# Novel CCU Technologies, research and climate aspects. A SAPEA Report

Marco Mazzotti, ETH Zurich

**ECRA/CEMCAP/CLEANKER Workshop**

Brussels – October 17th, 2018

# Acknowledgements

SAPEA

Science Advice for Policy by European Academies

## 10. Working Group members

| | | | |
|---|---|---|---|
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https://www.sapea.info/ccu/
https://ec.europa.eu/research/sam/pdf/sam_ccu_report.pdf


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Professor Marco Mazzotti, Deputy Chair of Working Group

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Dr. Wolf Gehrisch

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All workshop participants and organisers

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# The questions by the EC

- Under what circumstances CCU for production of fuels, chemicals and materials can deliver climate benefits and what are their total climate mitigation potential in the mid- and long-run?
- How can the climate mitigation potential of $CO_2$ incorporated in products such as fuels, chemicals and materials be accounted for considering that the $CO_2$ will remain bound for different periods of time and then may be released in the atmosphere?

# Outline

1. The CCU system
2. RES efficiency in delivering energy services
3. Carbon balances of technology chains
4. Innovation needed

# 1. The CCU system

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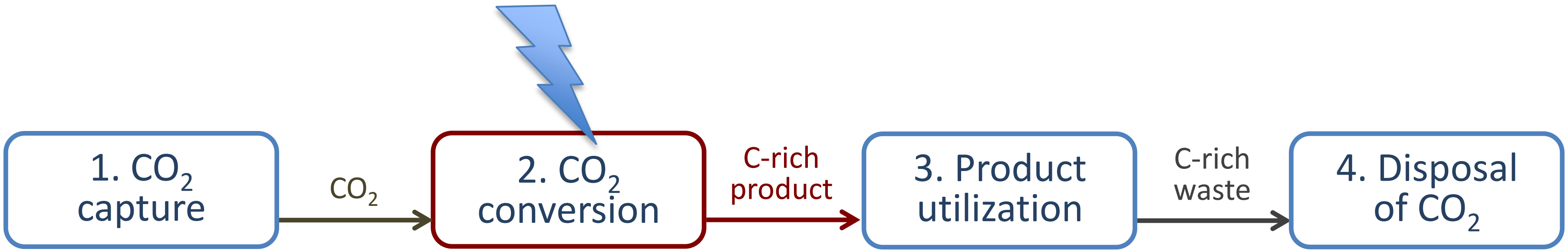

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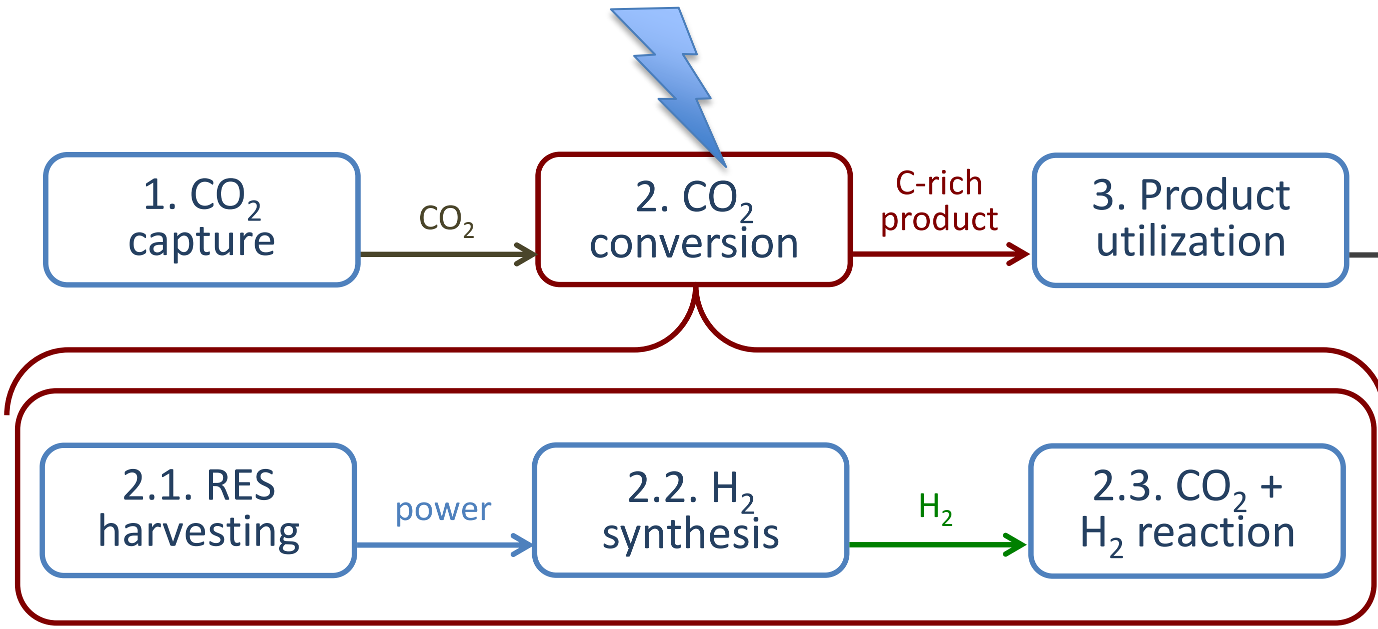

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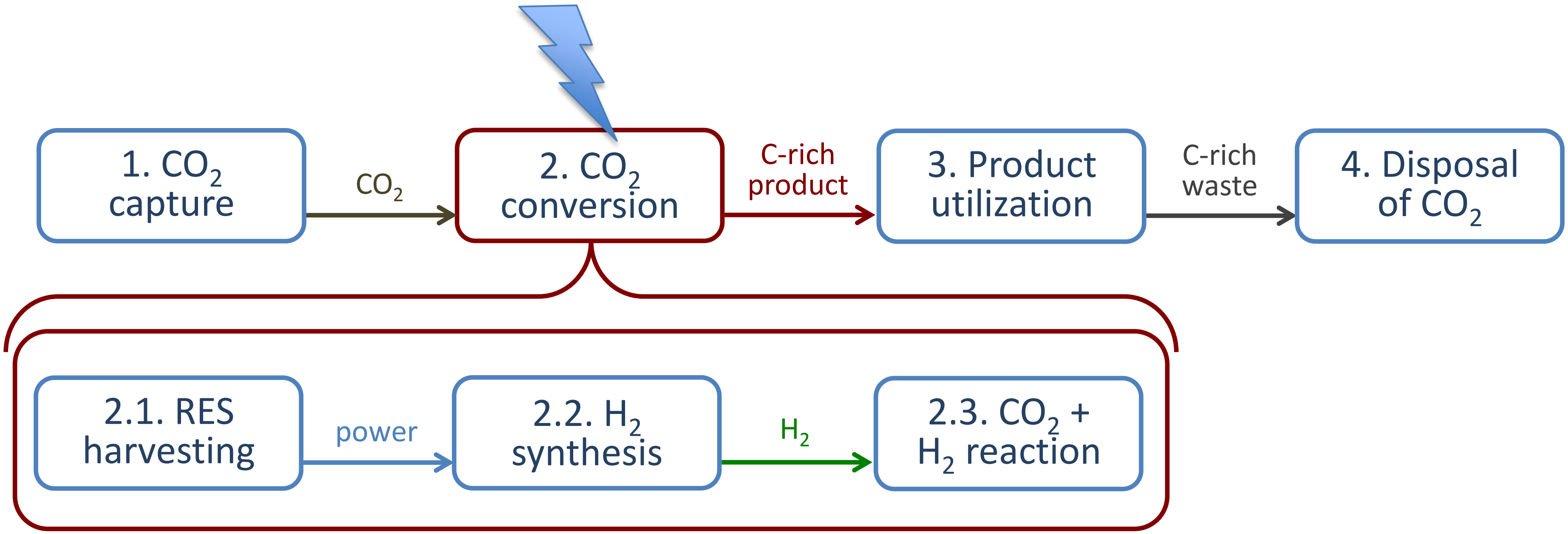


CCU POTENTIAL IN EU TO SUPPORT:

- climate change objectives;
- circular economy (O- vs. L-economy);
- energy security and RES deployment;
- evolution of $CO_2$ capture systems.

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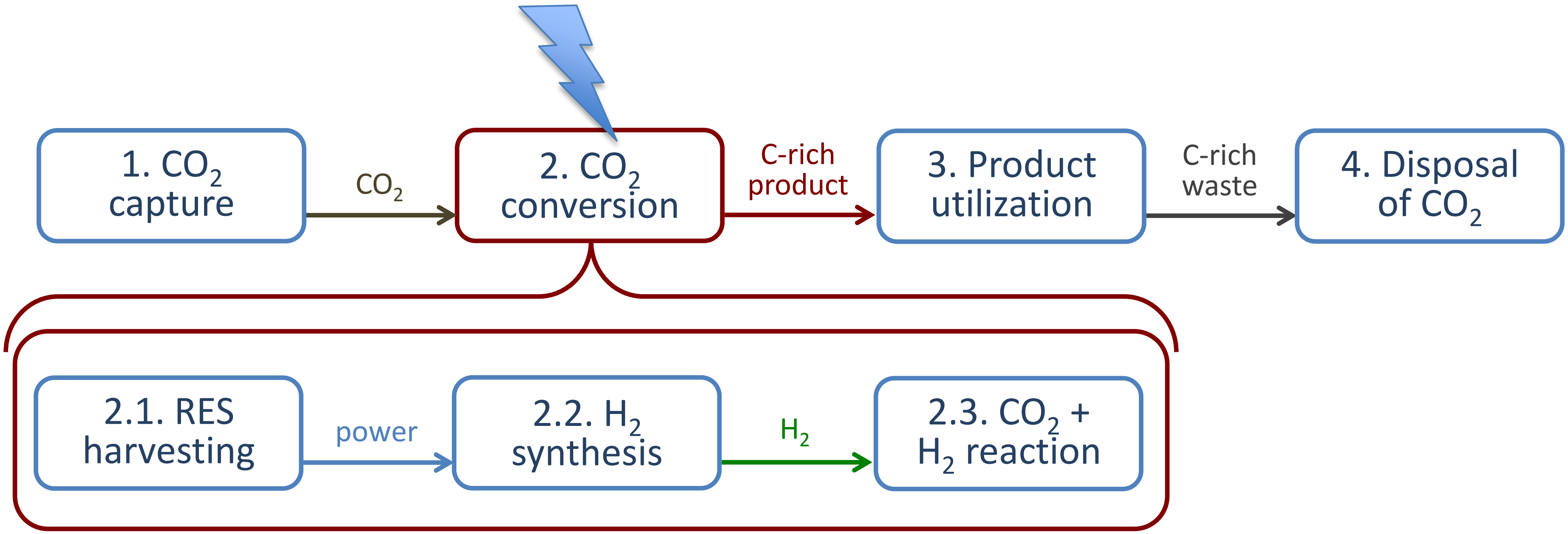


WG VIEW: SOCIETAL SERVICES

- power generation and distribution;
- fuels (and power) for transport;
- long-term long-range RES storage;
- industrial products and materials.

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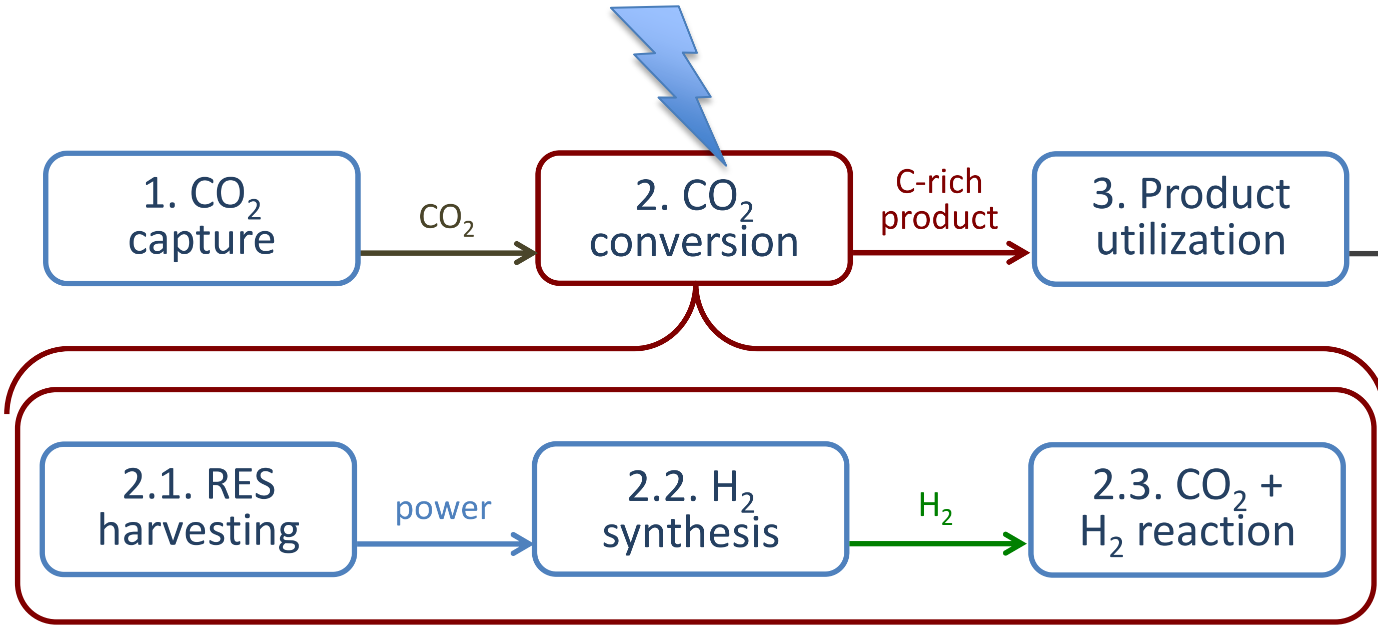


