of $CO_2$** in the polyol (cardyon®)
- **Reduced carbon footprint** of the product due to the replacement of fossil propylene oxide by $CO_2$

**Carbon4PUR**: Adaption of an established industrial technology towards the use of $CO_2$-containing gas mixtures instead of pure $CO_2$

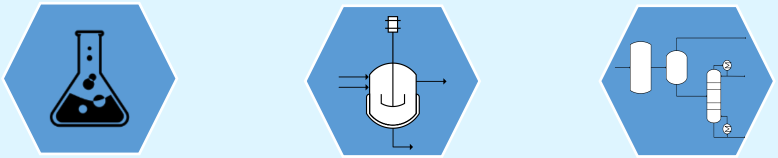
## 2. CO conversion technology

- **Computational tools** for improved catalyst design




$= E_a$

- **Experimental catalyst development and process design**



Catalyst Development | Reaction Engineering | Conceptual Process Design


**Carbon4PUR**: Development of an emerging academic technology towards technological readiness for industrial use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Carbon4PUR

# Upscaling of the CO-polyol production

Parallel development to speed up the innovation process

10/2018 → 03/2021

## Polyol development with **carbonylated “CO-intermediate”**

g-scale carbonylation


kg-scale carbonylation

CO-intermediate


CO-containing polyol and rigid foam

## Polyol development with **commercially obtained “CO-intermediate”**

g-scale polyol synthesis

kg-scale polyol synthesis

pilot plant polyol synthesis

Delivered to

RECTICEL The passion for comfort

MEGARA RESINS



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SPIRE PROJECT

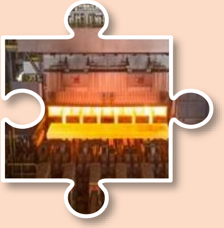
RECTICEL
*The passion for comfort*

# INSULATION BOARDS

## Geert Snellings

**$CO/CO_2$**

- Steel production
- Steel mill gas treatment



**INTERMEDIATES & POLYOLS PRODUCTION**

- Catalyst design
- Process design
- Upscaling

**PRODUCTS & APPLICATION**

- Insulation boards & Coatings

**ACCOMPANYING**

- Industrial symbiosis analysis
- LCA, economic & social analysis – Acceptance
- Exploitation – Dissemination

# Further processing and evaluation of Carbon4PUR polyols at Recticel

## Thermal insulation based on rigid polyurethane foams:

- **Polyurethanes** (PUR or PIR) are the most efficient thermal insulation materials with **lowest thermal conductivity**, leading to thinner applications
- Thermal insulation solutions for building renovations and new construction make a significant **contribution to a low-carbon society**:
  - In 2020, $CO_2$ emissions avoided by our insulation solutions offset more than 46 times the carbon footprint of all Recticel activities combined
  - **Structurally growing market** for thermal insulation in Europe
    - **Driven by the EU regulation aiming to save energy and reduce $CO_2$ emissions**
- R&D focus on **sustainable innovations** uncovering new solutions for the **circular economy**, including **more lower-carbon raw materials**

FEEL GOOD INSIDE

RECTICEL insulation



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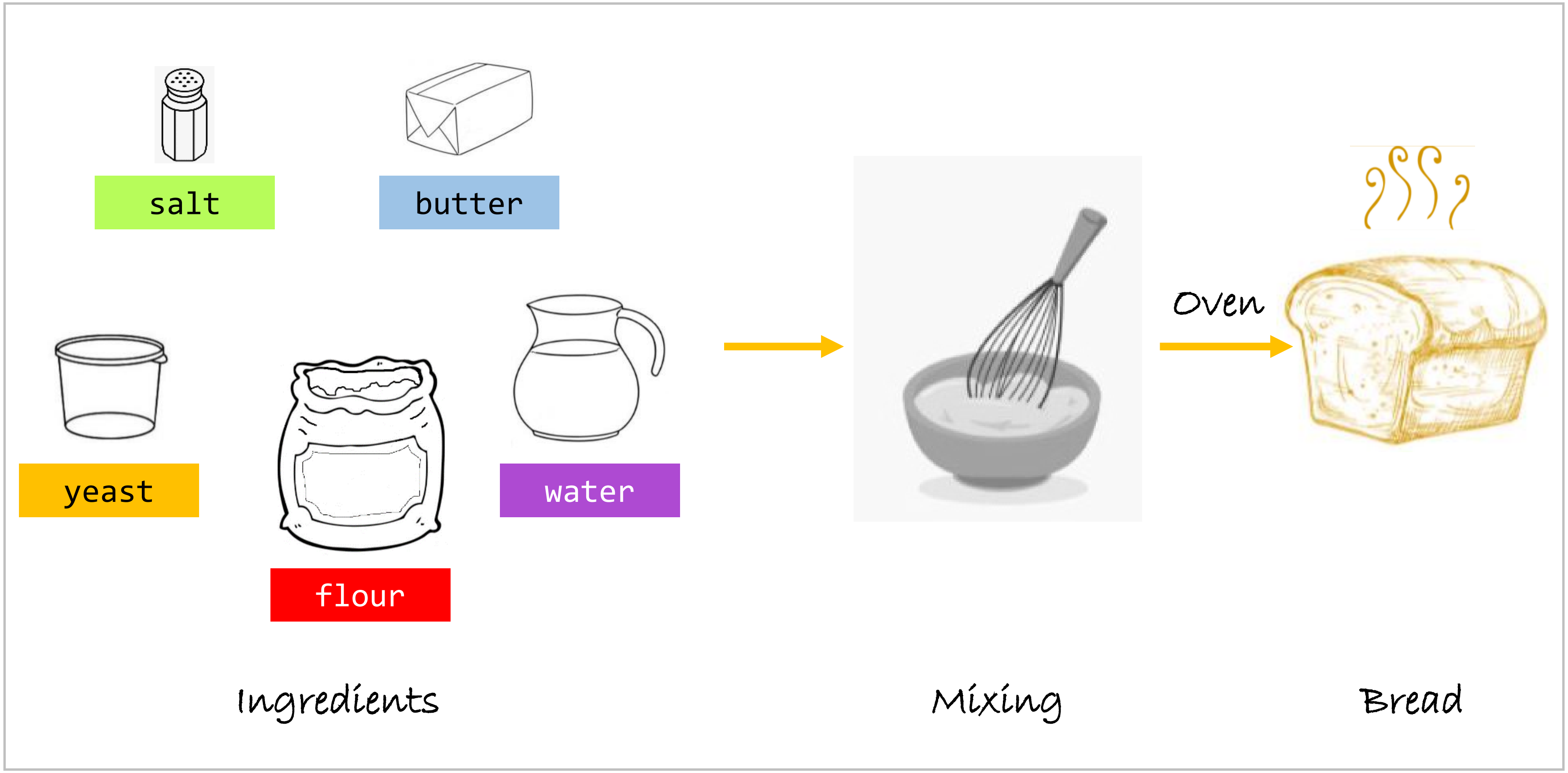
# Further processing and evaluation of Carbon4PUR polyols at Recticel

How are polyurethane foams made? ▶ Similar to making bread



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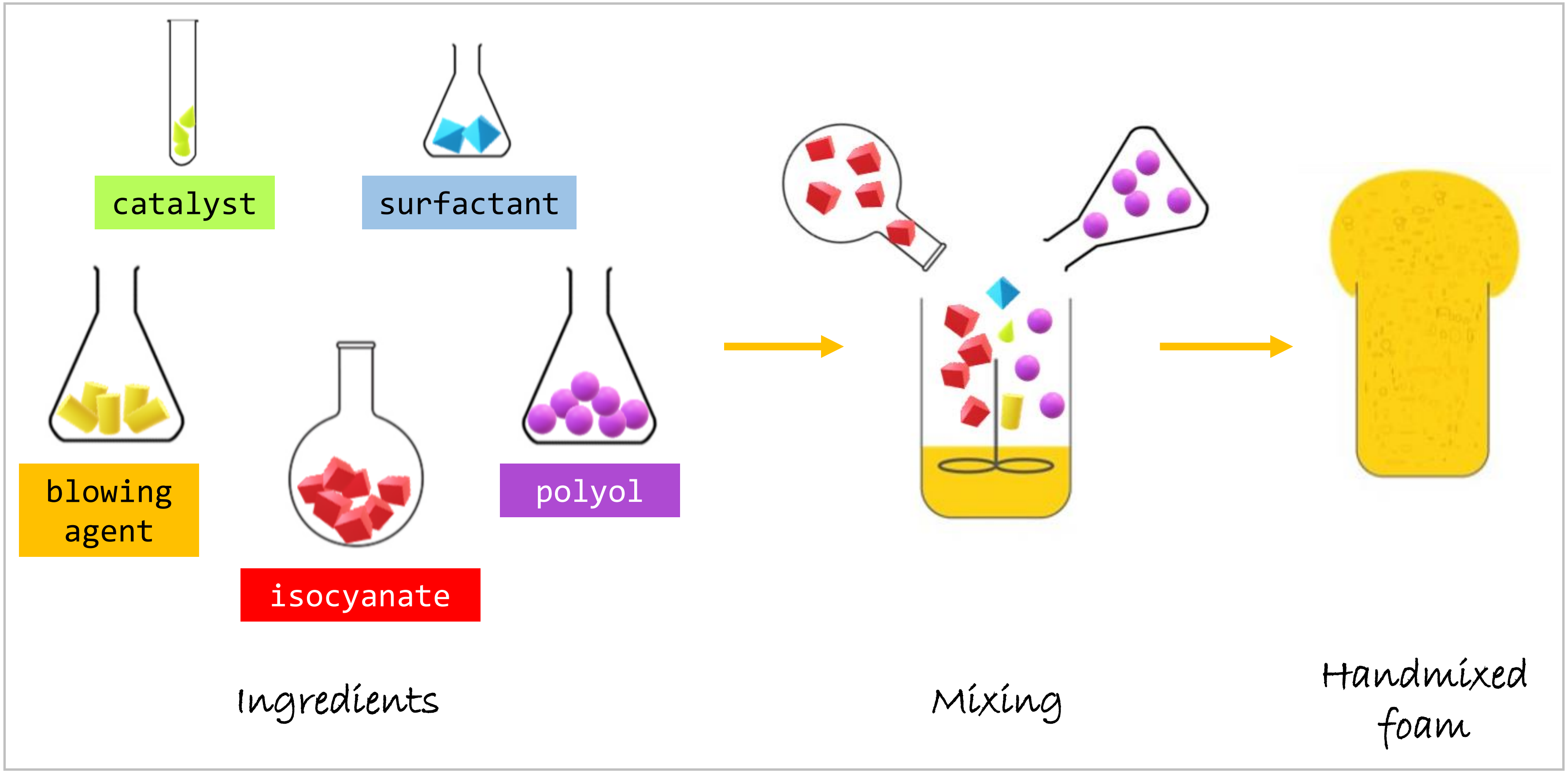




