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Can "stranded" fossil fuel reserves drive CCS deployment?

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Abstract

Recent studies have evaluated the climate change implications of burning all of the world's proven reserves of carbon. To stay below the ambitious target of two degrees Celsius of warming above average pre-industrial temperatures, the International Energy Agency (IEA) estimates that we would need to emit no more than 884 $GtCO_2$ globally between 2012 and 2050, equivalent to burning approximately one third of current global carbon reserves. This would require leaving large amounts of coal, oil and natural gas in the ground. These unutilized fossil reserves have been referred to as "stranded". In this paper, we analyze CCS not as a cost, but as a potential enabler of utilizing otherwise stranded fossil fuels. We examine case studies at Boundary Dam and Gorgon, introduce a "CO_2 Normalized Price" as a useful metric for bottom-up assessments, and evaluate top-down model results to help value CCS as a way to rescue stranded fossil fuel assets.

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Keywords: Carbon capture; CCS Policy; Stranded Assets; Climate Change; Gorgon; Boundary Dam;

1. Introduction

Recent studies have evaluated the climate change implications of burning all of the world's proven reserves of coal, oil, and natural gas [1,2]. To meet ambitious climate targets, the International Energy Agency (IEA) estimates that we would need to emit no more than 884 $GtCO_2$ globally between 2012 and 2050, equivalent to only burning approximately one third of global carbon reserves [3]. The Carbon Tracker Initiative estimates that only 975 $GtCO_2$ can be emitted by 2100 to reach the same goal of two degrees Celsius of warming above average pre-industrial temperatures (consistent with a 450 ppm stabilization scenario) [1]. The two-degree goal is admittedly among the

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most ambitious, but even less stringent targets will require leaving large amounts of coal, oil and natural gas in the ground and unutilized.

“Reserves” can be defined in different ways. Estimates are broken down into groups by what has already been discovered and what will be discovered based on geologic surveys and past experiences, what type of technology is necessary to recover reserves, and how financially viable it will be to access the resources, as illustrated in Fig. 1.

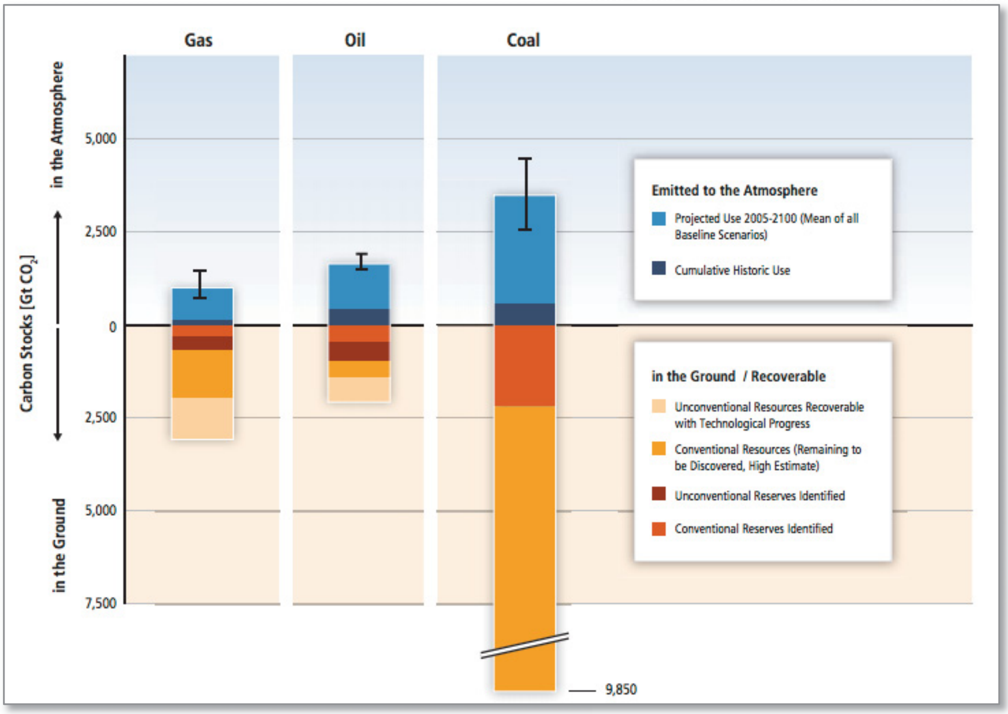

Fig. 1. Carbon dioxide emissions already released and embedded in fossil fuel reserves [4]

