Supergen Bioenergy Hub

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Research and innovation needs for biomass to energy with carbon capture and storage (BECCS)

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1. Background

Biomass to energy with carbon capture and storage (BECCS) is a critically important technology for global decarbonisation. Over 100 of the 116 scenarios that limit average temperature rises to 2°C depend on BECCS [1], and 3 of the 4 pathways in the IPCC special report on 1.5°C involve BECCS removing 151-1,191 Gt CO_2 pa [2]. Arguably it is even more significant for the UK, where it is envisaged that BECCS could deliver 20 to 70 Mt CO_2 pa negative emissions [3], reducing the cost of meeting our 2050 emissions target by up to 1% of GDP [4]. In 2019, five BECCS facilities were operating globally (4 in the U.S., 1 in Canada) all linked to corn to ethanol production; with three in progress in Japan, Norway and the UK pilot facility at Drax [5]. So, there is a significant gap between the commercial experience to date and the scale of ambition; in terms of rate of implementation, scale of facility required and breadth of technologies that might be considered.

While the potential of BECCS to date has been extensively discussed and evaluated from the perspective of econometric, partial equilibrium and other energy-economic modelling approaches, there has been relatively little focus on the engineering and scientific challenges associated with implementation of BECCS. Achieving a greenhouse gas removal (GGR) of 20 Mt CO_2 pa (15% of the UK's overall emissions target for 2050 and a significant contribution from a single technology) would require around 80 BECCS facilities around the UK (not dissimilar to the current number of waste incinerators). In particular modular BECCS installations of 80 x 50MWe and 0.25 Mt CO_2 pa would offer local biomass supply chain and CO_2 utilisation flexibility for a range of feedstocks and CO_2 products.

Longer-term, a more ambitious scale-up could be envisaged with significant investment in large utility-scale facilities that would likely make use of centralised CO_2 transport, pipeline and storage infrastructure. A 250 MWe unit would be similar in size to existing units at large power stations, and 12 of these (e.g. 3 plants each with 4 x 250 MWe units or 12 plants each of 250 MWe) would remove 20 Mt CO_2 per year. These would be well-suited to pressurized CO_2 transport and storage e.g. in saline aquifers or salt caverns.

Whether BECCS deployment is centralized or decentralized visions, around 1.2 M ha of land would be used to support the GGR potential, which is well within the Committee on Climate Change projections that the UK can grow an additional 0.7 M ha of perennial energy crops and 1.2 M ha of forest by 2050 and represents around 13% of the utilised agricultural area in 2019 (note there is significant opportunity to use other non-agricultural land). Higher levels of CO_2 removal, e.g. the maximum 70 Mt pa CO_2 removal envisaged by the Royal Society would require maximization of GGR benefits with UK land and then additionally require imports.

With such a significant potential deployment there will inevitably be scope for consideration of different scales, technologies, feedstocks and configurations. There will be some common challenges and some specific to certain pathways and so a workshop was convened in order to establish what the key BECCS innovation needs are to support deployment at the scale envisaged in coming decades. This combined discussion with policy makers about the rationale and energy system need for BECCS; allowed the identification by industrialists of the current deployment landscape and where they see key risks and challenges; as well as identification by academics of areas where research could support deployment.

2. Identifying the research and innovation challenges

The Supergen Bioenergy Hub has extensive existing knowledge of bioenergy and BECCS, but it is a fast-moving, diverse area and so we gathered together relevant stakeholders to discuss the challenges and issues surrounding BECCS in order to assist EPSRC with the definition of research priorities for any new initiatives in BECCS. We selected a set of 30 academics and 35 industrialists and 8 contacts from government departments and funding bodies to invite to the meeting, as we knew they were active in the topic area. Around 48 attended with 16 from industry, 10 from government/funders and the remainder from academia.

After introductory presentations from Supergen and EPSRC on the scope for the meeting, BEIS gave an overview of what is happening in BECCS in relation to the Biomass Strategy. A panel of four people from industry presented their priorities and challenges for BECCS. Academics were then given the opportunity to speak for 2 minutes each on their top priority / challenge. Notes on all the presentations have been captured in the write up.

