BECCS (Bioenergy with Carbon Capture and Storage): Climate saviour or dangerous hype?

Rachel Smolker and Almuth Ernsting

Ethanol refinery in North Dakota: Cheap source of CO2 …

…for enhancing oil production?

Summary

Bioenergy with carbon capture and storage (BECCS) has received increasing attention in recent years, with claims for its potential as a "carbon negative" technology, to reduce atmospheric CO2 concentrations. The logic behind BECCS is revealed in the opening sentences of a report by the International Energy Authority's Greenhouse Gas R&D Programme (IEAGHG):[i]

> *"Biomass use for energy production in processes such as combustion and gasification and its use to produce biofuels such as bioethanol, result in emissions of CO2. This CO2 produced during combustion is approximately the same quantity consumed during biomass growth; therefore emissions from biomass combustion are considered to be CO2 neutral. (Demirbas, 2009). Capture and long term storage of these CO2 emissions would effectively result in net removal of atmospheric CO2, and Biomass with CCS is potentially one of the few options for negative emissions."*

This logic is seriously flawed for a number of reasons set out in this report. A critical look at the claims made about BECCS is important because a growing cadre of hopeful enthusiasts are overlooking the serious risks and hazards and advocating massive upscaling of BECCS as "carbon negative" climate geoengineering. They claim that BECCS is one of the few currently available means of removing carbon from the atmosphere and that as such it is essential for averting climate catastrophe.[ii] They also claim that, compared to some proposed climate geoengineering technologies, BECCS appears less risky and more benign. These two claims combined raise the specter of BECCS being supported and advanced rapidly which would lead to massively increased demand for biomass and attendant negative impacts on peoples and lands.

The flaws in the claims made by IEAGHG and other BECCS proponents include:

+ high levels of uncertainty about the possibility of securely storing carbon underground and potential risks to human health and ecosystems associated with CCS;
+ faulty reasoning about the availability of plentiful biomass feedstocks, and the "neutrality" of biomass carbon emissions based on assumed regrowth and re-sequestration: Large-scale bioenergy without CCS is already creating an enormous new demand for biomass – a root cause of deforestation, biodiversity loss, human rights violations and escalating carbon emissions;
+ high additional energy requirements for carbon capture, resulting in significantly more fuel demand to produce the same energy output. Large-scale bioenergy with CCS would thus further increase the demand for biomass and worsen impacts.

High costs are associated with capturing carbon (except from nearly pure CO2 streams such as from ethanol fermentation), compressing and transporting it (including building new CO2 pipelines) and pumping it underground and major technical challenges are associated with the majority of CCS proposals.

Storing CO2 below ground requires access to underground spaces, beneath both ocean and land areas. Current mapping of geological formations, with the expectation that these spaces will be accessed, is setting the stage for a new form of "underground" land grab. Resistance has already begun with communities opposing the injection of CO2 into the ground beneath them. This resistance is at least slowing down CCS developments in some areas, for example in the Netherlands where it has led to the government putting a halt to carbon sequestration projects except off-shore. Concerns over the reliability of storage, and the consequences of any leakage make liability and insurance problematic.

Finance for BECCS is further challenging. Currently there is little immediate prospect of significant carbon finance, whether through regional emissions trading, offsets or a possible carbon tax. Although significant steps were taken at the UN climate conference in Durban in 2012 to include CCS into the Clean Development Mechanism[iii], given the collapse in carbon prices in recent months, large-scale funding is likely to remain dependent on direct government subsidies (including through public private partnerships) for some time yet.

In spite of the numerous concerns and barriers to BECCS and CCS in general, as the impacts of global warming become more obvious and severe, there is greater willingness to embrace risky techno-fixes, including under the guise of "climate geoengineering" even where there is clear potential to significantly worsen rather than mitigate climate change impacts.

Crucially, the promotion of CCS, including BECCS for climate change mitigation and geo-engineering, coincides with the oil industry's fast-growing demand for cheap continuous supplies of CO2. As discussed in detail below, flooding oil reservoirs with CO2 allows for the recovery of a far higher proportion of oil than would be possible with conventional means. In the US and the North Sea, where conventional oil production has already peaked, CO2 flooding, or 'Enhanced Oil Recovery' offers the prospect of perhaps several decades more oil production. Despite the fact that Enhanced Oil Recovery leads to the recovery and burning of potentially vast quantities of fossil fuels which would otherwise have remained under the ground, use of CO2 for this purpose is classed as a form of CCS, a claim accepted even by the Intergovernmental Panel on Climate Change. Not surprisingly, this type of "CCS" is receiving particular attention from industry and governments particularly in North America and North Sea states alike. Ethanol fermentation emits almost pure CO2 which can be captured relatively easily and cheaply. Classed as a type of BECCS, it is thus of particular appeal to oil companies, many of which already have strong interests and investments in the ethanol sector.

Oil companies are not the only players with an economic interest in public support for CCS, including BECCS. For the coal industry, government-supported CCS as well as biomass both offer them means of either staying within their CO2 allowances in the EU (and thus avoiding the costs associated with carbon trading) and of safeguarding themselves against potentially stricter and more widely applied future CO2 caps or pricing mechanisms. Promises of power stations being made ‘capture ready’ as well as conversion to biomass and coal co-firing have already resulted in permitting of new coal power stations and the expansion of existing ones. The facts that industrial biomass is far from climate friendly and CCS far from proven do not pose an obstacle as long as governments’ carbon accounting rules treat biomass as (completely or almost) carbon neutral and CCS as secure long-term carbon storage. Energy companies investing in coal have a clear interest in maintaining such false policy assumptions.

What is BECCS?

BECCS is the application of Carbon Capture and Sequestration (CCS) to any form of bioenergy. This could mean capturing CO2 from ethanol or some types of biodiesel production facilities, from coal power stations that co-fire or co-gasify biomass and coal, or from dedicated biomass combustion or gasification power stations. CO2 capture can be achieved by using chemical and physical absorption, filtering membranes, or adsorption, and may be performed at various stages on a variety of processes. Post combustion, CO2 can be purified from the flue gases emitted from boilers, etc. These emissions often contain a mixture of compounds. Purification of CO2 adds further to cost and complexity. Pre-combustion capture is possible especially for gasification technologies that break down biomass into “syngas”, (largely CO2 and H2), from which the CO2 can be separated relatively easily. This process is cheaper and simpler than post-combustion carbon capture but existing power stations cannot be retrofitted to make it possible and the power station technology required to allow for it is highly complex and expensive, and has not yet been commercialized. Ethanol production involving fermentation results in a pure stream of CO2 that can be directly captured. In theory, biodiesel production using the Fischer-Tropsch method, which involves production of syngas as an intermediary step offers opportunity for CO2 capture, although this type of biodiesel production has such poor energy balances (even without CCS) that it is so far not commercially available. Another possible capture technique involves oxyfuel combustion processes, where fuel is burned not in air but in nearly pure oxygen streams (i.e. with the nitrogen having been removed from the air first). This process results in emissions of CO2 and water from which the CO2 can be captured. However, this technique is still in the early research and development stages.

Once captured, the carbon is compressed, transported via truck, ship and/or pipeline, and then pumped underground for long term storage in underground geological formations, or used for enhanced oil recovery (EOR). The potential for storing CO2 in deep ocean “lakes” is also being explored although it is accepted that CO2 mixed with water at any depth will eventually find its way back into the atmosphere. Some industry and BECCS proponents also describe the use of CO2 emissions for cultivation of algae (to produce oil for biofuel) as BECCS, however this technique remains almost entirely undemonstrated and, furthermore, since algal biofuels would be combusted, the CO2 could not actually remain sequestered. As we shall see below, Enhanced Oil Recovery is by far the most profitable use of CO2 in the name of CCS.

Hype and claims about the potential of BECCS

Despite a near complete lack of real world experience with BECCS, numerous hyped claims are made about its’ potential:

Perhaps most striking was the claim made by Read and Lermit (2005) who argued that large scale application of BECCS over about 50 years could result in “*restoring atmospheric CO2 levels to preindustrial levels.*” [iv]

More recently an IEAGHG 2011 report on BECCS[v] assessed potential for six possible bioenergy pathways:

- Co-firing for biomass in pulverized fuel coal power stations[1] (likely up to 30% biomass in

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[1] Pulverized fuel combustion is the standard technique for coal power stations worldwide, having replaced grate-firing from early in the 20th century.