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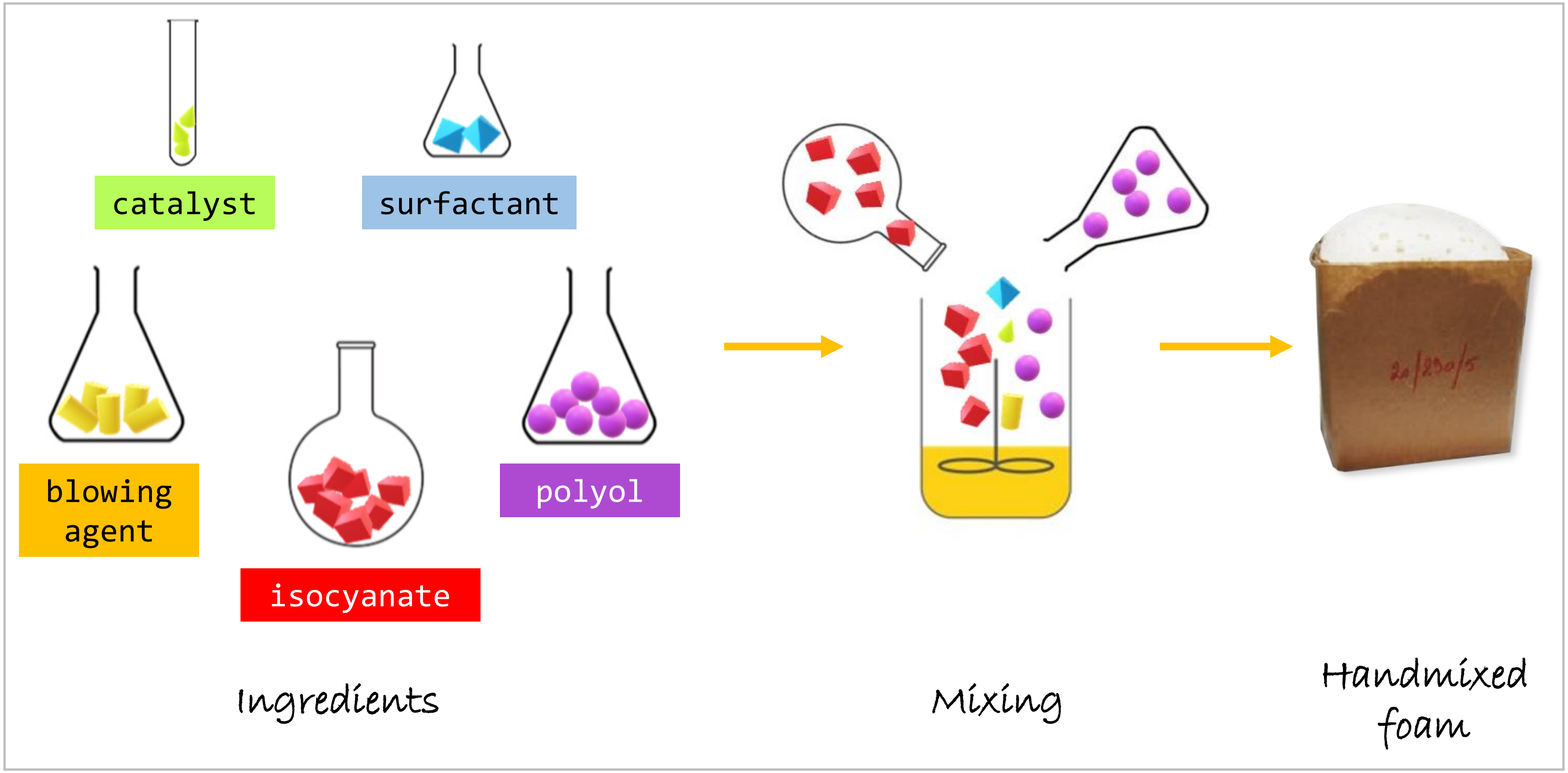



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# Further processing and evaluation of Carbon4PUR polyols at Recticel

Carbon4PUR

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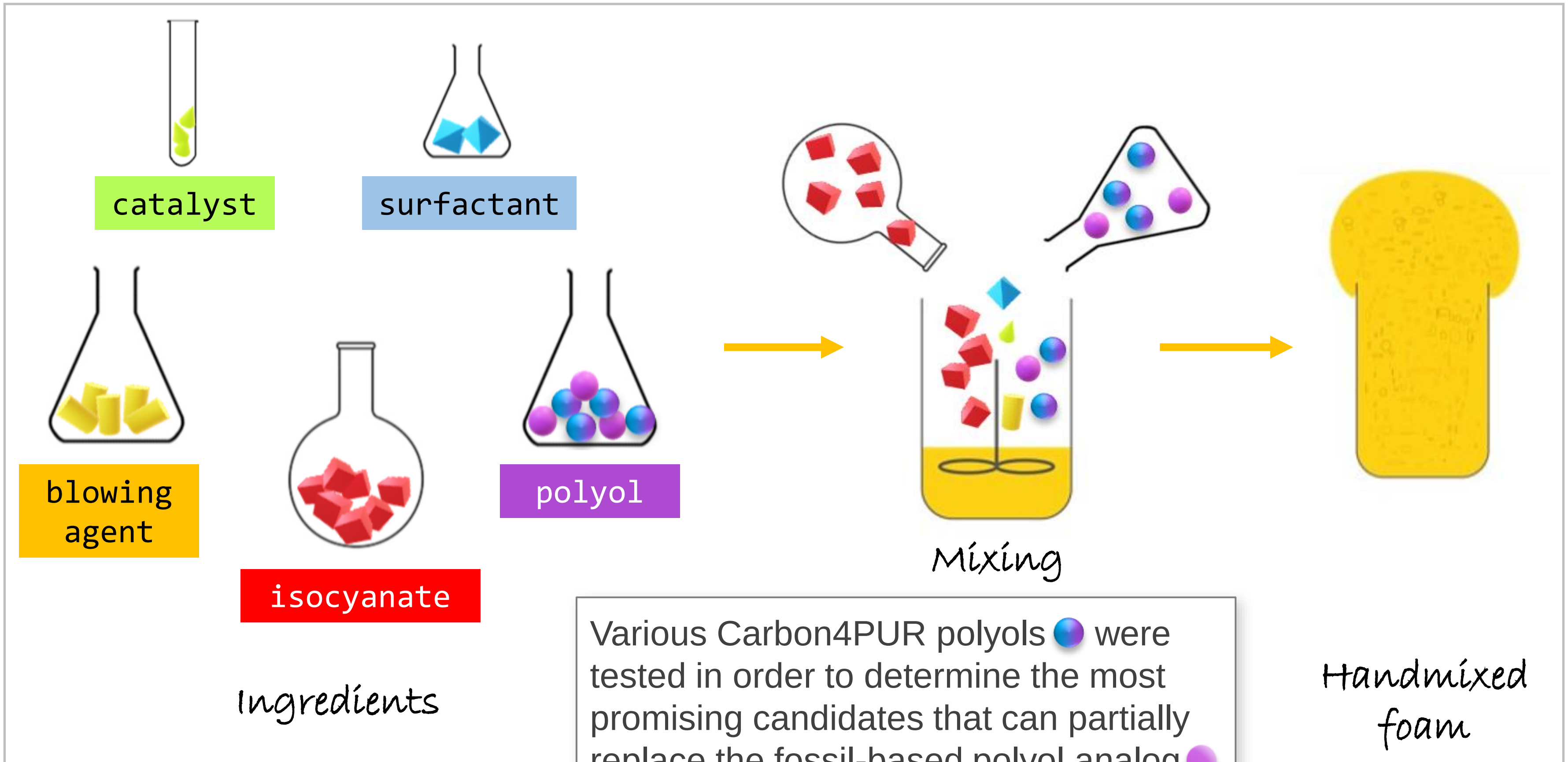


Various Carbon4PUR polyols were tested in order to determine the most promising candidates that can partially replace the fossil-based polyol analog



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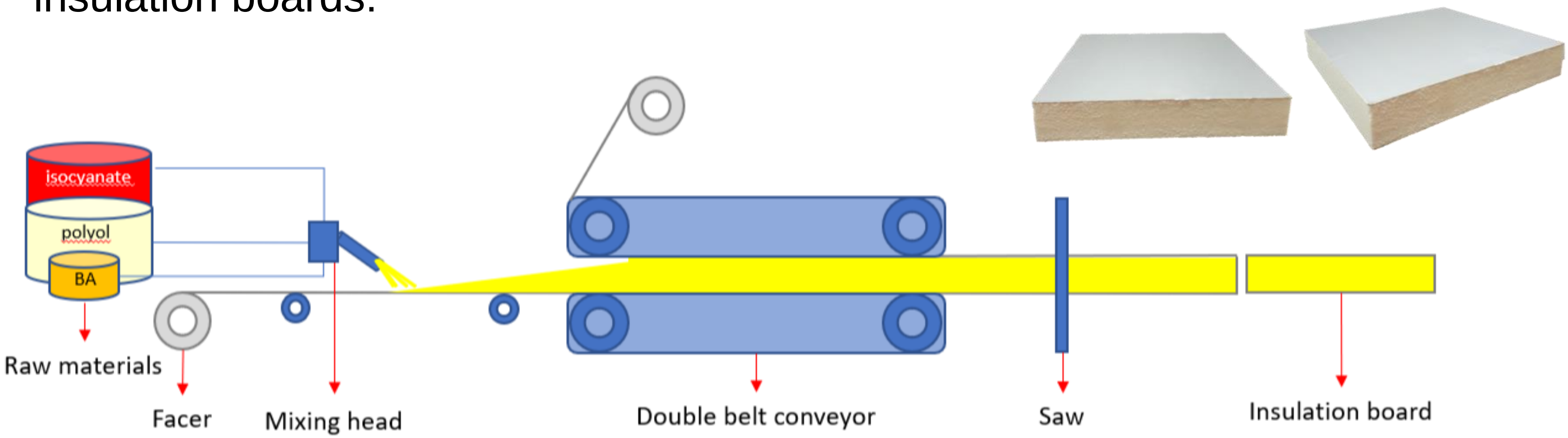
# Further processing and evaluation of Carbon4PUR polyols at Recticel

Carbon4PUR

## Thermal insulation boards based on polyurethane rigid foams:

- **1 Carbon4PUR polyol** selected to do further **formulation adaptations** on small scale (lab) first in order to overcome processing issues and to obtain required properties, such as thermal conductivity
  - Finally **up to 70 parts of reference polyol could be replaced** in the formulation!
- Transfer from **handmix to semi-industrial scale** to produce flex faced insulation boards:



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# Further processing and evaluation of Carbon4PUR polyols at Recticel

Carbon4PUR

## Thermal insulation boards based on polyurethane rigid foams:

| Property \ Sample | Reference | Carbon4PUR polyol 60% | Carbon4PUR polyol 70% |
|---|---|---|---|
| Compressive strength | | | |
| Tensile strength | | | |
| Dimensional stability | | | |
| Under extreme conditions | | | |
| Flammability | | | |
| Thermal conductivity | | | |
| Normality | | | |
| Water absorption | | | |


: slightly worse than reference but still within specifications

Final result = pilot scale rigid foam fulfilling rigid foam specifications partially made with polyols based on the Carbon4PUR technology.



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MEGARA RESINS®
ANASTASSIOS FANIS S.A.

# WATERBORNE PUDs FOR COATINGS

Poppy Krassa

| $CO/CO_2$ | | INTERMEDIATES & POLYOLS PRODUCTION | | | PRODUCTS & APPLICATION |
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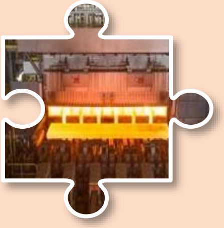


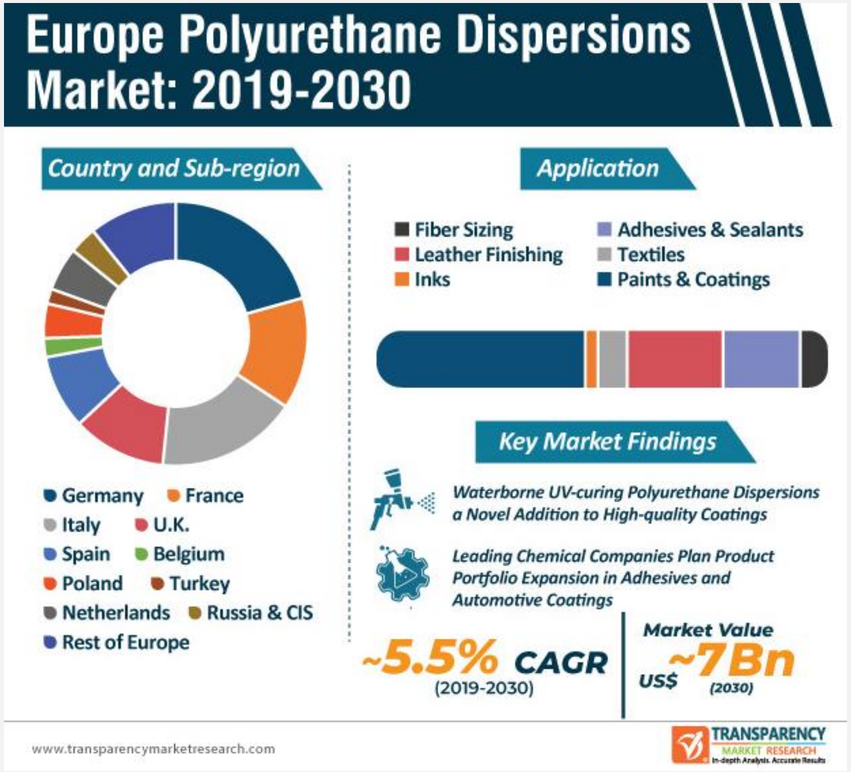



**ACCOMPANYING**

| | | |
|---|---|---|
| Industrial symbiosis analysis | LCA, economic & social analysis – Acceptance | Exploitation – Dissemination |

