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„Valuable (by-)products of gasification”
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150 YEARS FEATURING FUTURE 1872 - 2022

UNIVERSITY OF NATURAL RESOURCES AND LIFE SCIENCES, VIENNA

(Biomass Based) Negative CO_2 Emission Technologies

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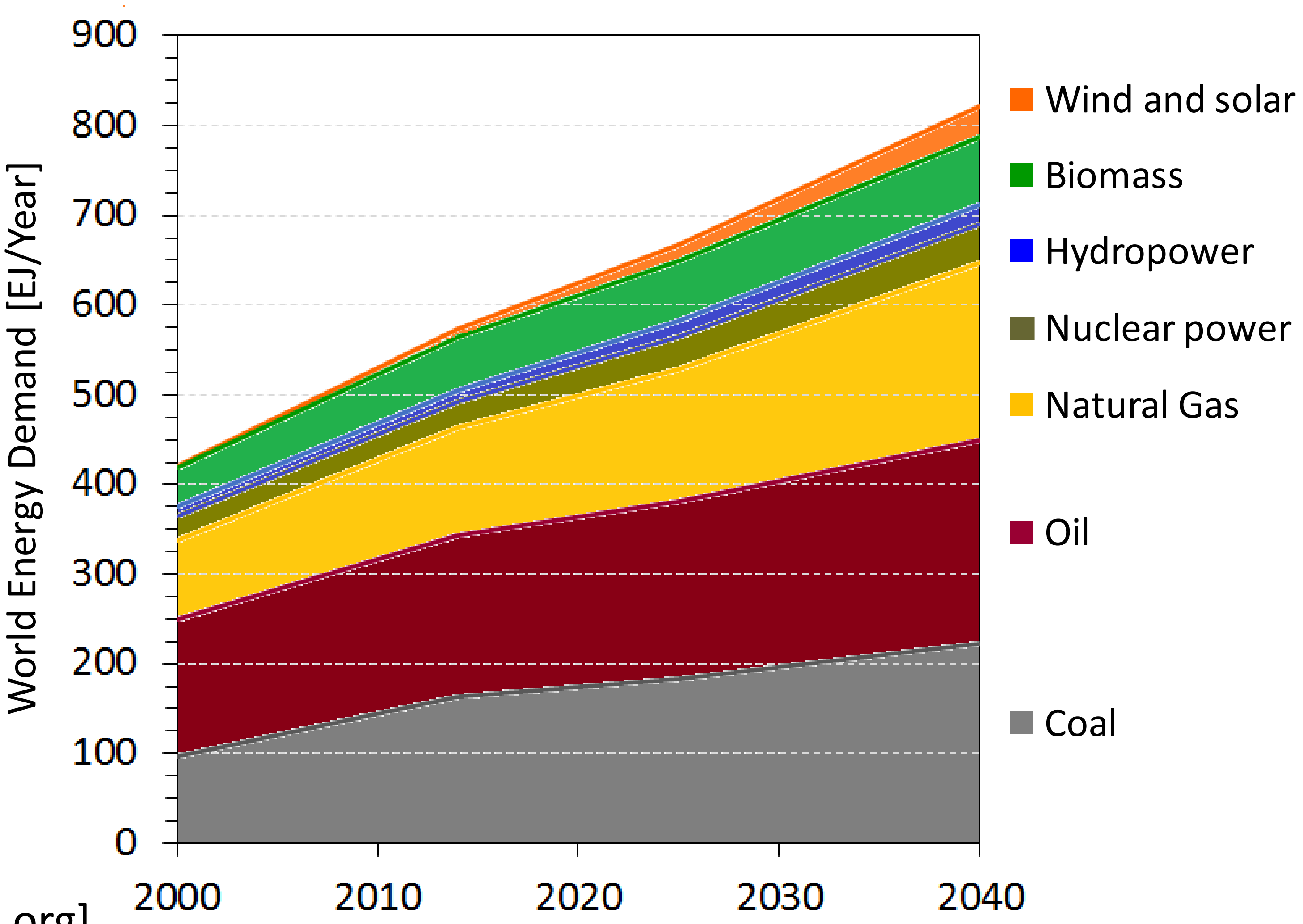
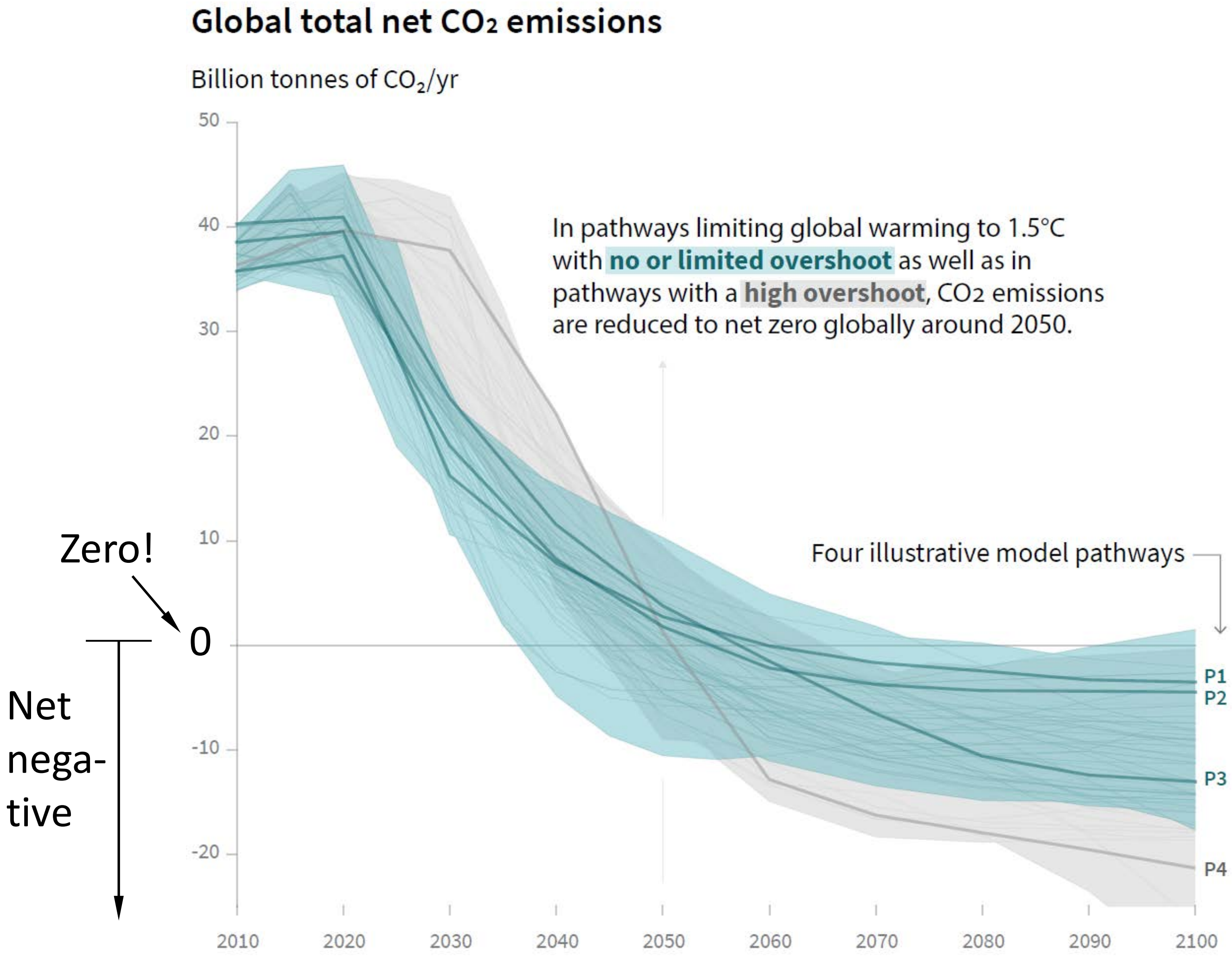
Where we stand, what we reasonably "expect"