2030, up to 50% in 2050) – this would require post-combustion carbon capture;

- Dedicated biomass power stations using Circulating Fluidized Bed (CFB)[2] combustion technology with CCS;
- Integrated Gasification Combined Cycle (IGCC)[3] coal power stations with biomass co-firing and CCS – this would involve pre-combustion carbon capture;
- Dedicated biomass IGCC power stations with CCS;
- Carbon capture from advanced ethanol production;
- Carbon capture from Fischer-Tropsch biodiesel production (i.e. from the syngas).

IEAGHG provides detailed estimates of technical, realizable and economic potentials. It defines the technical potential as being constrained only by the availability of resources (including basic future biomass sustainability standards) and CO2 storage space. According to IEAGHG, the technical potential for BECCS is up to 10 billion tonnes of CO2 a year of "negative emissions." Such negative emissions would be greatest for biomass combusted in IGCC plants, although the report confirms that this technology is not yet proven at a commercial scale. The second greatest potential for negative emissions would come from dedicated biomass plants with Circulating Fluidized Bed Combustion and CCS. Carbon capture from ethanol and Fischer-Tropsch biodiesel production presents the lowest potential for negative emissions, since a smaller fraction of the CO2 contained in the biomass would be captured (maximum 54% with Fischer-Tropsch, less with ethanol).

Deploying the full technical potential assumed by IEAGHG equates to up to 59 exajoules (EJ) of bio-electricity or, alternatively, 47 EJ of biofuels a year. This would require annual biomass supplies amounting to 73 EJ in 2030 and 125 EJ by 2050.

Translating exajoules, i.e. the energy content of biomass, into land requirements is not straightforward – it depends on assumptions about future yields which in turn depend on assumptions about which type of biomass would be produced on which lands, on the availability of water, climate conditions, etc. An assessment of "Biomass energy: the scale of the potential resource" estimates that 386 million hectares of (supposedly) 'abandoned croplands' would need to be converted to biomass production in order to yield 27 EJ[vi] – far less than IEAGHG consider to be the maximum technical potential required for BECCS. According to a 2007 briefing by the International Energy Authority (IEA):

> "Present global modern bio-energy production is estimated at some 9 EJ/year of which industrial biofuel production is only 1 EJ per year (around 1% of transport fuels from crops grown on some 1% of all arable land – 14 million hectares)[4]."[vii]

The IEGHG assumptions about potential future biomass supplies for BECCS thus represent a more than six-fold increase in industrial bioenergy production from 2007.

The impacts on lands and peoples, should even a small fraction of the assumed technical potential for BECCS ever be realized, would thus be very high.

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[2] CFB is a relatively common form of fluidized bed combustion. Fluidized bed combustion involves suspending coal or biomass in upward-blowing air jets during combustion, mixing the solid fuel with gases to increase the efficiency of combustion and chemical processes. No project involving CCS with CFB power plants exists as yet.

[3] IGCC involves gasifying coal or other fuels into synthetic gas (syngas), cleaning that syngas and then combusting it. Inn theory, IGCC could be more efficient and result in less polluting air emissions than other forms of coal and biomass combustion, in practice, however, this is a highly complex and expensive process and there is little evidence to suggest that it is close to commercialisation.

[4] Current figures for biofuel production in particular will be significantly higher, with an estimated 25 million hectares of land now devoted to biofuel production, however the 14 million hectares per 1 EJ figure for biofuels remains highly relevant.

The 'realizable potential' is smaller – it is assessed by starting with the technical potential and applying constraints resulting from capital stock turnover, energy demand and possible deployment rates. The realizable potential would thus increase with BECCS deployment. IEAGHG estimates that the realizable potential would be greatest if biomass was co fired in pulverized fuel (i.e. standard) coal power stations, assuming that all new coal power stations would be equipped for carbon capture by 2020 and that existing ones would be retro-fitted later. The economic potential is the smallest – it takes account of whether CO2 prices are high enough for companies to not incur additional costs by using BECCS and it thus depends heavily on the carbon price. IEAGHG suggest that at a carbon price of 50 Euros ($65) per tonne of CO2, the economic potential would be one third of the technical potential and that potential would be greatest for biomass IGCC plants because the costs of ongoing energy production with carbon capture in such plants would be relatively low (although capital costs are very high). For biofuels the highest economic potential would come from Fischer Tropsch biodiesel. It should be noted however that, at the time of writing this report, the price of a tonne of CO2 traded under UN mechanisms has fallen to just 2.05 Euros ($2.66)[viii].

While these assessments are highly technical, the reality is that there is little real-world experience with BECCS. There is however considerable, (disproportionate) hype and expectation.

The IPCC Assessment Report 4, published in 2007, reviews different future emissions reduction scenarios that would be needed to achieve various stabilization targets. The authors point out that many scenarios to stabilize CO2 levels at or below 400 ppm (compared to around 392 ppm at present) would require negative emissions later this century[ix]. Some of these models assume that as much as 90% of the reduction would be achieved by CCS (applied to both fossil and bioenergy).[x]

Some researchers argue that BECCS is the only such technique that is "large scale and near market".[xi] Some claim that achieving low(er) greenhouse gas stabilization concentrations cannot be achieved without BECCS.[xii]

The International Energy Agency (IEA) projects that CCS will have to account for around 20% of all CO2 reductions in order for there to be a realistic chance of reducing global greenhouse gas emissions by half by 2050 compared to current levels and that overall mitigation costs for such reductions would be significantly higher without it.[xiii]

The IPCC Special Report on Renewable Energy 2011 states:

> *"Bioenergy technologies coupled with CCS...could substantially increase the role of biomass-based GHG mitigation if the geological technologies of CCS can be developed, demonstrated and verified to maintain the stored CO2 over time."* [xiv]

A recent report by the European Technology Platform for Zero Emission Fossil Fuel Power Plants and the EU Biofuels Technology Platform[5], produced by Norwegian NGO Bellona, is titled "Biomass with CO2 Capture and Storage (Bio-CCS): The Way Forward For Europe.[xv]" Amongst its key claims are that CCS could provide 20% of global emissions reductions, that BECCS could remove 10Gt of CO2 from the atmosphere annually by 2050, 800 Mt a year in Europe alone (also by 2050), which would be equivalent to half of all current EU power sector emissions. These projections are based on further assumptions that "*A wide range of biomass feedstock is available worldwide for biofuel and bioenergy production, such as energy crops (e.g. miscanthus, jatropha, short-rotation coppice); wastes (e.g. waste oils, food processing wastes); agricultural residues (e.g. straw, corn*

[5] According to the European Commission, "European Technology Platforms (ETPs) are industry-led stakeholder for a charged with defining research priorities in a broad range of technological areas. (http://cordis.europa.eu/technology-platforms/)

stover); forestry residues; and novel feedstocks (e.g. algae". Algal biofuels have not been successfully scaled up despite years of research and development and significant levels of investment. The report written by Bellona also assumes that secure underground storage space is plentiful and available. While numerous claims have been made suggesting there is adequate space for storing thousands of years worth of CO_2 emissions, this was recently seriously challenged when scientists pointed out that previous estimates of storage capacity had been based on erroneous assumptions about constant pressure during CO_2 injection processes.[xvi] In an interview in the Guardian, Michael Economides, an author of that study and Professor of Chemical & Biomolecular Engineering at Houston University, stated that CCS "*is not a practical means to provide any substantive reduction in CO2 emissions, although it has been repeatedly presented as such by others….CCS is the last refuge of the scoundrel."*[xvii]

Amongst the backers and proponents of BECCS as a 'promising' technology that would allow for 'negative emissions' are fossil fuel and ethanol companies, some government ministries (e.g. in Norway), the UK's Committee on Climate Change (and independent advisory body to the UK Government), a Swedish company dedicated to BECCS development called Biorecro and various mainly Nordic organizations such as Bellona, the Stockholm School of Economics, Innovation Norway and the Swedish Agency Tillcaxtverket, the UK-based non profit organization, Natural Step, as well as the UN Industrial Development Organization (UNIDO) and World Wildlife Foundation.

BECCS promotion for geoengineering

As a result of such optimistic claims as those described above, BECCS has featured as a potential climate geoengineering technique in most major reports assessing geoengineering technologies to date. For example the Royal Society report includes BECCS among "land based carbon dioxide removal" techniques (along with biochar and large scale afforestation and others).[xviii] Similarly, BECCS is listed as a potential geoengineering technology in the US Government Accountability Office (GAO) report[xix], and even in a recent report commissioned by Friends of the Earth England, Wales and Northern Ireland.[xx]

Though BECCS features in geoengineering discussions, it is met with varying degrees of reserve. The US GAO report states (pg 25):

> "*The literature describes BECS's technical feasibility and potential as a negative-emissions energy system that is benign and free of risks associated with some other climate engineering approaches (Read and Lermit 2005). As with direct air capture, however, the CO2 sequestration aspects may pose risks. Furthermore, diverting resources to large-scale BECS activities could pose land-use trade-offs or affect food prices, water resources, and fertilizer use."*

Indeed, such precaution is highly appropriate.