2.1 Policy Rationale for BECCS

BECCS is an essential technology for the UK to meet its climate targets. The UK pathway to net zero by 2050 described in the Climate Change Committee (CCC) 6th Carbon Budget requires an engineered emissions removals of 58 Mt pa by 2050. BECCS has the largest potential with different types of BECCS together contributing 52 Mt pa removal by 2050. A wide variety of different technologies are possible including power, manufacturing and construction, biofuels, energy from waste, hydrogen and biomethane; all incorporating biomass that extracts carbon from the atmosphere during biomass growth and then locks it up in the biosphere in some way during the process.

BEIS have commissioned external research on the costs and deployment potential of different GGR methods, including BECCS, DACS and others. They are supporting upstream innovation for feedstock production up to farm gate (call launched in March 2021) and have commissioned a review and benchmarking project to establish the potential performance of gasification systems. Academic modelling work uses information to explore running profiles for BECCS (baseload, flexible, mix/transition) that deliver greatest system value and a consultancy project is focusing on viable business models considering value for money, investability, speed, net-negativity and system value.

The UK government published an Energy White Paper in November 2020 that committed to reviewing the Biomass Strategy by 2022. This will almost certainly include consideration of the role of BECCS as well as the sustainability of biomass and the role of standards in supporting that.

Supply chains and net negativity will be important in that review, as BEIS seek to ensure that the total amount of negative emissions is maximised and fully accounted for. There will also be consideration of interlinked policies from other areas e.g. the Renewable Transport Fuel Obligation, Environmental Land Management scheme, carbon capture utilisation and storage strategy, emissions trading scheme, tree strategy, as well as industrial links, product demands, feedstocks (imported and domestic) and the total negative emissions requirements.

The CCC's 6th Carbon Budget report published in January 2021 contained more detail of different types of BECCS systems than had been the case previously, but gave only economic and performance assumptions, with no consideration of engineering challenges.

2.2 Key engineering challenges

Industrialists spoke about the engineering innovation needs to accelerate BECCS deployment. **Sustainable biomass sourcing** is the key starting point of a sustainable BECCS system**.** They noted that the 6th Carbon Budget required 30,000 ha in 2035 increasing to 700,000 ha by 2050. Spatial analysis of this was considered lacking with a need for more work to focus on optimising biomass sourcing to reduce transportation costs and improve sustainability. Also, there are unanswered questions around how to develop supply chains, engagement strategies and identification of barriers.

Feedstock flexibility was identified as a key issue by some industrialists with pre-treatment seen as one potential approach; while the importance of waste was flagged for economic viability and business models, as this generates a gate fee for most plants. There was an emphasis on feedstock flexibility as a way of opening up commercial and economic opportunities.

Syngas clean-up was highlighted as a complex area that needed further detailed engineering study, with particular focus on methods for dealing with tars that support overall process efficiency.

Efficiency improvement was seen as an important topic in need of further research and innovation

It was pointed out that **transportation and storage** was a key part of most projects' cost base and work that focused on reducing this would be valuable, alongside consideration of cost reductions by economy of scale, leading to an assessment of integrated cost optimisation. This could consider potential for co-location at clusters where existing infrastructure and CO_2 storage could be leveraged.

A new generation of sustainable plants must be financially viable and examination of the conditions for this are important. This should include **process modelling** to explore the impact of parameters like pressure and temperature on overall process optimisation.

Advanced gasification was flagged as a strategic technology in need of further development to demonstrate compatibility with CCUS, which could be devised by research. The benefits of pressurized gasification in terms of producing high pressure hydrogen that minimized downstream gas compression costs needed to be robustly evaluated. Carbon capture at pressurized pre-combustion conditions offered potential technical/performance advantages on paper, but practical confirmation is needed.

For **post combustion capture** systems uncertainties remain about efficiency, sensitivity to flue gas characteristics and the challenges related to solvent degradation that will influence costs and viability c.f. flexibility in design and operation of technology, carbon capture, focus on low cost and gate feed generating waste feedstocks.

The effectiveness of different **support measures** e.g. carbon taxes, subsidies etc. needed to be evaluated across desirable technologies. An integrated approach to carbon impacts that fully incorporated supply chain issues requires independent investigation/research.

