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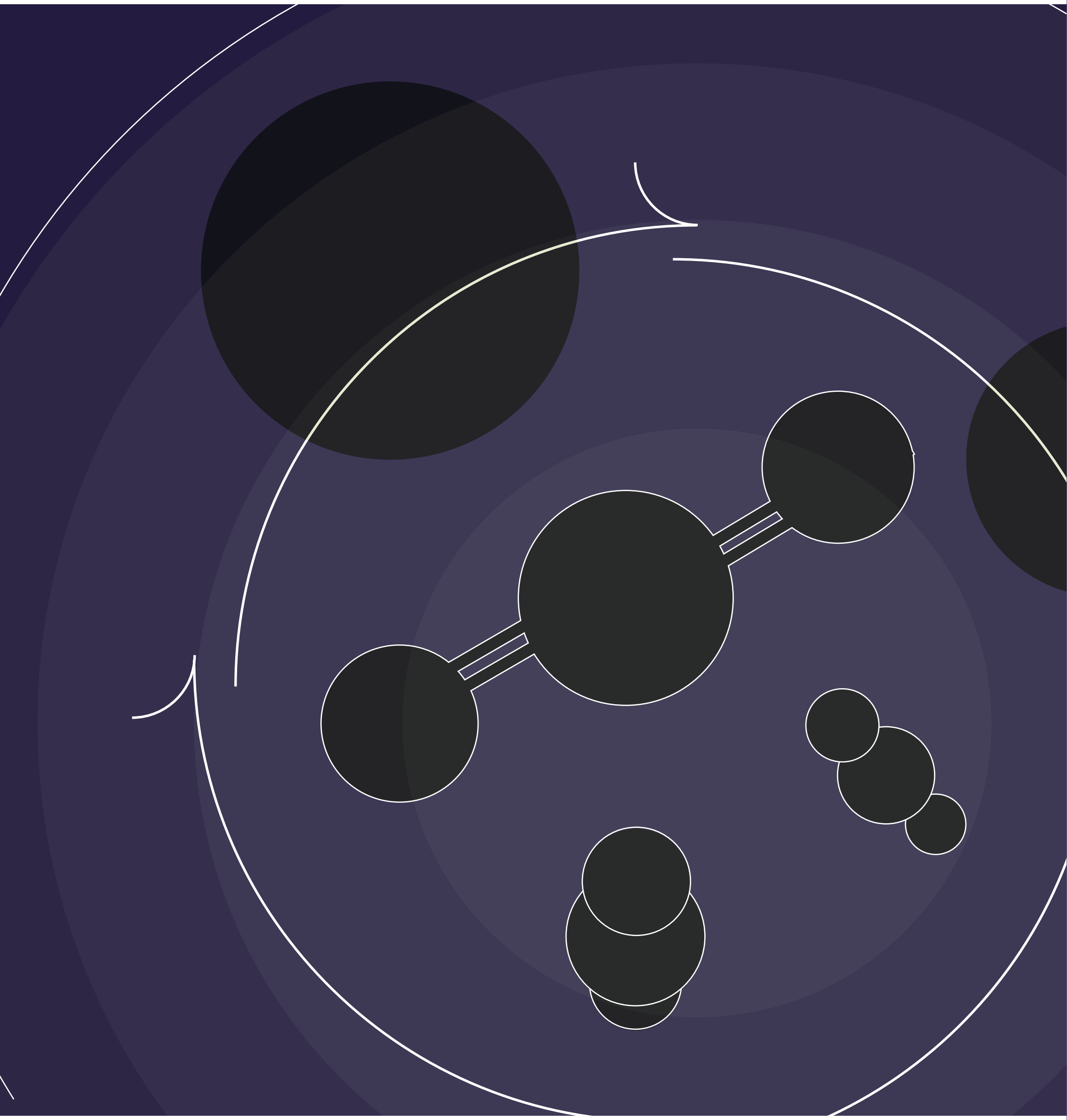
Carbon Capture and Usage

By Dr Sarah Mander & Jack Miller



Inside:

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Overview

Carbon capture and usage (CCU) is a basket of processes that have collectively gained attention in recent years from industry and policymakers as a potential approach to climate change mitigation. It involves capturing waste carbon dioxide (CO_2) from power production and industrial processes, and using it in a broad number of economically productive ways. This can include in, amongst others processes, the production of chemicals, minerals, synthetic fuels, plastics, or as a solvent.