CCU CYCLES
- Energy cycle
- Carbon cycle
- Material cycles

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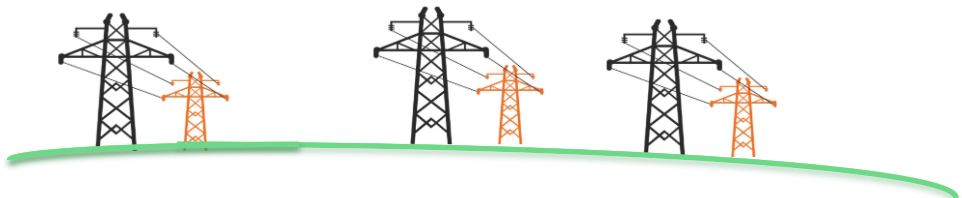

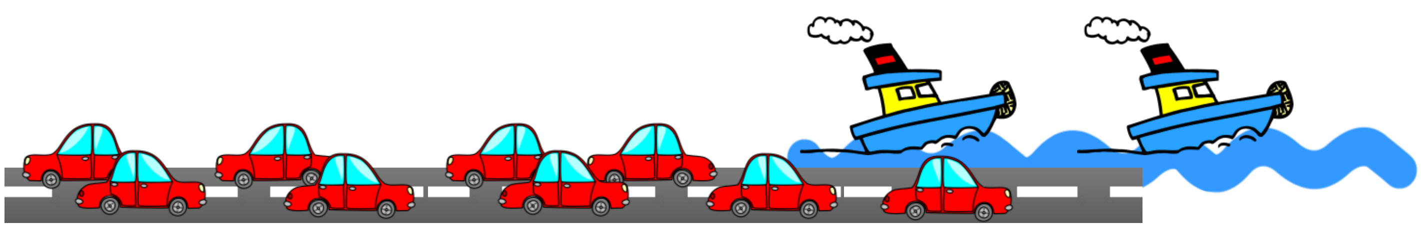

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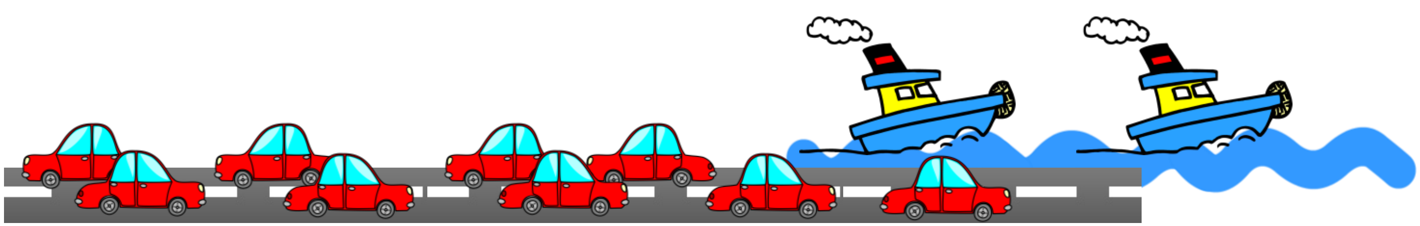

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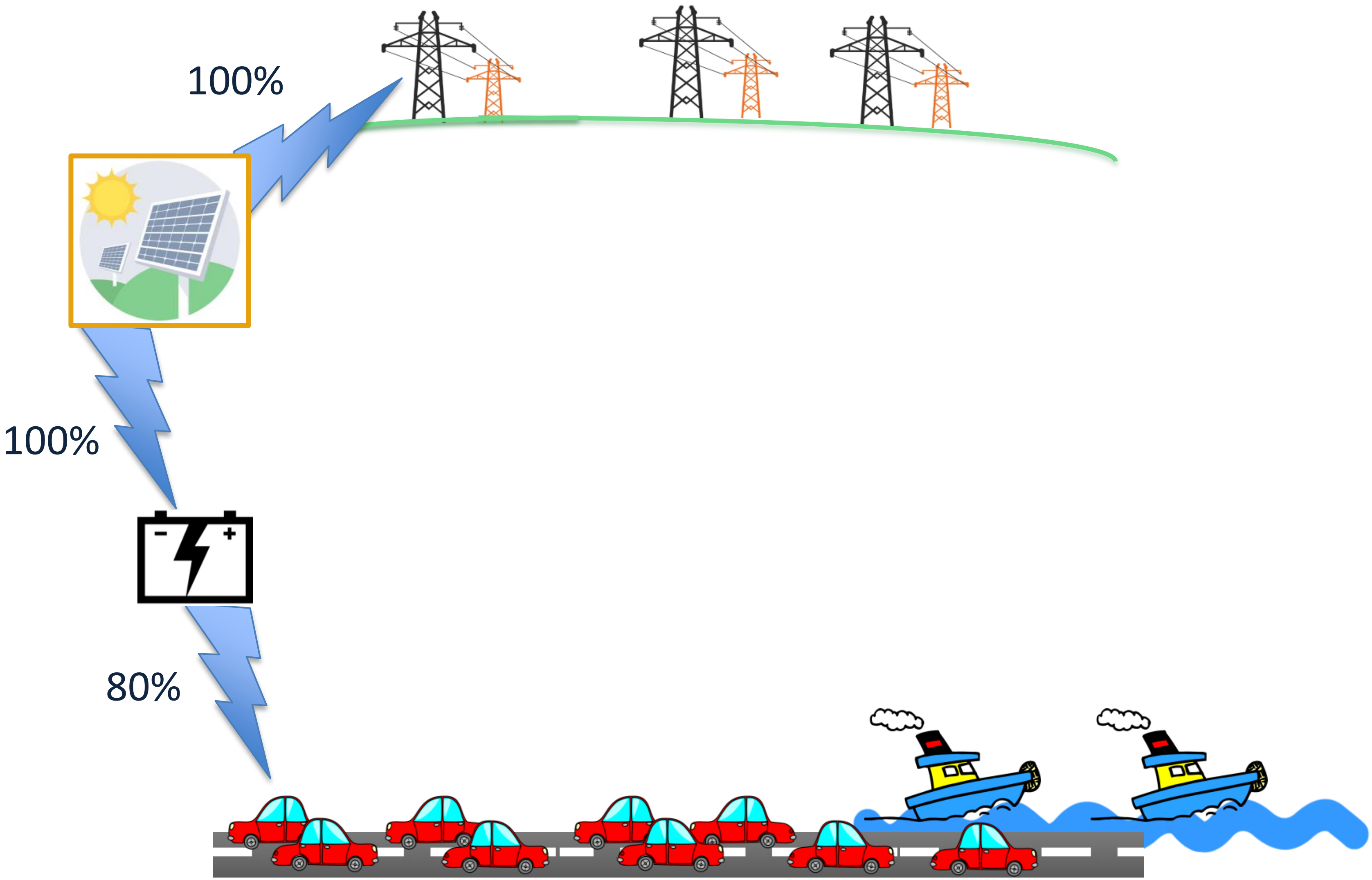

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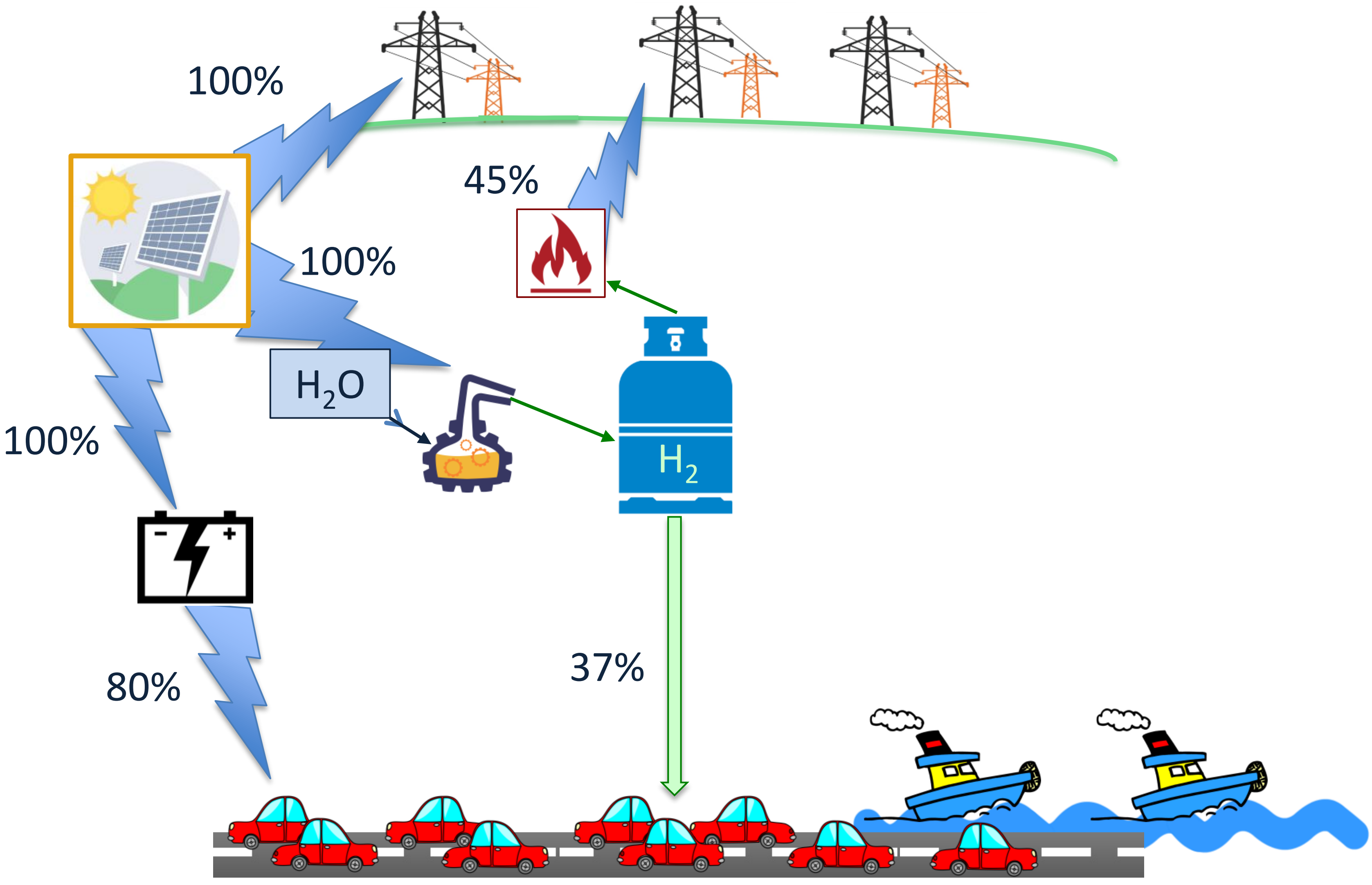

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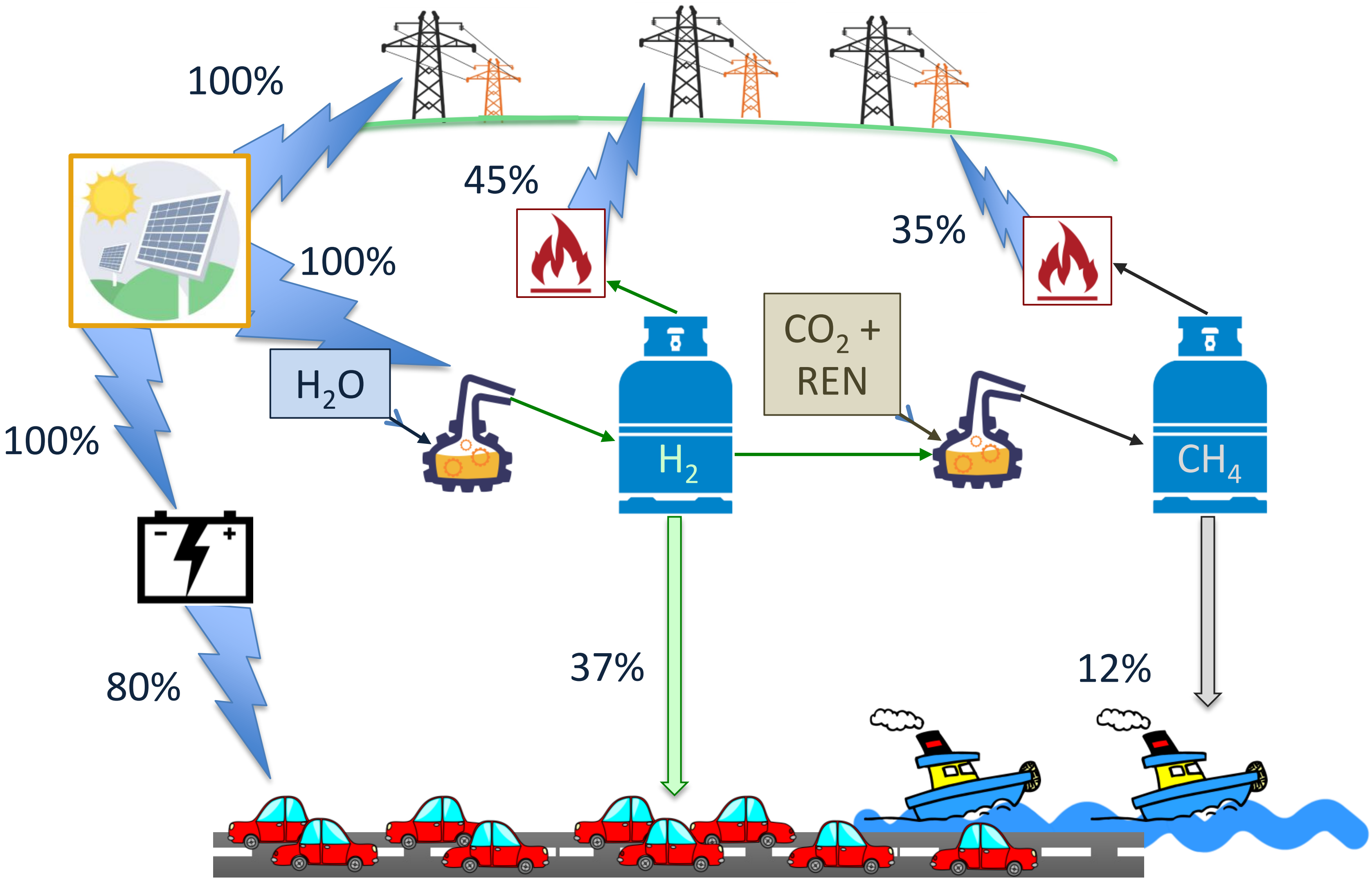