Why BECCS cannot be carbon neutral

Fundamental to the logic behind BECCS is the assumption that bioenergy – all bioenergy - is "carbon neutral". This is based on the idea that following biomass harvests, regrowth will occur, and, in theory, resequester an amount of carbon equivalent to that released during energy generation (whether through direct combustion, refinement into ethanol etc). BECCS builds on this assumption: It is claimed that since bioenergy is classed as completely or largely carbon neutral in principle, CO_2 can be withdrawn from the atmosphere by capturing all or part of the carbon released from bioenergy generation and storing it securely, in which case the CO_2 sequestered by new plant growth would be ***additional***, not just replacing what has been emitted through biomass electricity generation, ethanol combustion, etc. This is the basis for the claim that BECCS is 'carbon negative'.

However, the notion that industrial bioenergy is completely or largely carbon neutral in the first place has been repeatedly challenged, including by a growing volume of scientific studies. If bioenergy is not carbon neutral in the first place, then adding capture and storage certainly cannot render it carbon negative.

Proponents of BECCS dangerously lump ***all*** forms of bioenergy - including combustion or gasification of wood chips or pellets in combination with coal to generate electricity and heat, as well as CO2 capture from corn or other ethanol refineries under the same leaky umbrella. While the carbon neutrality argument has been vigorously promoted in the context of wood based bioenergy, few people claim, for example, that corn ethanol refineries are "carbon neutral".

Various studies have shown that, once direct and indirect land use related changes in carbon stocks are taken into account, large-scale bioenergy including biomass combustion and other processes generally result in even more greenhouse gas emissions that the fossil fuels they are intended to replace.

For example, biomass combustion for electricity, including co-firing wood with coal, requires massive quantities of wood. Such large scale demand cannot be met from genuine "wastes and residues", but requires additional logging. When ***forests or tree plantations are logged*** for bioenergy, significant quantities of carbon are emitted from equipment, transportation of bulky materials, processing (chipping or pelleting) as well as from soil disturbance leading to soil carbon losses and the loss of carbon contained in any surrounding vegetation destroyed during logging. These life-cycle emissions are in addition to smokestack emissions from combustion. There is simply no guarantee that new trees will grow back. Even if they do, and resequester all the carbon released from harvest, transport and burning of the previous generation of trees, it will likely take decades or even centuries to do so. This time lag is referred to as a "carbon debt". According to a study by scientists from the Joanneum Research Institute, the carbon debt from burning trees logged from 'well-managed European forests' can be 200 years.[xxi] Since wood has a very low energy density compared to fossil fuels, using wood for energy releases more carbon per unit of energy production even than coal, so the carbon debt will be very large, as well as long. Climate scientists warn that greenhouse gas emissions must be reduced immediately. Yet policies continue to entirely ignore emissions from biomass combustion, as if they are nonexistent, with dire consequences. In an article entitled "Fixing A Critical Climate Accounting Error", Searchinger et al state:

> "*The accounting now used for assessing compliance with carbon limits in the Kyoto Protocol and in climate legislation contains a far-reaching but fixable flaw [failing to count emissions from bioenergy] that will severely undermine greenhouse gas reduction goals.*"[xxii]

The European Environment Agency's Scientific Committee[xxiii] warned in 2011:

> "*It is widely assumed that biomass combustion would be inherently 'carbon neutral' because it only releases carbon taken from the atmosphere during plant growth. However, this assumption is not correct and results in a form of double-counting, as it ignores the fact that using land to produce plants for energy typically means that this land is not producing plants for other purposes, including carbon otherwise sequestered. If bioenergy production replaces forests, reduces forest stocks or reduces forest growth, which would otherwise sequester more carbon, it can increase the atmospheric carbon concentration*."

This statement was followed by a letter signed by nearly 200 scientists warning about the role of indirect land use change.[xxiv]

Some advocate using shorter rotation trees, claiming that this would significantly shorten the carbon debt. However***, industrial tree plantations*** **are not forests** but rather "green deserts' that contain far less carbon than real forests or other natural ecosystems, require synthetic fertilizers and other agro-chemicals, and deplete freshwater and soils. Similarly, crop monocultures which are being fast expanded especially for biofuel production are a major driver of deforestation and other ecosystem destruction, as well as requiring use of agro-chemicals and resulting in large-scale emissions of the powerful greenhouse gas nitrous oxide. Bioenergy is fast becoming a major driver for the expansion of industrial tree and crop plantations, and for the development of genetically engineered trees and crops, including trees engineered for fast growth and cold resistance, at the expense of forests, grasslands and people's farmlands and livelihoods. According to a study published in Science, putting a price on fossil fuel carbon emissions while ignoring emissions from bioenergy will result in a scale of demand for biomass that would drive conversion of virtually all remaining natural forests, grasslands and most other ecosystems to bioenergy crop plantations by 2065. [xxv]

Economies of scale will dictate that larger facilities are needed to carry the investment in equipment etc required for application of CCS. These larger facilities will necessarily depend upon dedicated plantations to ensure continuous supplies very large quantities of biomass, and to keep transportation costs down as far as possible.

Many in the industry claim they will not harvest from forests, but only use "*wastes and residues*" from forest harvests that "would happen anyway". But, realistically, there is nowhere near enough waste and residue even to supply current demand. A biomass power station producing 50 MW of electricity requires woodchips and pellets made from around half a million tonnes of wood, burned year after year – and 50 MW is not large-scale when compared in particular to European biomass power station plans which are up to 750 MW in size. Supplying that quantity of wood from nearby forests (to avoid long distance transportation) is not possible from wastes and residues alone. Forests are already being cut specifically for biomass.[xxvi] In fact, wood chips and pellets for burning are in ever greater demand, and an expanding international trade (especially to Europe) has emerged, threatening forests worldwide.[xxvii] Removing more materials from harvest sites - branches, twigs, leaves, "non merchantable" timber and even stumps from forest harvest sites means removing nutrients, leaving soils exposed to compaction, erosion and drying, and diminishing future regeneration potential as well as releasing soil carbon. Nobody openly advocates the destruction of natural forests for BECCS, but there are no credible ways of preventing that from happening both through destructive logging and through conversion to industrial tree plantations, especially in the face of subsidies and mandates for bioenergy, as experience with biofuels has shown.

Biofuels for transportation – largely refined from corn and sugar cane, are lumped together with all other bioenergy processes, though very few cling to the assumption that ethanol or biodiesel manufacture is carbon neutral. A variety of lifecycle assessments have been conducted, with widely differing results depending on whether direct and indirect land use change impacts are included, whether co-products are taken into account, whether direct and indirect nitrous oxide emissions from fertilizer applications are estimated, whether the refining process is powered by coal, natural gas or biomass (assumed to have zero emissions…) and other variables. Corn ethanol is widely accepted as having especially poor energy and greenhouse gas balances. Among the more optimistic assessments, was an evaluation of six previous studies by Farrell et al, published in Science in 2006 which offered a 'best estimate' of 13% greenhouse gas savings from corn ethanol compared to petroleum.[xxviii] More recently the US Environmental Protection Agency (EPA) undertook a Life Cycle Assessment of corn ethanol LCA[xxix] and reported that over a 30 year horizon, corn ethanol processes range from a net 26% reduction in GHG emissions (for very rare case where the refinery is powered using biomass, and the wrongful assumption that biomass emissions are nonexistent is accepted, and with combined heat and power) to a 34% ***increase*** in GHG emissions (for coal powered refineries) relative to gasoline. Refineries powered with natural gas are most common, and these ranged from "best case" 18% reduction to (most common) 5% increase in emissions over 30 year timeline.[xxx] However, it is important to keep in mind that there is a significant margin of error with such life cycle assessments. For example, fertilizer applications which lead to N20 emissions play a very significant role in greenhouse gas implications of biofuels. In fact, according to Crutzen et al, these N20 emissions alone – not even counting all the other sources – can be greater than the emissions from burning fossil fuels (petrol).[xxxi]

Highly relevant for the greenhouse gas balance of ethanol is the energy balance. In the case of corn ethanol in particular, whether or not there are any net energy gains at all (i.e. whether more or less energy is used to produce the ethanol than is released when burning it) has been subject to scientific dispute. While the above-cited study by Farrell et al suggests that there are significant net energy gains, a study by David Pimentel and Tad Patzek calculated that corn ethanol requires 29% more (generally fossil) energy inputs than the fuel produces[xxxii]. Differences primarily arise from different attributions of co-products, with optimistic studies assuming that ethanol by-products will be fed to cattle and reduce the requirement to crow soya for animal feed. (The debate about the suitability and effects of cattle feeds from ethanol byproducts is discussed in detail by others.)[xxxiii]

Since most current BECCS projects involve capture of CO2 from corn ethanol refineries, understanding of energy and greenhouse gas emission assessments for ethanol is of key importance. Proponents of BECCS hold a blanket assumption that ***all*** forms of bioenergy production are 'carbon neutral' and that BECCS would render any and all of them "carbon negative". Yet the carbon neutral claim has been soundly challenged, and few have ever assumed corn ethanol to be carbon neutral process. Lumping all bioenergy processes together as "carbon neutral" is invalid and highly misleading. If bioenergy processes are not "carbon neutral, then adding CCS certainly cannot possibly make them 'carbon negative'.

