Identifying the role of hydrogen and CCS for reaching the Swiss climate targets

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With many contributions from the large Swiss Case Study WP% team

ETH Zurich

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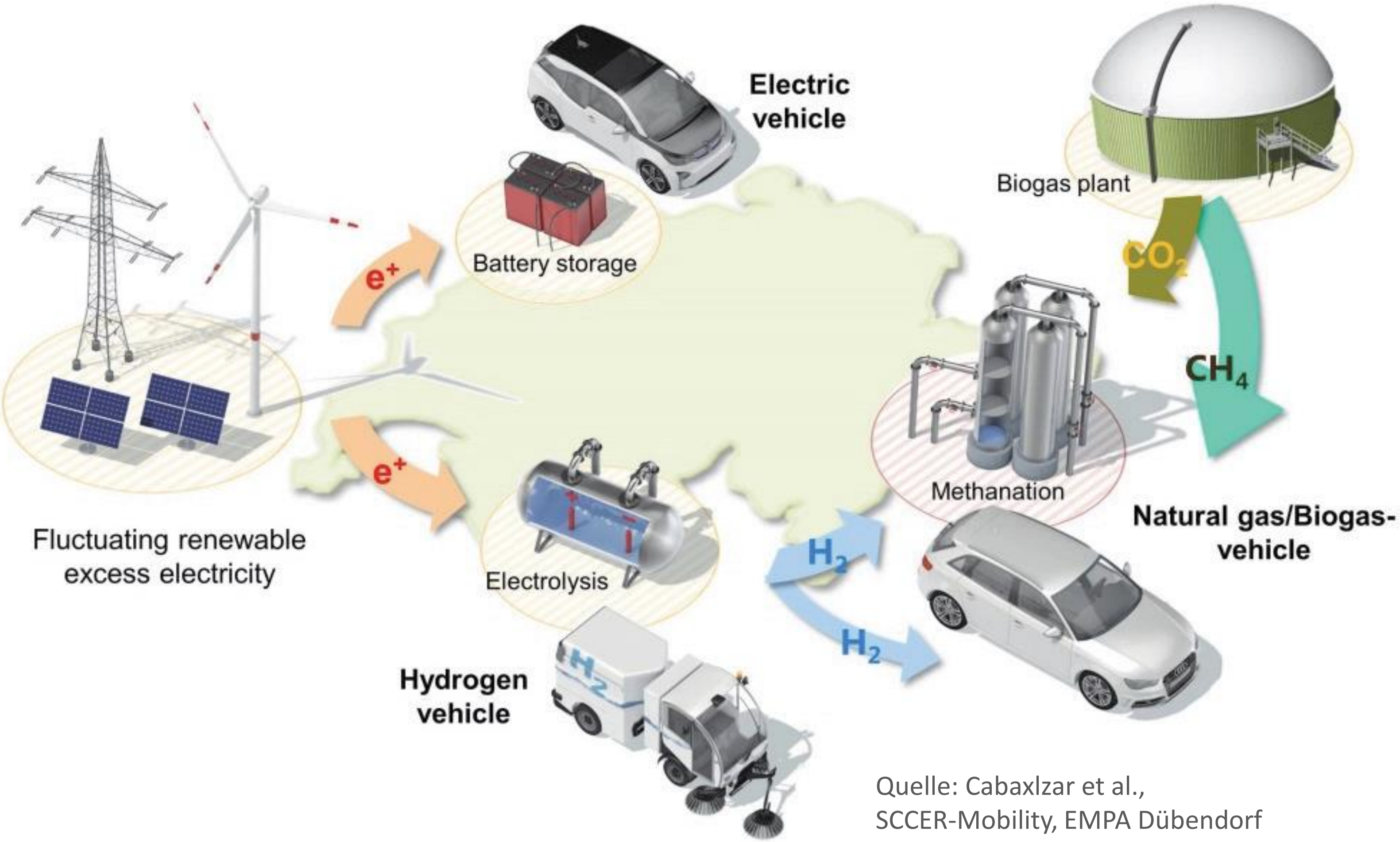
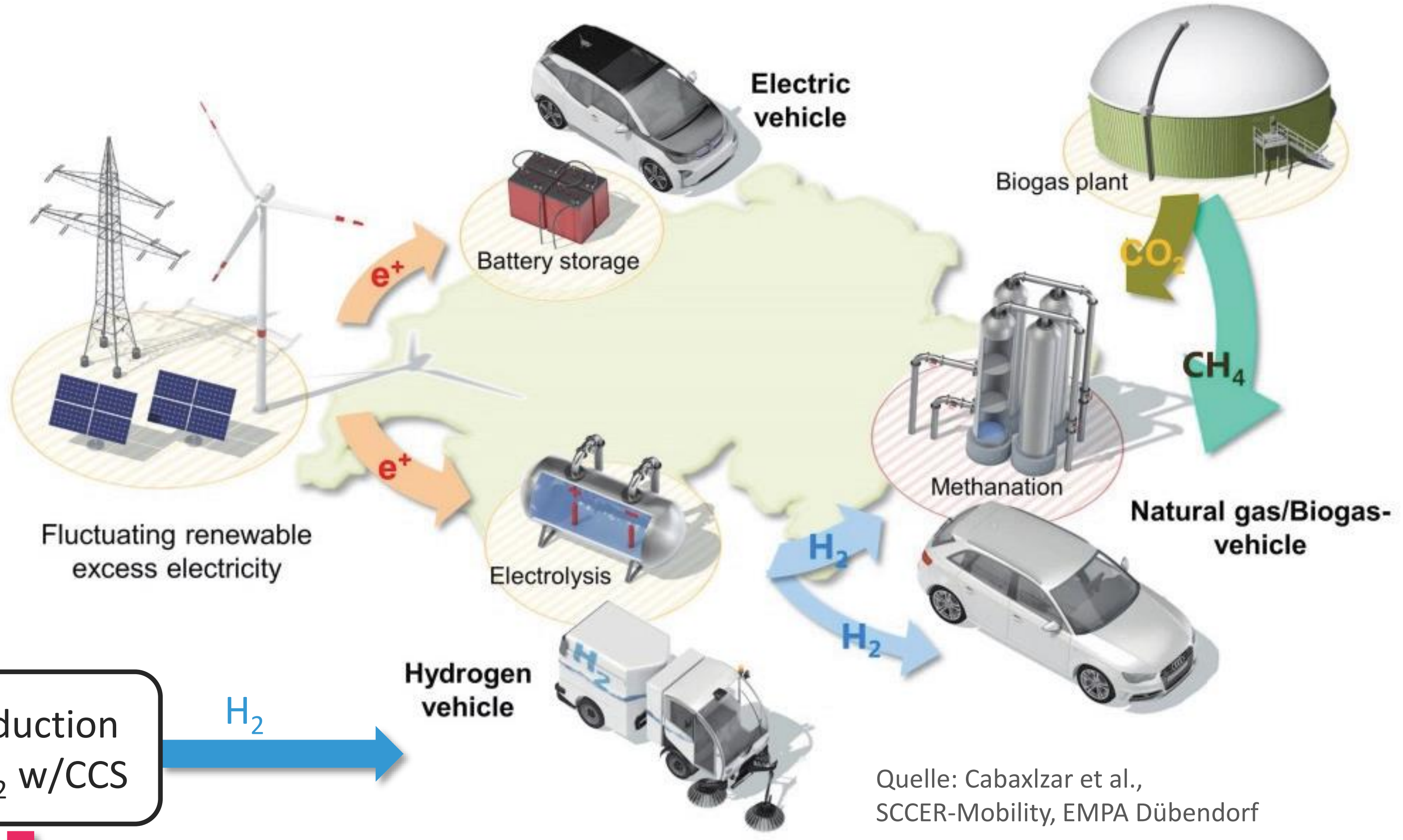
Decarbonizing mobility



