Technical Article – Energy Systems Engineering

Can Technology Unlock 'Unburnable Carbon'?

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Abstract: The following article is an extract of the second white paper of the work carried out by CPSE colleagues in the Sustainable Gas Institute, Imperial College London: "Budinis, S., Krevor, S., Mac Dowell, N., Brandon, N. & Hawkes, A. (2016). *Can technology unlock 'unburnable carbon'?* The Sustainable Gas Institute (SGI) is a unique academic-industry partnership, and a ground-breaking collaboration between the United Kingdom and Brazil. Its role is to provide thought leadership and drive research into the technology that could underpin a sustainable role for natural gas in the global energy landscape. The aim of the SGI White Paper series is to conduct systematic reviews of literature on topical and controversial issues of relevance to the role of natural gas in future sustainable energy systems. This results in highly accessible and widely circulated reports on the state of knowledge with regard to the issue in question, along with identification of the key areas for future research to resolve shortcomings in understanding, identify key technologies and provide critique of assessment processes. The full paper can be downloaded here.

In 2015, the Conference Of the Parties in Paris (COP21) reached a universal agreement on climate change with the aim of limiting global warming further to below 2° C. To stay below 2°C, the total amount of carbon dioxide (CO_2) released, or 'carbon budget' must be less than 1,000 gigatonnes (Gt) of CO_2, which is equivalent to annual emissions of approximately 34 $GtCO_2$ per year. Meeting this target on a global scale is challenging and will require prompt and effective climate change mitigation action. But how much carbon can be emitted if we want to stay below two degrees and how can technology help us?

The concept of 'unburnable carbon' emerged in 2011, and stems from the observation that if all known fossil fuel reserves are extracted and converted to CO_2 (unabated), it would exceed the carbon budget and and have a very significant effect on the climate. Therefore, if global warming is to be limited to the COP21 target, some of the known fossil fuel reserves should remain unburnt.

Several recent reports have highlighted the scale of the challenge, drawing on scenarios of climate change mitigation and their implications for the projected consumption of fossil fuels. Carbon capture and storage (CCS) is a critical and available mitigation opportunity that is often overlooked. The positive contribution of this technology to timely and cost-effective de-carbonization of the energy system is widely recognised. However, while some studies have considered the role of CCS in enabling access to more fossil fuels, no detailed analysis on this issue has been undertaken.

The second White Paper of the Sustainable Gas Institute has presented a critical review focusing on the technologies that can be applied to enable access to, or 'unlock', fossil fuel reserves in a way that will meet climate targets and mitigate climate change. The key findings reported in the White Paper can be summarised as follows:

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1. Carbon capture and storage (CCS) technology underpins the future use of fossil fuels in scenarios that limit global warming to 2°C. Recent studies have examined the extent to which CCS impacts on unburnable carbon but have only considered the timeframe to 2050, which showed a small impact. However, models used in the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report find that on average almost 200 Exajoule (EJ) per year more fossil fuels are consumed by 2050 in a scenario with CCS compared to a scenario without CCS (Figure 1). This margin continues to 2100. Therefore, while the difference in cumulative fossil fuel consumption between a CCS and no CCS scenario is only approximately 3,500-5,000 Exajoule (EJ) in 2050, this will have increased to 14,000-16,000 EJ by 2100.

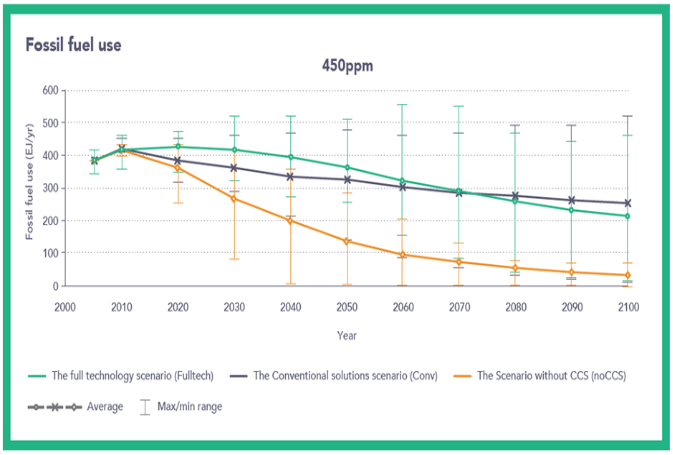

Figure 1. Average consumption of fossil fuels (oil, coal, gas) across a range of integrated assessment model outputs. Scenarios plotted are Fulltech (all technologies available), Conv (renewables constrained), and noCCS (no CCS available)[1]. Error bars represent the maximum and minimum model result observed. Timeframe 2005-2100.

2. The potential role of CCS in unlocking unburnable carbon is greater in the second half of this century. 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. This increases to 37% 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. This is shown in Figure 2, and demonstrates the significance of CCS in enabling access to fossil fuel reserves post 2050.

Among the three key fossil fuels (oil, gas and coal), gas and coal consumption are the most strongly affected by the adoption of CCS, with an increase in coal use of 82-86 EJ/yr and of gas use of 65-104 EJ/yr by 2100, while oil consumption could increase by 29-31 EJ/yr.

Figure 2. Cumulative fossil fuel consumption in the timeframes 2005-2050 and 2005-2100 in a 2°C scenario. $GtCO_2$ includes both emitted and abated CO_2. Reserves estimate is the 'low' value from McCollum et al. 2014[1]. The "woCCS" scenario corresponds to the EMF27 noCCS scenario while "wCCS" scenario corresponds to the EMF27 Fulltech scenario.