The resources accounted for in Fig. 1 are likely to far exceed the allowable emissions for any global climate target. Any reserve surplus greater than a given carbon budget has been referred to as “stranded” or “unburnable” carbon, because external constraints may render these assets unable to be utilized for energy end uses. As with many buzzwords, stranded assets have been previously analyzed with different objectives in mind. IEA and others focus on the environmental risk of burning more than an environmentally healthy amount of greenhouse gas emissions, as illustrated in Fig. 2 [3]. Groups like the Carbon Tracker Initiative have focused on the economic value of fossil fuel assets and financial risk asset holders will face [1]. IEA and the Carbon Tracker Initiative have looked at carbon capture and storage (CCS) as a potential risk mitigation technology to increase allowable carbon budgets in the near and long term. They conclude that CCS can increase allowable carbon budgets, but disagree on the extent.

In Fig. 2, we compare two estimates of fossil fuel assets to carbon dioxide budgets. Fossil fuel stocks are defined as “recoverable carbon from fossil fuels in the ground,” and includes fossil fuels recoverable with technological progress, as well as and those fossil fuels expected to be discovered (see Fig. 1) [5]. Proved fossil fuel reserves are defined by BP as “those quantities that geological and engineering information indicates with reasonable certainty can be recovered in the future from known reservoirs under existing economic and operating conditions” [6]. Carbon dioxide budgets for 2°C and 3°C were taken from the Carbon Tracker Initiative, and are assumed to have an 80% probability of not exceeding the temperature threshold [1].

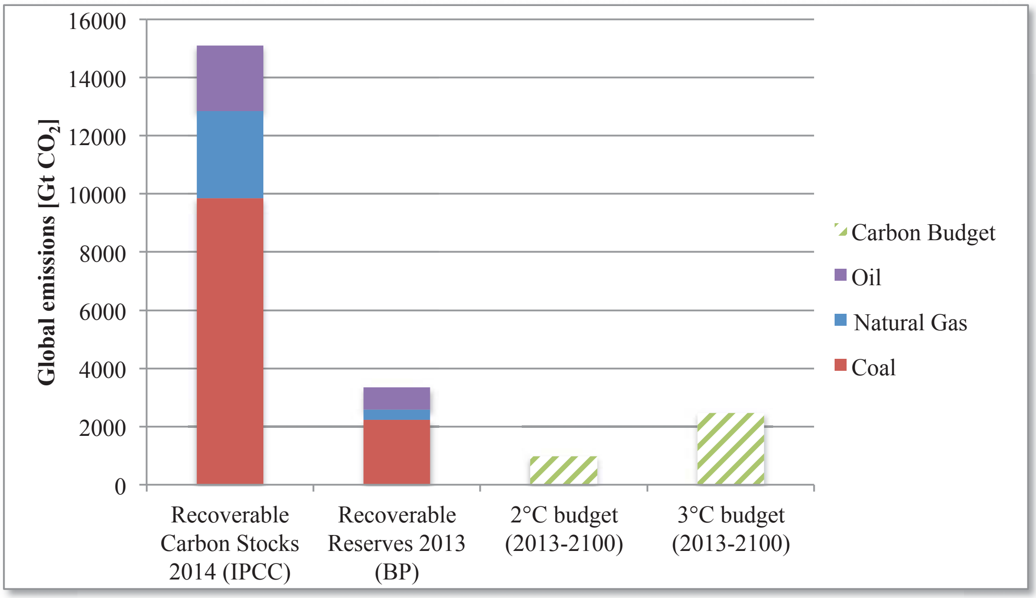

Fig. 2. Global carbon stocks and reserves compared to the allowable emissions for a 2- and 3-degree Celsius emissions target

Despite the potential for CCS to rescue stranded assets, deployment has been slow. While several commercial-scale CCS projects have been implemented in the past two decades, none were at a power plant (though two CCS projects at power plants will start-up in the next year). A major barrier to CCS in the power industry is the high capital costs and energy penalty of CCS compared with conventional fossil fuel-fired generators.