# Market Potential of PUDs

- European PUDs market expected to reach **~USD 7** bn by the end of 2030. Increasing penetration in paints and coatings.
- Steady shift to waterborne PUDs due to environmental considerations.
- PUDs meet **low-carbon economy** and **environmental protection** requirements.
- **Growing demand** from industries such as **furniture**, **automotive** and **wood** flooring coatings.
- Potential **challenges** include the higher cost compared to acrylic emulsions and of new green polyols.




https://www.transparencymarketresearch.com/europe-polyurethane-dispersions-market.html



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# Polyurethane dispersions (PUDs)

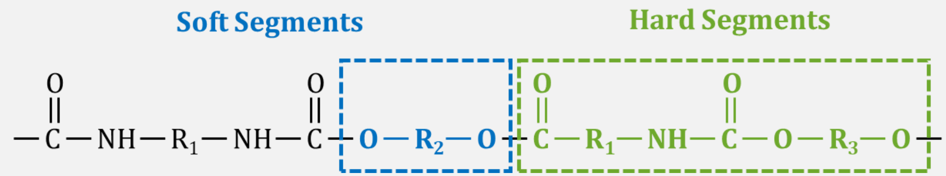
Environmentally friendly coatings

Waterborne Polyurethane Dispersions (PUDs)

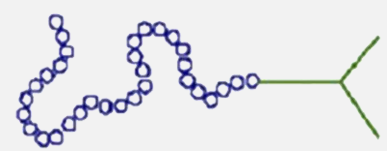
Flexible coatings for textile and leather finishing

Hard coatings for flooring, wood and metallic finishes

- ❑ Performance requirements: resistance to heat, UV, hydrolysis, chemicals, stains, scratch, abrasion and solvents




**Soft segments (SS)**:
Polyol
**Hard segments (HS)**:
Isocyanate + chain extender





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# The transition from lab to pilot and semi-industrial scale

Carbon4PUR

Lab-scale

2 kg

Pilot scale

25 kg

Semi-Industrial scale

150 Kg


***Pigmented coating***

***Clear coating***



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Disclaimer: The information contained in this document has been prepared solely for the purpose of providing information about the Carbon4PUR project. The document reflects only the Carbon4PUR consortium's view and the EC is not responsible for any use that may be made of the information it contains.

# Comparison of Carbon4PUR PUDs vs benchmark dispersions

Carbon4PUR

| Type of Polyol | | Film Hardness | Scratch Resistance | Chemical Resistance | Cross-cut adhesion | Blocking Resistance |
|---|---|---|---|---|---|---|
| Benchmark | Polyether | 5B | 1 | 2 | 5 | 5 |
| | Polycarbonate | 5B | 4 | 4 | 5 | 5 |
| Carbon4PUR | $CO_2$-polyol | 5B | 2 | 2 | 5 | 5 |
| | CO-based polyol | 5B | 2 | 3 | 5 | 5 |

**Very good application characteristics:**

- ✓ Rapid hardness development & High substrate coverage
- ✓ Good chemical and stain resistance
- ✓ Low to medium scratch resistance
- ✓ High thermal stability / low yellowing & storage stability (> 6 months)
- ✓ Excellent cross-cut adhesion & blocking resistance
- ✓ Excellent high gloss potential and gloss retention
- ✓ Technical characteristics close to the market standards in the wood application area
- ✓ Low VOC
- ✓ Improved environmental profile compared to traditional fossil-based PUD coatings



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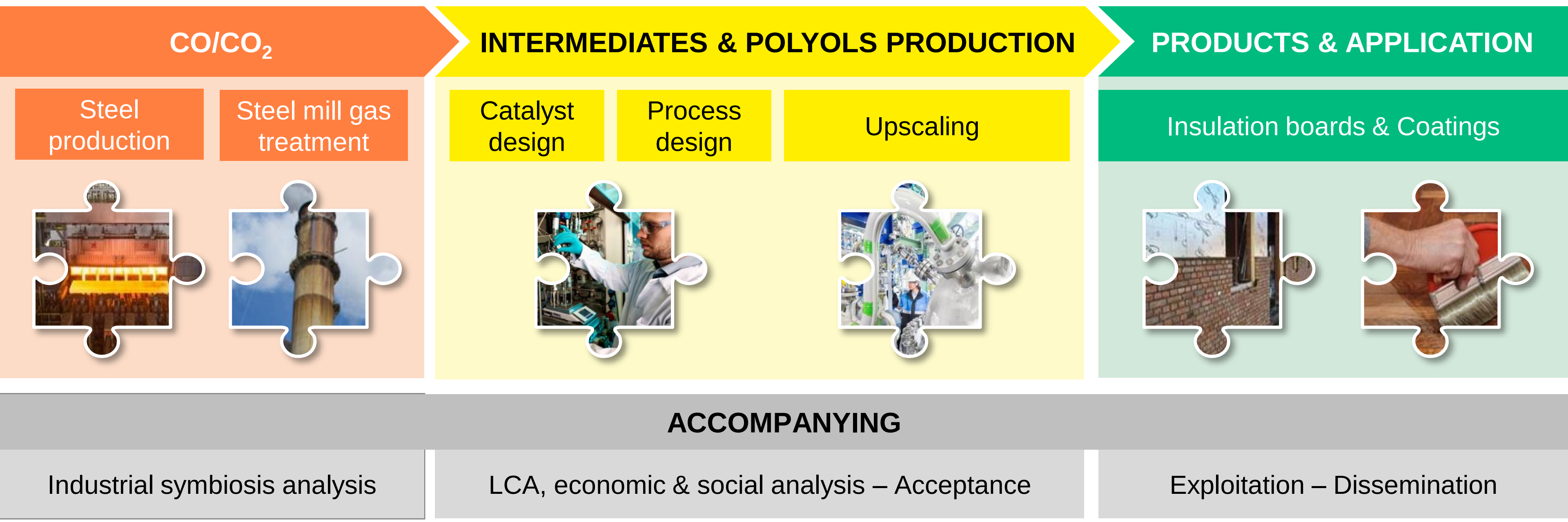
Imperial College London