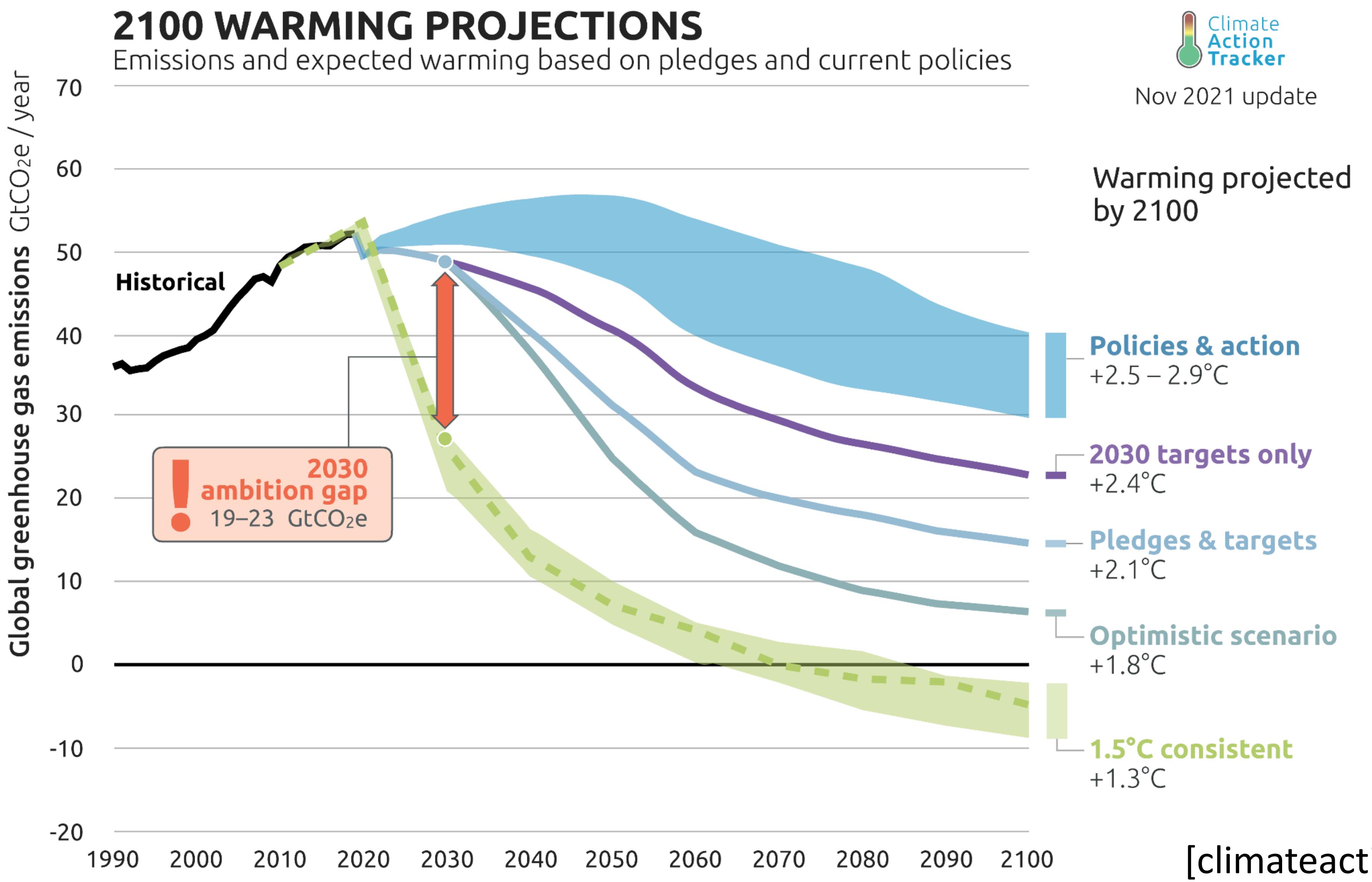
[IEA World Energy Outlook 2016 – iea.org]

Where we should go to: CO_2 emission budget for +1.5°C



[IPCC Special Report on GLOBAL WARMING OF 1.5 °C, October 2018]

- To reach the +1.5°C target, we need **net negative emissions** from 2050 onwards!
- The longer we wait with deep emission reduction, the greater the problem will get.



[climateactiontracker.org]

Conclusions from the IPCC SR1.5

- +1.5°C goal requires net zero emissions by 2050
- Immediate action is required to reduce emissions
- Delay will result in temperature overshoot
- Net negative emissions required after 2050

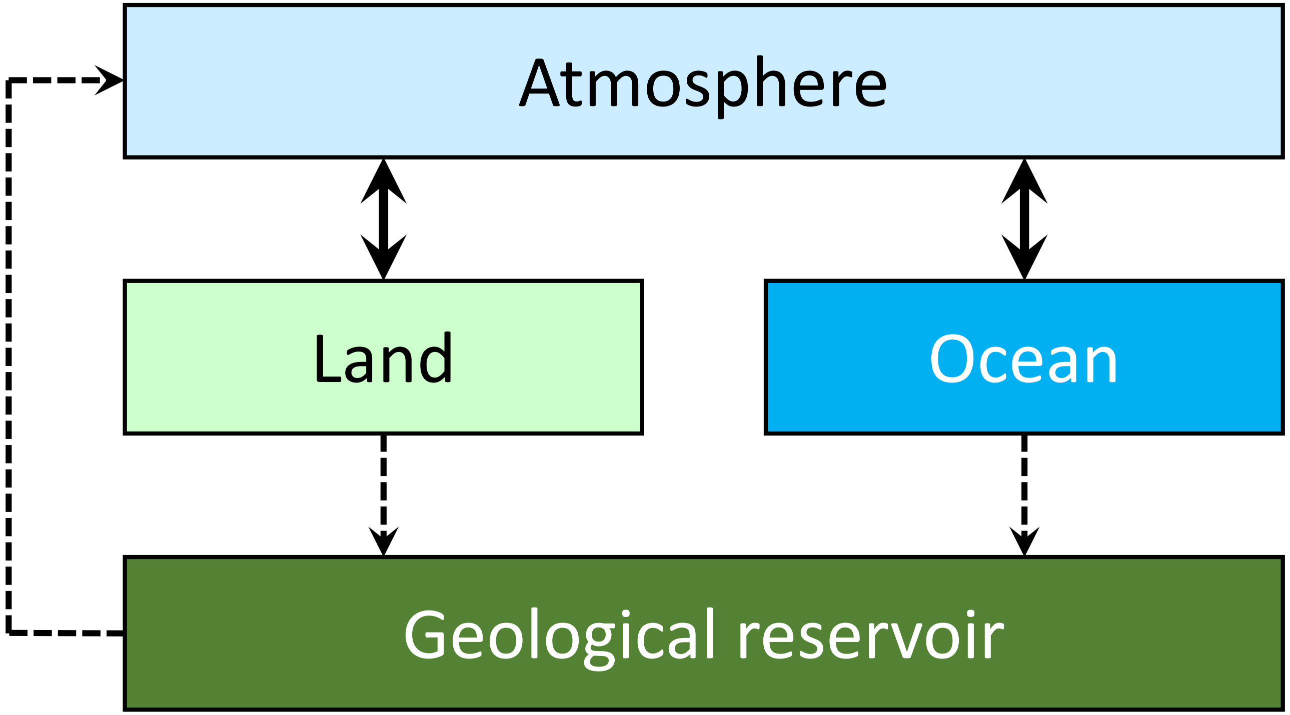
→ **Important: Option of negative emissions is required additionally and must not serve as an excuse to slow down action on emission reduction.**

→ **There is no magic formula, i.e. the statement above applies to all negative emission technologies known today.**

Starting point for this talk

- Negative emission technologies (NETs) are/will be required
- Competition **between emission reduction** (efficiency, renewables, carbon capture and storage - CCS) **and NETs**
  → highest climate change mitigation effect per EUR invested
- **How should research and policy makers react now?**
  - Sharp cuts on greenhouse gas emissions needed.
  - Therefore: efficiency increase, renewables, CCS.
  - **Will NETs appear on the agenda? When?**
  - **What could be the role of biomass (gasification) therin?**