Quelle: Cabaxlzar et al.,
SCCER-Mobility, EMPA Dübendorf

Decarbonizing mobility by H_2 and CCS

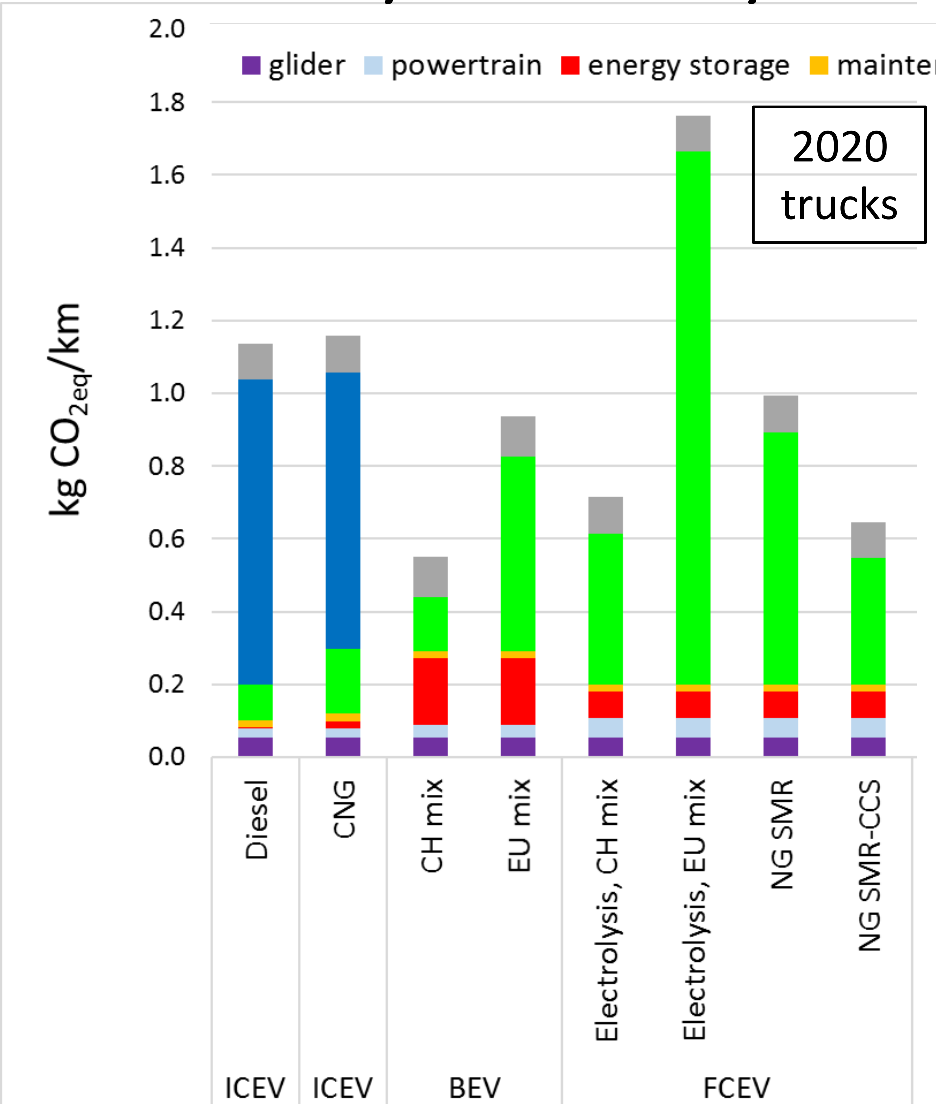


Natural Gas or biomass → Production of H_2 w/CCS → H_2

CO_2 to storage

Quelle: Cabaxlzar et al., SCCER-Mobility, EMPA Dübendorf

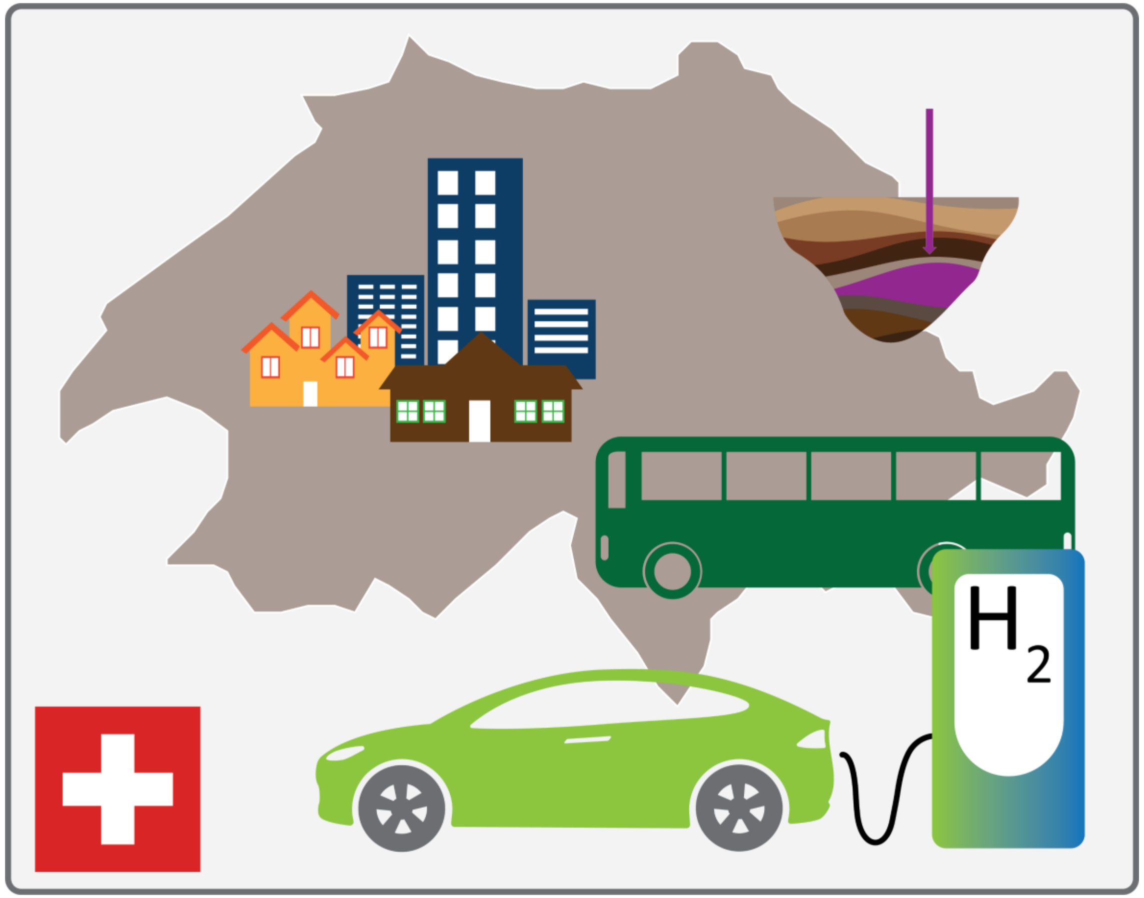
Mobility: Life Cycle Assessment of C-footprint



- Calculations based on https://carculator.psi.ch
- Fossil fuel Internal Combustion Engines cause direct emissions, whereas electric vehicles are responsible for indirect emissions
- FCEV (Fuel Cell Electric Vehicle) are less limited than Battery EV in terms of range and fuelling time
- FCEV (and BEV): up to 50-60% GHG emission reduction
- Substantial reduction requires low-Carbon H_2 / electricity
- H_2 from Natural Gas with CCS (esp. ATR) is a low-Carbon option

Sacchi et al. (2020) in preparation

Enabling CO_2–free transport by H_2 and CCS

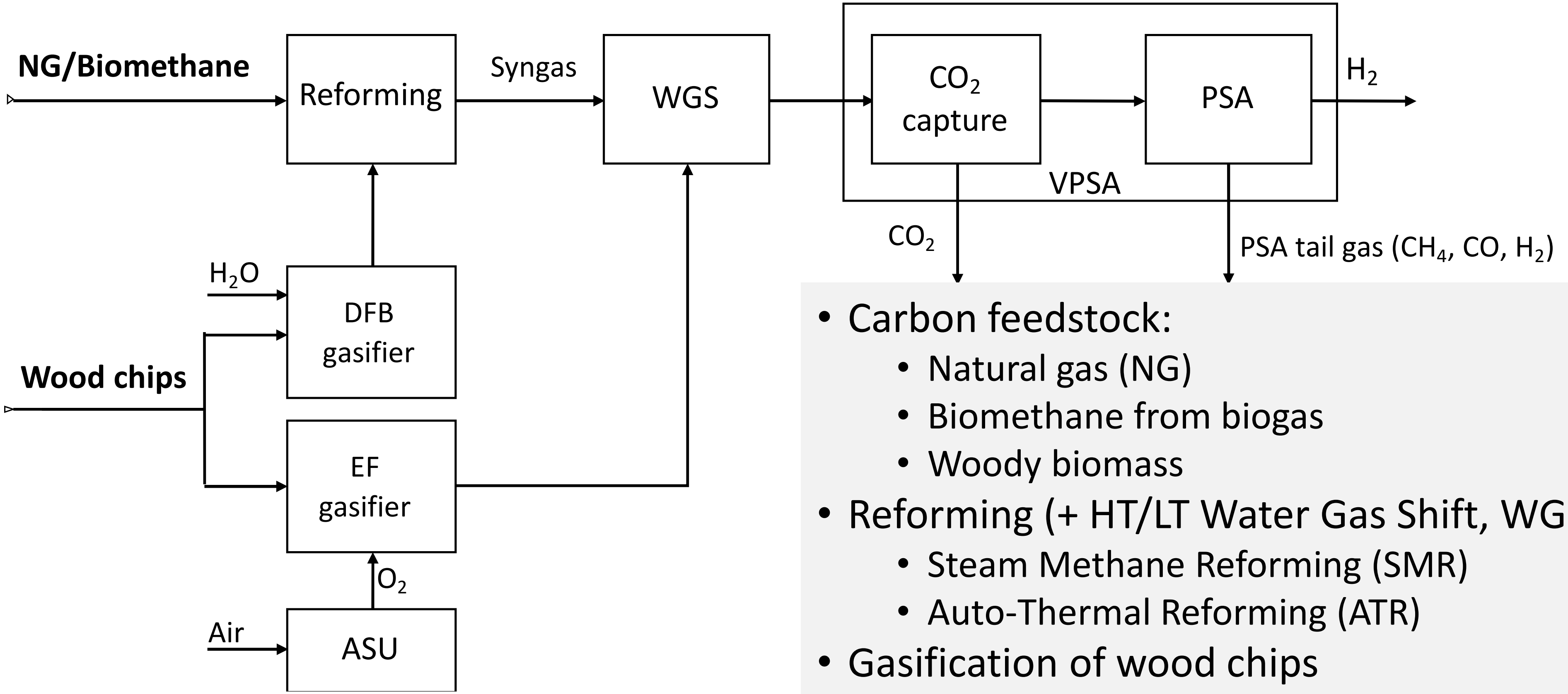


Swiss climate goal: net-zero-CO_2 by 2050

33% CO_2 emissions from transport

1. Clean hydrogen production and distribution
2. CO_2 storage
3. Business case and acceptance
4. The need of H_2 in the future Swiss energy system

1. H_2 synthesis with CO_2 capture



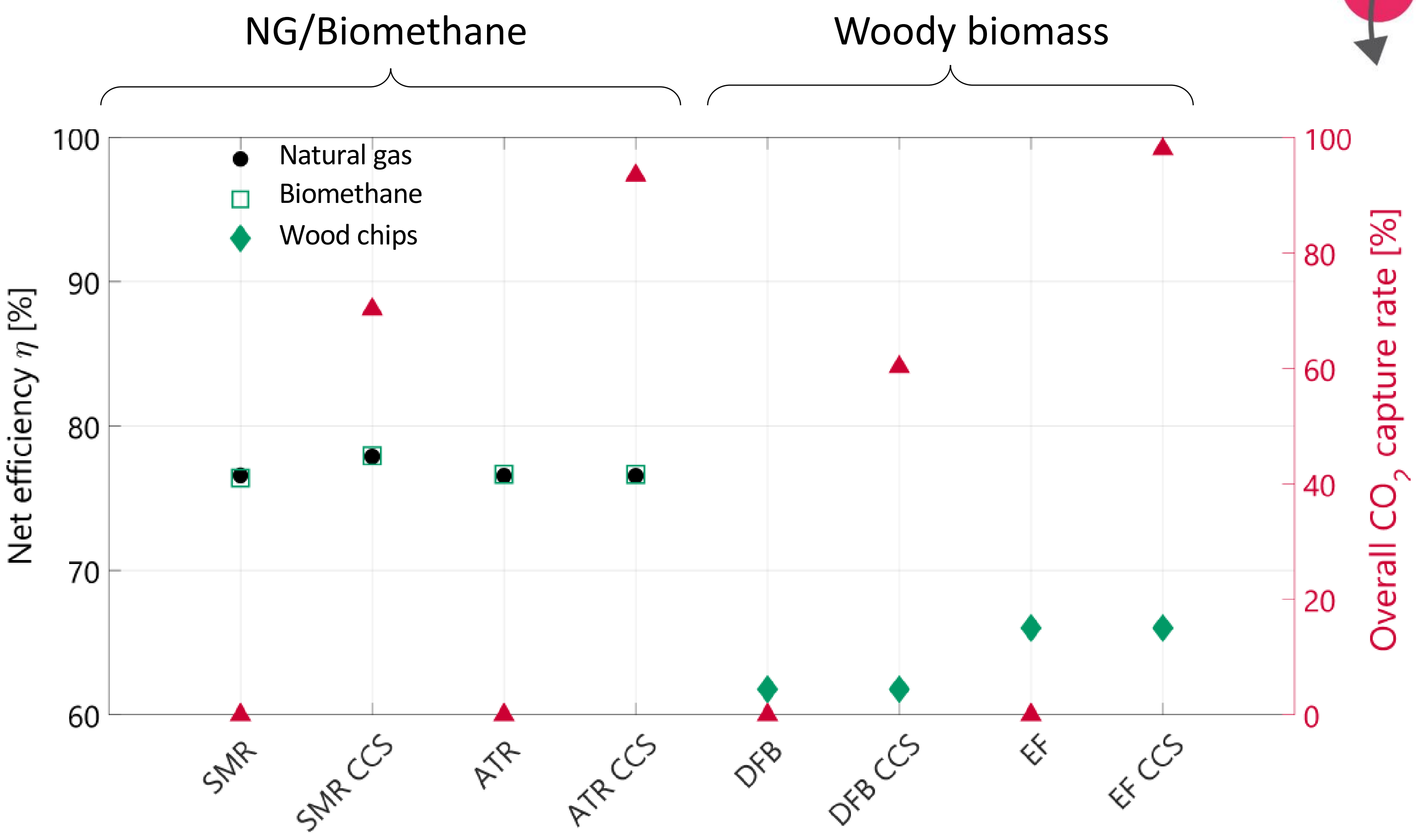
- Carbon feedstock:
  - Natural gas (NG)
  - Biomethane from biogas
  - Woody biomass
- Reforming (+ HT/LT Water Gas Shift, WGS):
  - Steam Methane Reforming (SMR)
  - Auto-Thermal Reforming (ATR)
- Gasification of wood chips
  - Dual Fluidized Bed gasifier
  - Entrained Flow gasifier
- CO_2 capture:
  - MDEA scrubbing
  - Vapor Pressure Swing Adsorption (VPSA)