Without policies that effectively put a price on carbon dioxide emissions to the atmosphere, the added costs of CCS can be hard to justify. CO_2 emissions reductions agreements are not being reached on either a national or global level, so no benchmark carbon price is being established. Where a price is established, as in the European Emissions Trading System, it is much lower than the cost needed to justify CCS. Australia did establish a carbon tax in 2012, but it was repealed July of 2014 [7]. In the United States, the Environmental Protection Agency has proposed new regulations that limit CO_2 emissions from power plants, but these will not incentivize CCS deployment for new power plants [8,9] or existing ones [10].

In this paper we explore whether the spectre of stranded fossil assets can help drive CCS deployment. Despite lack of strong climate policy today, it seems stranded assets may have played a role in at least two major CCS projects. In order to better understand the role stranded assets can play in CCS deployment, we first analyze these projects, then perform a bottom-up calculation to relate the value of fossil assets to the cost of CCS, followed by an analysis of top-down energy-economic model results.

2. Case studies

Two major CCS projects where stranded assets seem to have been critical are the Boundary Dam retrofit power plant project in Saskatchewan, Canada and the Gorgon LNG project in Australia. In this section we will investigate how the fossil fuel assets (lignite and natural gas, respectively) have affected the viability of these projects.

2.1. Boundary Dam

SaskPower is retrofitting one unit (110 MW) of the Boundary Dam lignite pulverized coal (PC) power plant in Saskatchewan, Canada, aiming to capture one million tonnes of CO_2 per year through post-combustion to sell for

EOR to the nearby Weyburn oil field [11].

Canada's 2012 update to the Environmental Protection Act requires new coal plants to be compliant with an emissions limit of 420 tonnes of CO_2 emitted per GWh of electricity produced, as well as existing plants when they turn 40 years old [12]. Lignite coal has a high emission factor (~1050 t CO_2/GWh for a PC plant[2]), and therefore would not be able to meet this requirement without CCS. This policy left SaskPower only two choices: include CCS in their project or allow regulations to strand some of their lignite assets. The current price tag of adding CCS to a power plant makes it near impossible to compete with other cleaner technologies such as natural gas combined cycle (NGCC) systems. However, Saskatchewan has a valuable 300-year supply of coal that SaskPower does not want to be wasted or kept underground [13].

SaskPower considered two primary options: retrofit the existing unit with CCS or replace it with a base load natural gas combined cycle (NGCC) power plant. Fig. 3 shows the initial gross costs of the Boundary Dam unit retrofit along with the financial instruments that bring the cost down and compares this to the base load NGCC option. There is no scale in Fig. 3 because SaskPower did not release the absolute costs, only the relative costs [14]. Also included in Fig. 3 is an assumption that the CCS addition is about 50% of the total capital costs [15].

Fig. 3 showcases how Boundary Dam can compete with a base load NGCC plant at current natural gas prices in Canada. Four components played a critical role:

1. There was a substantial federal subsidy from the Canadian government
2. The CO_2 was sold as a by-product for enhanced oil recovery (EOR)
3. The fuel cost was significantly lower for lignite than natural gas
4. The project was a retrofit, lowering the capital costs compared to new plant

