Can technology unlock ‘unburnable carbon’?

Dr Sara Budinis

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#unlockCCS
Sustainable Gas Institute (SGI)
Overview: Sustainable Gas Institute

- Academic-industry international collaboration **UK and Brazil**
- Established in 2014 with the vision of a **hub and spoke model**, the hub at Imperial College London and spokes overseas
- **First Spoke** - Research Centre for Gas Innovation, University of Sao Paulo since Dec 2015

- **Aim**: Examine the **environmental, economic and technological** role of natural gas in the global energy landscape

- **Research activities:**
  - Develop a unique energy systems simulation tool (**MUSE**) to analyse the energy system, and the role of technologies within it
  - Deliver **white papers** that inform the debate around the role of natural gas
‘Is there a future role for gas networks in the decarbonisation of the global energy system?’

- Should gas networks be discarded?
- What are the alternative options?
- H2 in the gas network?
The Hub Core Team

Prof Nigel Brandon
Director

Dr Adam Hawkes
Deputy Director

Prof Velisa Vesovic
Theme Lead - LNG

Prof Anna Korre
Theme Lead - EIA

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Operations Director

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Dr Sara Budinis
Research Associate

Dr Daniel Crow
Research Associate

Dr Jamie Speirs
Research Fellow

Dr Julia Sachs
Research Associate
Can technology unlock ‘unburnable carbon’?
Overview

CLIMATE CHANGE:
• From COP21 we know there is a carbon constraint
• Target: “(...) holding the increase in the global average temperature to well below 2°C above pre-industrial levels”

ENERGY SYSTEM AND TECHNOLOGY:
• Emerging literature looking at decarbonisation of the energy system
• Can we access energy resources while meeting the climate target?

UNBURNABLE CARBON:
• Technology: Carbon Capture and Storage (CCS)
• This paper quantifies its potential impact on ‘unburnable carbon’

All the reported scenarios: 2°C climate target
Methodology

1. Systematic review:
   - Academic, industrial and governmental literature
   - Methodology adapted from UK-Energy Research Centre
   - Well-defined search procedures to guarantee clarity and transparency
   - External expert advisory group appointed

2. Analysis of energy scenarios:
   - Selection of database and scenarios
   - Comparison “with CCS” vs “without CCS”

3. Primary research:
   - The Grantham Institute’s TIMES Integrated Assessment Model (TIAM-Grantham)
1. Carbon budget and ‘unburnable carbon’

2. Carbon capture and storage
   - Overview
   - Potential barriers
   - Current status

3. Potential role of CCS up to 2050

4. Can technology unlock ‘unburnable carbon’?
   - Database and scenarios
   - Potential role up to 2100
   - A key parameter: the capture rate

5. Conclusion
1. Carbon budget and ‘unburnable carbon’
Global reserves and carbon budget

FIG. 1
2. Carbon capture and storage
Carbon capture and storage: overview

CCS is a technology that aims to capture, separate, transport and store carbon dioxide (CO$_2$).

• Three capture technologies:
  • Post-combustion
  • Pre-combustion
  • Oxy-combustion

• A variety of separation technologies (absorption, adsorption, membrane, etc.)
Carbon capture and storage: An example

Post-combustion CCS for power generation

FIG. 4
Carbon capture and storage: An example

Post-combustion CCS for power generation

FIG. 4
Potential barriers to CCS

- Cost of CCS
- Geo-storage capacity
- Source-sink matching
- Supply chain and building rate
- Policy regulation and market
- Public acceptance
- Requirement for Research, Development and Demonstration (R,D&D)
Potential barriers:
1 - Cost of CCS

**Cost of avoided CO₂**

<table>
<thead>
<tr>
<th>Process Plant</th>
<th>Cost ($/tCO₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal-fired power</td>
<td>94, 100, 103-105</td>
</tr>
<tr>
<td>Gas-fired power</td>
<td>96, 100, 103-105</td>
</tr>
<tr>
<td>Iron and steel</td>
<td>96, 99, 106</td>
</tr>
<tr>
<td>Refineries</td>
<td>96, 99, 106</td>
</tr>
<tr>
<td>Pulp and paper</td>
<td>106</td>
</tr>
<tr>
<td>Cement production</td>
<td>96, 99, 106</td>
</tr>
<tr>
<td>Natural gas combined cycle</td>
<td>97-99, 102</td>
</tr>
<tr>
<td>Oxyfuel combustion</td>
<td>99, 102</td>
</tr>
<tr>
<td>Integrated Gasification Combined Cycle</td>
<td>99, 102</td>
</tr>
<tr>
<td>Chemicals +bio/synfuel</td>
<td>96, 106</td>
</tr>
</tbody>
</table>