1. H_2 synthesis with CO_2 capture: KPIs

- Detailed process modeling using ASPEN plus
- Multi-objective optimization of exergy penalty and productivity
- Key Performance Indicators (KPIs) are: CO_2 capture rate and

$$\eta = \frac{E_{\mathrm{H_2}}[\mathrm{MW}]}{E_{\mathrm{feedstock}}\,[\mathrm{MW}]}$$

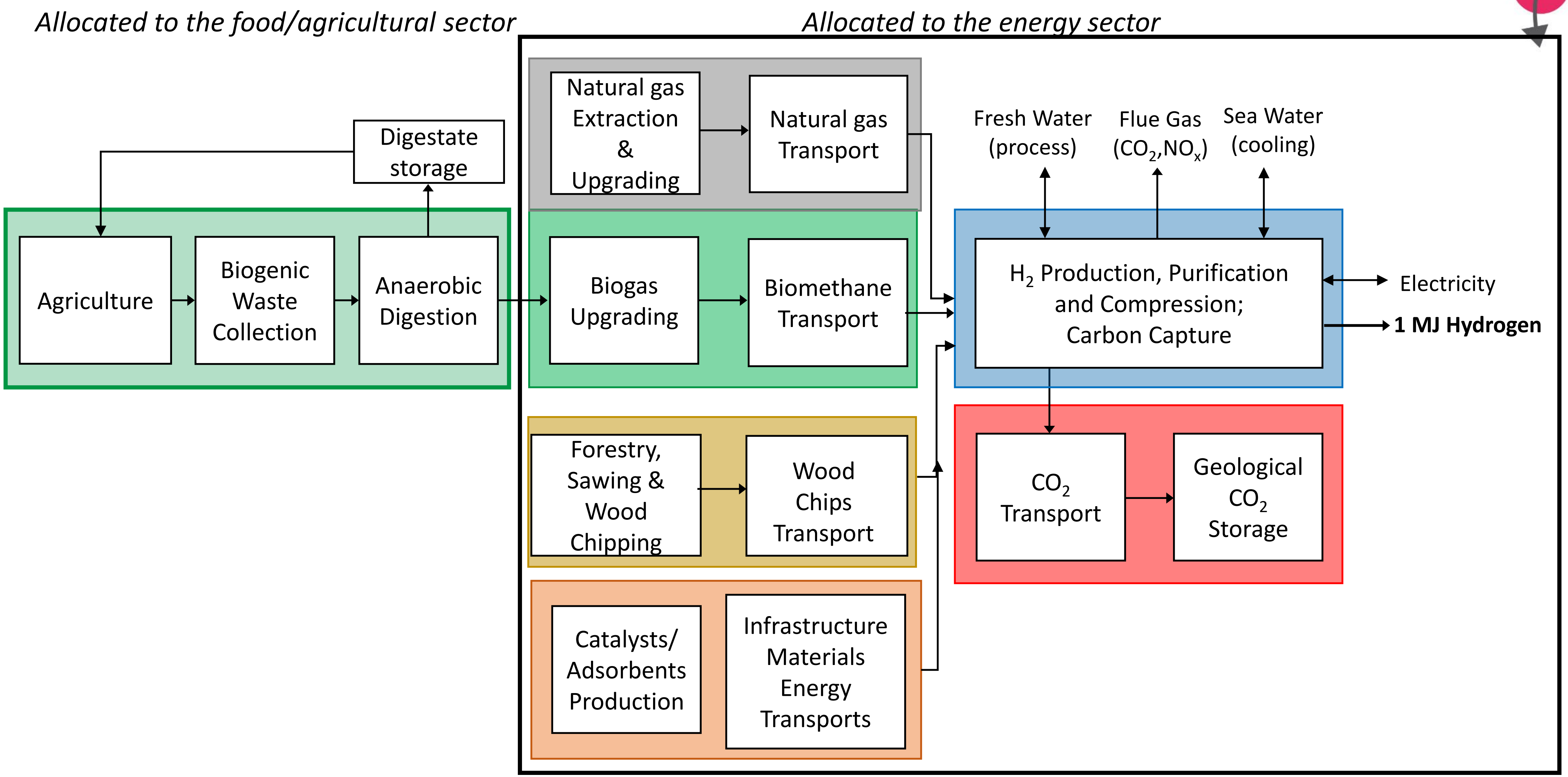
- Techno-environmental performance of VPSA is similar to that of MDEA scrubbing



SMR: Steam methane reforming
DFB: Dual fluidized bed
ATR: Autothermal reforming
EF: Entrained flow
CCS: benchmark CO_2 capture with MDEA

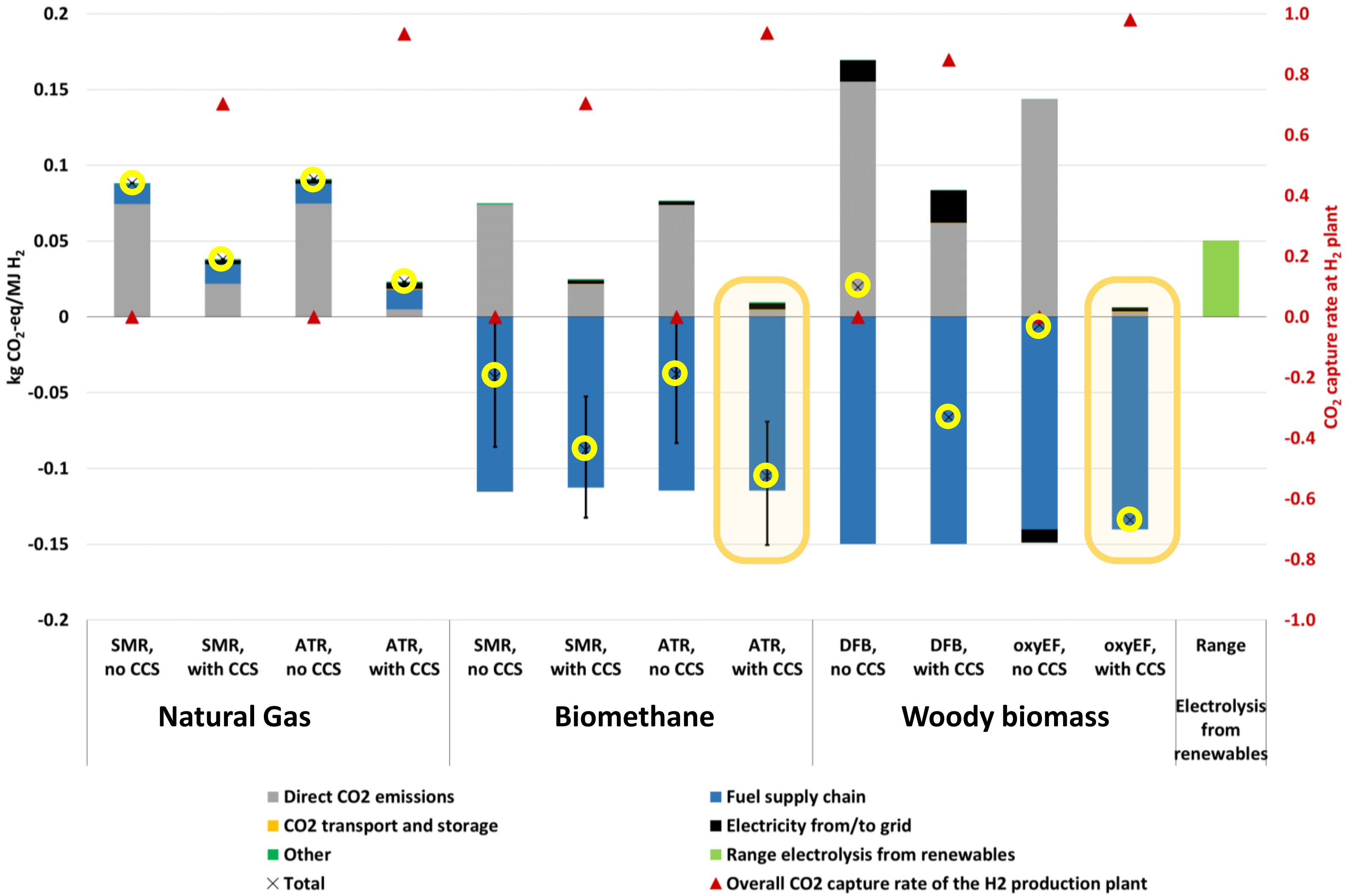
Antonini, Treyer, Streb, van der Spek, Bauer, and Mazzotti (2020) *Sustainable Energy & Fuels*.

1. H_2 synthesis with CO_2 capture: LCA



1. H_2 synthesis with CO_2 capture: LCA

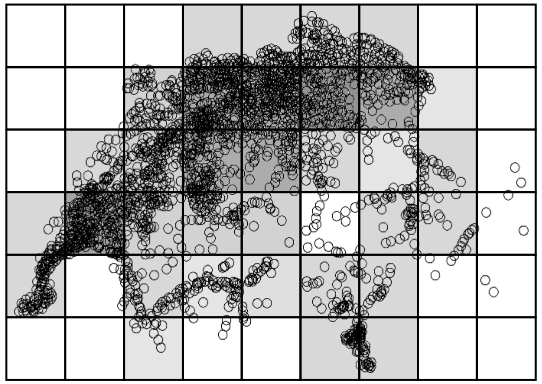
- Highest C capture rates w/ ATR and oxyEF: 98%.
- CCS reduces effects of H_2 production on climate change.
- Trade-offs with other environmental or health impacts: CCS increases only slightly impacts in other impact categories.
- Neutral or negative emissions are achieved using biomass feedstock.
- Availability of biomass and CO_2 storage is key.



Antonini, Treyer, Streb, van der Spek, Bauer, and Mazzotti (2020) *Sustainable Energy & Fuels*.

