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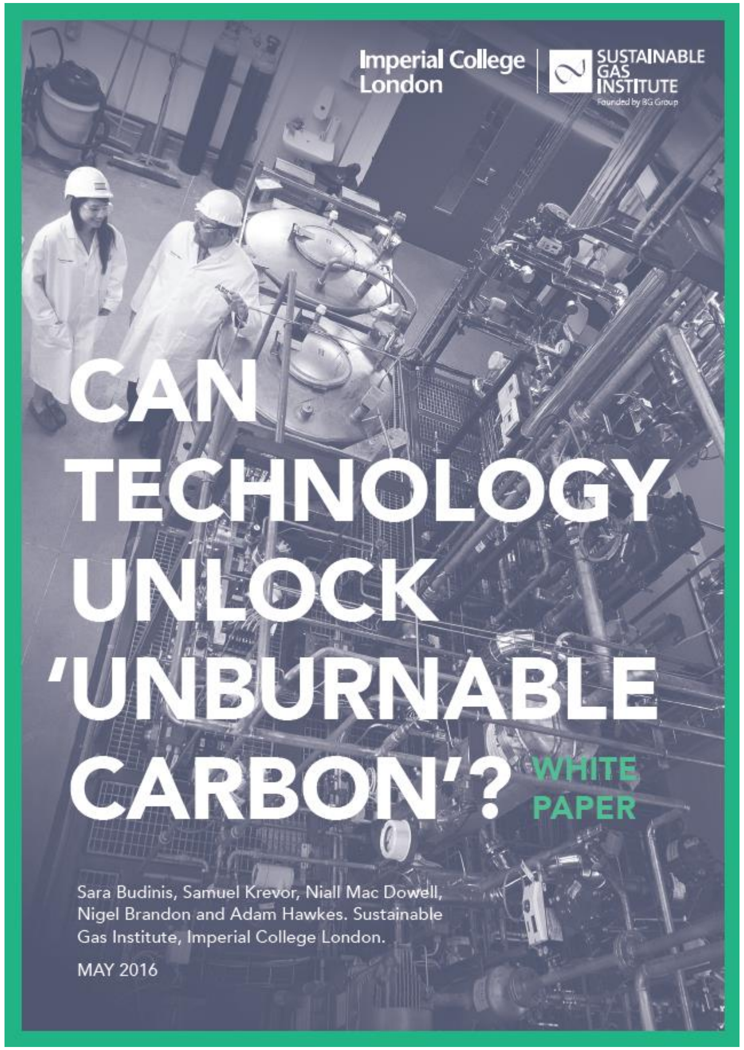
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Founded by BG Group

CAN TECHNOLOGY UNLOCK ‘UNBURNABLE CARBON’?

WHITE PAPER

Sara Budinis, Samuel Krevor, Niall Mac Dowell, Nigel Brandon and Adam Hawkes. Sustainable Gas Institute, Imperial College London.

MAY 2016

Can technology unlock ‘unburnable carbon’?

Dr Sara Budinis

Sustainable Gas Institute
www.sustainablegasinstitute.org/
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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

Energy efficiency

Gas innovation

Carbon capture, storage and use

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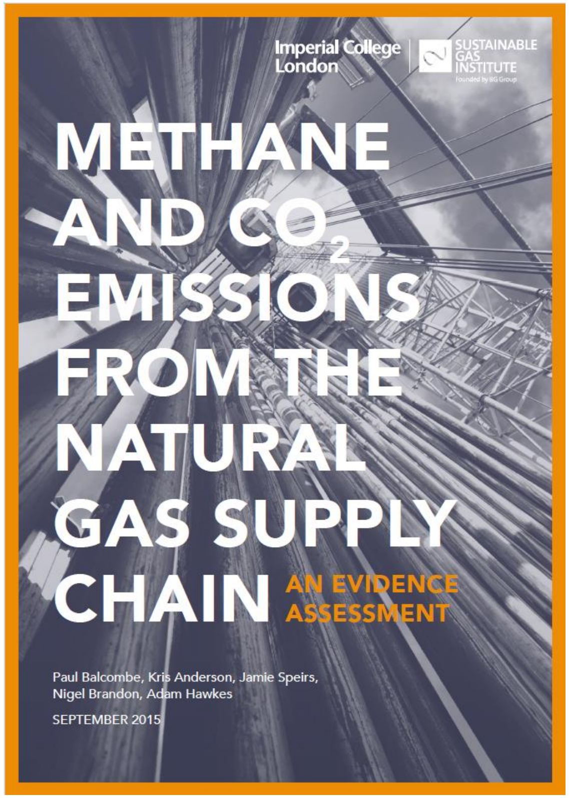
White paper series

1.



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METHANE AND CO$_2$ EMISSIONS FROM THE NATURAL GAS SUPPLY CHAIN

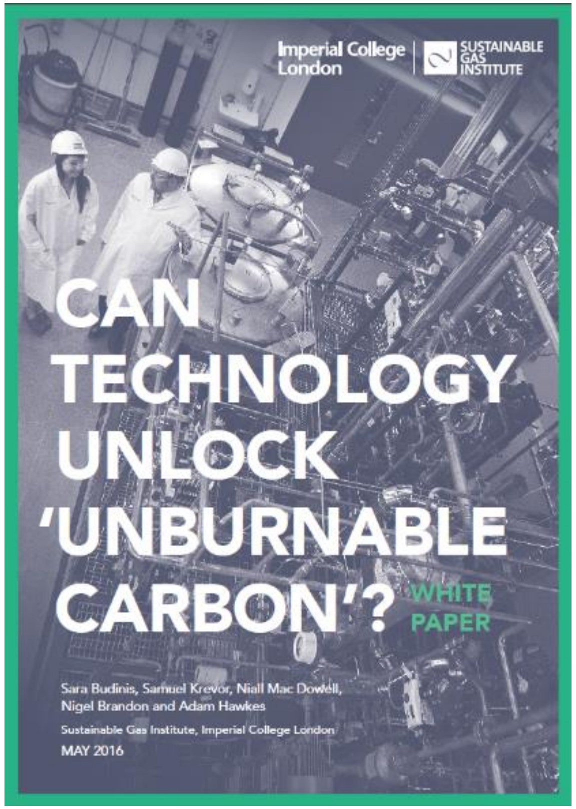
AN EVIDENCE ASSESSMENT

Paul Balcombe, Kris Anderson, Jamie Speirs,
Nigel Brandon, Adam Hawkes

SEPTEMBER 2015

September 2015

2.



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Sustainable Gas Institute, Imperial College London

MAY 2016

May 2016

3.

‘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?

July 2017

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


Dr Chris Jones
Operations Director


Zara Qadir
Communications


Dr Sara Giarola
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Dr Jamie Speirs
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Dr Paul Balcombe
Research Associate


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University of British Columbia

Professor Zheng Li
Professor & Dean, Department of Thermal Engineering,
Tsinghua University

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 2ºC** above pre-industrial levels”

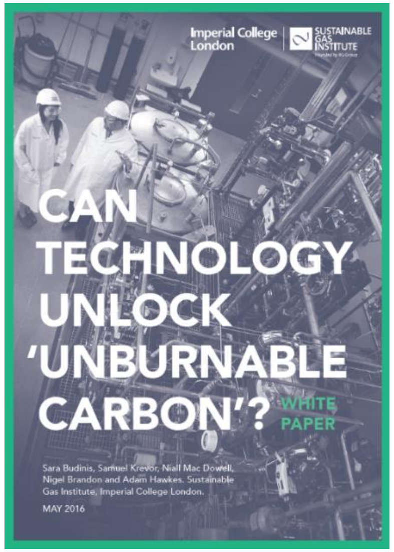
ENERGY SYSTEM AND TECHNOLOGY:

- 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: 2ºC climate target



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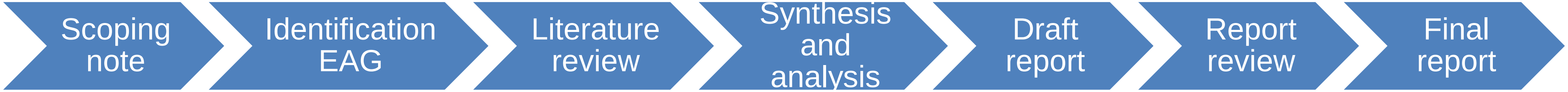
Methodology

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

1.


Scoping note

Identification EAG

Literature review

Synthesis and analysis

Draft report

Report review

Final report

2. Analysis of energy scenarios:

- Selection of database and scenarios
- Comparison "**with CCS" vs "without CCS"**

2.

3. Primary research:

- The Grantham Institute's TIMES Integrated Assessment Model (TIAM-Grantham)

3.

In the next 15 minutes…

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

1.