# INDUSTRIAL SYMBIOSIS ANALYSIS

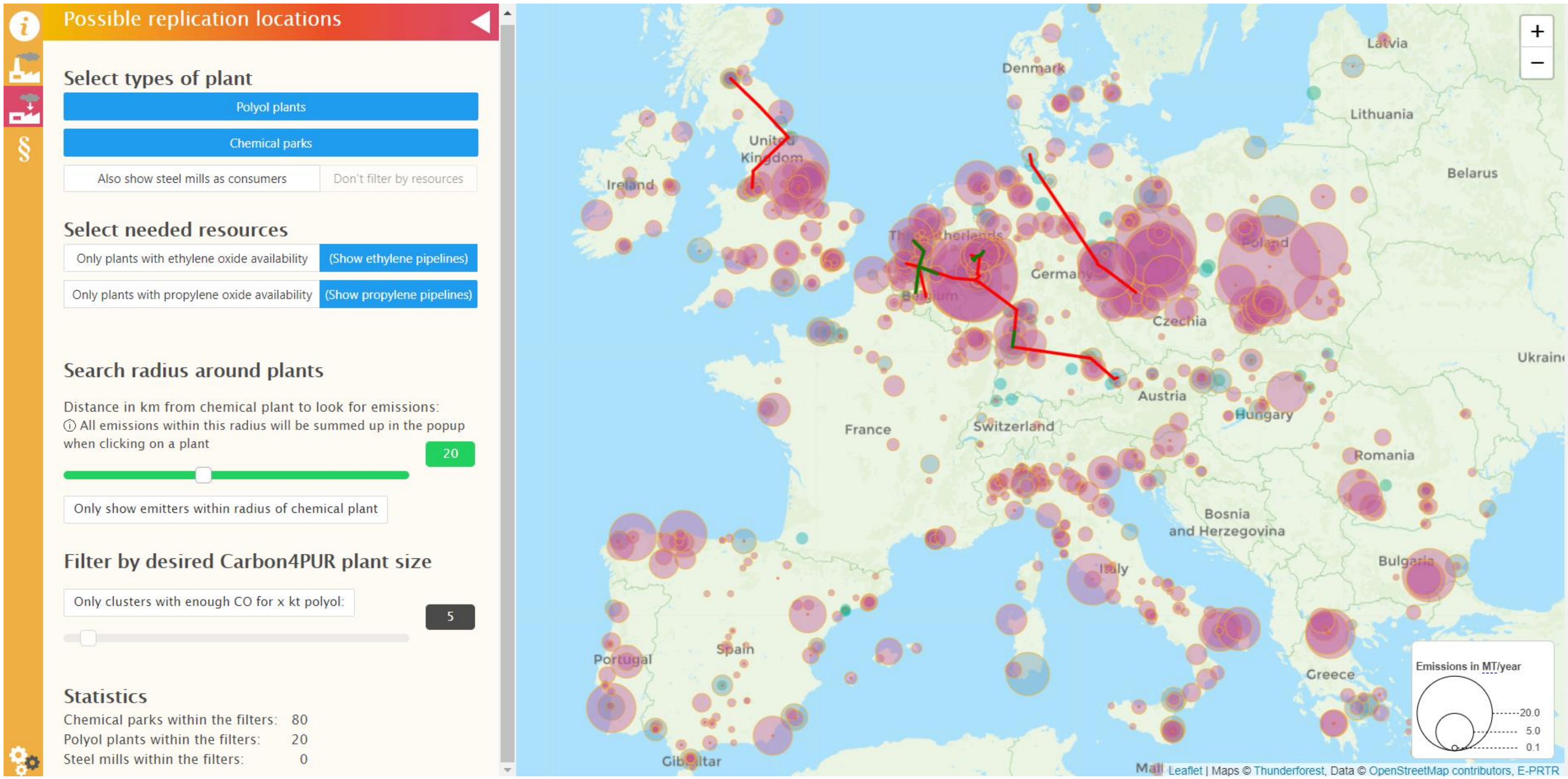
Arturo Castillo



# Explore further $CO/CO_2$ reuse

Public sector; Investors & project developers; Industrial parks; Researchers

Available at: https://www.carbon4pur.eu/public-documents/mapping-tool/



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# Identify options

Providing geographical data and guidance

I. Define emissions and uptake preconditions
(***Hard criteria***)

II. Locate potential sites

III. Assess regional conditions, e.g. funding and support institutions
(***Semi-hard criteria***)

IV. Assess non-technical, non-regulatory parameters e.g. acceptance
(***Soft criteria***)


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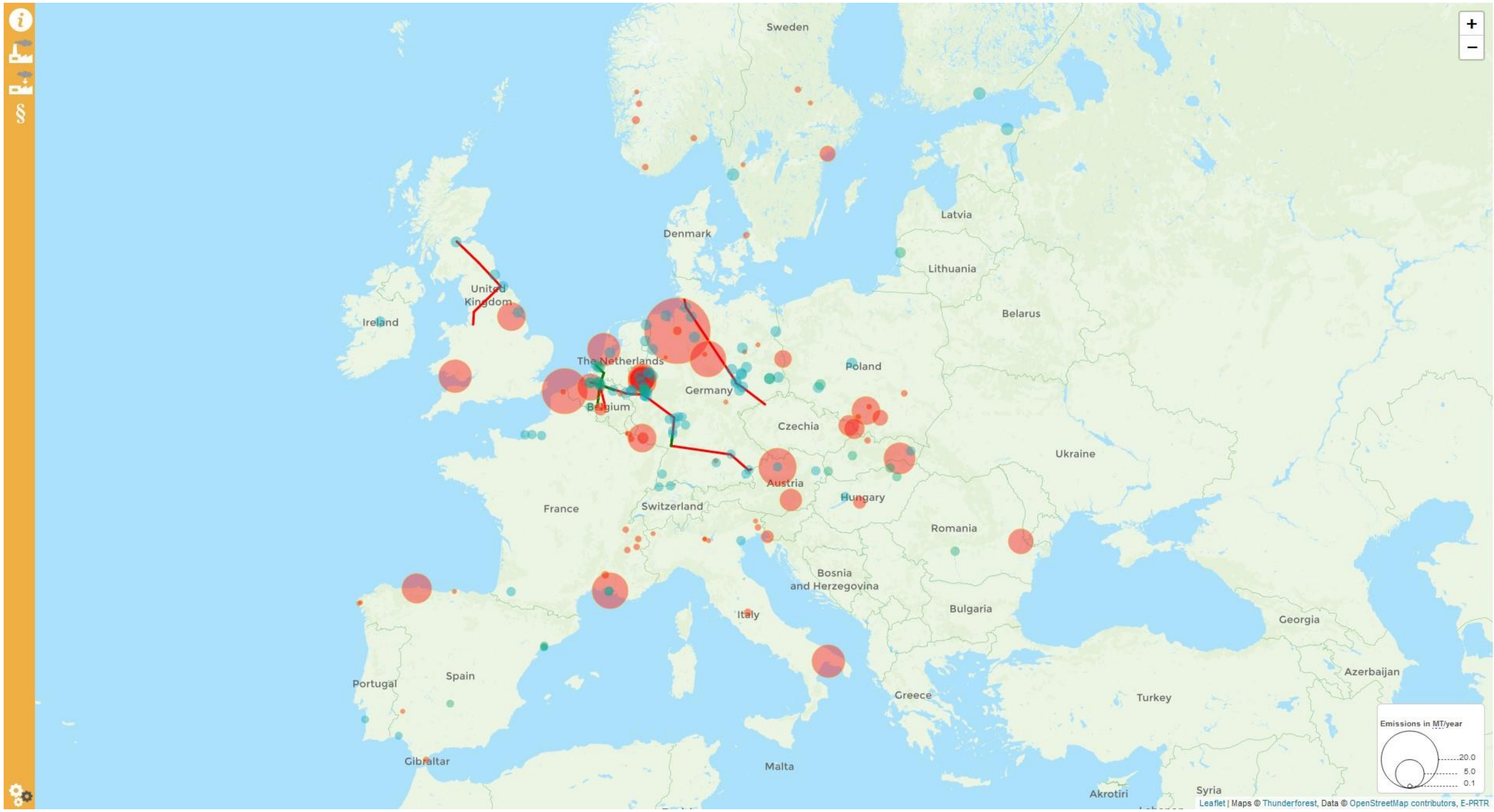
# Example: Explore steel mills

Sources, radius, uptake, prepare for due diligence




* Amsterdam * Marseille * Duisburg * Scunthorpe * Terneuzen



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Marseille Fos
Le port euroméditerranéen

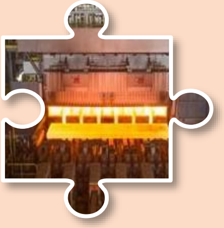
# INDUSTRIAL SYMBIOSIS ANALYSIS

Sylvain Pichon

**$CO/CO_2$**

Steel production

Steel mill gas treatment



**INTERMEDIATES & POLYOLS PRODUCTION**

Catalyst design

Process design

Upscaling

**PRODUCTS & APPLICATION**

Insulation boards & Coatings

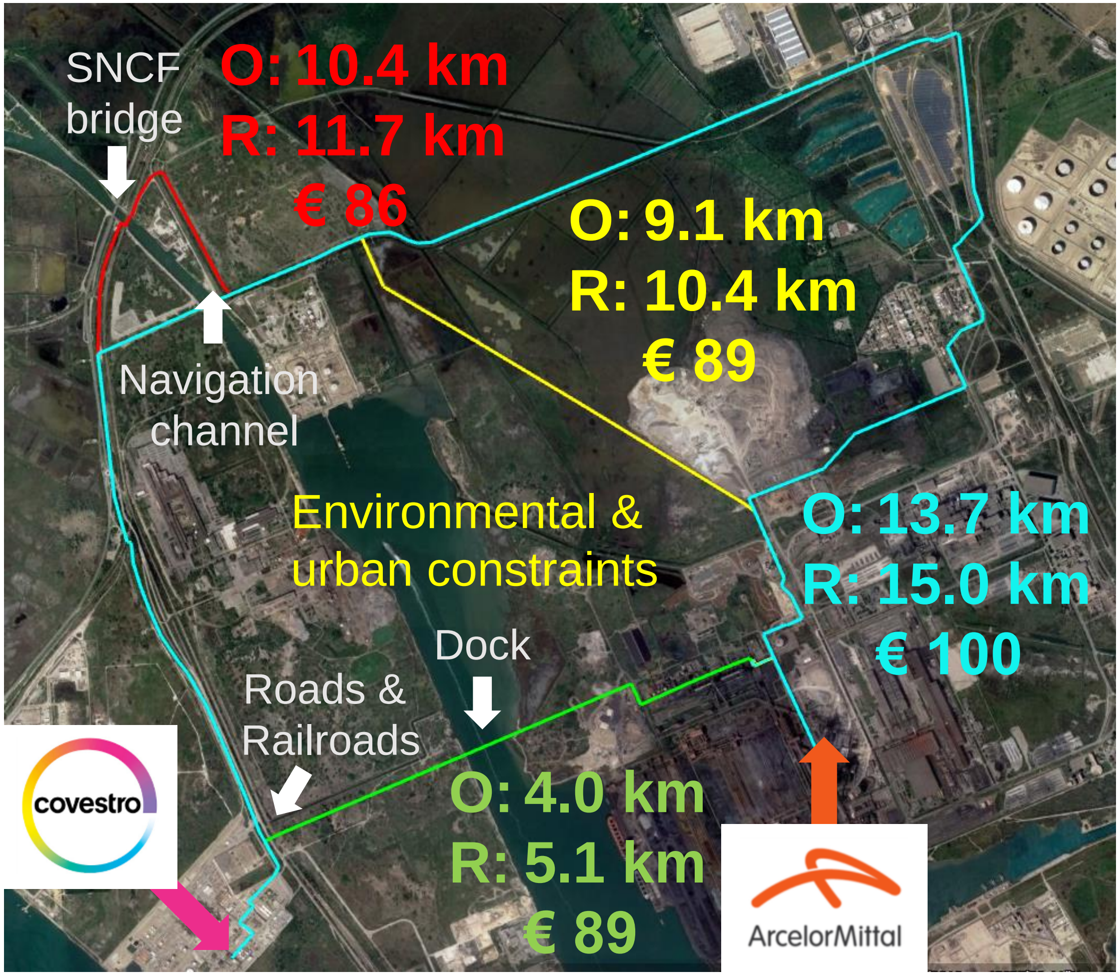
**ACCOMPANYING**

Industrial symbiosis analysis

LCA, economic & social analysis – Acceptance

Exploitation – Dissemination

# Pathways scenario studied, managing flexibility and complexity …




## ISSUES TO OPTIMIZE:

- Legal
- Technical
- Envrionmental
- Economic
- Symbiosis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# Pathways comparison

| Pathways | **Pathway 1** (direct) | **Pathway 2** (North & under the dock) | **Pathway 3** (North & SNCF bridge) | **Pathway 4** (East) |
|---|---|---|---|---|
| Advantages | - **Shortest pathway**<br>- Possible synergy: passing other pipes under the dock | - Existing pipeline corridor<br>- Middle length pathway | - Existing pipeline corridor<br>- Middle length pathway | - Existing pipeline corridor<br>- **Few environmental issues**<br>- **Few technical constraints**<br>- Possible synergy with Air Liquide |
| Disadvantages | - Technical issues: dock<br>- No existing pipeline corridor<br>- High price/km | - **Local urban plan: prohibition to lay pipelines**<br>- **Environmental issue** zone: wetland<br>- Security distance with gas pipe<br>- Uncertainty about the planning & administrative authorizations & costs | - **Local urban plan: prohibition to lay pipelines**<br>- **Environmental issue** zone: wetland<br>- SNCF Bridge: Impossible to put the pipe on the bridge and no more space under | - **Longest pathway**<br>- Costs |

**Pathways 1 & 4 selected**


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# Marseille-Fos: C and $CO_2$ issues industrial symbiosis for value creation …

- **Environmental and social acceptability**
- **Sustainability issues for established industries**
- **Attractiveness challenges of the port**
- **Exemplarity, image and international influence**

… The port of Marseille is involved in projects directly related to the capture, recovery and $CO_2$ storage :

**Jupiter 1000, Carbon4PUR, VASCO, Southern Lights, GREEN IMPACTS (Green Deal call response), …**

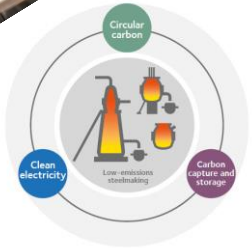
… and looks forwards to NEW industrial symbiosis opportunities:

**Bio chemicals, conversion into methanol, etc. …**

> 10MT of $CO_2$/y



GREEN IMPACTS



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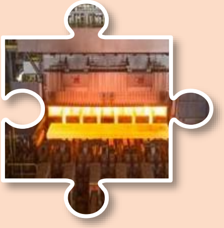
Technische Universität Berlin

# ECONOMIC ANALYSIS

Jason Collis

| $CO/CO_2$ | | INTERMEDIATES & POLYOLS PRODUCTION | | | PRODUCTS & APPLICATION |
|---|---|---|---|---|---|
| Steel production | Steel mill gas treatment | Catalyst design | Process design | Upscaling | Insulation boards & Coatings |






**ACCOMPANYING**

| Industrial symbiosis analysis | LCA, economic & social analysis – Acceptance | Exploitation – Dissemination |
|---|---|---|

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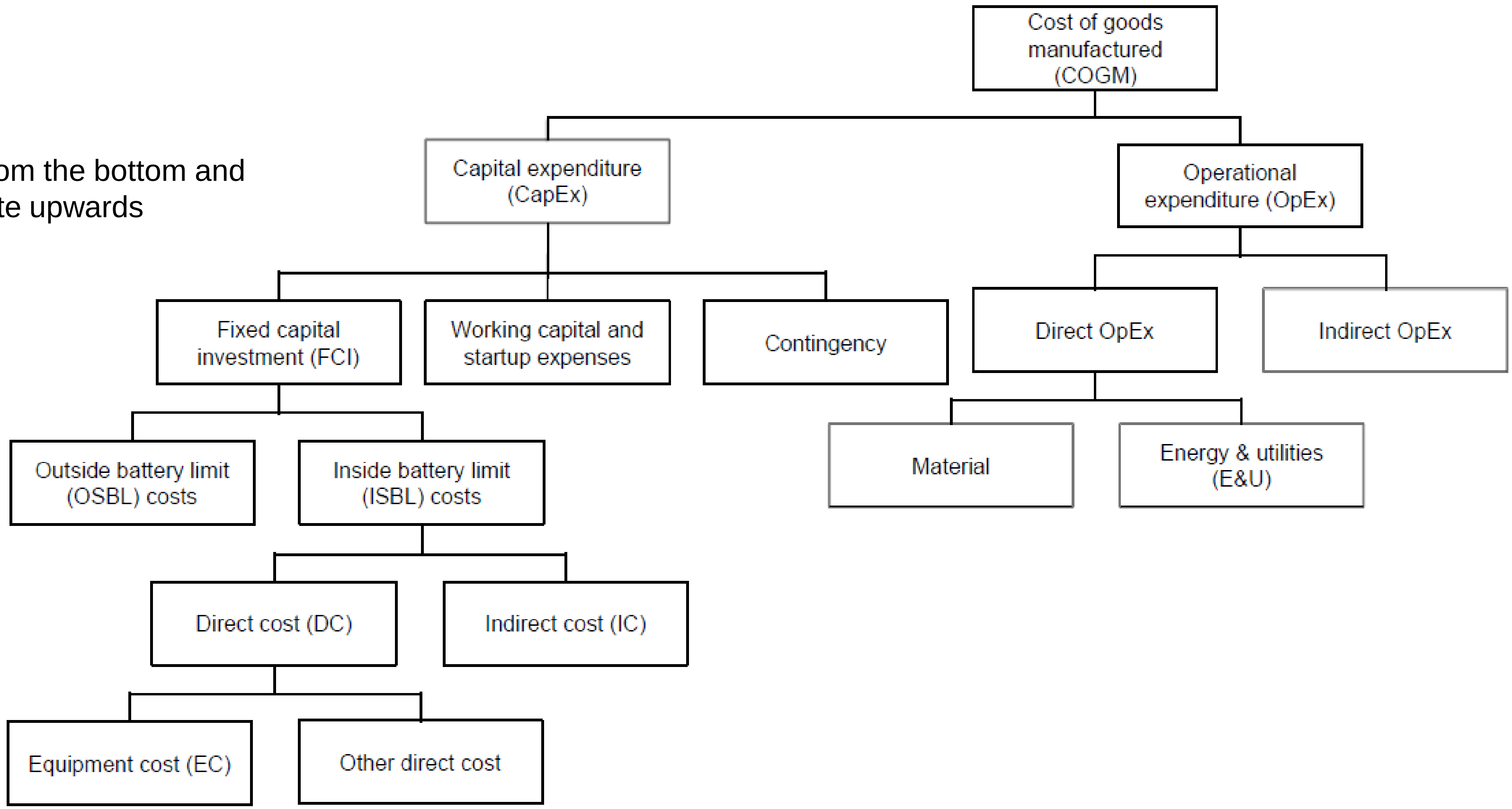
# Techno-economic assessment of novel process