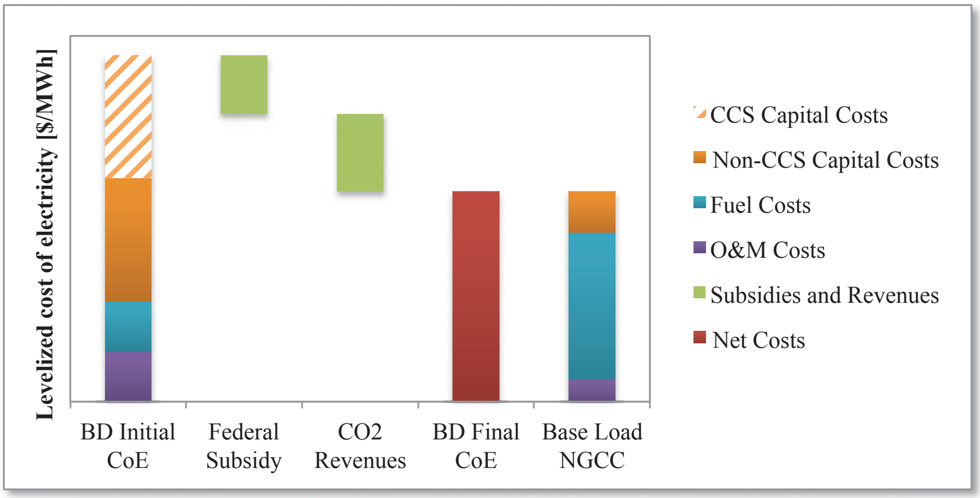

Fig. 3. Relative levelized cost of electricity estimates of the Boundary Dam retrofit by cost category compared to a base load NGCC plant [14]

As can be seen, stranded assets played a role, via the fuel cost savings (point 3 above) and reusing existing power plant infrastructure (point 4 above). However, stranded asset considerations alone would not have driven this project.

SaskPower is considering future retrofits of units 4 and 5 of Boundary Dam with CCS, and believes that the experience of retrofitting unit 3 can reduce future capital costs by up to 30% [15,16]. We estimate that the federal

[2] Calculated using average heat rates from US power plants generating more than 300,000 MWh/yr, totaling 347 PC plants [28] and average emission factors from United States lignite [29].

subsidy accounts for about 20-30% of total capital costs, so the expected reductions would negate the need for future subsidies. SaskPower will be gathering data at unit 3 for two years (2014-2016) to evaluate the viability of replicating CCS retrofits at Boundary Dam before making investment decisions starting in 2017 [15].

The value of the lignite assets and the value of the existing power plant infrastructure are clearly factors in the decision to construct this project. However, just as key was the possibility to sell the CO_2 for EOR. It should also be emphasized that policy was in place that forced SaskPower to make the choice of utilizing CCS or forgoing the lignite assets. It remains to be seen whether the successful experience at unit 3 can be replicated at other units at Boundary Dam, let alone other locations.

2.2. Gorgon

The Gorgon project is a large liquefied natural gas (LNG) plant on the northwest shelf of Australia set to produce 15.6 million tonnes of LNG per year. The plant will be operated by Chevron in a joint venture with Shell, ExxonMobil and others. Once operational, Gorgon will inject CO_2 into deep onshore sandstone reservoirs, 2.5km below Barrow Island [17]. Chevron aims to capture 0.2 tonnes of CO_2 for every tonne of LNG produced, equating to over 3 million tonnes of CO_2 stored every year when producing at capacity [18,19].

Australia recently enacted a carbon tax in 2012, only to repeal it in the summer of 2014 [7]. These changes in climate legislation had seemingly no impact on Gorgon, as preparations for CCS at Gorgon have been in progress for over two decades. Instead of a carbon tax, what drove the use of CCS was the fact that a collaborative decision was made by Chevron and the government of Australia to develop resources at Gorgon using CCS [20].

We have not been able to locate specific project costs for Gorgon but we can document two reasons that the economics worked out at Gorgon:

1. The cost to add CCS was a relatively small fraction of total costs (compared to power plant projects)
2. There are high market prices for the LNG product

Costs of CCS for the Gorgon project were less than 10% of the total capital costs [21]. Unlike power plant CCS projects where adding carbon capture is often 50% of the cost [15] (as is the case at Boundary Dam), natural gas processing projects can include carbon capture with a much lower expense in proportion to the project as a whole [21].

The baseline natural gas price in Asia is very high compared to other places in the world. Fig. 4 shows that LNG was selling for almost $17/MMBtu in 2012, much higher than in the US or Europe and rising since 2007 [6]. The Gorgon project clearly benefits from high LNG prices in the area, that leave a sufficient profit margin in spite of the CCS capital cost additions. However, it would be much more difficult for a similar project to be able to compete with local natural gas markets in North America or in Europe.