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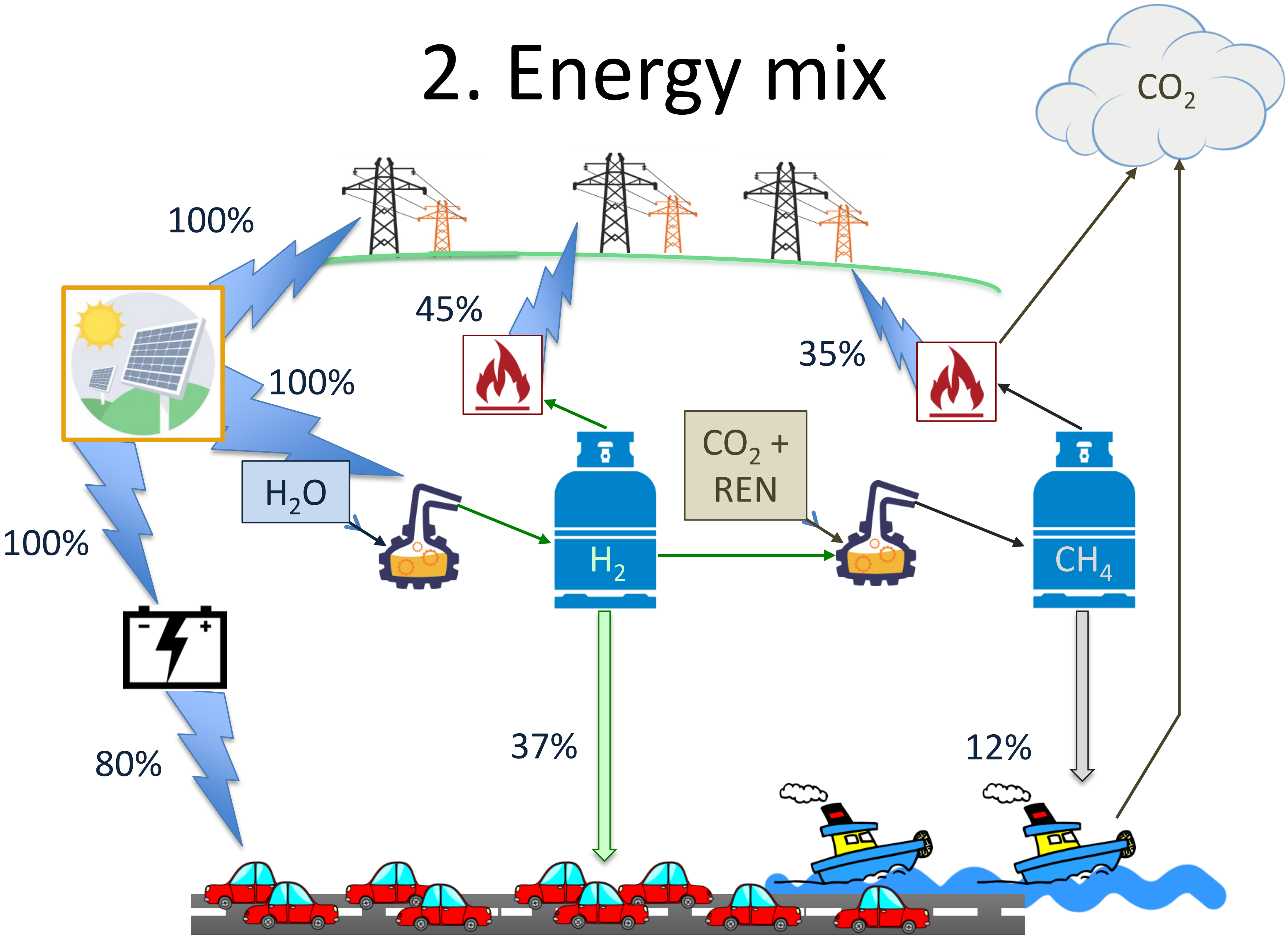

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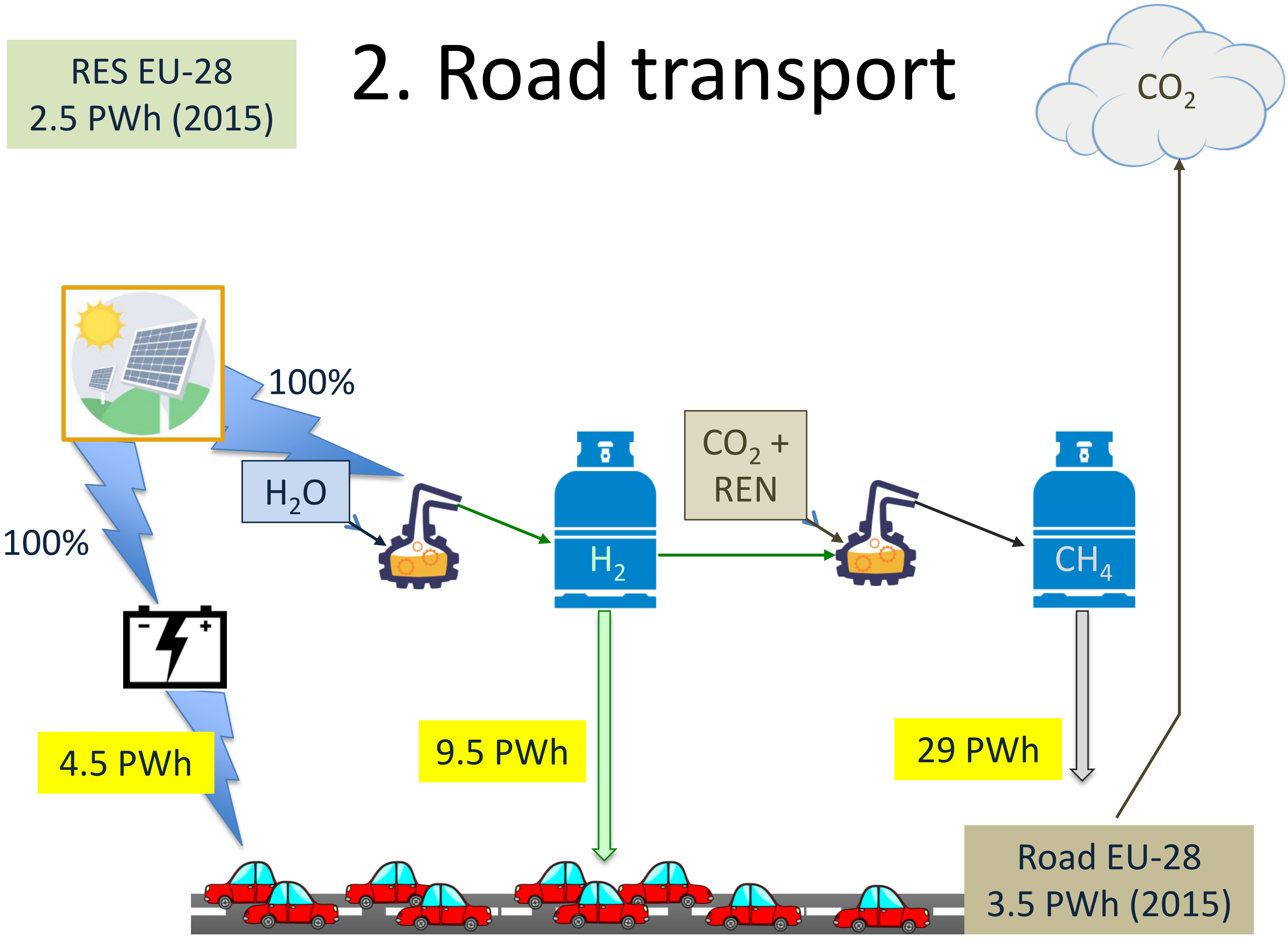

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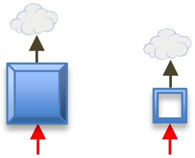
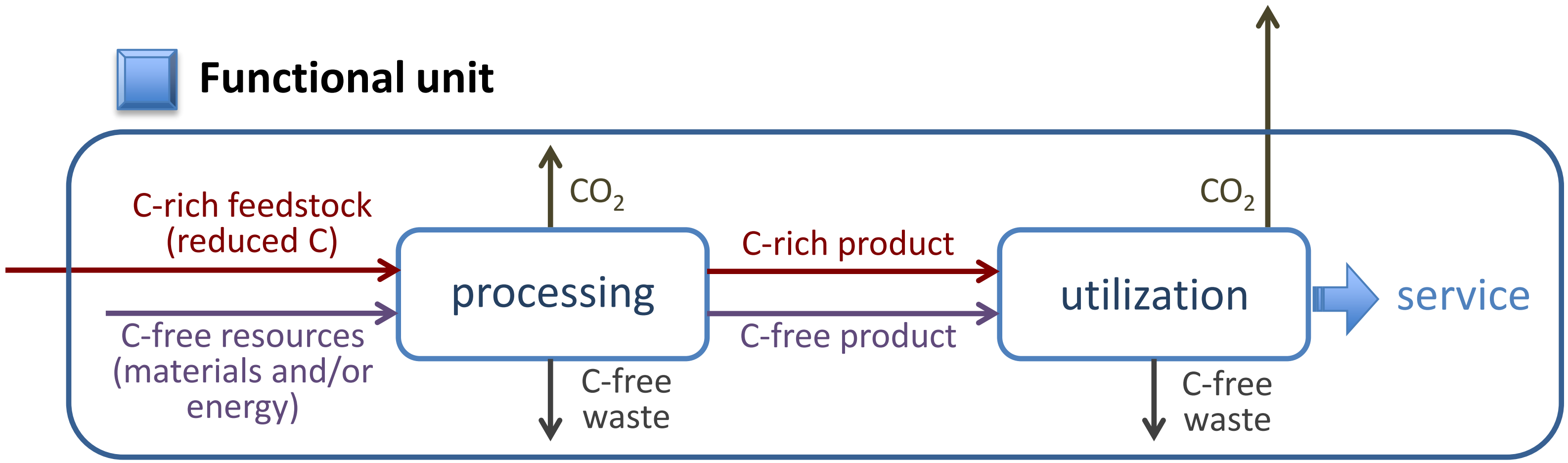


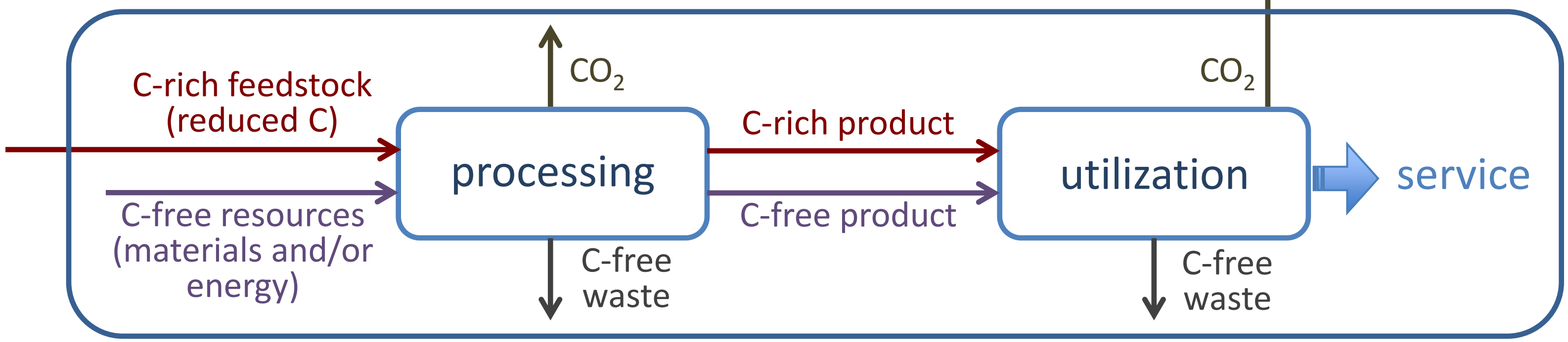
1. L-economy

# 3. Carbon balances



# 3. Carbon balances

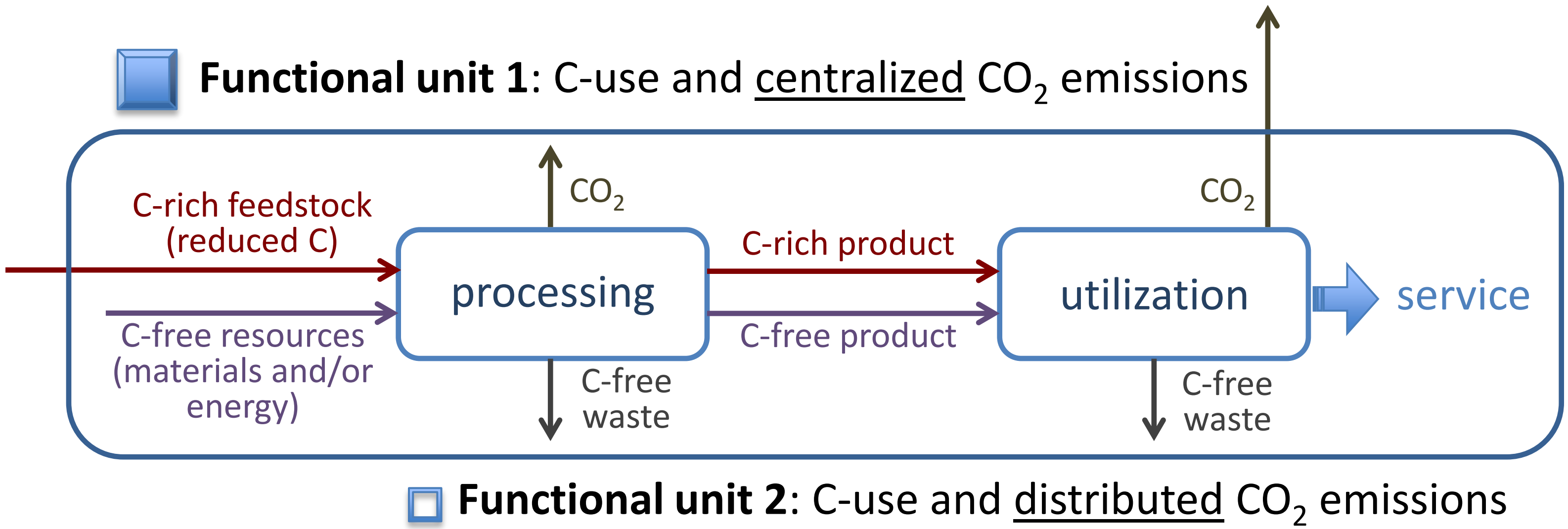
**Functional unit 1**: C-use and centralized $CO_2$ emissions