This POSTbrief presents a broad overview of CCU processes, and reports evidence on their potential for climate change mitigation. It finds that because of a number of barriers including costs, energy requirements and the fact that the majority of processes eventually release CO_2 back into the atmosphere (either immediately, or via products that break down within a short amount of time), CCU's direct mitigation potential may be relatively small. However, CCU could develop an early-stage market for wider CO_2 capture technologies. This would help to develop capture carbon and storage (CCS), which is widely accepted to be a likely and substantial component of future mitigation efforts at the global level.

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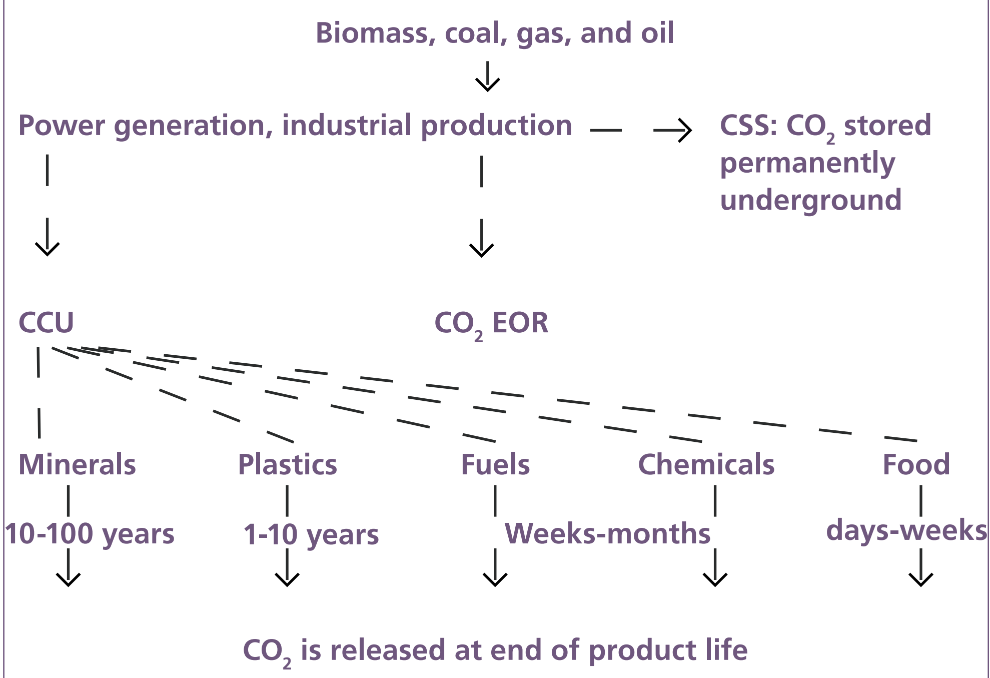
Background

Carbon dioxide (CO_2) is produced as a by-product of a number of industrial processes such as fermentation, cement production and ammonia production, as well as of electricity production from fossil fuel power stations. CO_2 is a greenhouse gas (GHG), and human activities that release CO_2 into the atmosphere are the primary cause of climate change. Capturing and storing this waste CO_2 at scale will be necessary for meeting international goals on limiting climate change to well below 2 degrees Celsius, as set out in the Paris Agreement. [1,2]

Carbon capture and usage, or utilisation (CCU), is a set of processes that capture waste CO_2 and use it in a commercially productive way (such as a feedstock in chemical processes). Some CCU processes are already in use, while a greater number are under development. Similar processes for capturing CO_2 are also the first stage of carbon capture and storage (CCS), which seeks to capture waste CO_2 and permanently store it within geological formations (fig. 1). Though commercially unproven in the UK, CCS has been identified since the early 2000s as a method of reducing UK CO_2 emissions. However, CCS has been slow to develop in the UK and internationally. Although much of the associated technology is now well-developed, costs of deployment appear to be high and there is little policy incentive to capture and store CO_2. Two competitions to develop CCS in the UK were cancelled in 2011 and 2016,[3,4] and there are currently few examples of commercial CCS plants globally.

