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

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

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All workshop participants and organisers

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Working Group members and Euro-CASE staff

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Organisers, speakers and sponsors at the Amsterdam and Ljubljana public engagement events, particularly Robert Thijssen, Royal Dutch Academy of Sciences/Netherlands Academy of Technology and Innovation (KNAW/ AcTI); Professor Slavko Kaucic, Slovenian Academy of Engineering.

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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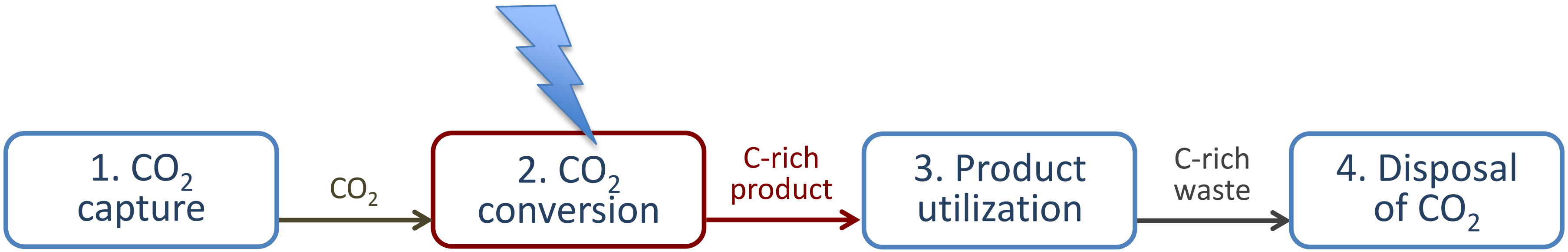

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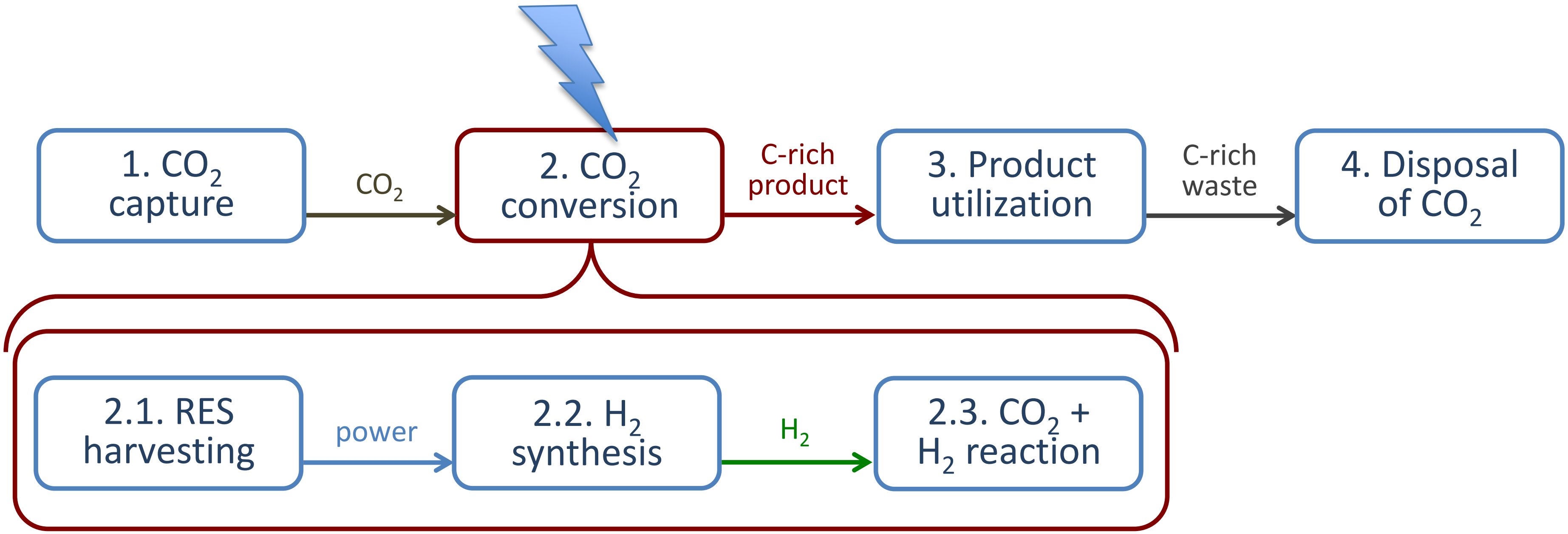

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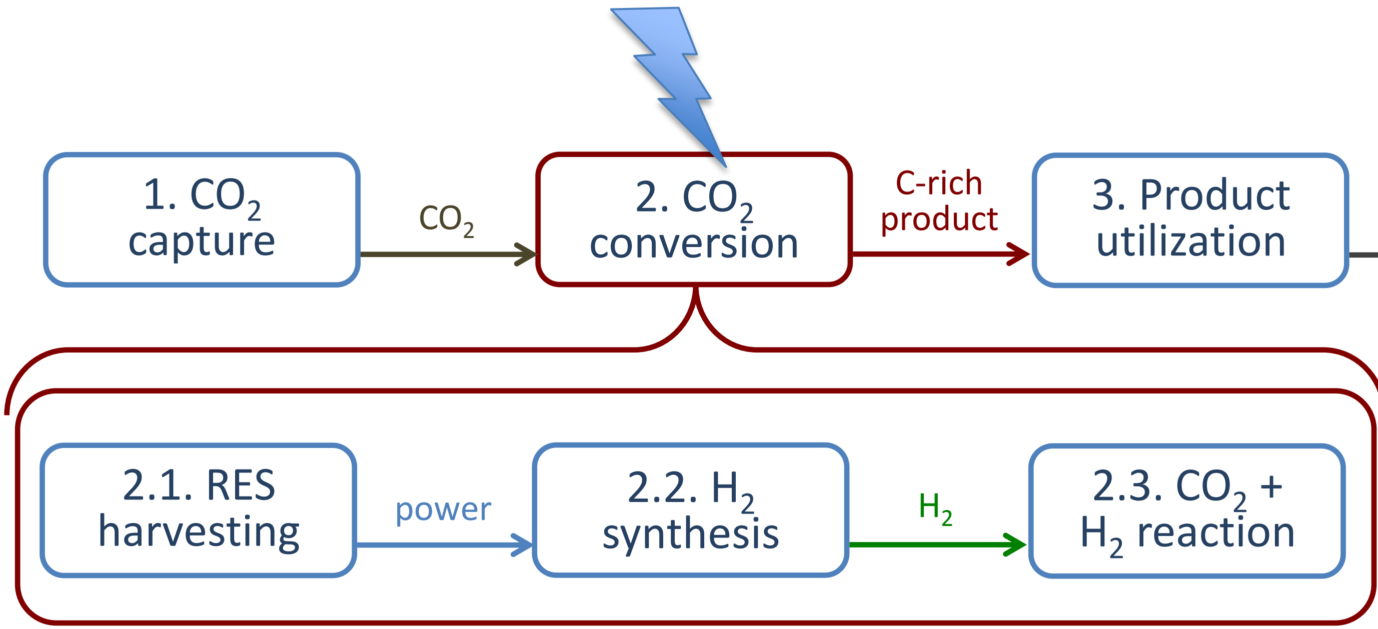

CCU POTENTIAL IN EU TO SUPPORT:

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

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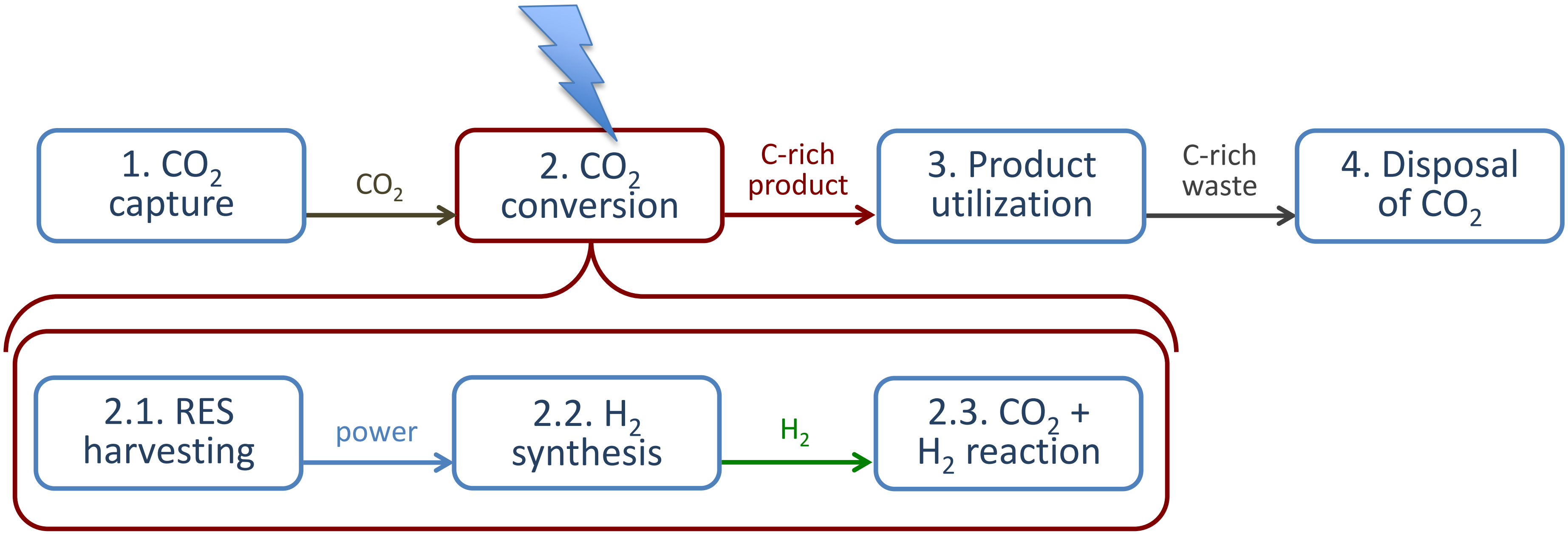

WG VIEW: SOCIETAL SERVICES

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

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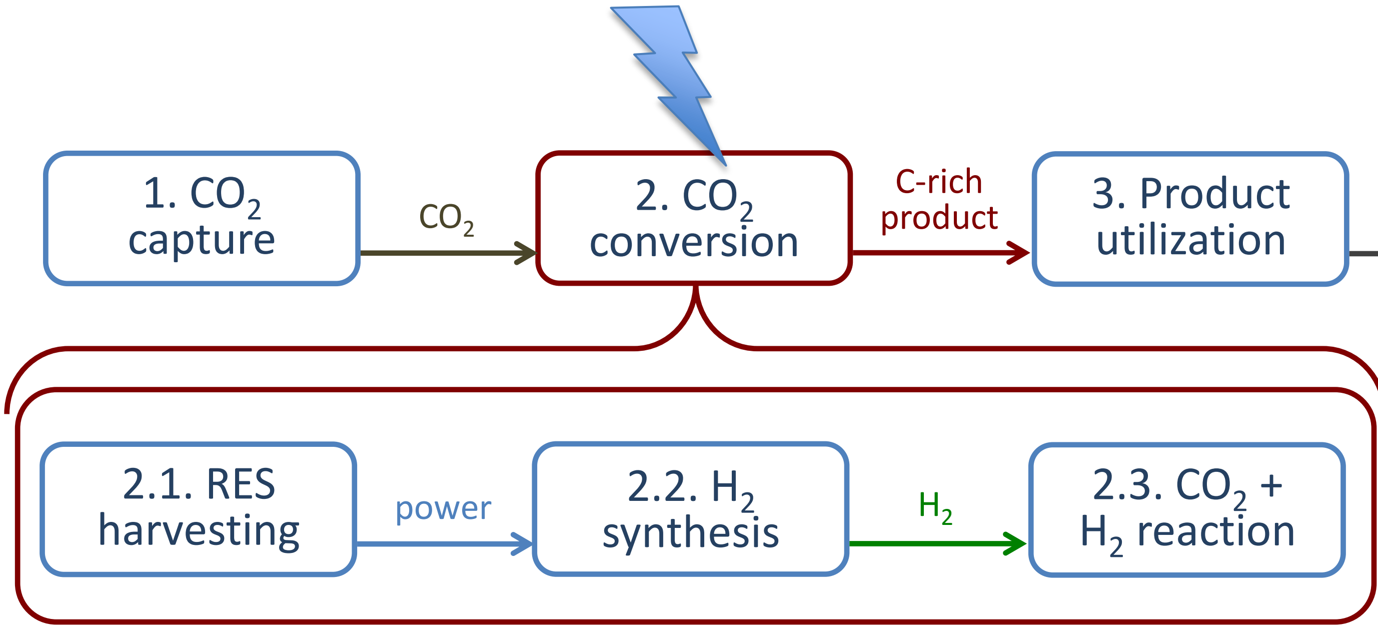

CCU CYCLES

- Energy cycle
- Carbon cycle
- Material cycles

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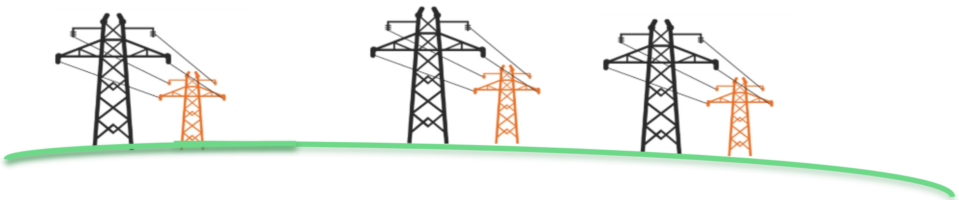

