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by Fredrik Lundberg

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Bioenergy CCS – too little, too expensive, and not net negative

Bioenergy carbon capture and storage (BECCS) is presented as an option for achieving 'negative emissions.'[1] The International Energy Agency (IEA) characterises BECCS as involving 'any energy pathway where CO_2 is captured from a biogenic source and permanently stored.'[2]

Several kinds of BECCS applications have been proposed or are currently used: ethanol, power and heat generation using biomass from forestry or agriculture, hydrogen produced from biomass or paper pulp, and anaerobic digestion or biomass syngas.

Several **ethanol** plants with carbon capture and storage (CCS) operate in the United States (US). They use corn (maize) as feedstock. The ethanol produced is blended with petrol for use in the transportation sector and serves as an indirect subsidy for the American farmers who grow the corn. For this reason, ethanol is especially favoured by Republican climate deniers, but it also enjoys bipartisan support.

Some studies claim that corn-based ethanol is worse than petrol for the climate, even when other environmental and resource factors, such as eutrophication from fertiliser use, pesticides, water use, and water pollution, are ignored.[3] Unsurprisingly, most US non-governmental organisations (NGOs) oppose the use of corn-based ethanol. The majority of US ethanol refineries are powered with fossil gas, and the amount of CO_2 that can be captured from fermentation is less than the CO_2 emitted from burning that gas. For that reason alone, the process could never be carbon negative.[4]

Only very large facilities are suitable for CCS because it costs much more per tonne to collect and transport CO_2 from many small sources rather than a few very large ones.

The ethanol industry is relatively small outside the US and Brazil. The potential for CCS is therefore limited. Ethanol plants do not show the way to large-scale BECCS, even if the application of the technology at these facilities could truly be described as BECCS. The CO_2 is of biogenic origin but originates from *fermentation*, not from the *combustion* of biomass. The CO_2 produced is not mixed with nitrogen, nitrogen oxides, and oxygen, so it is easier and cheaper to handle. As such, the experience gained from ethanol CCS is of limited value for developing other forms of BECCS.

Biomass combustion is a heterogenous category. Various methods are proposed for carbon capture. Of these, post-combustion carbon capture, generally involving amines, is the most advanced method.

Most boilers are either too small or located in places where it is difficult to transport captured CO_2 to storage sites at a reasonable cost. Space must also be available at a particular facility to host the huge carbon capture equipment. For example, the Beccs Stock-

1 Negative emissions refers to the process of removing carbon dioxide (CO2) from the atmosphere at a rate that exceeds human-induced CO_2 emissions to the atmosphere. Note that the ability of BECCS to reduce climate emissions remains an open question as the technology would remove carbon from the biogenic carbon pool (mostly plants), not the atmosphere. See Fern, Six Problems with BECCS (2022).

2 IEA, Bioenergy with Carbon Capture and Storage webpage (accessed 14 October 2024).

3 Reuters, U.S. corn-based ehtanol worse for the climate than gasoline, study finds (2022).

4 Biofuelwatch, Carbon capture from biomass and waste incineration: Hype versus reality, pg. 22-23 (2022).

holm project,[5] if built, will require an area of 10,000 square metres for absorbers (two at a height of 75 metres), desorbers, and intermediate storage for 0.8 million tonnes (Mt) per year of captured CO_2.[6] This figure does not include the shipping facilities that would be required to transport the CO_2 offshore for sub-seabed storage in the North Sea.

Whilst **power and heat generation** represent a big potential market for CCS, the use of CCS in the power and heating sector is extremely limited. For example, CCS has not been implemented on any biomass, gas, or oil-fired power station, and only a handful of coal plants have operated intermittently with CCS and captured portions of their CO_2 emissions.[7]

A few large power, heat, or combined heat and power (CHP) plants use or can use biomass for fuel. Some power plants in the United Kingdom (UK) and elsewhere have shifted fuel from coal to wood. The Drax power station in North Yorkshire, England is a huge plant of this type.[8]

Wood may be preferable to coal in some respects, but only if forest-industry residues (bark, sawdust, etc.) are used and the wood itself is used for construction and furniture. However, the demand for wood biomass energy far exceeds the availability of forest-industry residues, and wood pellet and biomass plants across Europe routinely use wood from whole trees.[9] Cutting down trees simply to burn them is not sustainable, efficient, or practicable in the timescale remaining to avoid the worst impacts of climate change, as stated in an open letter signed by hundreds of scientists[10] and in a recent Nature editorial.[11]

The wood used in Europe's biomass plants is often imported from far away, including the south-eastern US, Canada, Portugal, and the Baltics, and more than a third of the wood is large whole trees.[12] The Drax power station, which imports 99 per cent of its wood pellets from abroad, has a net thermal efficiency of just 38 per cent[13] (for comparison, the best gas-fired power plants have an efficiency of almost 64 per cent).[14] With CCS, this low efficiency would be reduced by as much as one-third as carbon capture and compression require a lot of energy.