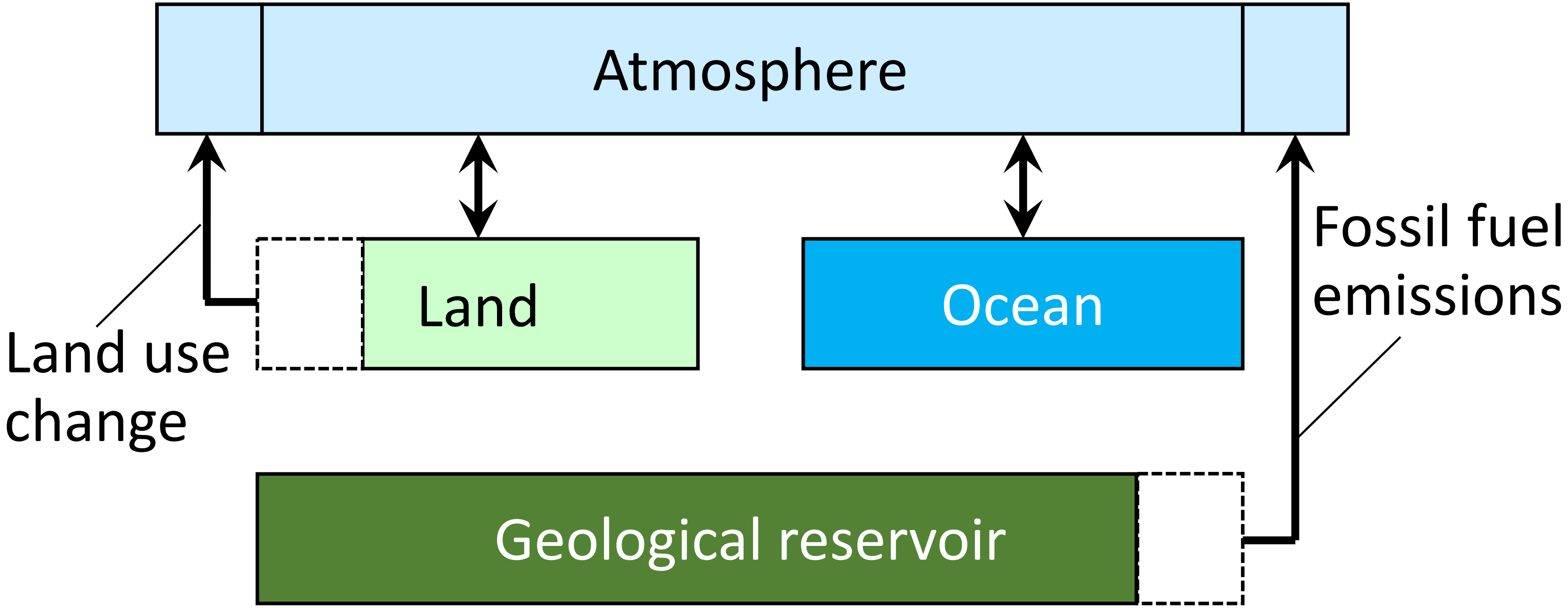
Unperturbated carbon cycle



→ **Bold arrows indicate active equilibria**

→ **Broken-lined arrows indicate slow geological processes**

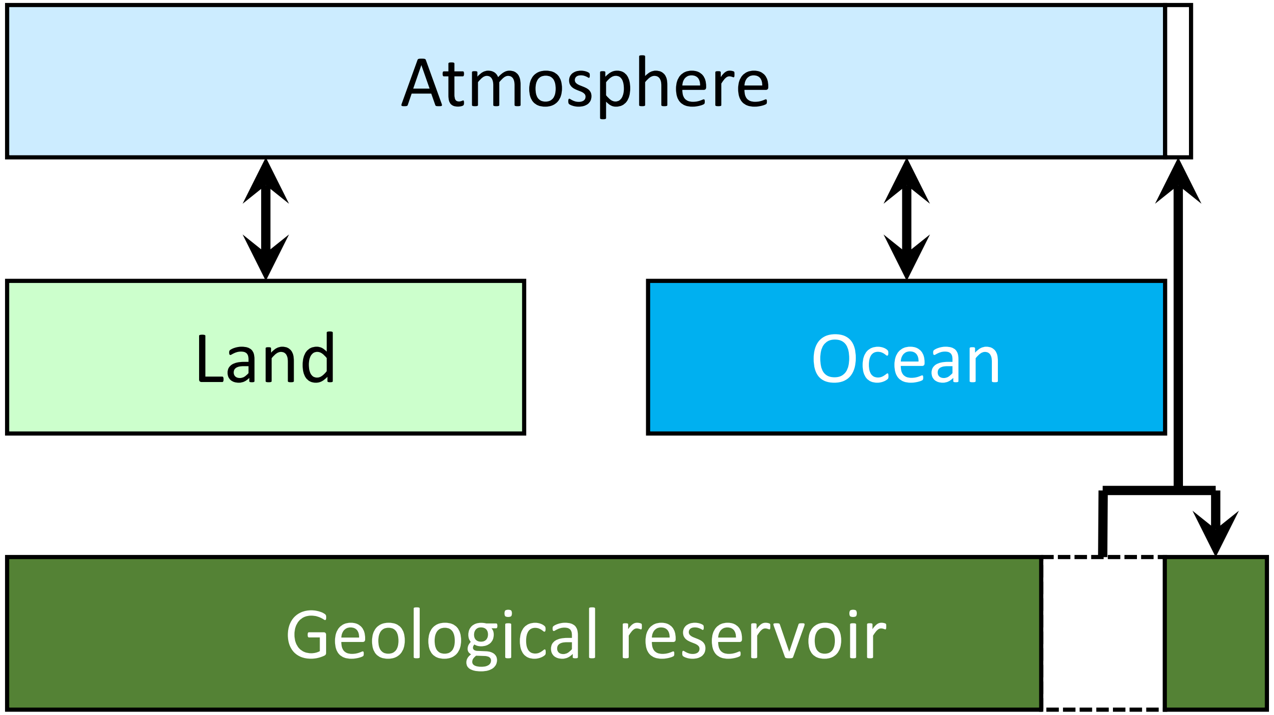
Currently: land use change and fossil fuels



→ **Increasing CO_2 concentration in the atmosphere**

→ **Increasing CO_2 concentration in the ocean via equilibrium**

Carbon capture and storage (CCS)



→ **Classical CCS: Partially avoids CO_2 emissions from fossil fuels**

→ **Roughly 20% of the fuel energy required for CO_2 capture**

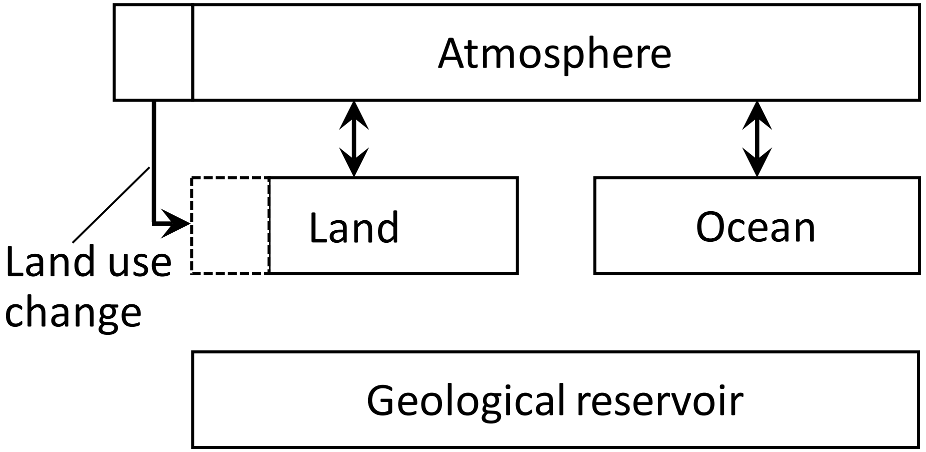
How to get to negative CO_2 emissions?

Carbon dioxide removal (CDR) options

- Agriculture, forestry and other land use change (AFOLU)
  - Afforestation and reforestation, Land restoration
  - Soil carbon sequestration
- Biochar addition to soil
- Bioenergy with carbon capture and storage (BECCS)
- Direct air capture and storage (DACS)
- Enhanced weathering
- Ocean alkalinisation

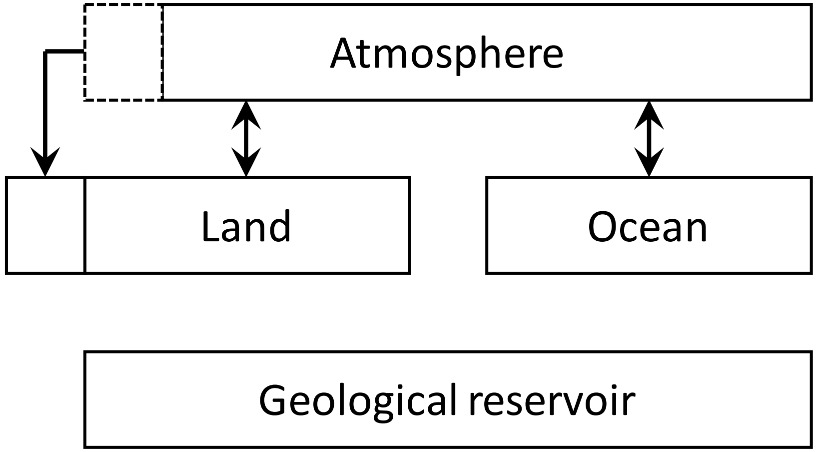
Negative emission technologies (NETs)

