Bioenergy with CO$_2$ Capture and Geologic Storage

Joint Global Change Research Institute (JGCRI)

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Thanks to Rich Richels for the invitation to talk today.

Thanks to EPRI for research support that has been essential to the development of our program in particular and integrated assessment in general.
Why are we interested in bioenergy with CCS?
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ENERGY with NEGATIVE emissions are a major feature of the new low-climate-forcing scenarios.

Bioenergy and CCS

- Both bioenergy and CCS are technologies that exist today.
  - The combination of both is also being explored.
- CCS is not deployed at scale.
- Deployment of each depends on the institutional environment.
  - Carbon price
  - Institutional framework that facilitates a business model for deployment.
CO$_2$ Capture and Storage
CO₂ Capture and Geologic Storage

- CO₂ capture and geologic storage (CCS).
  - Isolation of CO₂ from the exhaust gas stream.
  - Transport to an injection site.
  - Injection into a deep reservoir.
Potential CO$_2$ Storage Reservoirs

- Deep saline formations
- Depleted oil and gas fields
- CO$_2$ driven enhanced oil recovery
- Deep unminable coal seams
- CO$_2$ driven enhanced coal bed methane recovery
- Deep saline filled basalt formations and other formations.
CCS and Cumulative Emissions

Cumulative global CO₂ capture and maximum potential global storage capacity.

Ratio of Cumulative Emissions 1990 to 2095 to Maximum
Potential Geologic Storage Capacity by Region

- Cumulative emissions from MiniCAM CCSP SAP 2.1a
- Potential geologic storage from Dooley et al. (2004) and subsequent updates.
Present State of CCS Technology

- CCS systems have been used with coal and gas power generation systems since the 1970’s. (But not at scale.)
- 3,900 miles of CO$_2$ transport systems.
- CO$_2$ has been used with EOR for 35 years.
- CCS can potentially be applied to a wide range of industrial systems ranging from fossil fuel power generation (coal, gas and oil), cement kilns, refineries, chemical manufacture, etc.
- There are 4 end-to-end commercial systems in place today.
Four Sites with CO₂ Capture-to-Storage-to-MMV

**Weyburn**
- CO₂ storage began in 2000
- 2 MtCO₂/year being injected via approximately 85 injection wells over a 40 km² area
- Projected 30 MtCO₂ lifetime storage

**Sleipner**
- Started injection in 1996
- More than 10 MtCO₂ have been injected via 1 injection well with a plume approximately 5 km² with
- Projected 20 MtCO₂ lifetime storage
- 150 km of the Norwegian coast

**Snøhvit**
- CO₂ storage began April 2008
- 0.7 MtCO₂/year injected into DSF
- 23 MtCO₂ injected over 30 years
- 150 km of the Norwegian coast

**In Salah**
- CO₂ storage began in 2004
- Three 1.5 km horizontal CO₂ injector wells are used to inject 1.2 MtCO₂/year
- Projected 17 MtCO₂ lifetime storage
Institutional arrangement for CCS

- CCS is a CO₂ emissions mitigation technology.
  - It raises capital costs by 50%.
  - It takes a substantial fraction of a power plant’s power production to run.

- There is no business model for deploying CCS without either a significant positive price on carbon, or a regulatory requirement.
  - New plants would be cheapest.
  - Retrofits are possible at extra cost.

- For most of the world’s carbon emissions, the price of carbon is zero.

- The regulatory model that governs CCS for most of the world’s carbon emissions is still under development.
  - Exceptions exist, e.g. Norway
  - Significant progress in many parts of the OECD in defining CCS rules.
Bioenergy
Bioenergy

- Bioenergy is derived from plant material—a very young hydrocarbon.
  - Bioenergy derives its carbon from the air.
  - If the plant material is oxidized, then there is no NET change in carbon in the atmosphere. Though there are indirect emissions to be discussed shortly.

- Bioenergy is generally considered a renewable energy form.

- Bioenergy was the dominant preindustrial energy form.
  - It was supplanted by higher energy density forms, e.g. fossil fuels and nuclear power.

- It is still used today, e.g. the pulp and paper industry but also traditional bioenergy use in developing regions.

- It is a major source of liquid fuel in Brazil today.
There is more bioenergy used today than when it was the dominant energy form.

Bioenergy is not cheap and without a subsidy, it does not compete effectively with energy forms such as fossil fuels.