**Functional unit 1:**

- fossil-fuel-fired power plant
- large scale industrial boiler for heat generation
- chemical plant coupled to incinerator for C-rich waste disposal (polymeric materials)

# 3. Carbon balances



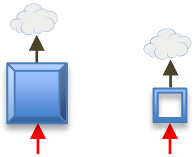

**Functional unit 1:**

- fossil-fuel-fired power plant
- large scale industrial boiler for heat generation
- chemical plant coupled to incinerator for C-rich waste disposal (polymeric materials)

**Functional unit 2:**

- urea production and use
- fuels (cars, ships, planes) synthesis and use
- chemical plant not-coupled to incinerator, or to incinerator without $CO_2$ capture

# 3. Carbon balances

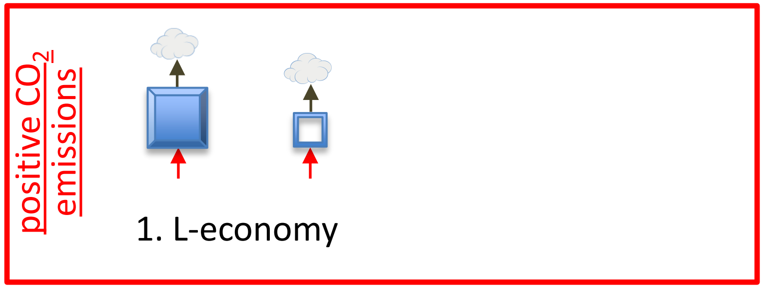


1. L-economy

 Functional unit 1: point source $CO_2$ emissions

 Functional unit 2: distributed $CO_2$ emissions

# 3. Carbon balances

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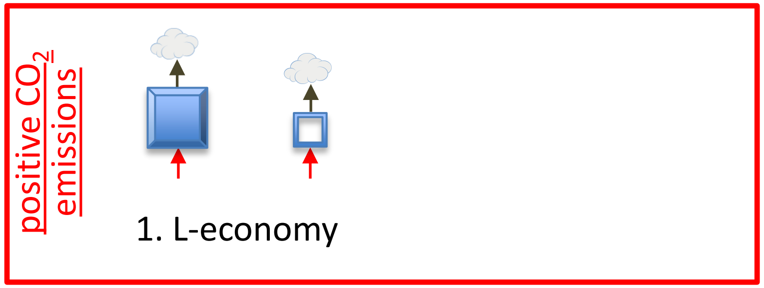



Functional unit 1: point source $CO_2$ emissions

Functional unit 2: distributed $CO_2$ emissions

Fossil (reduced) carbon

Oxidized carbon ($CO_2$)

Synthetic (reduced) carbon

Biogenic (reduced) carbon

Renewable energy source

$CO_2$ in the atmosphere

Post-combustion $CO_2$ capture (PCC)

Direct air capture of $CO_2$ from the atmosphere (DAC)

Underground $CO_2$ storage

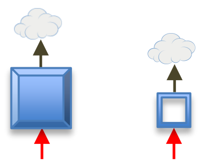
$CO_2$ conversion plant, incl. electrolyzer for $H_2$

Managed biomass growth

Biomass treatment plant

# 3. Carbon balances

positive $CO_2$ emissions



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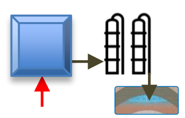
net-zero $CO_2$ emissions



3. L-economy w/ CCS

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Functional unit 2: distributed $CO_2$ emissions

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Synthetic (reduced) carbon

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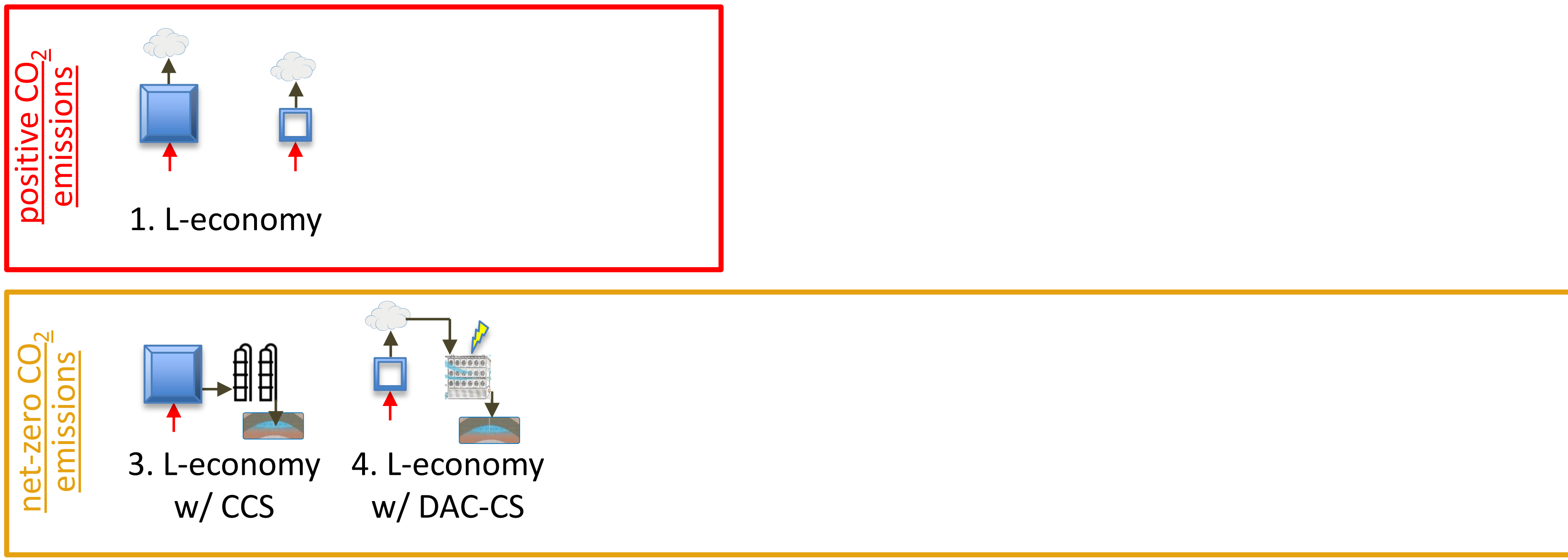


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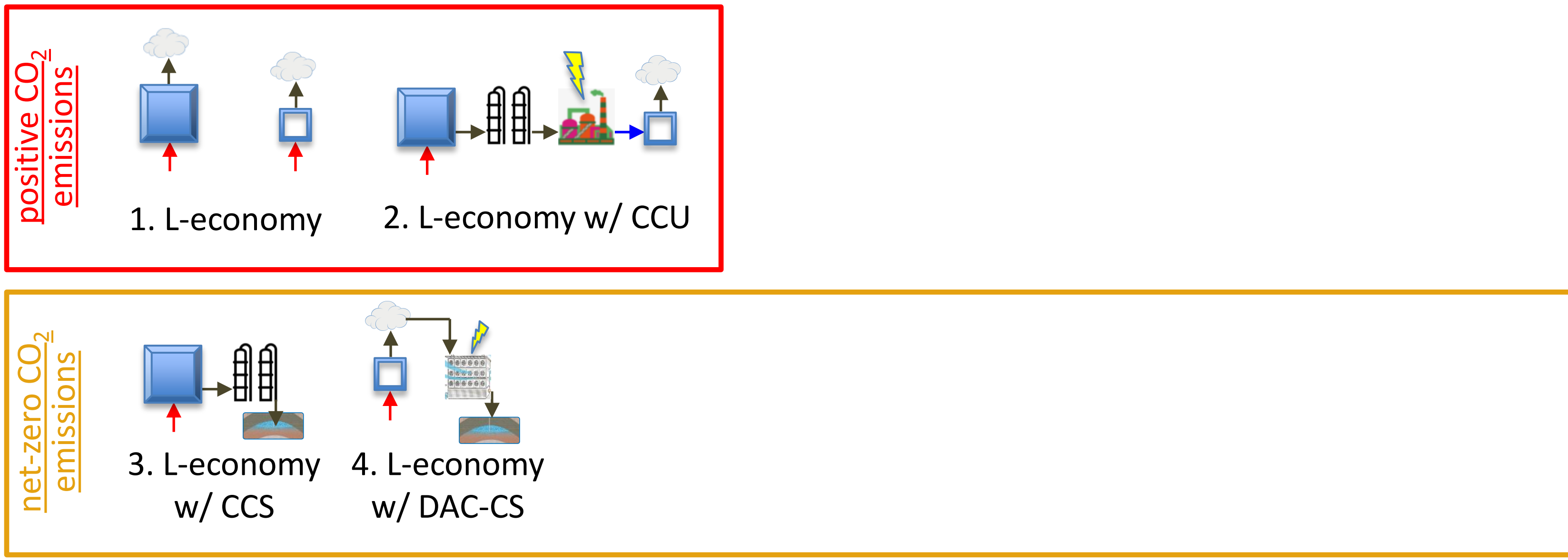


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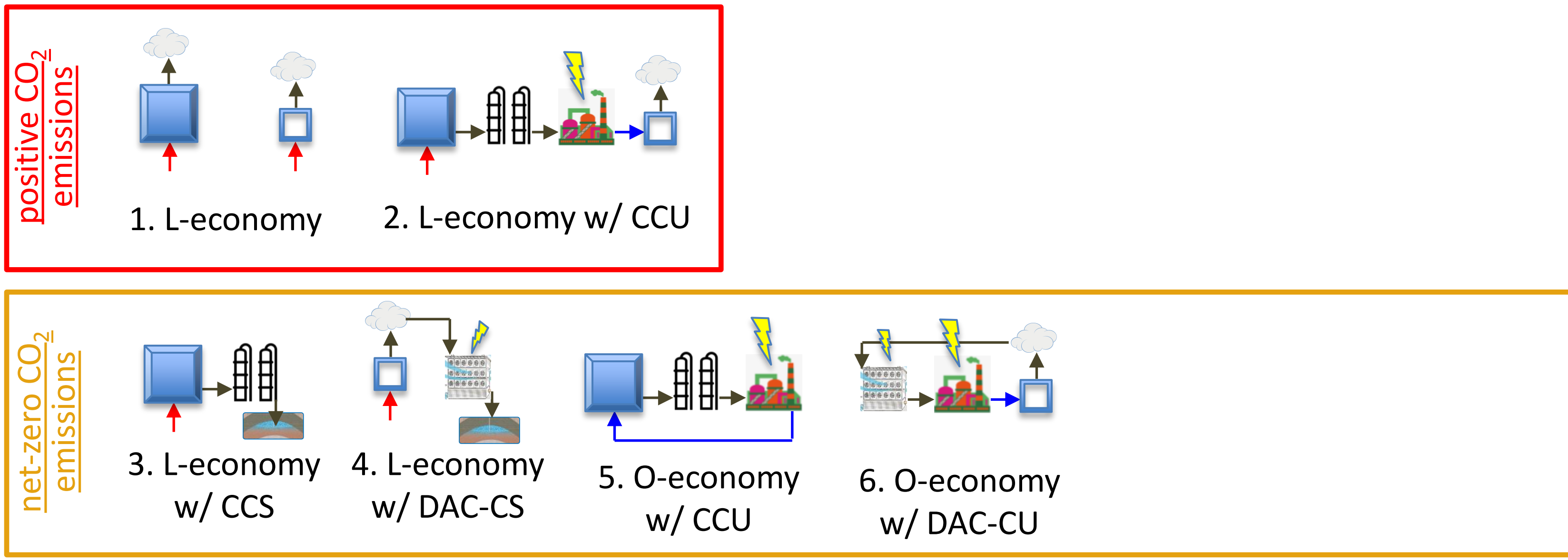


