Deep Decarbonization: What Role for BECCS and Other Negative Emissions?

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Great Barrier Reef bleaching would be almost impossible without climate change.
My remarks today

• Quantifying the 2 degree challenge.
• Emissions pathways that can meet the challenge, according to the models.
• Negative emissions (BECCS) in the models.
• Reality of BECCS today.
• What is needed going forward.
Warming is determined by cumulative emissions

Human-induced warming
Temperature change relative to 1861-1880 (°C)
Cumulative anthropogenic CO₂ emissions from 1870 (GtCO₂)

CO₂ “budget” left to spend from 2016 for 2°C warming:
600 to 1,200 GtCO₂

Fossil fuel reserves:
4,000 to 7,000 GtCO₂

Warming increases linearly with cumulative CO₂ emissions

Most models want negative \( \text{CO}_2 \) emissions for 2\(^\circ\)C

Many (integrated assessment) models could not limit \textit{likely} warming to below 2\(^\circ\)C if bioenergy, CCS, and their combination (BECCS) are limited (\textit{high confidence}).” [IPCC, AR5, WGIII]
BECCS Carbon Flows

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BECCS Carbon Flows

1. Large cumulative negative emissions needed to limit warming to 2°C in many scenarios.

2. Negative emissions are deployed starting in 2030.

3. Emissions increasing since 2010; trajectory is not tracking the 2°C scenario pathway.

LCOEs for fossil fuel plants are based on capital cost estimates in the *Baseline Power Studies* of the National Energy Technology Laboratory (US Dept. of Energy). BECCS estimate by ESAG, Princeton University.
Electricity Generating Cost with CO$_2$ Emissions Price

LCOEs for fossil fuel plants are based on capital cost estimates in the Baseline Power Studies of the National Energy Technology Laboratory (US Dept. of Energy). BECCS estimate by ESAG, Princeton University.

- Levelized fuel prices for U.S. context: $3, $6, and $5 per GJ$_{HHV}$ for coal, natural gas, and biomass.
- $15/tCO_2$ cost for storage in deep saline aquifer.
- 85% plant capacity factors.
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How much commercial BECCS?

Global CO₂ emissions (Gt CO₂/year)

Approximate emission pledges (INDCs) [Intended Nationally Determined Contributions]

Net emissions (for 2°C)

Emissions from fossil fuels, industry, and net land-use change

Net negative emissions

Median model outcomes

Historical emissions

2015

Negative Emissions

BECCS construction to achieve negative emissions

Each BECCS plant:
- 1 million t/ year biomass
- 170 MW electric
- 90% carbon captured
- 30-y operating life

For comparison, globally:
- 50 GW of PV and 63 GW of wind added in 2015.

<table>
<thead>
<tr>
<th>Year</th>
<th>BECCS generating capacity, GW_e</th>
</tr>
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<tbody>
<tr>
<td>2030</td>
<td>220 plants/year 38 GW/year</td>
</tr>
<tr>
<td>2040</td>
<td>100/y 17 GW/ y</td>
</tr>
<tr>
<td>2050</td>
<td>340/y 58 GW/ y</td>
</tr>
</tbody>
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Size of BECCS-related CO$_2$ storage industry quickly exceeds size of today’s global oil industry
What if emissions don’t peak until 2030?

If emissions don’t peak until 2030...

2030 peak based on INDCs

Total required negative emissions more than doubles (for 600 GtCO₂ budget)
Biomass is a complicated energy source

• Land use competition – fuel vs. food vs. forests.
• Water availability and quality.
• Soil productivity.
• Biodiversity, and other ecosystem services.
• Proper GHG accounting, e.g., including N₂O and iLUC impacts.

• Candidate sustainable biomass energy sources:
  1. Crop residues
  2. Sustainably harvested wood and forest residues
  3. Municipal and industrial wastes
  4. Perennial plants grown on degraded/abandoned agricultural land
  5. Double crops and mixed cropping systems
Costs for new technologies start high

- **FOAK (First of a Kind)**
- **NOAK (N\textsuperscript{th} of a Kind)**

**Increases in capital cost are common as technologies are first deployed at scale**

- "Learning by doing"

Adapted from EPRI TAG

Ed Rubin (Carnegie Mellon University) at Carbon Sequestration Leadership Forum, Regina, Saskatchewan, 16 June 2015
Kemper County (Mississippi) Coal-IGCC w/CCS