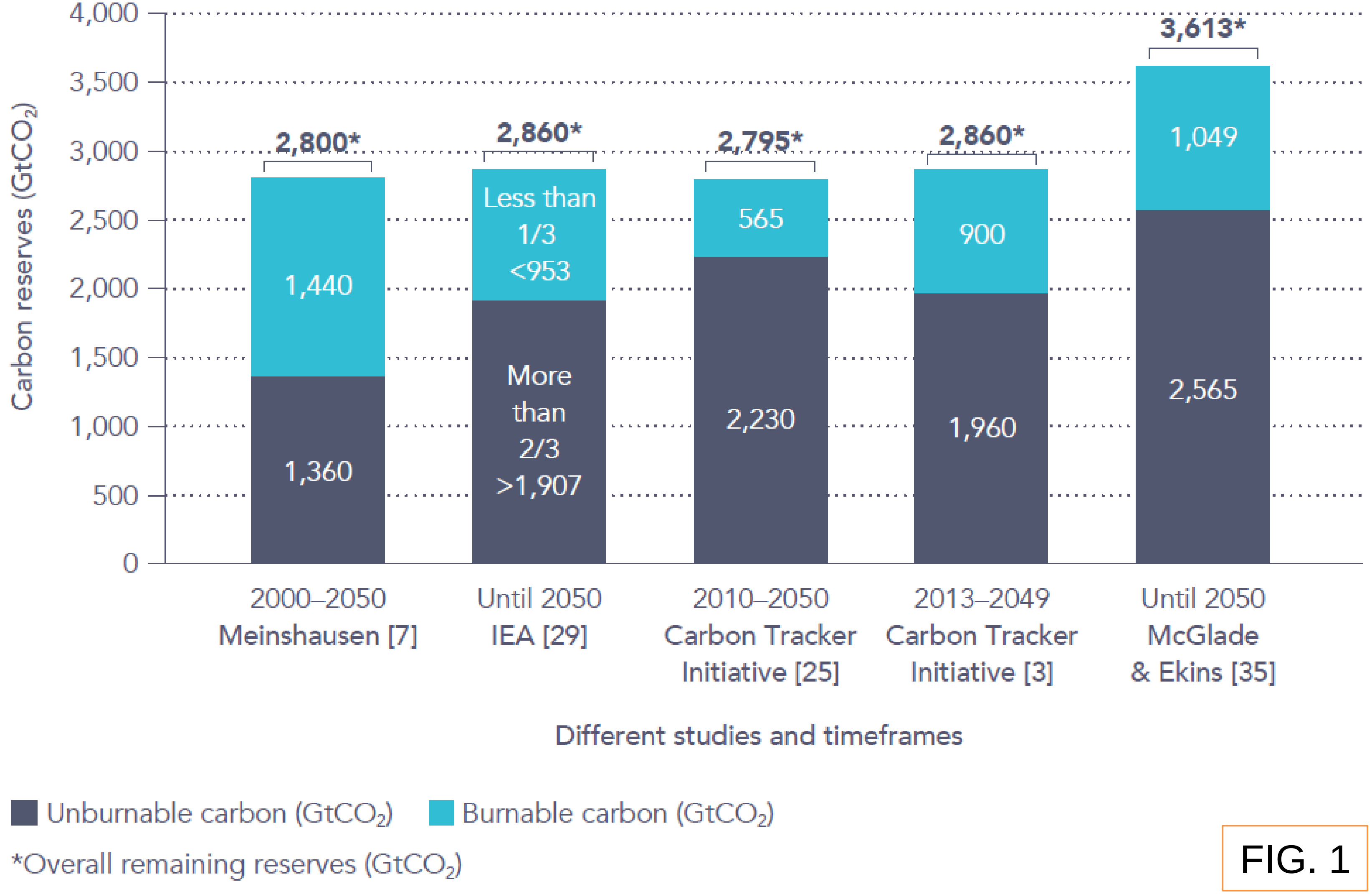


FIG. 1

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.)

CCS Pilot Plant, Chemical Engineering Department, Imperial College London

Carbon capture and storage: An example

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Post-combustion CCS for power generation

