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An assessment of CCS costs, barriers and potential

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ABSTRACT

Global decarbonisation scenarios include Carbon Capture and Storage (CCS) as a key technology to reduce carbon dioxide (CO_2) emissions from the power and industrial sectors. However, few large scale CCS plants are operating worldwide. This mismatch between expectations and reality is caused by a series of barriers which are preventing this technology from being adopted more widely. The goal of this paper is to identify and review the barriers to CCS development, with a focus on recent cost estimates, and to assess the potential of CCS to enable access to fossil fuels without causing dangerous levels of climate change.

The result of the review shows that no CCS barriers are exclusively technical, with CCS cost being the most significant hurdle in the short to medium term. In the long term, CCS is found to be very cost effective when compared with other mitigation options. Cost estimates exhibit a high range, which depends on process type, separation technology, CO_2 transport technique and storage site.

CCS potential has been quantified by comparing the amount of fossil fuels that could be used globally with and without CCS. In modelled energy system transition pathways that limit global warming to less than 2 °C, scenarios without CCS result in 26% of fossil fuel reserves being consumed by 2050, against 37% being consumed when CCS is available. However, by 2100, the scenarios without CCS have only consumed slightly more fossil fuel reserves (33%), whereas scenarios with CCS available end up consuming 65% of reserves. It was also shown that the residual emissions from CCS facilities is the key factor limiting long term uptake, rather than cost. Overall, the results show that worldwide CCS adoption will be critical if fossil fuel reserves are to continue to be substantively accessed whilst still meeting climate targets.

1. Introduction

Carbon Capture and Storage (CCS) is a technology aiming at separating, transporting and permanently storing carbon dioxide (CO_2) underground in order to avoid its emission into the atmosphere. CCS is often argued to be a key technology for the decarbonisation of the global energy system and can be applied to both power generation and industrial production. For the industrial sector in particular, when material or process replacement is not technically or economically feasible, CCS is currently the only technology able to drastically reduce carbon emissions.

The pivotal role of CCS as a transitional technology towards a low or zero emission future has been highlighted by a number of recent publications [1,2]. A key tool in the assessment of possible pathways for the decarbonisation of the energy system are global Integrated Assessment Models (IAMs). These models are used to produce scenarios of energy system transition to a low carbon world, providing estimates of the future use of fossil fuels, CCS, and other energy resources that are consistent with climate change mitigation targets. IAMs use a range of methodological approaches that determine which technologies are selected, along with a range of input data assumptions like costs and performance, which all have a strong bearing on outcomes. For example, the IEA [3] has employed an integrated assessment model to support a roadmap assisting governments and industry in integrating CCS in their emissions reduction strategies. Adoption of this roadmap would enable storage of a total cumulative mass of approximately 120 $GtCO_2$ between 2015 and 2050 (according to the Carbon Tracker Initiative, this value would be higher and equivalent to 125 $GtCO_2$ [4]).

In this context, the importance of CCS is evident. This technology could enable countries to continue to include fossil fuels in their energy mix [5] without further exacerbating climate change and therefore could unlock assets that would otherwise be stranded [6,7]. Moreover,

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Abbreviations

AR	Assessment Report
BECCS	Bio Energy with Carbon Capture and Storage (CCS)
CCGT	Combined Cycle Gas Turbine
CCS	Carbon Capture and Storage
CDR	Carbon Dioxide Removal
CO_2e	Equivalent carbon dioxide
COE	Cost Of Electricity
COP	Conference Of the Parties
CPS	Current Policies Scenario
ECBM	Enhanced Coal Bed Methane
ECMR	Enhanced Coal Bed Methane Recovery
EGR	Enhanced Gas Recovery
EMF	Energy Modelling Forum
EOR	Enhanced Oil Recovery
EWS	Efficient World Scenario
FOAK	First Of A Kind
GHG	Greenhouse Gas
HadSCCCM1	Hadley Centre Simple Climate-Carbon-Cycle Model
IAM	Integrated Assessment Model
IEA	International Energy Agency
IGCC	Integrated Gasification Combined Cycle
IPCC	Intergovernmental Panel on Climate Change
LCOE	Levelized Cost OF Electricity
LHV	Low Heating Value
NET	Negative Emission Technology
NGCC	Natural Gas Combined Cycle
NGO	Non-Governmental Organization
NOAK	N^{th} Of A Kind
NPS	New Policies Scenario
NPV	Net Present Value
PC	Pulverised Coal
SiMCaP	Simple Model for Climate Policy assessment
TRL	Technology Readiness Level
UKERC	UK Energy Research Centre

meeting climate targets without adopting CCS would mean up to 138% increase in total discounted mitigation costs [8].