AFOLU and Biochar to Soils

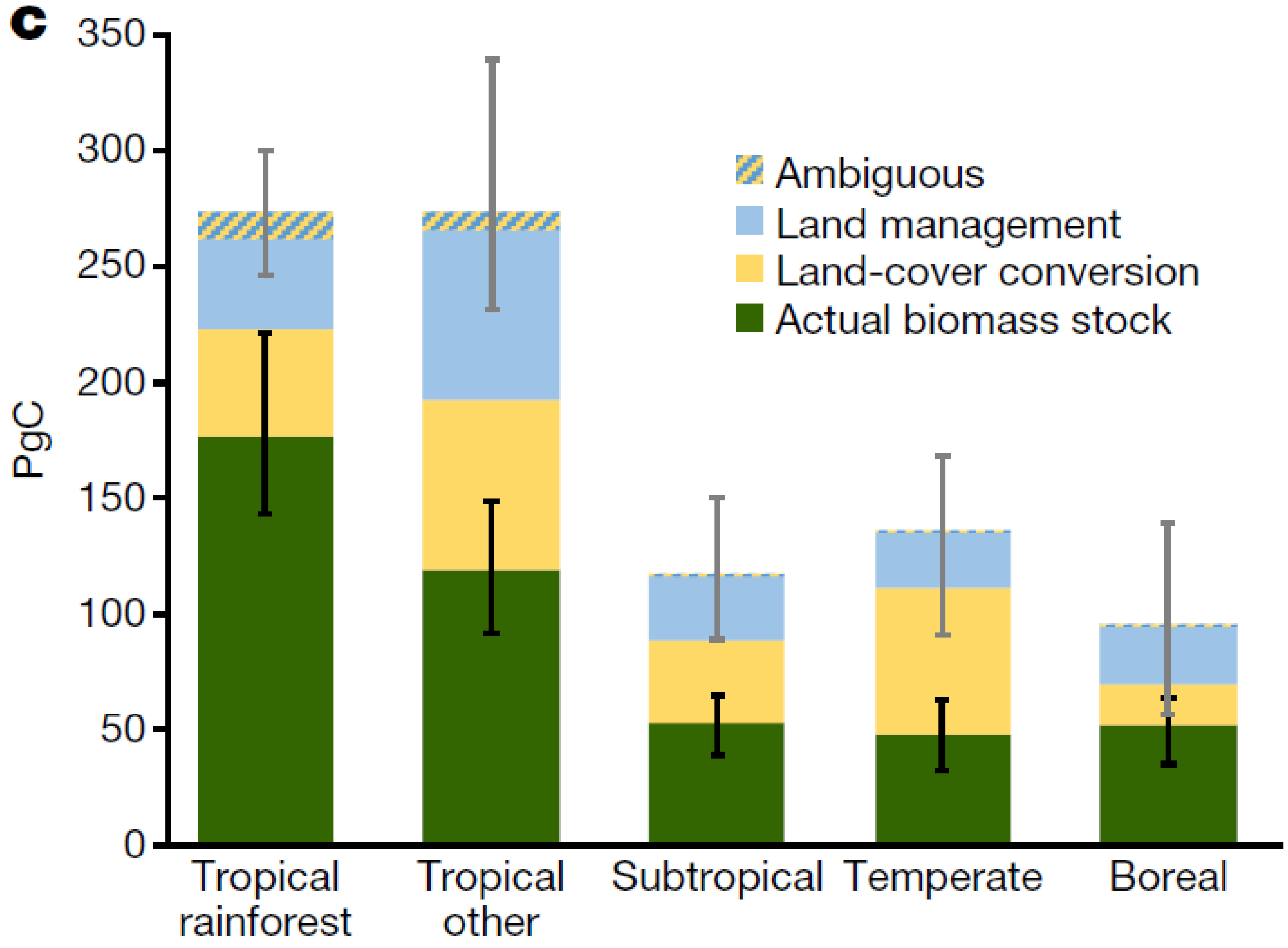


- Afforestation
- Soil carbon increase
- Restoring the original organic carbon stocks

- Conversion of biomass to non-biodegradeable char
- Additional to natural stocks
- Increased lifetime in storage

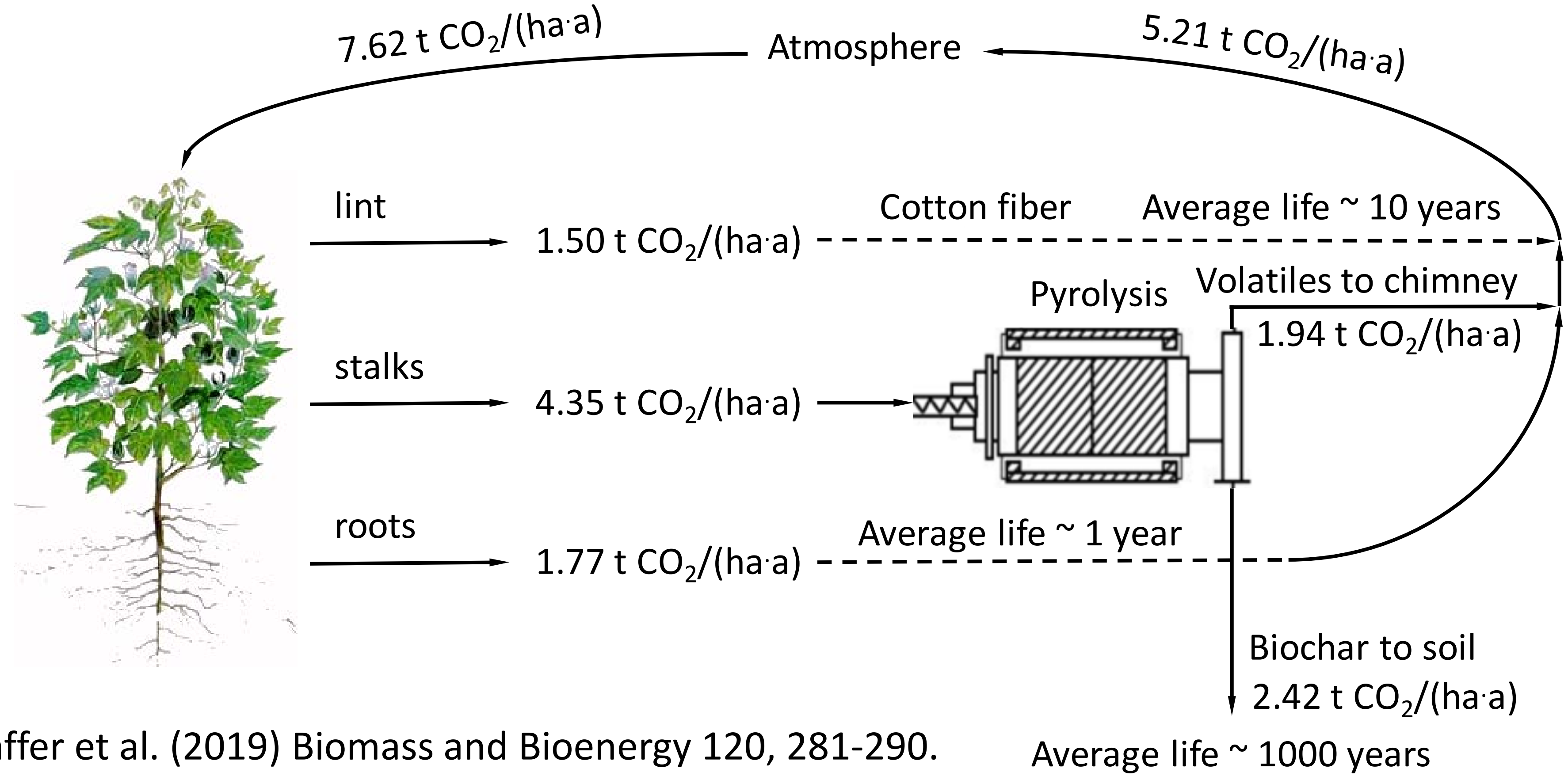


AFOLU – Potential Impact



Source: Erb et al. (2018) Nature 553:73-76 (doi:10.1038/nature25138).

Biochar soil storage (e.g. within cotton industry)



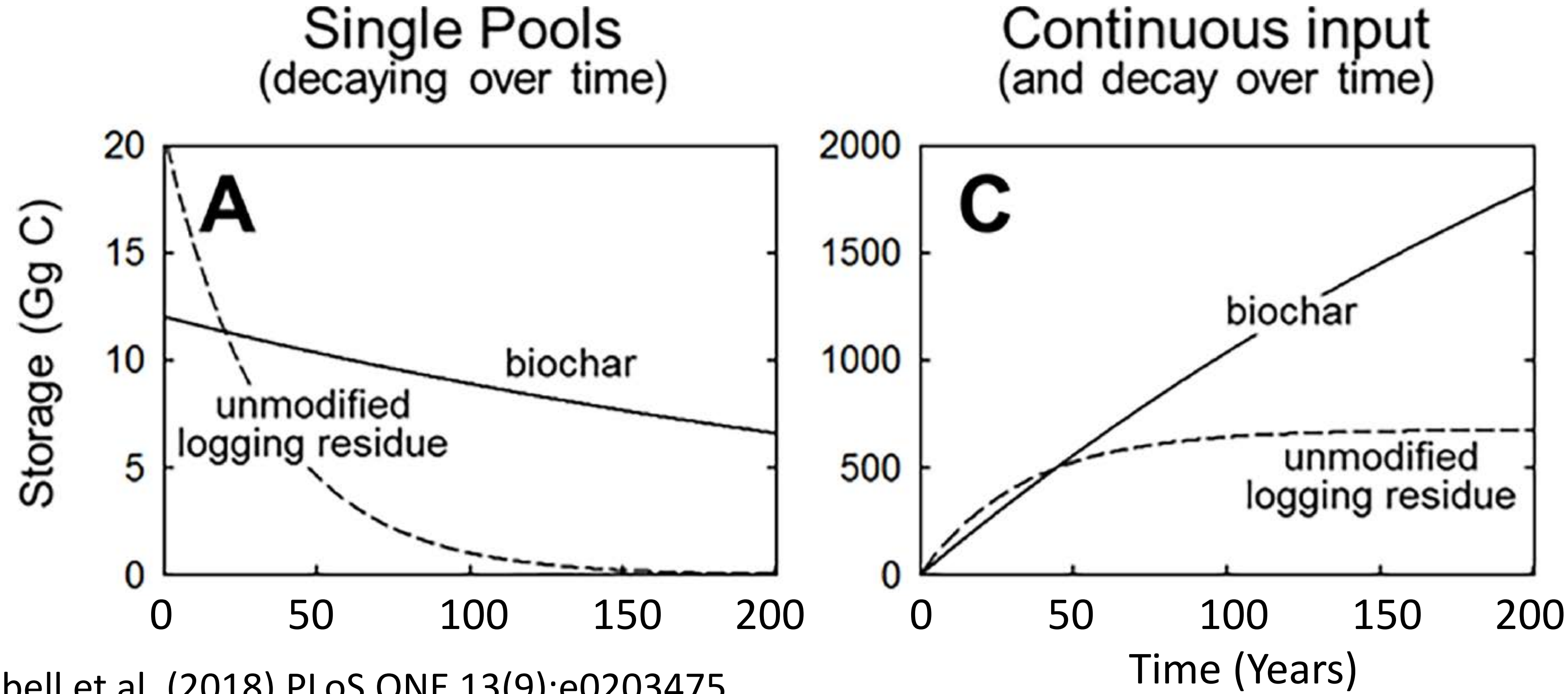
Source: Schaffer et al. (2019) Biomass and Bioenergy 120, 281-290.

