Low-carbon hydrogen supply with CCS and biomass-based hydrogen: Life Cycle Assessment

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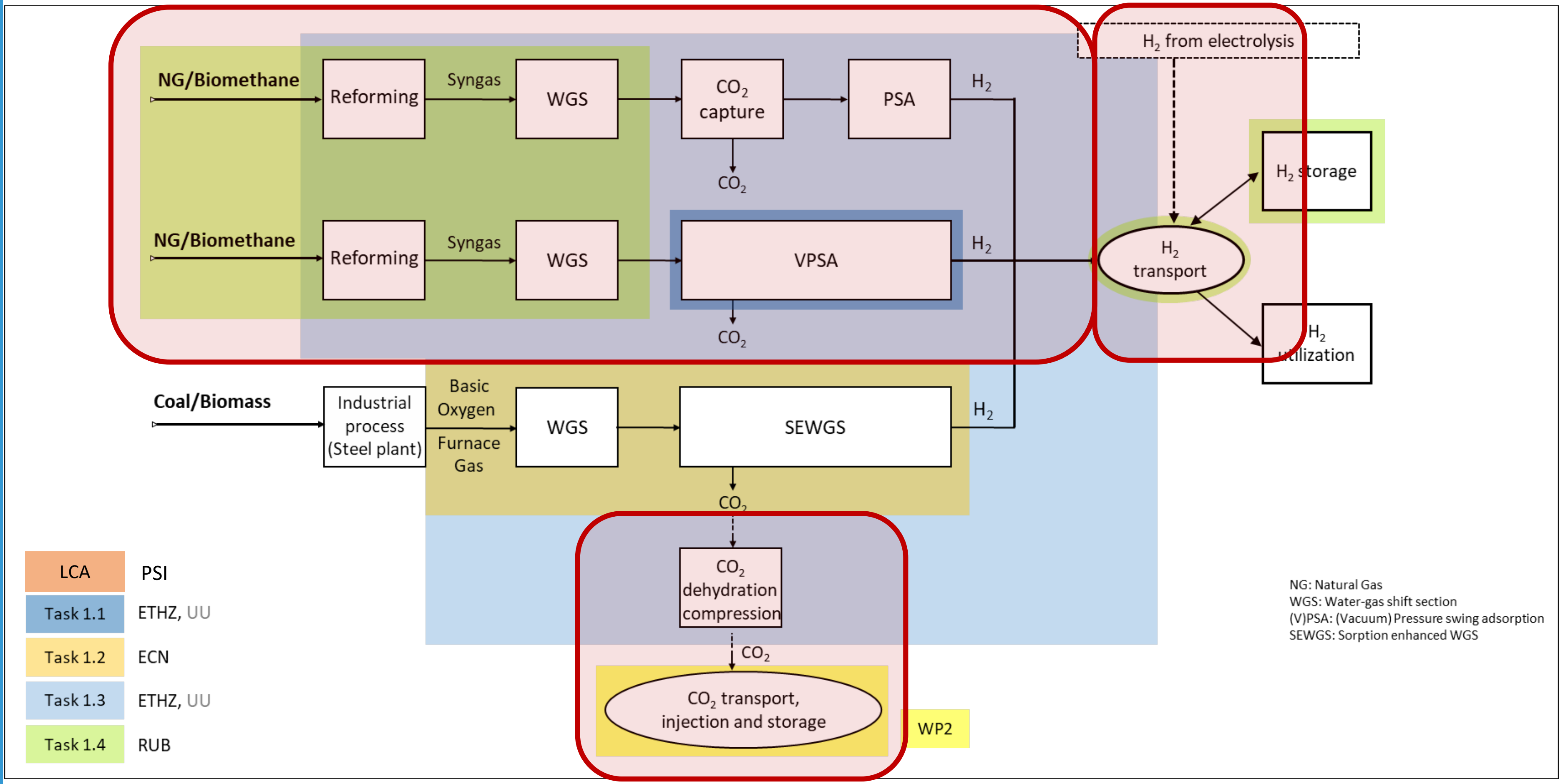
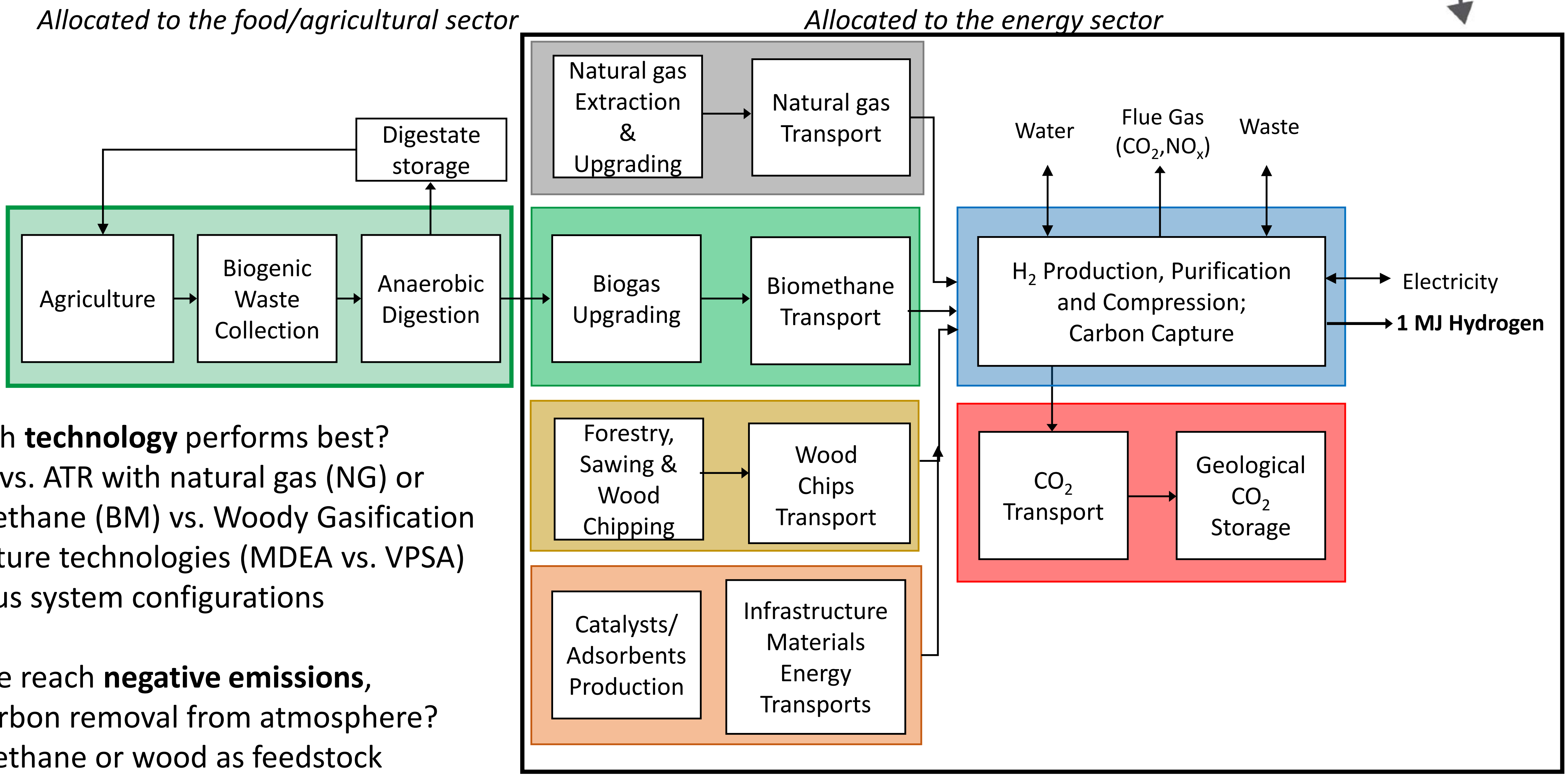
ELEGANCY - LCA of H_2 production