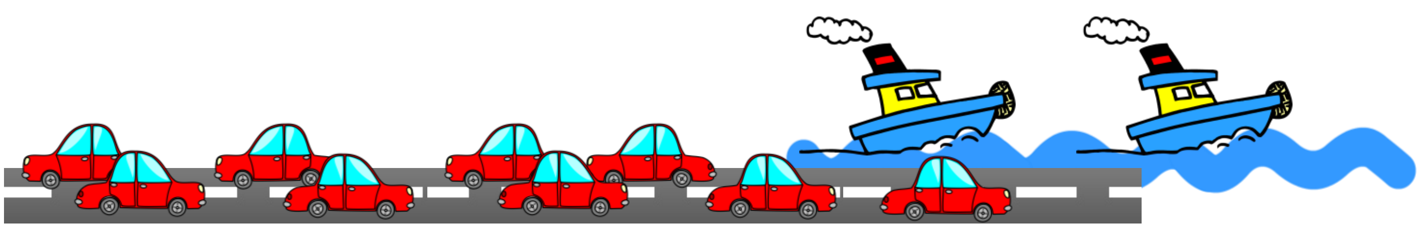

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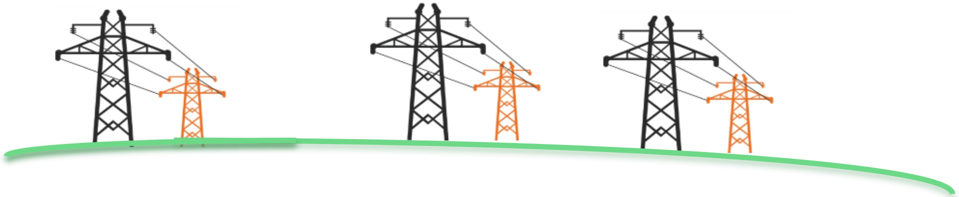

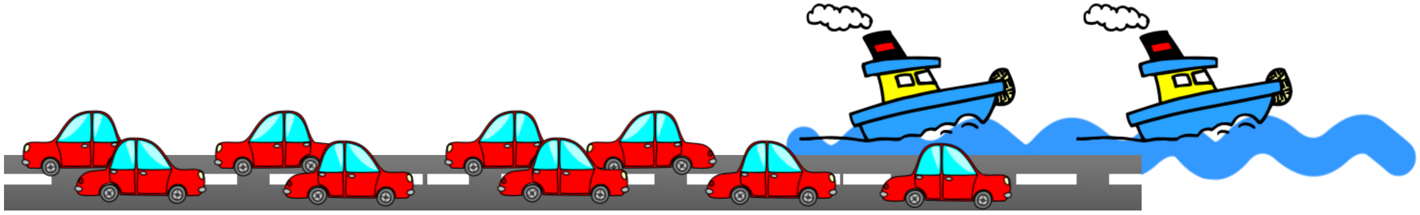

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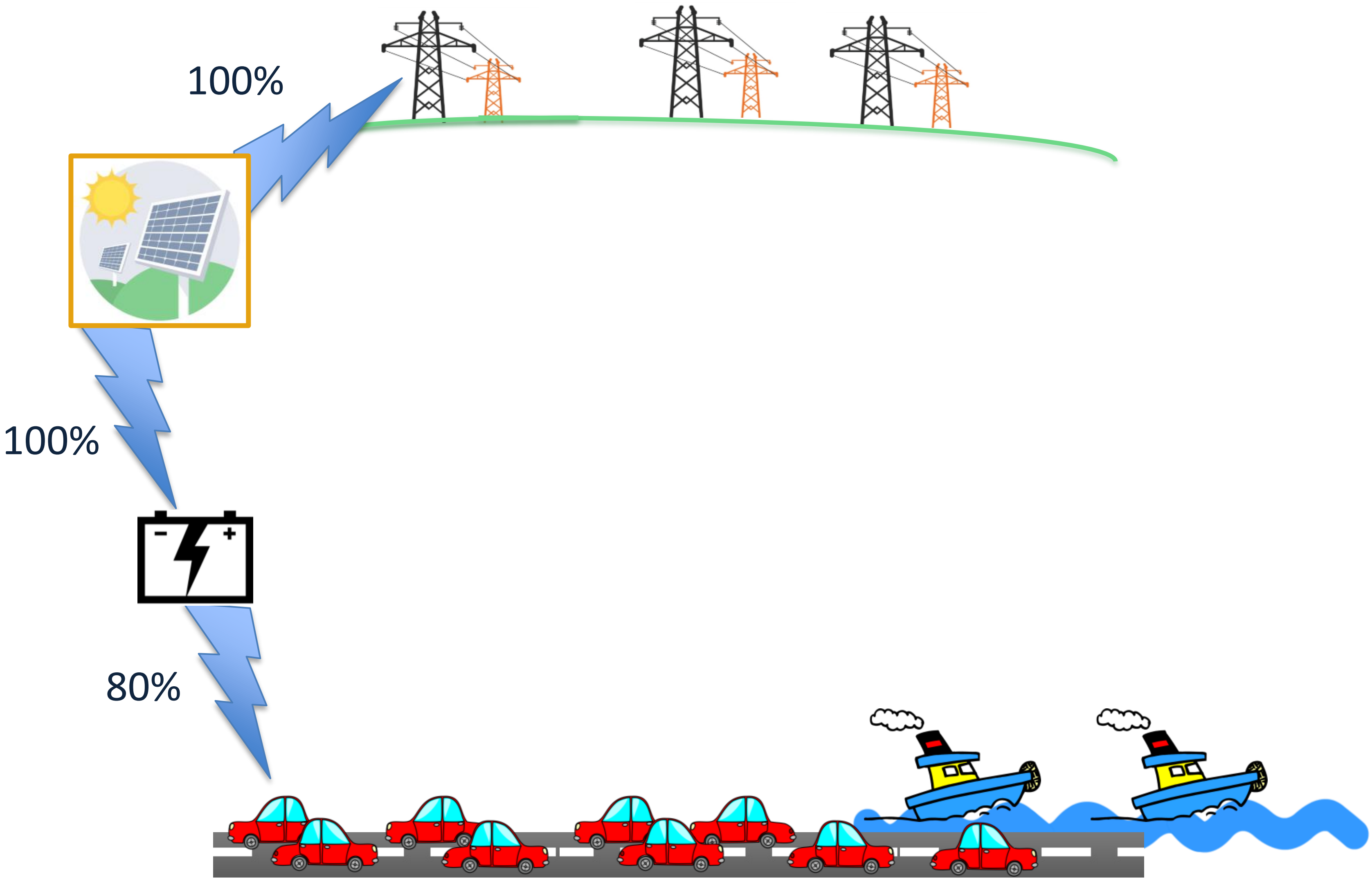

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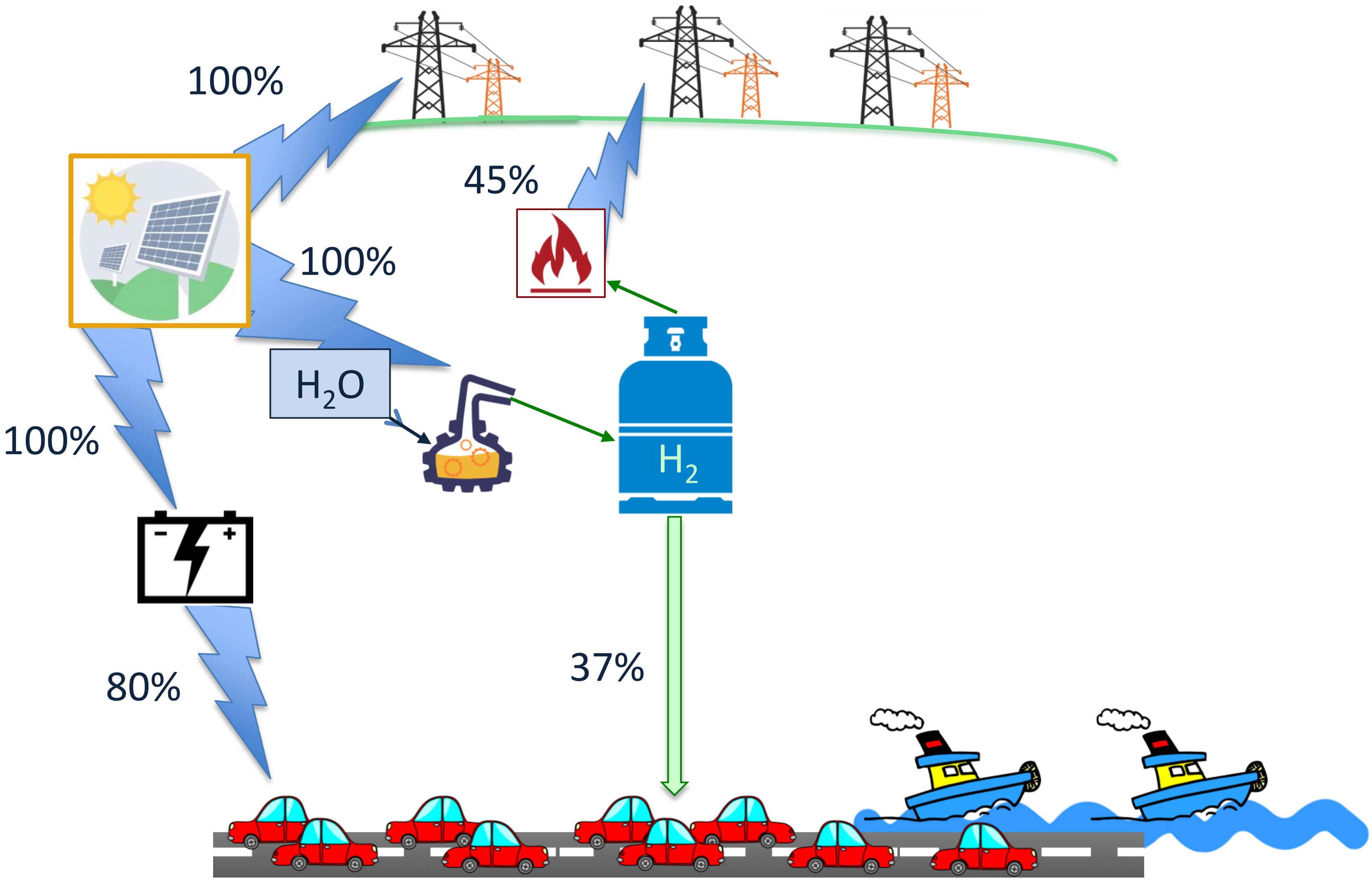

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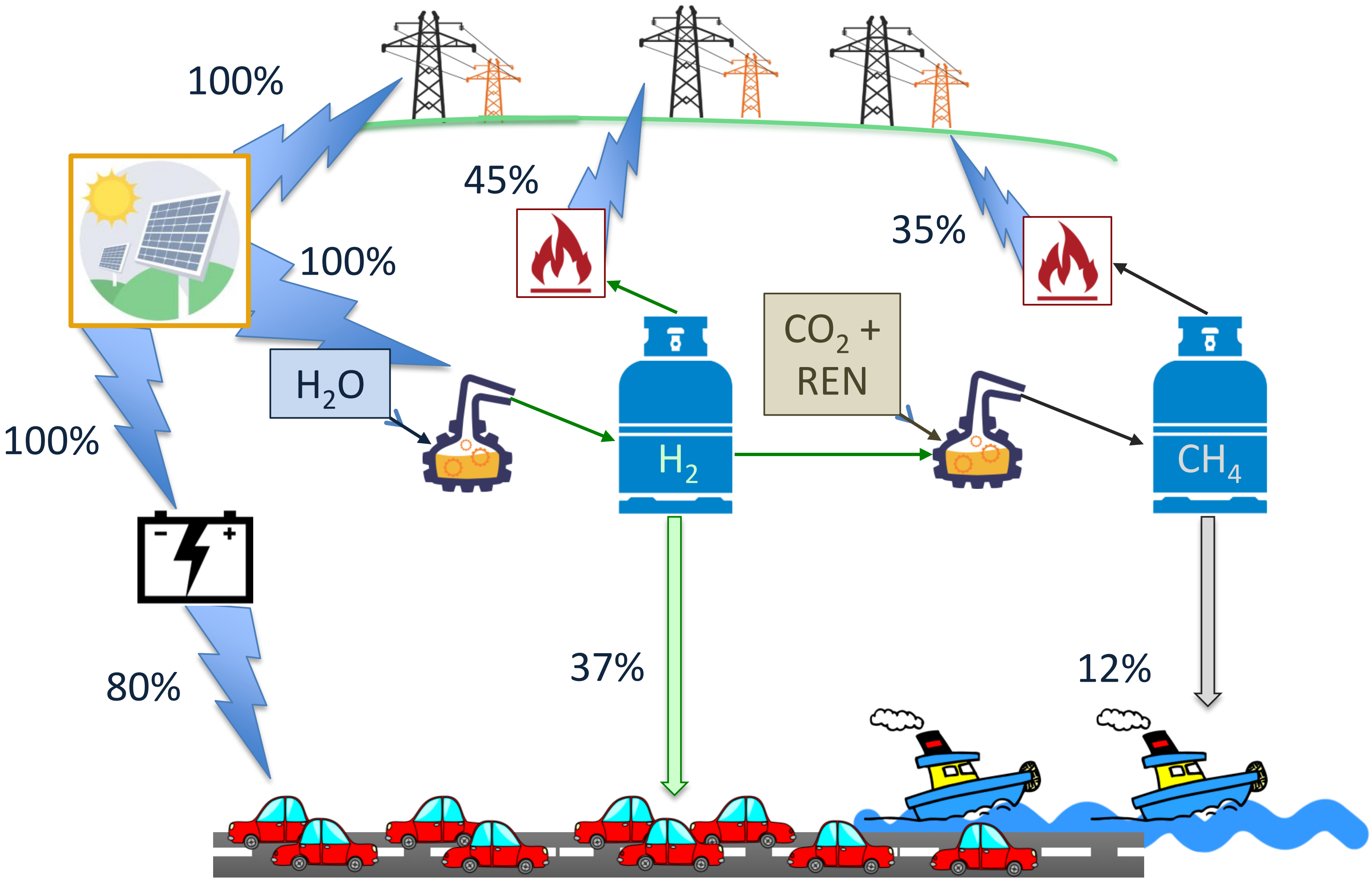