Despite the positive estimates on the potential role of CCS reported in the literature, the current number of operating CCS plants is limited. According to the Global CCS Institute, there are currently 39 large-scale CCS projects worldwide in either 'early development', 'advanced development', 'in construction' or 'operating' phase [9]. Among the projects currently in operation (17), nine are based in the United States, followed by Canada (3 projects), Norway (2 projects) and Brazil, Saudi Arabia and United Arab Emirates (1 project each). The Boundary Dam Carbon Capture and Storage Project [10] and the Petra Nova Carbon Capture Project [11] are the only two examples of CCS applied to power generation, while the remaining 15 operating projects are on industrial production (ethanol, fertilizers, hydrogen, iron and steel, synthetic natural gas) and natural gas processing [12].

The total number of large scale CCS projects has fallen in the past five years, from 75 (2012) to 39 currently (2017). At the same time the number of projects in the 'operating' phase has increased from 8 (2012) to 17 (2017). These trends reflect both the technical feasibility of CCS and its struggle to emerge as a game-changing technology against climate change.

The cost of CCS has been previously identified as a major barrier to its adoption, however there are other potential barriers which are preventing its wider implementation. One of the goals of this article is to identify the barriers to the global adoption of CCS, with a focus on its costs. The second goal of the paper is to quantify CCS potential, in particularly with reference to the concept of 'unburnable carbon'. This concept points out that known fossil fuel reserves cannot all be converted to CO_2 emitted to the atmosphere (i.e. burned or otherwise) if the world is to avoid dangerous climate change. A number of reports have been published recently on the topic, though it is by no means a new issue, with analysis available from as early as the 1990s. These studies present a range of insights, from commentary on how the unburnable issue may or may not imply the existence of a 'carbon bubble' in terms of impact on fossil fuel company value, through to analysis identifying specific fossil fuel related projects that may not be needed given the perception of an impending reduction in fossil fuel demand, combined with their potentially high cost relative to other projects.

Analyses on unburnable carbon exists in the grey literature, produced by banks, consultancies, insurers, think tanks and NGOs (Non-Governmental Organisations). Academic research behind the insights is also available in specific areas, but few studies exist that span the topic. In particular, a substantial body of research exists in the climate science domain on the extent of the global carbon budget and the impacts of climatic change. Also, the extent of fossil fuel reserves is fairly well understood, at least to the extent that these reserves, if converted to CO_2 and released into the atmosphere, are demonstrably larger than the allowable carbon budget for a 2 °C world. Less compelling evidence exists on likely outcomes with respect to fossil fuel utilisation, where the use of abatement technology such as CCS might unlock fossil fuel reserves whilst meeting carbon emission targets.

This article identifies and reviews potential CCS barriers, with a focus on CCS costs, and reviews the evidence for the potential role of CCS technology in unlocking fossil fuel assets that would otherwise be stranded in a world where CO_2 emissions are severely constrained.

In section 2, the paper covers the evidence on this broad issue including the climate science, global data on fossil fuel reserves and resources and quantification of unabated burnable carbon. Section 3 summarises the potential barriers to the full development of CCS, including costs (which are covered in details in section 4), geo-storage capacity, source-sink matching, supply chain and building rate, policy regulation and market, and public acceptance. Section 4 summarises cost metrics and estimates for CCS energy and efficiency penalty; CO_2 capture, transport and storage; capital and operating costs. Section 5 includes a review of a multi-model IAM comparison study that considered CCS in relation to the unburnable carbon concept, and quantifies the potential of CCS to give access to fossil fuels in the long term while meeting stringent climate targets. Section 6 provides an analysis on the influence of residual CO_2 emissions on the adoption of CCS in the energy scenarios. This leads to recommendations on the treatment of this aspect of CCS in unburnable carbon assessments in future (section 7) and conclusions (section 8).

2. Background

2.1. The global greenhouse gas budget

2.1.1. The need for emissions mitigation

It is unequivocal that climate change is influencing the planet, with a range of effects already observable [13]. It is also extremely likely that this is caused by emissions of GHG ensuing from human activities, directly (e.g. fossil fuel combustion, cement production) or indirectly (e.g. deforestation). Given the observed impacts to date, the extreme nature of potential future effects on natural and human systems [14], and the rapidly increasing emissions [8], it is pressing that decision makers consider options to mitigate climate change by reducing emissions, and plan adaptation to deal with climate change that does occur.

On the mitigation side, this has led to the concept that the world has a constrained greenhouse gas emissions budget; a cumulative emissions limit which if breached is likely to lead to a global mean surface