Goals:

1) Direct coupling to technical modelling
2) Evaluation of Negative Emission Technology and environmental trade-offs

Life Cycle View on H_2 Production with CCS



1. Which **technology** performs best?
- SMR vs. ATR with natural gas (NG) or biomethane (BM) vs. Woody Gasification
- C capture technologies (MDEA vs. VPSA)
- Various system configurations

2. Can we reach **negative emissions**, i.e. carbon removal from atmosphere?
- Biomethane or wood as feedstock

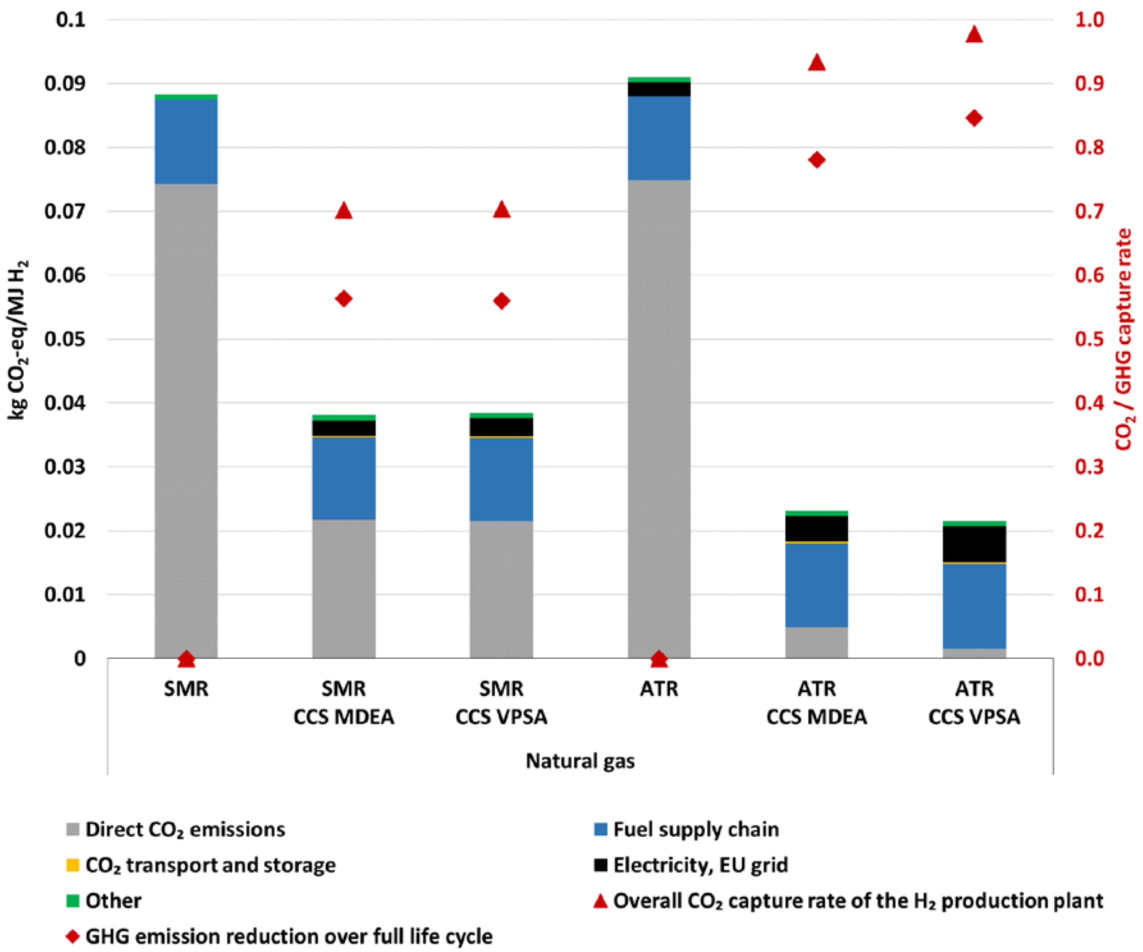
Antonini, C., Treyer, K., et al. (2020)