1. Swiss H_2 supply chain with CCS

System structure

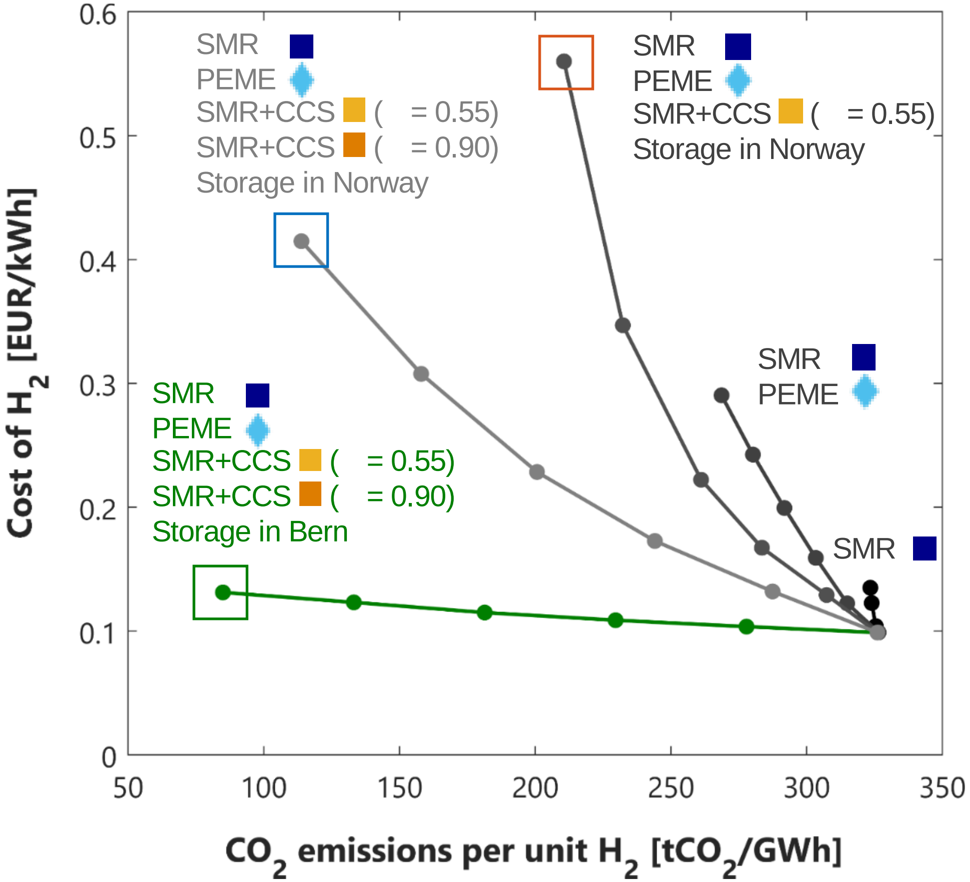


Objective functions

- Total cost
- Total CO_2 emissions

Constraints

- Energy balances
- Behavior of individual technologies



Gabrielli et al. (2020) *Applied Energy*
10.1016/j.apenergy.2020.05.19x

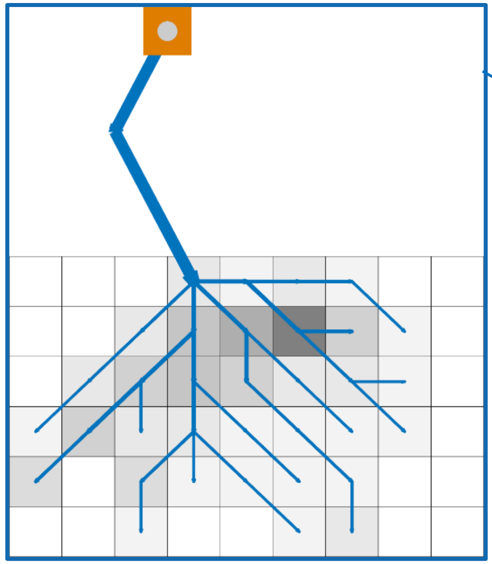
Decision variables

- Technology selection, size and location
- Network selection, size and location
- Energy import/export

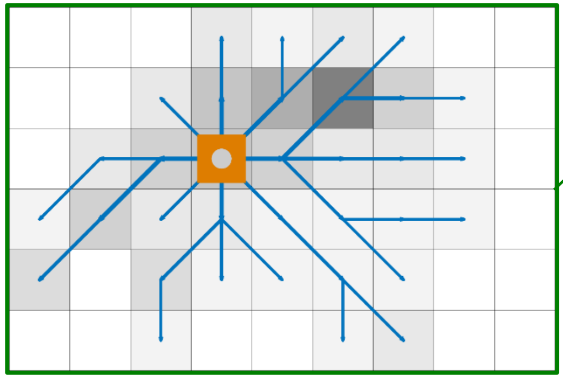
Input data

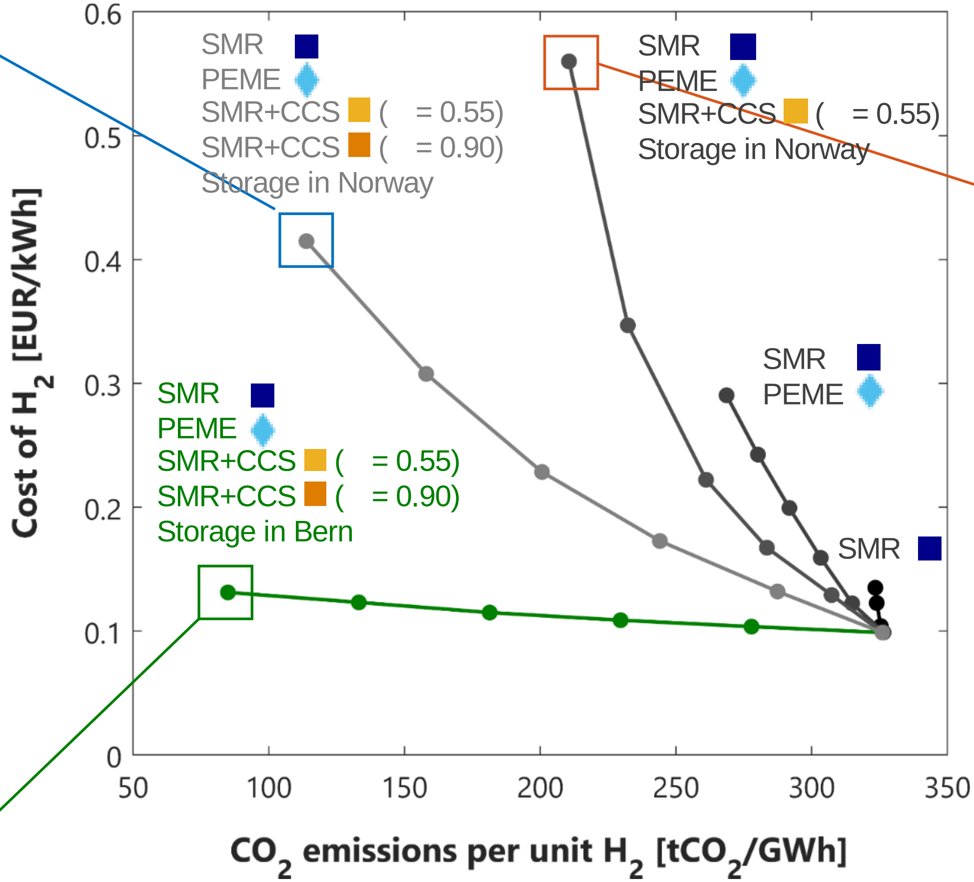
- Energy demands
- Energy prices
- Grid carbon intensities
- Technology parameters
- System structure

1. Swiss H_2 supply chain with CCS



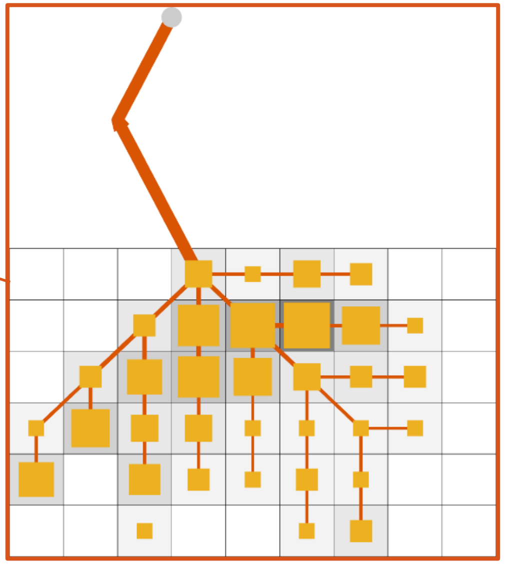
H_2 transport for smaller networks and higher amounts of CO_2





Gabrielli et al. (2020) *Applied Energy* 10.1016/j.apenergy.2020.05.19x

CO_2 transport for larger networks and lower amounts of CO_2

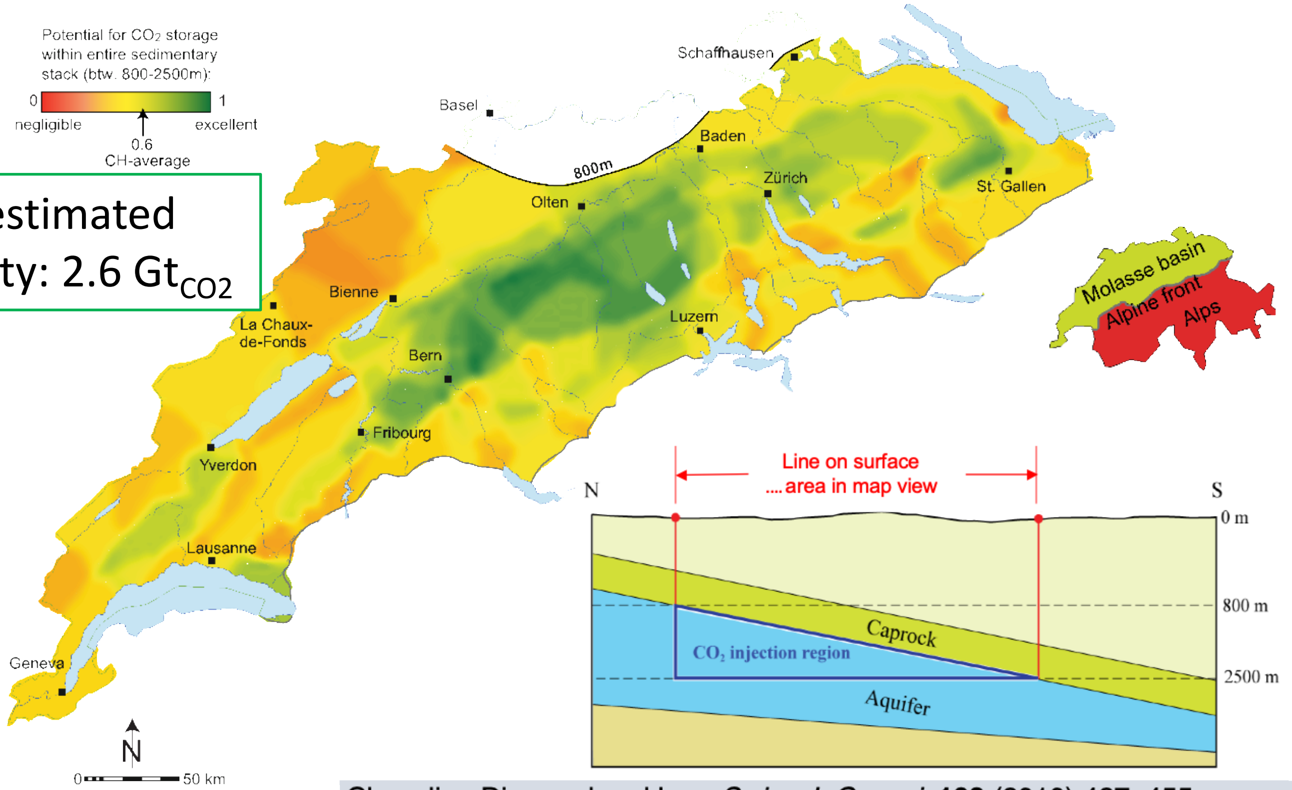


Low Carbon Hydrogen with CCS

- Deciding factors:
  - amount of H_2 and CO_2 transported
  - network cost and losses
  - network extensions (i.e. distance between storage and consumption)
  - availability and acceptance of storage sites
- Biomass enhances decentralization