PLANT

CAPTURE

TRANPORT

STORAGE

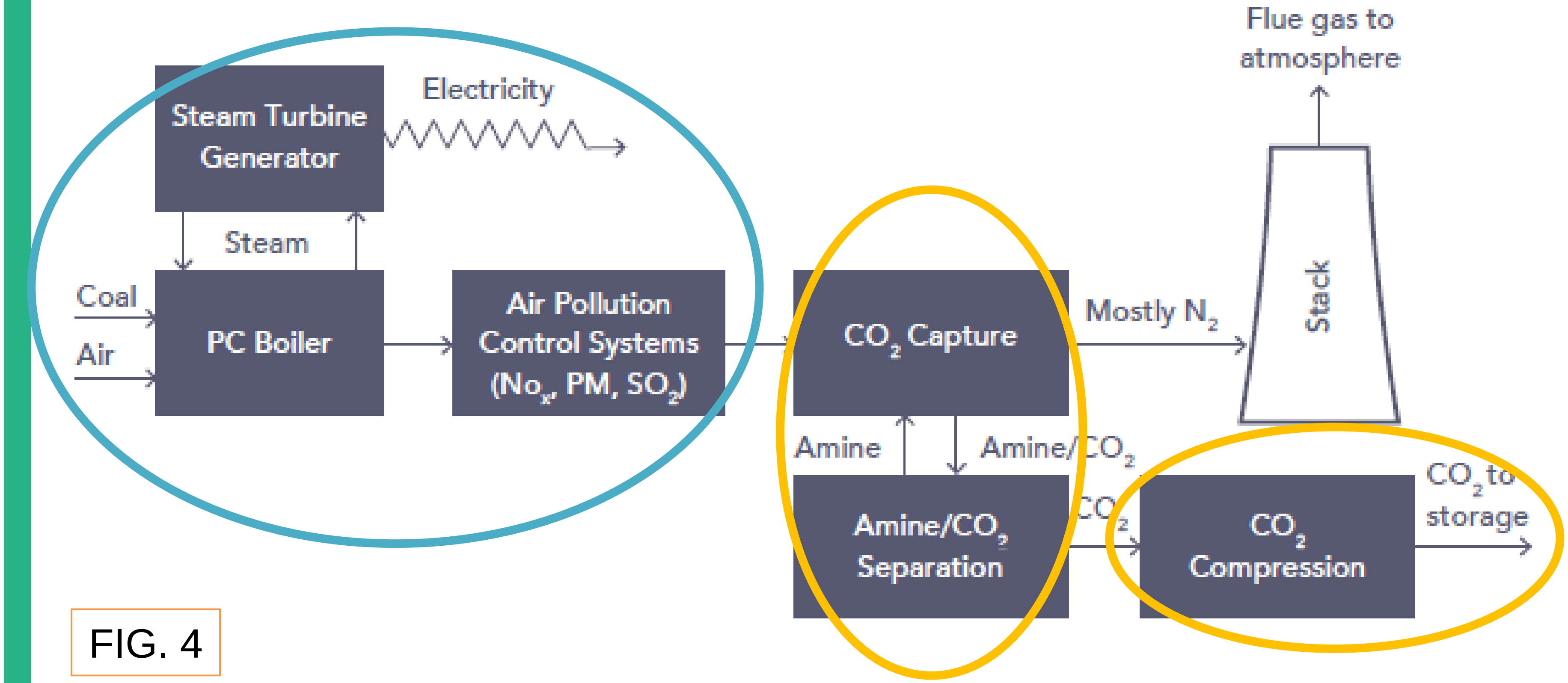

FIG. 4

Carbon capture and storage: An example

Post-combustion CCS for power generation

PLANT

CAPTURE

TRANPORT

STORAGE

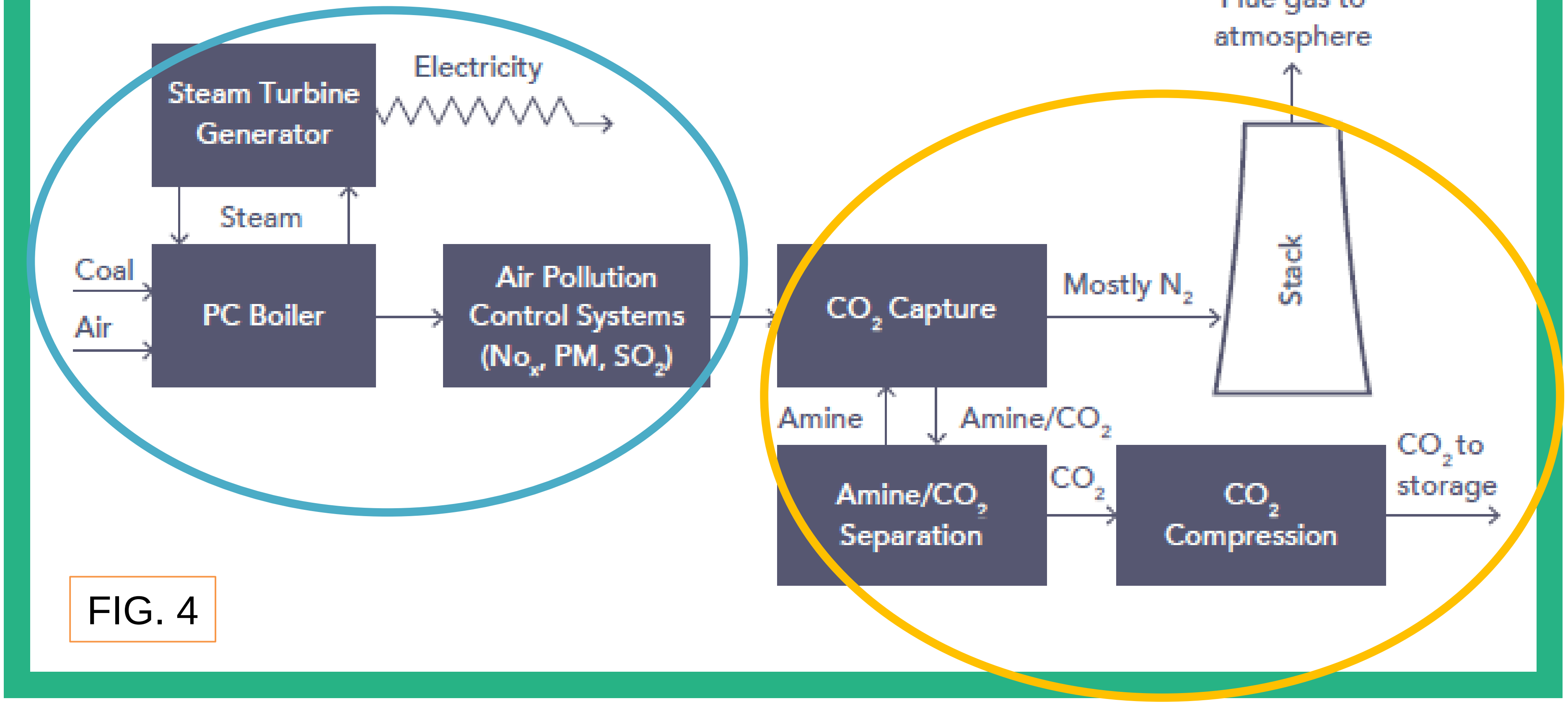

FIG. 4

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

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FIG. 14

Maximum from literature:
160 US$/$tCO_2$

CAPTURE

TRANPORT

STORAGE

Potential barriers:
2 - Geo-storage capacity

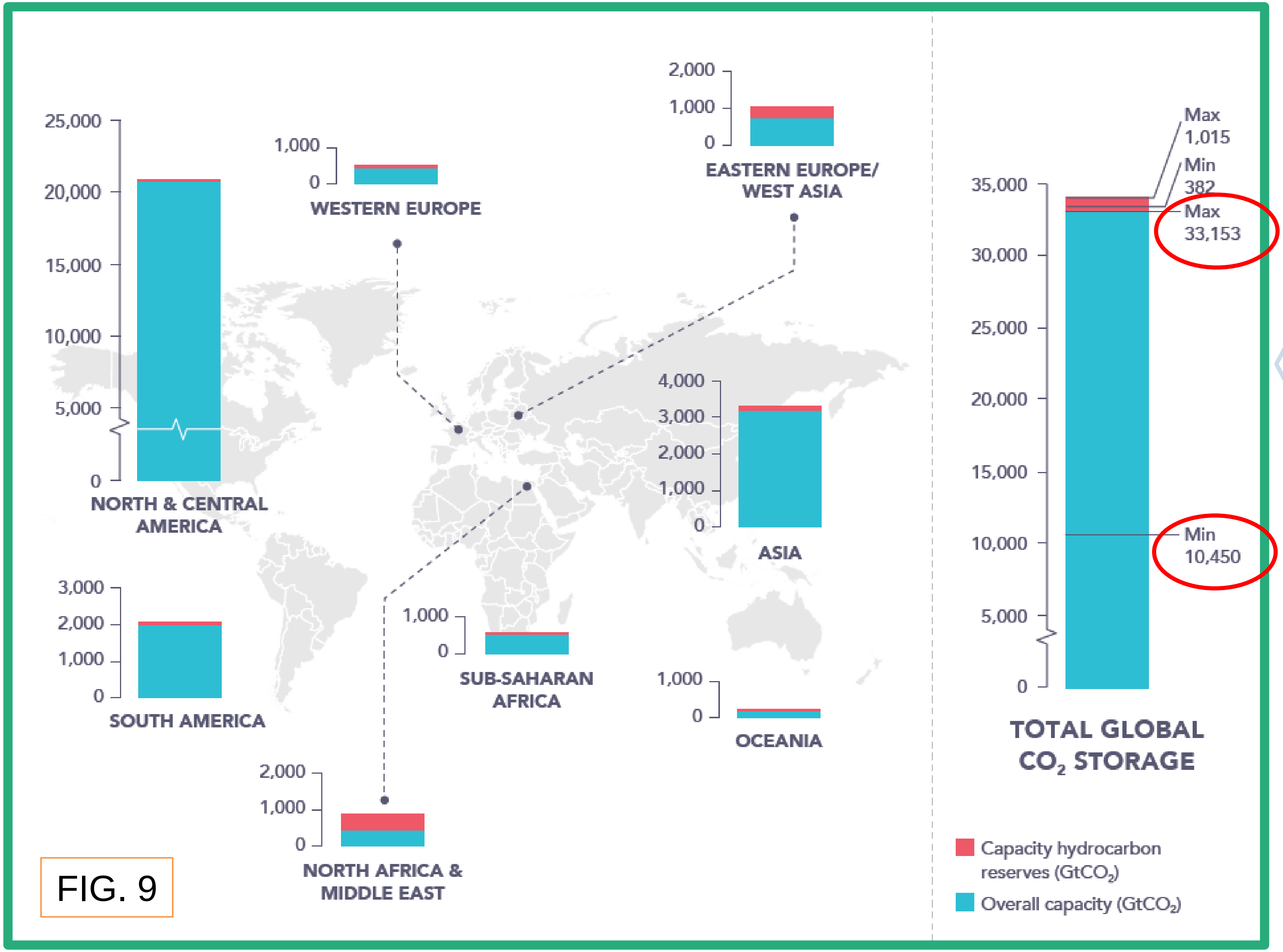


FIG. 9

Range from literature: 10,000 to 33,000 $GtCO_2$

STORAGE

Current state of CCS

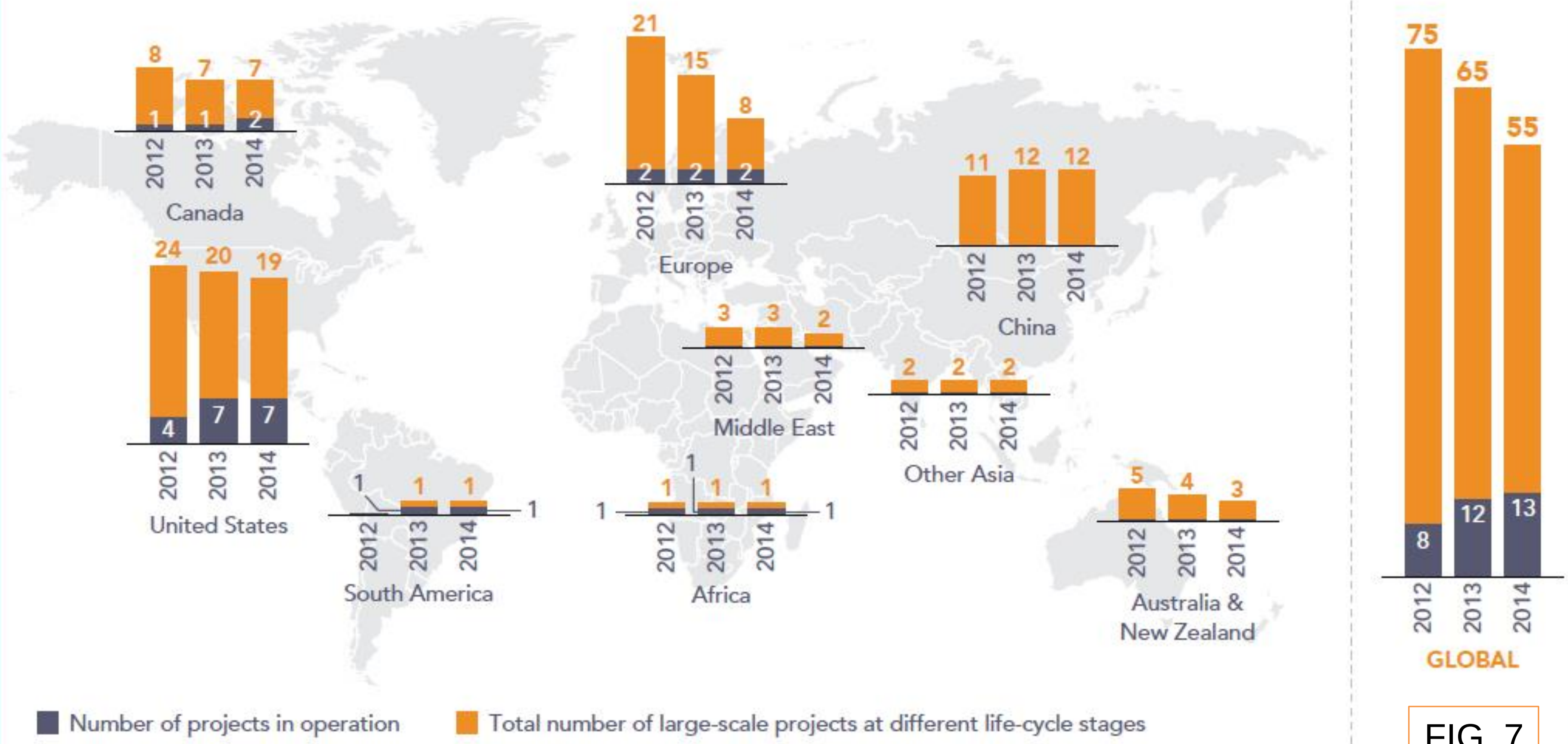
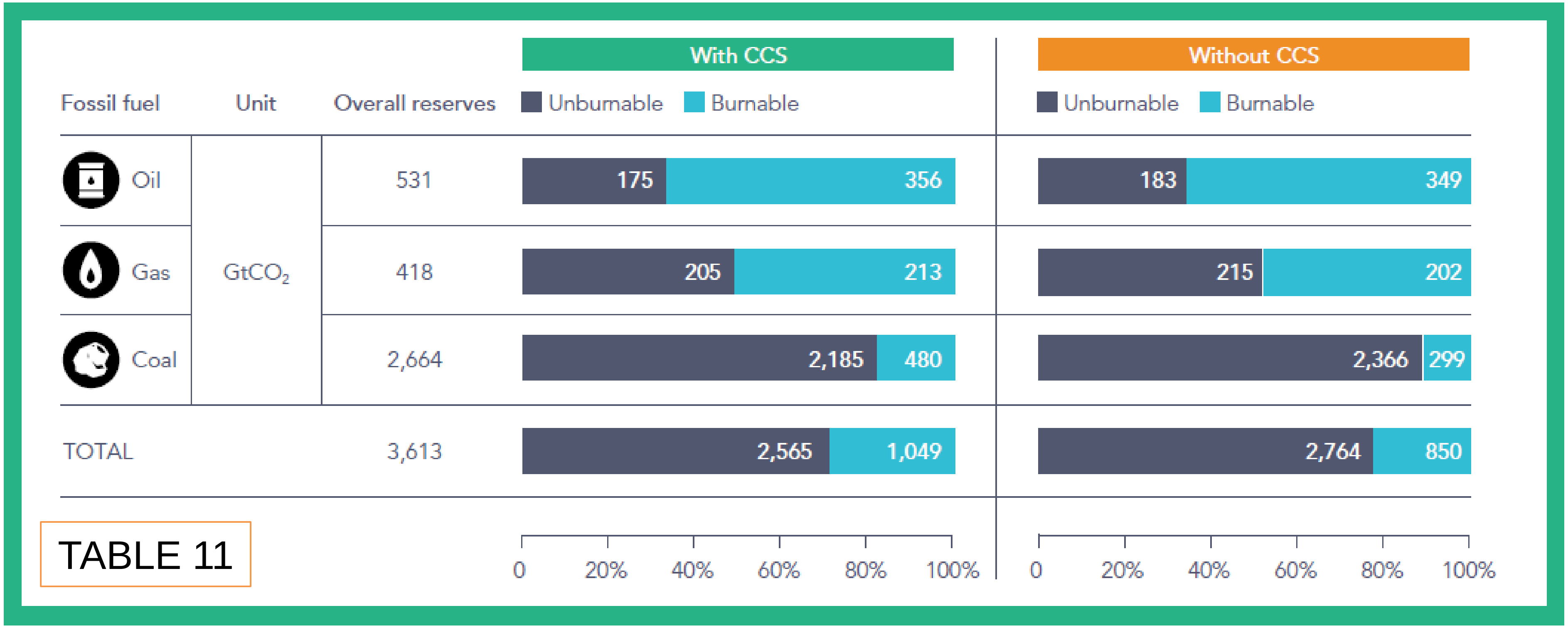


FIG. 7

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).