Life Cycle Assessment frame

- Functional unit: 1 MJ of H_2 produced via specified technology with a purity of > 99.97% (SMR, DFB) or >99.9% (ATR, oxyEF) at a pressure of 200 bar.
- Life Cycle Inventory:
  – Directly linked to the technical modellings from ETH
  – Background database: ecoinvent v3.6 «cut-off» system model
- Life Cycle Impact Assessment:
  – ILCD 2.0 2018: 16 impact categories for climate change, ecosystem quality, human health, resources
- Open source software package «Brightway2» https://brightway.dev/; https://carculator.psi.ch

- Antonini, C., Treyer, K., Streb, A., van der Spek, M., Bauer, C., Mazzotti, M. 2020. Hydrogen production from natural gas and biomethane with carbon capture and storage – A techno-environmental analysis. Sustainable Energy & Fuels, 2020, 4, 2967-2986
- Publication on H_2 production from wet and dry biomass in preparation

Life Cycle Climate Change impacts: H_2 production from natural gas, technical comparison

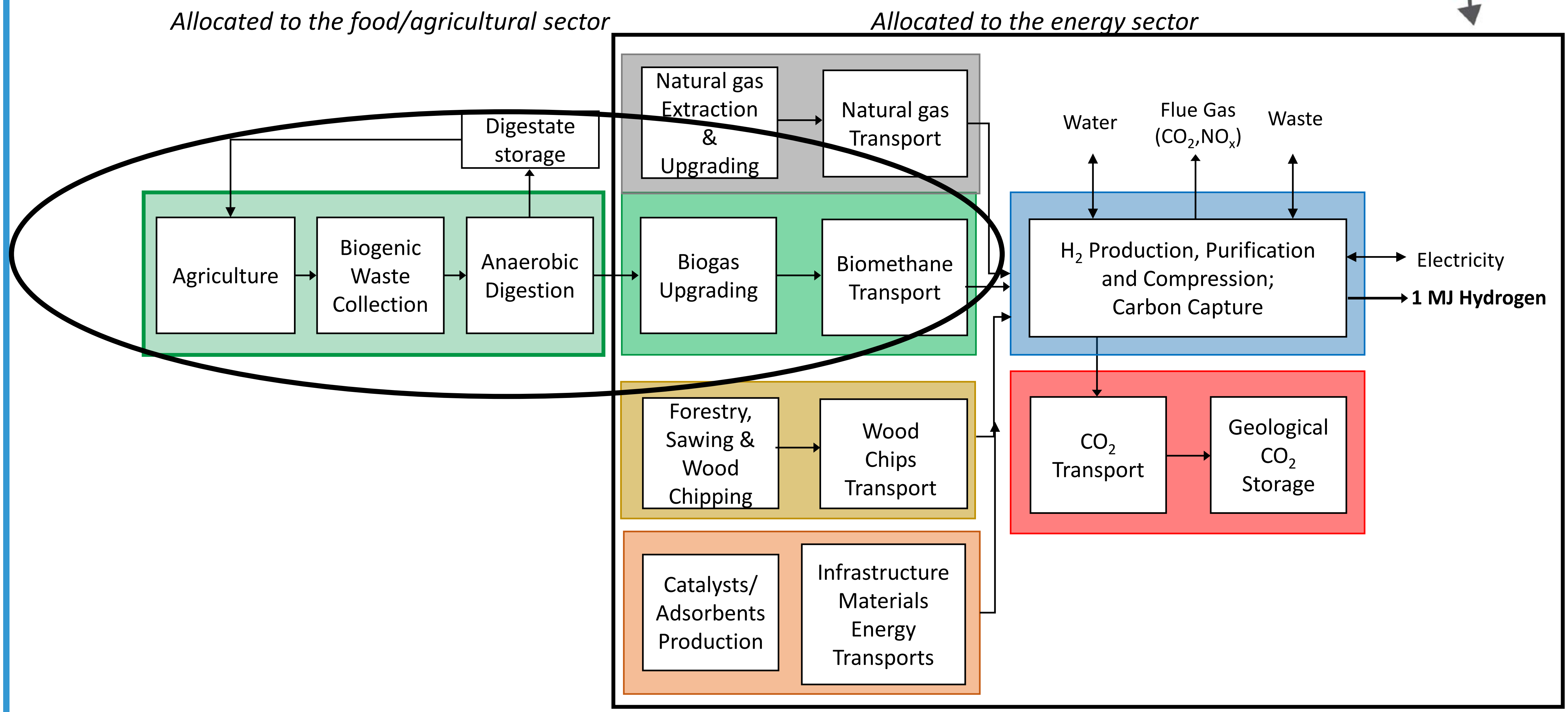