Figure 1. Flow diagram of CCU and CCS processes

When some fuels are used in power generation or industrial production, carbon can be relesed in the form of CO_2. If captured, it can be stored permanently underground (CCS). Alternatively it can be used as a solvent to extract oil with some of the injected CO_2 permanently stored (EOR). The processes captured carbon can be used in are refered to as CCU.



More recently, attention has turned to CCU as, unlike large-scale CCS, it offers the potential for direct commercial opportunities from waste CO_2, and CCS and CCU are increasingly being considered in an integrated way.[5, 6] The 2017 Clean Growth Strategy emphasised the UK Government's ambitions to become a leader in Carbon Capture, Utilisation and Storage (CCUS) technology.[7] It aims "to have the option of deploying CCUS at scale during the 2030s, subject to costs coming down sufficiently" (p.70). In August 2018 the Government announced a £15m call for CCUS innovation projects to encourage cost reduction.[8]

Some established CCU processes have been in commercial use internationally for a number of years. However, the motivation for these activities has primarily been commercial, rather than to permanently sequester CO_2. Some existing CCU processes use naturally occurring CO_2 extracted from geological formations, rather than waste CO_2 captured from industrial or energy processes. Many of these processes may also release captured CO_2 into the atmosphere after use. The extent to which CCU could complement CCS as a way of permanently sequestering CO_2 is unclear.

This POSTbrief provides an overview of CCU technologies and processes, and their potential for deployment at scale in the coming decades. It evaluates their potential to contribute to climate change mitigation, and outlines key opportunities and challenges.

Carbon Capture and Usage Technologies

CCU broadly consists of three steps:

- capturing waste CO_2 from industrial or energy conversion processes,
- transporting the CO_2 to a suitable destination (possibly following compression),
- and using the CO_2 as part of a commercial process.

While the capture process is common to both CCU and CCS, the key difference between the two is the ultimate destination for the CO_2. CCS seeks to permanently store CO_2 where it cannot contribute to climate change, while CCU uses the CO_2 as a commercial product.

Capturing CO_2

Processes for capturing CO_2 fall into one of three broad categories.

- **Post-conversion capture:** CO_2 is removed from waste gases at the end of an industrial process such as cement or iron and steel production, or of fossil fuelled power stations. There are number of ways of separating the CO_2. Current commercial CCS plants use solvents with absorbents or membranes. Cryogenic separation may provide more cost effective and cheaper capture in the future.[9]

- **Pre-conversion capture:** CO_2 is produced as a by-product during a process and captured before the final stage of a reaction. This approach can be used during ammonia production, or in gasification power plants where a fuel such as natural gas is broken down into CO_2 and hydrogen. The CO_2 is typically absorbed using solvents.
- **Oxy-fuel combustion:** fuel is combusted in an oxygen-rich environment, producing a waste product which is mainly CO_2 and water (which is separated by cooling and condensation). This process can be used for generating electricity and is under development for CO_2 capture from cement production and the iron and steel industry.

Transporting CO_2

Captured CO_2 can be transported to a location for storage or usage by pipeline, or by road, rail, and shipping. Developing a CO_2 transport network would be a key condition for a future CCUS system. Because of this, much of the preliminary UK CCS development has focused on 'clustering' infrastructure around hubs (such as Teesside, Humberside, South Wales, and Grangemouth) in part to benefit from the network effects of transport infrastructure such as ports and pipelines. Because CCU uses (rather than stores) CO_2, 'co-locating' CCU processes with sources of waste CO_2 could enable emission reduction from industrial sites situated away from clusters by potentially removing the need to transport CO_2 to a distant storage location.[10] Co-location of CCU and CCS could also support the business case for CCS. A 2018 Government-commissioned CCUS Cost Challenge Task Force recommended that business models for CO_2 transport and storage be separated from those of capture activities.[11]

Utilising CO_2

A 2017 BEIS-commissioned study identified 25 technologies or processes that use CO_2 at varying degrees of technology readiness and market potential.[12] These can broadly be divided in two.