→ Low-tech approach compared to other NETs

→ About 30% of the assimilated carbon are stored in the soil

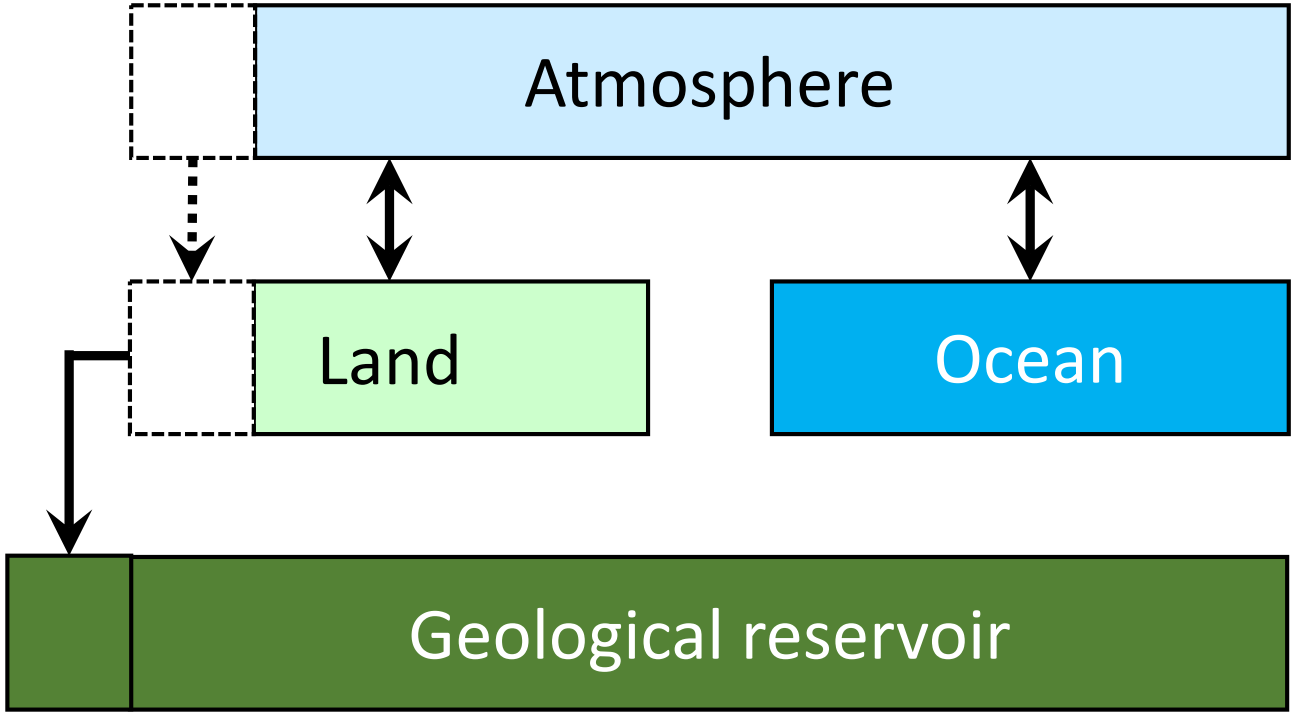
Biochar vs. fresh biomass

Recent study on storage of biochar from logging residues (slash) in Oregon/U.S.



Source: Campbell et al. (2018) PLoS ONE 13(9):e0203475.

Bioenergy with CCS (BECCS)

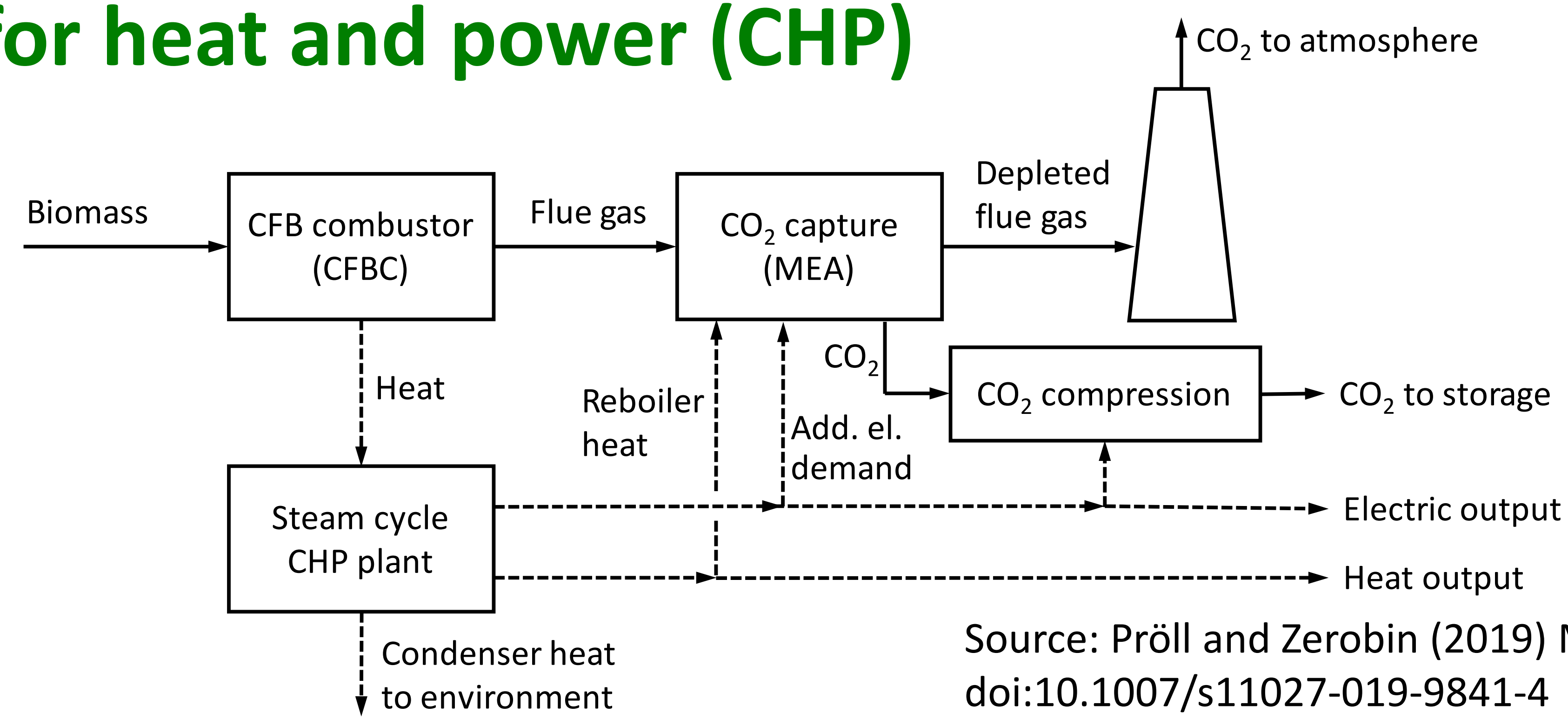


→ **Pre-concentration of carbon in biomass using sunlight**

→ **Biomass converted to energy, CO_2 captured and stored**

→ **Lower energy output compared to bioenergy without CCS**

BECCS for heat and power (CHP)



Source: Pröll and Zerobin (2019) MITI, doi:10.1007/s11027-019-9841-4

Parameter	Unit	CHP	MEA	CLC
Max. electric efficiency with CO_2 compr. (90% capture)	%	37.1	27.0	31.4
Maximum heat efficiency	%	53.0	25.1	47.7
El. efficiency in max. heat case with CO_2 compr.	%	26.5	22.0	21.9
Maximum fuel power utilization rate with CO_2 compr.	%	79.5	47.1	69.6