SMR: Steam Methane Reforming // ATR: Autothermal Reforming
MDEA: Methyl-Diethylamine // VPSA: Vacuum Pressure Swing Adsorption
GHG: Greenhouse gases

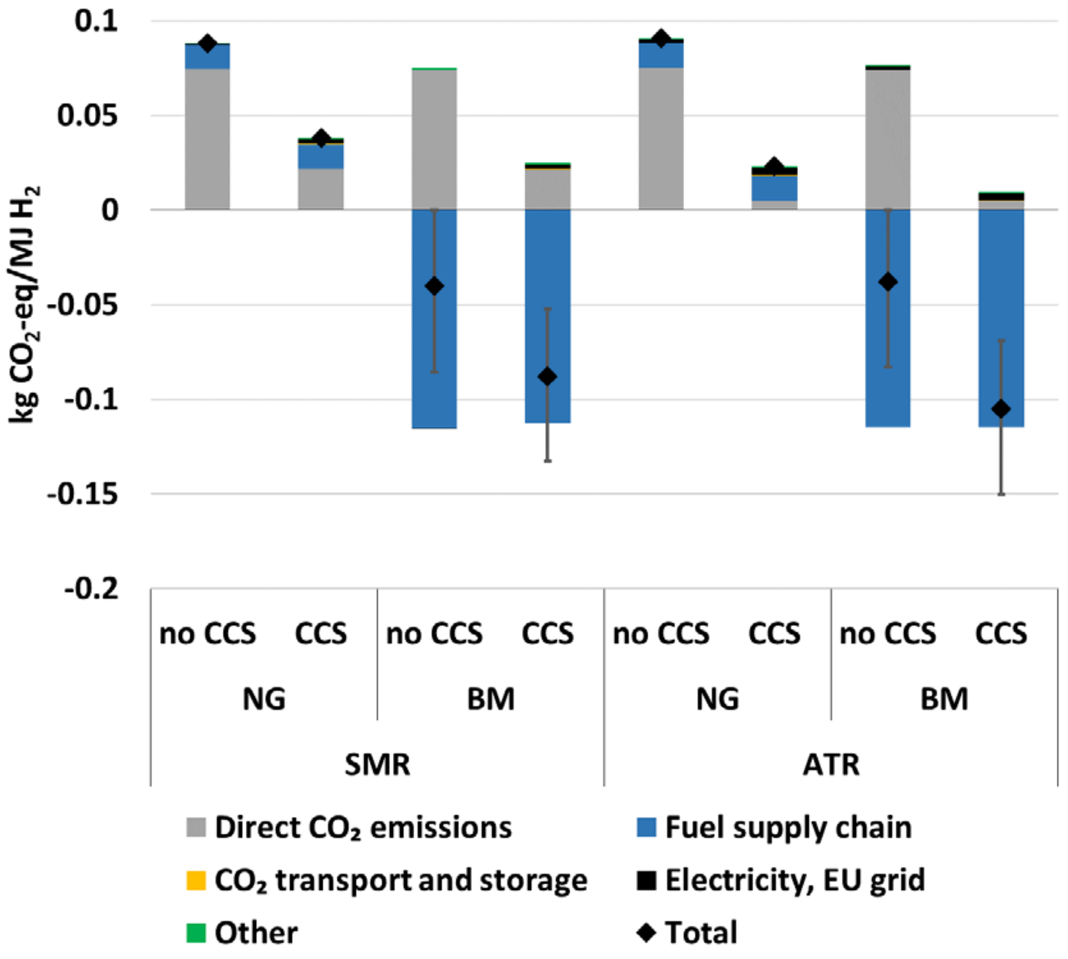
- **Direct CO_2 emissions** are most important, next to fuel supply chain
- **CCS** reduces impacts on climate change
- The **CO_2 transport and storage** is not driving the results.
- **MDEA and VPSA** show nearly identical performance
- **ATR** shows better performance than SMR with CCS
- Higher **overall CO_2 capture rates** are beneficial
- Capturing 85% of total greenhouse gas emissions during the life cycle is achievable

Antonini, C., Treyer, K., et al. (2020)

Life Cycle View on H_2 Production with CCS



Life Cycle Climate Change impacts: H_2 production from natural gas or biomethane



- Biomethane from wet biomass: Organic household waste/green waste
- Use of BM leads to **lower climate change impacts**
- Negative impacts can be reached

→ System boundaries are important!