- **Indirect use:** captured CO_2 is first converted into a product using a chemical or biological process before being used commercially.
- **Direct use:** captured CO_2 is used directly within a commercial process.

Indirect use of CO_2

CO_2 can be used in chemical conversion processes as a 'feedstock' (raw input) for the manufacture of synthetic transport fuels and chemicals, and to produce minerals. It can also be used within biological conversion processes. With the exception of biological conversion processes, there are existing commercial examples of all the processes described below either in the UK or globally (Box 1).

Box 1. Examples of commercial UK and international CCU projects

Icelandic firm Carbon Recycling International produce methanol from the flue gases of a geothermal plant using renewable electricity.[13]

UK firm Econic make polymers containing up to 50% CO2 by weight which can be used in a range of products including mattresses, furnishings and clothing. [14]

Carbon8 operates two UK plants which treat industrial waste and contaminated soils. They use waste CO2 product from bioethanol and fertilizer production to produce limestone aggregate which is sold to breeze block manufacturers. This can substitute for naturally occurring aggregate, effectively permanently storing the waste CO2.[15]

A number of onshore enhanced oil recovery (EOR) projects, using waste CO2, operate globally including the Boundary Dam power station (Saskatchewan, Canada) and the Weyburn project, which uses CO2 captured from a synthetic fuel plant in Dakota.[16]

One offshore EOR project currently operates in Lula, Brazil.[17]

Cornerways Nursery uses waste CO2 from the gas fuelled CHP plant at British Sugar's Wissington refinery to support plant growth. [18]

Production of synthetic fuels

CO_2 can be used to produce 'synthetic fuels' which may be used in transport (by blending with conventional petrol or diesel or as a standalone fuel). There is a diversity of processes for producing synthetic fuel, but the basic principle is to combine CO_2 with hydrogen in the presence of a catalyst. The hydrogen may be a waste product from another process or be produced by the electrolysis of water (POSTnote 565).

A large amount of electrical energy is required to produce synthetic fuel, often more than the amount of energy that is provided when the fuel is combusted.[19,20] As a result, the energy used in production would need to be 'low-carbon' in order to contribute to GHG emission reductions. Technical assessments suggest that synthetic fuel production could act as a store of excess renewable energy (such as wind power generated at night which may not otherwise be used).[19] Producing synthetic aviation fuel in this way could reduce the carbon footprint of aviation (which is widely considered a sector that will be difficult to decarbonise) if it reduces the use of conventional (fossil fuel-sourced) aviation fuel.[20,21]

There is uncertainty in the potential for synthetic fuels to contribute to GHG emissions reductions, because of the number of production techniques and sources of hydrogen. CO_2 used in synthetic fuel production is ultimately emitted to the atmosphere when it is combusted, so synthetic fuel production is not a method of permanently storing carbon.[23] However, synthetic fuel could still help to forego emissions if used in place of conventional fossil fuel products.

Production of chemicals

Waste CO_2 can be used to manufacture a variety of chemicals, including polymers (the basis of plastics) and other commodity chemicals.[24] The most commercially viable process in the short term is to use CO_2 to produce polymers (which are conventionally made using fossil fuels) using innovative catalysts. This would reduce energy input requirements, which are currently high (see Barriers to CCU).[14] The CO_2 would be stored for the lifetime of products, which could be a number of years.[23]

Mineralisation

Waste CO_2 can be used for the manufacture of minerals that form the basis of building materials. A 2017 BEIS study identified three processes of relevance to the UK, on the basis of how close the technology is to market, and the potential size of the UK market by 2030:[12]