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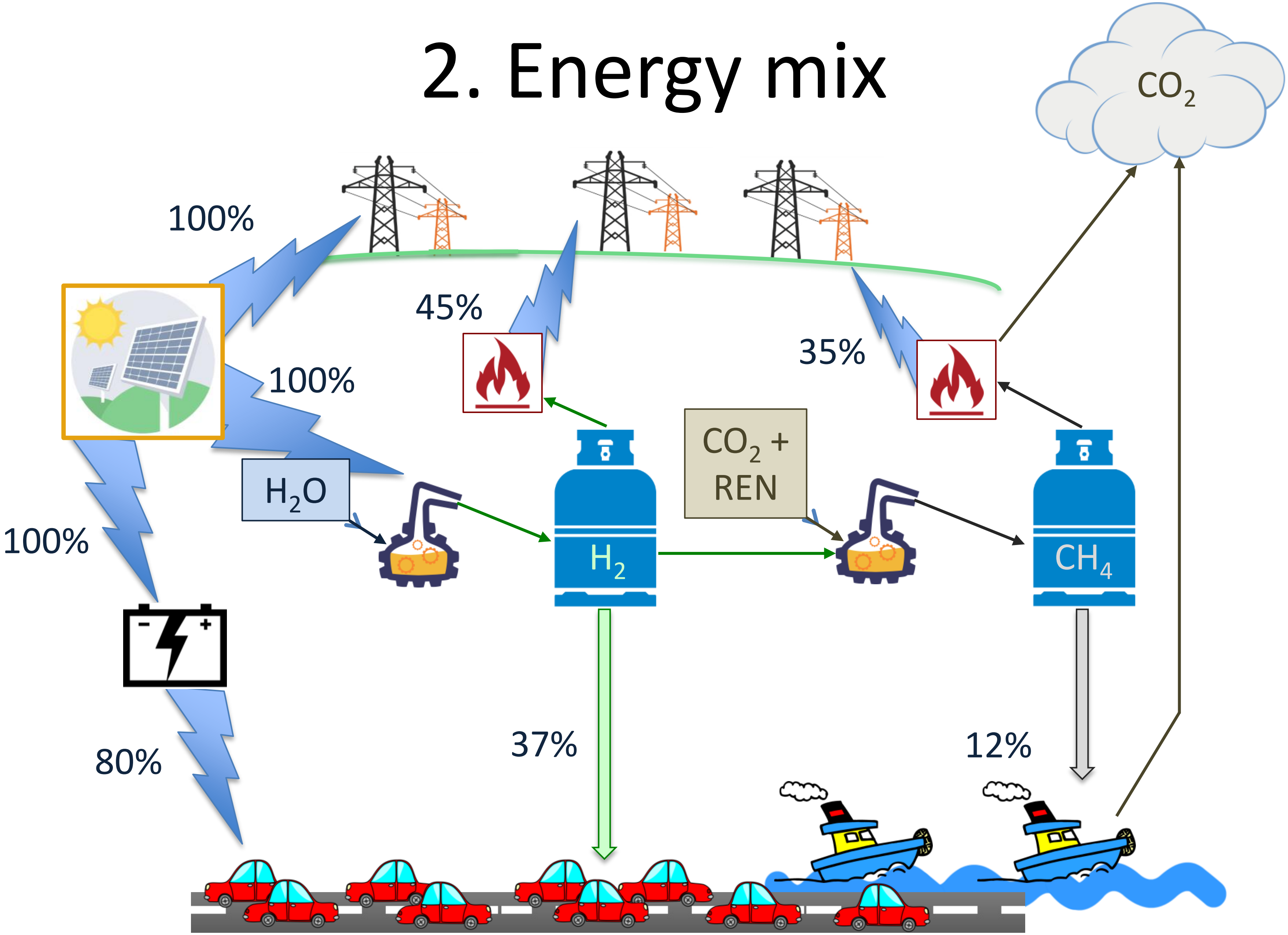
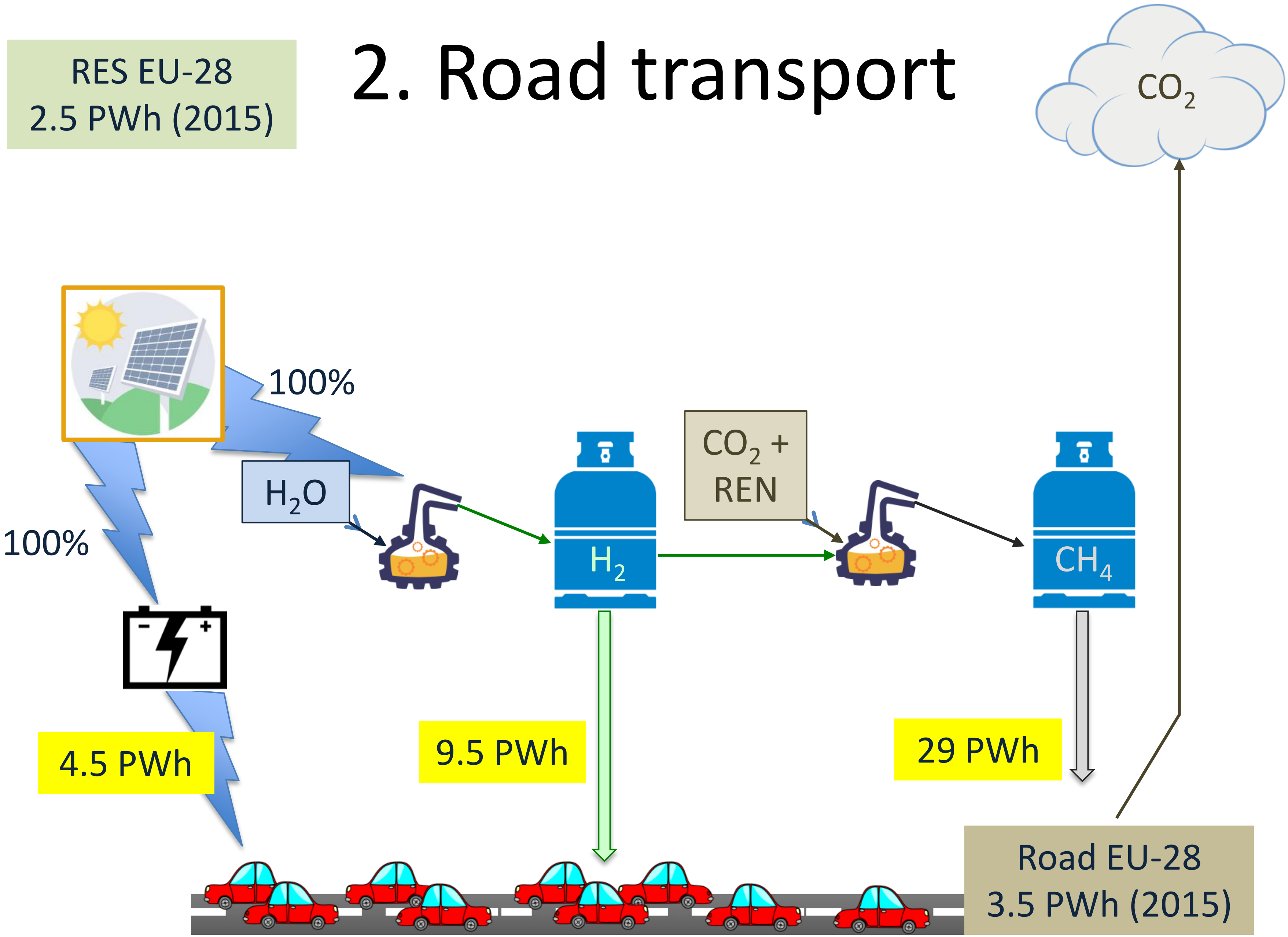


2. Road transport



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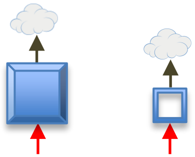

1. L-economy

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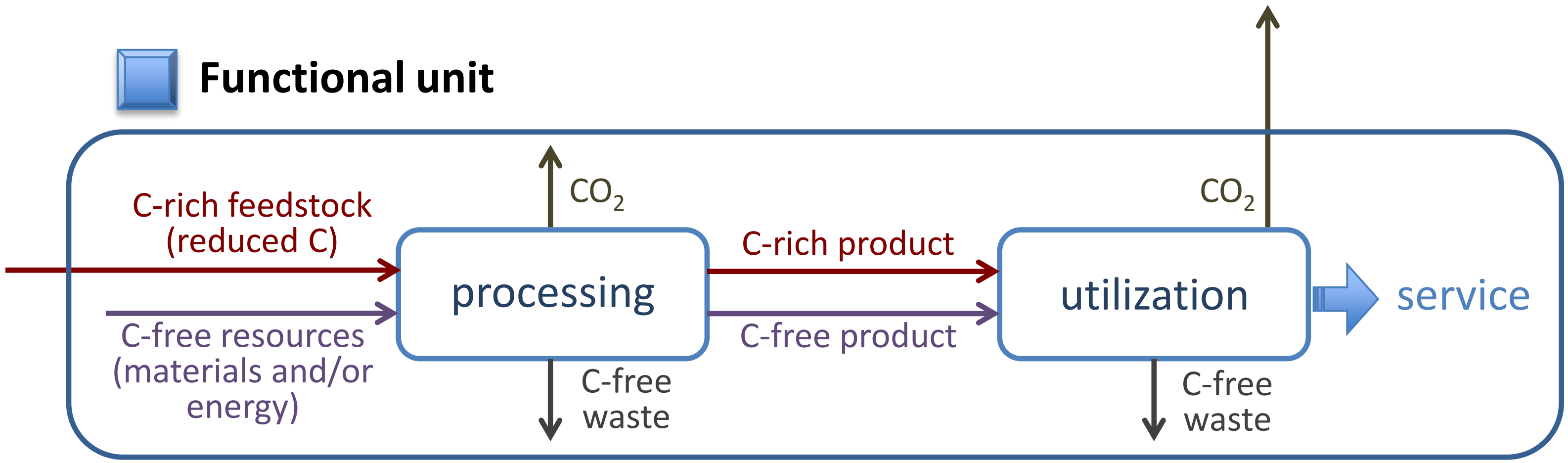
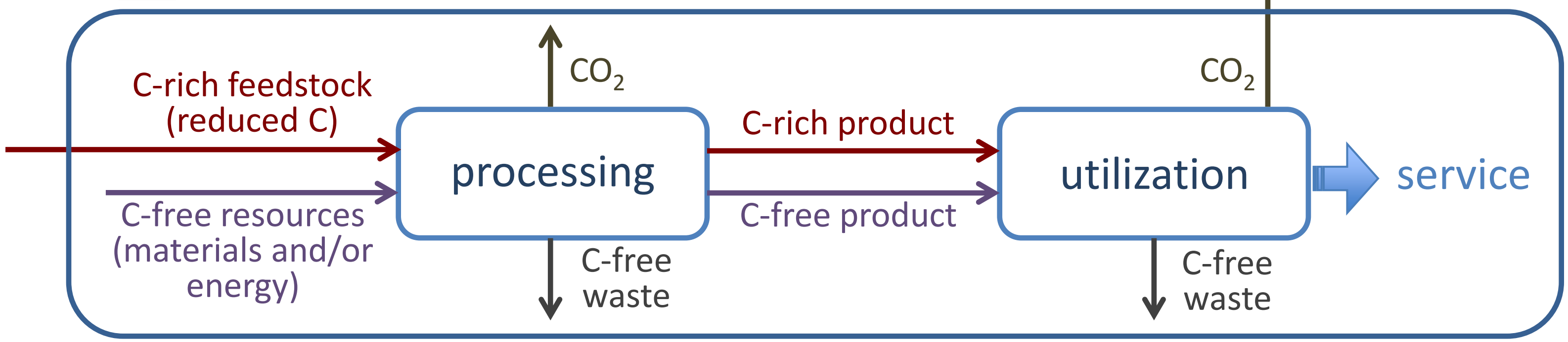


3. Carbon balances

Functional unit 1: C-use and <u>centralized</u> 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)