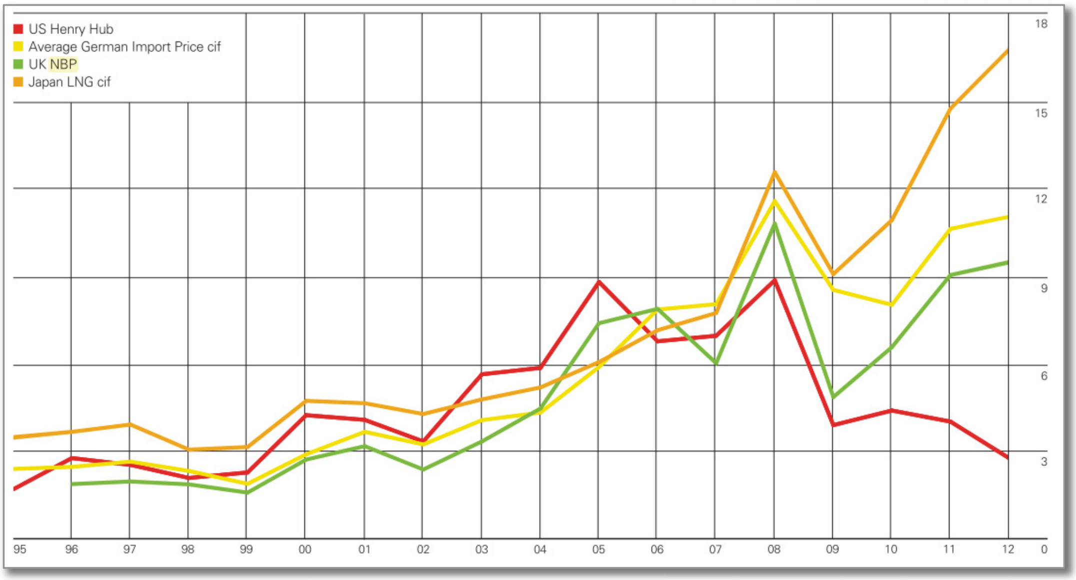

Fig. 4. Natural gas prices by regional market and year in US$/MMBtu [6]

3. Bottom-up analysis

In this section we conduct a bottom-up calculation to understand how the cost of CCS is related to the value of the fossil assets. We are focusing on coal and natural gas, as those two resources are most likely to see CCS additions going forward and they provide us with a meaningful comparison in the Boundary Dam and Gorgon projects.

For this analysis we define a new metric termed the "CO_2 Normalized Fuel Price" to compare the carbon impact of different assets. The CO_2 Normalized Fuel Price (in $/tCO_2$) is defined simply as the fuel price (in $/MMBtu) divided by the emission factor (in tCO_2/MMBtu, see Table 1) for that fuel. Fig. 5 plots the CO_2 Normalized Fuel Price for various prices of lignite coal and natural gas. We use lignite coal as the example since this is the type of coal used at Boundary Dam. Results for other coals (i.e., bituminous or subbituminous) may vary by up to 5% based on emission factor [22].

Table 1. Emission factors and heat rates used in bottom-up analysis

Fuel	Emission factor[3] [tCO_2/MMBtu]	Heat rate for PC and NGCC[4] [Btu/kWh]
Lignite Coal	0.097	10825
Natural Gas	0.053	7638

[3] US national averages for lignite coal and natural gas are used. Natural gas average equates to higher heating value of 1029 Btu/scf [22].
[4] Averages of US power plants over 300,000 MWh annual output [28]

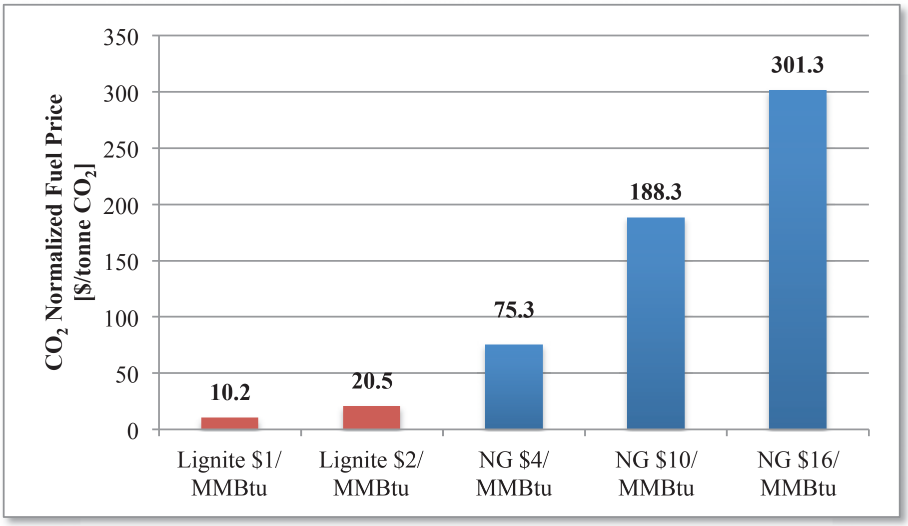

Fig. 5. CO_2 Normalized Fuel Price of lignite coal and natural gas (NG) at different market fuel prices