2. CO_2 storage

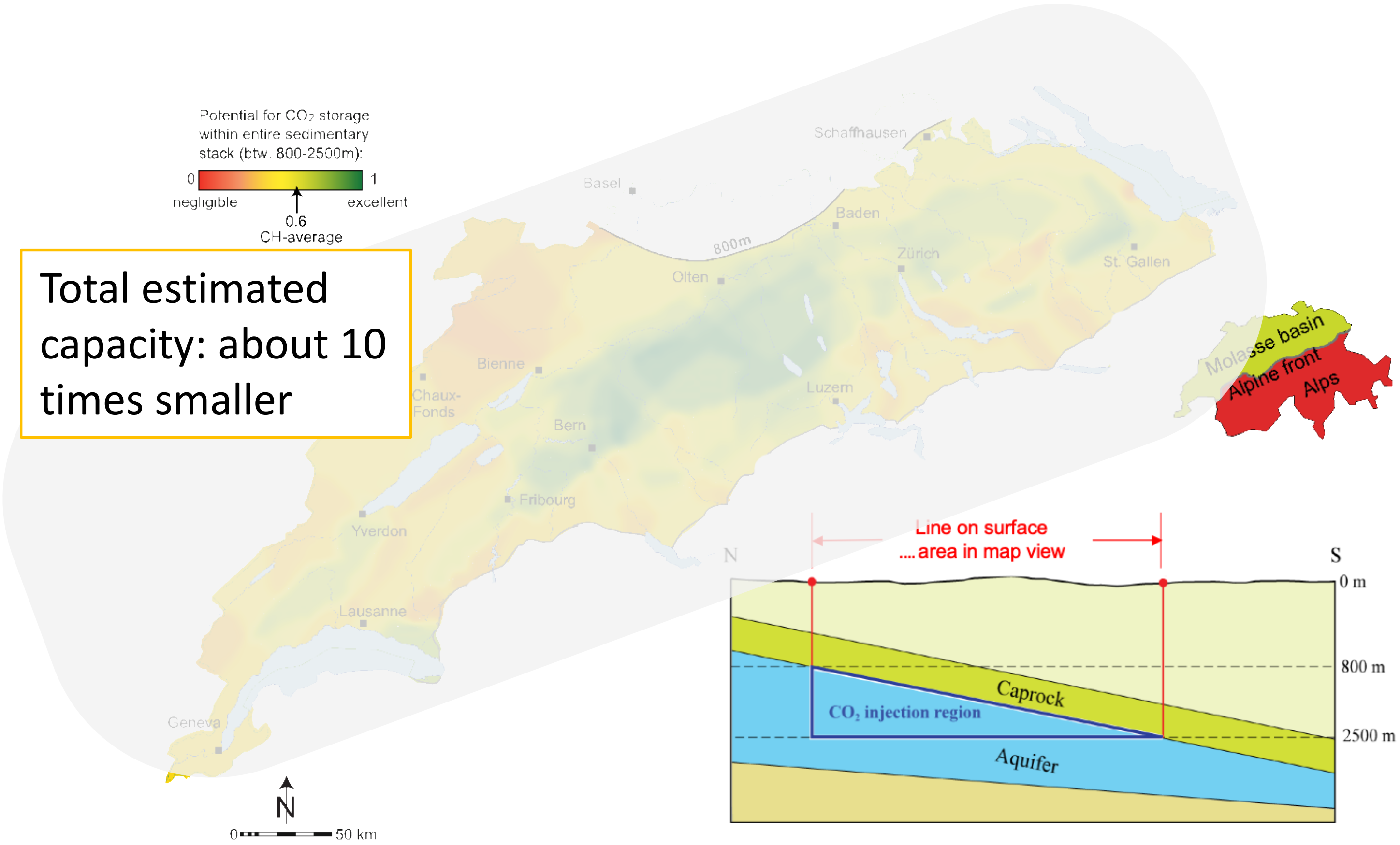
Total estimated capacity: 2.6 Gt_{CO2}



Chevalier, Diamond and Leu, *Swiss J. Geosci.* **103** (2010) 427–455

- Estimate of total capacity
- Site selection for CO_2 storage
- CO_2 plume geothermal
- Multi-criteria decision analysis
- Direct Air Capture and storage

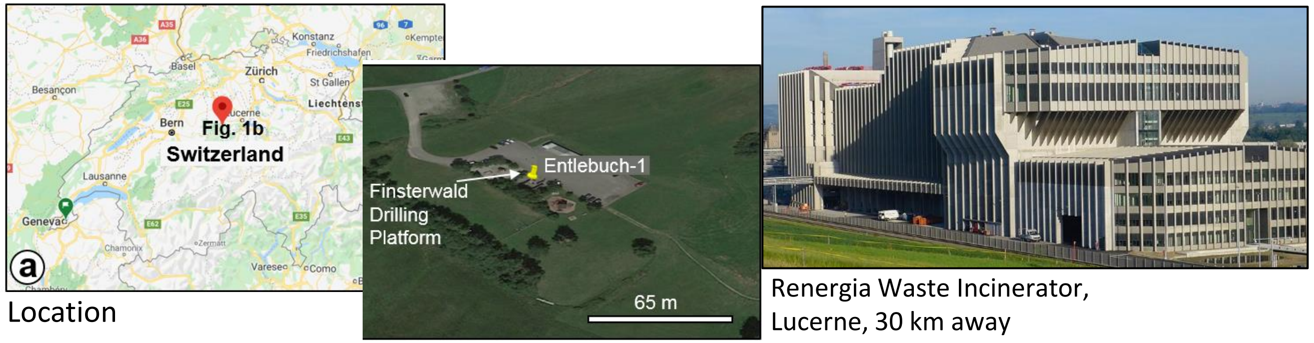
2. Can one store Swiss CO_2 in Switzerland?



Total estimated capacity: about 10 times smaller

- Revision of the high-level estimate of CO_2 storage volume available leads to much lower total estimated capacity.

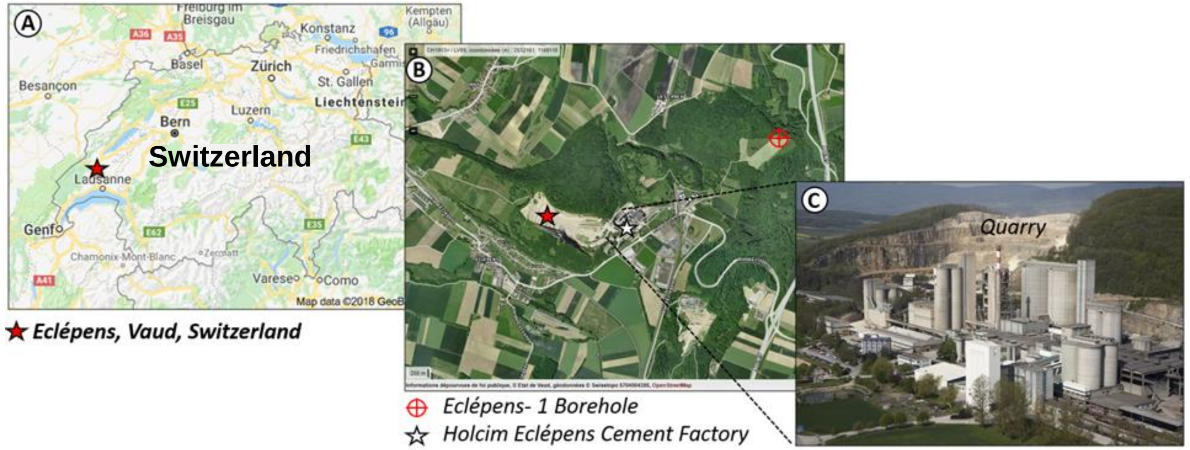
2. Can one store Swiss CO_2 in Switzerland?



Location

Site

Renergia Waste Incinerator,
Lucerne, 30 km away



★ *Eclépens, Vaud, Switzerland*

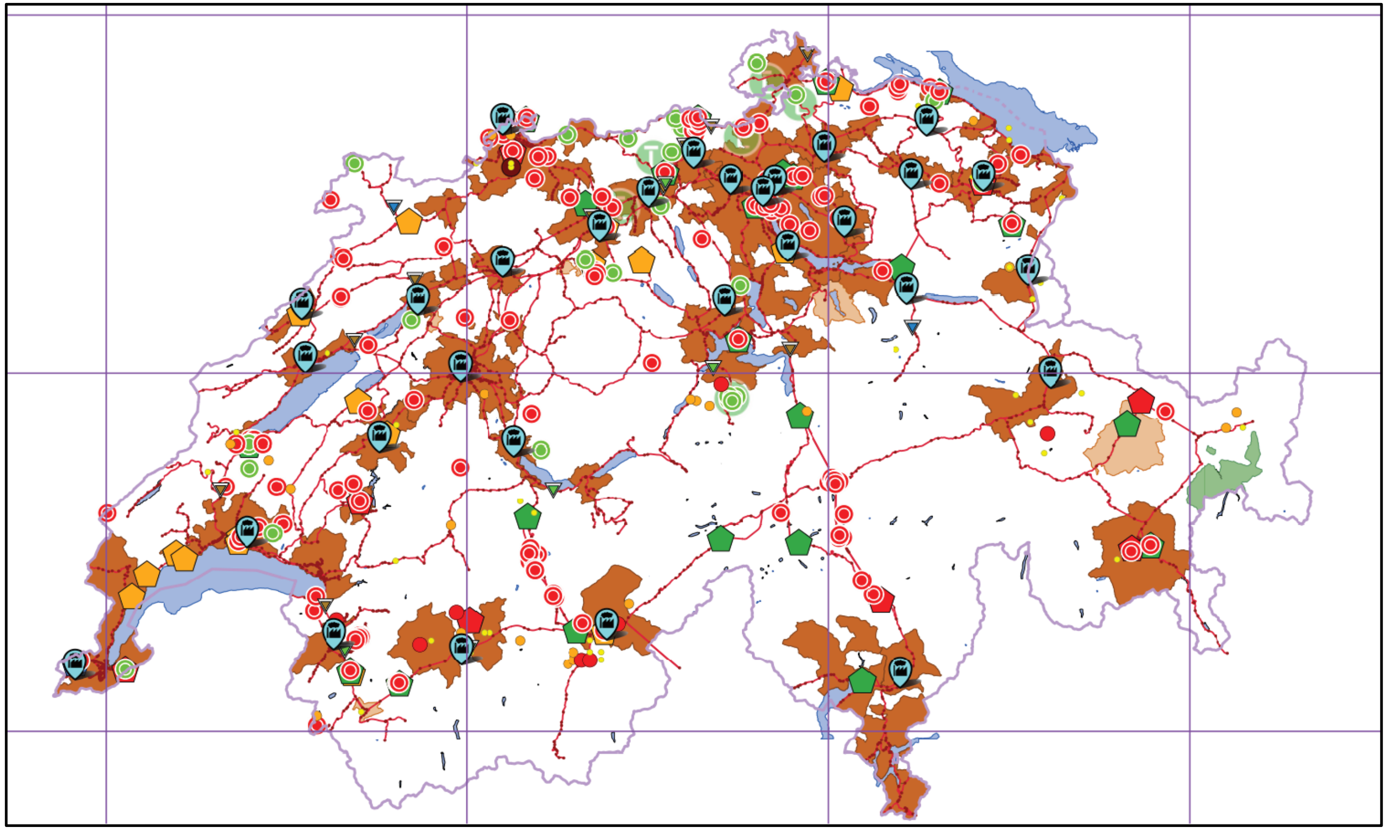
Eclépens- 1 Borehole
Holcim Eclépens Cement Factory
Quarry

Holcim Eclépens Cement Factory

- Site screening to identify sites that fulfil the necessary conditions for CO_2 safe injection and long term storage complying with best practices and the uniqueness of the Swiss subsurface.
- Specific sites studied (Finsterwald, Eclépans and Entlebuch) do not exhibit clear feasibility.
- Consideration of small-scale, low-containment sites under way.
- On-going model-based evaluation of potential for CPG, CO_2-Plume-Geothermal, to reduce energy penalty associated to CO_2 storage.