More demand for biomass means more land-grabbing and deforestation

BECCS on a scale that would have a global impact on atmospheric CO2 levels (for climate geoengineering) would require massive amounts of biomass – in the order of hundreds of millions of hectares of new dedicated plantations. The impacts on lands, ecosystems and biodiversity and human rights would be severe. According to a report by the International Lands Coalition, at least around 42% of land grabs are currently for purposes of biofuel crops.[xxxiv] Advocates of BECCS and other forms of bioenergy assume that hundreds of millions of hectares of 'marginal' or 'abandoned' lands are 'available', mostly in the global south, a claim which entirely ignores the livelihoods of hundreds of millions of people who live on those lands and depend on them for their livelihoods, whether they rely on farming, pastoralism or other activities – as well as the biodiversity on lands classed as 'marginal'.[xxxv]

Underground storage space: Another kind of land-grab?

CCS, whether involving bioenergy or fossil fuels, raises the potential for a new "underground" land grab, bearing resemblance to current land grabs for mining. Efforts are underway to map geological storage potentials for different regions around the globe to establish where CO2 could be stored in geological substrates, with the expectation that commercialization of CCS will proceed. One such effort, for example, is the "North American Carbon Storage Atlas" which brings together Natural Resources, Canada, The Mexican Ministry of Energy and the US DOE.[xxxvi] The website proclaims:

> "*The primary purpose of the Atlas is to show the location of large stationary carbon dioxide (CO2) emission sources and the locations and storage potential of various geological storage sites. This Atlas is a first attempt at providing a high-level overview of the potential for large-scale carbon storage in North America*."

These maps mirror the (mostly southern) "biomass availability" maps created to assess availability of large quantities of biomass to supply (mostly northern) industrial bioeconomies.[xxxvii] Such 'biomass availability maps' have dangerously failed to take into account the interests and uses of those lands by their current inhabitants, especially peasant farmers, indigenous peoples, and pastoralists. Similarly, there is little discussion concerning communities' rights to determine whether or not they would choose to have the ground beneath them, or nearby lakes or coastal areas, injected with CO2.

Community resistance to CO2 storage is already occurring. For example, in Greenville, Ohio, residents successfully opposed plans for an underground carbon sequestration project.[xxxviii] Protestors blocked the highway entrance to the German North Sea resort island of Sylt to draw attention to the dangers of an RWE plan to transport CO2 from a facility in Cologne for storage under the North Sea.[xxxix] In Barendrecht, Netherlands, plans to store carbon in depleted gas wells under the city were met with strong resistance.[xl] Those led to a government decision to not only stop carbon storage in Barendrecht, but to stop all CO2 storage under Dutch lands, nationwide[xli].

Protests and resistance especially in light of the EU CCS directive, have been ongoing in Germany, too, and resulted in various changes to state level policies regarding storage under their territories. Interestingly, this "lack of policy coherence" is viewed as a threat to EU CCS plans overall since pipeline infrastructure would require collaboration among states.[xlii]

General risks associated with CCS

The basis for growing resistance to CCS is raising awareness of the very serious risks of CO2 storage, as well as of the role which CCS plays in legitimizing new investments in dirty energy, especially coal. A report published by Greenpeace, along with a review by Sourcewatch has contributed to this.[xliii] The evidence suggests that the long term reliability of underground storage cannot be guaranteed. Neither slow nor long term leakage, including from pipelines can be ruled out. In a chapter on accounting issues for CCS, the IPCC provides a simplified flow diagram of possible CO2 emission sources during CCS.[xliv] These include: leakage from imperfect capture, from additional energy requirements for capture, additional energy requirements for transportation, fugitive emissions from transport (i.e. leaking pipelines, freighters, etc), emissions from additional energy requirement for injection, fugitive emissions from injection processes, and, last but not least, potential leakage from storage sites. Not mentioned here are potential accidents and natural disasters such as earthquakes that could fracture storage formations.[xlv]

Any sudden large release could be extremely dangerous, since exposure to elevated concentrations of CO2 can be lethal. While normal atmospheric concentration (0.037%) is not toxic, concentrations of 3% or higher result in hearing loss, visual disturbances, labored breathing, headache, impaired vision and confusion. Concentrations of 20% are quickly fatal, resulting in asphyxiation. Because CO2 is heavier than air and thus leakage tends to collect in hollows or low lying areas where it can concentrate. Any large release below fatal levels could nonetheless have abrupt impacts on human health and on biodiversity (including marine biodiversity if carbon storage takes place offshore).

Any ongoing slow release would undermine efforts to reduce emissions and protect climate – even a 1% leakage rate would result in all of the CO2 being released again within a century. Storage would need to be permanently secure to protect future generations. Long term monitoring would be necessary as well as effective plans for responding to any leakage that does occur. This would be extremely difficult to implement, much less guarantee into the future. Long term CO2 storage issues are similar in many respects to those associated with nuclear waste. In a report published in Nature Geosciences, the author modeled various scenarios of leakage from CCS and reports:

> "*Most of the investigated scenarios result in a large, delayed warming in the atmosphere as well as oxygen depletion, acidification and elevated CO_2 concentrations in the ocean. Specifically, deep-ocean carbon storage leads to extreme acidification and CO_2 concentrations in the deep ocean, together with a return to the adverse conditions of a business-as-usual projection with no sequestration over several thousand years.*"[xlvi]

So far, practical experience, such as it is, offers little basis for confidence:

- Monitoring of the BP and Statoil collaboration Sleipner CCS project off Norway, one of the largest and biggest CCS projects to date, revealed a large discrepancy between the amount of CO2 injected and what was subsequently detected in seismic surveys. Researchers concluded that the discrepancy was inexplicable, possibly due to miscalculations in their modeling, or, potentially, leakage.[xlvii] Recently a previously unknown fracture in the subsea bed was discovered just 25 km north of the site where a million tonnes per year of CO2, from gas processing, is injected. This raises further concerns about potential leakage but also is indicative of the difficulties and potential miscalculations that geologists and engineers face in trying to ensure reliable storage.[xlviii]

- A recent study by researchers at Duke University revealed that leakage of CO2 from storage formations into overlying freshwater aquifers can occur and in some circumstances result in up to tenfold increase in dangerous contaminants (arsenic, uranium, barium and other).[xlix]

- A letter from scientists and environmental justice advocates to the U.S. Environmental Protection Agency called for precaution, citing not only the energy demand and costs, but also the acidification of aquifers which can result in arsenic and lead contamination of ground water as well as leading to fractures and hence dangerous releases of CO2. Further they cite the risk of destabilization of underground faults and potential earthquakes, as well as impacts of associated gases on microbial communities.[l]

A different risk associated with CO2 use for Enhanced Oil Recovery (a technique discussed in detail below and which is widely classed as CCS) is that recovering oil by pumping CO2 into reservoirs brings large quantities of brine to the surface which can contain toxic metals and radioactive materials. The brine has to be reinjected but nonetheless poses serious additional risks to environment and human health[li].

CCS: High costs and monumental infastructure demand

The financial costs associated with CCS for bioenergy or fossil energy, are very high. Carbon capture, dehydration, compression, transport and injection of CO2 underground (or into depleted oil wells for use in enhanced oil recovery) all require further equipment, infrastructure (including pipelines), monitoring, energy and financial investment. The U.S. Department of Energy website states that their analyses indicate that "*today's commercially available post-combustion capture technologies may increase the cost of electricity for a new pulverized coal plant by up to 80 percent and result in a 20 to 30 percent decrease in efficiency due to parasitic energy requirements*."[lii] Estimates are that capturing carbon from power stations could cost up to $80 or more per metric ton.[liii] Those costs would most likely be passed on to ratepayers. Carbon capture costs are particularly high in the case of power stations using standard combustion technology, such as pulverized fuel combustion of coal. They are significantly lower for IGCC coal or biomass power stations; however those are not yet fully commercialized and involve very high upfront capital investments and technical support.

