Can technology unlock ‘unburnable carbon’?

Dr Sara Budinis

Sustainable Gas Institute
www.sustainablegasinstitute.org/
twitter.com/sgi_London
sgi@imperial.ac.uk

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

- Academic-industry international collaboration **UK and Brazil** with **hub and spoke** structure: enables engagement with a number of research themes

- **Hub** at Imperial College since May 2014
- **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
Can technology unlock ‘unburnable carbon’?
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
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**

  - Unburnable carbon: 1,360 GtCO₂
  - Burnable carbon: 1,440 GtCO₂
- Until 2050: IEA [29]
  - Less than 1/3 <953 GtCO₂
  - More than 2/3 >1,907 GtCO₂
  - Carbon Tracker Initiative: 2,795 GtCO₂
  - Carbon Tracker Initiative: 2,860 GtCO₂
- Until 2050: McGlade & Ekins [35]
  - Carbon Tracker Initiative: 3,613 GtCO₂

*Overall remaining reserves (GtCO₂)*

Different studies and timeframes:

- Unburnable carbon (GtCO₂)
- Burnable carbon (GtCO₂)
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

**FIG. 14**

**Maximum from literature:** 160 US$/tCO₂

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**Cost of avoided CO₂**

### PROCESS PLANT
- Coal-fired power: $24 - $110
- Gas-fired power: $52 - $120
- Iron and steel: $67 - $115
- Refineries: $110
- Pulp and paper: $93
- Cement production: $27 - $146
- Natural gas combined cycle: $48 - $146
- Oxyfuel combustion: $99
- Integrated Gasification Combined Cycle: $3 - $140
- Chemicals +Bio/synfuel: $20 - $111

### CAPTURE TECHNOLOGY
- Post-combustion (amine): $63 - $87
- Pre-combustion

### STORAGE
- With CCS [99]: $20 - $113
- With Enhanced Oil Recovery/Enhanced Gas Recovery (EOR/EGS) [100]: $71 - $84

Minimum  |  Maximum
Potential barriers: 2 - Geo-storage capacity

Range from literature: 10,000 to 33,000 GtCO₂

FIG. 9

STORAGE

Capacity hydrocarbon reserves (GtCO₂)
Overall capacity (GtCO₂)
Current state of CCS

FIG. 7

- Number of projects in operation
- Total number of large-scale projects at different life-cycle stages
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>
<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>
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<td>Unburnable</td>
<td>Burnable</td>
</tr>
<tr>
<td>Oil</td>
<td>GtCO₂</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>TOTAL</td>
<td></td>
<td>3,613</td>
<td>2,565</td>
<td>1,049</td>
</tr>
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</table>

**TABLE 11**
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

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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

- Green: The full technology scenario (Fulltech)
- Blue: The Conventional solutions scenario (Conv)
- Orange: The Scenario without CCS (noCCS)

- Dashed: Average
- Vertical lines: Max/min range

Year:
- 2000
- 2010
- 2020
- 2030
- 2040
- 2050
- 2060
- 2070
- 2080
- 2090
- 2100

Fossil fuel use (EJ/yr)
Potential role of CCS up to 2100 - 2

FIG. ES2
A key parameter: the capture rate

Capture rate: the percentage of CO₂ 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 2ºC (+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** – UCL/IEA

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

Dr Sara Budinis

Sustainable Gas Institute
www.sustainablegasinstitute.org/
twitter.com/sgi_London
sgi@imperial.ac.uk
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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 CO$_2$ (GtCO$_2$/yr) for 450 ppm and 550 ppm scenarios across EMF27 models.

<table>
<thead>
<tr>
<th></th>
<th>GtCO₂</th>
<th>Exajoules (EJ)</th>
<th>% of reserves</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Without CCS</td>
<td>With CCS</td>
<td>Without CCS</td>
</tr>
<tr>
<td>Up until 2050</td>
<td>953</td>
<td>1,347</td>
<td>13,166</td>
</tr>
<tr>
<td>Up until 2100</td>
<td>1,208</td>
<td>2,380</td>
<td>16,823</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.