## Structure of a TEA

Start from the bottom and calculate upwards




Buchner et. al. 2018



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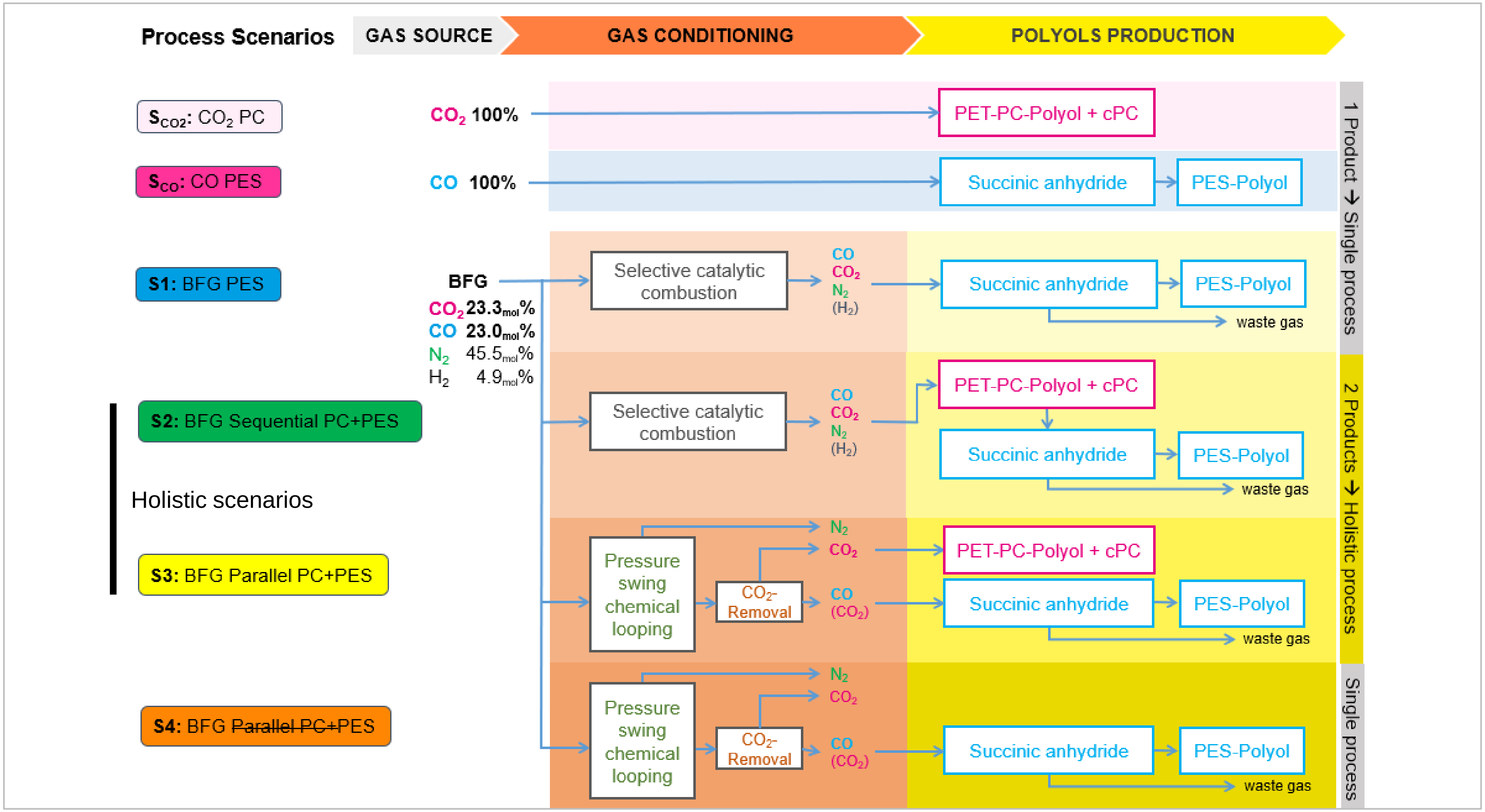
# Scenarios Analysed



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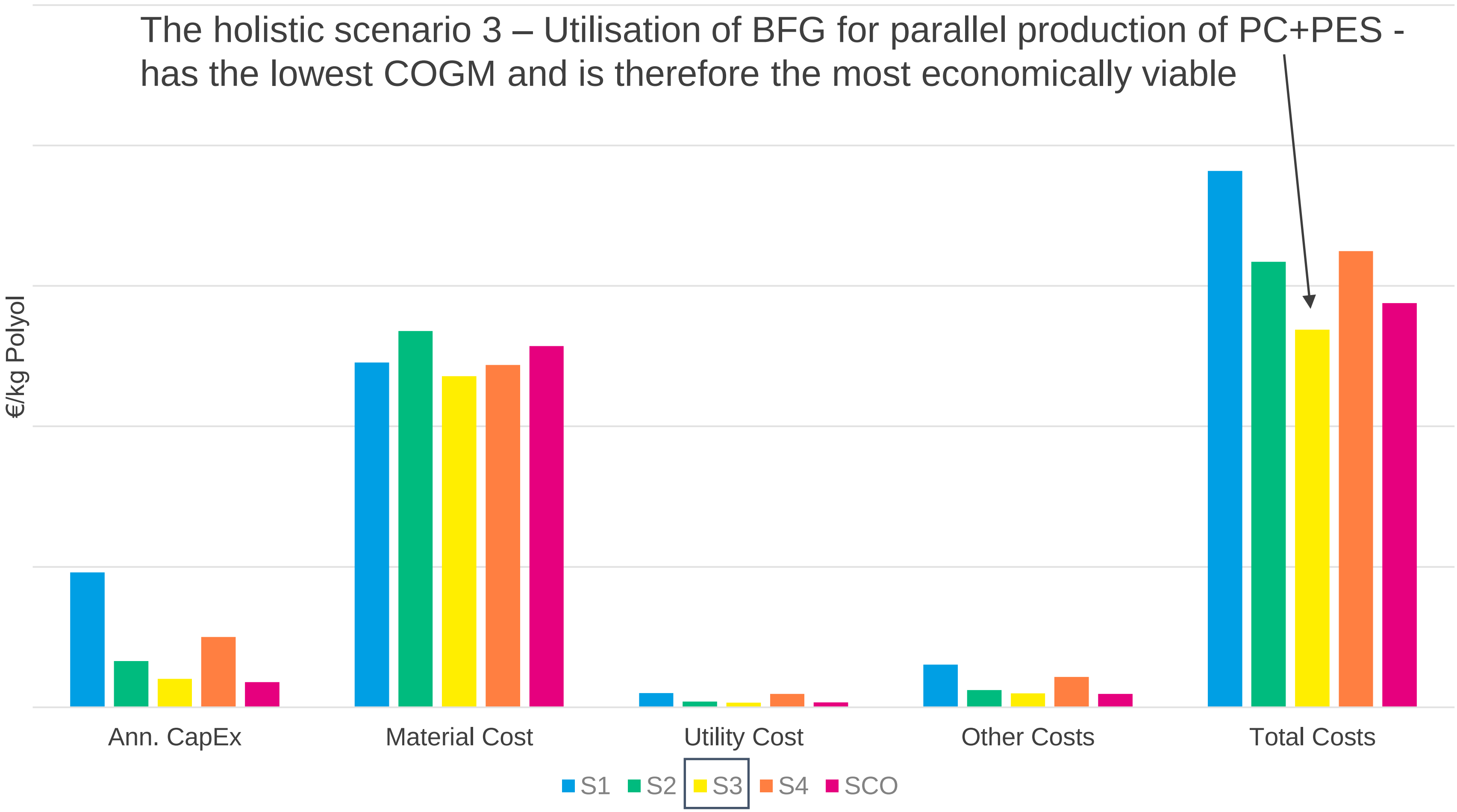
# Cost of goods manufactured
# Production cost



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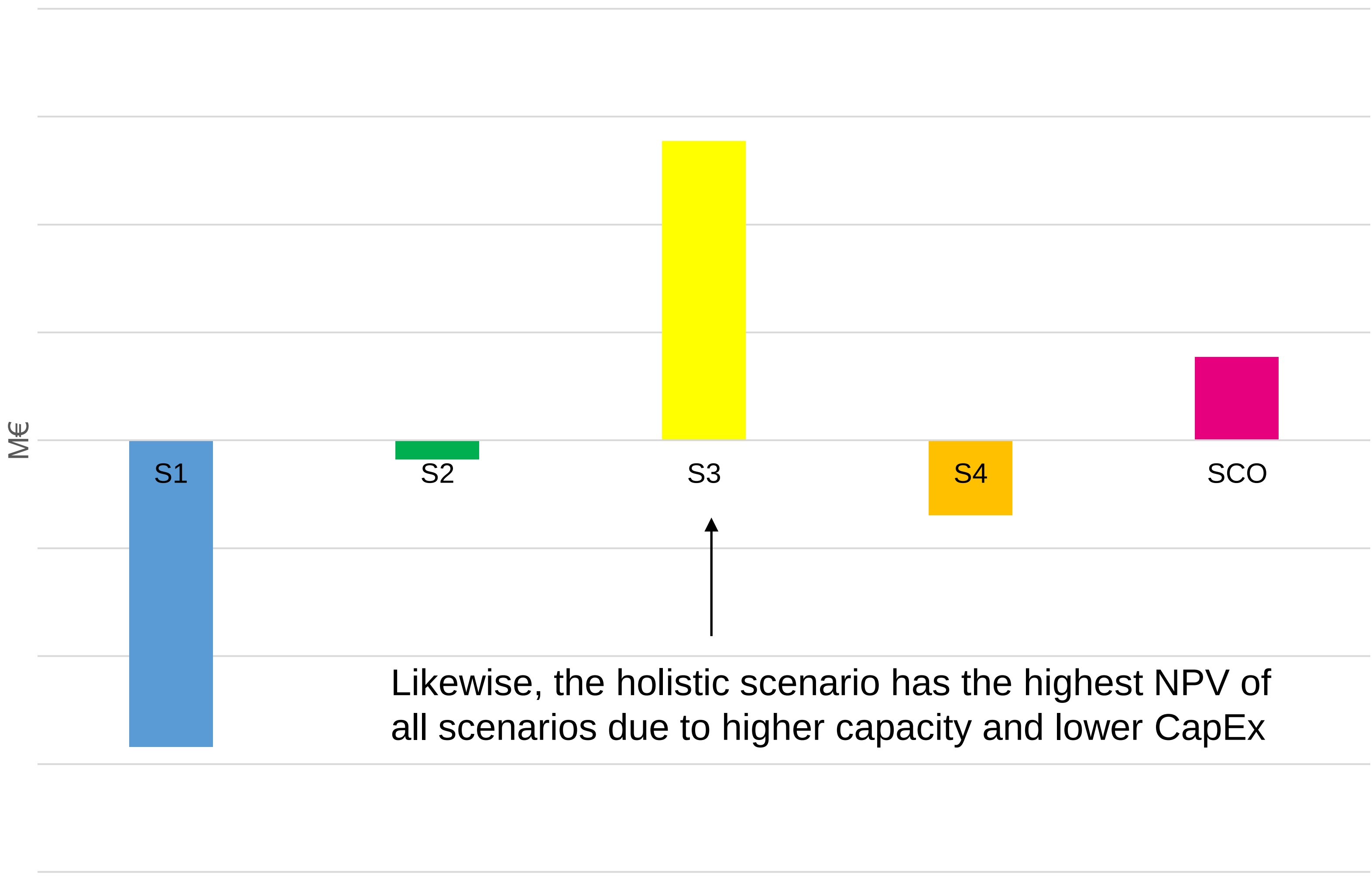
# Net Present Value