The relative attractiveness of bioenergy use could be dramatically different if under a carbon price regime.
Indirect Land-use Change Emissions (ILUC)

- Bioenergy production requires land, a limited resource.
- Any number of papers have identified the problem of indirect land-use emissions (ILUC).
  - Fargione et al. (2008); Searchinger et al. (2008); Edmonds et al. (2003); and Wise et al. (2009).
- ILUC occurs when a major new demand for land is introduced in the face of a fixed land resource.
  - Increased demand for land for purpose-grown bioenergy crops results in higher rental rates for crops and potentially expansion into “unmanaged” lands.
- Crutzen et al. (2008) also raised the question of expanded non-CO₂ GHG emissions, most notably as a consequence of N₂O from fertilizer applications.
ILUC and Limiting Atmospheric CO₂ Concentrations

- There are more than 2000 billion tons of carbon in terrestrial ecosystems including soils and above ground plants.

- Limiting atmospheric CO₂ concentrations to low levels, e.g. 450 or 550 ppm implies limits for total anthropogenic carbon emissions.
  - 450 ppm ⇒ ~500 PgC (2005 to 2100)
  - 550 ppm ⇒ ~800 PgC (2005 to 2100)
  - Note that these concentrations are NOT CO₂-equivalent

- The extent of ILUC depends on the policy environment.
BioCCS
Carbon Pricing

- CCS only deploys in the presence of either a carbon price of a regulatory requirement.
- Purpose-grown bioenergy production is enhanced by the presence of a carbon price.

- The BioCCS combination produces a negative emission
  - Need for a mechanism that allows for payment for negative emission.
  - Note that negative global emission scenarios not only produce no revenue, but are a net public expenditure.
Carbon Pricing in for Two Contrasting Scenarios

1. Immediate, universal participation by all regions to limit CO$_2$ concentrations in 2095.

2. Two alternative carbon pricing regimes

1. **Fossil fuel and industrial carbon tax (FFICT)**—in this regime only fossil fuel and industrial carbon emissions are valued. Bioenergy is treated as having no net carbon. Terrestrial carbon is valued at zero.

2. **Universal carbon tax (UCT)**—in this regime all carbon is valued equally regardless of either its origins or the activity that introduces it to (or removes it from) the atmosphere.
Net Land Use Change Emissions & Fossil Fuel and Industrial CO₂ Emissions

For a given CO₂ concentration limit

- In the UTC regime ILUC disappears as an issue.
- In the FFICT regime high carbon prices drive bioenergy demands and ILUC

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Land use: 450 ppm atmospheric CO$_2$

450 ppm Stabilization Scenario When ALL Carbon is Valued (UCT)

450 ppm Stabilization Scenario When Terrestrial Carbon is NOT Valued (FFICT)
Bioenergy can play many roles in climate stabilization:

- Provider of liquid fuels for transportation ( ), or
- If CO₂ capture and storage (CCS) is an available technology, bioenergy could be used in power generation with CCS ( ) and provide a means of achieving negative global CO₂ emissions.
- Bioenergy with CCS is a key technology for achieving low climate stabilization levels.
BioCCS and carbon prices

![Graph showing the fraction of bioenergy to BioCCS versus carbon price ($)tC, with different lines for 550 FFICT, 500 FFICT, 450 FFICT, UCT 550, UCT 500, and UCT 450.](image-url)
BioCCS and carbon prices

The graph illustrates the relationship between the fraction of bioenergy to BioCCS and the carbon price ($/tC). The x-axis represents the carbon price, ranging from $150 to $450, while the y-axis shows the fraction of bioenergy to BioCCS, ranging from 0% to 100%. Different lines represent different FFICT and UCT values. The graph demonstrates how the fraction of bioenergy to BioCCS increases with higher carbon prices, indicating a stronger economic incentive for bioenergy production in BioCCS.
BioCCS in electricity is a minor energy form in the first half of the century. Even in the 450 ppm case.

Total BioCCS energy use for power production in 2095: 16% of total for the 450 ppm case.
Final Thoughts

BioCCS holds the potential to deliver negative carbon emissions and energy.

While the “seeds” of BioCCS are with us now, much needs to change before the potential of this technology could be realized:

- A price on carbon (and a payment for negative emissions)
- Institutions that recognize CCS and manage risks
- Institutions that manage indirect land-use carbon emissions (ILUC).

Even with the realization of the many conditions for success, the higher cost of BioCCS—relative to CCS with fossil fuels—places it at least 15 years behind fossil fuel CCS in deployment in our scenarios.
A technical report on "The Implications of Limiting CO₂ Concentrations for Agriculture, Land Use, Land-use Change Emissions and Bioenergy” can be found on our website at:


A GTSP special report on CCS can be found at:
http://WWW.PNL.GOV/GTSP/docs/ccs_report.pdf

END