**Capture Technology**
- Post-combustion (amine)
- Pre-combustion

**Storage**
- With CCS [99]
- With Enhanced Oil Recovery/Enhanced Gas Recovery (EOR/EGS) [100]

Maximum from literature: 160 US$/tCO₂

FIG. 14
Potential barriers: 2 - Geo-storage capacity

FIG. 9

Range from literature: 10,000 to 33,000 GtCO₂
Current state of CCS

- Canada:
  - 2012: 8 in operation, 1 total
  - 2013: 7 in operation, 1 total
  - 2014: 7 in operation, 1 total

- United States:
  - 2012: 24 in operation, 4 total
  - 2013: 20 in operation, 7 total
  - 2014: 19 in operation, 7 total

- Europe:
  - 2012: 21 in operation, 2 total
  - 2013: 15 in operation, 8 total
  - 2014: 8 in operation, 2 total

- China:
  - 2012: 11 in operation, 1 total
  - 2013: 12 in operation, 1 total
  - 2014: 12 in operation, 1 total

- Middle East:
  - 2012: 3 in operation, 1 total
  - 2013: 3 in operation, 1 total
  - 2014: 2 in operation, 1 total

- Africa:
  - 2012: 1 in operation, 1 total
  - 2013: 1 in operation, 1 total
  - 2014: 1 in operation, 1 total

- Australia & New Zealand:
  - 2012: 5 in operation, 1 total
  - 2013: 4 in operation, 1 total
  - 2014: 3 in operation, 1 total

- Global:
  - 2012: 75 in operation, 8 total
  - 2013: 65 in operation, 12 total
  - 2014: 55 in operation, 13 total

Legend:
- Black: Number of projects in operation
- Orange: Total number of large-scale projects at different life-cycle stages

FIG. 7
3. Potential role of CCS up to 2050
Potential role of CCS up to 2050

Unburnable reserves before 2050 for the 2°C scenarios with and without CCS (modified from McGlade and Ekins 2015).

**TABLE 11**

<table>
<thead>
<tr>
<th>Fossil fuel</th>
<th>Unit</th>
<th>Overall reserves</th>
<th>With CCS</th>
<th>Without CCS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Unburnable</td>
<td>Burnable</td>
</tr>
<tr>
<td>Oil</td>
<td></td>
<td>531</td>
<td>175</td>
<td>356</td>
</tr>
<tr>
<td>Gas</td>
<td>GtCO₂</td>
<td>418</td>
<td>205</td>
<td>213</td>
</tr>
<tr>
<td>Coal</td>
<td></td>
<td>2,664</td>
<td>2,185</td>
<td>480</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td><strong>3,613</strong></td>
<td><strong>2,565</strong></td>
<td><strong>1,049</strong></td>
</tr>
</tbody>
</table>
### Potential role of CCS up to 2050

Unburnable reserves before 2050 for the 2°C scenarios with and without CCS (modified from McGlade and Ekins 2015).

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</tr>
<tr>
<td>Gas</td>
<td>GtCO₂</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coal</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Impact of CCS on burnable carbon:**

- "The availability of CCS has the largest effect on cumulative production levels" ✓ ✓
- Its impact (up to 2050) is equal to 5.5% (from 23.5% to 29%) × ×
4. Can technology unlock ‘unburnable carbon’?
Database and scenarios

- IPCC Fifth Assessment Report
- EMF27
  - 18 integrated assessment models
  - Three technology scenarios
    - Full technology portfolio
    - Conventional portfolio
    - No CCS
  - Two climate change scenarios
    - 450 ppm = 2°C target
    - 550 ppm
  - Two timeframes
    - until 2050
    - until 2100
Potential role of CCS up to 2100 - 1

Fossil fuel use

450ppm

- The full technology scenario (Fulltech)
- The Conventional solutions scenario (Conv)
- The Scenario without CCS (noCCS)

FIG. ES1
Potential role of CCS up to 2100 - 2

FIG. ES2
A key parameter: the capture rate

**Capture rate:** the percentage of CO$_2$ emitted by the process that will be ultimately stored (≤90%)
5. Conclusion
Can technology unlock ‘unburnable carbon’?

**CCS underpins the future use of fossil fuels** in scenarios that limit global warming to 2°C (+32%).

Its potential role is greater in the **second half of the century**.

The **capture rate** is a crucial factor. Engineering challenge: to go **above 90%**.