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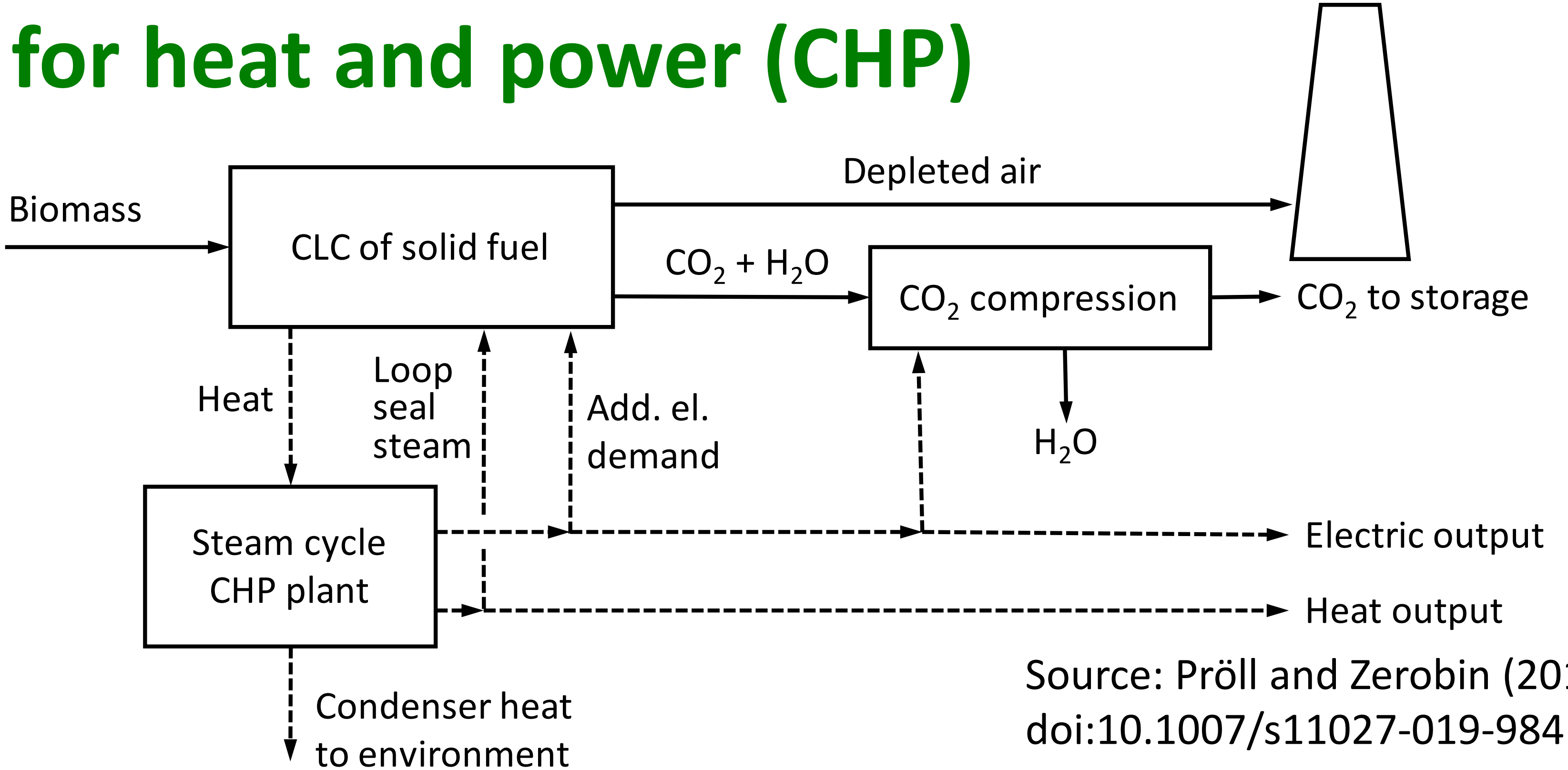

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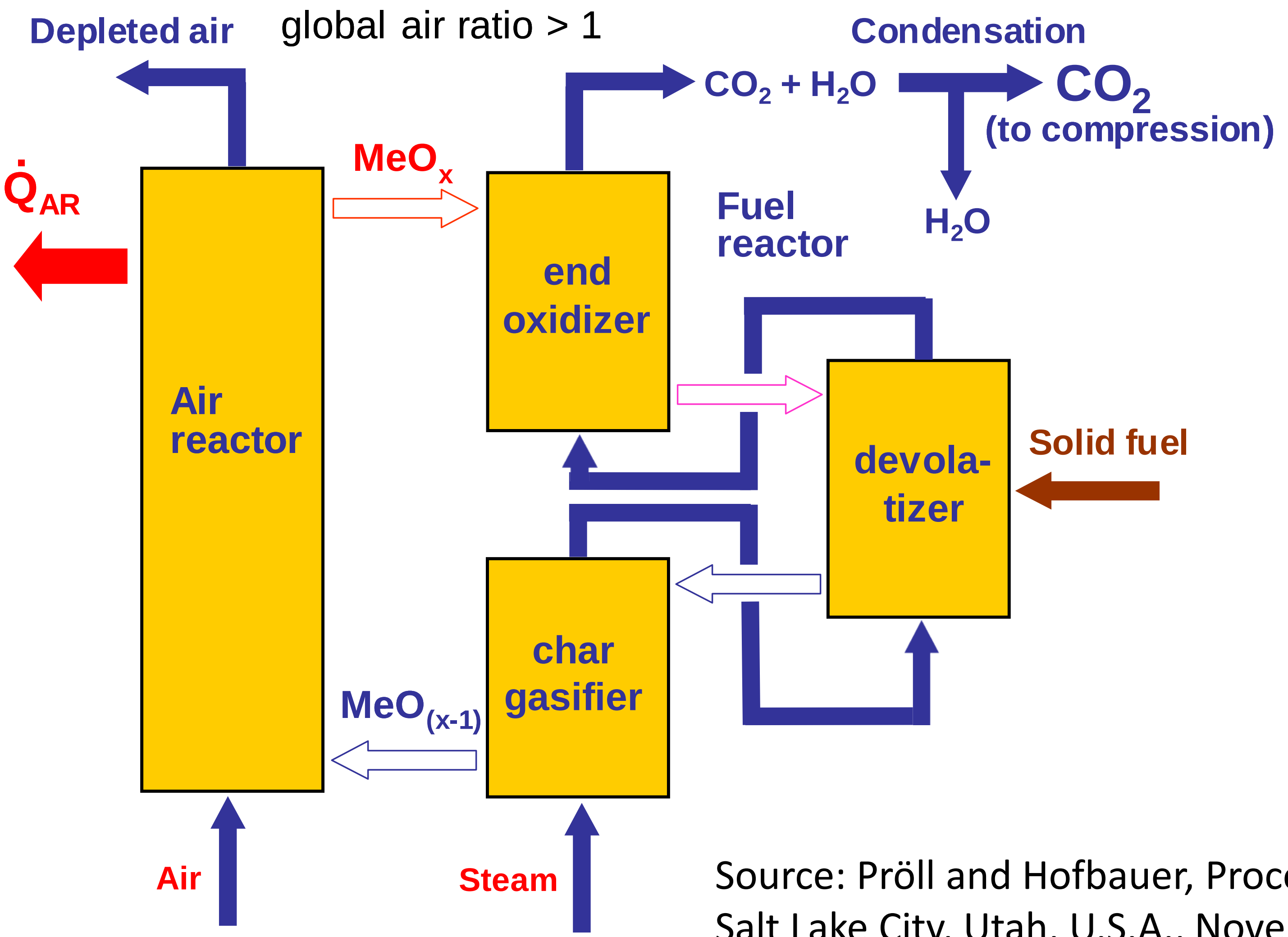
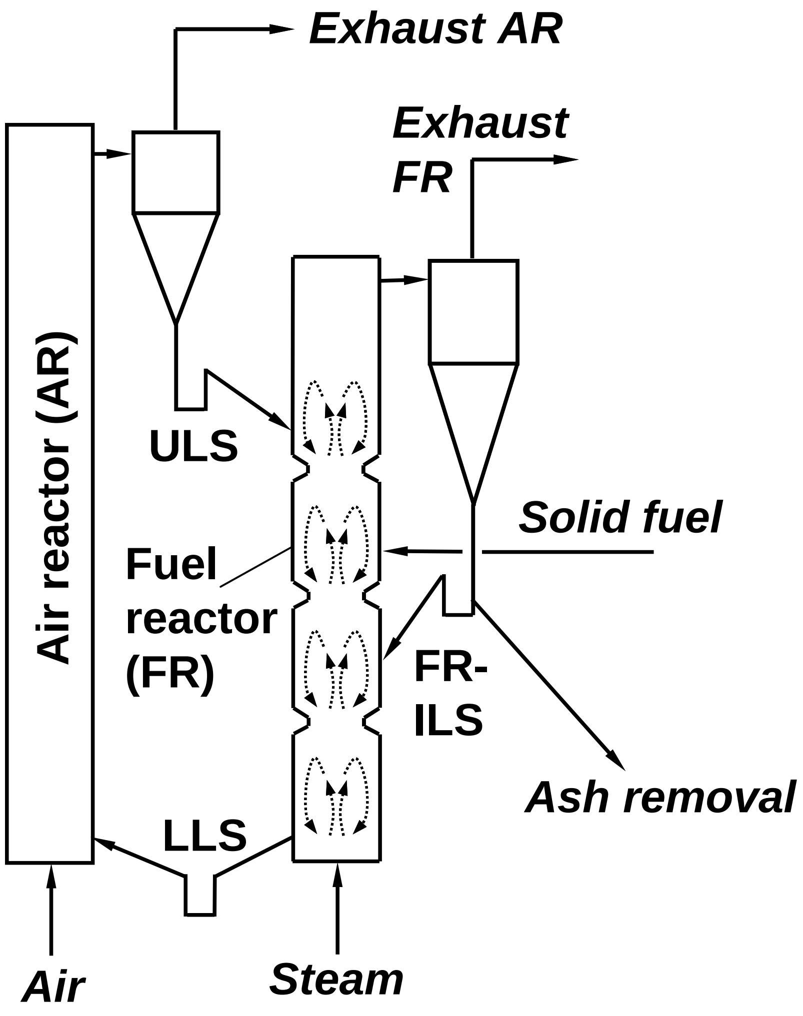
Chemical-looping combustion (CLC) of solid fuels - Theory