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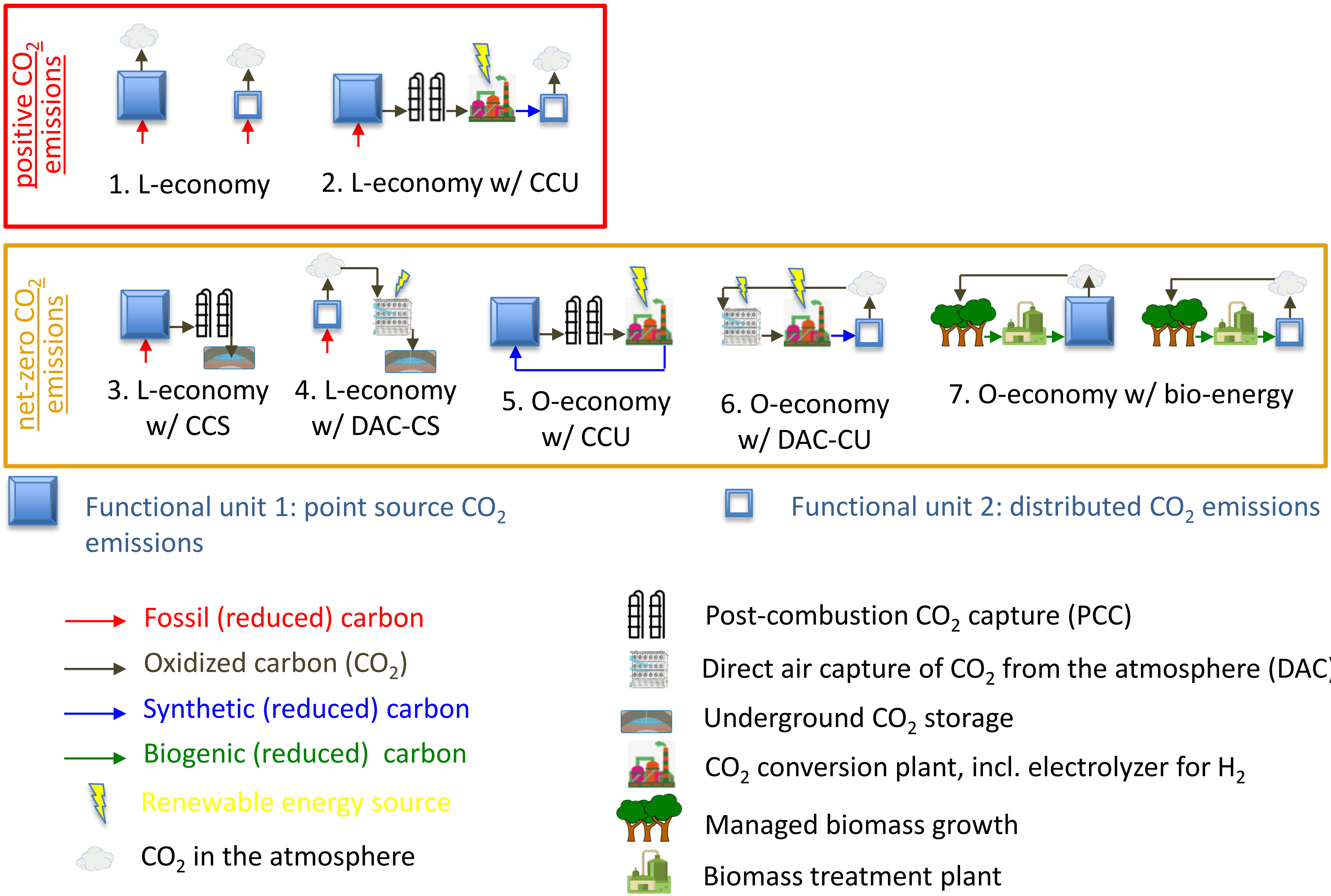

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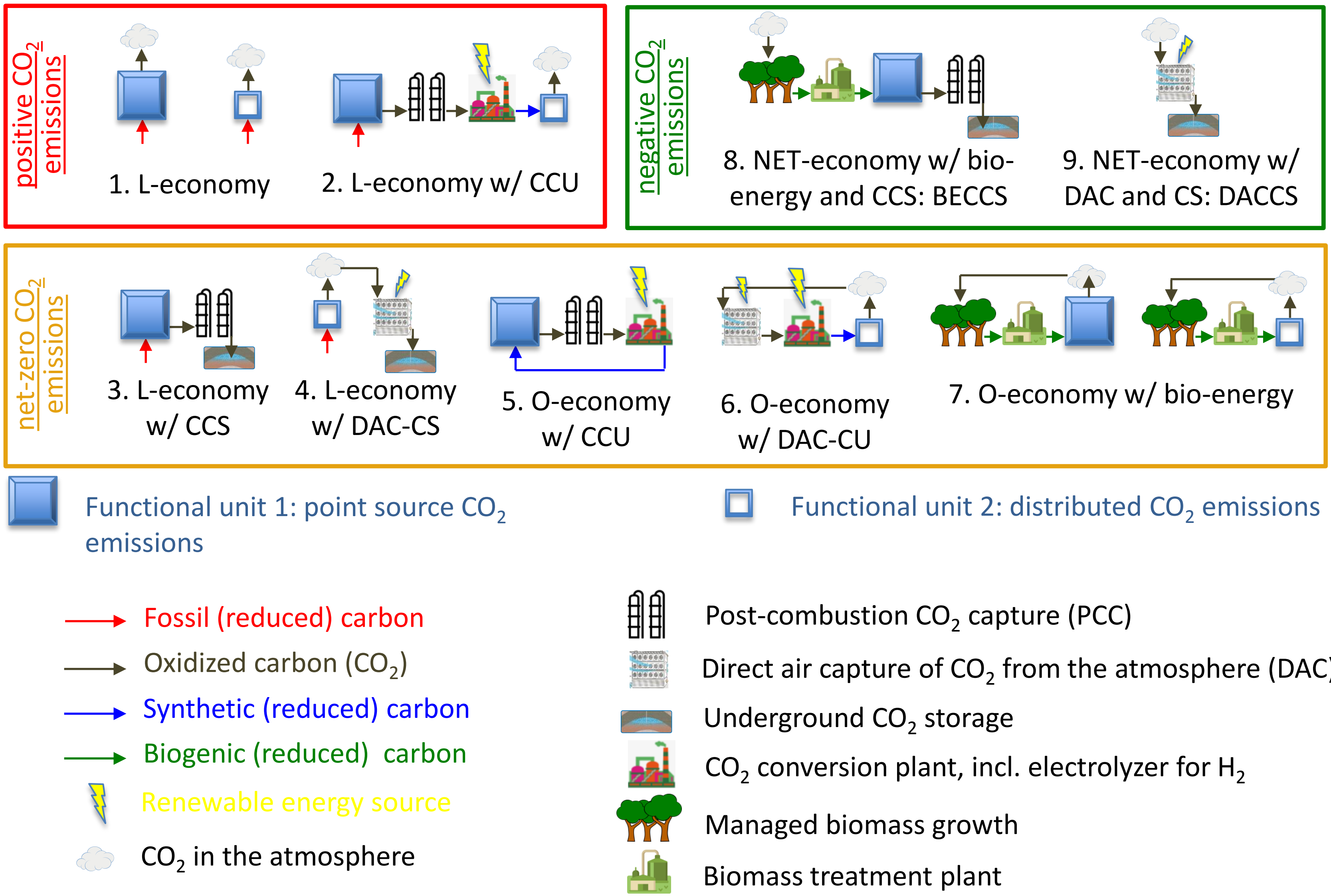

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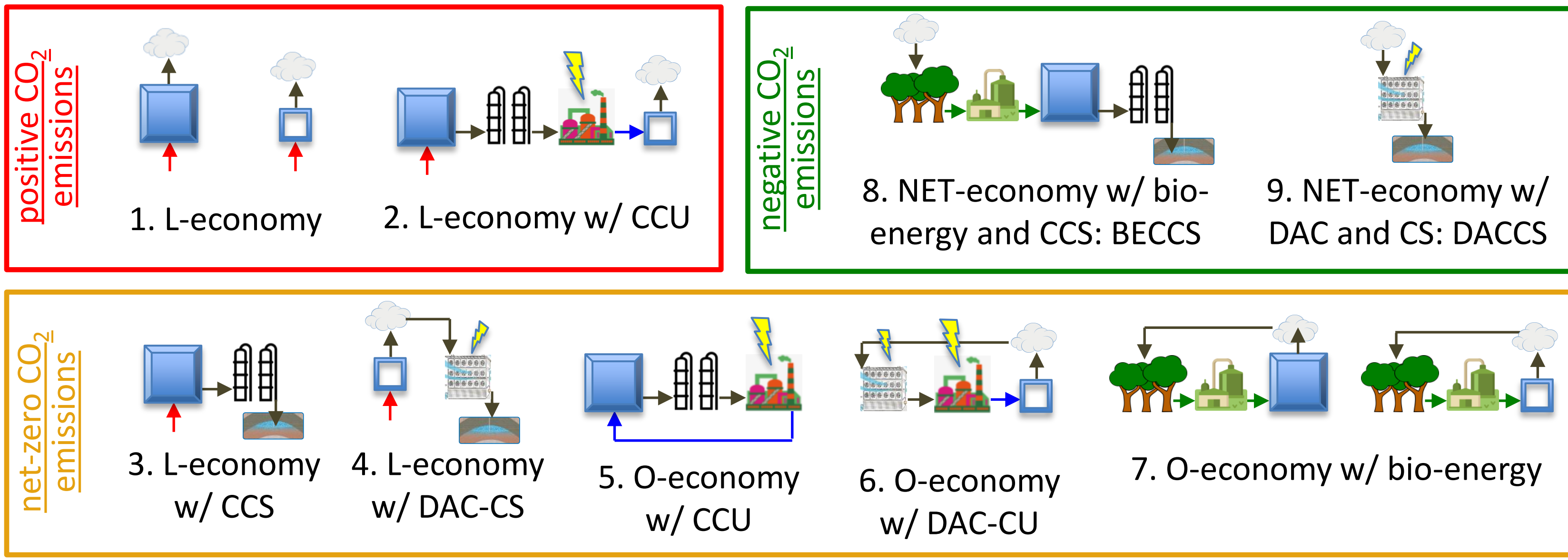


A FEW COMMENTS

- C-free RES to be LCA-assessed;
- CCU neither sufficient nor needed for O-economy, while $CO_2$ capture needed;
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- full LCA needed to allocate $CO_2$ emissions to stakeholders.

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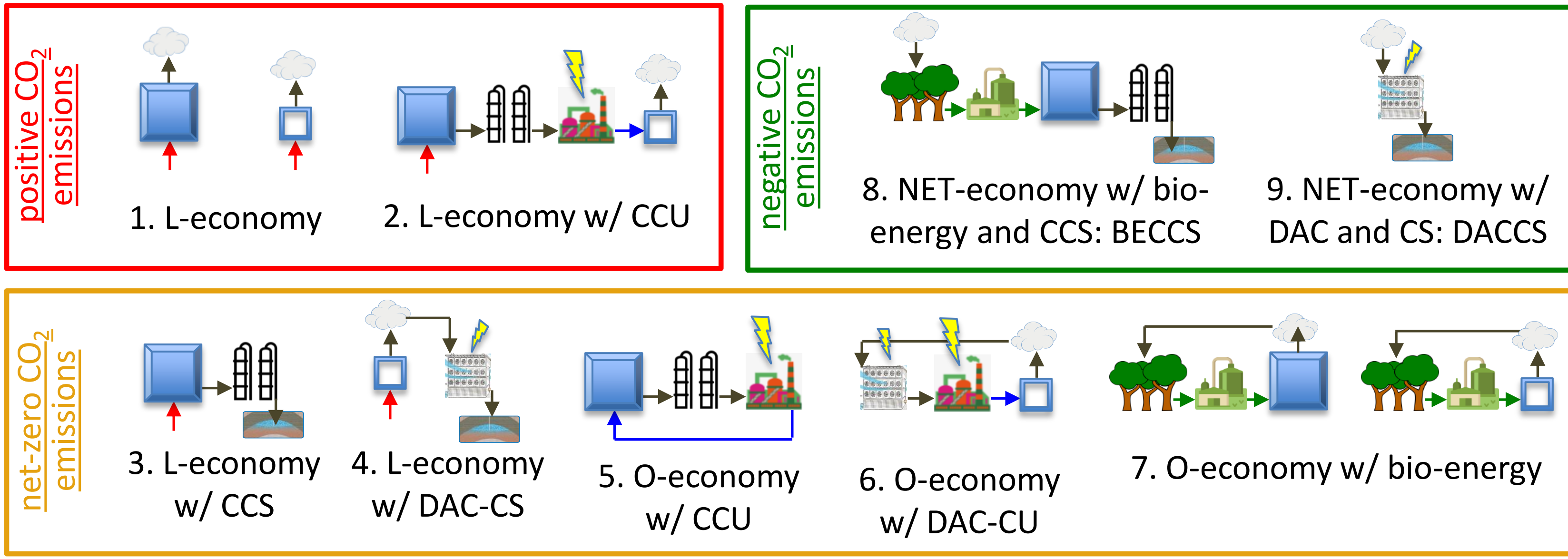


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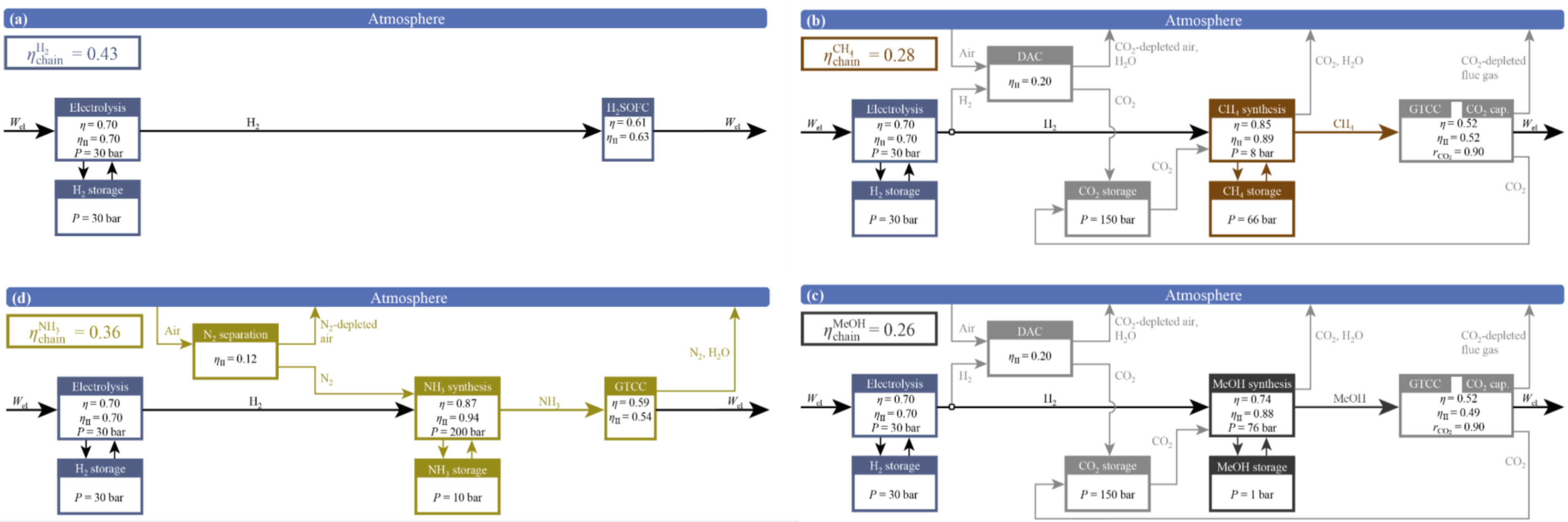
SIMPLIFIED SYSTEM ANALYSIS

- the whole technology chain, incl. RES, $CO_2$ source, product, C-waste release;
- Carbon and energy balances around the system boundaries;
- infrastructure and land use needs;
- deployment current and projected scale.