Carbonate mineralisation: Waste CO_2 is reacted with minerals such as calcium and magnesium to form carbonates, which can in turn be used to produce aggregates (coarse material used in construction). The process is an accelerated form of natural 'weathering' and uses materials which can be found naturally, or in waste streams (such as water treatment sludge, fly ash from power stations or slag from steel manufacture).[15]

Concrete curing: Waste CO_2 can replace steam for the curing of concrete during production; this both stores CO_2 and reduces the energy required for manufacture.[25]

Novel cements: Cements which are based on waste CO_2 could be used as an alternative to conventional Portland cements. These products are at an early stage of development and have yet to be proved commercially.[26]

The stored CO_2 can be sequestered for the lifetime of building materials, on the order of decades to hundreds of years.[23] Mineralisation reactions give out heat which could be productively used in other processes,[19] but requires substantial amounts of process electricity, such as for grinding rocks to a sufficiently small size.[27]

Biological conversion

Micro algae can be grown in open ponds or bioreactors using waste CO_2 as a feedstock and used to manufacture biodiesel and other fuels or chemicals. Facilities can be located on marginal land, making use of salt water and waste CO_2 to potentially produce high value products.[19] These processes have greater potential in warmer climates than the UK, and current projects are at the pilot stage.[12]

Direct use of CO_2

CO_2 can be used directly as a solvent (in enhanced oil recovery for example), in horticulture to aid plant growth and in the food and drink sector. Apart from enhanced oil recovery, where a large proportion of the injected CO_2 will remain within the reservoir, direct use does not physically confine CO_2 and hence does not provide permanent storage.

Enhanced oil recovery (EOR)

When oil is produced from an underground reservoir (via a drilled well), the rate at which it is extracted will decline from an initial maximum, until the point that production from that well is no longer economical. Towards the end of a well's lifetime, its production rate can be increased (and its lifetime hence extended) by injecting CO_2 back into it. This 'enhanced oil recovery' using CO_2 CO_2 (CO_2-EOR) changes the physical properties of the oil or the flow patterns in the reservoir,[28] allowing more oil to be ultimately extracted. CO_2-EOR can increase the proportion of oil extracted from 20-40% to 30-60%.[29] The exact approach varies according to the overall ambition, i.e. whether the aim is to maximise oil extraction or CO_2 storage. Research suggests that in the latter case, up to 80% of injected CO_2 can be stored.

The techniques underpinning CO_2-EOR have been employed directly in a number of commercial settings (Box 1), though not yet with a primary aim of permanently storing CO_2 (i.e. for CCS). Although not yet in use in the UK, CO_2-EOR could make use of UK offshore pipelines, and extend North Sea oil production whilst at the same time permanently storing CO_2.[30] It may also help to maintain skills within the UK's offshore oil and gas industry and develop expertise in an area where experience is currently limited globally.[11] However, the 2018 CCUS Cost Challenge Taskforce concluded that CO_2-EOR is not currently economically attractive for the UK, and would have to be considered in light of the UK's climate objectives.[11] Some stakeholders such as NGOs have also expressed concern around CO_2-EOR's viability as a climate change mitigation technique, given its role in extending the lifetimes of fossil fuel-producing processes.[31] Others argue that it could help develop the wider CCS market.[30]

Horticulture

Artificially increasing the concentration of CO_2 within greenhouses enhances their productivity, increasing crop yields. Nearly all of the CO_2 added to a greenhouse is vented once the desired concentration is reached, and CO_2 will only be stored within a crop until it is eaten, so horticultural use of waste CO_2 is not a means of storing CO_2. However, co-locating greenhouses with facilities which produce waste CO_2 can reduce the net emissions from that facility, by replacing the use of CO_2 that would otherwise be sourced from natural gas.[32]

The food and drink sector

CO_2 is widely used for carbonating drinks, such as beer and soft drinks, and to a lesser extent to extend the shelf life of fresh produce and to keep produce chilled in transit.