2. Can one store Swiss CO_2 in Switzerland?

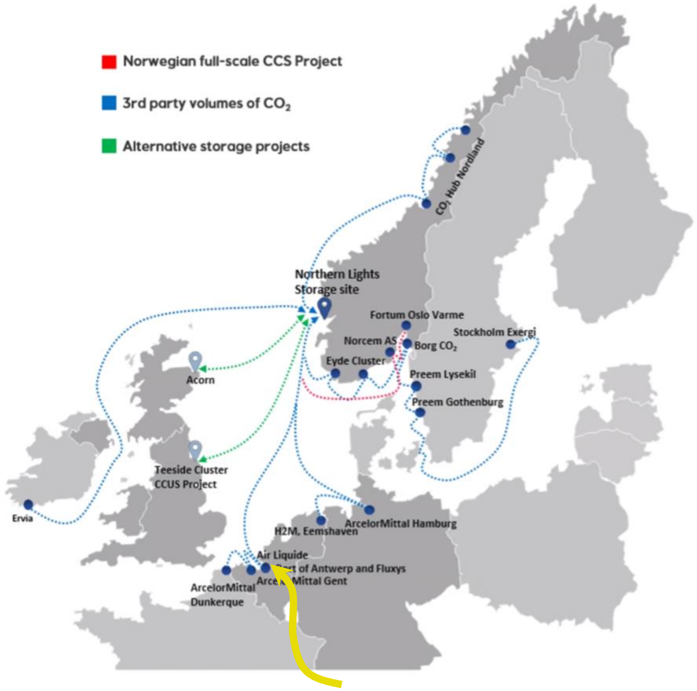
Spatial Multi-Criteria Decision Analysis

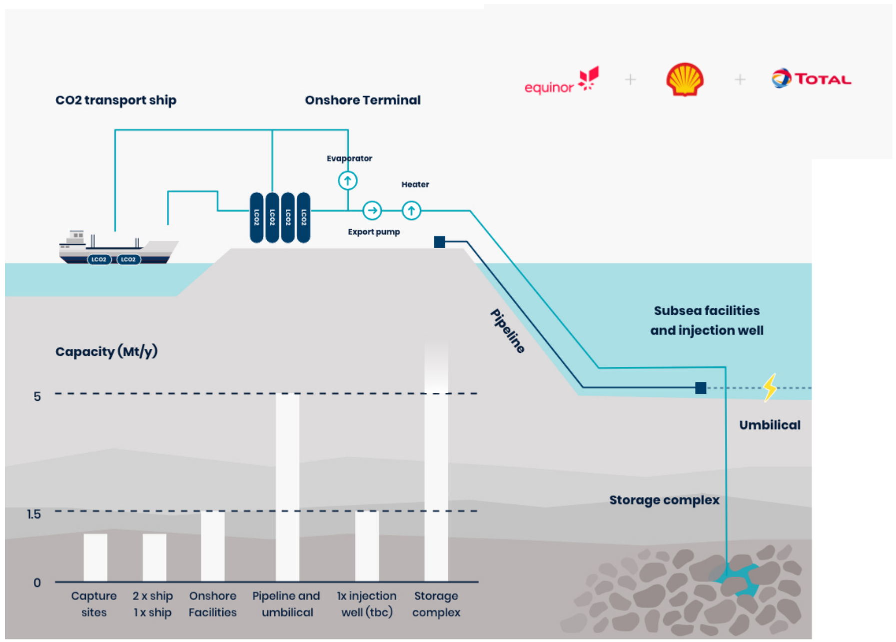


GIS Layers data source: FOEN, ARE, SFOE, FOT, swisstopo, SED, swisstopo, sgtk

- It supports decision-making and guides public participation, and allows combining different weighted spatial criteria to generate scores of alternatives (e.g. potential CCS sites), namely:
  - Site accessibility
  - Distance to CO_2 source
  - Existing surface facility
  - Proximity to population centers
  - Environmentally protected areas
  - Uses of the subsurface
- Direct Air Capture technology improved by Climeworks to deliver specifically negative emissions.

2. Roadmap for storage of Swiss CO_2





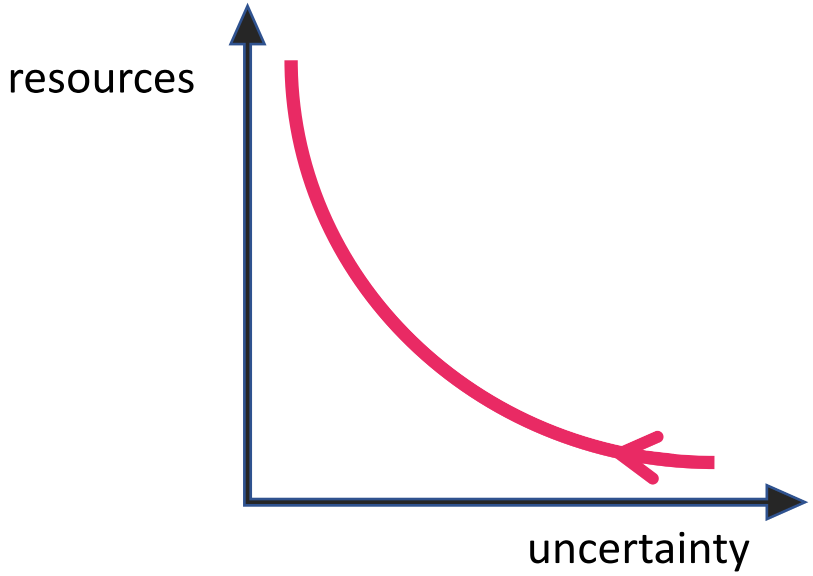
Swiss early movers

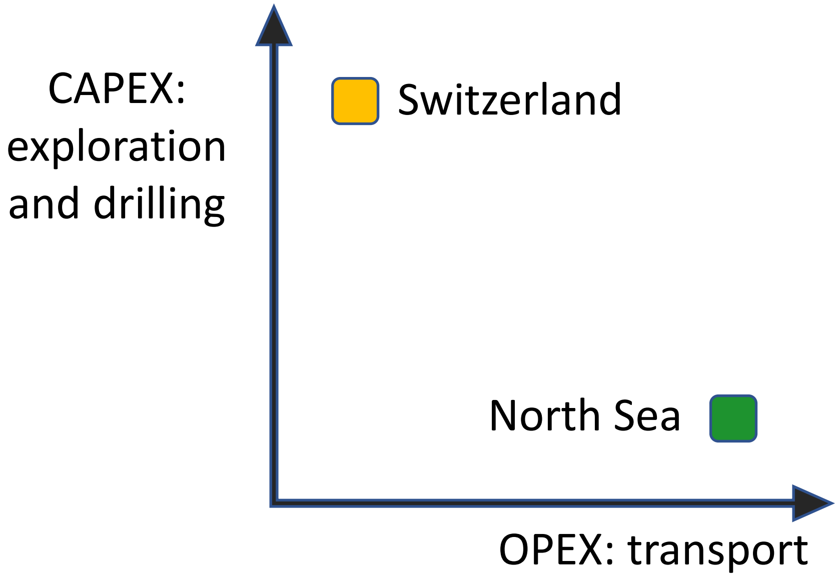
- Waste-to-Energy plants
- Biogas upgrading plants
- Cement plants

Build-up of CO_2 capture and transport facilities, to North Sea CO_2 storage hubs (Northern Lights from 2024)

2020 → 2050

2. Roadmap for storage of Swiss CO_2





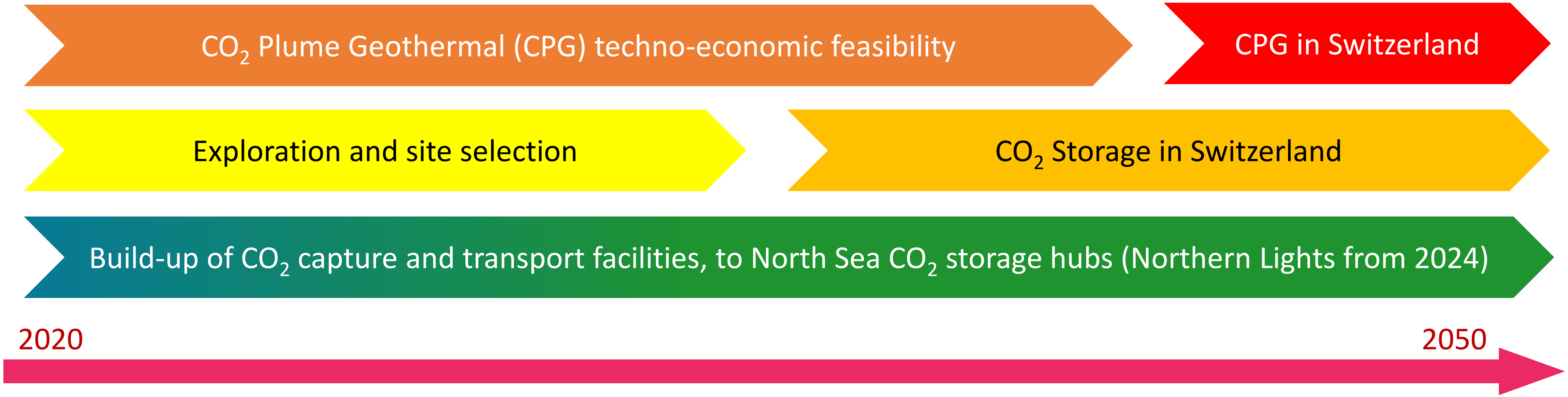
Exploration and site selection

CO_2 Storage in Switzerland

Build-up of CO_2 capture and transport facilities, to North Sea CO_2 storage hubs (Northern Lights from 2024)