There was significant interest among industrialists in the advantages of BECCS as a **route to generate dispatchable fuels**, as opposed to baseload (bio)electricity generation. It was pointed out that the former has twice the efficiency of the latter, with a warning not to focus too much on electricity were there were other competitive options.

The **ethics of BECCS** was considered important, especially in the context of achieving the CCC's targets to be evaluated and the risks associated with developing a future that rested on "biomass imperialism" and associated risks.

2.3 Addressing the challenges

Academics were invited to indicate what experience, skills and expertise they had within their research groups that could address the challenges identified by industrialists and policy makers.

There was experience on feedstock and supply chain issues around contaminants and technical options for dealing with them as well as transportation, handling, sustainability, cost and flexibility of supply chains. Academics could support agri-residue and waste mapping for whole system BECCS supply-chain models that could include consideration of transportation routes for feedstocks, CO_2 and products to storage sites or end-users.

Some participants felt that land competition issues, meant that developments should target residues as the raw materials. This could increase issues with feedstock variability that could then be addressed with improved process control and optimisation (including tar detection for gasification), while one option for transcending feedstock supply constraints beyond wood could be ocean-sourced biomass.

While there are some more technically mature conversion technologies, academic expertise could be applied to tar reduction and hydrogen production for gasification-based BECCS systems, to Allam cycles (oxygen-fired turbines) and fuel cell options.

Experience of infrastructure and systems analysis could help evaluate flexible designs to prioritize technological approaches from an energy systems perspective. This could include consideration of pathways to biomethane, biodiesel or hydrogen informed by carbon performance heatmaps, since there was an acknowledged need to consider alternative technologies especially for storage infrastructure.

Strong academic credentials in whole systems analysis were presented that could generate evidence as to when BECCS is likely to be needed and quantify the role and value of BECCS in the power and industrial sectors, including the social benefits associated with job creation and economic gross value added from at scale deployment of BECCS in the UK.

Expertise in sustainability (economic, environmental and economic) analysis would allow life cycle assessment of integrated processes including economics and social impacts, such as who participates and who benefits. BECCS could be incorporated into technological processes that focus on pathways to aviation fuels or pathways to hydrogen and other products as well as electricity. Such expertise could be applied to evaluate the benefits and trade-offs along the system, understanding how synergies affect different parts of the system and how scale/scale-up affect demand and markets for energy/fuels/products.

Academics agreed that there were issues around public acceptance and there was acknowledgement that future research work needed to integrate an element of public engagement alongside exploration and implementation.

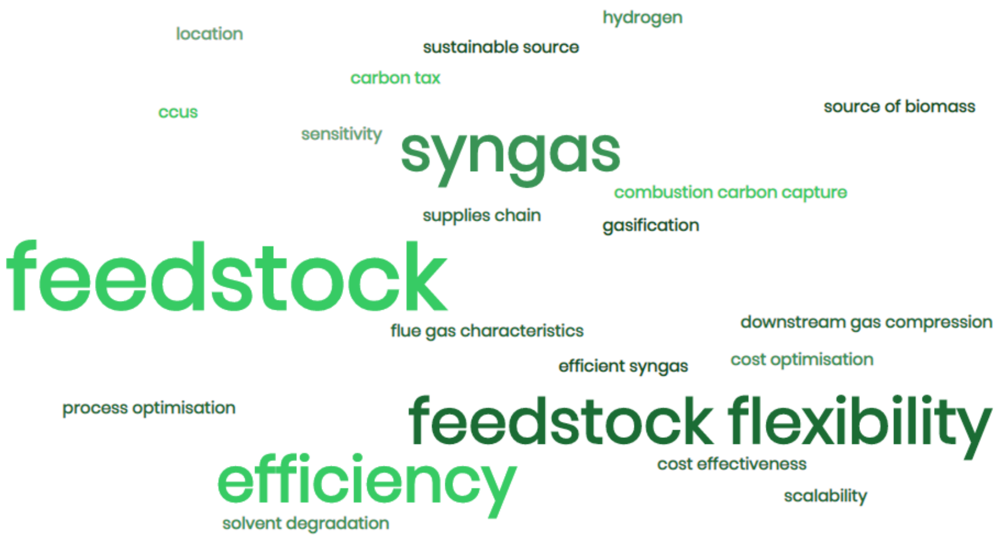
This was reinforced by UKRI emphasizing the importance of recognising that BECCS is moving from something that might happen to something that is expected to happen. The industrial clusters are planning for and assume BECCS will be happening on a big scale, so we need to work together to build confidence that it will work.