Opportunities and challenges for CCU

CCU activities may increase in magnitude over coming decades if the scale of existing CCU processes expands and new products become commercially viable. The extent to which CCU will directly contribute to climate change mitigation is likely to be small, but many stakeholders believe that wider benefits can arise from CCU development. For example, CCU may provide an early-stage commercial incentive for developing carbon capture technologies, which could in turn encourage wider CCS development.

Scale of potential CCU and CO_2 markets

Given that few CCU processes permanently store waste CO_2, the actual contribution of CCU to global climate change mitigation is unlikely to amount to more than 1%.[33] Compared to total UK CO_2 emissions, the total amount of CO_2 used in CCU processes will be small, and estimates suggest that CCU's potential is more limited than that of CCS.[24] Estimates of future CO_2 market demand suggest that around 0.5-6.0% of global CO_2 emissions could be used,[10,34] while a government-commissioned study suggested that 0.1-2.2% of emissions from the UK's largest sources (such as iron, steel, oil refining and cement production) could be used by 2025.[35] In 2018, the independent Committee on Climate Change stated that:

"Whilst CCU could help to facilitate progress [on CCUS] in the 2020s, the volume of CO_2 that can be utilised as a feedstock rather than permanently sequestered appear likely to be small relative to the necessary role for CCS in the long-term. However, CCU could be of benefit in particular niche areas (e.g. where CO_2 capture costs are relatively low but geological sequestration of the CO_2 is impractical." (p.47) [36]

Barriers to CCU for climate change mitigation

Many of the technologies used to capture and use CO_2 are in early stages of development, and the costs of products that use captured CO_2 are often higher than conventional equivalent products (e.g. synthetic fuels are more costly than petroleum products). This is in part due to the chemical properties of CO_2. It is a stable chemical, and reactions that turn CO_2 into other products require a catalyst. Innovations in catalyst science have been identified as a key driver of future CCU cost reductions.[24, 37, 38] Its stability also necessitates a large amount of energy to drive the reaction process which, without a low-carbon energy source (such as renewable electricity), would increase GHG emissions.

Additional potential barriers to widespread CCU deployment include:

The need for high-purity CO_2 source for many usage processes. Many capture processes provide lower-purity CO_2 than required, necessitating a further separation process which requires additional energy input.

Public perception and acceptability issues. CCU currently has low public visibility, but researchers suggest that issues of social acceptance should form part of the CCU research agenda.[39]

A suitable accounting mechanism for accounting for captured CO_2 and assessments of the net reductions made using a 'whole system approach'.

Wider opportunities for CCU

Although many CCU processes do not store CO_2 for long periods of time (e.g. in horticulture or food and drink), in these instances waste CO_2 may displace the use of 'new' CO_2 from geological sources. The overall effect of this would be to reduce net emissions (compared to in the case that new CO_2 is used).

Although CCU may not directly provide substantial emissions reductions relative to CCS or other mitigation measures, its development could potentially support the development of a business case and provide an additional revenue stream for CCS, for example through low carbon products.[11] Other potential benefits exist for users of CCU processes outside of emissions reduction. For example, mineralisation turns waste streams into useful products, CO_2 based polymers can displace more polluting feedstocks and using waste CO_2 for horticulture can reduce exposure of users to volatility in natural gas prices.

Endnotes

1. IPCC, 2014. AR5 Synthesis Report: Summary for Policymakers.
2. IPCC, 2018. Global Warming of 1.5°C. Summary for Policymakers.
3. National Audit Office, 2017. Carbon capture and storage: the second competition for government support. and Oxburgh (2016)
4. Parliamentary Advisory Group on CCS, 2016. Lowest Cost Decarbonisation for the UK: The Critical Role of CCS. CCS Association
5. Endres et al., 2016. Putting the U in carbon capture and storage: rhetorical boundary negotiation within the CCS/CCUS scientific community. Journal Of Applied Communication Research. vol. 44 pp.362-380
6. Bruhn et al., 2016. Separating the debate on CO_2 utilisation from carbon capture and storage. Environmental Science & Policy. vol. 60. pp 38-43
7. HMG, 2017. The Clean Growth Strategy: Leading the way to a low carbon future.
8. Innovate UK, 2018, [online] Funding call. Accessed 26/10/18.
9. ETI, 2016. Reducing the costs of CCS: Developments in capture plant technology.
10. Naims, H, 2016. Economics of carbon dioxide capture and utilization a supply and demand perspective. Environ Science and Pollution Research, vol.23 pp.22226–22241
11. CCUS Cost Challenge Task Force, 2018. Delivering Clean Growth: CCUS Cost Challenge Task Force Report.
12. Ecofys, 2017. Assessing the potential of CO_2 utilisation in the UK: Final report.
13. Carbon Recycling International [online]. Carbon Recycling International. Accessed