Likewise, the holistic scenario has the highest NPV of all scenarios due to higher capacity and lower CapEx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Universiteit Leiden
The Netherlands

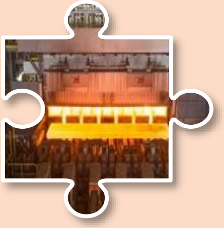
# LIFE-CYCLE-ASSESSMENT

## Jeroen Guinee

**$CO/CO_2$**

Steel production

Steel mill gas treatment



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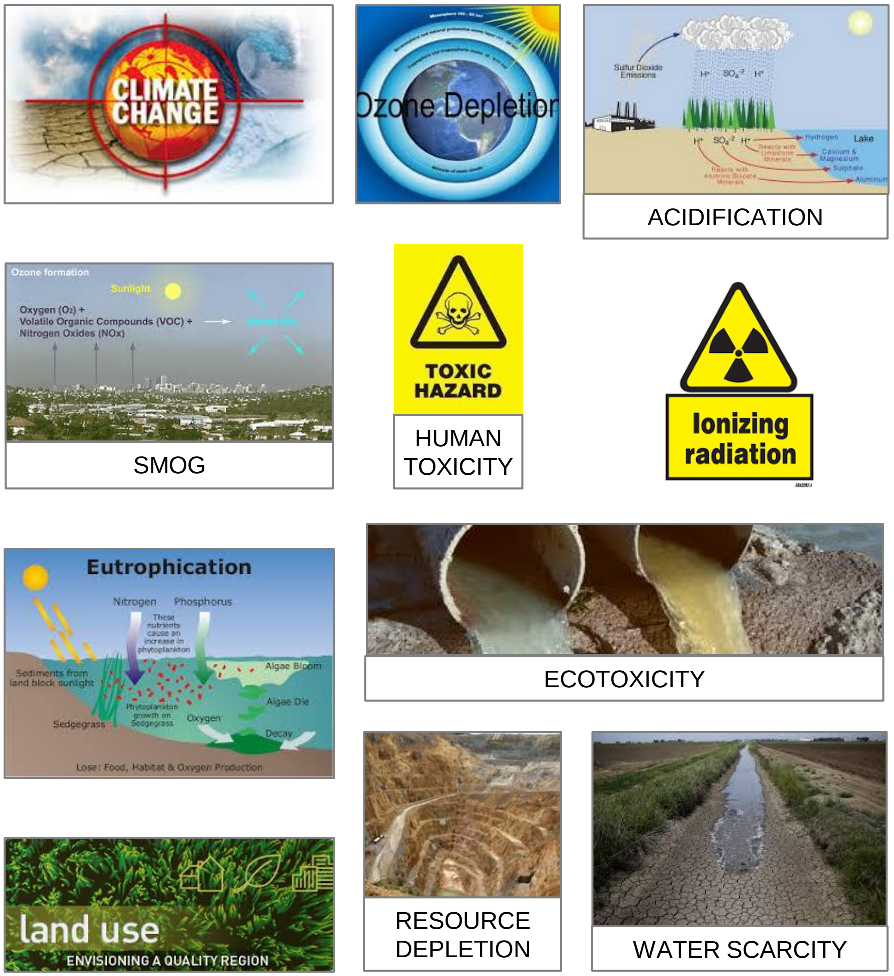
# Life cycle assessment in a nutshell


- Assessment of the environmental impacts of a product *system* over its entire *life cycle*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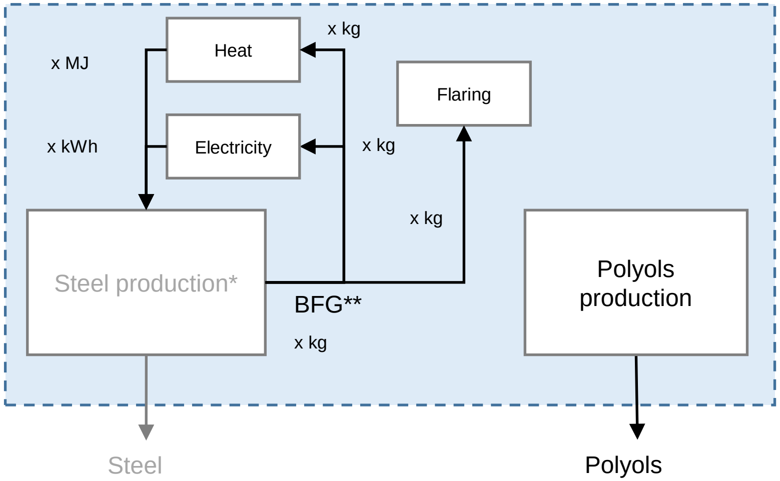
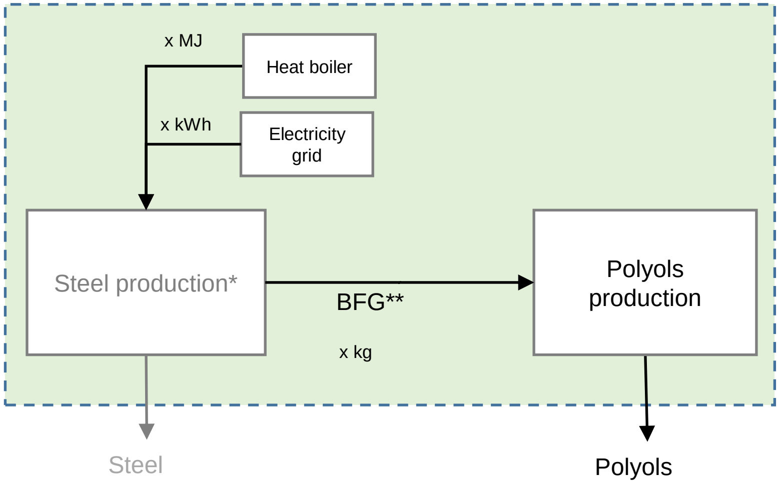
# LCA: systems compared

## BASELINE SYSTEM




* Grey parts are excluded as they are the same for both systems
** quantity of BFG used for polyols production

## CARBON4PUR




* Assuming polyols store the same amount of C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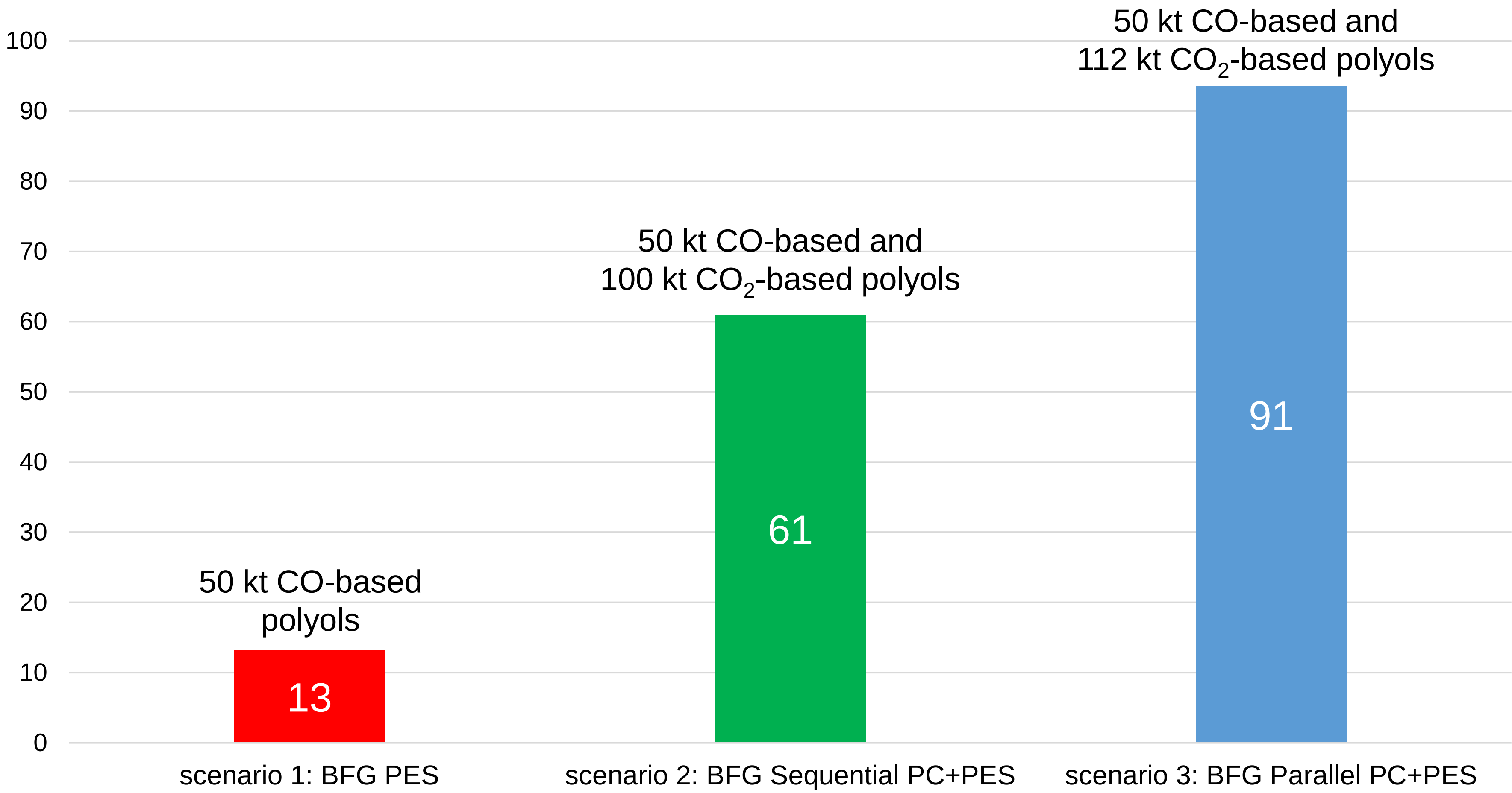
# Indication of yearly carbon savings ($kt\ CO_2$-eq./ 50 kta CO-based polyol)

Savings for each scenario



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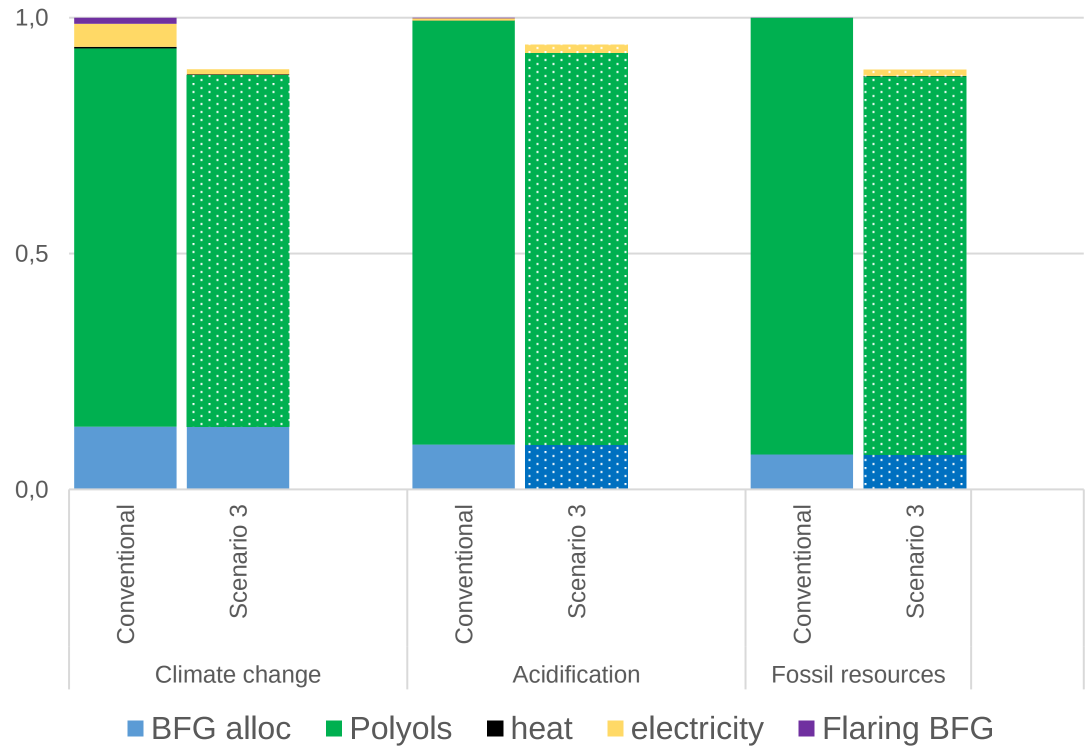
# Scenario 3 results for selected impacts

TAKE AWAY MESSAGES:

– based on today's knowledge –

- Scenario 3 most promising
- Estimated impact reductions between 5 – 15 % for most impact categories
  - up to 10% for climate change by integrating just up to 20 % $CO/CO_2$
- Results represent a low TRL
  - higher TRLs may show better environmental performance when integrating higher $CO/CO_2$ levels
  - however, filling data gaps may also lower expectations



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Lehrstuhl für Communication Science
communication

HCIC - Human-Computer Interaction Center

RWTH AACHEN UNIVERSITY

# ACCEPTANCE

## Lisanne Simons

**$CO/CO_2$**

**INTERMEDIATES & POLYOLS PRODUCTION**

**PRODUCTS & APPLICATION**

Steel production

Steel mill gas treatment

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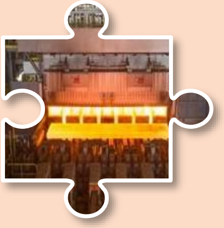

**ACCOMPANYING**

Industrial symbiosis analysis

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# What did we set out to do?

