editorial

NET gains

Negative emissions technologies face numerous challenges, from techno-economic hurdles to public acceptance concerns, but progress in research, collaboration and regulation provide indications that they may yet form part of future energy systems.

In May, the Drax bioenergy plant in Yorkshire, UK, announced a pilot project to incorporate carbon capture and storage (CCS) into its operations; the first project of its kind in Europe to combine bioenergy and CCS (BECCS). The pilot will burn biomass that has absorbed CO_2 from the atmosphere during its growth, turning the carbon in the biomass back into CO_2 that can be separated out from the other flue gases and stored permanently.

BECCS is one of a number of negative emissions technologies (NETs), whose aim is to actively reduce the amount of CO_2 present in the atmosphere. BECCS indirectly exploits the natural process of photosynthesis to produce a relatively concentrated stream of CO_2. However, the concentration of atmospheric CO_2 is much lower than in a power plant's flue gas stream. For direct air capture (DAC) of CO_2 — another NET — the capture process must therefore pull much lower concentrations of CO_2 out of gas mixtures, typically employing sorbents with a strong affinity for CO_2. The bound CO_2 must then be liberated, ideally with minimal energy input, to form a concentrated CO_2 stream for sequestration. These constraints present difficulties that R&D efforts are still working to overcome. In this issue of *Nature Energy*, for example, Radu Custelcean and colleagues demonstrate a lab-scale DAC system that employs organic reagents as part of a two-stage capture cycle. The system requires only mild heating to release the CO_2, meaning that it can run on solar thermal power. See also Christopher Jones' News and Views article for more discussion.

Such lab-scale studies are still needed to further increase efficiency and minimize the energy demands of such processes. But there are also now a handful of companies working on commercialization of DAC who can provide valuable information to support further efforts. For example, Canadian company Carbon Engineering recently provided an analysis of a DAC plant that could remove 1 $MtCO_2$ per year (ref. [1]). The paper discusses process designs and provides a breakdown of capital costs, while also estimating levelized costs of between US$94–US$232 per ton of CO_2 sucked out of the air. While these numbers are notable in themselves — being rather lower than some previous analyses have suggested — more broadly, the principle of a company reporting its DAC technology in such detail is to be applauded. Data about operations at the pilot plant scale (in this case, at the $1tCO_2$ per day scale) is valuable for informing future avenues of pursuit to further decrease the cost of DAC. Moreover, as the authors note, the feasibility of DAC has been questioned in the past due to insufficient engineering detail being present in the literature. The authors' transparency, allowing the numbers they provide to be independently evaluated, is a welcome change.

Efforts to facilitate information sharing should also be encouraged. One example is the recently launched project from the CO_2 storage data consortium (CSDC) — a mixture of international industrial partners, universities and government agencies — that plans to build and operate a platform for sharing data relevant to the storage of CO_2 (ref. [2]). The aim is to make available well-documented datasets that detail, for example, site geology, geophysical modelling and well data from full-scale projects and field tests. The benefits range from enabling identification of technology gaps and reducing uncertainty, to promoting networking and collaboration between academia and industry.

While sharing information can help to focus efforts to bring down costs, carbon capture will remain a challenging area in which to make headway commercially unless more value can be found in it. Indeed, companies are exploring ways to make entry into the DAC industry more attractive through utilization of the CO_2 they produce. Avenues include the sale of CO_2 to greenhouses and conversion of captured CO_2 into transportation fuels. Of course, putting the CO_2 to some use beyond burying it in the ground complicates the net benefit in terms of atmospheric CO_2 levels; nevertheless, if it paves the way for further development of large-scale technologies and infrastructure then it should not be dismissed, at least not without further careful exploration. Policy also has a role to play in encouraging carbon capture through regulatory frameworks, such as California's Low Carbon Fuel Standard, which provides incentives for fuels with reduced carbon footprint. Proposed changes may allow fuels produced using CCS as part of the value chain — as well as fuels synthesized from DAC CO_2 — to qualify for incentives. In the United States there appears to be a rare bipartisan consensus on supporting CCS, as seen through the passing of additional tax credits for captured carbon as well as funding for CCS research.

Other types of value presented by CCS should also be explored. It is still generally considered that some level of base load is required in our power systems and at present the most readily available option for this is through fossil fuel power plants. CCS could lower the carbon intensity of these operations, but is unattractive if it only increases operation costs. However, this would change if the fact that CCS-enabled fossil plants would provide the necessary inertia to the energy system — at reduced carbon intensity — were appropriately valued. Viewing CCS-enabled fossil plants as providing a necessary service and rewarding this appropriately could encourage development and build-out of CCS infrastructure in a way that could benefit its application in the context of NETs. However, the importance of public acceptance of large-scale energy projects, such as BECCS, also must not be forgotten when designing such incentives, as argued by Rob Bellamy in his Comment.

For NETs to deliver the rapid success required for them to make a significant contribution to mitigation of CO_2 levels — the kind often included in pathways to limit global warming to 2 °C or less — advances in a number of areas are required. Progress is slowly being made, yet further, more concerted efforts to back technological innovation, encourage co-operation and develop responsible policy support are still needed to make this possible. ❒

Published online: 10 July 2018
https://doi.org/10.1038/s41560-018-0216-y

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