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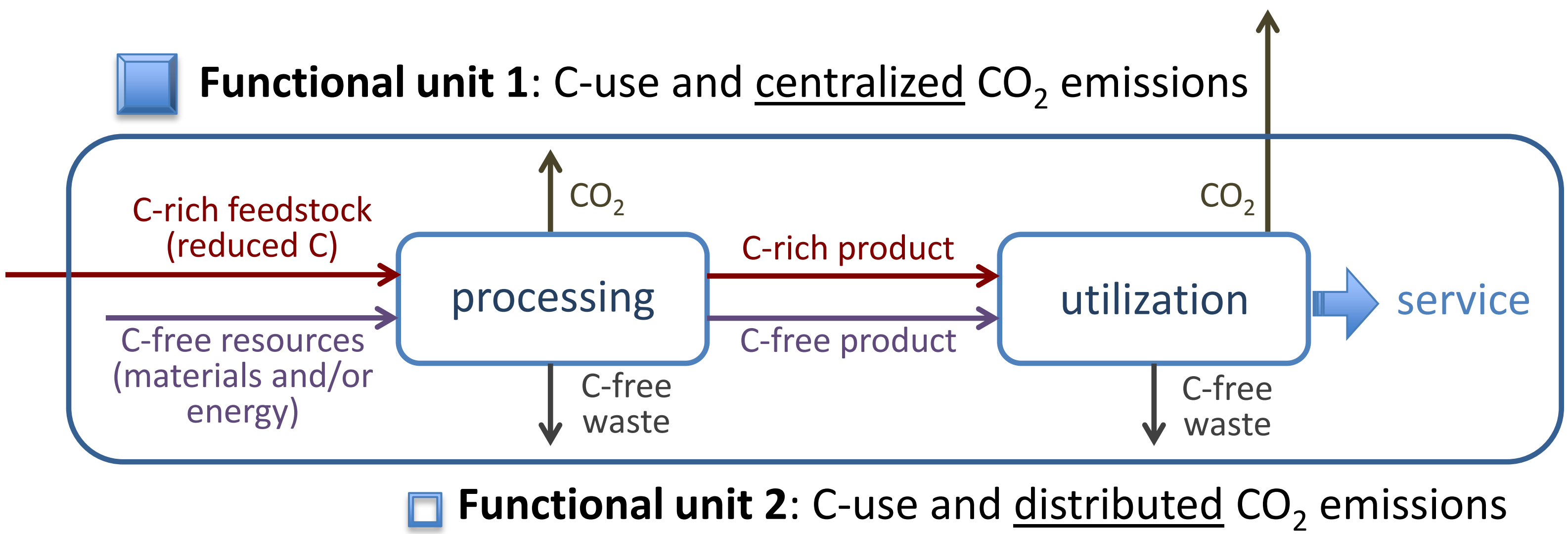

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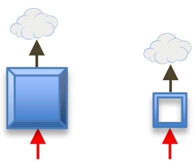
Functional unit 2:

- 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

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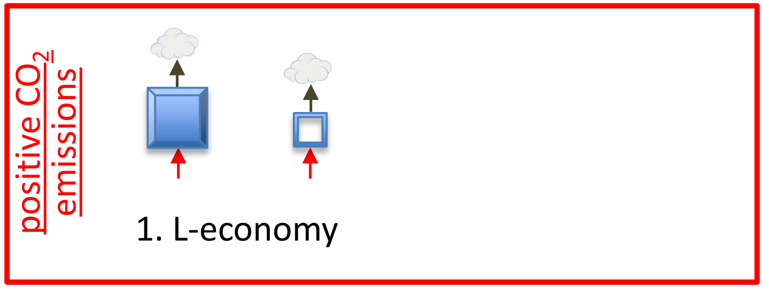

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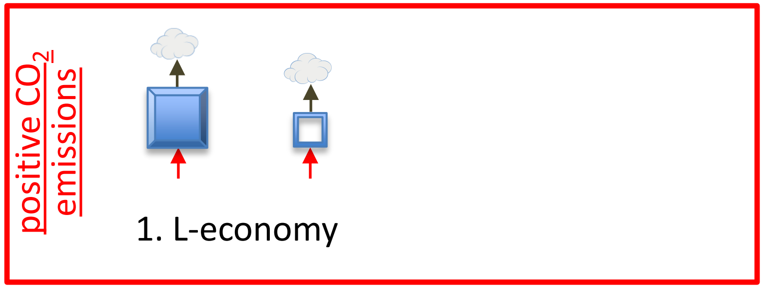

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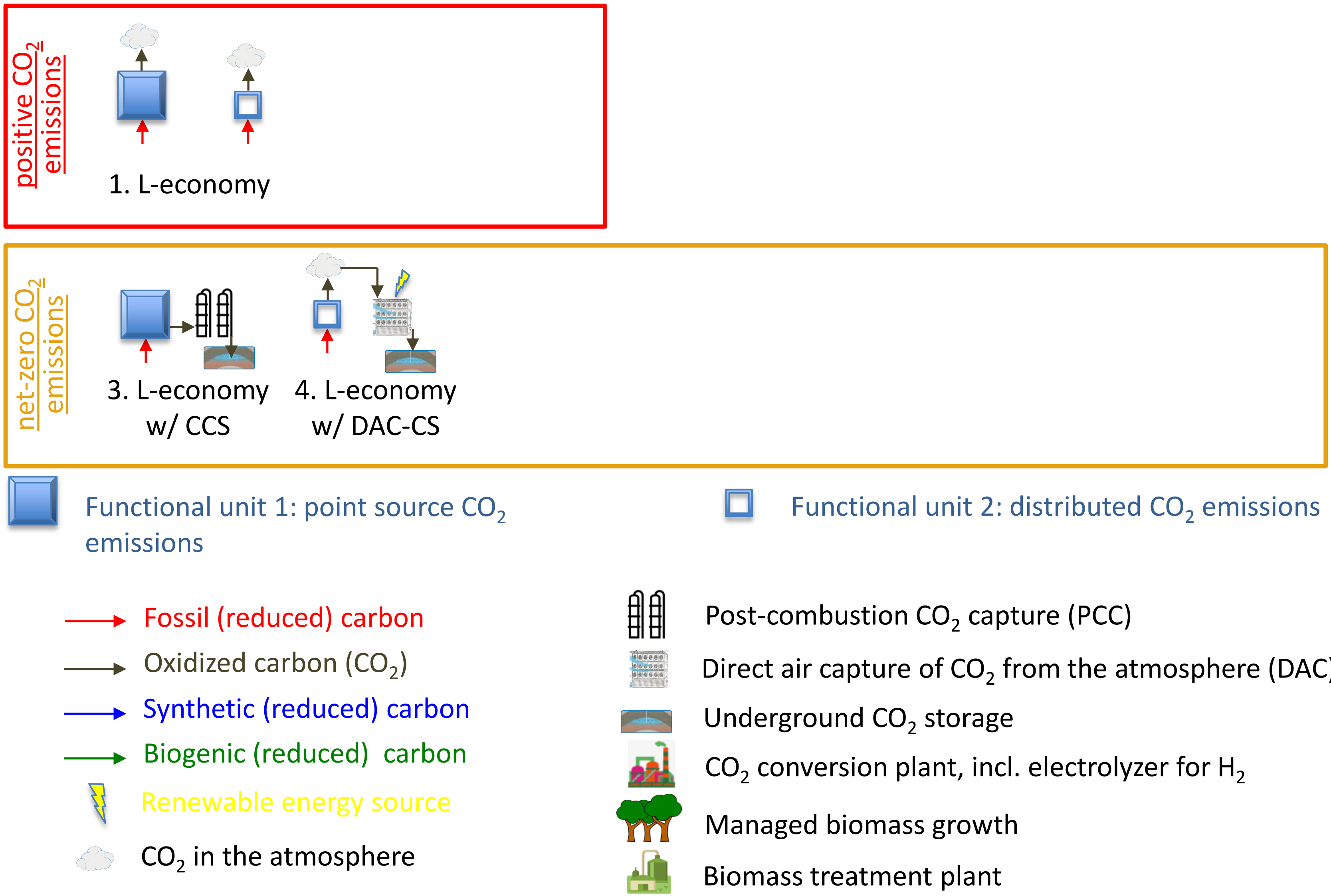

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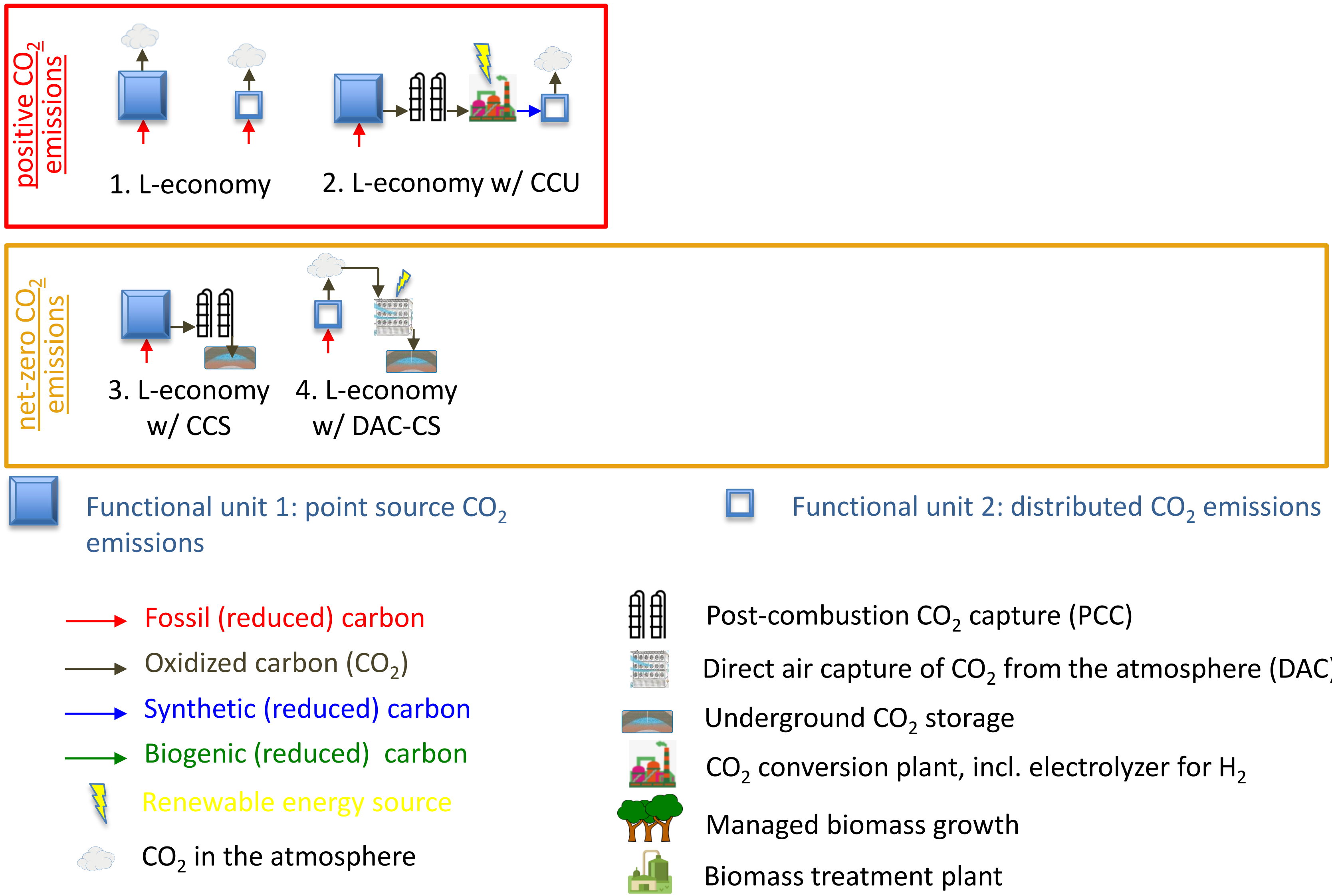

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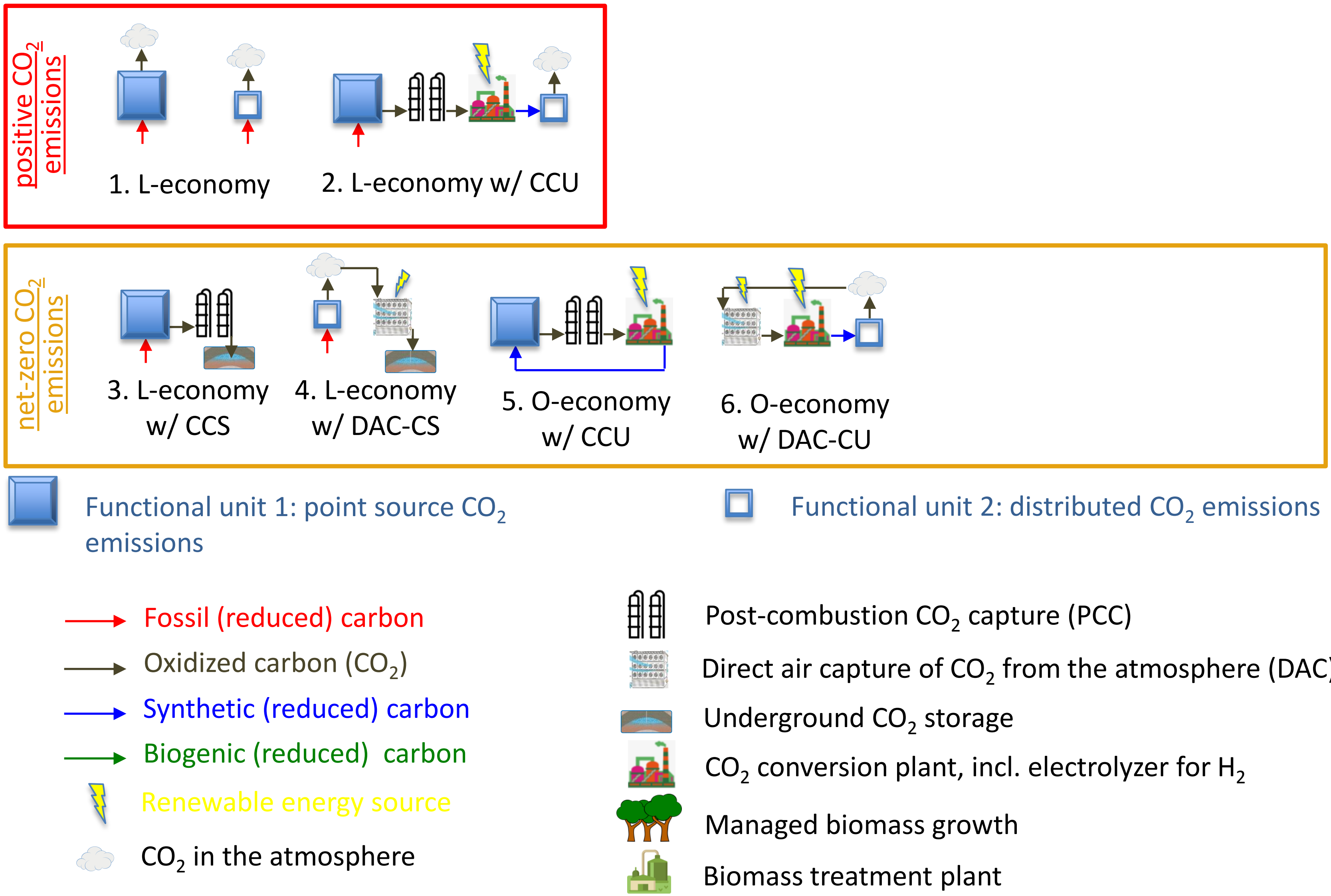