# 4. Innovation needed

1. *Policy perspective* – Measures, regulations and incentives should examine the energy system, including CCU, in a holistic, integrated, coordinated and transparent manner.
2. *Systemic perspective* – A system approach is required when evaluating the energy system and its CCU sub-systems; progress is needed, in terms both of stakeholder awareness and of consistent definitions of system boundaries and of reference datasets.
3. *Technology perspective* – There are scientific and technical challenges in the areas of:
    1. collection and purification of $CO_2$ from different sources;
    2. synthesis of green-hydrogen via water splitting powered by RES;
    3. reductive activation catalytic technologies for $CO_2$ conversion to fuels and chemicals.

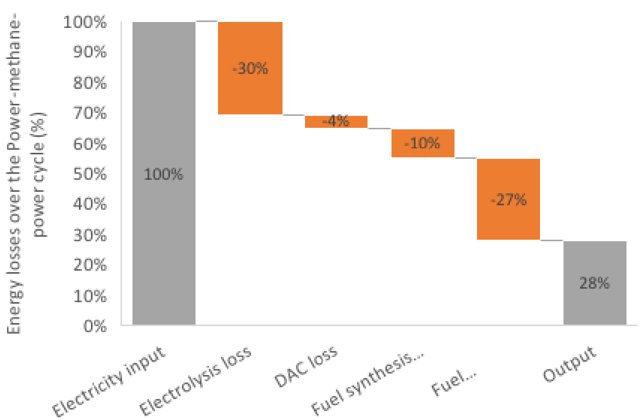
# 5. Comparison of net-zero CCU loops to C-free systems



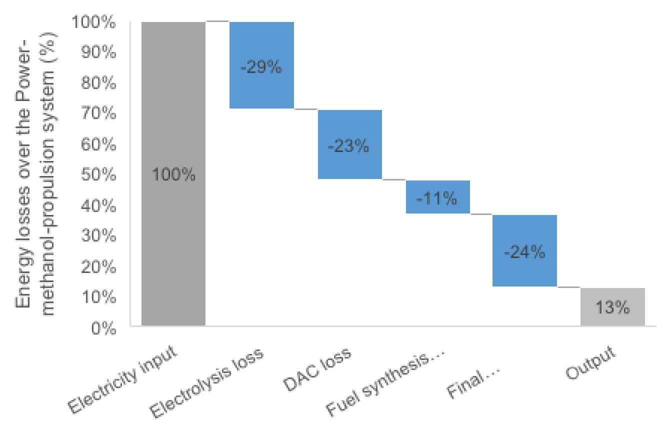

Sutter, van der Spek, Mazzotti, submitted (2018)

# 5. The efficiency cost of seasonal energy storage

Power-methane-power




Power-methanol-propulsion

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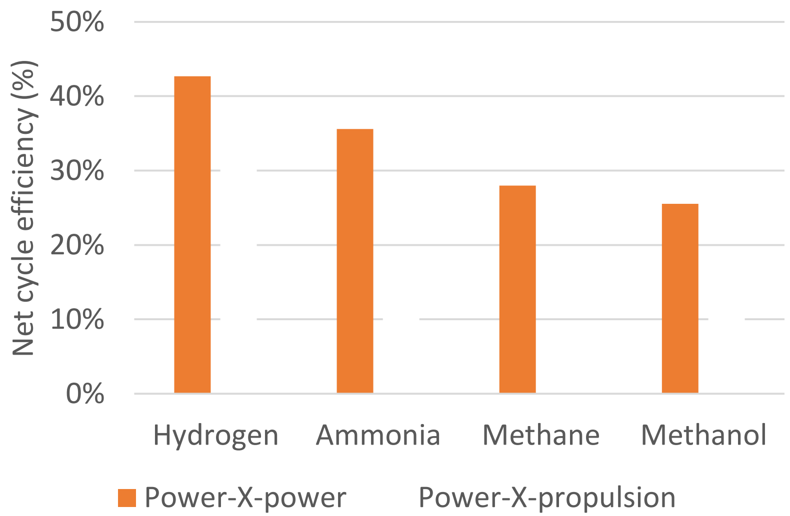
# 5. CCU fuels for power generation and propulsion

- Power-methane-**power**
  - ~30% net cycle efficiency

- Power-ammonia-**power**
  - efficiency > CCU fuels: ~35%

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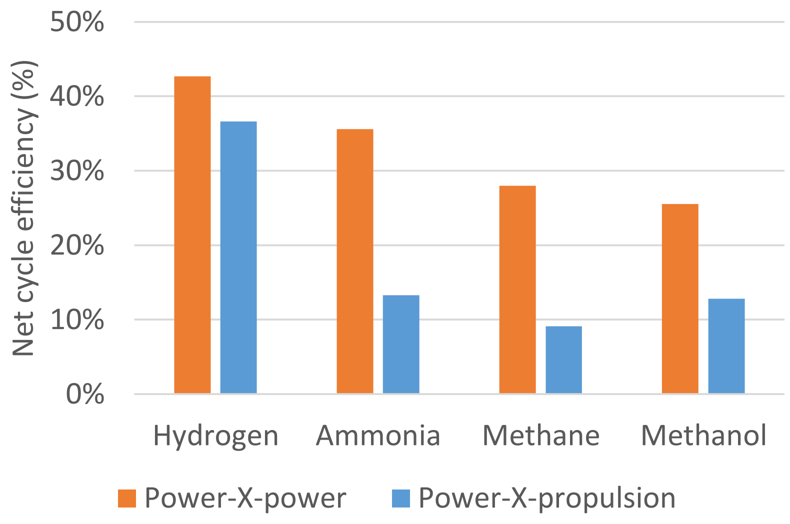
- Power-ammonia-**power**
  - efficiency > CCU fuels: ~35%
- Power-methanol-**propulsion**
  - ~13% net cycle efficiency
- Power-hydrogen-X
  - Highest efficiencies for power and propulsion
  - Transport fuel of choice!?

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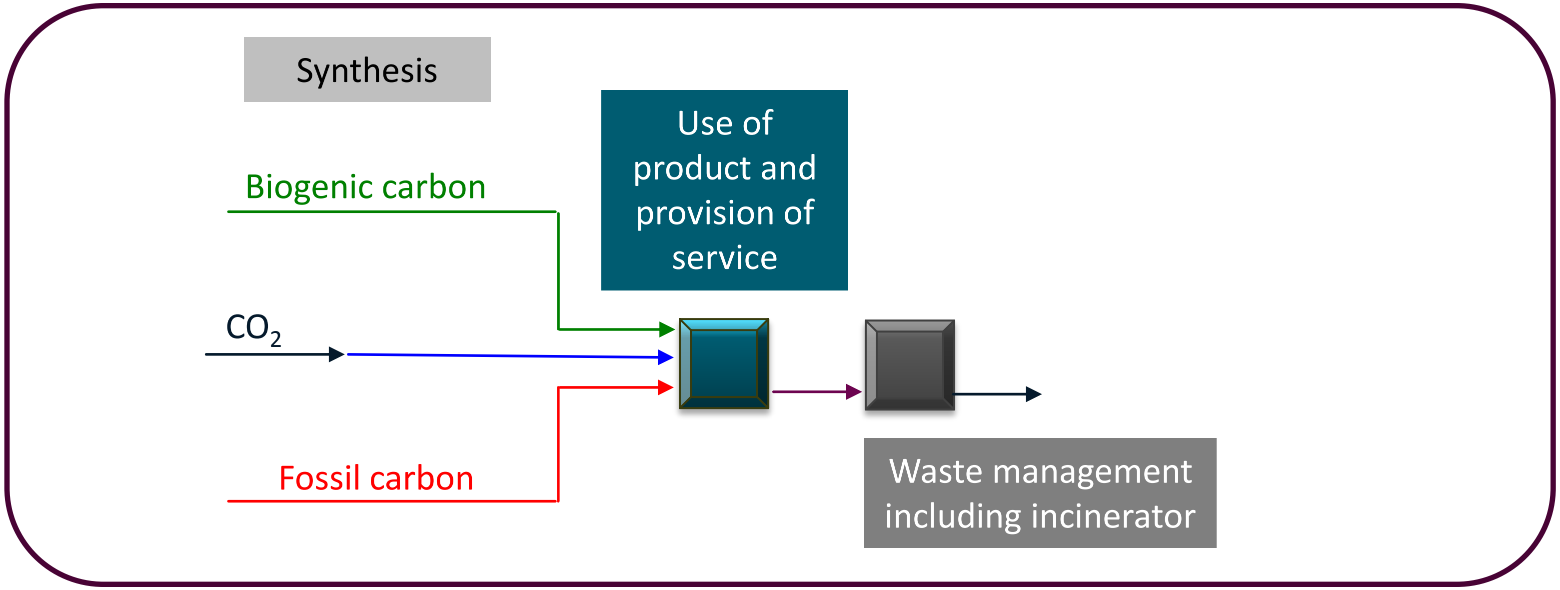
# Chemical products provide services



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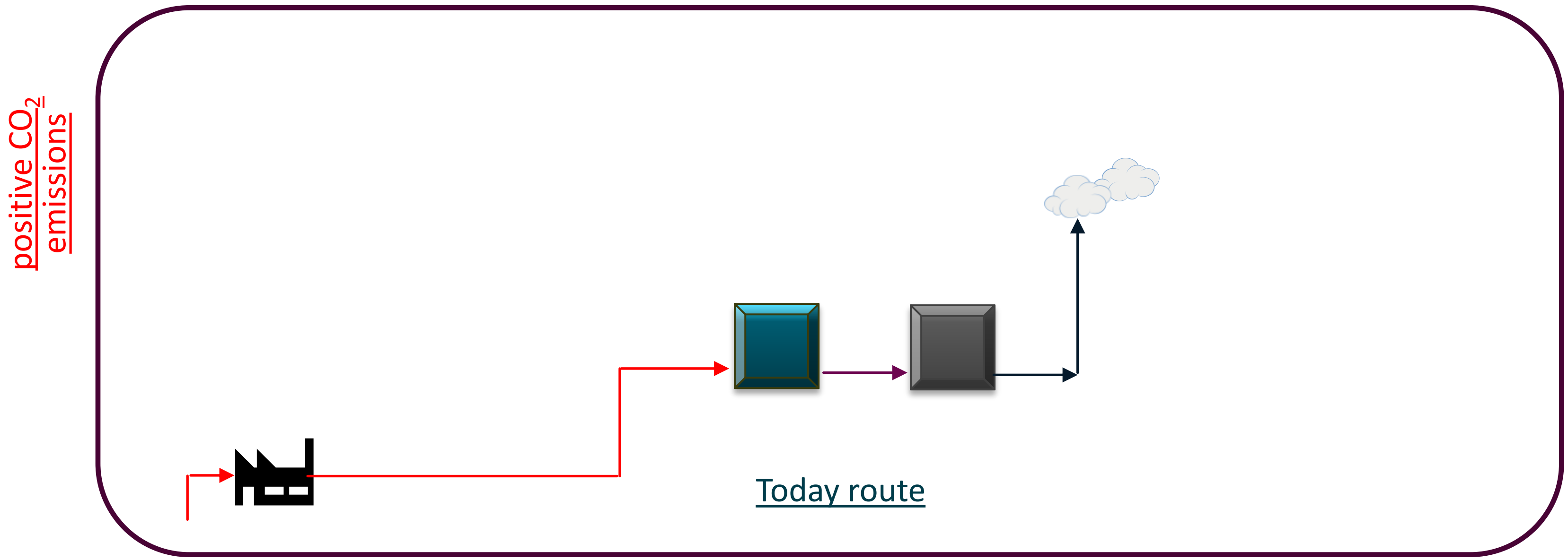