It is clear that natural gas has a higher CO_2 Normalized Fuel Price compared to coal because of both a higher fuel price and a lower emissions factor. The higher the CO_2 Normalized Fuel Price, the more flexibility there is within a project to absorb CCS costs and still have an economically viable project. For example, Gorgon benefits from high fuel prices equivalent to the bar on the far right in Fig. 5, meaning that it is easier to incorporate CCS for Gorgon at CCS costs on the order of 10% of the CO_2 Normalized Fuel Price, consistent with the conclusions of the previous section.

Fig. 5 also shows that lignite has much lower $/tonne CO_2 estimates for all market prices. Boundary Dam has coal prices closest to the far left bar in Fig. 5. However, unlike Gorgon that is selling natural gas directly, Boundary Dam is not selling coal, but electricity generated from coal. Therefore, we define a new metric of CO_2 Normalized Electricity Price by dividing a target levelized cost of electricity (LCOE) by the heat rate and emission factor (see Table 1). For this exercise we estimate a target LCOE of $90/MWh. The results are shown in Fig. 6.

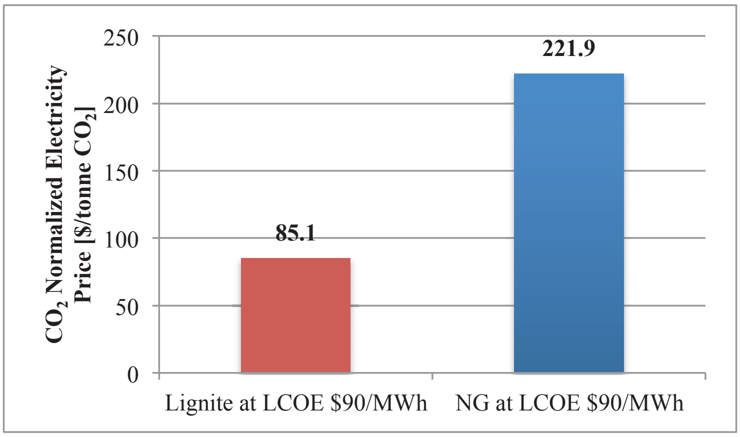

Fig. 6. CO_2 Normalized Electricity Price generated by pulverized lignite coal and NGCC power plants at a $90/MWh LCOE

Carbon capture and compression on a coal-fired power plant cost more than \$50/tCO_2 [23], which is a substantial component of the CO_2 Normalized Electricity Price for lignite in Fig. 6. In order for SaskPower to have a viable project, it needed additional EOR revenues, the ability to use existing infrastructure, low fuel prices, and a substantial government subsidy. This analysis shows that all else being equal, natural gas has more flexibility than does coal for adding CCS to a project. However, to understand the full picture, one must also take into account the differences in capital costs, fuel costs, and costs of adding CCS.

It is important to point out an additional difference between Boundary Dam and Gorgon. At Gorgon, only the CO_2 from the production of fuel is captured, not the CO_2 from final end use. At Boundary Dam, the CO_2 released during coal combustion is captured, resulting in a much higher fraction of the lifecycle CO_2 emissions of the fossil fuel being mitigated.

4. Top-down analysis

Working Group III of the Intergovernmental Panel on Climate Change (IPCC) selected over 50 climate-consistent scenarios from various top-down energy-economic models to be compared based on their different mix of technologies that help them achieve a variety of CO_2 targets in 2100 [24]. Assuming a global carbon price, these top-down models found a significant increase in total mitigation costs if they excluded CCS as a portfolio option on power plants [25]. The IPCC found that excluding CCS from a mitigation technology portfolio would increase discounted mitigation costs 138% and 39% when trying to reach a 450 and 550 ppm target respectively over the time period of 2015-2100 [25]. This increase in mitigation costs includes the cost of stranding valuable fossil fuel assets.