Further, the infrastructure demands that would be needed to implement CCS on a large scale would be extremely costly. For example, it is estimated that at current emissions rates in the U.S. as many as 100,000 CO2 injection wells would have to be drilled (currently about 40,000 oil and gas wells per year are drilled, costing upwards of $1.5 trillion). Costs associated with characterization of geological storage sites are huge, as are the costs for the construction of pipelines to transport CO2. Add to these the currently inestimable costs associated with long term monitoring and verification as well as insurance. The scale necessary to have any impact on climate would necessitate massive infrastructure. According to Valclav Smil, Professor Emeritus at the University of Manitoba and a Fellow of the Royal Society of Canada:

> *"Sequestering a mere 1/10 of today's global CO2 emissions (less than 3 Gt CO2) would thus call for putting in place an industry that would have to force underground every year the volume of compressed gas larger than or (with higher compression) equal to the volume of crude oil extracted globally by petroleum industry whose infrastructures and capacities have been put in place over a century of development."*[liv]

So far, costs have been largely prohibitive even for implementing CCS at a relatively small scale. This is especially the case in the absence of financial incentives to reduce emissions such as a carbon tax. Given the collapse of carbon prices across all existing larger global carbon markets such incentives appear unlikely in the near future. Because of these costs to industry, and also in some cases because of concerns over the implications for electricity bills, many CCS projects have already been abandoned, even in some cases following very significant initial investments (examples below).

There is, however, one very important exception to this conclusion: Capturing of near pure CO2 streams, including from ethanol production for the purpose of increasing oil production in partially depleted oil fields. This particularly questionable but potentially highly profitable type of CCS is discussed in detail below. Oil companies' quest for cheap, continous CO2 streams might well provide sufficient incentive for large-scale CCS to be implemented in future.

CCS: Increased energy demand

One of the reasons CCS is so expensive is that the process itself requires energy. According to the IPCC (table 8.3), the increased fuel requirement for pulverized coal, IGCC coal and combined cycle natural gas facilities would range from 11-40%. This means that 11-40% more fuel would need to be burnt for the same energy output. This added fuel demand is due to the energy requirements inherent to the capture and pressurization of CO2 as well as, transport, injection.[lv] The IPCC estimates that the cost of electricity from power plants utilizing CCS will increase from 21-91%. Marketing and consulting company Pike Research estimates 50-70% increased cost of energy, stating that "*This cost will be underwritten by governments in the next decade and then passed on to ratepayers over the longer term*." Most biomass combustion facilities already operate at an average of 25% efficiency. Adding CCS will make them even more inefficient, and the additional demand for energy will result in even more deforestation, land use change and air pollution. In the case of ethanol refineries, as we have seen above, the net energy balance for corn ethanol in particular is already either poor or negative – adding additional energy demands for CCS (even if CO2 capture from fermentation is simpler than from smokestacks) will make the energy and thus the greenhouse gas balance of ethanol even worse.

The current status of BECCS

The most up to date list of BECCS projects is provided by Biorecro's "Global Status of BECCS report", which lists projects at different stages of conception and/or development and at different scales through late 2010 – including projects which had already been cancelled.[lvi] There are 16 BECCS projects on the map, although they do not include coal power station plans with CCS and various levels of biomass co-firing proposed. Of the projects listed, ten involved capture of CO2 from ethanol fermentation, three from pulp mills, one from biomass gasification, one from biogas production and one had been cancelled before the source of CO2 had been identified. Three of the projects listed involved CO2 use for enhanced oil recovery, one involved CO2 use in a greenhouse (which would not be classed as CCS by the IPPC), the others were looking at underground carbon sequestration in saline aquifers. Of the 16 projects, one small demonstration project (involving CO2 capture from ethanol fermentation for enhanced oil recovery) had been completed and was no longer running, four projects had been cancelled and just one project – also involving CO2 from ethanol fermentation for enhanced oil recovery – was operational, in Kansas, U.S. The largest of the listed BECCS projects involves CO2 capture from an ethanol refinery run by Archer Daniels Midland at Decatur, Illinois, U.S. This is expected to be fully operational in 2013, following years of delays and additional public expense. Some CO2 from the project has already been injected into the Mt Simon sandstone formation in advance of full operations commencing.

However, the role of CO2 capture for enhanced oil recovery (EOR) in CCS in general, especially in North America becomes clearer when looking at the Global CCS Institute's updates on all large-scale CCS projects in 2011 and 2012[lvii]. The Decatur ethanol project is the only BECCS project included on that list although several of the coal power station projects for which CCS is proposed in Europe would involve significant levels of biomass co-firing.

The region with the largest number of large-scale CCS projects is North America, with 11 projects either operational or under construction and 21 planned. 26 of those involve EOR. In Europe, there are two active CCS projects and 19 more planned of which four are to involve EOR and another one might do so. China has no active CCS projects but is planning 10, four of which are to definitely involve EOR and two which might do so. In the Middle East, three CCS projects are planned, all of them involving EOR. EOR does not so far play a role in CCS developments in Australia and New Zealand (one active and five planned projects), Africa (one active project) and Korea (two planned projects).

Four planned CCS projects have been put forward in 2012 so far and all of those involve EOR.

The overall trend towards increasingly linking CCS to Enhanced Oil Recovery is likely to be reflected in future BECCS developments, too, although those still play a small role in CCS overall.

In Europe in particular, several proposals for CCS would involve coal and biomass cofiring and "CCS ready" design, though none are operational and funding uncertainties loom. Those developments are discussed in detail below.

In spite of the limited experience with BECCS facilities, much hype is associated with their supposed "negative emissions", and it is possible that BECCS could be advanced for climate geoengineering, and also to provide the oil industry with cheap CO2 from ethanol refining and possibly in future second-generation biodiesel production (Fischer-Tropsch gasification).

Since capturing CO2 (and separating it from other emissions) adds particularly to high costs, being able to capture from nearly pure CO2 streams is a key advantage. The dedicated BECCS company Biorecro states:

> "*The ethanol industry is seen as another [in addition to chemical pulp production facilities] promising source for BECCS. The emissions in ethanol plants arise from fermentation of biomass such as sugar cane or corn. Fermentation results in a pure stream of CO2, which significantly reduces the cost for applying CCS. Plants are typically emitting 50 000 to 300 000 tonnes annually, with a few emitting more than 1 000 000 tonnes per year*".[lviii]

BECCS for getting more oil out of ground - Enhanced Oil Recovery

CCS, especially in North America, relies heavily on the profitability of using captured CO2.

"Enhanced Oil Recovery" (EOR) –i.e. forcing more oil out of existing depleted wells with EOR (CO2 flooding) has been used since 1972, i.e. long before CCS was proposed. According to the US Department of Energy there are 114 active commercial CO2 injection projects injecting over 2 billion cubic feet of CO2 into oil wells and resulting in extraction of about 280,000 BOPD (barrels of oil per day.[lix] This compares with total US oil production of around 5.4 million barrels per day in 2009[lx] - a figure which would decline steeply in coming years without increased use of EOR.

While the first ever EOR project used CO2 separated from natural gas processing, so far, most of the CO2 used for EOR has come from natural reservoirs. However, the high cost of transporting and injecting CO2 from the limited number of such reservoirs has so far restricted the use of EOR. Capturing 'anthropogenic CO2' is thus of great interest to the oil industry, given that it would allow for CO2 being captured more locations (thus keeping transport costs down) as well as offering the prospect of that CO2 being available at low costs thanks to government incentives for CCS.