3. The capture rate is a crucial factor in determining the extent of future use of fossil fuels. In the vast majority of global abatement studies, an assumption is made that approximately 85-90% of the emissions produced by a process can be captured by CCS technology. This assumption is rarely discussed, but the remaining 10-15% residual emissions is likely to be really important in determining the extent of the role for fossil fuels with CCS in extremely emissions constrained global scenarios.

In the White Paper, a global integrated assessment model (TIAM-Grantham), was applied to produce an initial investigation into the sensitivity of fossil fuel consumption to CCS capture rate. Figure 3 presents the result of this investigation for natural gas. In the earlier stages of mass CCS uptake around the year 2050 the capture rate is not particularly important, but in the second half of the 21st century its role becomes pivotal, with high capture rates (>90%) leading gas to maintaining its 2050 share of primary energy supply. At 2015 UK wholesale gas prices, the additional 100 EJ global gas sales is worth almost £500bn per year. Further studies are needed to comprehensively understand the sensitivity of this result to energy prices, technology cost, performance and availability parameters, and modelling approach.

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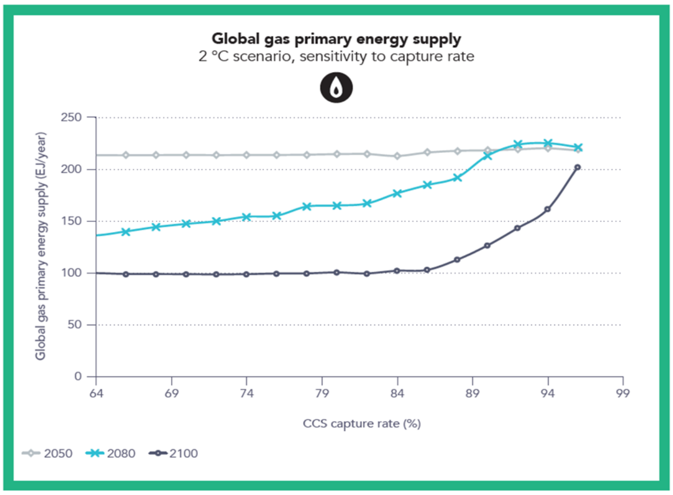

Figure 3. Sensitivity of primary energy supply of natural gas in 2050, 2080 and 2100 to CCS capture rate.

4. In the short-term, there are a range of important barriers to CCS, particularly cost, lack of market and regulatory arrangements, potential supply chain gaps and cautious public perception. The use of CCS entails non-trivial capital costs and energy penalties, leading to relatively high overall cost versus unabated energy production. These costs are particularly high for early-stage demonstrations of the technologies. Compounding cost issues, there are also no effective market arrangements to enable the value of the emissions reductions achieved to be incorporated into CCS investment decisions. For the long-term future of CCS to be realised, all of these issues need to be addressed via a package of research, development and demonstration, along with an effective set of policy instruments to support early-stage demonstration through to mass-market application.

5. In the long term, the cost of CCS is not a significantly limiting factor in the deployment of the technology. The marginal abatement cost produced by the global climate change mitigation models reviewed is high, on average US_{2015}\$473-1,100/tCO_2 by 2050, and rising further to 2100. This is well above the abatement cost associated with CCS reported across the literature, which is a maximum of US_{2015}\$160/tCO_2 for the whole capture, transport and storage chain. Therefore, the cost of CCS is not limiting long-term adoption of the technology in the modelled climate mitigation scenarios. Competition with other low carbon energy technologies is also not limiting the uptake of CCS, otherwise a lower marginal abatement cost would be observed. As discussed, the key factor limiting uptake of CCS is likely to be residual emissions.

6. Geo-storage capacity available for CO_2 is much larger than the CO_2 embodied in present-day fossil fuel reserves. Whilst some uncertainty is still present, recent academic literature has assessed that the global capacity is well above the extent of known fossil fuel reserves, by approximately one order of magnitude. At the same time, in the absence of pressure management strategies, reservoir pressurisation limits (to prevent fracture of sealing caprock) in saline aquifers will limit the accessible CO_2 geo-storage capacity. Recent work using reservoir simulation has found that 0.01 – 1% of the pore volume of saline aquifers will be available for storage over decadal timescales, in the absence of brine production from the reservoir. This will not prevent access to the remaining ~99% of capacity, but the required pressure management will often entail higher costs.

7. Suggested priorities for Research, Development and Demonstration (R,D&D) are:

(a) To move forward with demonstration of large-scale CCS in power and industry sectors, and to establish what conditions will enable the technology to become mainstream

(b) To invest in research to establish the trade-off between CCS cost and maximum capture rate achievable, including further development of capture engineering, with a view to achieving lifetime capture of greater than 95% of emissions produced, and

(c) To ensure any jurisdiction considering large-scale deployment of CO_2 storage should perform regional dynamic assessments of the geo-storage resource and R,D&D on increasing storage efficiency (e.g. through brine extraction for pressure management).

[1]*"Fulltech" scenario has a full portfolio of technologies which may scaled up in the future in order to meet the climate targets. "Conv" scenario has limited solar, wind and biomass potentials and therefore energy demand is met by means of conventional technologies based on fossil fuel deployment in combination with CCS and/or nuclear. In the "noCCS" scenario carbon capture and storage never becomes available.*

[2]McCollum, D., et al. (2014). Fossil resource and energy security dynamics in conventional and carbon-constrained worlds. Climatic Change, 123, 413-426.