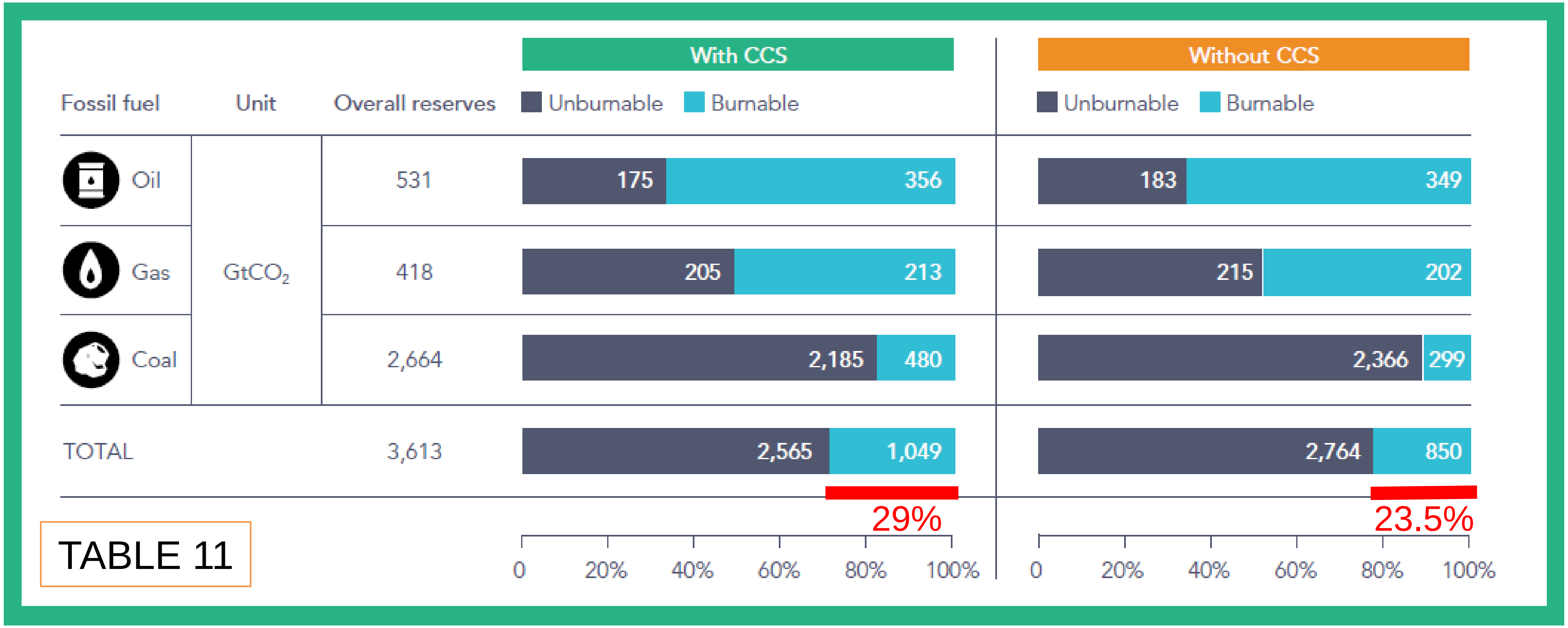


Fossil fuel	Unit	Overall reserves	With CCS		Without CCS	
			Unburnable	Burnable	Unburnable	Burnable
Oil	$GtCO_2$	531	175	356	183	349
Gas		418	205	213	215	202
Coal		2,664	2,185	480	2,366	299
TOTAL		3,613	2,565	1,049	2,764	850

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).



			With CCS		Without CCS	
Fossil fuel	Unit	Overall reserves	Unburnable	Burnable	Unburnable	Burnable
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TOTAL		3,613	2,565	1,049	2,764	850

TABLE 11

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%) ××

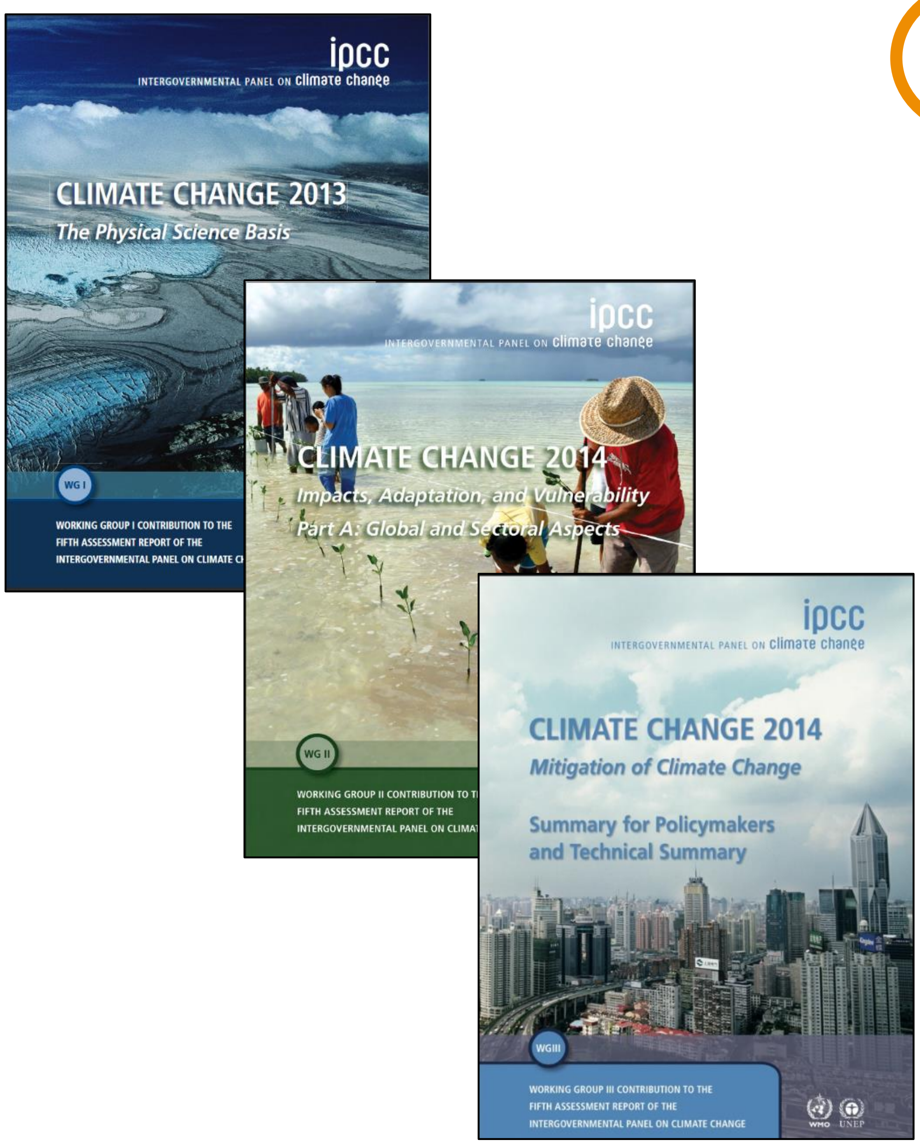
4. Can technology unlock ‘unburnable carbon’?

Database and scenarios

2.

- **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 = 2ºC target
        - 550 ppm
    - Two **timeframes**
        - until 2050
        - **until 2100**



ipcc
INTERGOVERNMENTAL PANEL ON climate change

CLIMATE CHANGE 2013
The Physical Science Basis

WG I

WORKING GROUP I CONTRIBUTION TO THE
FIFTH ASSESSMENT REPORT OF THE
INTERGOVERNMENTAL PANEL ON CLIMATE CH

ipcc
INTERGOVERNMENTAL PANEL ON climate change

CLIMATE CHANGE 2014
Impacts, Adaptation, and Vulnerability
Part A: Global and Sectoral Aspects

WG II

WORKING GROUP II CONTRIBUTION TO T
FIFTH ASSESSMENT REPORT OF THE
INTERGOVERNMENTAL PANEL ON CLIMAT

ipcc
INTERGOVERNMENTAL PANEL ON climate change

CLIMATE CHANGE 2014
Mitigation of Climate Change

Summary for Policymakers
and Technical Summary

WGIII

WORKING GROUP III CONTRIBUTION TO THE
FIFTH ASSESSMENT REPORT OF THE
INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