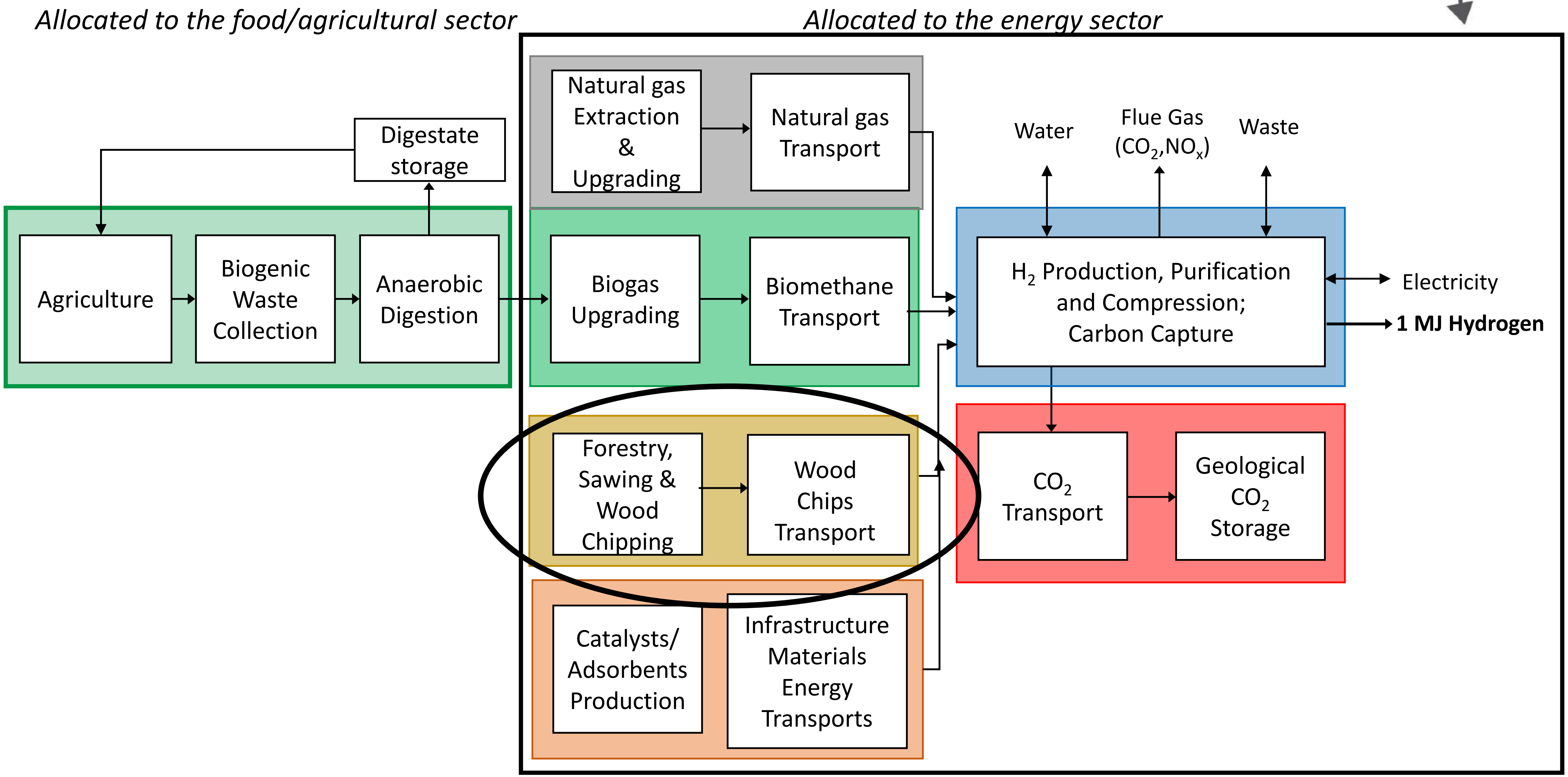
→ Variance in carbon balance: CO_2 *uptake* to biomass; *emissions* from anaerobic digestion, upgrading, and H_2 production; fate of *C in digestate*.

- **Blend** natural gas/biomethane: Ca. 1/3 to 2/3 BM needed to achieve **neutral** climate change impacts