How EOR increases oil recovery:

Oil recovery depends on pressure. When a new oil field is first drilled, underground pressure in the oil reservoir forces oil to the surface. During this early stage, net energy gains from oil recovery are greatest. Once 5-15% of the oil in a reservoir have been exploited, underground pressure drops to make this 'primary recovery' impossible. Once this happens, water is injected into the reservoir to create the necessary pressure and pumps may be used to recover the oil– a process which requires significant energy. This 'secondary recovery' stage works until around 35-45% of the reservoir is depleted. At that stage, pumping oil from the reservoirs becomes reliant on enhanced oil recovery (EOR). There are different EOR methods: Energy intensive injection of steam, in-situ burning of some of the oil in the reservoir to heat the surrounding oil, injection of detergents, microbial treatments (not widely used), and injection of pure CO2. CO2 injections reduce the viscosity of oil and allow it to flow more freely. If oil companies can obtain cheap sources of pure CO2 then CO2 flooding becomes a favorite approach. For the purpose of this report, we will refer to EOR as being synonymous with CO2 flooding. EOR currently allows a further 5-15% of oil in a reservoir to the exploited, which is equivalent to all 'primary', i.e. initial easy recovery and thus highly significant for overall oil production – especially in regions such as the US where oil reservoirs are too depleted to allow for easier recovery methods. The US Department of Energy and others are researching ways of further increasing the proportion of oil that can be recovered with CO2 flooding, for example through nanoparticle stabilization of foams and gels.

The cheapest supplies of anthropogenic CO2 can be obtained from capturing almost pure CO2 streams for example from ethanol refineries. Carbon capture from power stations provides the largest potential source of CO2 but, as we have seen elsewhere in the report, would depend on higher subsidies or CO2 prices. According to the US Department of Energy Office of Petroleum Reserves,

> *"CO2 EOR can provide a significant market for "EOR-ready CO2", from industrial sources, including unconventional fuels projects such as shale oil, oil sands, and coal-to-liquids. The potential market is about 380 trillion cubic feet (Tcf,) or about 20 billion metric tons of CO2. Future oil prices and CO2 cost will determine how much of this market may be economically captured."* [lxi]

Carbon capture for EOR is thus being driven very much by the quest to exploit more oil from partially depleted reservoirs which requires large continuous stream of cheap CO2. Another potential market for such CO2 streams is coal bed methane extraction with CO2, which is being explored.

At least 80% of BECCS projects in the United States (including those in the planning stages) involve capturing CO2 from ethanol refineries and using it to extract more oil. Increased oil production combined with subsidies make this carbon capture from ethanol fermentation for EOR viable.

EOR, and specifically BECCS application for EOR are promoted in the U.S. by the Midwest Governors Association, for example, as the most "economically viable" strategy for CCS in the near term[lxii] (again, co-firing coal and biomass with CCS is considered to have more potential in the longer run.) The U.S. National Enhanced Oil Recovery Initiative a project of the "Center for Climate and Energy Solutions (formerly Pew Center for Climate Change) was established in July 2011 with supporting statements from members of Congress. The initiative is promoting tax credit and other policy supports for EOR, claiming as much as 60 billion barrels of oil (compared to 25 billion barrels exploited form all US oil reserves to date) could be accessed from US oil deposits using EOR to "*enhance US energy security, promote job and economic growth and reduce CO2 emissions*." In particular they promote CO2 capture from agricultural processes including ethanol production, fertilizer production and co-gasification of coal with biomass.[lxiii]

In order for EOR to work, a significant proportion of the injected CO2 has to mix with the oil and will thus be pumped up again through oil production wells. If some of the CO2 bypasses the oil then it can permeate directly to the production wells and thus leave the reservoir unmixed[lxiv]. CO2 is then separated out again from the fluids and gases recovered and reinjected – an energy and carbon intensive process. Between 30 and 70% of the injected CO2 will be returned through production wells. In theory, all of it would be reinjected and then remain permanently in the oil reservoir. In reality, CO2 can escape into atmosphere during various parts of the process, such as leakage during transport, losses during venting for maintenance or unplanned, fugitive emissions from CO2 returned through production wells as well as potential leakage. According to a report by the Bureau of Economic Geology and the Gulf Coast Carbon Centre, CO2 losses from EOR will exceed those from other types of CCS[lxv]. Just how large the losses are is highly uncertain.

It is difficult to see how CO2 capture from ethanol refineries or other bioenergy pathways for EOR can be credibly considered "carbon negative". EOR facilitates large-scale recovery (and thus burning) of fossil fuels which would otherwise remain under the ground. Furthermore, extracting oil through EOR is highly energy intensive at different stages, involving CO2 capture, compression, transport, injection, separating CO2 from oil and gases, compressing and injecting it again.

Those are in addition to emissions linked to bioenergy: from the growth and harvest of biomass (including soil disturbance, fertilizer use, land use change etc), added to which are emissions from conversion, such as ethanol refining and power station emissions. Finally, if part of the CO2 used for EOR escapes or is vented, the overall carbon balance becomes poorer still.

Nonetheless, such highly carbon intensive processes are being classed as BECCS. Biorecro, for example, describes the first BECCS project, the Russell project in Kansas, which captured CO2 from an ethanol refinery for the purpose of using it to enhance oil recovery from depleted oil well. They state that the project was considered a failure for having weak results in oil recovery, but nonetheless:

> "*Though, as often is the case in research, the project delivered a truly ground breaking side result. The Russell project was the first small scale demonstration of BECCS, even though by serendipity, or in other words by enlightened accident. To our knowledge, the project delivered the very first permanent negative emission of CO2 with BECCS.*"

The "CCS ready" myth – an excuse to build more coal and coal+biomass power stations

For the coal industry, CCS may be the "best hope" for a future, given growing pressures to address C emissions and the destruction caused by mining, including mountaintop removal. The myth of "clean coal" has long been touted by the industry as a pathway to a viable future for the industry, should mandates to reduce CO2 emissions come about. Expressing frustrations in a recent interview, Michael Liebreich, chief executive of Bloomberg New Energy Finance, commented:

> "*It has been clear for years that if the world's industrial and power generation sectors are not to see a large part of their asset base rendered obsolete, they need carbon capture and storage to work. But not one large-scale, end-to-end project has yet been built, and the technologies still have to prove their cost-effectiveness.*"[lxvi]

Promises of future CCS capability have been used as rationale for construction of new "CCS-ready" coal and biomass burning facilities. In different countries, new coal power stations have obtained planning consent because of promises regarding potential future (and then usually only partial) carbon capture, combined with the promises of co-firing large amounts of biomass falsely classed as 'carbon neutral'. One example of such allegedly 'capture ready' power stations (which will open without any actual carbon capture at all) is the 1.6 GW Eemscentrale coal-biomass power station currently under construction by RWE subsidiary Essent, despite legal challenges by NGOs including Greenpeace.

Promises of future partial carbon capture combined with biomass co-firing[6] are also being used to legitimize the extension and expansion of existing coal power stations.

The EU's biggest coal power station is the Belchatów Power Station in Poland, operated by Polska Grupa Energetyczna SA's (PGE), with a maximum capacity of 5.35 GW. In 2008, CO2 emissions from the power station were over 30 million tonnes a year and expected to rise by 20% by 2012[lxvii]. Those emissions exceed the highly generous and recently increased free emissions allowances allocated to the operators under the EU Emissions Trading Scheme. Under pressure to be seen to reduce CO2 emissions, the operators, in 2008, signed a contract to retrofit one 250 MW unit to capture just 0.1 million tonnes of CO2 a year. For this, the company received 180 million Euros from the European Commission's European Energy Program for Recovery[lxviii]. A new 850 MW unit of the same power station is currently underway, with the promise that it will be capture-ready, with any actual capture (of up to 1.85 million tonnes a year) dependent on whether the company wins a much larger EU CCS grant. PGE has combined CCS promises and (minor) investments with investments in biomass co-firing in order avoid exceeding their CO2 allowances. All bioenergy is classed as carbon neutral under the EU Emissions Trading Scheme. Here is how Belchatów Power Station's role in biomass markets is described in an announcement for a forthcoming industry conference:

> "*The future of biomass – at least large scale, utility co-firing – is in jeopardy [from proposed subsidy cuts for co-firing in Poland] . All the more reason to go to Belchatów, the site of the largest coal-fired power plant in Poland, to learn from Polish experts about how they plan to burn the forests and fields to create heat and power from plants [sic].* "[lxix]

In the UK, too, coal companies are combining plans and claims for new 'capture-ready' coal power stations or units with biomass co-firing plans. "Carbon reduction" plans by Drax, operators of the country's largest coal power station, also involve a combination of large-scale biomass burning with CCS investments. Drax, who have already been burning more biomass than any other UK power station, have announced plans to convert initially half of their 4 GW[lxx]. This would mean burning pellets made from around 20 million tonnes of imported wood annually, twice as much as all the wood produced by the UK every year. At the same time, Drax is bidding for public funding to build a new, additional 426 MW unit "*with the potential to co-fire sustainable biomass and be fully equipped with CCS technology from the outset*"[lxxi].