WMO UNEP

Potential role of CCS up to 2100 - 1

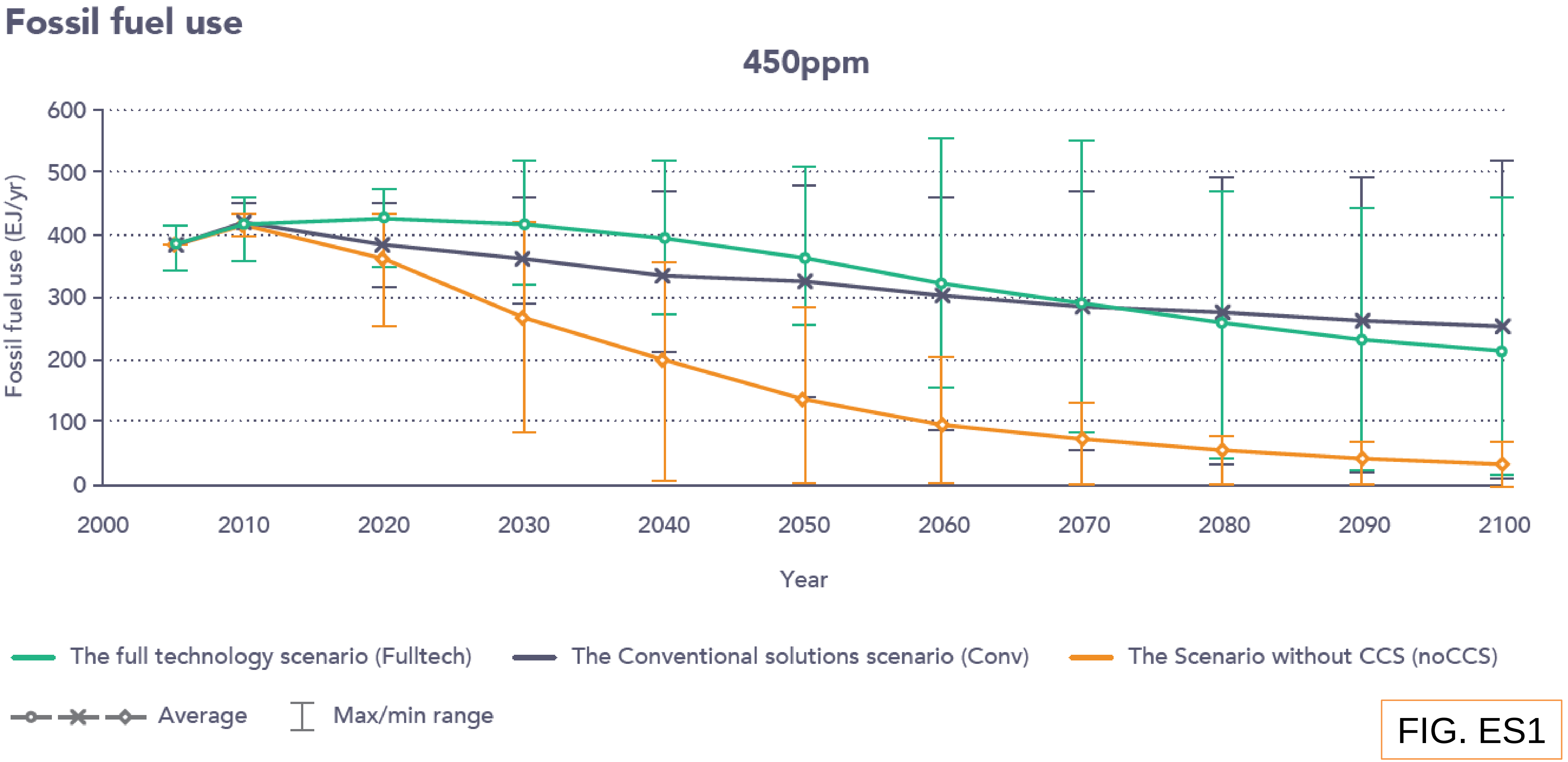


FIG. ES1

Potential role of CCS up to 2100 - 2

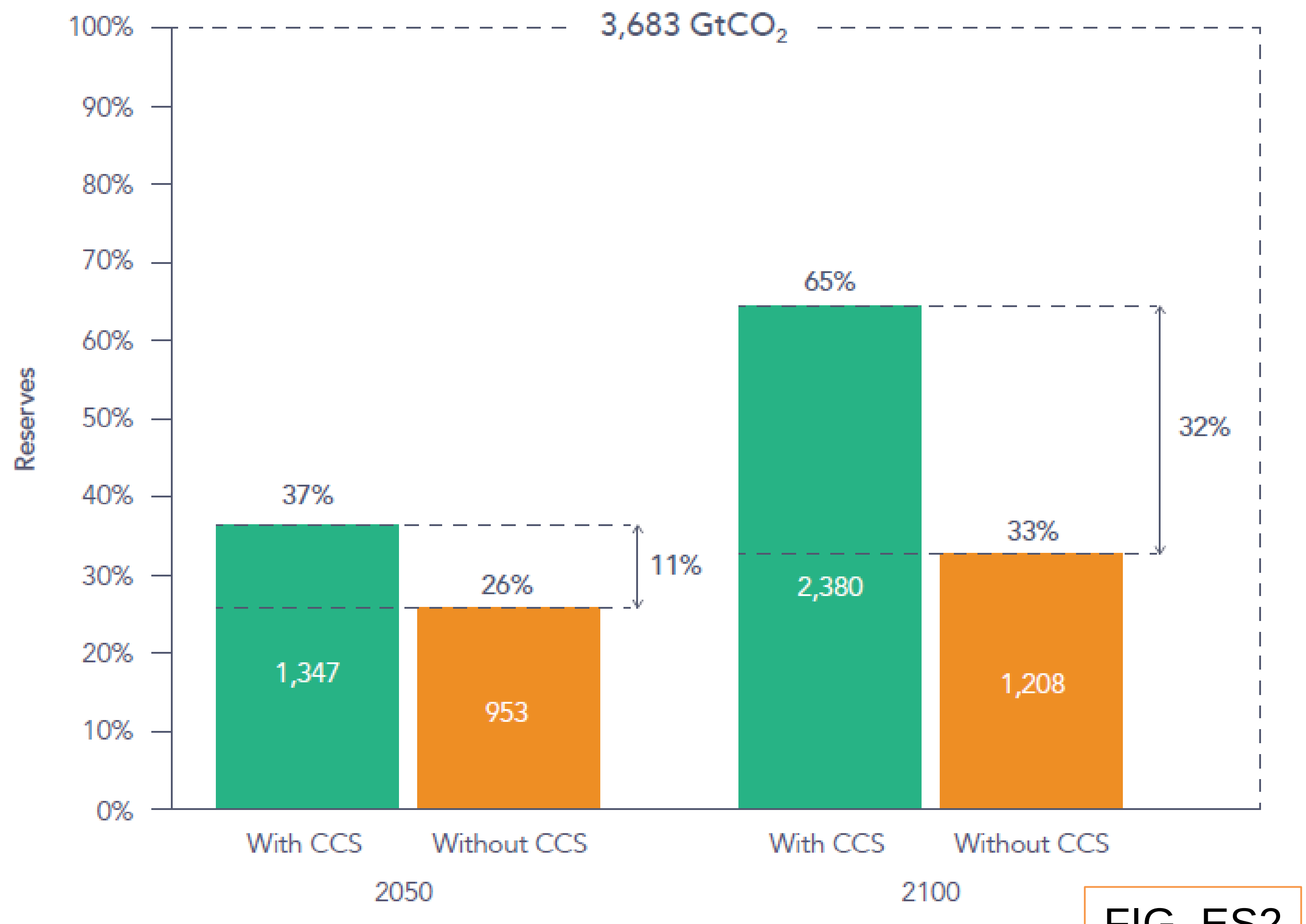


FIG. ES2

A key parameter: the capture rate

3.

Capture rate:

the percentage of CO_2 emitted by the process that will be ultimately stored (≤90%)

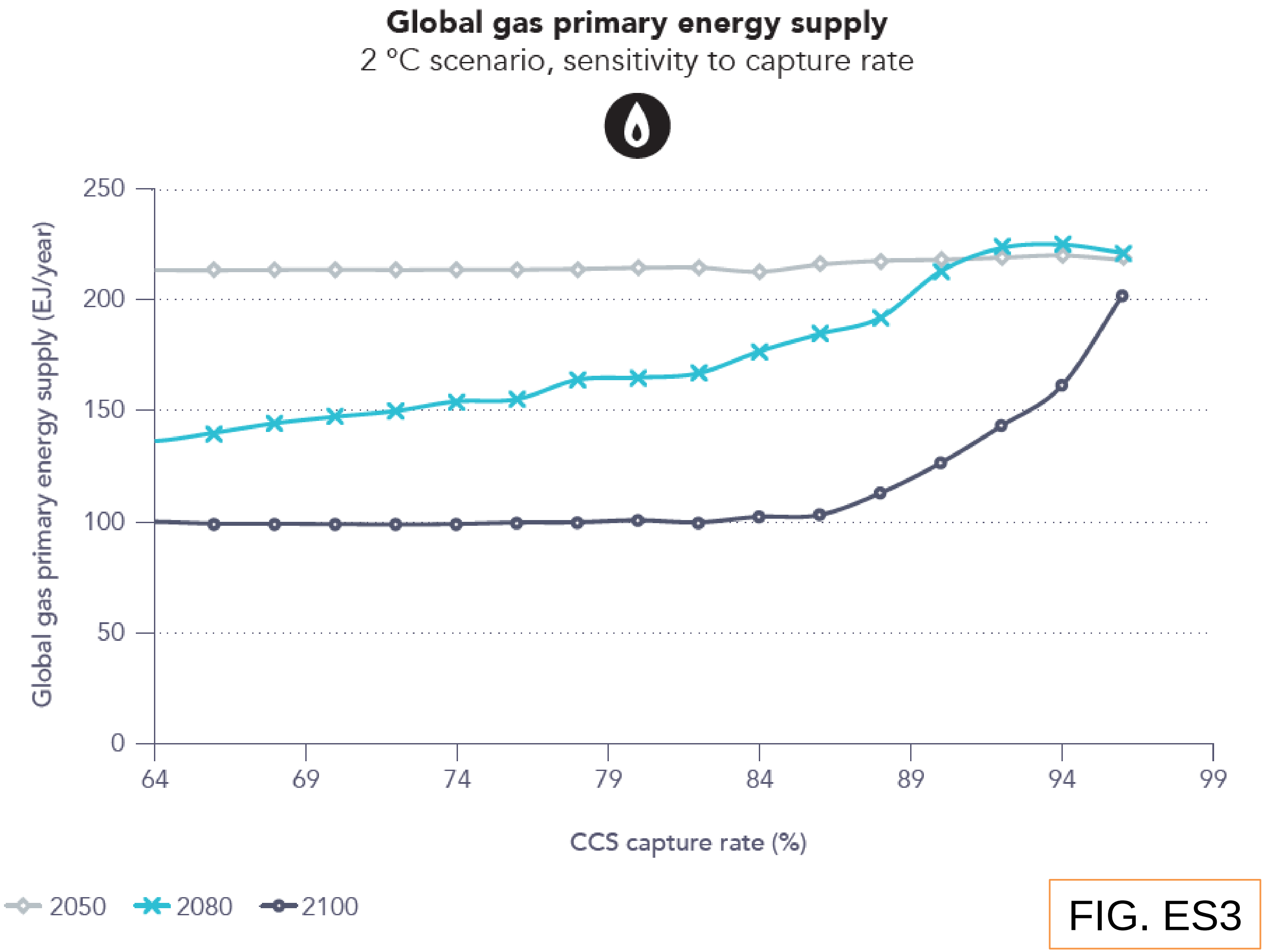

Global gas primary energy supply
2 °C scenario, sensitivity to capture rate

FIG. ES3

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**

Acknowledgment

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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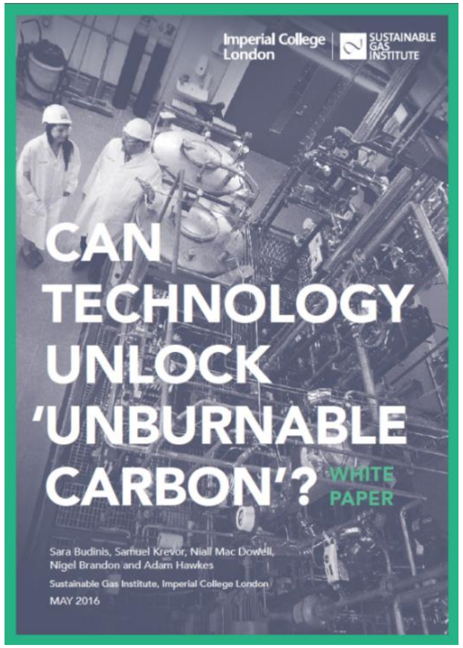
Download the paper:

www.sustainablegasinstitute.org/technology-unlock-unburnable-carbon/

Download the summary:

www.sustainablegasinstitute.org/briefing-note-can-technology-unlock-unburnable-carbon/