Oil & gas petrochemical route

Use of product and provision of service

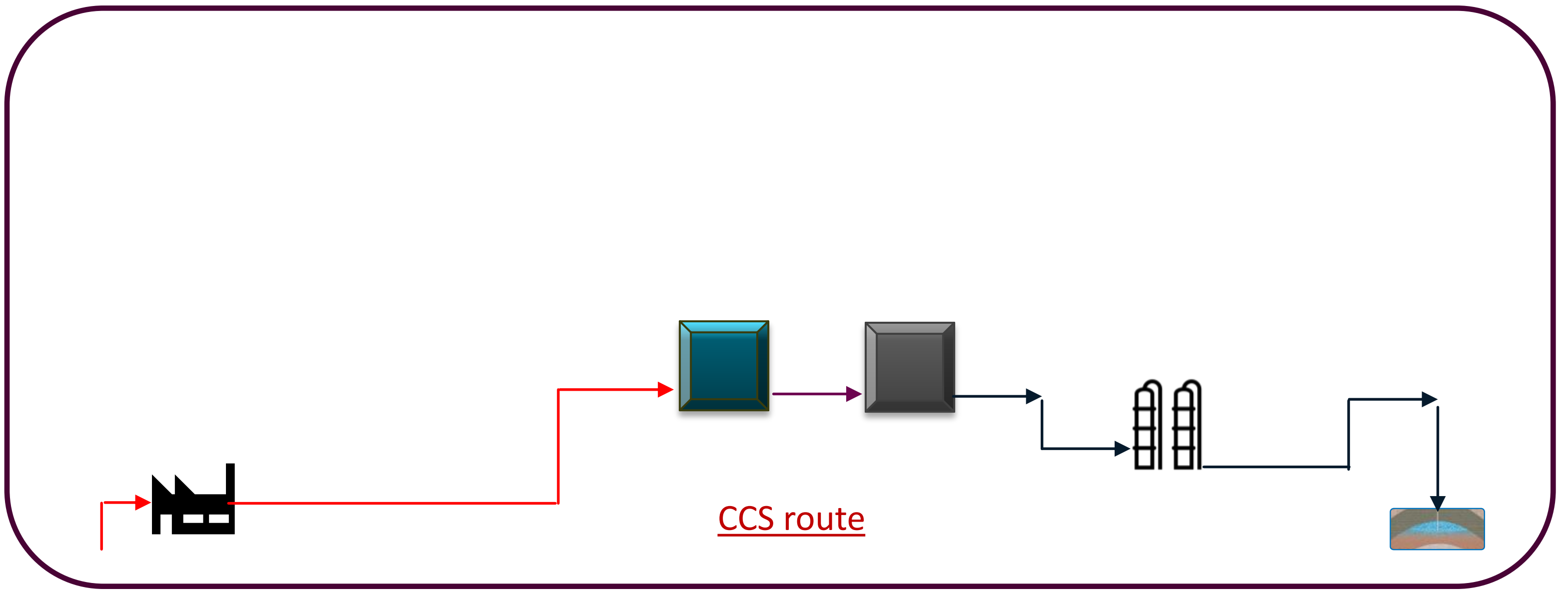
Waste management including incinerator

Fossil (reduced) carbon

Oxidized carbon ($CO_2$)

$CO_2$ in the atmosphere

# Chemical products in a net-zero-$CO_2$-emissions world

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ETH zürich

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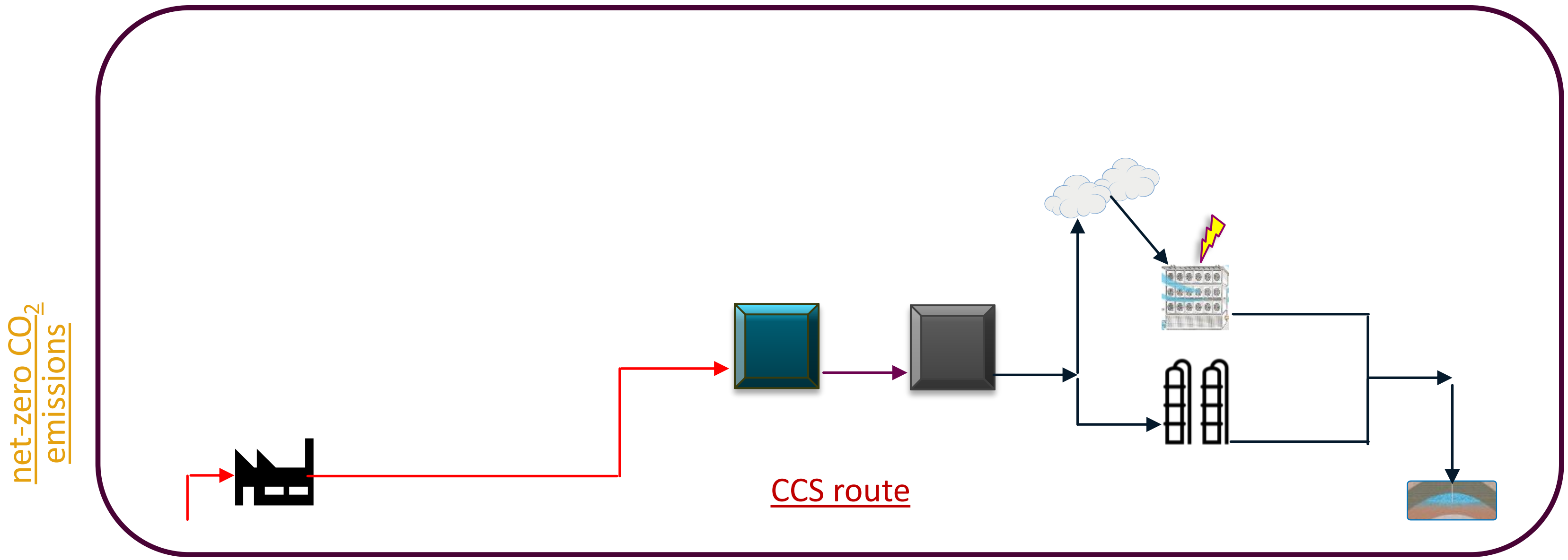


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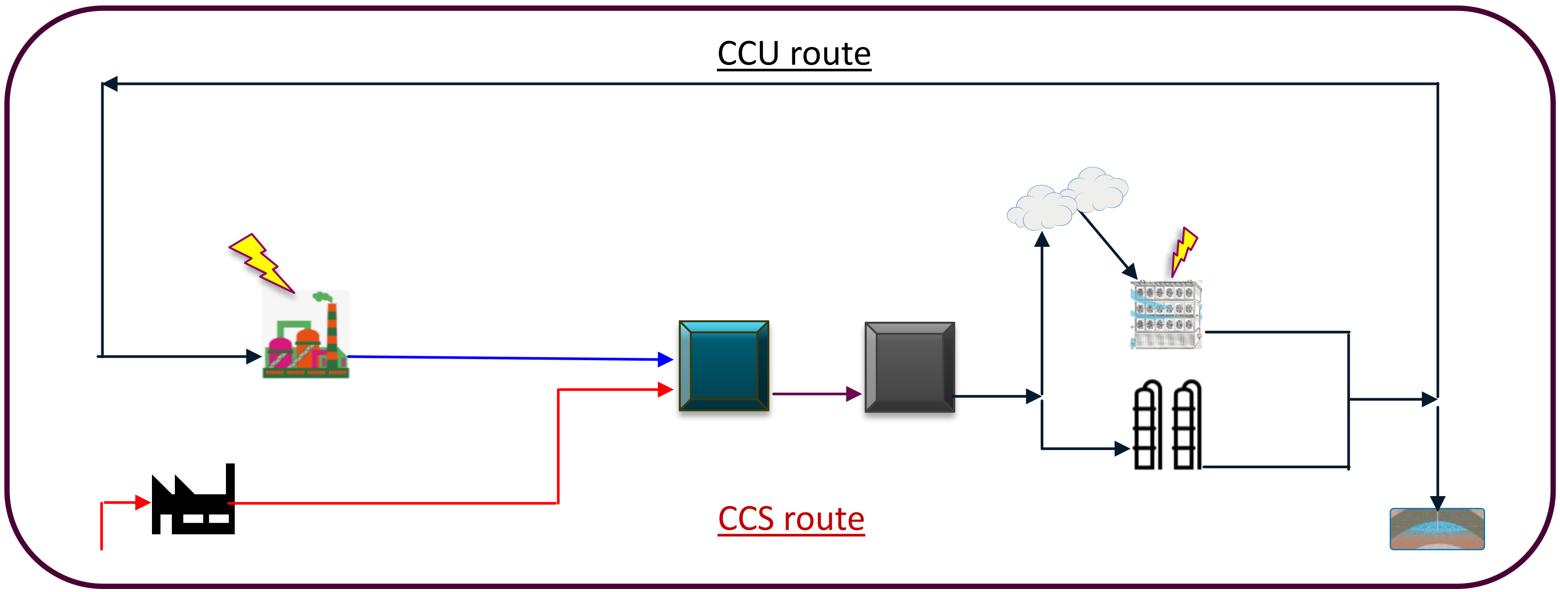


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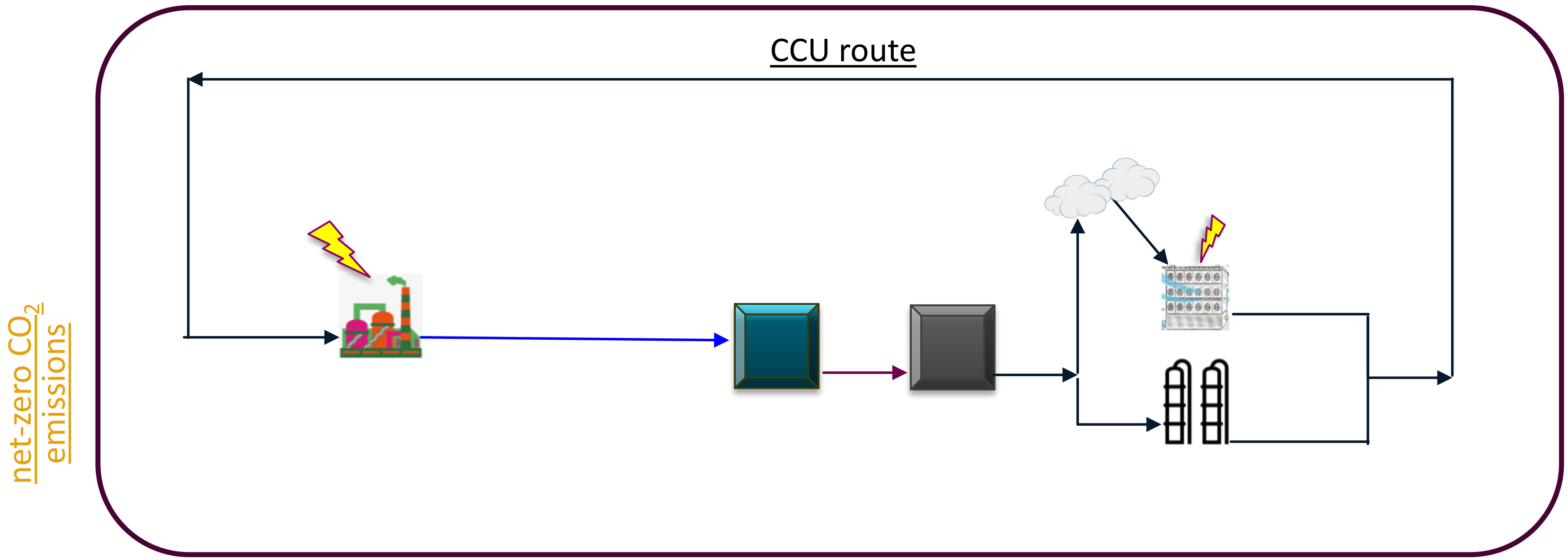


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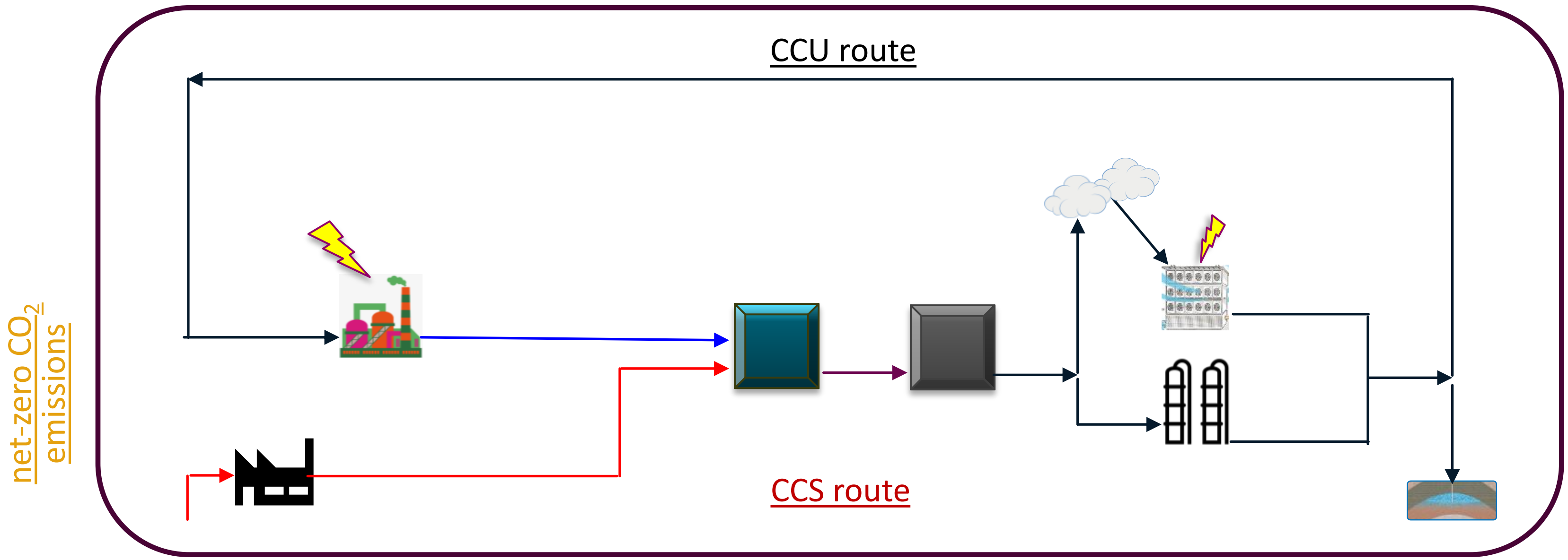
Post-combustion $CO_2$ capture (PCC)