To quantify this further, we chose to evaluate the results of the MESSAGE model, an engineering optimization model used in the IPCC report as well as in the 2012 Global Energy Assessment (GEA) conducted by the International Institute for Applied Systems Analysis (IIASA) [26]. The GEA explored six high-level scenarios of low, intermediate, and high energy demand, each with conventional and advanced transportation options over the timeframe of 2005 through 2100. We chose this model for a more detailed analysis because within each scenario, the GEA compared technology portfolios that prohibit CCS to a full portfolio of mitigation technologies [26]. Similar to the IPCC cost summary above, the restricted CCS scenario represents potential stranded assets that would result from policy decisions that limit or restrict entirely the use of CCS. In the 2012 Global Energy Assessment, three of the six scenarios for 2050 that excluded CCS could not meet climate targets [26].

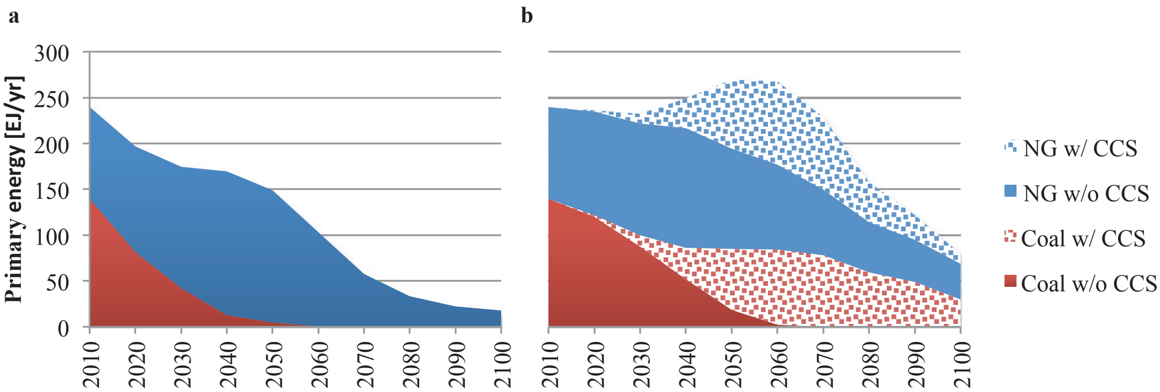

Fig. 7. Annual primary energy of coal and natural gas consumed in GEA-Mix scenarios where (a) policy prohibits the use of CCS on power plants and (b) where a full portfolio of supply side technologies including CCS is available to reach a 2°C climate target

Fig. 7 displays relevant results of two scenarios within the GEA-Mix scenario, which represents an intermediate level of energy demand, a mix of supply and demand mitigation options, advanced transportation options, and a climate target of two degrees Celcius. The graph to the left (a) represents the energy used across all sectors if CCS is not allowed as a mitigation option over the time period 2010-2100 and the right graph (b) represents the energy used when CCS is allowed starting in 2015 [26].[5] The difference in area between cases (b) and (a) above represent the stranded assets that can be "rescued" by the use of CCS under stringent climate policy. As shown in Fig. 8, we estimate that a total of approximately 5400 EJ of coal and 3500 EJ of natural gas can be rescued by CCS over this time period [26]. This inclusion of coal- and gas-fired electricity with CCS also rescues oil assets amounting to 2400 EJ from 2010-2100 [26]. This GEA scenario shows that CCS increased fossil fuel utilization close to a 70% with no increase in CO_2 emissions.