2020 → 2050

2. Roadmap for storage of Swiss CO_2



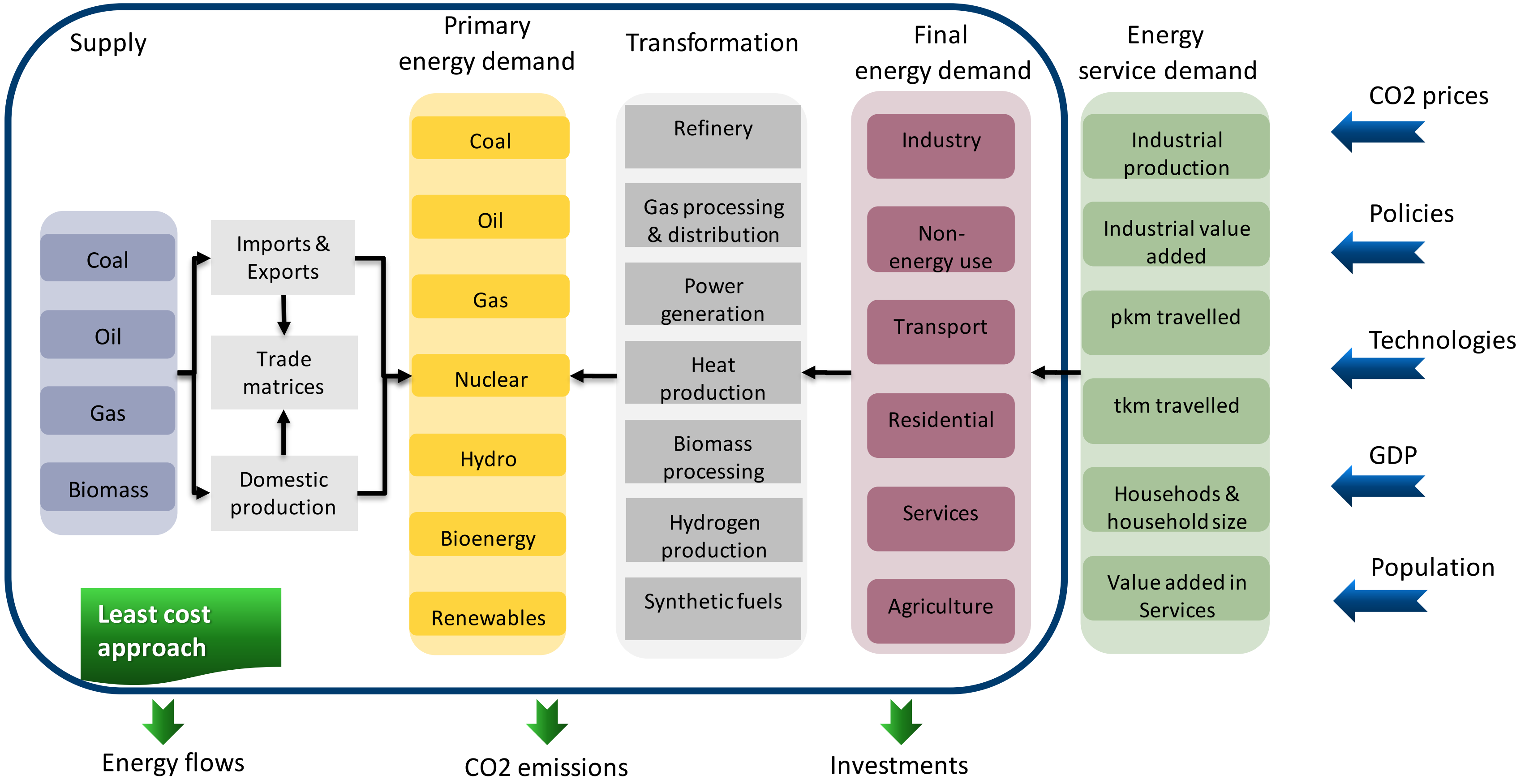
3. Business case and acceptance

- Toolkit for Business Model Selection and Business Case Assessment:
  - Includes assessment of business context (macro-economic, regulatory and policy background), business risks (mitigation and allocation of risks), business model selection, business case definition;
  - Enables simplification of business environment, early identification of critical issues, and stakeholders' collaboration and engagement.
- Application to Swiss cases study highlights:
  - Missing markets for low-carbon H_2 and for deployment of CO_2 storage;
  - Need of targeted carbon pricing instruments;
  - Limitations of existing climate policy instruments, but revisions are under way.
- Surveys on social acceptance of Elegancy technologies reveal:
  - CCS perceived as neutral, compared to others;
  - Most preferred solution: biogas without CO_2 storage or with CO_2 storage in Switzerland and transportation of H_2 via pipeline.

4. Need of H_2 in the Swiss energy system

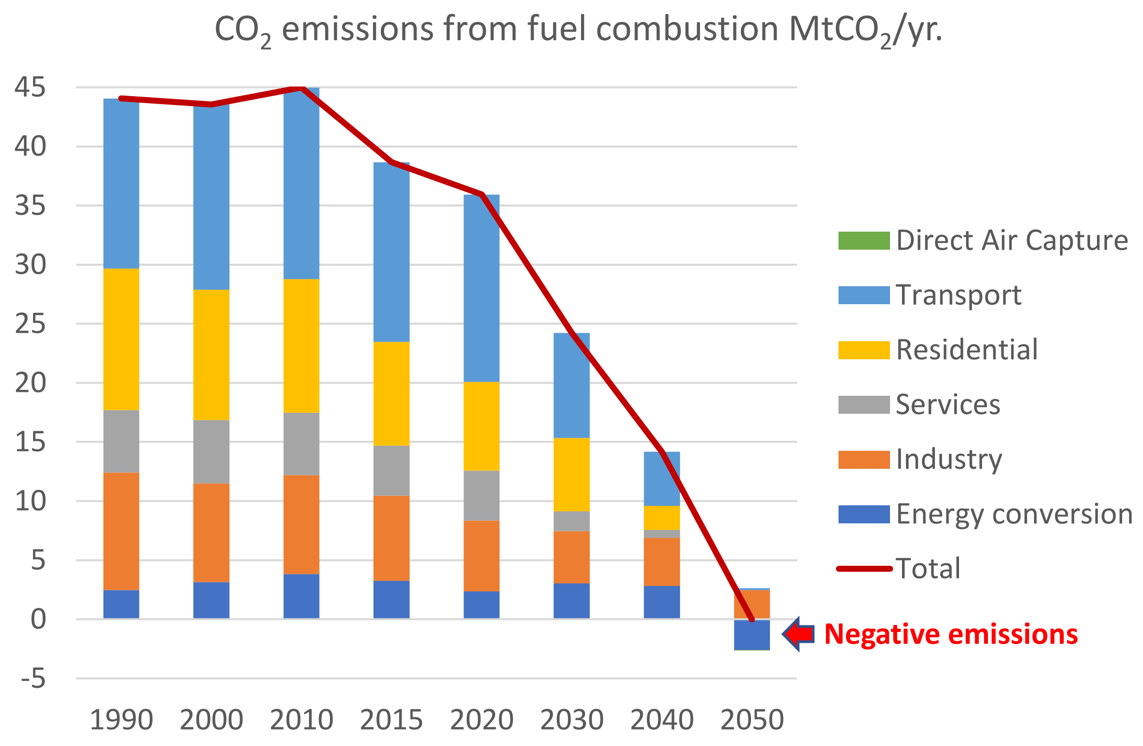
The Swiss TIMES Energy Systems Model

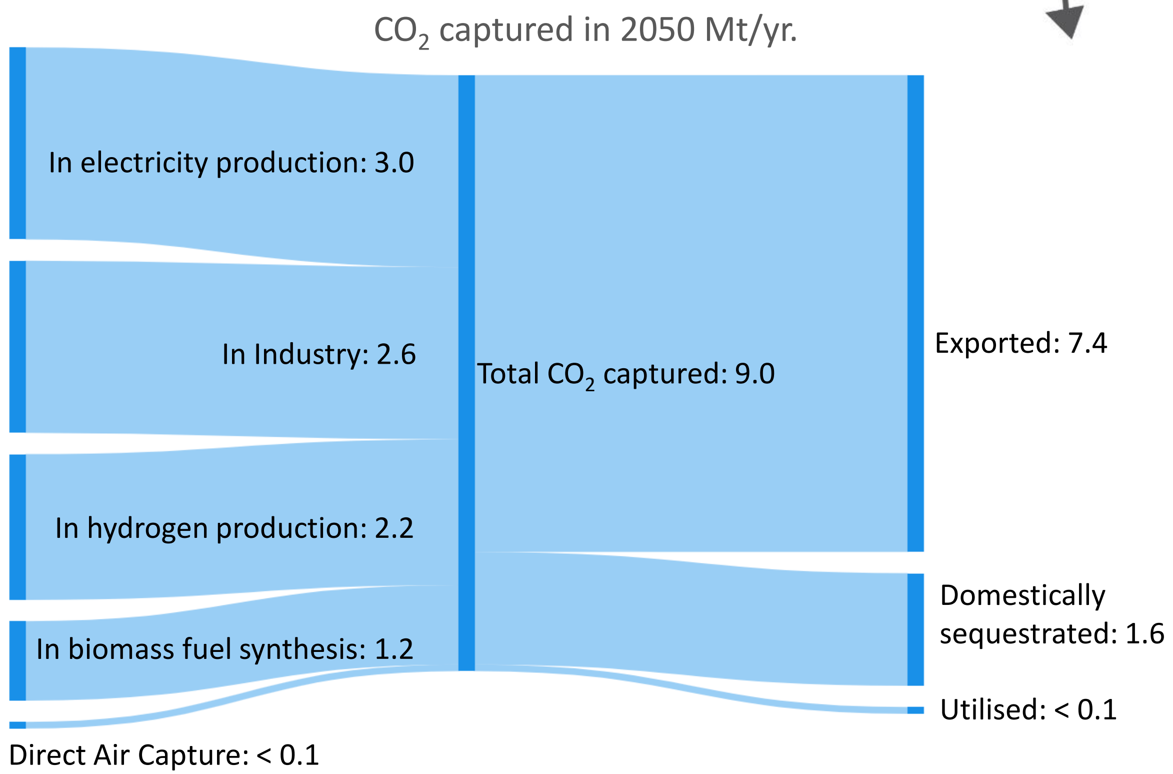
- Based on the IEA-ETSAP TIMES modelling framework
- **Complete representation of the Swiss energy system** from resource supply to energy end uses
- Bottom-up cost optimization framework to assess the long-term transformation of the Swiss energy system
- Modelling horizon 2020 – 2060 in periods of 10 years
- High intra-annual resolution (288 typical operating hours)



- Used in Elegancy to assess a **business as usual scenario** vs. several variants of a **climate scenario targeting at zero Mt/a CO2 emissions** within the energy system

4. Net-zero-CO_2 can be reached, with CCS





Panos, E., et al. (2020) to be published

- CO_2 needs to be captured from electricity generation, industry and hydrogen production (gas reforming, gasification)
- Hydrogen is produced with a mix of technologies
- Production from biogas / wood allows for negative emissions