Direct air capture of $CO_2$ from the atmosphere (DAC)

Underground $CO_2$ storage

$CO_2$ conversion plant, incl. electrolyzer for $H_2$

# Chemical products in a net-zero-$CO_2$-emissions world




Oil & gas petrochemical route

Use of product and provision of service

Waste management including incinerator

Fossil (reduced) carbon

Oxidized carbon ($CO_2$)

Synthetic (reduced) carbon

Biogenic (reduced) carbon

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ETH zürich

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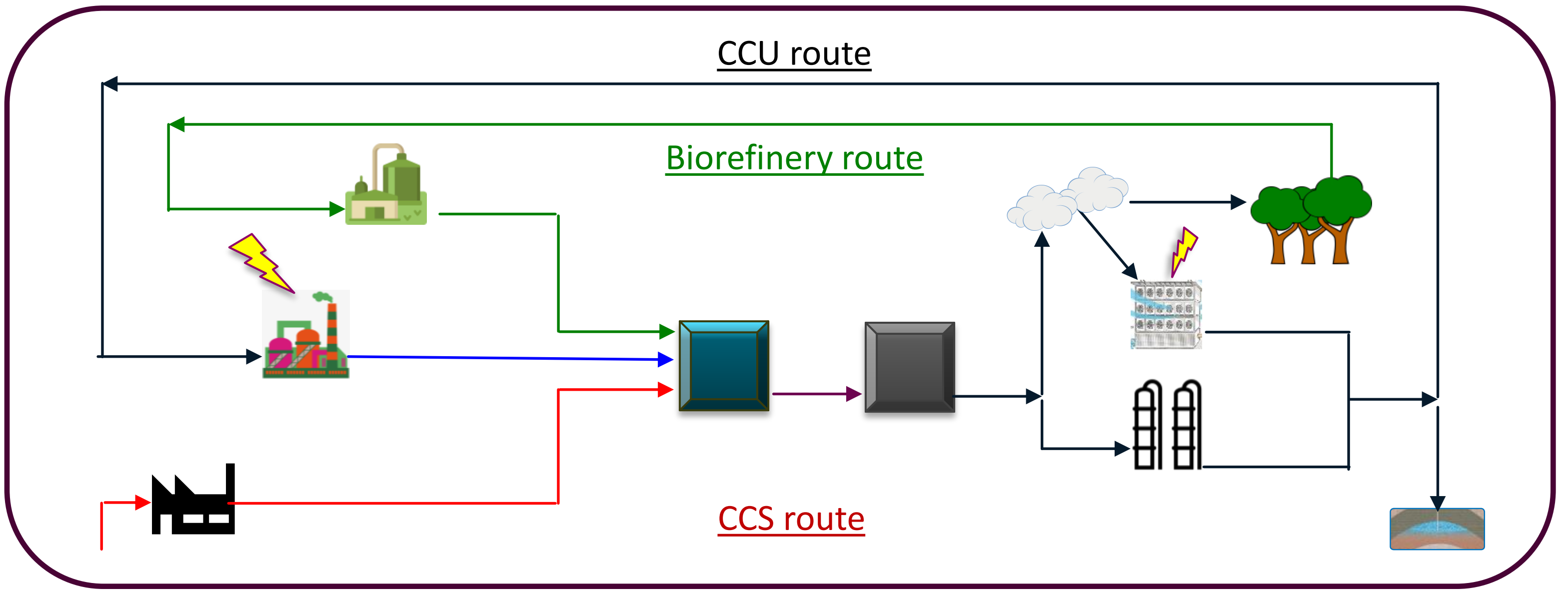


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Biorefinery

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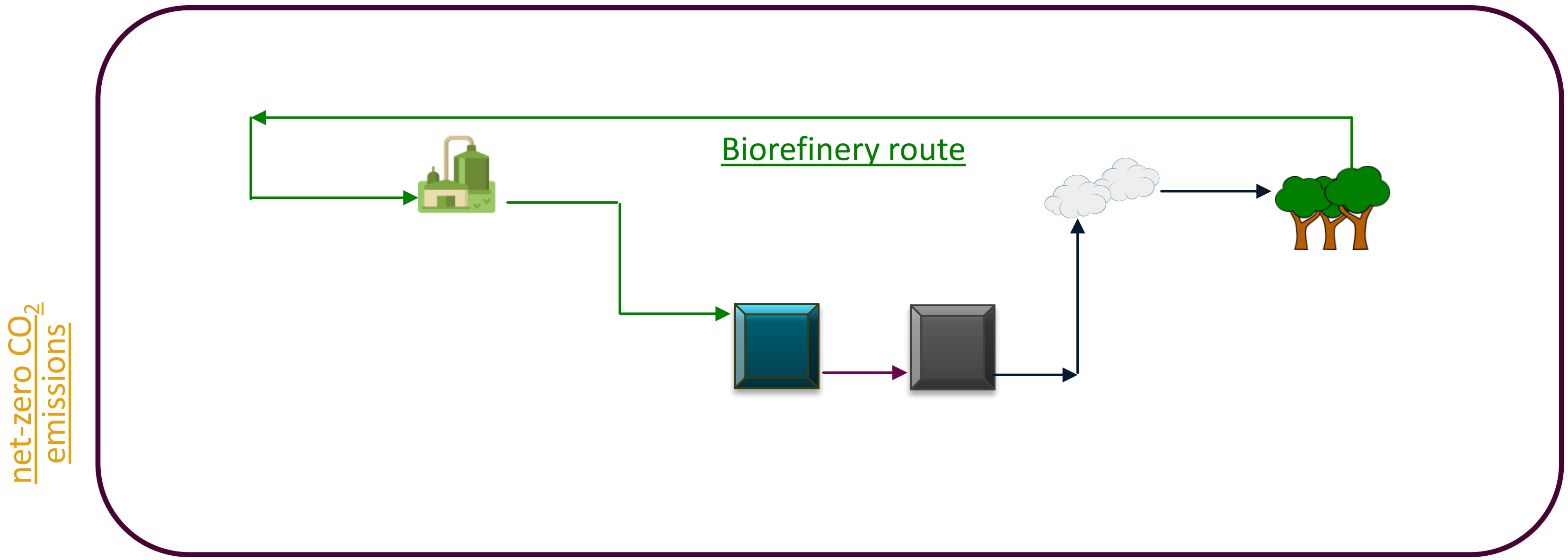


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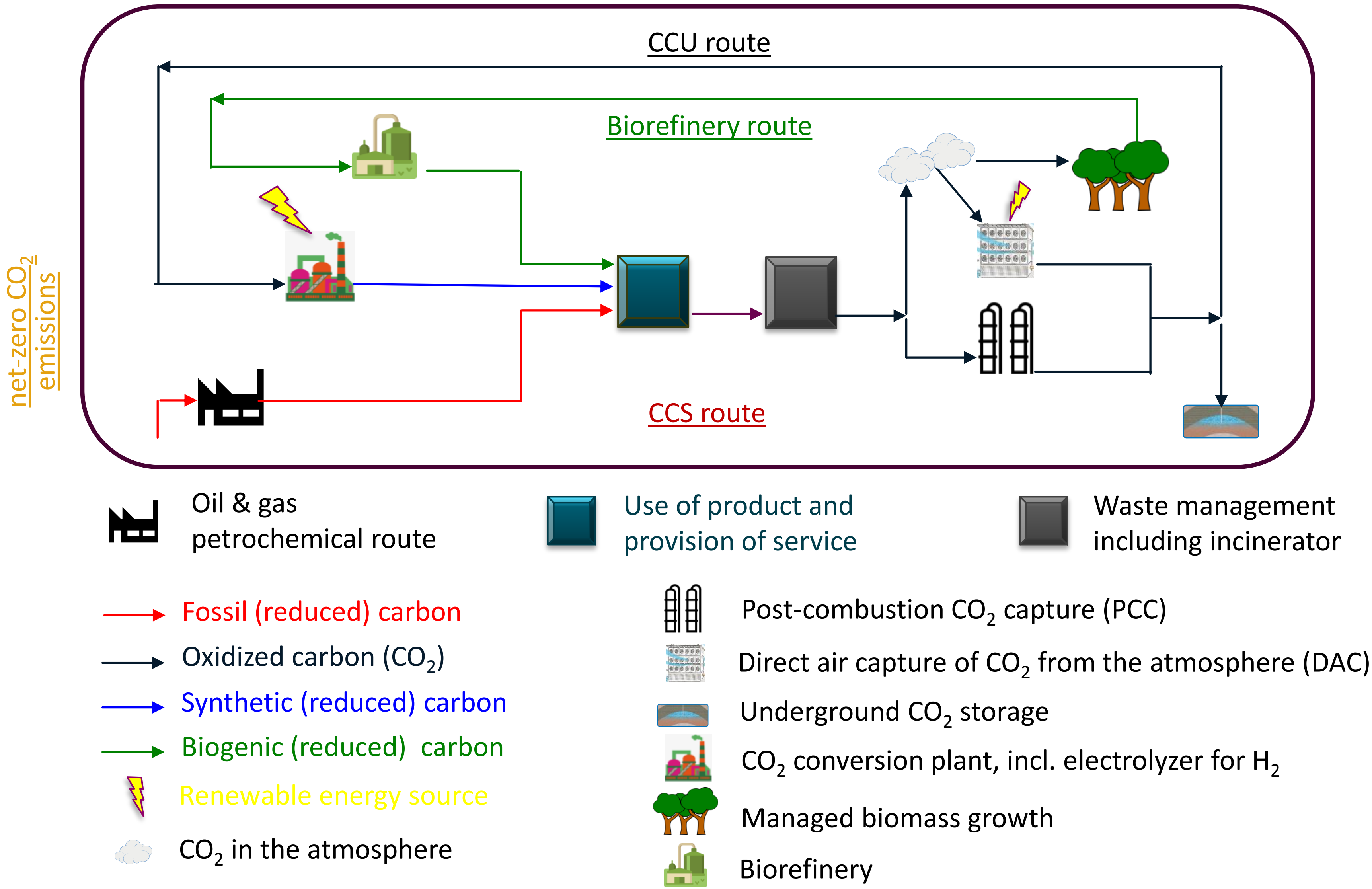

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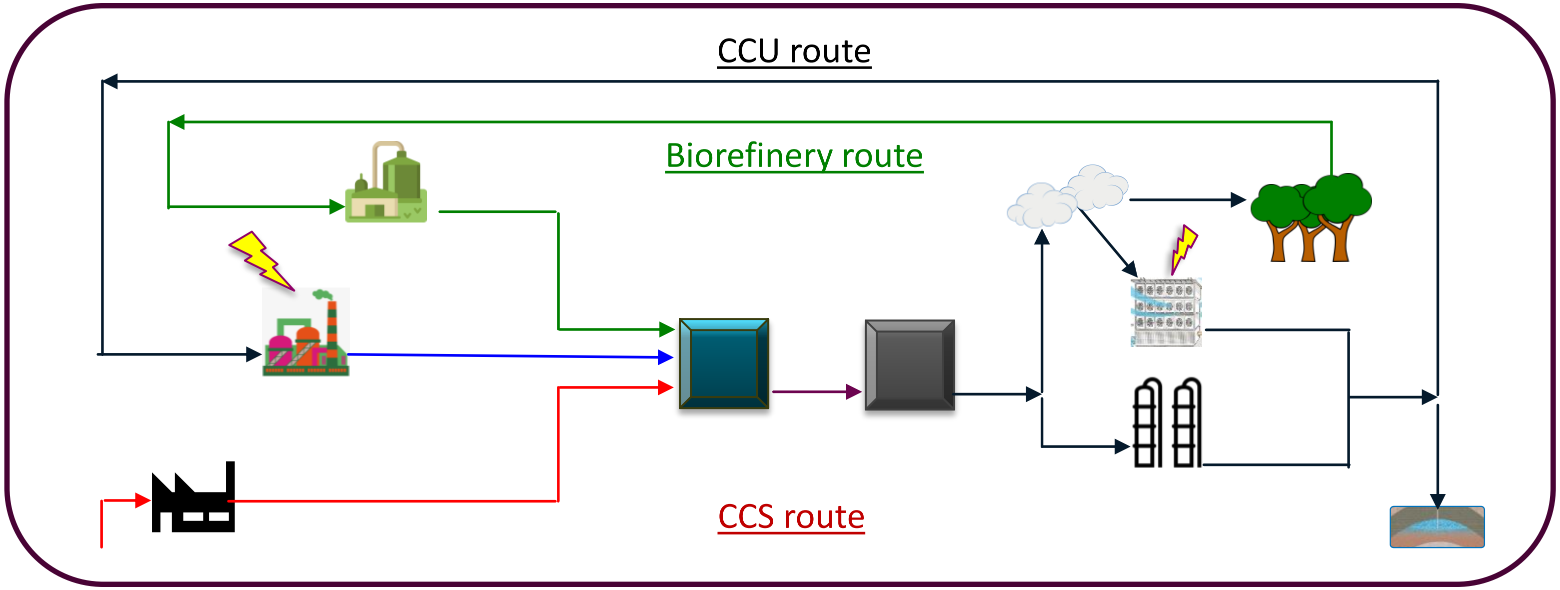


- Only 15% of oil (i.e. only about 5% of all fossil-Carbon) is used for chemicals.
- CCS route seems feasible (1-2 Gt $CO_2$/y) in terms of costs, resources and impact.
- Effective coupling of waste management and $CO_2$ capture is a prerequisite.
- Full LCA needed to allocate $CO_2$ emissions to stakeholders.

- CCU route requires new chemistry and possibly new products.
- Renewable energy penalty is substantial.
- Land use footprint for renewables and DAC is to be evaluated.

- Biorefinery route involves new products and requires new chemistry.
- Natural resources footprint is critical.