→ **Understanding the acceptance of CCU insulation boards**


https://www.managementtoday.co.uk/deal-consumer-protest/article/1168359


https://www.jewson.co.uk/p/recticel-eurothane-gp-pir-insulation-board-2400-x-1200-x-100mm-IRESR100

rejection neutral acceptance



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# How did we approach this goal?

Qualitative interviews with technical experts, field experts, and laymen

*Identification of acceptance relevant factors*

03/2020

Pre-study on the acceptance of CCU insulation boards

*Calibration of measurement instrument and first insights*

06/2020

Quantitative survey on the acceptance of CCU insulation boards

*Targeted at Dutch and German respondents (houseowners)*

09/2020

**Sample:** *N = 643 respondents*

M = 55.7 years
SD = 12.9 years

43% female
57% male

51% German
49% Dutch



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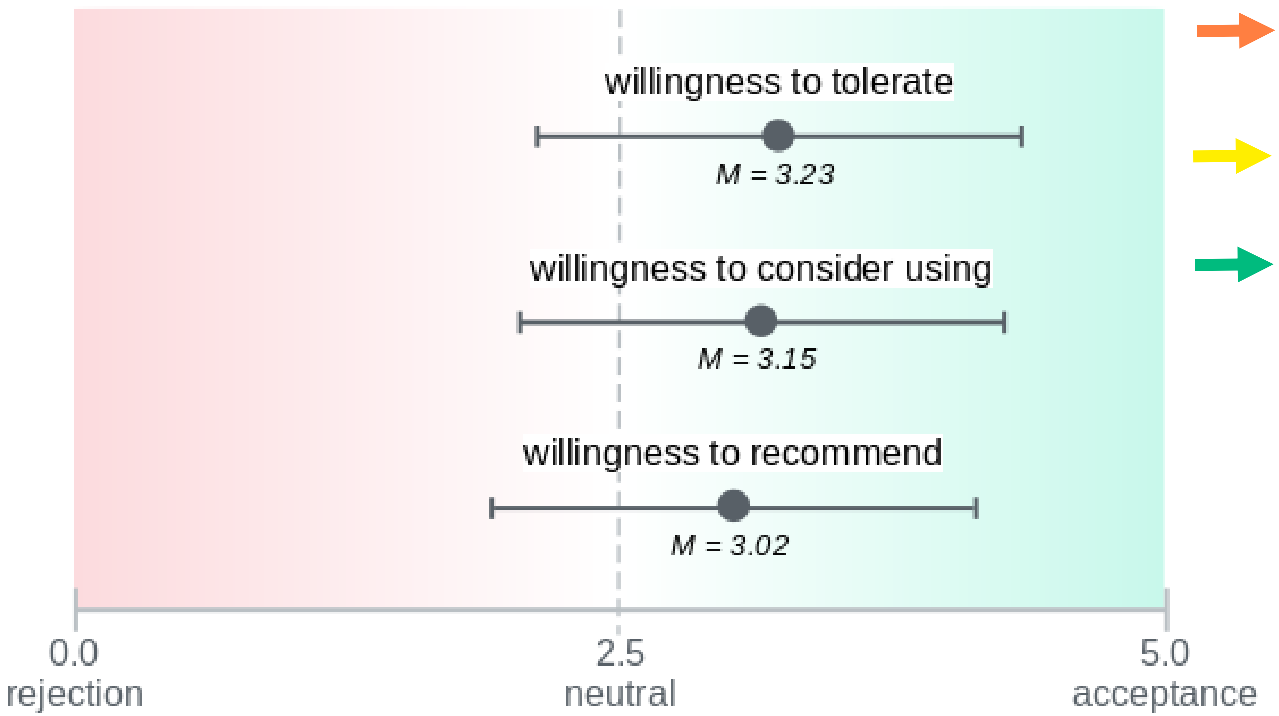
SPIRE PROJECT

# What did we find?

## The acceptance of CCU insulation boards




- generally positive, but tentative, acceptance
- good starting conditions
- central for acceptance:
  - the perception (benefits and barriers)
  - environmental factors (e.g., environmental concern)
  - the affective evaluation (i.e., the feelings towards the product)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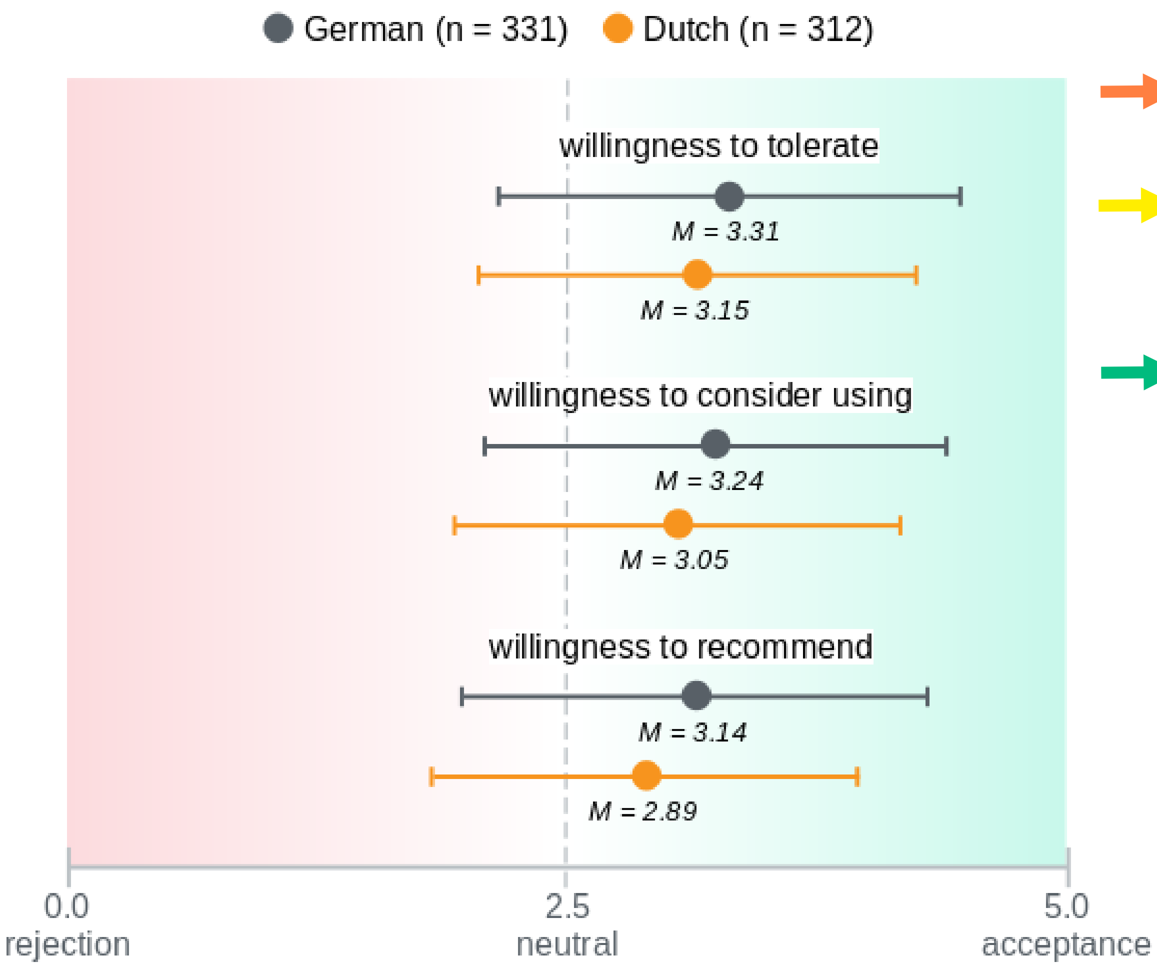
# What did we find?

## The acceptance of CCU insulation boards




- Germans slightly higher acceptance than the Dutch
- Germans significantly more willing to consider using CCU insulation boards
- Germans significantly more willing to recommend CCU insulation boards



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# Want to learn more about acceptance research?

Carbon4PUR

## Visit our YouTube channel

**Chair for communication science, RWTH Aachen university**

communication



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south pole

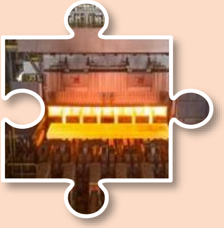
# SOCIAL ANALYSIS

Francisco Koch

**$CO/CO_2$**

Steel production

Steel mill gas treatment



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# Current policy and regulatory framework

## Does it support Carbon4PUR's upscaling?

- ✓ **Strong policy push** (European Green Deal) to support CCU
  - ✓ $CO_2$ mitigation
  - ✓ Resource efficiency
- ✓ **Planned regulatory actions to stimulate demand for CCU derived products** as part of the Circular Economy Action Plan

European Green Deal

Greater regulatory framework **alignment with EU Green Deal objectives still needed:**

- Fit for purpose: Storing $CO_2$ underground (CCS) and using $CO_2$ to produce a more sustainable product (CCU) are not the same. Regulatory framework needs to reflect this
- Two key regulatory hot spots
  - Monetising $CO_2$ emissions avoided
  - Transport infrastructure development



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# Policy and regulatory hotspots

Monetising $CO_2$ avoided to stimulated investment in CCU

✓ **ETS puts a price on $CO_2$**

| | | |
|---|---|---|
| the more you emit | + $CO_2$ | the less you emit | − $CO_2$ |
| the more you pay | + $ | the less you should pay | − $ |

✓ Large industrial, hard to abate emitters could **reduce their $CO_2$ emissions** by using $CO_2$/CO to produce chemicals instead of using fossil-based feedstocks

- But … still must pay for the $CO_2$ as if it had been emitted
- EU ETS does have the GHG accounting tools needed to address key issues



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# Policy and regulatory hotspots

## Enabling transport infrastructure

**Current regulatory framework still too CCS centered**

- **CCS directive:** large $CO_2$ transport infrastructure for underground geo storage – not for use as a chemical feedstock.
- **TEN-E:** address barriers that slow / prevent the development of EU wide energy transport infrastructures (CCS included), including:
  - complex and time-consuming permitting process to build pipelines and
  - delays caused by lack of public acceptance, amongst others.