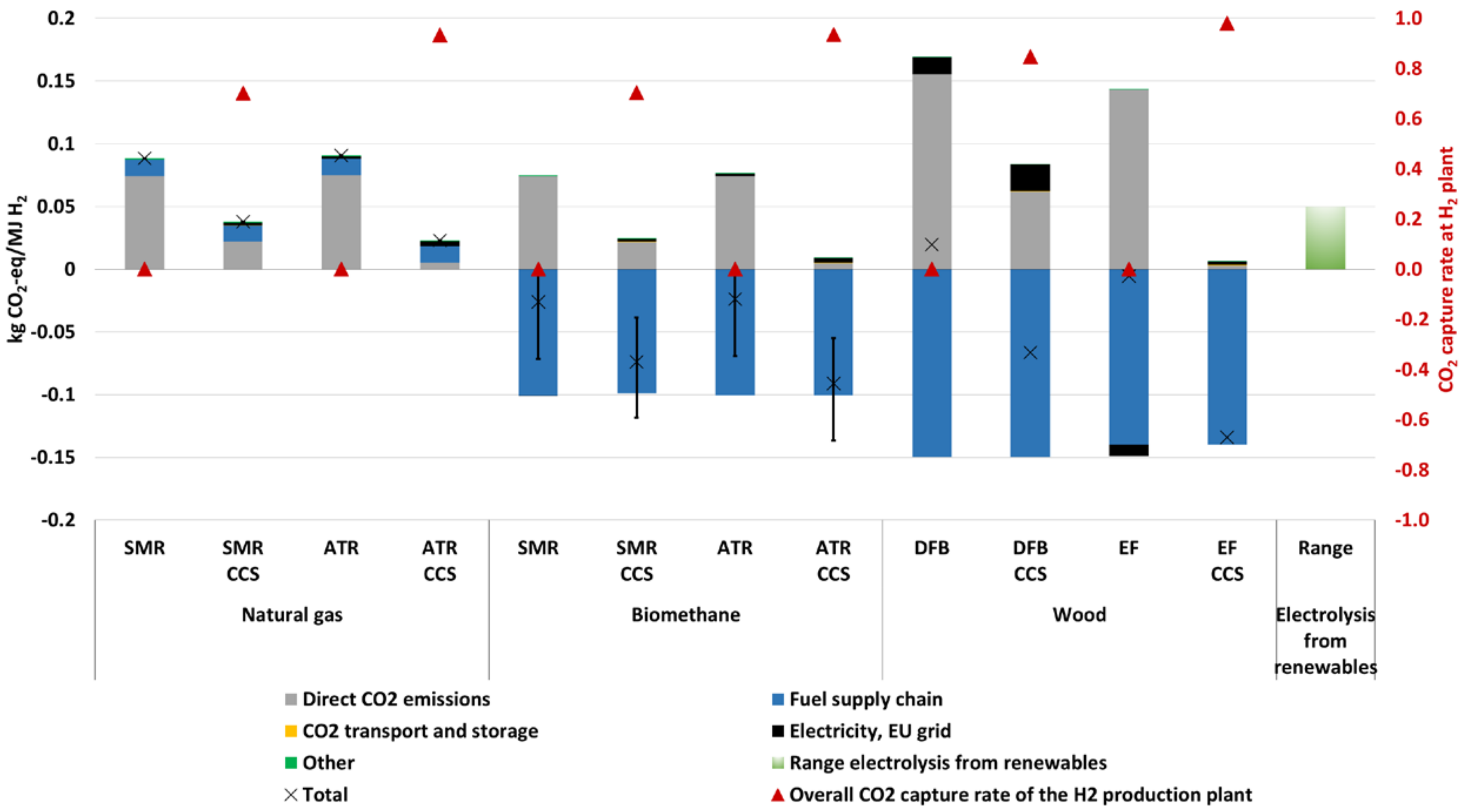
SMR: Steam Methane Reforming // ATR: Autothermal Reforming
NG: Natural gas // BM: Biomethane

Antonini, C., Treyer, K., et al. (2020)