21/09/18
14. Econic Technologies [online]. Product Potential. Accessed 21/09/18
15. Carbon8 [online]. Technology: Adding carbon dioxide to waste to give it commercial value. Accessed 28/09/18
16. GCCSI, 2018, CCS projects database. Accessed 28/10/18
17. Carbon Sequestration Leadership Forum, 2017. Enabling large-scale CCS using offshore CCUS infrastructure developments.
18. Agritech East [online]. YIF Blog: Cornerways Nursery. Accessed 21/09/18
19. Styring, de Coninck and Armstrong, 2011. CCU in the green economy: using CO_2 to manufacture fuel, chemicals and materials.
20. Malins, 2017. What role is there for electrofuel technologies in European transport's low carbon future?
21. SAPEA, 2018, Novel Carbon Capture and Utilisation Technologies: Research and climate aspects.
22. The International Council on Clean Transportation, 2017. CO_2-based Synthetic Fuel: Assessment of Potential European Capacity and Environmental Performance.
23. von der Assen et al, 2013. Life-cycle assessment of carbon dioxide capture and utilization: avoiding the pitfalls. Energy & Environmental Science. 6 (9), 2721-2734.
24. Royal Society, 2017. The potential and limitations of using carbon dioxide.
25. Patricio et al, 2017. Region prioritization for the development of carbon capture and utilization technologies. Journal of CO_2 Utilisation, vol. 17, pp.50-59.
26. Solidia tech [online] The patented process behind Solidia Cement(TM) & Solidia Concrete(TM) Accessed 04/09/18
27. Naraharisetti et al, 2017. Factors influencing CO_2 and Energy Penalties of CO_2 Mineralization Processes. ChemPhysChem, vol.18 pp.3189-3202.
28. IEA, 2015. Storing CO_2 through Enhanced Oil Recovery.
29. US Office of Fossil Energy [online] Enhanced Oil Recovery Accessed 01/01/18
30. Scottish Carbon Capture & Storage, 2015. CO_2 storage and enhanced oil recovery in the North Sea: Securing a low-carbon future for the UK.
31. Greenpeace USA, 2015. Carbon Capture SCAM (CCS): How a False Climate Solution Bolsters Big Oil.
32. Vermeulen, 2014. Combined Heat and Power (CHP) as a possible method for reduction of the CO_2 footprint of greenhouse horticulture. Journal of Energy Challenges and Mechanics, vol.1, pp.37-40.
33. Mac Dowell et al., 2017. The role of CO_2 capture and ulitization in mitigating climate change, Nature Clim. Ch., vol.7, pp. 243-249.
34. Olfe-Krautlein etl al., 2014. CO_2 as an asset? Challenges and potential for society. IASS
35. Element Energy, 2014. Demonstrating CO_2 capture in the UK cement, chemicals, iron and steel and oil refining sectors by 2025: A techno-economic study. DECC and BIS.
36. Committee on Climate Change, 2018. An independent assessment of the UK's Clean Growth Strategy.
37. The Global CO_2 Initiative, 2016. A Roadmap for the Global Implementation of Carbon Utilization Technologies.
38. Zimmermann, Kant, 2017. CO_2 Utilisation Today: Report 2017. Climate-KIC
39. Jones et al, 2017. The social acceptance of carbon dioxide utilisation: A review and research agenda. Frontiers in Energy Research, vol. 5, pp.1-11