BECCS has been proposed for the Drax power station as a 'scalable and affordable carbon removal technology'.[15] Retrofitting the 50-year-old plant with CCS and then

5 Beccs Stockholm is a BECCS storage project being advanced by Stockholm Exergi. The company is seeking to install CCS at an existing heat and power biomass plant in Stockholm, Sweden.

6 Stockholm Exergi and Structor, Bio-CCS-anläggning, Stockholm Exergi (2021) (in Swedish).

7 Real Zero Europe, Road to Nowhere: CCS and CDR technologies won't deliver for the climate (2024).

8 The power station has 2.6 gigawatts of biomass capacity. It is marketed as the UK's largest renewable power station and is the UK's largest single CO2 point source (see footnote 27).

9 Natural Resources Defense Council, Four Ways We Know Drax's Appetitie for Trees is Still Growing (2022) and New York Times, Europe is Sacrificing its Ancient Forests for Energy (2022).

10 Woodwell Climate Research Center, Letter Regarding Use of Forests for Bioenergy (2021).

11 Nature, How 'green' electricity from wood harms the planet – and people (2024).

12 Friends of the Earth Policy, The future of Drax: old, inefficient, damaging and expensive (2021).

13 Ibid. As noted by Friends of the Earth, this means that for every 10 trees burned, six are wasted as uncaptured heat.

14 Guiness World Records, Most efficient combined cycle power plant (accessed 14 October 2024).

15 Drax, Bioenergy with Carbon Capture and Storage (BECCS) webpage (accessed 14 October 2024).

continuing to operate it is currently estimated to cost the UK taxpayer up to £1.7 billion (€2 billion) per year.[16] With a proposed 8 Mt of CO_2 being captured annually (from 2035), this cost equals €249 per tonne of captured CO_2.[17]

The previous Conservative government in the UK expected CCS at the Drax power station to be realised by 2027,[18] but there is strong opposition and many questions have been raised.[19] Drax has also stated they will not achieve their carbon-negative goals at the facility until 2030.[20] The company itself lacks the expertise or technical know-how to capture carbon at scale. To date, they have captured a total of 27 tonnes of CO_2 and have halted any further tests or development.[21] Drax has requested new subsidies to replace the existing subsidies that are scheduled to expire in 2027 to give them more time (i.e. years of more subsidies for burning wood with no carbon capture). The company's stated expectation of 95 per cent CO_2 capture seems very optimistic.

Drax is the UK's largest single CO_2 source, emitting 11.5 Mt of CO_2 in 2023, which is important even though the CO_2 is biogenic not fossil.[22] The immediate climate change impact of a tonne of CO_2 is the same regardless of the source. The difference between biogenic and fossil CO_2 is philosophical and depends on assumptions about what would have happened if the forest *had not* been logged as well as what *will happen* on the site where it was logged. Either way, the timescales are important. If a forest is not logged, it will not decay immediately and release CO_2 into the atmosphere. When a forest is logged, new trees take decades or longer to sequester as much carbon as is lost by logging and burning trees in the first place. Thus, for a period of many decades, burning wood contributes to the climate crisis – and we do not have decades to dramatically reduce CO_2 emissions and avoid the worst impacts of climate change.

In theory, a BECCS plant might use only bark, sawdust, or other residues that would otherwise be left on the ground and emit carbon within a year or so, but that is not what happens at the Drax power station. Even if, for the sake of argument, the biomass burned at Drax is considered to be 50 per cent renewable, the plant would remain the largest single CO_2 source in the UK; the second-largest emitter is a steel plant, which emitted 5.7 Mt in 2023, but its blast furnaces are closing down in 2024.

New biopower plants may be more efficient than Drax as newer turbines are more efficient.