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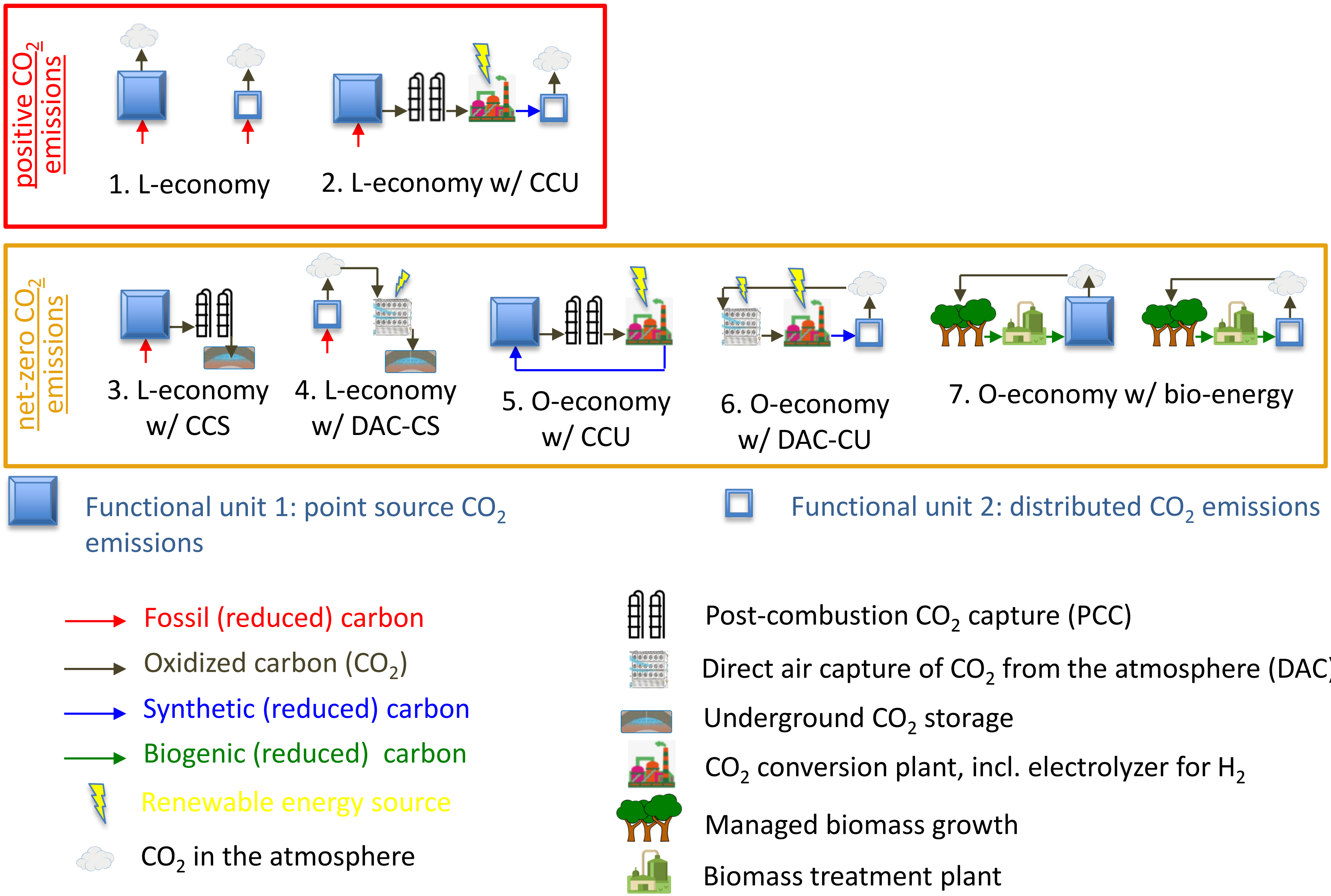

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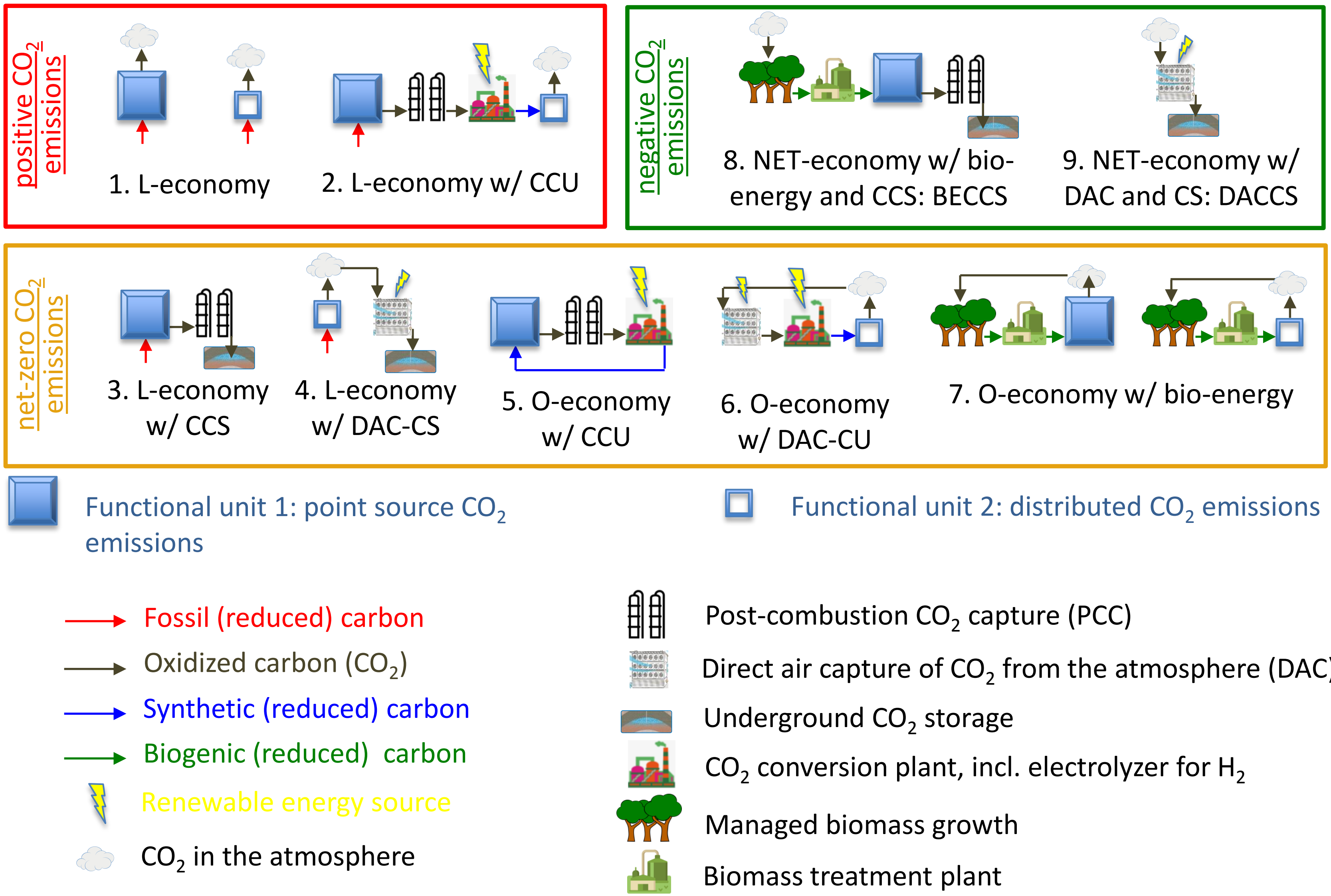

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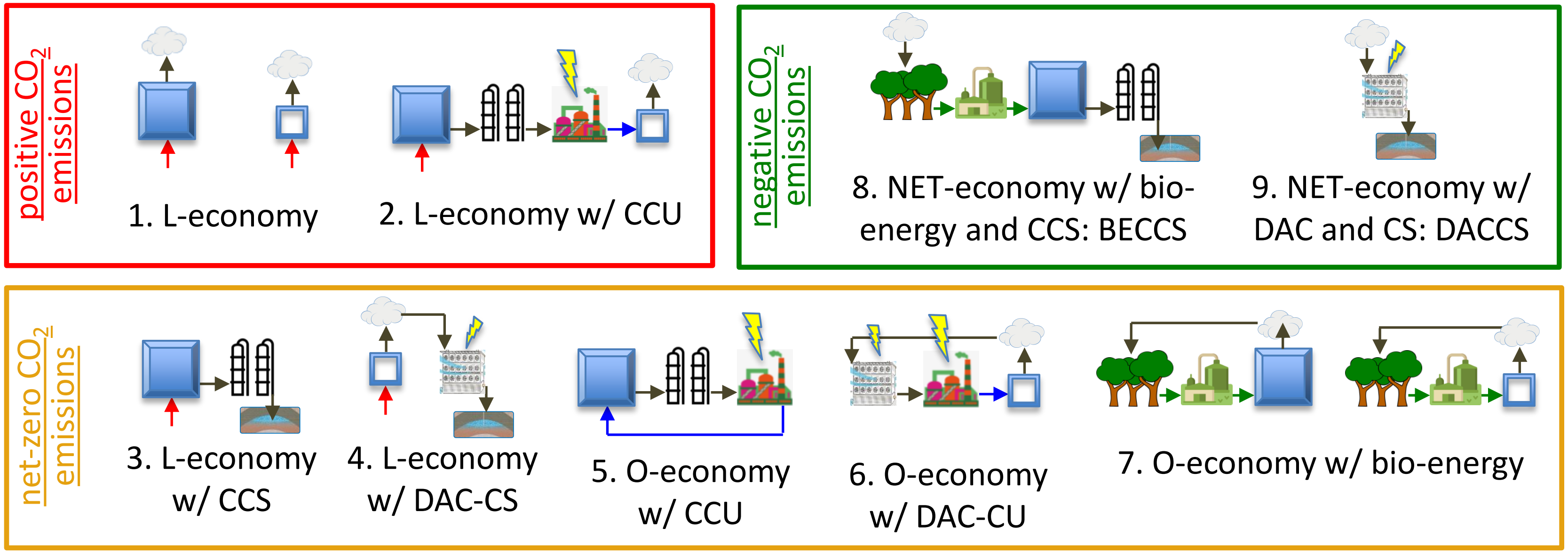

A FEW COMMENTS

- C-free RES to be LCA-assessed;
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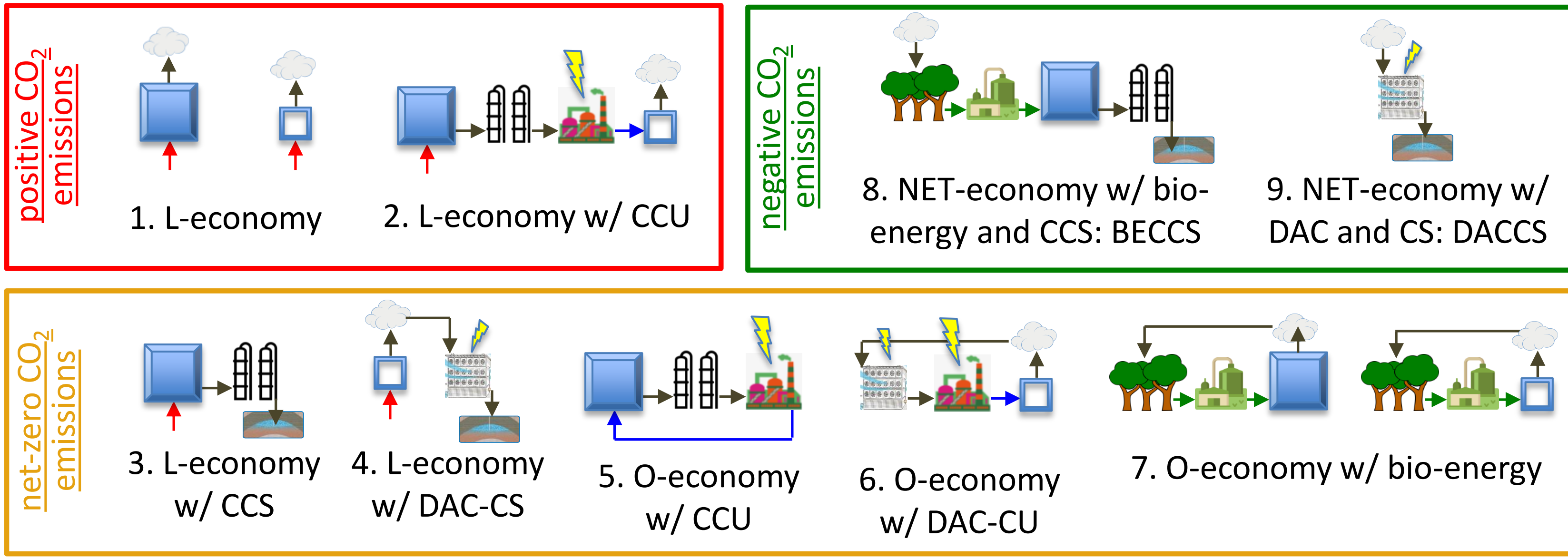

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SIMPLIFIED SYSTEM ANALYSIS

- 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.