A recent round of funding applications for EU's New Entrants Reserve for CCS funding includes several biomass cofiring facility proposals, including those listed above. Dedicated biomass combustion facilities with CCS are not considered likely in the near term – in part due to scale issues, but also because the most viable technology for capture would be from IGCC processes. Biomass IGCC currently is unproven.

The coal industry worldwide, having deeply invested in opposing climate change legislation, at the same time, argues for supports for CCS as well as for biomass co-firing.[lxxii] Both are their "lifeline" to a future, should limits on carbon emissions be put in place – and in Europe, a way of avoiding additional costs from exceeding their carbon emissions allowances (low as those are

[6] The term co-firing is being used here in the context of any power station which burns biomass as well as coal. It would thus include the full conversion of any individual unit(s) of a coal power station to biomass provided coal is still burnt in other units.

given the collapse of carbon prices). According to Sierra Club anti-coal campaign activist Bruce Nilles,

> *"CCS has been used as an excuse to delay action on regulating our existing fleet of coal-fired power plants. They've been talking about it for eight to 10 years, and we're no closer now than we were then to breaking ground on these demonstration projects.*[lxxiii]*"*

The recent funding of Shell's "QUEST" project for using CCS in association with tar sands extraction is another example of the role CCS plays in enabling extremely destructive practices, in this case, tar sands extraction.[lxxiv] BECCS is expected to serve as an "early mover" that will facilitate the technology development and ultimately allow these dirty industries to be perpetuated. The use of ethanol fermentation CO2 for EOR currently adds irony to insult and makes claims by BECCS proponents about 'carbon negative' technologies and reducing atmospheric CO2 levels appear ludicrous at best.

Investments in and subsidies for CCS in general:

Supports for BECCS come from two separate avenues- support for CCS which may go to fossil or bio energy projects or combinations of both (i.e. coal and biomass co-firing), and supports for bioenergy which generally derive from subsidies and mandates for renewable energy. Very significant investments have been directed to both and we review these briefly below:

At their 2008 meeting, the G8 announced their goal to launch 20 large-scale CCS demonstration projects by 2010 with "broad deployment" of the technology by 2020. Among those advocating for CCS are some international entities, including the "Carbon Sequestration Leadership Forum," comprised of ministerial level members from 24 countries and the EU Commission.[lxxv] The Clean Energy Ministerial "Carbon Capture, Use and Storage Working Group, (comprised of the governments of Australia, UK, UAE, Canada, the US and Norway along with industry representatives including Sasol, Shell and the World Coal Association) offered recommendations on CCS, which were endorsed by the Ministerial in 2011.[lxxvi] Among those recommendations is the suggestion to promote ratification of amendments made to the London Protocol and OSPAR Convention intended to enhance transboundary transport of CO2 across marine boundaries for access to offshore storage. The U.S. Obama administration announced an Interagency Task Force on CCS. [lxxvii] Already U.S. CCS projects attract tax credit supports, but a bill currently in consideration would allow companies to reserve those credits in advance of construction.[lxxviii]

Worldwide, governments have pledged on the order of $25 billion for the support of CCS projects[lxxix].

Despite high levels of supports, several advanced CCS projects have ben withdrawn due to costs – especially ones not involving EOR. Withdrawn projects include the FutureGen project in Illinois, a proposed IGCC coal power station from which CO2 was to have been captured and stored without EOR. Ten energy companies had participated and the federal government had approved $1 billion in August 2010.

American Electric Power recently backed out of a pilot capture facility alongside its' 1300 MW Mountaineer coal plant in West Virginia, having already spent $100 million on construction. The CO2 was to have been injected into sandstone formations. According to the company, the federal government had been funding half of the project cost up to $334 million, but this was not enough for them to continue[lxxx].

North Dakota's Basin Electric Power Cooperative dropped plans to retrofit for CCS despite a $100 mil federal grant.

The Decatur ADM ethanol refinery project described above – which is nearing completion, has received $141 million in stimulus funding from DOE through the Recovery and Reinvestment Act of 2009, and another $66.5 million in private sector cost-sharing[lxxxi]. The project cost is estimated to be around one quarter of a project involving CO2 capture from a power station, illustrating the economic advantages of capturing CO2 from ethanol fermentation rather than smokestacks.

The Port Arthur, Texas "Air Products and Chemicals" facility is expected to capture CO2 from steam-methane reformers in a facility that produces hydrogen fuels. The CO2 will be used for EOR. The total cost for this project is estimated at $430 million of which 284 million have so far been granted by the federal government. Millions of dollars in government subsidies have thus been granted to support development of CCS across North America, with many projects cancelled and rather little to show.

Nonetheless, "Clean Coal" thanks to CCS has become common parlance, and is widely publicly accepted as feasible. Ongoing investment continues and governments and industries proclaim their supports. The US Department of Energy's National Energy Technology Laboratory houses a "Carbon Storage Program" which supports core research and development, infrastructure development, and global collaborations. The goal is to provide a pathway to demonstration and commercialization of CCS. Seven Regional Carbon Sequestration Projects have been established across the United States - as public/private partnerships to map and develop underground carbon storage capacity. The American Recovery and Reinvestment Act of 2009, granted funds to establish seven CCS training centers and 10 geological site characterization projects throughout the U.S.[lxxxii] The "Schwarzenegger clause", mandating that large electricity generation plants limit their CO2 emissions, largely be achieved through applying CCS, was initiated in California, and later adopted by the states of Maine and Washington and copied by the EU Parliament Environment Committee.

Given huge uncertainties regarding the reliability and risks of underground storage of CO2, much debate and concern has focused on the issue of managing liability. Recommendations of the Obama administration's Interagency Task Force included consideration of various options, including limiting claims or transferring responsibility to the federal government.

The EU's official target is to reduce CO2 emissions by 20% by 2020 and by 80% by 2050 relative to 1990 levels. CCS is considered a central strategy for achieving these reductions. A CCS Directive was adopted, and plans for implementation as well as funding allocated by the European Commission and several member states. Project development has been slow however, due to the high cost of CCS and companies showing reluctance to invest in it given the low price of carbon allowances under the EU Emissions Trading Scheme. Furthermore, as the 2011 report by the Global CCS Institute stresses, North America has the most advanced market in CO2 for Enhanced Oil Recovery at present, far more so than the EU.

Many European projects so far have not meet deadlines and experienced serious cost overruns.
The UK government has been particularly strong in promoting CCS and has more large-scale projects in planning than any other EU country (six). As of April 2011, the publicly funded Engineering and Physical Science Research Council had spent over £24 million (more than $39 million) on CCS research[lxxxiii]. The government's CCS Commercialization Program opened a new funding round for $1 billion ($1.6 billion) of direct funding for commercial CCS projects in April 2012. Project selection has not yet been announced. Additional CCS 'innovation' funding of £20 million ($32 million) has also been announced[lxxxiv]. A previous funding round for £1 billion collapsed after nine proposed projects were withdrawn due to high costs. Current entrants to the funding competition include Drax's proposed new coal and biomass power station unit discussed above.

Public opposition to carbon sequestration especially onshore, has led several countries to push for amending the CCS directive. Germany has largely rejected CCS due to concerns about safety which spurred citizen protests. The German state of Schleswig-Holstein and Netherlands experienced similar resistance at least to onshore storage. Many EU CCS schemes are expected to depend in part on multi-country collaboration to construct pipeline infrastructure. There are concerns that this may be compromised by popular opposition.[lxxxv] Furthermore, European

Commission Funding for CCS projects through the NER300 fund was recently slashed by £800 million ($1.29 billion) as a result of the collapsing price of carbon on the EU ETS to which that fund is linked.[lxxxvi]

Outside the EU, Norway, with access to offshore storage sites, has been not only a European, but a global leader in developing CCS, with two operational large-scale projects, both of them led by Statoil. One of them (Sleipner) has been running since 1996. A new Carbon Dioxide Test Centre has just been opened at Mongstad. The viability of the Sleipner project in particular has been attributed to Norway's carbon tax, however the Mongstad project, owned mainly by the government through a state-run company, attracted $450 million of government funds in 2010 and a further $266 in 2011.[lxxxvii] It opened in 2012 after years of delay, with costs ten times higher than originally forecast.[lxxxviii]

China, heavily dependent on coal, is increasingly investing in CCS, including for Enhanced Oil Recovery. Some large utilities in the country are developing technology which they aim to sell to other countries. Duke Energy in the U.S. has signed a Memorandum of Understanding with the Chinese utility, Shenhua.[lxxxix]