3. Leveraging Academic Input to Support Industry in Delivering Policy Objectives

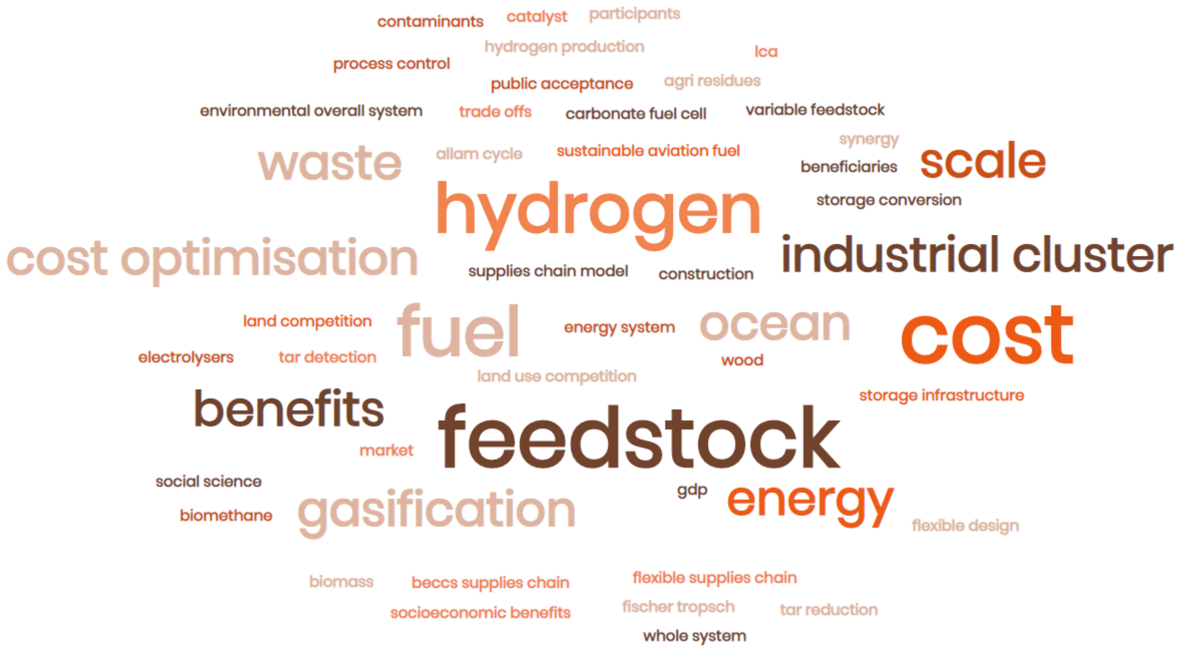
The word clouds below capture the key themes highlighted by the policy, industry and academic representatives at the meeting as key to unlocking BECCS potential.

Policy Themes Word Cloud

Industry Word Cloud



Academic Word Cloud



There are some obvious common themes where interests and capabilities are co-aligned and co-operation is likely to be particularly beneficial e.g. feedstocks, sustainability, supply chains, efficiencies. There is clearly significant interest from all parties in exploring gasification, syngas and hydrogen. But there are also many areas where detailed expertise in academia could support the broader objectives set out by policymakers and industrialists e.g. supply chains, infrastructure, socio-economic impacts. Focusing on the engineering and physical science strengths work on contaminants/fuel properties; supply chains; infrastructure and storage could be combined with a range of technological expertise in electrolysis, fuel cells, gasification, fuel synthesis, power cycles and materials to develop whole systems that deliver sustainable solutions judged against environmental and socio-economic criteria. There is a need to link these activities to public engagement and infrastructure assessment to support innovation that will deliver the next generation of BECCS plants in line with policy objectives.

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The Supergen Bioenergy Hub works with academia, industry, government and societal stakeholders to develop sustainable bioenergy systems that support the UK's transition to an affordable, resilient, low-carbon energy future.

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