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CAN TECHNOLOGY UNLOCK 'UNBURNABLE CARBON'? WHITE PAPER

Sara Budinis, Samuel Krevor, Niall Mac Dowell, Nigel Brandon and Adam Hawkes
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WHITE PAPER 2

Can technology unlock unburnable carbon?

17th May 2016

The words in bold font can be found in the glossary over the page.

BACKGROUND

In 2015, an agreement on climate change was made to limit global warming to below a 2°C temperature rise. As of 2011, the world had a carbon budget of roughly 1,000 gigatonnes of carbon dioxide (CO_2). This is the amount of CO_2 that could be emitted whilst still having a two-thirds or greater chance of staying below 2°C. However, at our current global emission rates, this budget will be completely used up within the next thirty years.

The term 'unburnable carbon' emerged in 2011, and refers to fossil fuel reserves which cannot be burnt if the world is to limit the impacts of climate change. **Carbon capture and storage (CCS)** provides a mitigation opportunity that could potentially unlock some of these reserves while minimising CO_2 emissions into the atmosphere.

Over recent years, several studies have examined the 'unburnable carbon' concept. Some of these have looked at the impact of CCS on the projected consumption of fossil fuels. However, while these studies have considered the role of CCS in enabling access to more fossil fuels, so far there has not been a comprehensive long-term analysis on this issue.

EXPLORING THE ISSUE

This evidence-based literature review focuses on the short and long-term potential of CCS technologies in enabling access to, or 'unlocking', fossil fuel reserves in a way that will still meet climate targets.

Key Questions

The paper tackles some important questions:-

- **What is the potential role of CCS in meeting the carbon budget?**
- **How much CO_2 storage is available globally?**
- **What are the current costs and barriers for this suite of technologies?**
- **What effect CCS performance has on unlocking 'unburnable carbon'?**

If CCS technology can be refined and deployed, this will enable the world to use some of its 'unburnable carbon' while still meeting climate targets.

Inside the Carbon Capture Pilot Plant at Imperial College London, Department of Chemical Engineering

DOWNLOAD THE FULL WHITE PAPER: WWW.SUSTAINABLEGASINSTITUTE.ORG/TECHNOLOGY-UNLOCK-UNBURNABLE-CARBON/

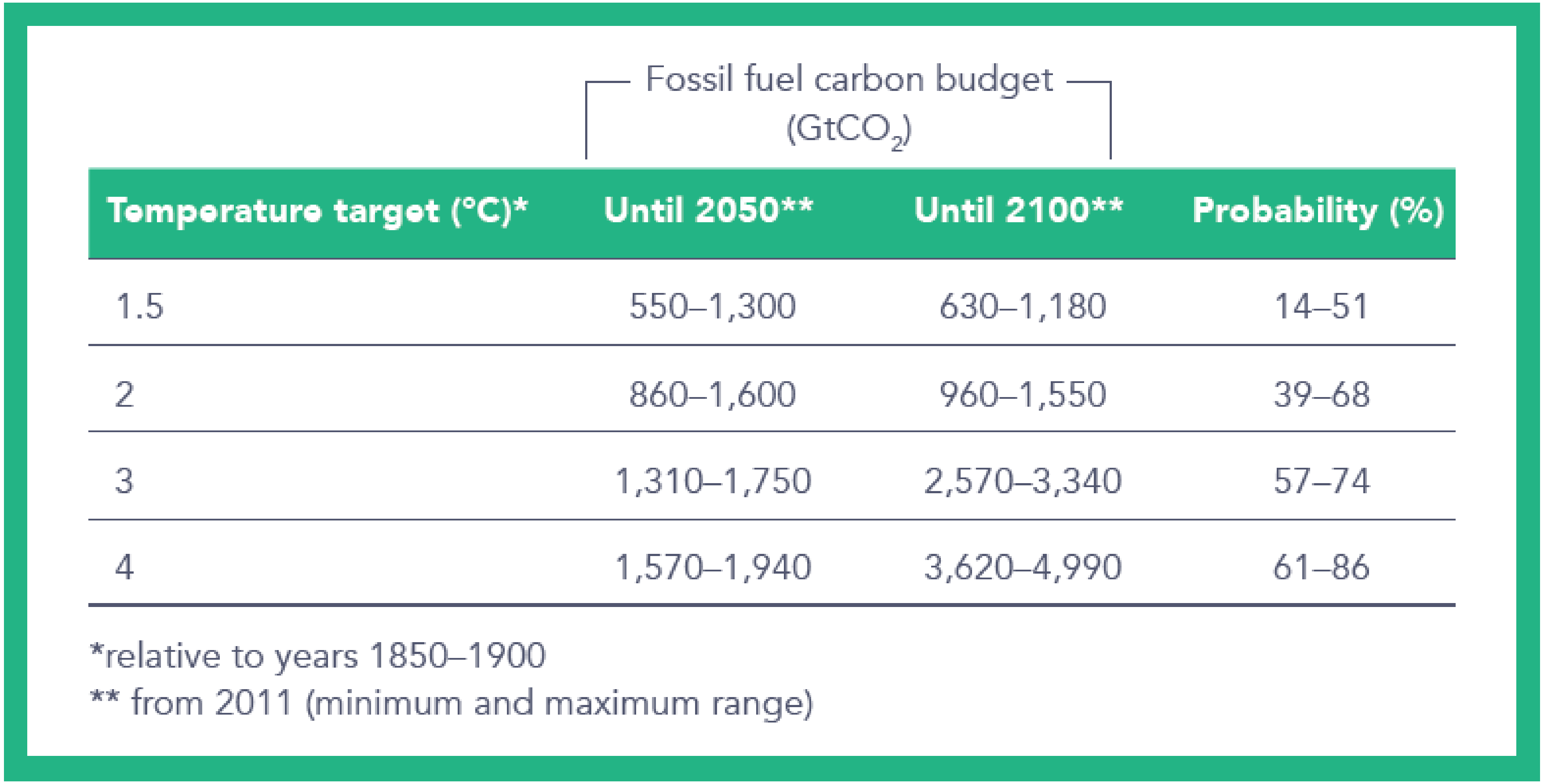
Back-up slides

TABLE 4. Estimation of reserves and resources of oil, gas and coal.

Fossil fuel		Gigatonnes (Gt)	Exajoules (EJ)	Carbon ($GtCO_2$)
Oil	Reserves	219 → 240	9,264 → 10,145	679 → 744
	Resources	334 → 847	14,128 → 35,845	1,036 → 2,627
Gas	Reserves	125 → 155	6,016 → 7,461	338 → 453
	Resources	427 → 540	20,518 → 25,921	1,151 → 1,454
Coal	Reserves	892 → 1,004	25,141 → 28,313	2,378 → 2,678
	Resources	21,208 → 22,090	598,066 → 622,924	56,577 → 58,929
TOTAL	Reserves	1,236 → 1,399	40,421 → 45,919	3,395 → 3,876
	Resources	21,969 → 23,477	632,712 → 684,690	58,764 → 63,010

Minimum ▨ → ■ Maximum

TABLE 5. Fossil fuel carbon budget for different maximum temperature rises.



	Fossil fuel carbon budget ($GtCO_2$)		
Temperature target (°C)*	**Until 2050****	**Until 2100****	**Probability (%)**
1.5	550–1,300	630–1,180	14–51
2	860–1,600	960–1,550	39–68
3	1,310–1,750	2,570–3,340	57–74
4	1,570–1,940	3,620–4,990	61–86

*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.