- Oxidation of both volatiles and charcoal
- Control on gas and solids residence time distribution → counter-current contacting pattern
- Fluidized bed systems

Source: Pröll and Hofbauer, Proceedings of the AIChE Annual Meeting 2010, Salt Lake City, Utah, U.S.A., November 7-12, 2010

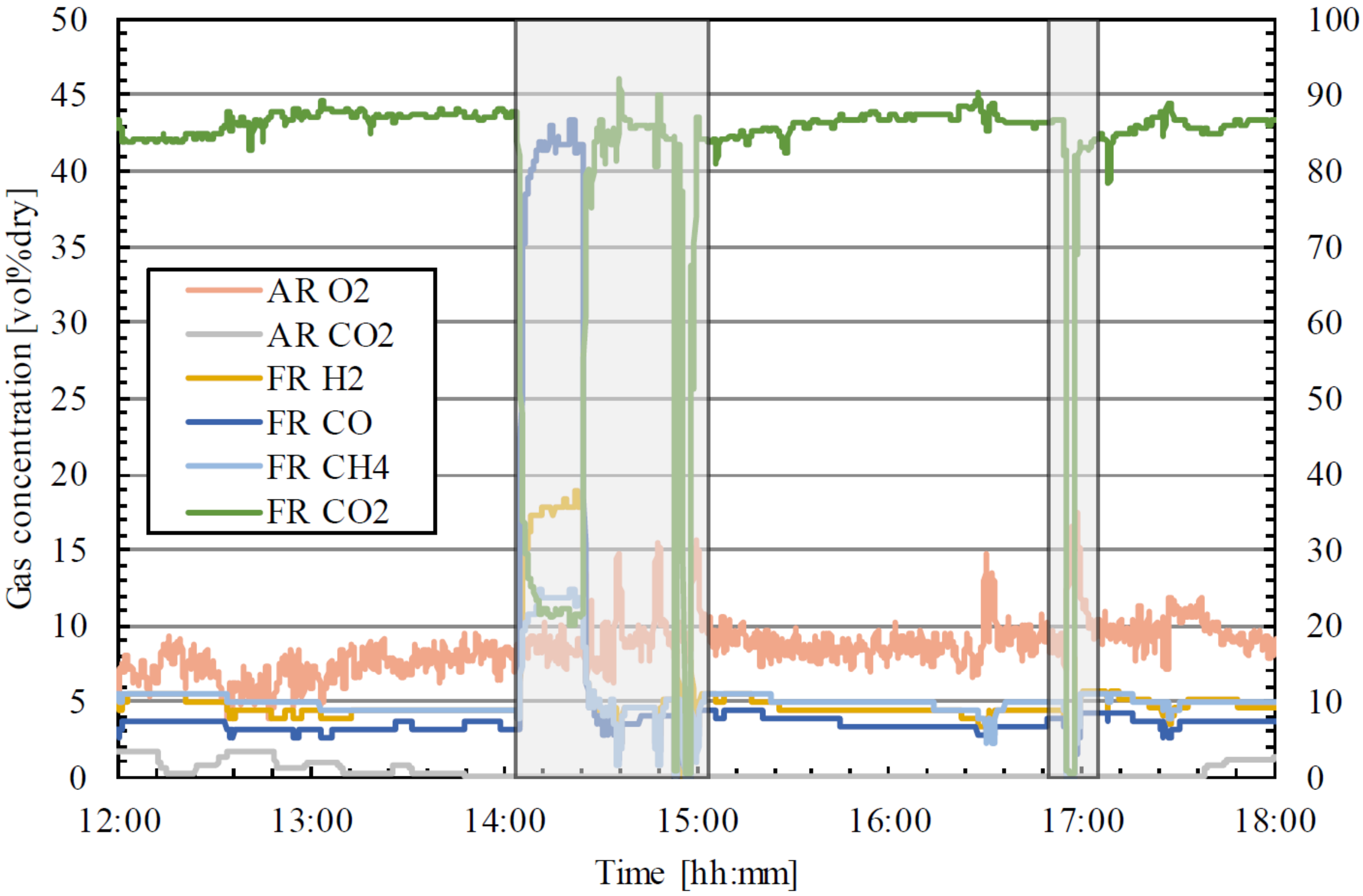
CLC of solid fuels – reactor system



- Fuel reactor divided in vertical sections by flow obstacles reducing the cross section
- Fast fluidization regime in the reduced cross section, bubbling to turbulent regime in the zones between
- Consecutive dense zones
- Gas-solid counter-current flow behavior
- Particle size separation possible

Source: Pröll and Hofbauer, Proceedings of the AIChE Annual Meeting 2010, Salt Lake City, Utah, U.S.A., November 7-12, 2010

Biomass CLC first results @ TU Wien (Penthor et al.)



Dual fluidized bed gasifier pilot plant @ 80 kW fuel input

- 85% CO_2 in FR exhaust gas
- No CO_2 from AR exhaust gas
- World record in solid fuel CLC performance

Source: Penthor et al., 5th International Conference on Chemical Looping, 24-27 September 2018, Park City, Utah, USA

Biomass-based NETs – comparison

Biochar

- Simple process, no CO_2 transport and storage infrastructure
- Lower energy output (about 50% of bioenergy w/o CCS)
- No ash melting – nutrients available for recycle
- Suitable for biomass residues with low ash melting point

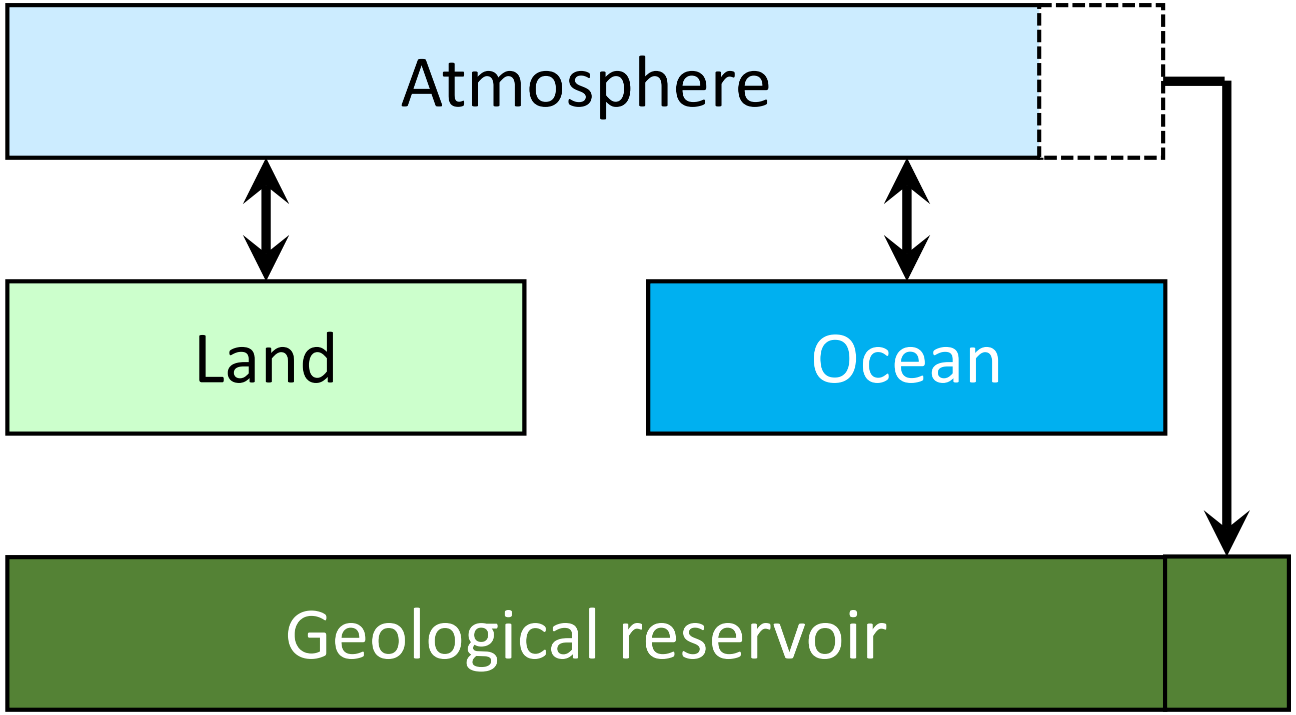
BECCS

- Higher energy output (about 80% of bioenergy w/o CCS)
- High temperature conversion, ash melting risk
- Suitable for wood as fuel (no ash melting issues)
- CO_2 transport and storage infrastructure required

→ **Biochar in sub-tropical and tropical regions where bioenergy is not competitive to solar power and soils are depleted**

→ **BECCS in cold climate where wood is sustainably available**

Direct air capture and storage (DACS)