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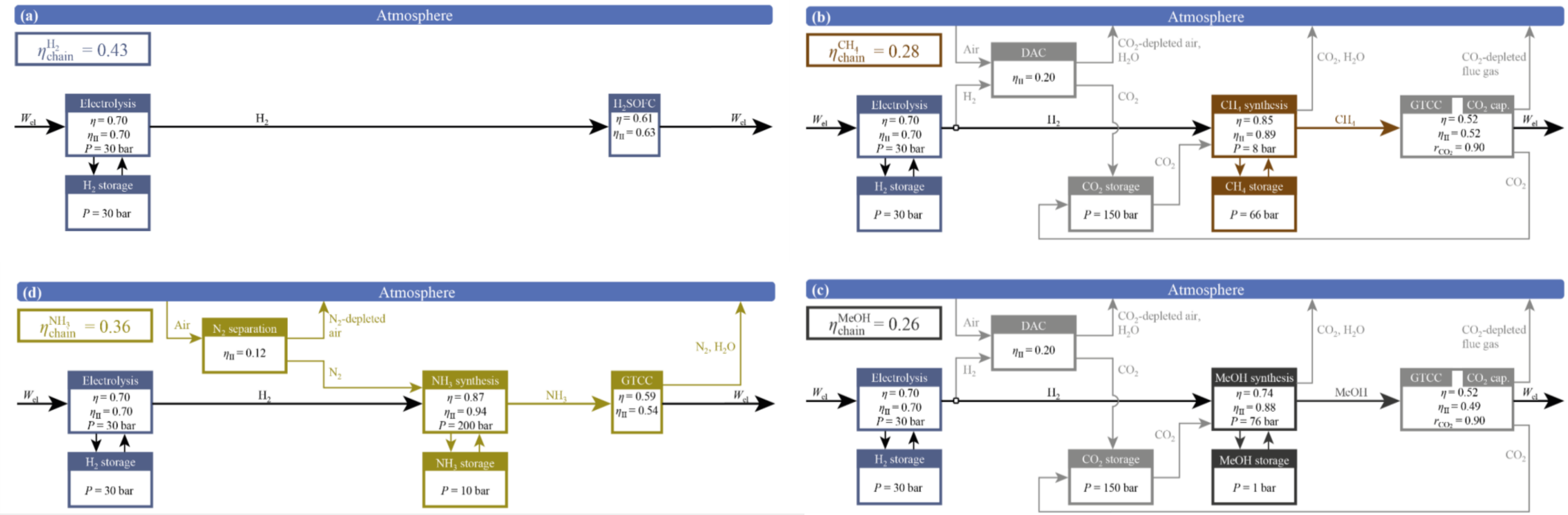
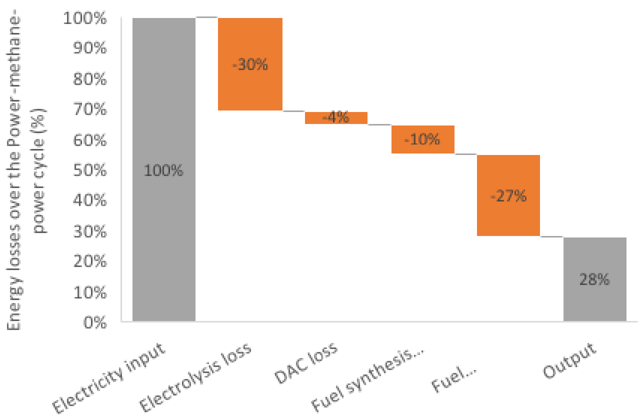
5. Comparison of net-zero CCU loops to C-free systems



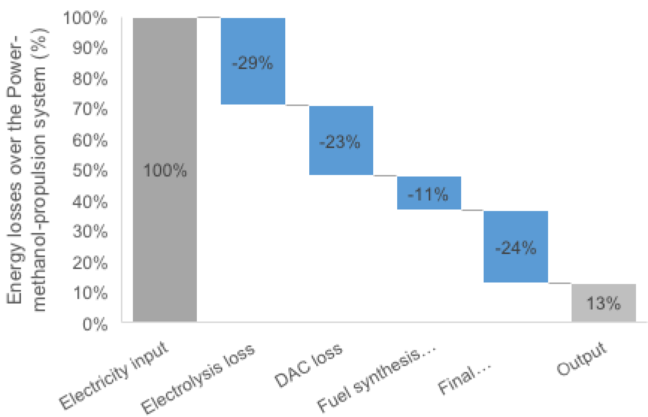
Sutter, van der Spek, Mazzotti, submitted (2018)

5. The efficiency cost of seasonal energy storage

Power-methane-power



Power-methanol-propulsion



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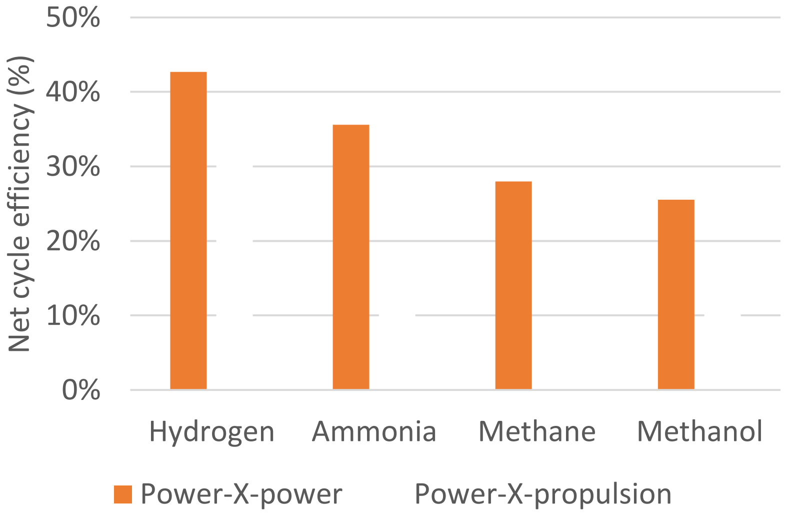
5. CCU fuels for power generation and propulsion

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

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



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  - ~30% net cycle efficiency
- Power-ammonia-**power**
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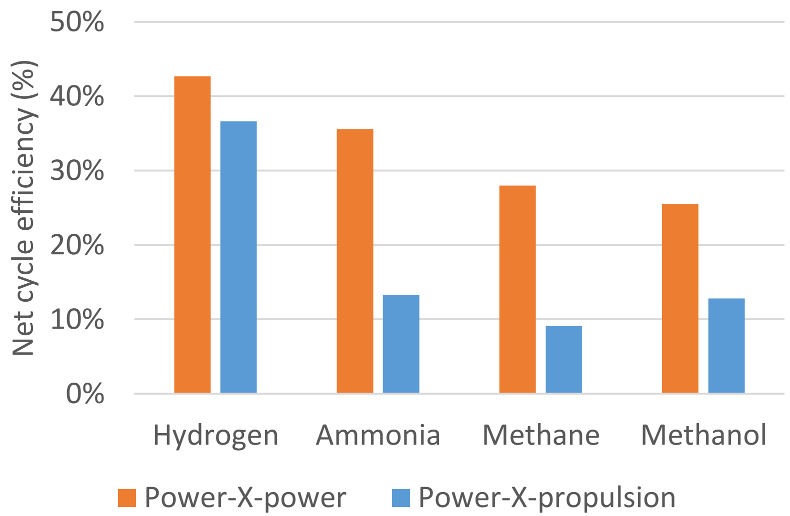
- Power-methanol-**propulsion**
  - ~13% net cycle efficiency
- Power-hydrogen-X
  - Highest efficiencies for power and propulsion
  - Transport fuel of choice!?



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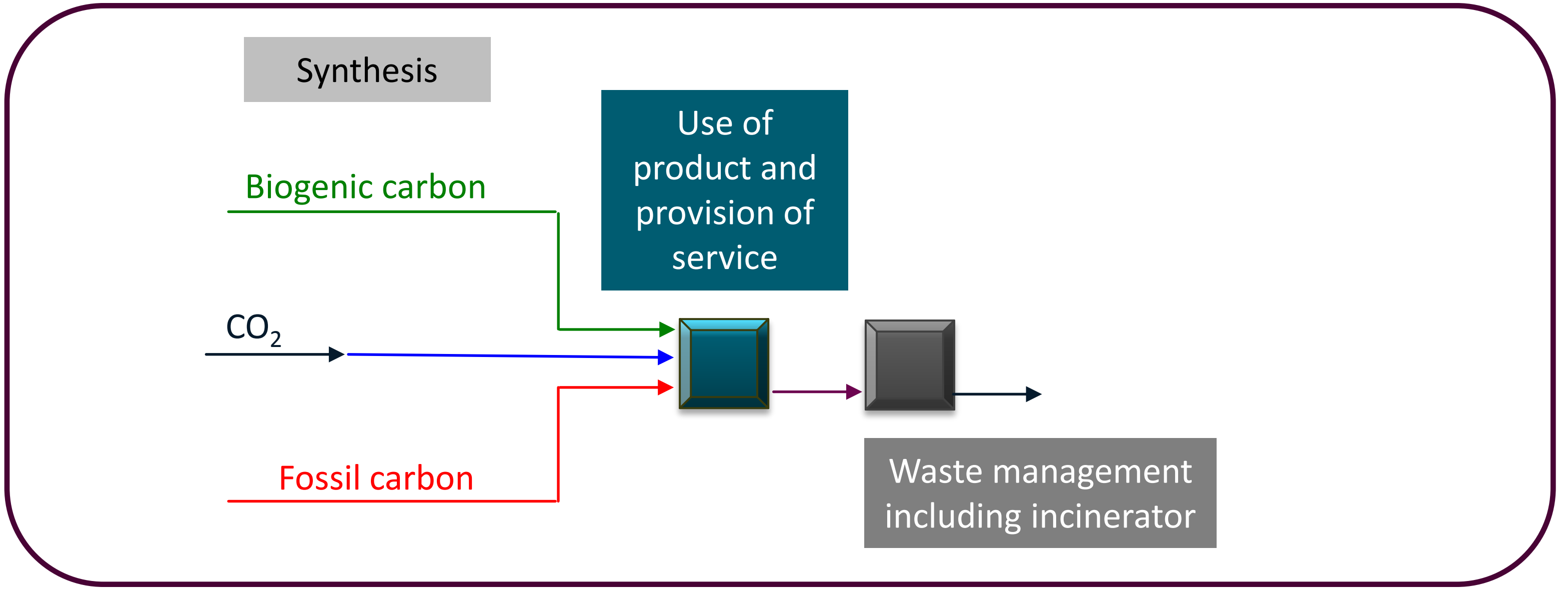
Chemical products provide services



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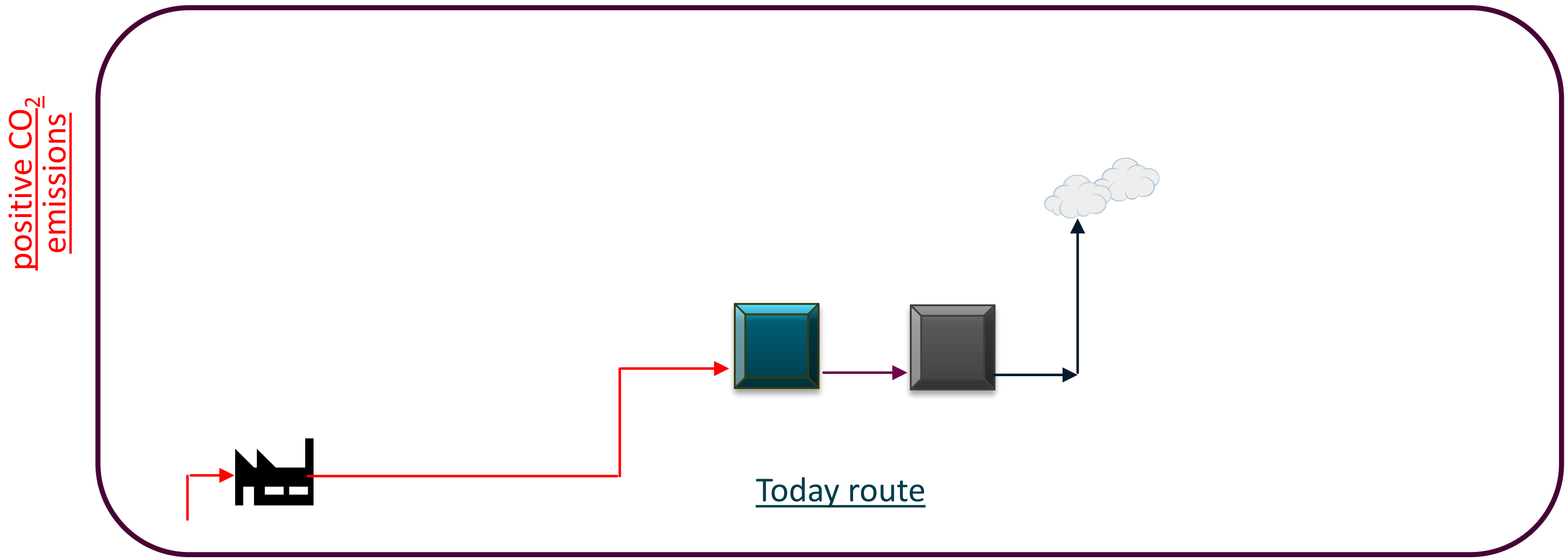

