Opportunities and Challenges of BECCS in Industry: comparison with alternative decarbonization pathways

Dr Piera Patrizio
Head of Research, Science Based Target initiative (SBTi)
Guest Researcher, Imperial College London
Outline

• **The role of BECCS in net zero energy systems**
  • Biomass demand versus supply
  • Mitigation and removal services of biomass
  • Multiple biomass based removal pathways

• **Pathways to low carbon steel: BECCS versus H2-DR**
  • GHG performance
  • Comparison with other BECCS pathways
  • Key factors affecting competitiveness

• **Pathways to low carbon cement: CCU versus CCS**
  • GHG performance
  • Comparison with other BECCS pathways
  • Key factors affecting competitiveness

• **Conclusion and areas for future work**
By 2050 the demand for sustainable biomass will exceed supply

Global tradable primary energy supply range between 14-84 EJ per year, based on different socio-economic scenarios.

Ranges of biomass demand in the aviation sector reflect uncertainties about the conversion efficiencies (30%-47%) of aviation biofuel production.

BECCS biomass demand reflects outcomes from IPCC 1.5C special report (0-200 EJ pa)

Adapted from: Committee on Climate Change (2018). Biomass in a low carbon economy.
The multiple uses of biomass in the energy system

The flexibility of sustainable biomass as a low-carbon resource means potential demand could be high across multiple sectors. As a result, decisions will need to be made as to where this scarce resource is best-used across the economy to maximise its overall contribution to mitigating climate change.

Source: Committee on Climate Change (2018). Biomass in a low carbon economy
Biomass mitigation potential decreases with time

The mitigation potential depends only on the counterfactual scenario: the carbon intensity of the product of energy carrier being substituted and its degree of substitution with low carbon alternative.

Source: Committee on Climate Change (CCC), 2019
BECCS removal potential

Illustrative example of the removal potential of BECCS to power. The example assumes the adoption of Miscanthus pellets:

Biomass dry mass is lost during transport and processing, at the rate of 10% (pelletising, >100k transport)

Post capture efficiency captures any post conversion process emissions associated with energy use ~ 6% for the transport and storage of CO2

The carbon footprint of biomass pellets is an European average calculated in the MONET framework and includes biomass production (seed, fuel for land preparation and harvest, fertiliser direct and indirect CO2,eq emissions), pelletising, average distance transport (100-200k), and pellet grinding.
Pathways to low carbon steel: BECCS vs H₂-DR
Low-carbon steel: the role of BECCS
Modelled CO$_2$ integration

CCS min

CCS max
Emission breakdown: Sensitivity to CI of electricity

CI = 170 KgCO₂/MWh (Belgium)
CCS Max CO₂ mitigation (%ref) = 76%

CI = 9 KgCO₂/MWh (Norway)
CCS Max CO₂ mitigation (%ref) = 82%
BECCS competitiveness:
impact of low carbon and low cost electricity
BECCS and other biomass based CO$_2$ removal pathways

Each biomass feedstock type will be more suitable for a given conversion pathway.

Each pathway generates a different product. Those generating a carbon based fuel will emit CO$_2$ back into the atmosphere.

The net CO$_2$ removal potential of each pathway will depend on the biomass carbon footprint and the CO$_2$ capture rate.

Note: BECCS sustainability is also influenced by other factors such as the land and water requirements, biomass yield, and the energy/carbon/water balance of the biomass supply chain (harvesting, processing, and transport).
Removal and mitigation value of BECCS

Source: Patrizio et al (2021). CO₂ Mitigation or removal: the optimal uses of biomass in energy systems decarbonization. iScience
Pathways to low carbon cement: CCU vs CCS
Status of CCU in the cement industry

Today, many CO$_2$ mineralisation technologies for concrete materials are emerging, including:

(1) carbonated concrete products
(2) carbonated aggregates
(3) Portland cement (PC) clinker substitutes
(4) accelerated curing of concrete using CO2

Some of these companies claim that their products are carbon negative and/or can reduce global CO2 emissions from concrete.

However, few rigorous publicly available LCA and economic analysis studies have interrogated these claims, which is of concern given the significant attention that they receive.

Life cycle assessment of CO2 mineralisation remains underexplored compared to other decarbonisation technologies like
We assess the global decarbonisation potentials of a wide range of CO$_2$ mineralisation technologies and feedstocks, by considering

1. their climate change impacts (using LCA), and
2. their economic viability (e.g. relative increase in production cost vs. comparable conventional product).

The analysis covers the 3 feedstocks for CO$_2$ mineralisation:

1. carbonatable solid wastes and by-products generated by industrial processes;
2. construction and demolition waste concrete; and
3. concrete products which can be directly treated by CO$_2$.

A key consideration here is the conventional products being substituted, which greatly affects the economic and environmental performance of CCU products.

Comparative economic analysis of CCU products

Four envelopes of environmental performances:

**Green area**: Superior decarbonisation technologies
**Yellow area**: Technically viable technologies
**Blue area**: Viable decarbonisation technologies
**Grey area**: Uncompetitive technologies

The great variation in location of CCU pathways demonstrate that research, business, and policy activities should target the individual CO2 mineralisation technologies with high environmental and/or economic performance rather than the general field, since some technologies are prohibitively uncompetitive
Sensitivity to policy framework

Of all the CO$_2$ mineralisation technologies analysed, costs to avoid 1 t of CO$_2$-eq. emissions are only lower than CCS (€80-100/t CO$_2$-eq.) for cement from carbonated end-of-life cement paste (€22/t CO$_2$ avoided).

These results are valid under current EU policy framework, only when carbon tax is higher than 100 eur/tco2 the higher mitigation benefits of CCS outperform the cost competitiveness of carbonated cement.

Note: results assumes raw material availability (in the case of CCU) in the proximity of carbonation plant (max radius 50 km), hence: LOCAL conditions matters!
Areas for future work #1: a system-wide approach

- To quantify the real GHG mitigation potential of any CCS/CCU/BECCS it is essential to adopt a system-wide approach, accounting for key factors such as:
  - *Comparison with substituting alternatives*
  - *Synergies with the energy system (e.g. availability of low carbon/low cost energy)*
  - *Market conditions*
  - *Policy levers*

- These factors become even more important when considering future competing demands for scarce biomass resources.

- In the long-run techno-economic differences in the performance of these pathways (e.g. costs and CO₂ capture rates) will determine which is optimal overall. In the short run is important to adopt a system-wide perspective to avoid technologies lock-in.
Areas for future work #2: Beyond carbon

• As the scale of the biomass potential is highly uncertain once accounting for economic, social and environmental impacts, real world implementation of biomass in the energy and industrial sectors requires accounting for the resource footprint associated with biomass supply. This particularly applies to pathways with low biomass conversion efficiencies.

• Quantifying the impact of a range of biomass procurement strategies across a multiple sustainability indicators will be key for balancing the ecosystems trade-offs:
  • Fresh water use and land use change
  • **Biodiversity impacts**

• Similarly within cement based CCU pathways, environmental issues other than CO2 emissions, e.g., **human toxicity, ecotoxicity, naturally occurring radioactivity**, must be considered in evaluating the utilisation potential of many carbonatable solid materials, because they can be hazardous