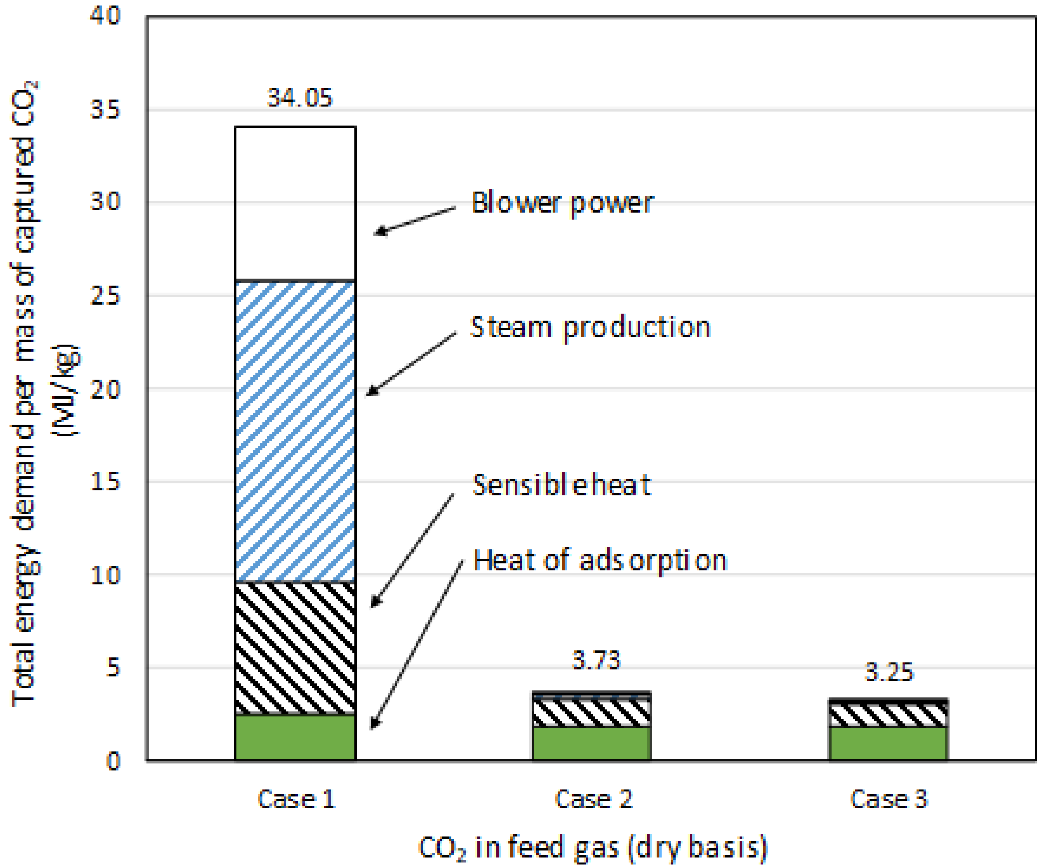


→ CO_2 technically separated from ambient air (e.g. by adsorption)

→ CO_2 concentrated to 100% (e.g. by desorption into steam)

→ CO_2 compressed for transport and storage

Comparison DACS versus CCS



Continuous temperature swing adsorption

CO_2 concentration in source gas:

Case 1: 0.04 vol% CO_2

Case 2: 4 vol% CO_2

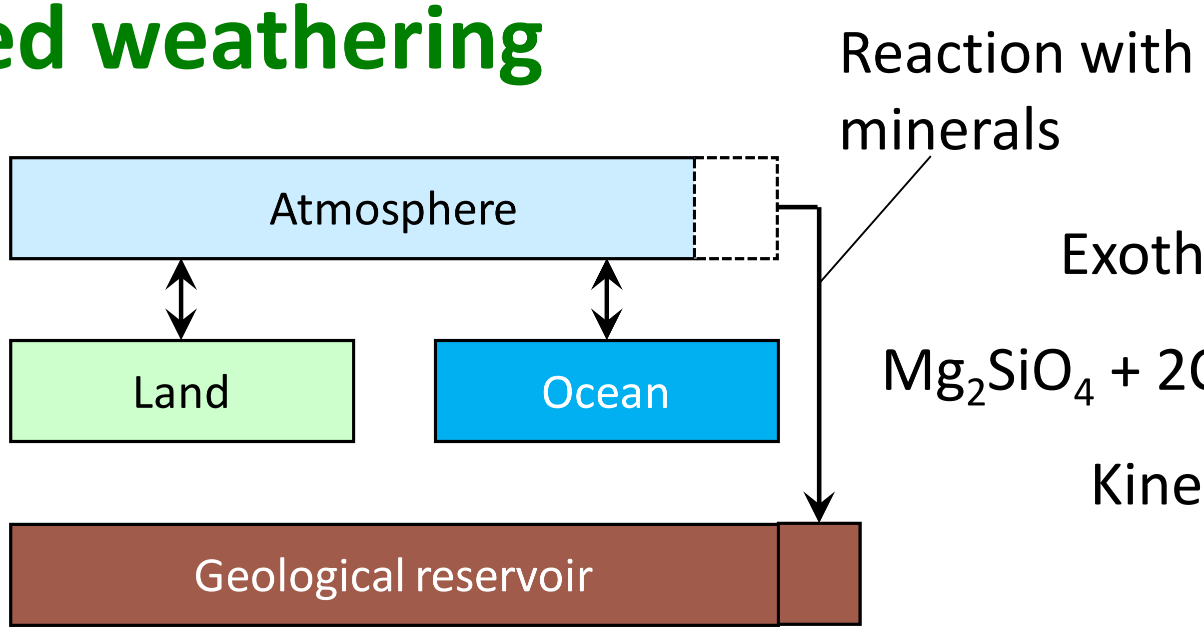
Case 3: 10 vol% CO_2

Source: Zerobin&Pröll (2020) Ind. Eng. Chem. Res. 59, 9207-14.

→ DACS requires about 10 times more energy than CCS

→ DACS comes with tremendously higher equipment costs

Enhanced weathering



Exothermic reaction

$$Mg_2SiO_4 + 2CO_2 \rightarrow 2MgCO_3 + SiO_2$$

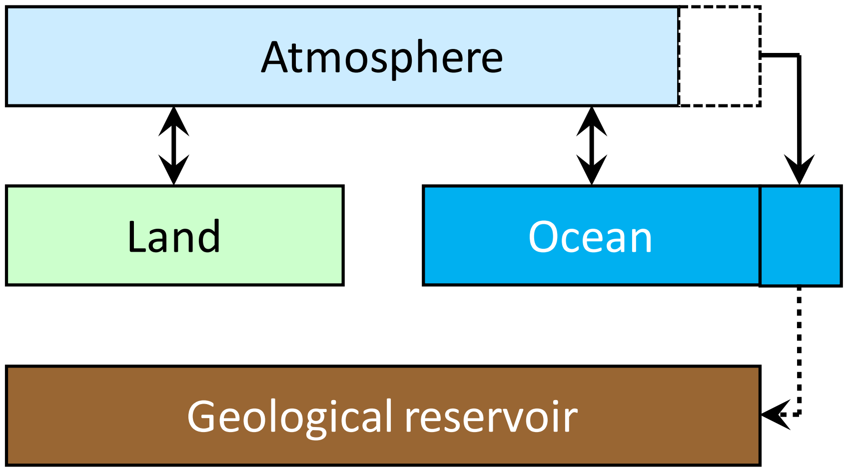
Kinetically limited

- In-situ methods: CO_2 injection in alkaline rock formations
- Ex-situ methods: Manipulation of rock (i.e. grinding) and reaction in a reactor at reasonable time scales

→ **Advantage: safe and stable storage option (in-situ with CCS)**

→ **Challenge: Costs and ecosystem effects of ex-situ approach**

Ocean alkalinisation



Addition of caustic lime to water

$Ca(OH)_2 + 2CO_2 \rightarrow Ca^{2+} + 2HCO_3^-$

Addition of alkaline minerals
→ Ex-situ enhanced weathering

- → **Could mitigate ocean acidification**
- → **Potential mineralisation as $CaCO_3$ (only 1 mol CO_2/mol CaO)**
- → **Zero emission lime kiln (through CCS) required**
- → **Ecological impact assessment is crucial (e.g. heavy metals)**

Cross-linkings between the CDR options

- Biochar-assisted afforestation and soil carbon recovery
- BECCS in possible conflict with AFOLU measures
- DACS with CCS (e.g. using natural gas instead of flaring)
- BECCS with in-situ enhanced weathering

No local competition between BECCS and DACS

- BECCS requires that energy is valuable
- DACS requires very cheap renewable energy

Summary

- Large potential in AFOLU measures (at reasonable cost)
- Biomass-based NETs need to obtain biomass from sustainably managed land in accordance with AFOLU
- Biochar suitable for residual agricultural biomass
- BECCS requires higher quality biomass (wood) without ash melting issues
- Efficient BECCS could be reached using Chemical Looping Combustion
- DACS can be used in future scenarios with high CO_2 prices in locations far from any chimney with renewable energy or highly effective CCS and access to suitable storage sites
- Large uncertainties for enhanced weathering and ocean alkalinisation

Conclusions

The present discussion about **negative emission technologies is no excuse to delay** effective and sharp reduction of CO_2 emissions through efficiency increase and decarbonisation of the global economy.

Low-tech and low-cost CDR options (AFOLU, Biochar) could be **applied immediately** and in parallel to emission reduction efforts.

BECCS may come along with CCS but **relies on sustainably produced biomass.**