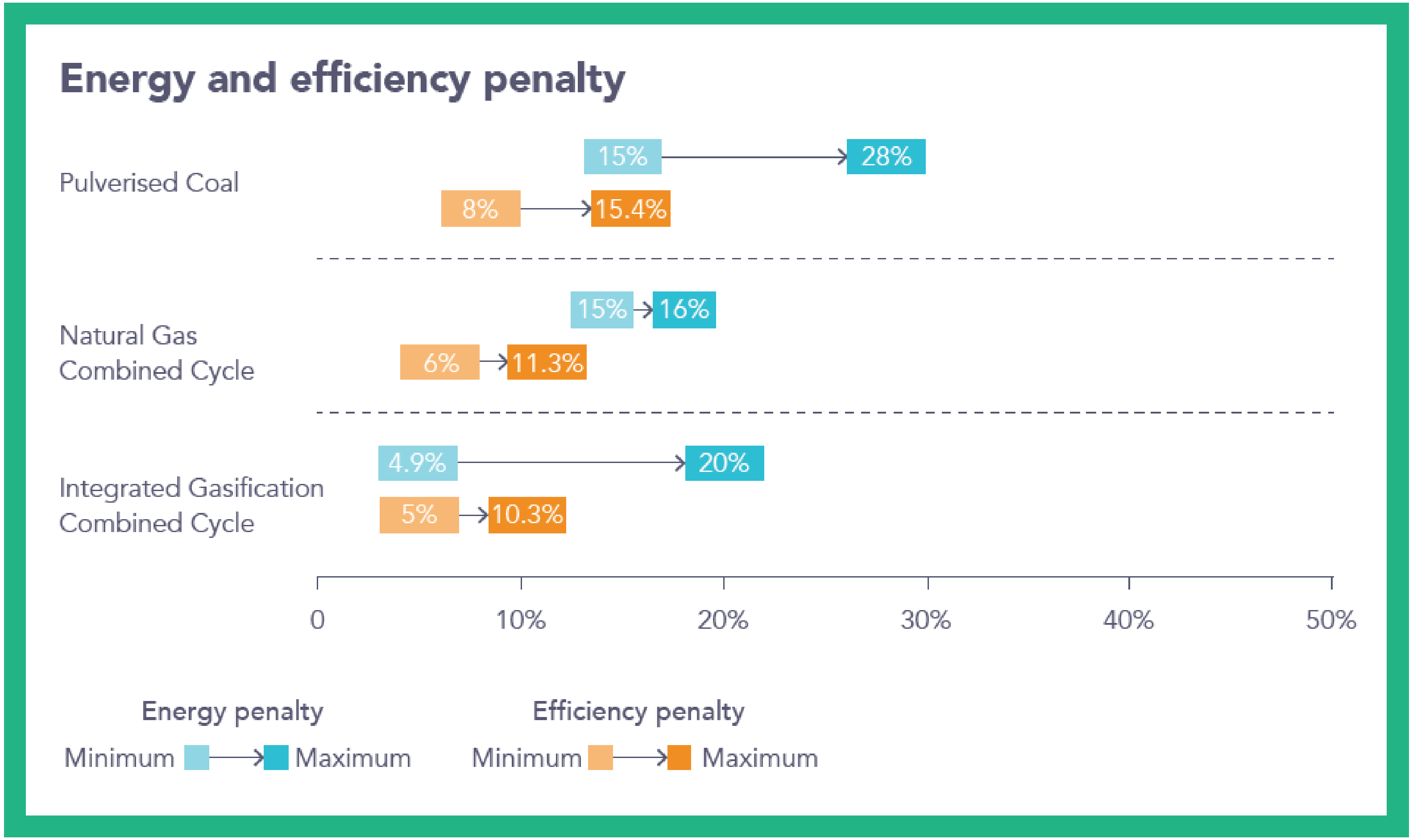


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FIGURE 16. Average global emissions of CO_2 ($GtCO_2$/yr) for 450 ppm and 550 ppm scenarios across EMF27 models.

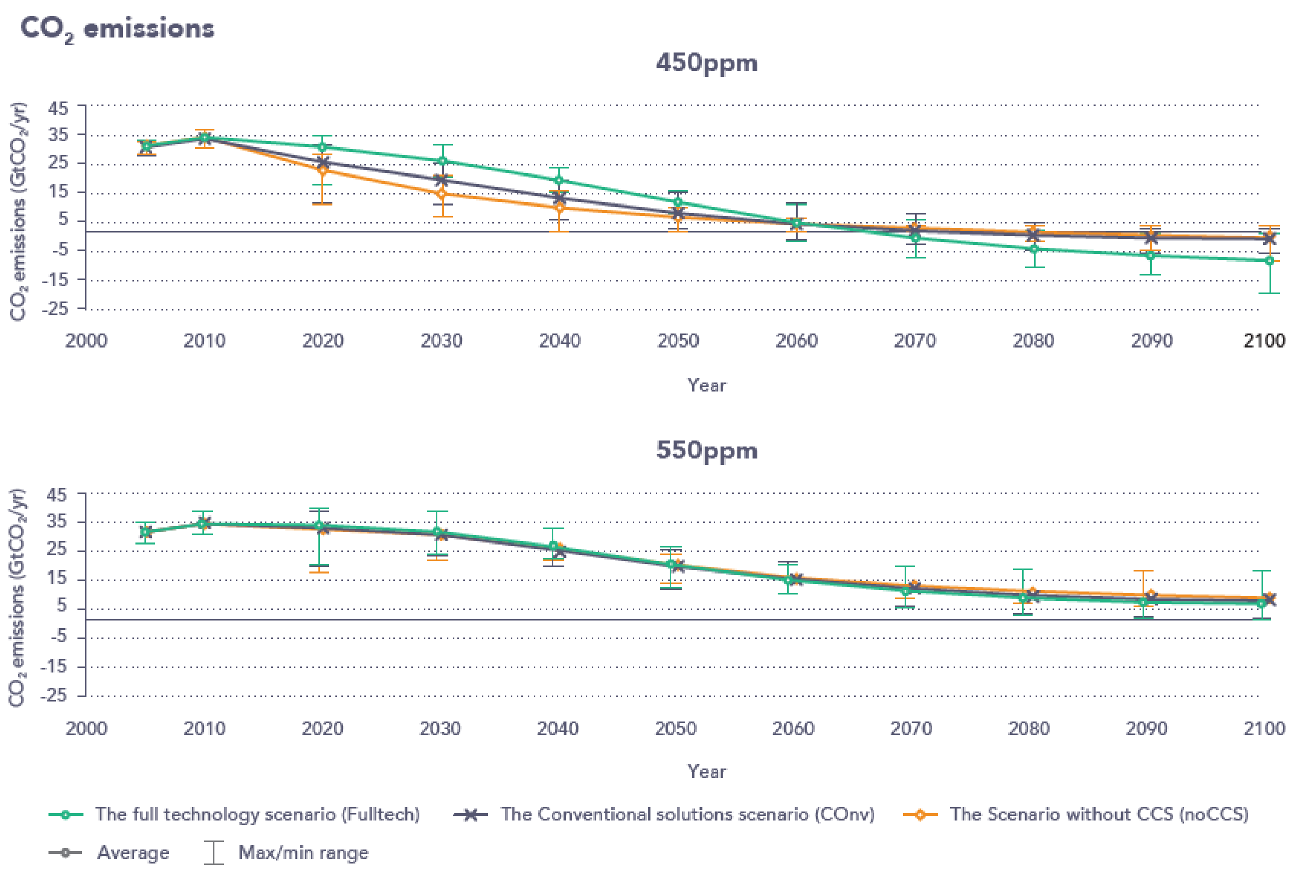


FIGURE 17. Average capture of CO_2 ($GtCO_2$/yr) for 450 ppm and 550 ppm scenarios across EMF27 models.

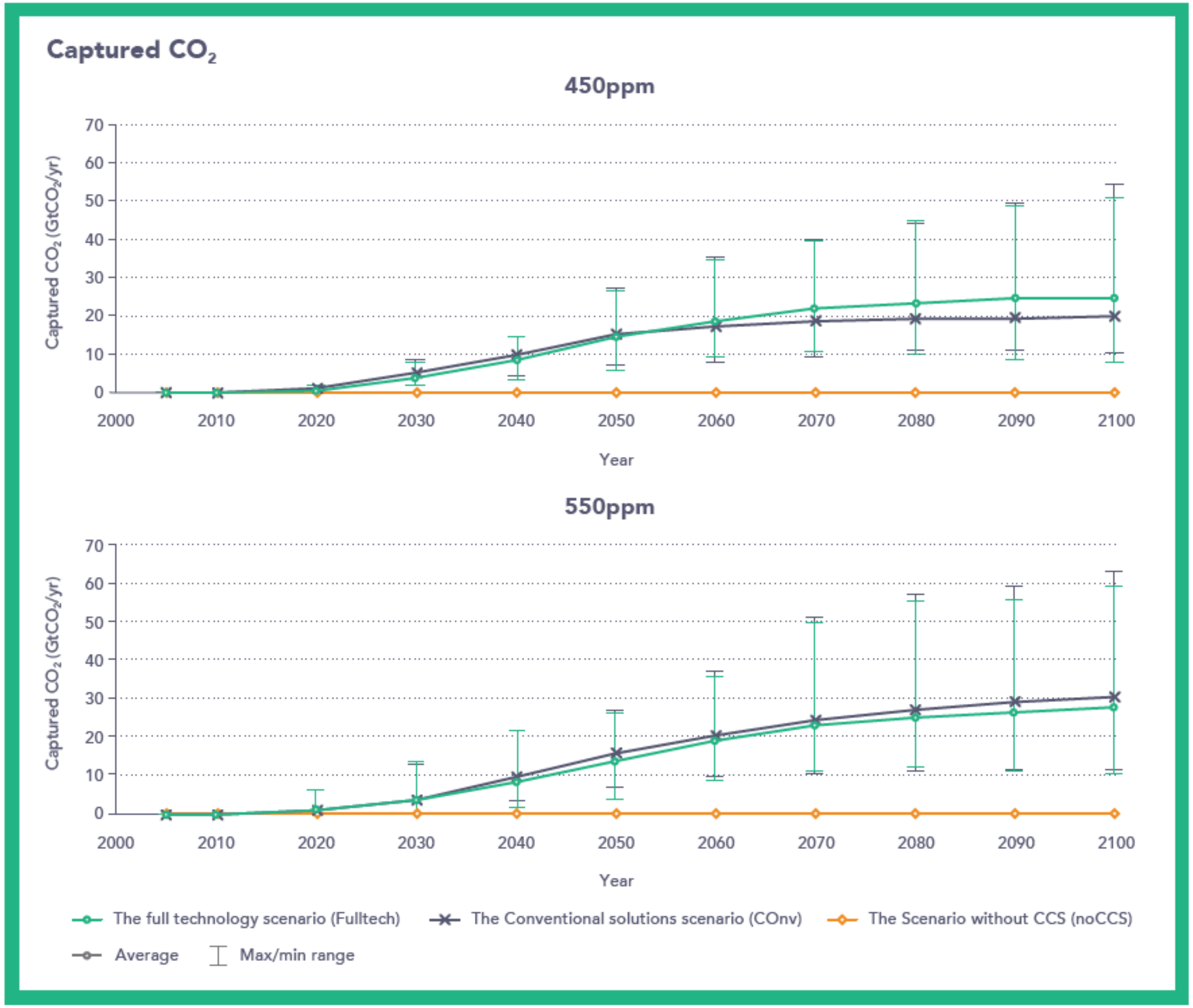
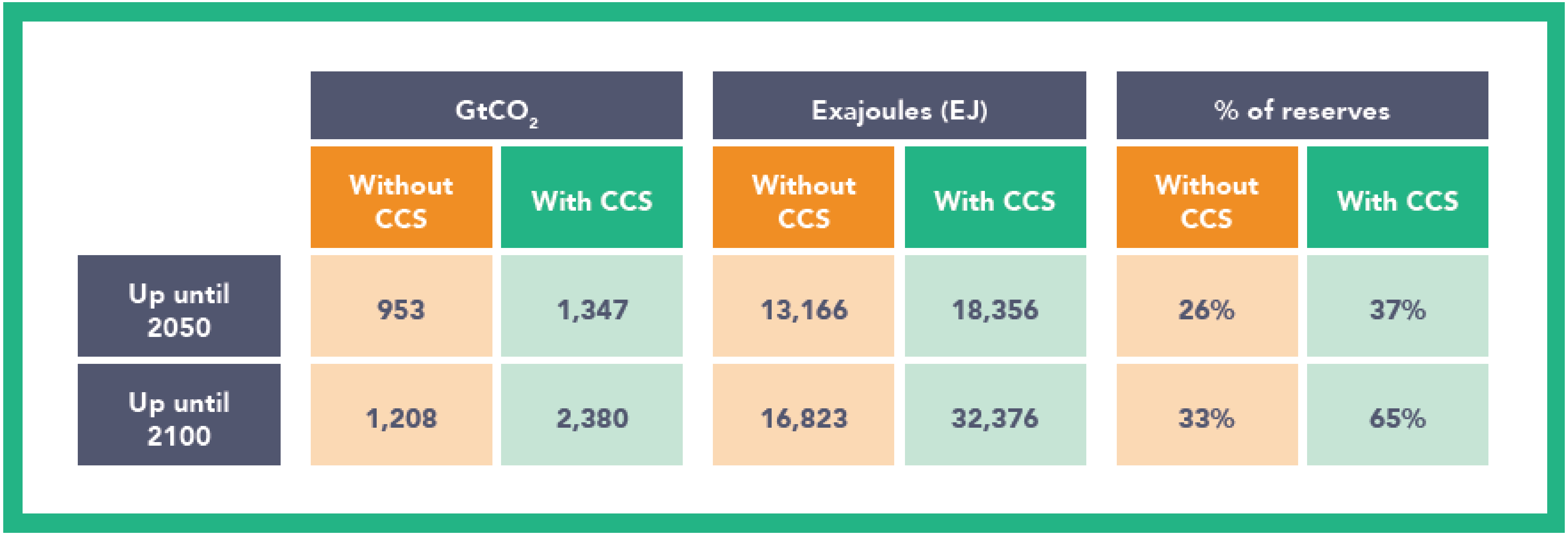