4. H_2 is key to decarbonize transport (2050)

Net Zero + R&D in FC + R&D in H2 Supply + Tax Recycle

Net Zero + R&D in both FC and H2 Supply

Net Zero + R&D in H2 supply + Tax Recycle

Net Zero + R&D in H2 supply

Net Zero + R&D in FC

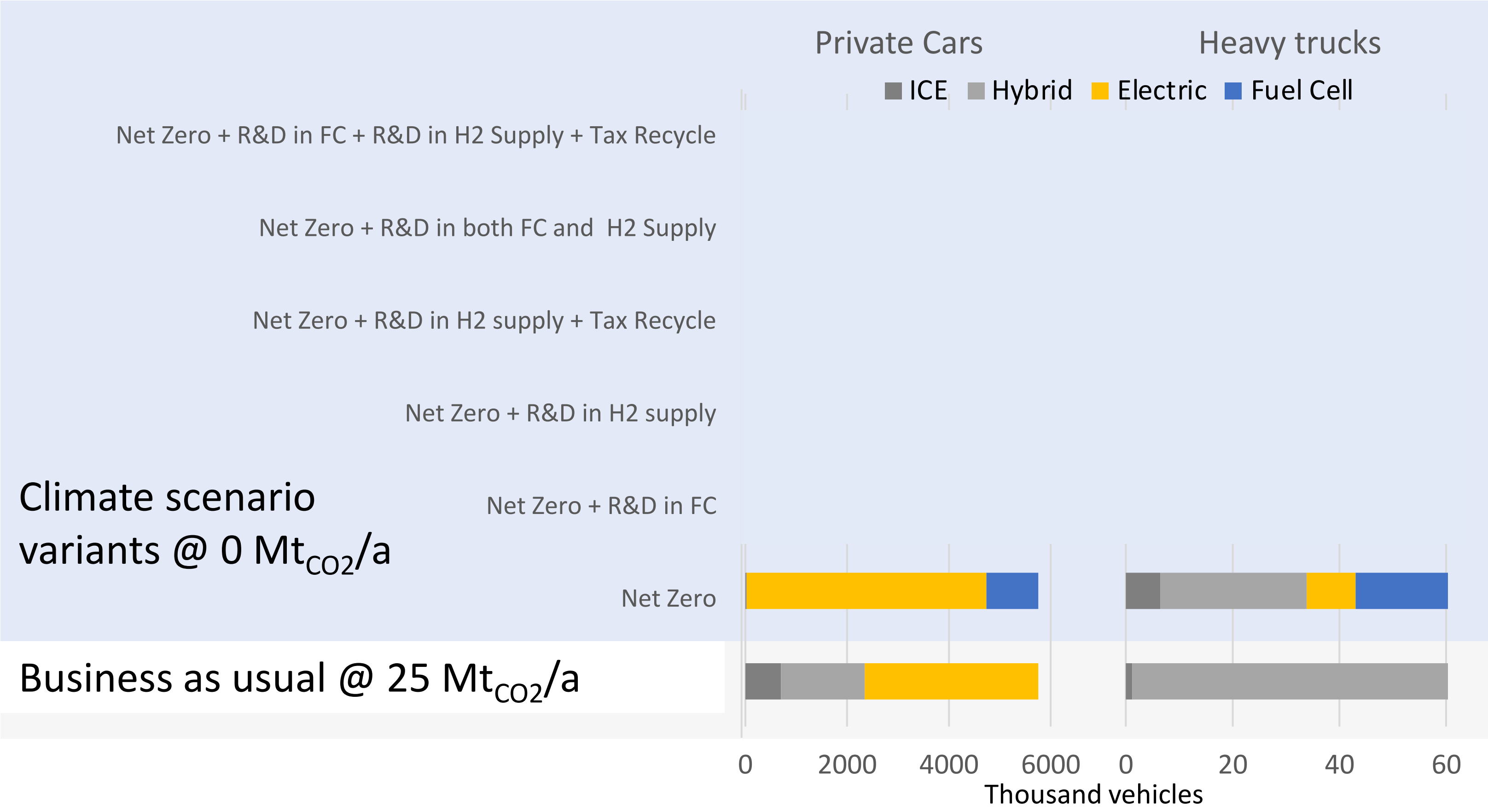
Net Zero

Climate scenario variants @ 0 Mt_{CO2}/a

Business as usual @ 25 Mt_{CO2}/a

Panos, E., et al. (2020) to be published

4. H_2 is key to decarbonize transport (2050)



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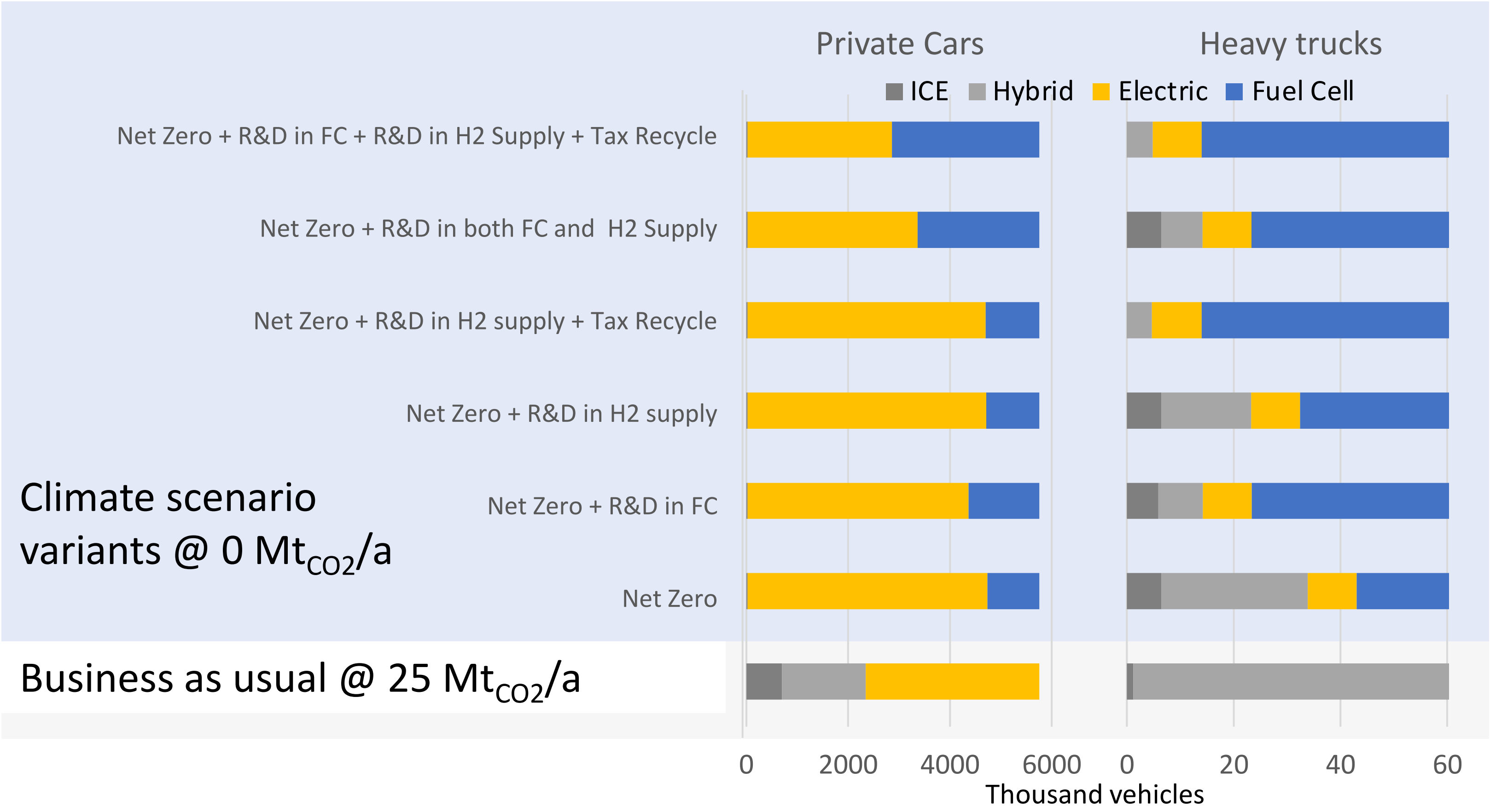

- Fuel cell and electric vehicles dominate the market in a climate scenario
- Hydrogen is essential especially for heavy duty freight transport

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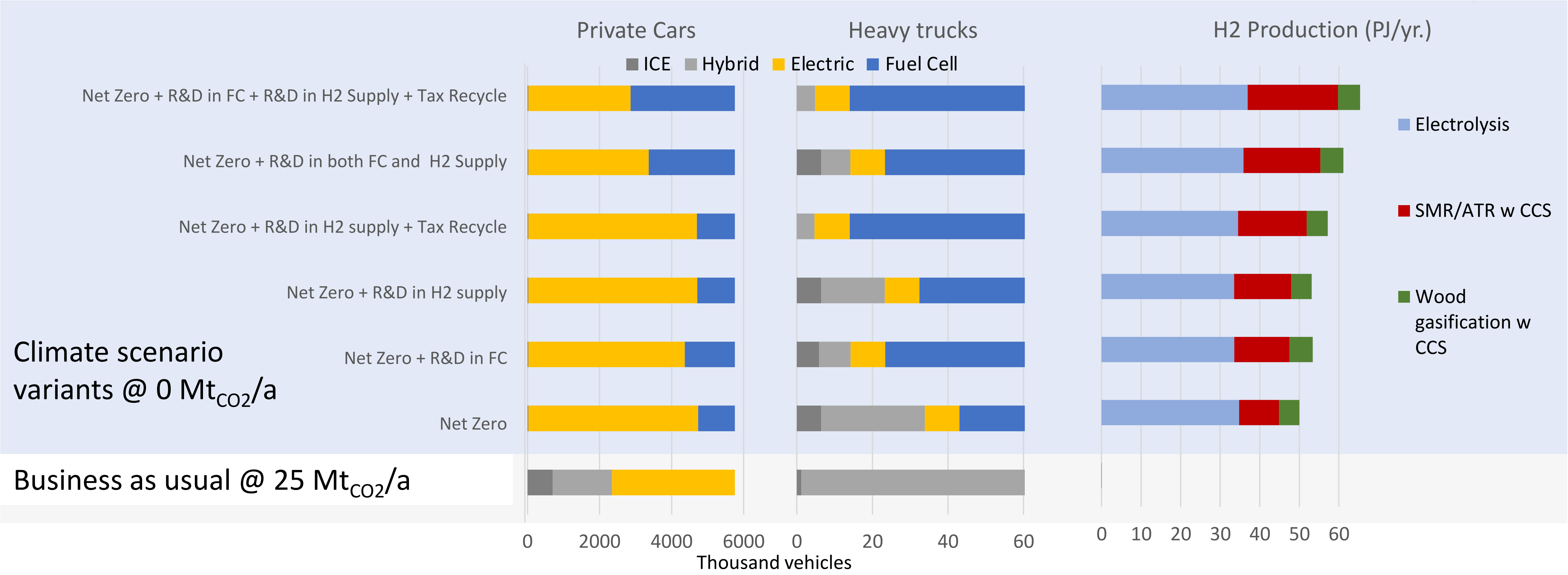

- Fuel cell and electric vehicles dominate the market in a climate scenario
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Take home messages

- The Swiss goals for net-zero-CO_2 by 2050 require negative emissions hence CCS.
- CO_2 storage in Switzerland and abroad is the challenge.
- Climate policy driven scenarios require clean H_2, SMR/ATR (w/ or w/o biomass) more than electrolysis in 2040, and further push ELEGANCY tech in 2050+.
- The timing of a hydrogen economy in Switzerland depends on technical developments, key among them is the fuel cell stack cost, but an early transformation is unlikely because of the slow transition of the transport sector.
- Automotive applications constitute a key sector for H_2 and lead to improvements that spill over to other applications and carry infrastructure development.
- Climate policy instruments, a case for building a H_2 infrastructure and demand, and the connection with European CO_2 and H_2 networks are key requirements.

Acknowledgement

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