Life Cycle View on H_2 Production with CCS



And now the big picture:
H_2 production pathways, climate change impacts

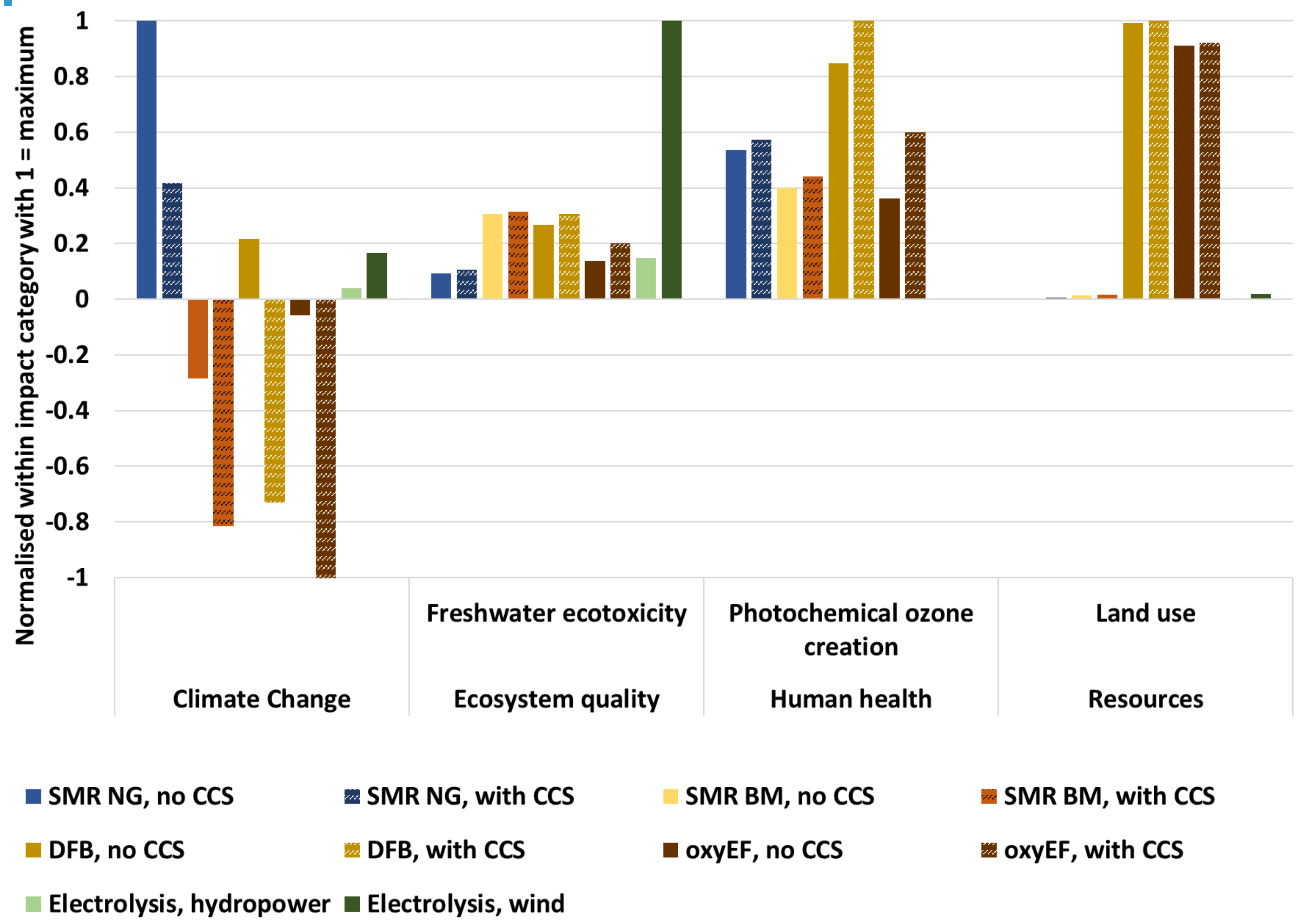


- Woody gasification:
  - Less efficient process, i.e. more C involved, but this is **biogenic C**.
  - Close to 100% CO_2 capture possible => more C captured
- **Carbon-neutral or negative emissions H_2 production possible** with both biomethane or wood as feedstock
- **Availability of (waste) biomass and CO_2 storage** are the challenges
- Combined with CCS, fossil-based hydrogen («**blue hydrogen**») is low-carbon and environmentally competitive with H_2 from electrolysis.

SMR: Steam Methane Reforming // ATR: Autothermal Reforming
DFB: Steam-blown dual fluidised bed gasifier // EF: oxy-fired entrained flow gasifier

Antonini, C., Treyer, K., et al. (2020)

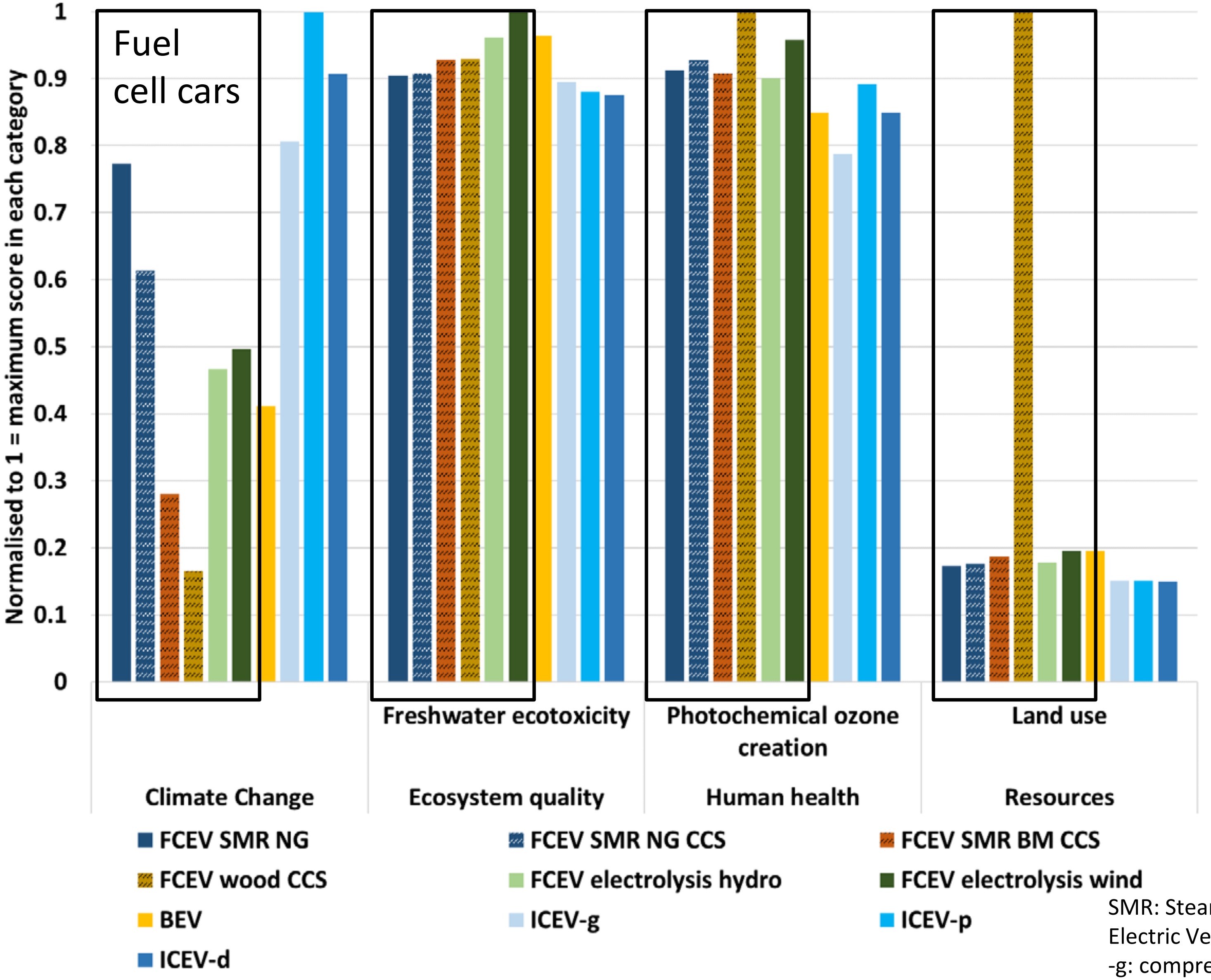
Looking for environmental trade-offs and winners