Efficiency is also higher for a bio-CHP plant. For example, approximately 90 per cent of wood's energy content is used to generate electricity and district heat at Stockholm Exergi's plant in Stockholm (there are various methods of calculating efficiency, but the figure is high.) However, there is a trade-off: a CHP plant generates a lot of heat but less electricity than a power-only plant. With CCS this gets even worse – Stockholm Exergi expects the heat output will remain the same once CCS is installed, but the power

16 Ember, Drax's BECCS project climbs in cost to the UK public (2024). Note that these monies would be in

17 The plan is to capture 4 Mt of CO2 per year from 2030 and 8 Mt of CO2 per year from 2035. See Baringa, The value of BECCS at Drax Power Station (2024).

18 Power Magazine, UK's Drax Eyes U.S. for Bioenergy CCS Expansion Drive (2024).

19 The Guardian, Why 'the UK's biggest carbon emitter' receives billions in green subsidies (2024).

20 Drax, Progress towards meeting our world-leading ambition to be a carbon negative company by 2030 webpage (accessed 14 October 2024).

21 DeSmog, Drax Wants to Capture State Subsidies, Not Carbon (2024).

22 Ember, The largest emitters in the UK: annual review (2024).

capacity will drop from 110 megawatts (MW; net) to just 36 to 50 MW in a city where electricity is a scarce commodity.[23] The *fuel-to-electricity* efficiency will then be only 9.9 to 13.7 per cent.

Beccs Stockholm was awarded €180 million from the European Union's (EU) Innovation Fund in April 2022. [24] The project is estimated to cost over €608 million and is claimed to have the potential to remove approximately 7 Mt of CO_2-equivalent in the first 10 years of operation.[25] The final investment decision is expected by the end of 2024. Scepticism abounds on whether Beccs Stockholm will be realised. For example, the previous owner of the facility tested the very same technology, which was supplied by the former owner of Stockholm Exergi's technology partner (now CO_2 Capsol, formerly Sargas), when the facility was still burning coal. It was unsuccessful.[26]

A much simpler, faster and more cost-effective climate measure would be to buy EU Emission Trading Scheme (ETS) credits and retire them. ETS credits cost between €57 and €74 for 2024 to 2032 futures,[27] and would deliver three times the mitigation of BECCS, even if BECCS is considered mitigation, which is far from evident.[28]

The Swedish government plans to support Beccs Stockholm, but it cannot be taken for granted that this support will be enough to make the project viable. The project is a "first-of-its-kind" so the next plant would presumably be cheaper. But the Stockholm plant may be the biggest in the world, so where would the next plant be? Few such plants are being built globally. District heating of any kind or with any fuel is not widely used other than in a few northern countries.

Of the more recent heat plants, in Scandinavia at least, most use mixed waste. These facilities can be fairly large, but burning plastics is not a great move for the climate. Waste combustion is a major (fossil) CO_2 source in countries. In Sweden, waste combustion resulted in the emission of 3.1 Mt of CO_2 out of total CO_2 emissions of 36.2 Mt in 2022 (this figure does not include the huge biogenic CO_2 emissions of 17.5 Mt in 2022).[29]

The very existence of mixed waste is a political failure. Incineration is the wrong answer to the wrong problem, and coupling it with CCS will require significant new infrastructure: large CO_2 capture buildings, pipelines, and storage sites. The biogenic fraction of the mixed waste could be better used for vehicle biofuel.

Burning waste is now very profitable as the energy company gets paid for receiving the waste and then gets paid by the heating and electricity customers. This creates an incentive to burn more waste rather than to help customers save energy or switch from CHP to wind and solar.

23 International Journal of Greenhouse Gas Control, BECCS with combined heat and power: assessing the energy penalty, Table 5 (2021).

24 European Commission, Innovation Fund, Beccs Stockholm: Bio Energy Carbon Capture and Storage by Stockholm Exergi (2022).

25 Ibid. Communications with Stockholm Exergi in February 2024 indicate that the project is estimated to cost upwards of SEK 3,000 (€267) per tonne of CO2, similar to the cost estimated for Drax.

26 Biofuelwatch, Carbon capture from biomass and waste incineration: Hype versus reality, pg. 15-16 (2022).

27 EEX, Futures webpage (accessed 8 March 2024)

28 National Resources Defense Council, A bad Biomass Bet: Why the leading approach to biomass energy with carbon capture and storage isn't carbon negative (2021).

29 Data from SCB Statistikdatabasen, Totala utsläpp och upptag av växthusgaser efter växthusgas och sektor. År 1990 – 2022 (2022).