**Cost** of CCS is a **short term barrier**.
Authors: Sara Budinis, Samuel Krevor, Niall Mac Dowell, Nigel Brandon and Adam Hawkes

The Expert Advisory Group (EAG), a group of independent experts who have offered valuable comments and guidance on both the scoping of the project and the final report:

• **Tim Dixon** (with contributions from Jasmin Kemper, John Davison and James Craig) – IEAGHG
• **Nick Steel** – Shell
• **Christophe McGlade** – IEA

Part of this paper has been developed in collaboration with the **IEA Greenhouse Gas R&D Programme (IEAGHG)**, who are gratefully acknowledged for their funding and intellectual contribution.

It should be noted that any **opinions stated** within this report **are the opinions of the authors only**.
Thank you for your attention

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Download the paper:
www.sustainablegasinstitute.org/technology-unlock-unburnable-carbon/

Download the summary:
www.sustainablegasinstitute.org/briefing-note-can-technology-unlock-unburnable-carbon/
Back-up slides
TABLE 4. Estimation of reserves and resources of oil, gas and coal.

<table>
<thead>
<tr>
<th>Fossil fuel</th>
<th>Gigatonnes (Gt)</th>
<th>Exajoules (EJ)</th>
<th>Carbon (GtCO₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Oil</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reserves</td>
<td>219</td>
<td>9,264</td>
<td>679</td>
</tr>
<tr>
<td>Resources</td>
<td>334</td>
<td>14,128</td>
<td>1,036</td>
</tr>
<tr>
<td><strong>Gas</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reserves</td>
<td>125</td>
<td>6,016</td>
<td>338</td>
</tr>
<tr>
<td>Resources</td>
<td>427</td>
<td>20,518</td>
<td>1,151</td>
</tr>
<tr>
<td><strong>Coal</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reserves</td>
<td>892</td>
<td>25,141</td>
<td>2,378</td>
</tr>
<tr>
<td>Resources</td>
<td>21,208</td>
<td>598,066</td>
<td>56,577</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reserves</td>
<td>1,236</td>
<td>40,421</td>
<td>3,395</td>
</tr>
<tr>
<td>Resources</td>
<td>21,969</td>
<td>632,712</td>
<td>58,764</td>
</tr>
</tbody>
</table>

Minimum [ ] Maximum [ ]
TABLE 5. Fossil fuel carbon budget for different maximum temperature rises.

<table>
<thead>
<tr>
<th>Temperature target (°C)*</th>
<th>Until 2050**</th>
<th>Until 2100**</th>
<th>Probability (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5</td>
<td>550–1,300</td>
<td>630–1,180</td>
<td>14–51</td>
</tr>
<tr>
<td>2</td>
<td>860–1,600</td>
<td>960–1,550</td>
<td>39–68</td>
</tr>
<tr>
<td>3</td>
<td>1,310–1,750</td>
<td>2,570–3,340</td>
<td>57–74</td>
</tr>
<tr>
<td>4</td>
<td>1,570–1,940</td>
<td>3,620–4,990</td>
<td>61–86</td>
</tr>
</tbody>
</table>

*relative to years 1850–1900  
** from 2011 (minimum and maximum range)
FIGURE 10. Energy and efficiency penalty for pulverised coal, natural gas combined cycle and integrated gasification combined cycle power plants.
FIGURE 16. Average global emissions of CO$_2$ (GtCO$_2$/yr) for 450 ppm and 550 ppm scenarios across EMF27 models.
FIGURE 17. Average capture of CO₂ (GtCO₂/yr) for 450 ppm and 550 ppm scenarios across EMF27 models.
<table>
<thead>
<tr>
<th></th>
<th>GtCO₂</th>
<th></th>
<th>Exajoules (EJ)</th>
<th></th>
<th>% of reserves</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Without CCS</td>
<td>With CCS</td>
<td>Without CCS</td>
<td>With CCS</td>
<td>Without CCS</td>
<td>With CCS</td>
</tr>
<tr>
<td>Up until 2050</td>
<td>953</td>
<td>1,347</td>
<td>13,166</td>
<td>18,356</td>
<td>26%</td>
<td>37%</td>
</tr>
<tr>
<td>Up until 2100</td>
<td>1,208</td>
<td>2,380</td>
<td>16,823</td>
<td>32,376</td>
<td>33%</td>
<td>65%</td>
</tr>
</tbody>
</table>
FIGURE 22 (top half). Cost of carbon (CO$_2$) for 450 ppm.
FIGURE 24. Sensitivity of primary energy supply of coal in 2050, 2080 and 2100 to CCS capture rate, produced by TIAM-Grantham.
FIGURE 25. Sensitivity of primary energy supply of oil in 2050, 2080 and 2100 to CCS capture rate, produced by TIAM-Grantham.