Canadian governments have committed around $3.5 billion to CCS, largely for projects in Alberta, a state particularly dependent on oil (tar sands) and gas production. Interestingly, Alberta passed a "CCS Act" intended to address issues of liability and "pore space ownership", which they granted to the state.[xc] The Canadian federal government and the state government of Saskatchewan recently funded a BECCS project to the tune of $14.5 million. This involves capturing CO2 from the Husky ethanol plant for enhanced oil recovery. Another recent CCS project, Shell Oil's QUEST project, would capture CO2 from a tar sands extraction oil "upgrader".[xci] The "Integrated CO2 Network", a coalition of coal, tar sands, pipeline and other energy industries, advocates for CCS at provincial and federal levels.[xcii]

At the recent UNFCCC climate conference in Cancun, it was agreed that CCS (including CO2 capture for enhanced oil recovery) would be potentially eligible for inclusion into the Clean Development Mechanism (CDM), i.e. the main UNFCCC-administered carbon trading scheme. Carbon Trade Watch states:

> "*The Cancun decision is not the end of the story of CCS in CDM. Implementing the agreement requires that a series of issues are 'resolved in a satisfactory manner.' The decision catalogues a series of pitfalls, including the risk that CO2 storage is not permanent and could leak from underground geological formations. Other environmental and public health risks, and legal liabilities in the case of leaks or 'damage to the environment, property or public health' remain to be addressed. The text of the decision also claims that projects will need to make 'adequate provision for restoration of damaged ecosystems and full compensation for affected communities in the event of a release of carbon dioxide.' The CDM contains no mechanism to enforce such provisions, and the nature of the scheme (which is primarily a means for subsidising polluting industries) makes it unlikely that such provisions will emerge."*[xciii]

Yet, as discussed elsewhere in this report, the collapse of carbon prices means that whether or not CCS will be included in the CDM will likely be of little practical consequence in the near future.

Support mechanisms for large-scale bioenergy

Investment in and public supports for bioenergy come from a wide variety of government mandates and subsidies intended to support renewable energy. These are reviewed elsewhere, so we refer readers to those sources and provide only cursory review here.[xciv] Public support for biofuels in Europe and North America has been increasingly shifting from direct subsidies (including tax breaks or reductions) towards mandates. However, mandates themselves are being regarded as a subsidy, for example by the Global Subsidies Initiative and the International Energy Authority because they work by driving up market prices and artificially improving the competitiveness of biofuels and thus allowing producers to raise additional capital in financial markets. The International Energy Authority estimates that global subsidies for biofuels, including indirect ones such as mandates, amounted to $22 billion in 2010 and may reach a cumulative $1.4 trillion between 2011 and 2035[xcv]. Key support measures include the 10% effective biofuel target for transport in the EU's Renewable Energy Directive, the EU's Fuel Quality Directive, the US Renewable Fuel Standard and the Canadian Renewable Fuel Standard.

Public sector support for biomass for electricity and heat primarily takes the form of direct subsidies (whether through taxation or market based systems) for achieving more generic renewable energy standards. In the Netherlands, the government has announced plans to make co-firing of biomass mandatory for coal power stations

In the U.S. supports for biomass projects are provided by a production tax credit and various other tax incentives as well as state renewable energy portfolios which mandate usage and provide credits. Supports are provided through provisions in the Recovery and Reinvestment Act, the Farm Bill, and numerous others.[xcvi] In the EU the Renewable Energy Directive sets and overall renewable energy target of 20% by 2020 (as well as the 10% renewable energy for transport target, a biofuel mandate in all but name). Member states can decide which measures and priorities they wish to adopt for achieving that overall target (as well as interim ones). According to the Renewable Energy Action Plans submitted by member states to the European commission in 2010, 54.5% of the overall 20% target is to be met from bioenergy – including biofuels but primarily biomass for heat and electricity. This suggests that bioenergy is likely to attract the greatest share of subsidies, too.[xcvii] In fact, subsidy rules and industry plans in several member states indicate that the 54.5% percentage figure may be a gross underestimate.[xcviii] No global assessment of subsidies for biomass has been published as yet, unlike those undertaken for biofuel subsidies; however it is clear that biomass subsidies are rapidly increasing.

The International Energy Agency projects that the bulk of growth in renewable energy worldwide will be filled by bioenergy and wind. This would include an estimated 4 fold expansion in bioenergy through 2035.[xcix] With ongoing subsidies and policy supports, bioenergy in general is likely to expand dramatically, and hence potential opportunities for BECCS.

What will determine the future of BECCS? Concluding thoughts

Capturing carbon from power stations and injecting it into geological formations involves such high costs – both in terms of finance and additional energy required – that the prospect of large-scale application appears remote. Carbon capture from biomass power stations for geological carbon sequestration appears particularly unrealistic. Biomass is far less energy dense than coal, hence the additional energy required for carbon capture would translate into significantly greater tonnage and thus transport and storage as well as other costs. Proponents suggest that industry investments could pay for themselves if a carbon price was in force and reached a minimum level. Estimates for how high that minimum level would need to be vary considerably according to different assumptions about future CCS costs, specific CCS technologies chosen, etc. According to a 2011 paper published by the World Bank, a carbon price of $15-$50 per tonne of CO2 could allow 7-26 CCS projects in developing countries by 2020, most of which would likely be in natural gas processing (i.e. involve capture of nearly pure CO2 streams, not the more difficult and expensive capture of CO2 from power station flue gases).[c]

Higher figures have been proposed for BECCS involving carbon capture from biomass power stations. According to a Working Paper published by the UK-based Tyndall Centre in 2010[ci]:

> *"A biomass gasification combined cycle plant with CO2 capture, bio-power could be competitive with coal or gas (without capture) at a carbon price of around $100/tC and cheaper at around $160/tC (Rhodes and Keith 2005; Azar, Lindgren et al. 2006; Keith, Ha-Duong et al. 2006). With reference to the EU ETS (Emissions Trading Scheme), the IEA GHG study estimates an ETS certificate price of €48-55/tCO2 (€176-202/tC) would be necessary for a biomass co-fired plant with capture to be competitive with an*

equivalent plant without capture and €65-76/tCO2 (€238-278/tC) for dedicated biomass plant with capture (IEAGHG 2009). At the time of writing, the current EU ETS price is only €15/tCO2."

Since the report was published, the carbon price under the EU Emissions Trading Scheme has collapsed to just over 2 Euros ($2.66) per tonne of CO2. The EU Emissions Trading Scheme accounts for 90% of carbon trading worldwide and prospects for a US-wide carbon price receded in 2010 when Government proposals were withdrawn due to political opposition.

Meaningful support for BECCS from carbon markets thus appear unlikely in the near future, regardless of whether carbon trading methodologies relevant to BECCS are approved. Projects thus remain reliant on public subsidies and the levels required are such that only a limited number of demonstration projects appear likely under current circumstances.

In theory, a future potential push for geoengineering could channel substantial funds into BECCS than are currently available. Yet given the reluctance on the part of most policy makers to commit to meaningful measures and funding to reduce greenhouse gas emissions, the prospect of an extremely costly and challenging global BECCS program still appears remote – unless there was an economic return, i.e. if BECCS happened to meet real economic interests.

As we have seen above, there are indeed real economic interests in CCS including BECCS – and those lie primarily in enhanced oil recovery (EOR). If optimistic forecasts by the US Department of Energy and others are proven true and CO2 flooding can indeed extend oil production from partially depleted oil fields for several more decades then different types of CCS could come to play a significant role in 'energy security' policies. Capture of nearly pure CO2 from various processes including ethanol fermentation, possible at around a quarter of the cost of capturing carbon from power plant flue gases, is already of significant interest in the US Midwest, the region with the most experience in EOR use.

In this context, it is worth considering potential parallels with US and EU biofuel policies. According to agricultural scientists and author of a biofuels report for the European Commission David Laborde:

"*The truth is that policy makers inside and outside Europe are doing biofuels for other reasons than environmental ones. It's a new and easy way to give subsidies to farmers, and it's also linked to industrial lobbies that produce these biodiesels and also what they will call energy security. They want to diversify the energy supply, and keep their foreign currencies instead of buying oil from the Middle East. They prefer to keep it for something even it is not efficient or even green.*"[cii]

Similarly, CCS and BECCS (involving for example ethanol fermentation and possibly in future Fischer-Tropsch biodiesel) could attract future government supports in the name of 'reducing atmospheric CO2' and limiting climate change but with a primary economic motive of enhancing oil production. Given that BECCS is being linked to the discourse on geoengineering as well as to endeavors to extend oil production from regions such as the US and the North Sea closer scrutiny and attention to those developments appears vital.

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