Oil & gas petrochemical route

Use of product and provision of service

Waste management including incinerator

Fossil (reduced) carbon

Oxidized carbon (CO_2)

CO_2 in the atmosphere

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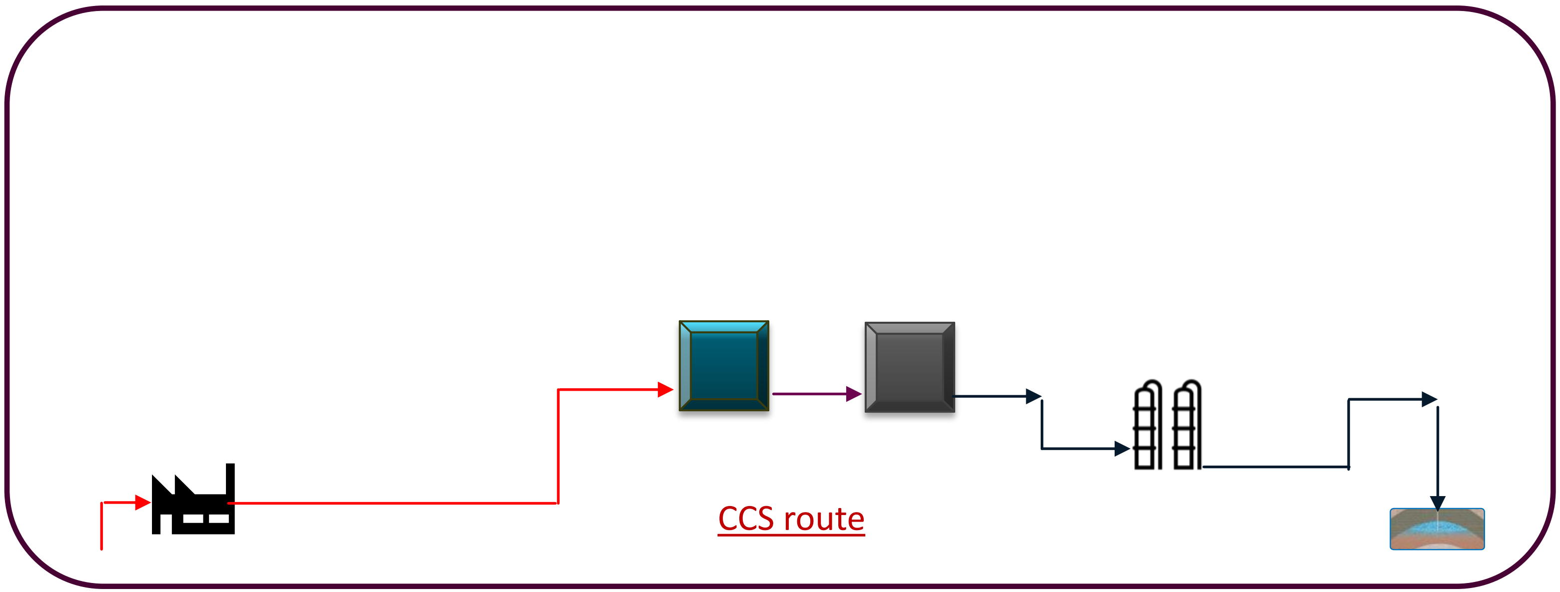
Chemical products in a net-zero-CO_2-emissions world



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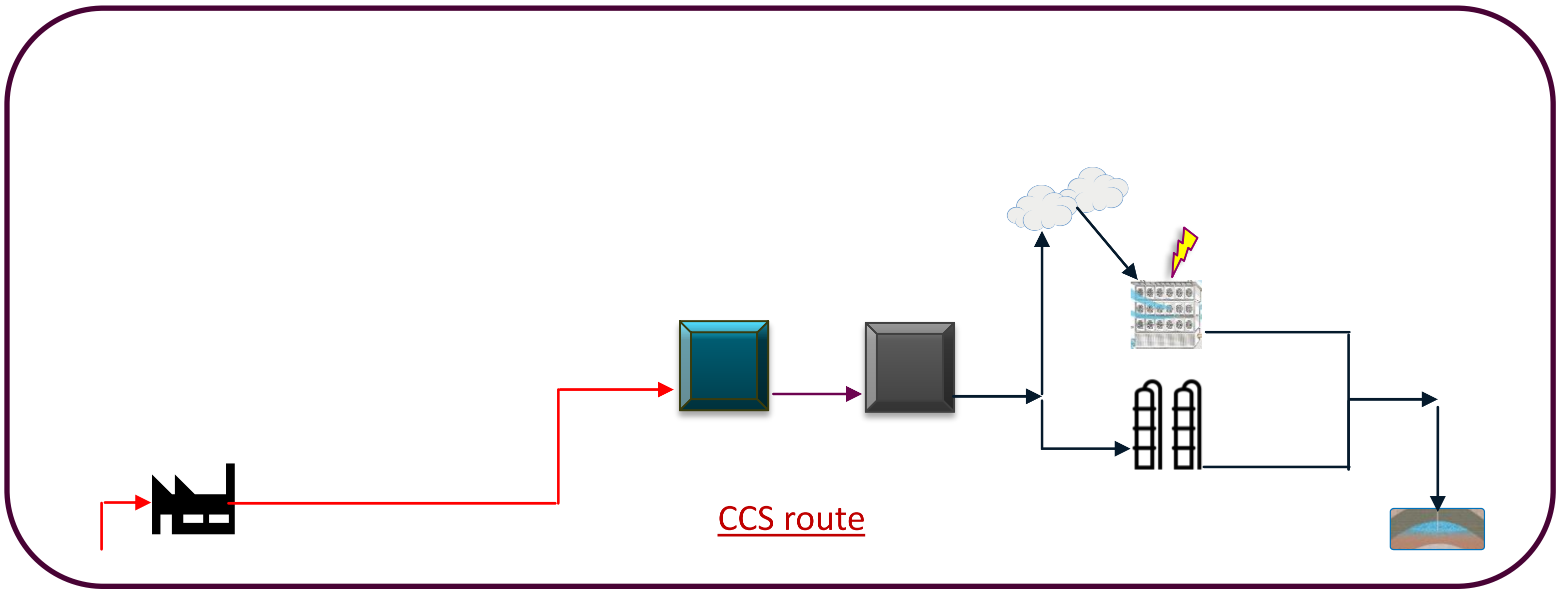

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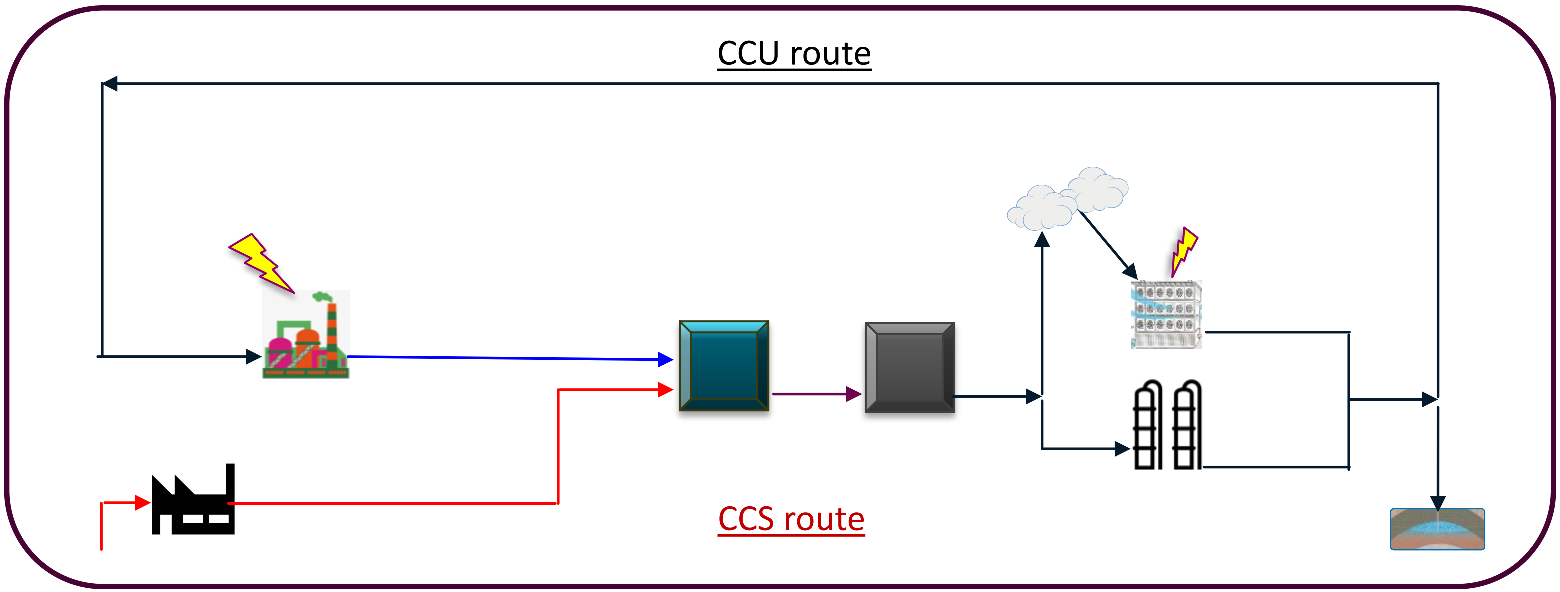

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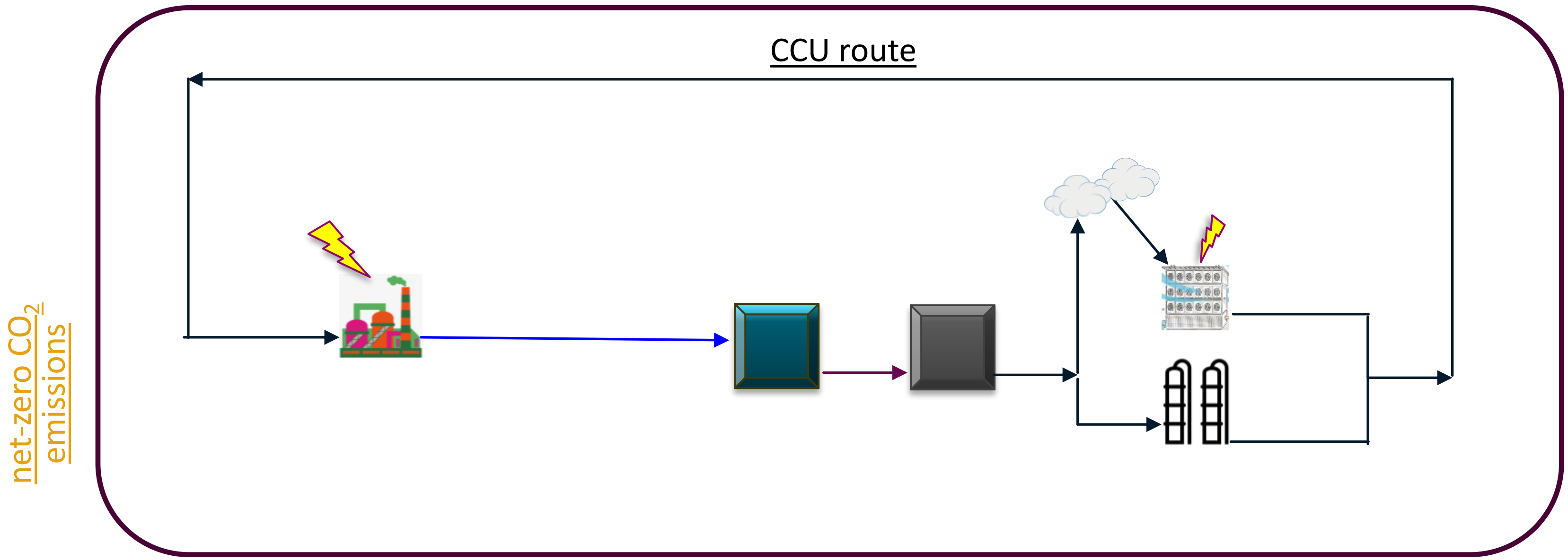