Stockholm Exergi also wants to use CCS on a mixed waste combustion plant, though the priority is now on the wood-fuelled plant. The Hafslund Celsio mixed waste plant was initially a part of the Norwegian Longship project but was put on hold in spring 2023 after costs increased.[30]

Hydrogen from biomass with CCS was promoted by the previous Conservative government in the UK, but if green hydrogen makes a breakthrough, it seems unlikely that the much more complex process of deriving hydrogen from biomass could compete. The economics are dreadful.[31]

The **paper and pulp industry** is a big emitter of CO_2 and theoretically offers a big opportunity for negative emissions given the number of large point sources. But a chemical paper pulp plant is already very complex, with a large number of pumps, fans, and pipes. Adding even more pumps, fans, and pipes (assuming there is space for them) presents some risk to the production output or quality of the core product. There must be a very strong incentive to override such risk perceptions.

Pulp and paper mills often have a long history and no two plants are the same. The engineering must be bespoke and little know-how can be transferred from one project to the next. And although pulp mills rely heavily on residues (black liquor and bark) for energy, many already burn large quantities of additional wood (and fossil fuels). Depending on the energy penalty, considerably more biomass would be required to meet the shortfall arising from the installation of carbon capture. A lot of investigation will be needed before a decision could be made to invest. It would take time, cost a lot of money, and will sometimes result in a no, even if the incentives are strong.

Biogenic CO_2 causes the same warming as fossil CO_2; however, this is not accounted for in the national inventory reporting under the United Nations Framework Convention on Climate Change.[32] This is because biomass is considered renewable, which is not always the case. It takes several decades for a cleared forest to regrow. If the forest is not cleared, it will remain a carbon sink for centuries. Forestry products emit their carbon on different timescales: paper tissues within months and timber structures maybe after a century.

In a 2016 Science article, two eminent climate scientists pointed out that in many scenarios BECCS would require a land area equivalent to two Indias to achieve negative emissions.[33] Seven years later, the IEA's Net Zero scenario in World Energy Outlook assumed an increase in liquid, gaseous, and solid biofuels from 40 exajoules (EJ) in 2022 to 99 EJ in 2050, an almost 150 per cent increase.[34]

The large-scale deployment of BECCS is certain to create huge land use conflicts. More biomass for BECCS would require a lot of land – fairly good land – that would then be unavailable for food, fibre, feedstuff, and medicine production; leisure and recreational uses; habitat conservation; and biodiversity protection. BECCS also requires vast amounts of water.

30 Gassnova, Celsio puts Klemetstrud carbon capture project on hold (2023).

31 Biofuelwatch, Biofuelwatch briefing about proposals to use bioenergy for hydrogen production (2022).

32 See e.g. United Nations Climate Change, National Inventory Submissions 2023 (accessed 15 October 2024).

33 Science, The trouble with negative emissions: Reliance on negative-emission concepts locks in humankind's carbon addiction (2016).

34 IEA, World Energy Outlook 2023 (2023)p 276.

Photosynthesis is just not very efficient. At best, it converts 2 per cent of solar energy into chemical energy, often much less than 1 per cent. Solar photovoltaic (PV) panels can convert more than 20 per cent of solar energy into electricity, or about half as much for a large solar park due to spacing requirements. Solar PV and other solar technologies use far less land than BECCS, and solar does not need fertile land or significant volumes of water to operate. Moreover, solar can be installed on water reservoirs where it uses no land at all. It can also be sited in deserts or on derelict land. Whilst poorly sited solar projects can create land use conflicts, this risk is much less severe than with bioenergy.

BECCS is just one potential negative emissions option. Other options include direct air capture CCS (not credible),[35] enhanced weathering of alkaline rocks (a bad idea),[36]and, most importantly, nature-based methods, such as wetland and mangrove restoration, re-forestation, and just leaving the forest to draw down carbon in growing trees and the soil.

35 Nature Communications, An inter-model assessment of the role of direct air capture in deep mitigation pathways (2019). Another calculation estimates that capturing the 32 billion tonnes of CO2 emissions emitted from fossil fuel combustion in 2020 would require more than five times the total global electricity consumption in that year. See Recharge, The amount of energy required by direct air carbon capture proves it is an exercise in futility (2021).

36 Massachusetts Institute of Technology, Climate Portal, Enhanced Rock Weathering webpage (accessed 14 October 2024).