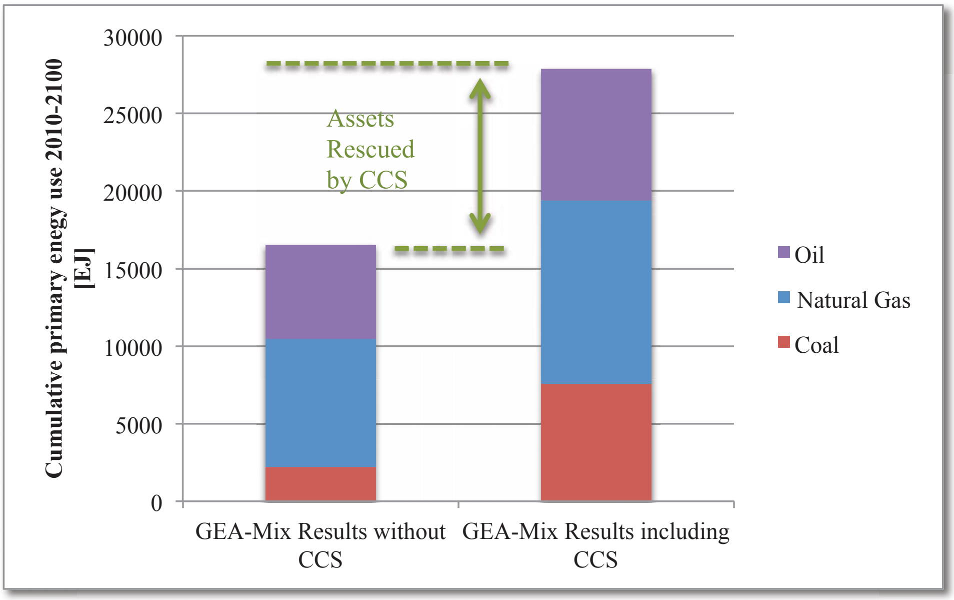

Fig. 8. Total primary energy use from 2010-2100 from fossil fuels in all sectors for the GEA-Mix scenarios where policy prohibits the use of CCS on power plants (left) and where CCS is included in a full portfolio of supply side technologies (right) to reach a 2°C climate target

It is important to take a step back and contextualize the results from the GEA. We show the results of two scenarios of a single top-down modelling methodology. This scenario assumes that CCS technologies will be ready for large-scale deployment before 2020 without consideration for geographic siting or policy constraints and assumes a single global carbon price that begins in 2010. The results of this model are not what is expected to happen, or even what is realistic, just a possible story of how the future energy and emissions trajectories could proceed under the defined assumptions. The results we show in Fig. 8 represent rescued fossil assets for a 2°C or 450ppm target, but any less stringent target would result in fewer (but not zero) stranded assets, as illustrated by the larger 3°C climate budget in Fig. 2.

5. Conclusions

Based on the above, we draw the following conclusions.

1. CCS can rescue stranded assets.

Most top-down models are in agreement that CCS can rescue significant fossil fuel assets stranded by a carbon constraint. Even today without strict climate policy, one can argue projects like Gorgon and Boundary Dam are

[5] GEA scenario assumptions and results are freely available online at http://www.iiasa.ac.at/web/home/research/Flagship-Projects/Global-Energy-Assessment/Chapte17.en.html

using CCS to rescue stranded fossil fuel assets.

2. A policy driver is necessary to strand assets.

In the top down models, a global carbon tax is the driver for stranding assets and incentivizing CCS. While widespread use of carbon pricing is unlikely in the near future, there are other policy drivers that can strand assets and incentivize CCS, such as at Boundary Dam. At Gorgon, the CO_2 storage planned is on the order of 1% of total emissions for Australia, enough to push for voluntary inclusion of CCS [27]. The stronger the policy drivers available nationally and globally, the greater incentive there will be to use CCS.

3. The type of policy is crucial for encouraging CCS

The specific policy driver is crucial to understanding the economics behind stranded assets. At Boundary Dam, a technology mandate on coal alone allowed uncontrolled NGCC to set the target electricity price, making it harder for the economics to work for coal with CCS. If natural gas were also subject to similar regulation, the target electricity price would rise, and therefore the CO_2 Normalized Electricity Price would rise, making it easier for CCS to be deployed on both coal and natural gas. This dynamic is being seen currently in US policy, as future coal power plants are required to implement CCS and compete with uncontrolled NGCC systems. Given today's low gas prices, it is anticipated that no new coal plants with CCS will be built in the US for the foreseeable future [9].

Going back to the original question posed in the title of this paper, "Can stranded fossil fuel reserves drive CCS deployment?", the answer is a qualified yes. If policy drivers strand fossil fuel assets, CCS can help rescue them. However, fossil fuel use with CCS must still be cost-competitive with the alternatives. As seen by Boundary Dam, Gorgon, and the results of GEA and IPCC analyses, this will happen when serious climate policy is enacted.

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