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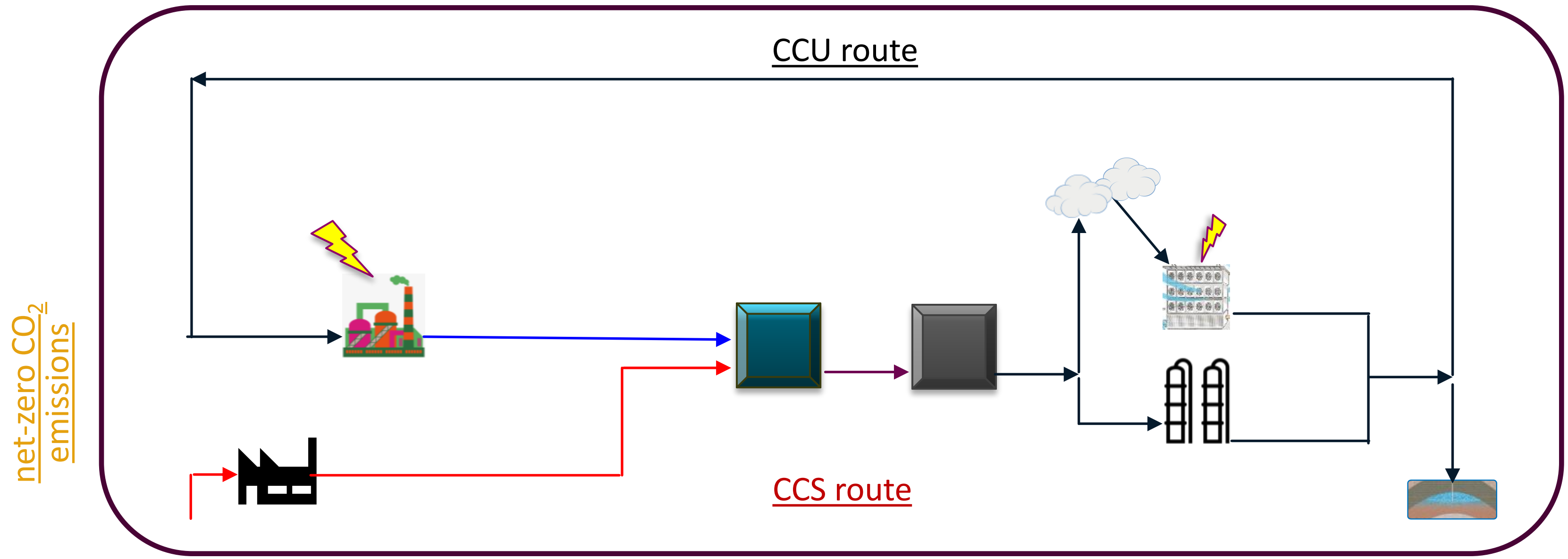

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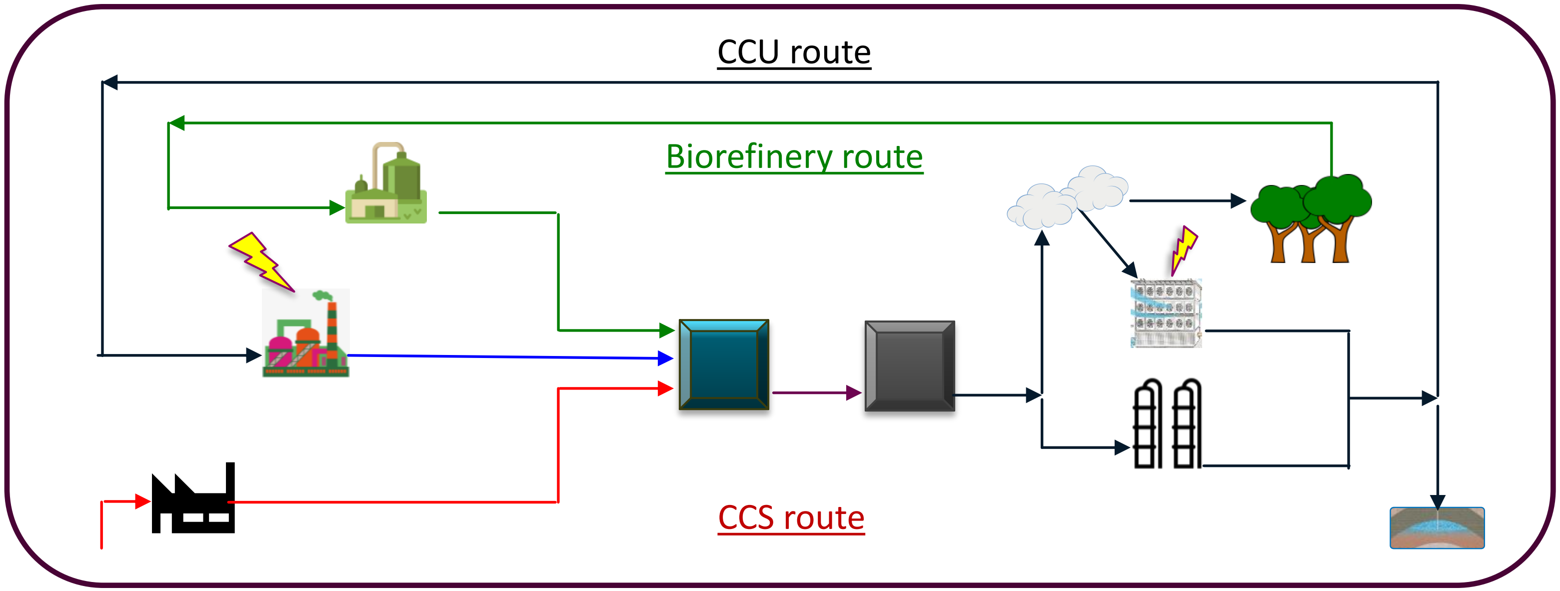

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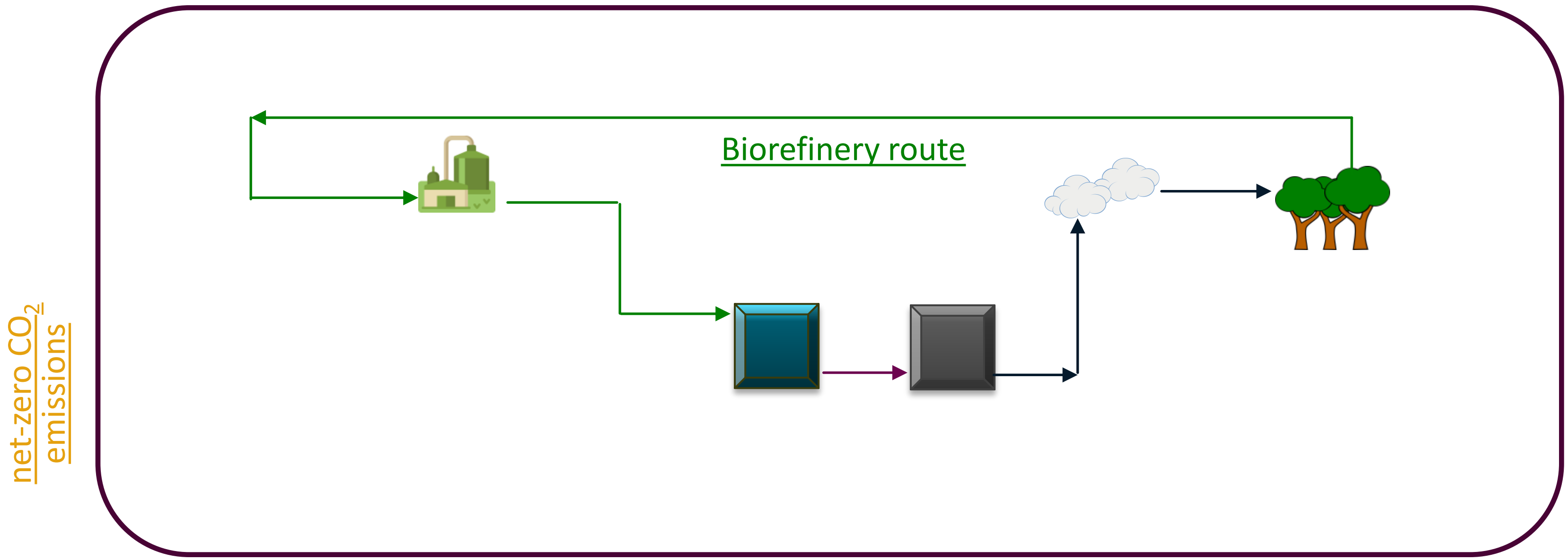

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Post-combustion CO_2 capture (PCC)

Direct air capture of CO_2 from the atmosphere (DAC)

Underground CO_2 storage

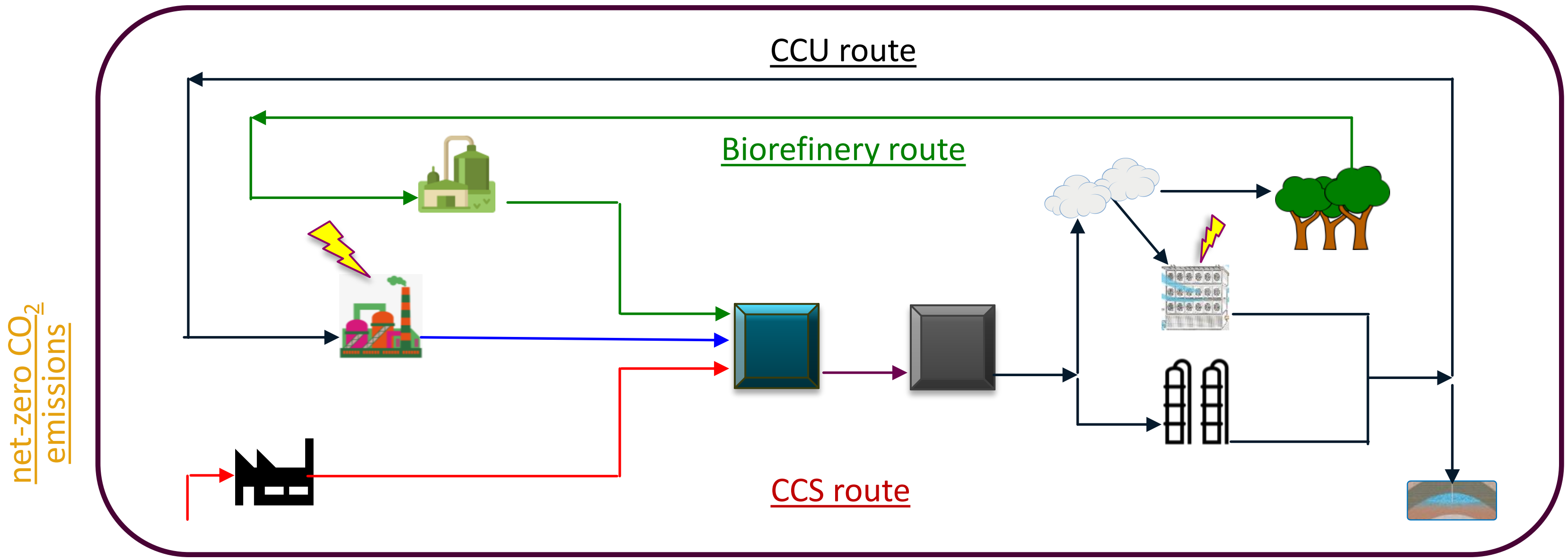
CO_2 conversion plant, incl. electrolyzer for H_2

Managed biomass growth

Biorefinery

ETH zürich

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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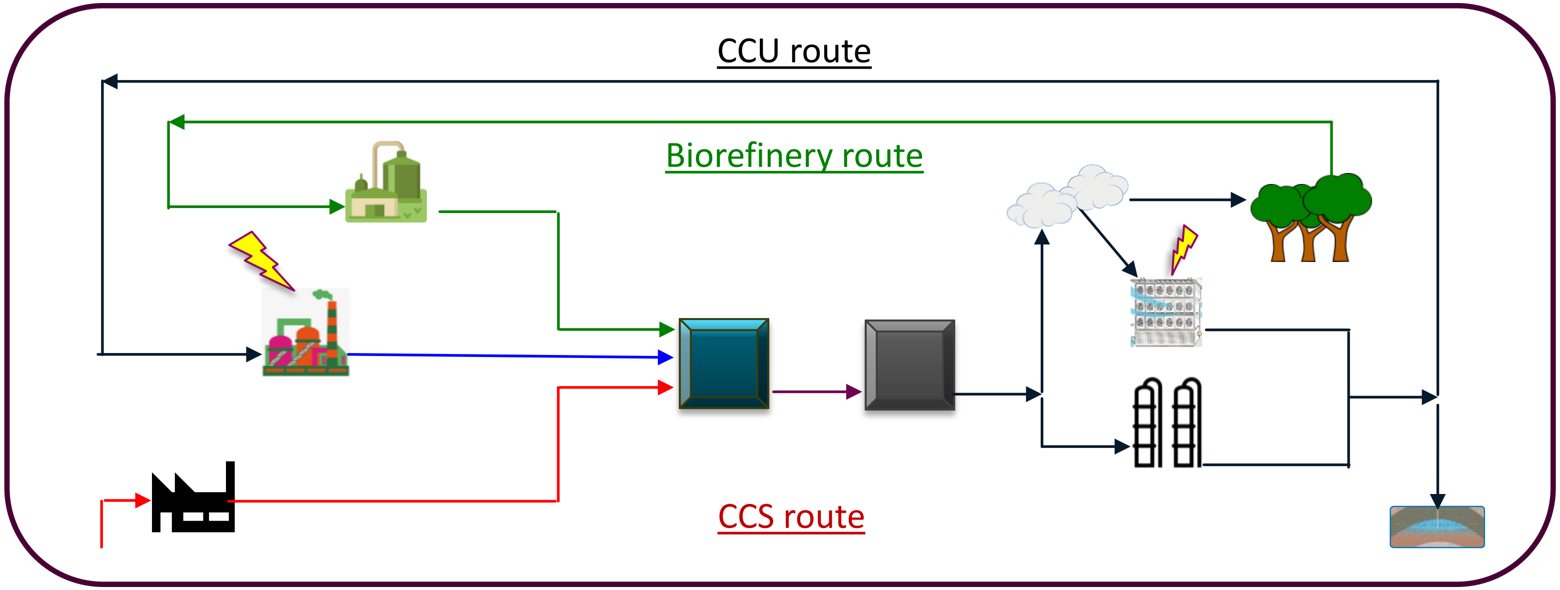

- Only 15% of oil (i.e. only about 5% of all fossil-Carbon) is used for chemicals.
- CCS route seems feasible (1-2 Gt CO_2/y) in terms of costs, resources and impact.
- Effective coupling of waste management and CO_2 capture is a prerequisite.
- Full LCA needed to allocate CO_2 emissions to stakeholders.

- 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.