TABLE 18. Cumulative fossil fuel use in the timeframes 2005–2050 and 2005–2100.



	$GtCO_2$		Exajoules (EJ)		% of reserves	
	Without CCS	With CCS	Without CCS	With CCS	Without CCS	With CCS
Up until 2050	953	1,347	13,166	18,356	26%	37%
Up until 2100	1,208	2,380	16,823	32,376	33%	65%

FIGURE 22 (top half). Cost of carbon (CO_2) for 450 ppm.

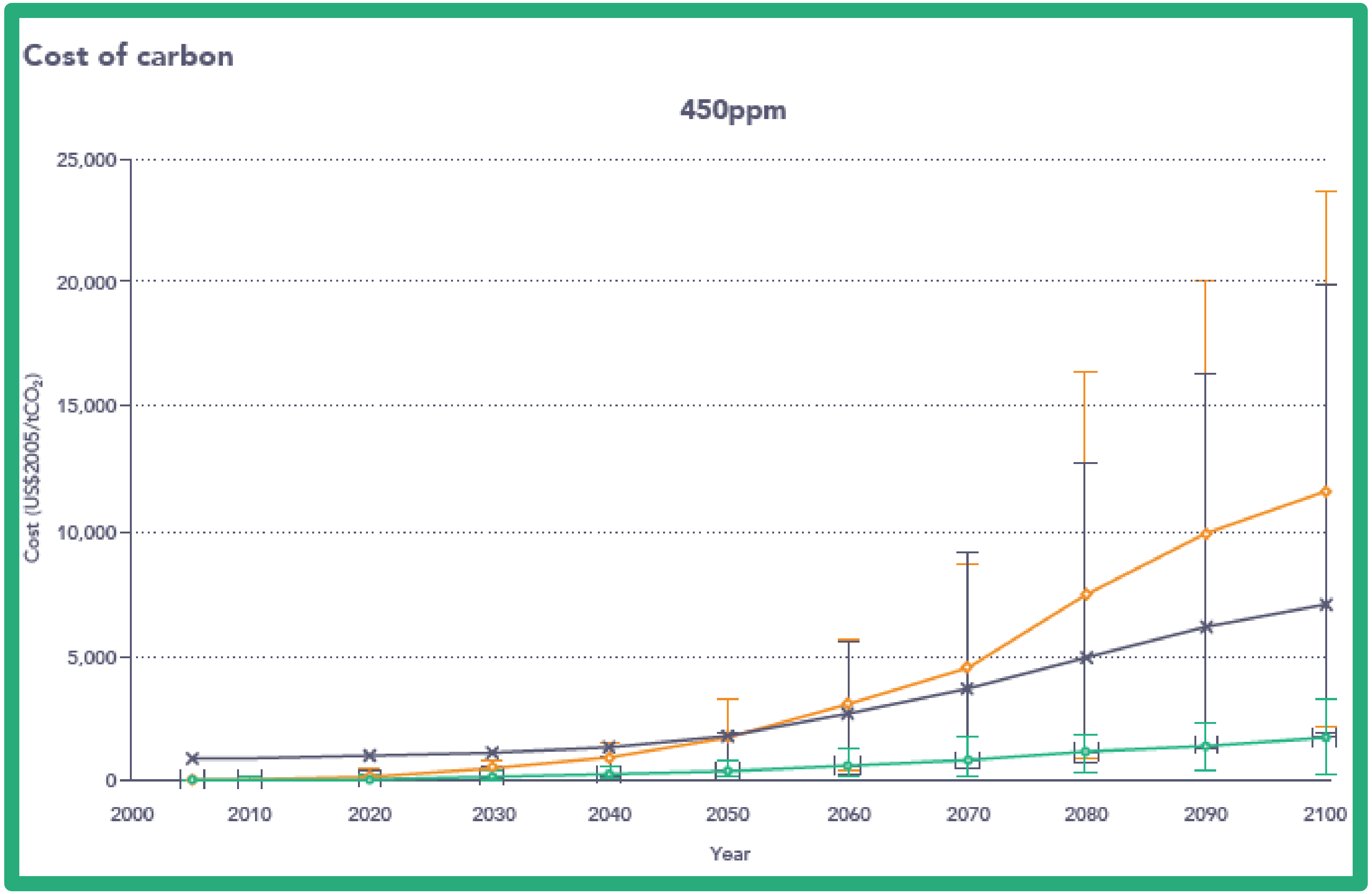


FIGURE 24. Sensitivity of primary energy supply of coal in 2050, 2080 and 2100 to CCS capture rate, produced by TIAM-Grantham.

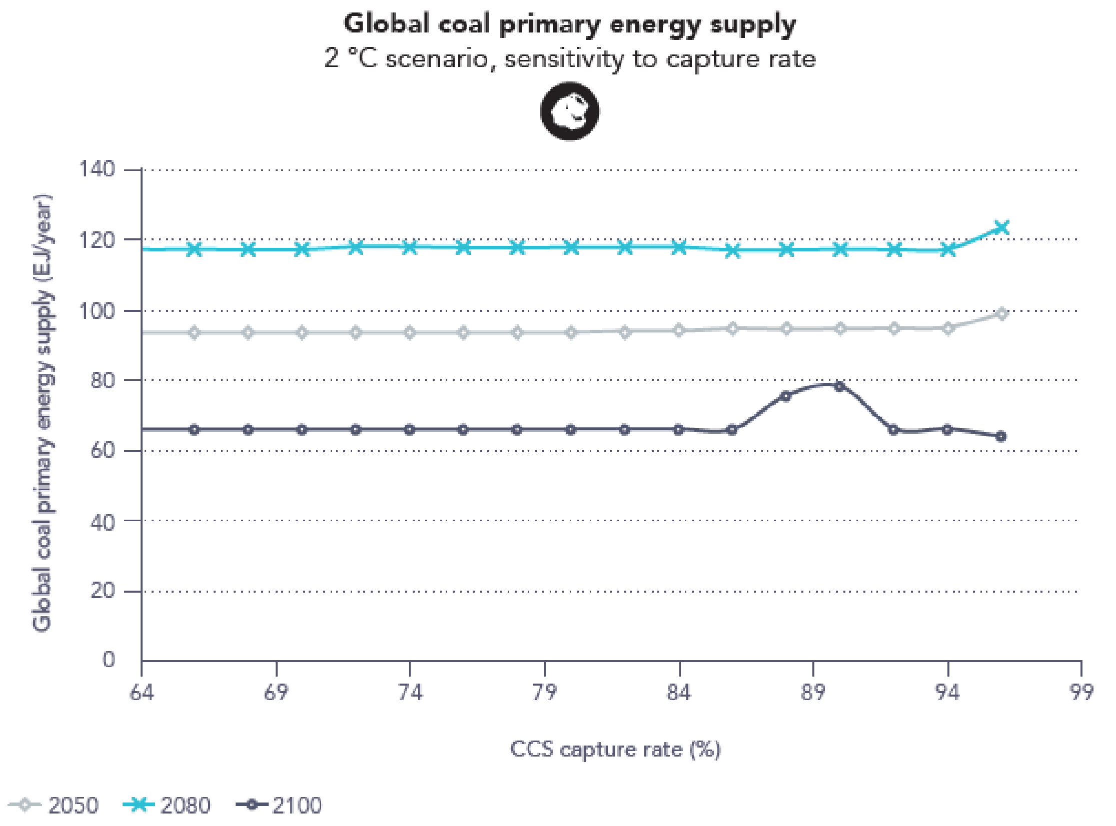


FIGURE 25. Sensitivity of primary energy supply of oil in 2050, 2080 and 2100 to CCS capture rate, produced by TIAM-Grantham.