- **CCS** generally results **in higher impacts in all categories** other than climate change
- Woody gasification (oxEF) reaches high carbon removal while performing well in most other impact categories.
- Differences between production pathways seem to be large

→ **Does this give us the full picture?**

Interpreting LCIA results of H_2 production: Comparison of passenger transport in passenger cars (1 pkm)



- The **fuel supply chain is not driving all environmental impacts**, and thus does not have the same importance in all impact categories.
- Metal depletion in the **battery** is important
- **E.g. battery, car infrastructure, direct emissions of substances or tire, break and road wear emissions** are also important

→ If you want to learn more, check out our new tool: http://carculator.psi.ch/

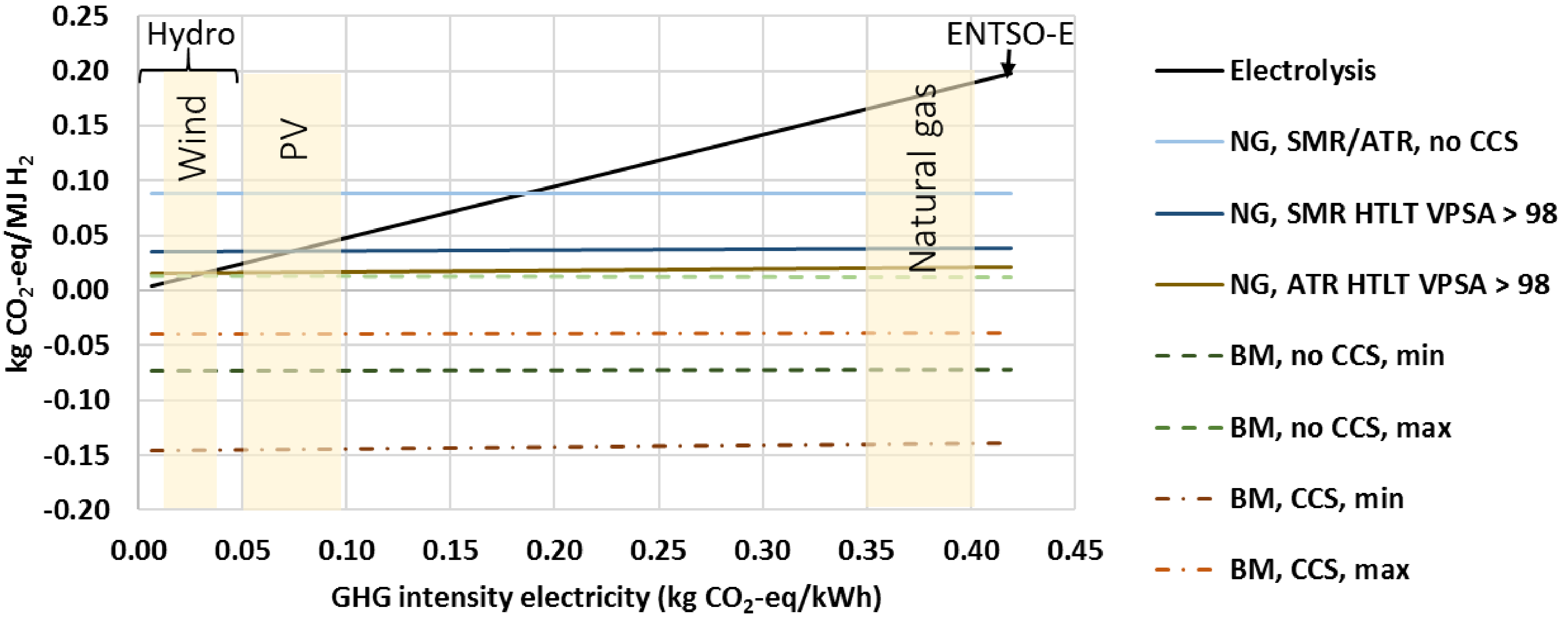
Sacchi et al. (2020) submitted

SMR: Steam Methane Reforming // NG: Natural gas, BM: Biomethane // FCEV: Fuel Cell Electric Vehicle, BEV: Battery Electric Vehicle, ICEV: Internal Combustion Engine Vehicle // -g: compressed natural gas, -p: petrol, -d: diesel

Take home messages

- **Low-carbon H_2** can be produced from **NG** (“blue H_2”) using commercial technologies (MDEA) and second generation technologies (VPSA) with comparable environmental performance.
- H_2 production can achive neutral climate change impacts or even act as **Negative Emission Technology** when using biomethane from waste biomass or wood as feedstock.
- A **net zero-carbon H_2 industry** can potentially be achieved by blue&green H_2 combined with negative emissions through biomethane- or wood based H_2.
- **Availability of biomass and CO_2 storage** are the challenges.
- **Trade-offs** with other environmental or human health impacts: Addition of CCS only slightly increases impacts in other impact categories.

Backup slide: H_2 production from electrolysis



Antonini, C., Treyer, K., et al. (2020)