Estimated Capital Cost

<table>
<thead>
<tr>
<th>Year</th>
<th>Billions of Dollars</th>
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<tbody>
<tr>
<td>2009</td>
<td>$2.01</td>
</tr>
<tr>
<td>2010</td>
<td>$2.97</td>
</tr>
<tr>
<td>2012</td>
<td>$3.44</td>
</tr>
<tr>
<td>Mar-13</td>
<td>$4.29</td>
</tr>
<tr>
<td>Jun-13</td>
<td>$4.72</td>
</tr>
<tr>
<td>Sep-13</td>
<td>$5.00</td>
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<tr>
<td>Dec-13</td>
<td>$5.04</td>
</tr>
<tr>
<td>Apr-14</td>
<td>$5.53</td>
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<tr>
<td>Oct-14</td>
<td>$6.10</td>
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<tr>
<td>Jul-16</td>
<td>$6.70</td>
</tr>
<tr>
<td>Nov-16</td>
<td>???</td>
</tr>
</tbody>
</table>

7+ years from concept to start-up

plant starts production

http://ieefa.org/kemper-power-plant-a-debacle-that-should-never-have-been-built/
CCS projects in operation

- Norway: Sleipner CCS project, 1 Million t/y CO₂ (since 1996).
- USA/Canada: Synfuels CCS via EOR at Weyburn, 3Mt/y CO₂ (since 2010).
- USA: Kemper Co., Mississippi IGCC w/CCS via EOR, 3Mt/y CO₂.
- USA: Petra Nova coal CCS retrofit in Texas via EOR, 1.4Mt/y CO₂.
- USA: CO₂ capture from SMR for EOR in Texas, 3Mt CO₂.
- Canada: Quest oil sands CCS project, 1Mt/y CO₂ stored.
- Canada: Boundary Dam coal retrofit CCS via EOR, 1Mt/y CO₂.
- Brazil: Santos Basin Oil Field CCS via EOR, 1Mt/y CO₂.
- UAE: Emirates Steel Industries CCS via EOR project (Phase 1), 0.8Mt/y CO₂.
- China: Jilin gas processing CCS via EOR demo, 0.3Mt/y CO₂.
- Japan: Tomakomai CCS Demo, 0.1Mt/y CO₂.

Developing CCS projects

- USA: Illinois ethanol-plant CCS, 1Mt/y CO₂. Construction complete.
- Japan: Mikawa coal CCS retrofit, 0.15Mt/y CO₂. In detailed design.
- China: Yanchang CCS demo, 0.45MtCO₂. Near final investment decision.
Decarbonizing Without Negative Emissions?

USA (1949 - 2015)
Decarbonizing Without Negative Emissions?

Relative Carbon Intensity of Energy Supply (tCO₂ per primary energy unit)

Years from start

USA (1949 - 2015)
FRANCE (1965 - 2013)
Decarbonizing Without Negative Emissions?

2°C scenario (2030 – 2070), assuming no negative emissions

Similar rates decarbonizing energy supply

2°C projection assumes:
Population: UN medium variant (9.7 billion in 2050; 11.2 billion in 2100)
GDP/capita: + 1.4 %/y (Global rate, 1970-2010)
Energy/GDP: - 1.6 %/yr (2x global rate, 1970-2010)
Negative Emissions Systems

Biological (agriculture, forestry, bioenergy)
• BECCS
• Soils
• Trees (afforestation/reforestation)

Chemical
• DACCS – direct air CO$_2$ capture and storage
• Accelerated weathering/mineralization of CO$_2$
• Fertilize the ocean
• Lime the ocean
450 Million Ha Abandoned Agricultural Land Globally

Perennial grasses can store C in roots/soils ➔ help restore soil productivity while removing CO$_2$ from atmosphere and providing aboveground biomass for energy.


Land-based GHG mitigation, including negative emissions options (other than BECCS)

Estimated global potential: Up to 8 Gt CO$_2$eq/year.
(400 GtCO$_2$ over 50 years)
Summing Up and Looking Ahead

• Remaining carbon budget for 2°C warming: 600 - 1200 GtCO₂.
• Negative emissions will be needed (sooner or later) to meet this budget.
• Models deploy BECCS widely and cost-effectively because they like BECCS costs.
• Will (When will) costs of sustainable BECCS reach levels assumed by the models?
• Without aggressive technology RD&D and new regulatory systems, e.g. governing biomass supply and CO₂ storage, BECCS will not be ready by 2030.
  – How should biomass supplies be provided so as to avoid negative impacts on food, water, or ecosystems?
  – Who will pay “mountain of death” technology development costs for BECCS?
  – Who will pay for assessing CO₂ storage opportunities?

• Going forward
  – First, stop digging!
  – Public–Private partnerships to support RD&D and initial commercial deployment, e.g., Mission Innovation / Breakthrough Energy Coalition
  – International knowledge and technology sharing to help reduce costs.
  – Work on other negative emissions options (in addition to BECCS), especially land-based.
  – Design and implement carbon mitigation policies that will induce and sustain commercial deployment of negative emissions options starting as early as 2030.