**Permitting often poses a problem**

- Need to narrow the CCU awareness gap within Europe:
  - General public, NGOs, local Govt
  - $CO_2$ and CO can be transported in a safe manner, despite CO being both flammable and toxic
  - Building on experience and communicating in a transparent manner
- Targeted, structured and systematic approach to dispel HSE concerns and “sell” CCU is warranted
- Collaborative effort supported by the EC as an European Green Deal policy goal enabler


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Carbon4PUR

# Is it all worthy?

Carbon4PUR offers a “social return on investment”

- ✓ Job preservation at industrial installations
- ✓ Employment in innovative industrial CCU/ symbiosis (100 +), that:
  - ✓ converts $CO_2$/CO into high value chemicals (polyols)
  - ✓ avoids $CO_2$ emissions (10%)
  - ✓ saves natural resources + reduces associated environmental / biological impact (up to 20%)
- ✓ Leverages additional investment (approx. EUR 5 MM/ EUR 1 MM invested)
- ✓ Enables technology transfer within Europe, through partnerships, research and investments.
- ✓ Position the EU as a front runner in innovative CCU technology

( ) = Estimated impact at FOS

**Genuinely more sustainable industry**



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# Results by the whole consortium

After 3.5 years most Puzzle Pieces are linked

| $CO/CO_2$ | INTERMEDIATES & POLYOLS PRODUCTION | PRODUCTS & APPLICATION |
| --- | --- | --- |



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# Results by the whole consortium

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|---|---|---|

**Gas cond.**
**TRL 1→3**
**TRL 2→6**

- **Selective combustion** developed from **TRL2→6** and tested with BFG at steel plant in Gent
- 90% CO possible from BFG by new gas technology **pressure swing chemical looping**
- Potential **industrial symbiosis investigated** by engineering study in Marseille-Fos



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Carbon4PUR

# Results by the whole consortium

## After 3.5 years most Puzzle Pieces are linked

| $CO/CO_2$ | INTERMEDIATES & POLYOLS PRODUCTION | PRODUCTS & APPLICATION |
|---|---|---|

Gas cond.
TRL 1→3
TRL 2→6

Mix gas
TRL 2→4

CO-polyols
TRL 3→6

Intermediates
TRL 2→5

- New catalysts found
- **Proof of principle** of CO- & $CO_2$-based polyol-production **with mixed gases at lab scale**
- **14% of $CO_2$ or 27% of CO bound in polyol** (supporting EC resource efficiency goals)
- **Proof of principle of CO-based rigid foam**
- **Production of polyols based** on comm. intermediate **upscaled to 400 kg: TRL3→6**


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# Results by the whole consortium

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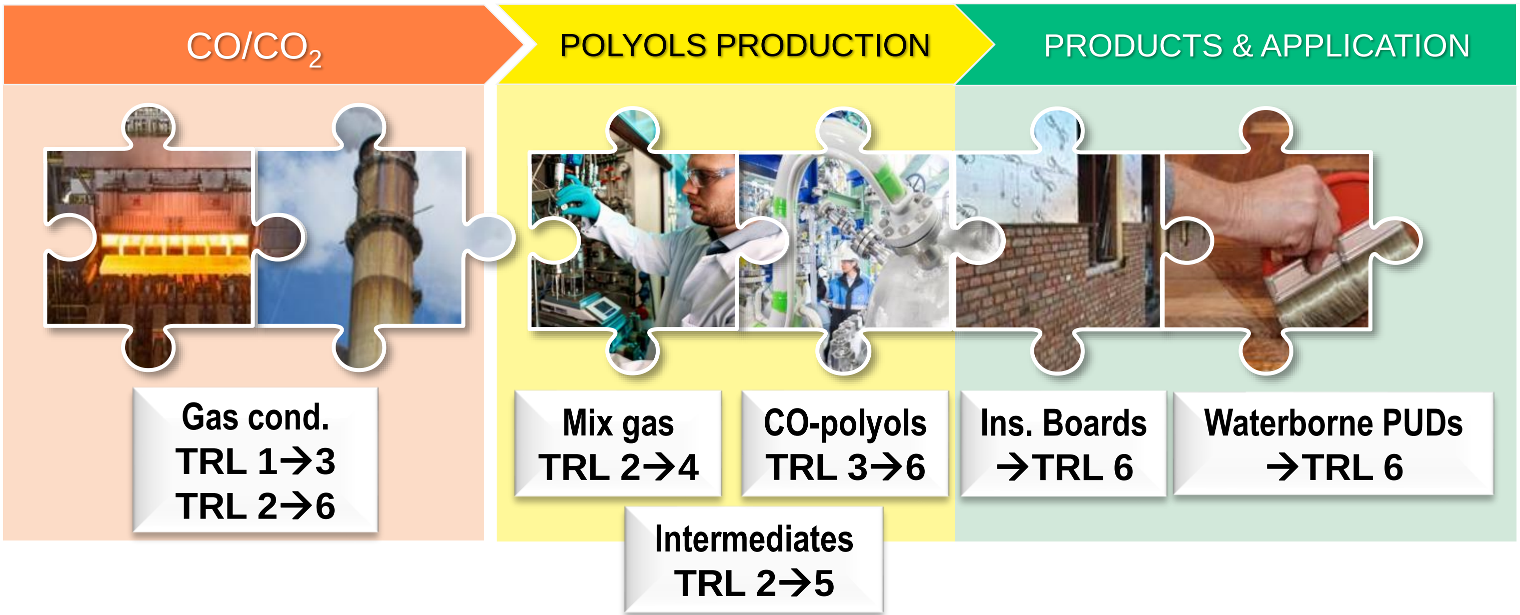


- **New polyols successfully implemented on a semi-industrial scale in rigid foams for insulation boards** and **in waterborne polyurethane dispersions for wood coatings**
- **LCA** showed **10% environmental impact reductions** for most environmental indicators
- **Reductions of up to 90 kt/a $CO_2$-eq. per 150 kt/a polyol produced possible**



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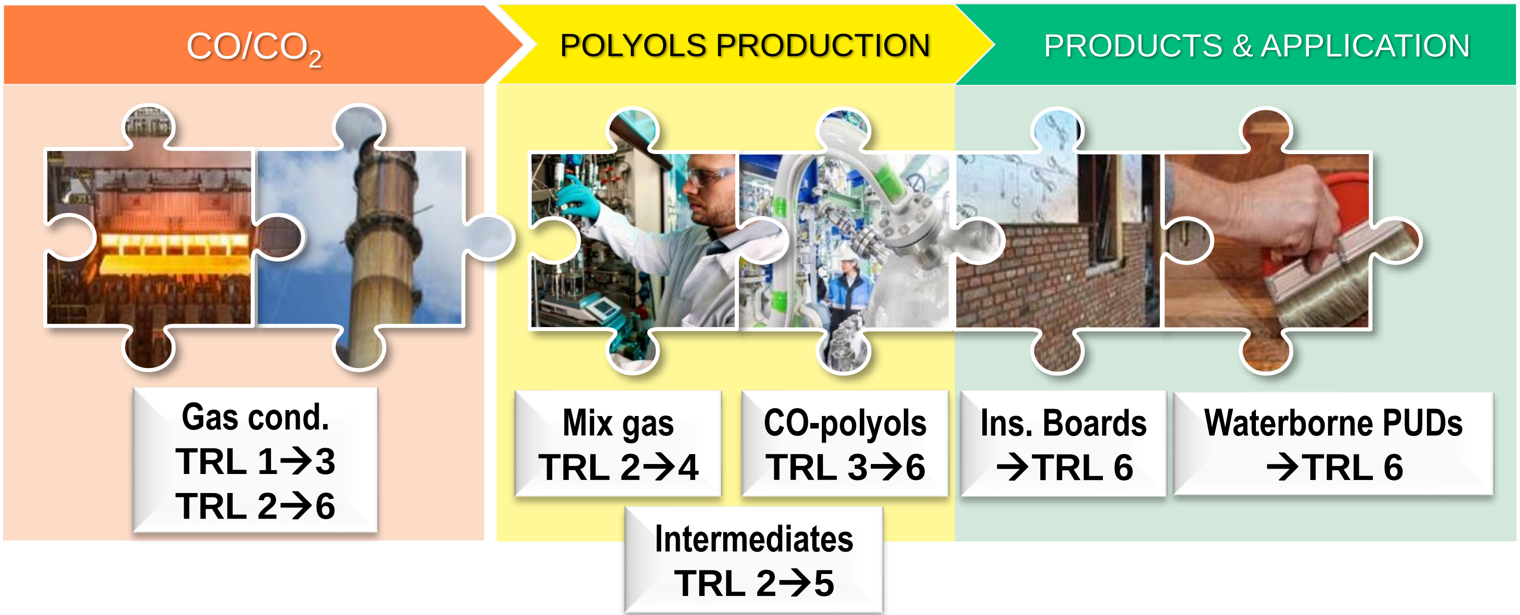


- **Techno-economic assessment** showed **lowest production costs for holistic process** producing $CO_2$-based PC and CO-based PES in parallel **with increasing CO content**
- **Further development on sustainable CO needed**
- **Acceptance study revealed that a generally positive attitude** emerges, when end-users receive information on CCU → **Raise awareness of new technologies**



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# Results by the whole consortium

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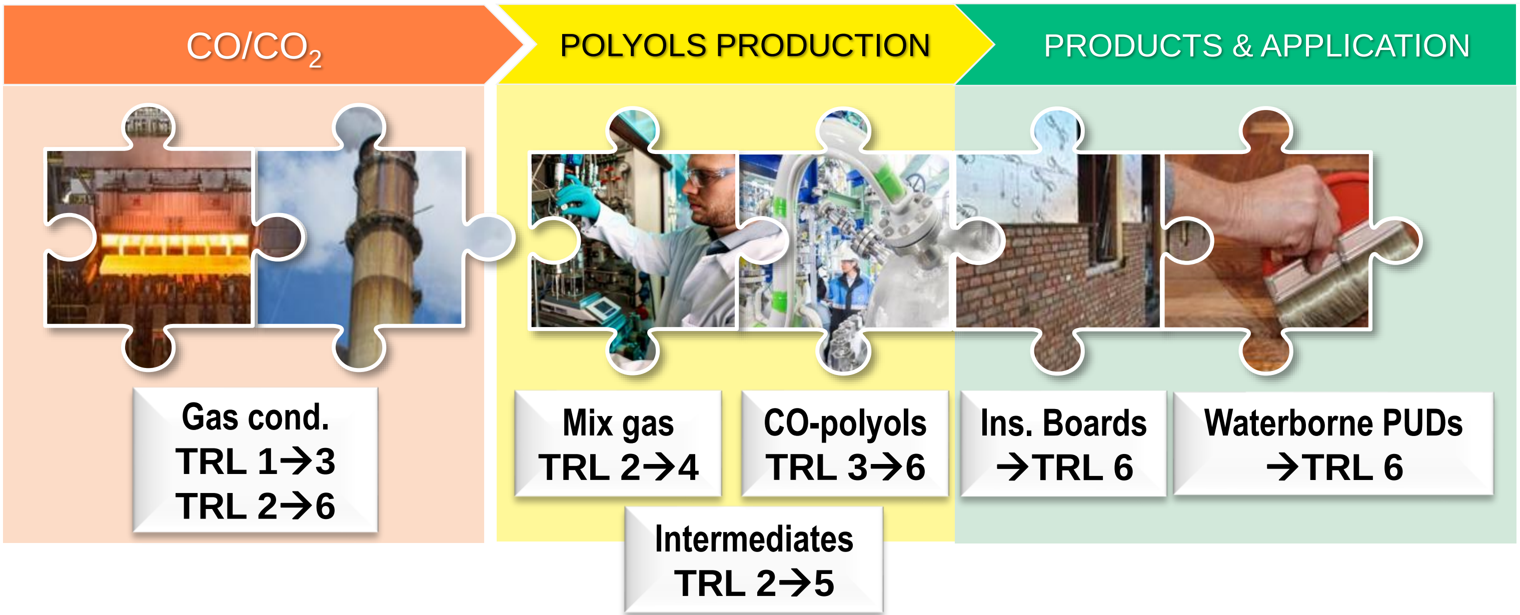


- **Social Return on Investment** (Fos, France): 100+ employed, and
- **High investment leverage potential**: EUR 5M / EUR 1M invested
- Carbon4PUR **contributes to EU Green Deal** climate and resource efficiency & transition to circular economy goals
- Current **regulatory framework does not incentivise the replication** of CCU technology



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# 3.5 Years of Carbon4PUR – Thank you!

Website www.carbon4pur.eu Follow @carbon4pur on Twitter and LinkedIn

Brussels October 2017


Gent September 2018


Gent September 2018

Marseille March 2018


Leverkusen September 2019


Carbon4PUR