Role of CCS in the Energy Transition

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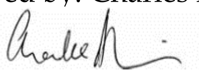
Signed: 

Position: Partner

Date: 1st May 2018

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EXECUTIVE SUMMARY

Transition to a low carbon economy requires near zero emissions in the coming decades and will also need technologies that will "...achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century …," as stated in the Paris Agreement. Therefore, CO_2 capture and geological storage (CCS) should be central to the discussion of mitigating future GHG emissions from fossil fuels because CCS can remove CO_2 emissions from combustion or remove the carbon even prior to combustion, thus providing a low or zero carbon fuel.

In this report, we find that 14 of 163 submitted nationally determined contributions (NDCs) to the UN Framework Convention on Climate Change (UNFCCC) which specifically mention CCS, and five nations submitted mid-century strategies (MCS) that include some description of CCS. Those handful of nations that do mention CCS do so with extensive discussion about barriers to investments in CCS projects including the cost of CCS, the lack of finance and the lack of implementation of government policies and incentives.

Our report also finds that the International Energy Agency, Massachusetts Institute of Technology, Intergovernmental Panel on Climate Change, Global CCS Institute, Deep Decarbonisation Pathways Project, and the EU Joint Research Centre have all projected the need for CCS to achieve the Paris Agreement goals.

The contributions of CCS to scenarios that could successfully achieve the Paris Agreement goals range from 10 to 25 percent of the total GHG emissions response effort depicted in those scenarios.

This points to the critical need for the rapid scale-up of CCS in the coming decades which has yet to begin. The pipeline of major CCS projects has dried up in recent years and no new significant CCS projects are being developed. Further, because of costs and a range of issues from lack of policy framework, policy uncertainty, public perception, and potential long-term storage site stewardship issues, some business leaders in a World Energy Council survey have expressed negative sentiments about the prospect of deploying CCS.

These difficult challenges point to a fundamental gap between the ambitious goal of the Paris Agreement and the reality of deployment of CCS projects.

This report also points out that even if nations did not mention CCS in their nationally determined contributions or in a mid-century strategy, nations could still benefit from developing CCS as part of their future actions. In particular, as nations go through the every-five-year global stocktake, it could be beneficial for nations to analyse for and plan the conditions that would help in the future deployment of CCS in order to reduce emissions significantly.

MAIN FINDINGS

The 'energy transition' is a widely-used term referring to the evolution of the global energy mix toward a low-carbon (many activists say near zero-carbon) footprint for the production, transformation, delivery and end-use of energy in all its forms and applications.

The biggest challenge for the energy sector – both producers and consumers in both developed and developing countries – is to confront the reality of the dominant share of fossil fuels in today's energy mix and consider viable pathways for the transition over time to a more climate-friendly energy mix.

With the dominance of oil today in all modes of transport and the growing share of gas in power generation and petrochemicals, not to mention the many other end-uses for oil & gas, it is challenging to imagine in practical terms the low-carbon energy mix envisaged across all global energy scenarios. Logically, CCS should be central to the discussion of mitigating future GHG emissions from fossil fuels.

Thus, this report looks in some detail at current views on and projections for the role of CCS in the energy sector and what aspects need to be addressed for CCS to play a significant role in the energy transition.

NATIONALLY DETERMINED CONTRIBUTIONS AND MID-CENTURY STRATEGIES

Across the 163 parties which have submitted Nationally Determined Contributions (NDCs)[1] to the UNFCCC, only 13 countries and the European Union on behalf of its 28 member states, have mentioned Carbon Capture and Storage. These are: Bahrain, China, Egypt, Iran, Iraq, Japan, Malawi, Mexico, Montenegro, Norway, Saudi Arabia, South Africa, United Arab Emirates and the EU. The extent to which CCS is discussed varies considerably, from a mention as part of the scope, to its own section in the NDC.

Table 1: The inclusion of CCS by different UNFCCC Parties in their NDCs

-Party	In table or list	In text with other policies	Own section of text	No data
Bahrain			✓	
China		✓		
Egypt		✓		
EU	✓			
Iran		✓		
Iraq				✓
Japan	✓			
Malawi	✓			
Mexico	✓			
Montenegro	✓			
Norway		✓		
Saudi Arabia			✓	
South Africa		✓		
UAE			✓	

[1] All countries NDCs available at http://www4.unfccc.int/ndcregistry/Pages/All.aspx

It is useful to remember that countries may have more interest and focus on CCS than what is mentioned in their NDC, which is only a short document. For example, this is proven by the larger extent to which the EU comments on CCS within its Low Carbon Economy Roadmap for 2050, which is discussed later in this report.

The main messages from the 14 parties' NDCs are summarised below.

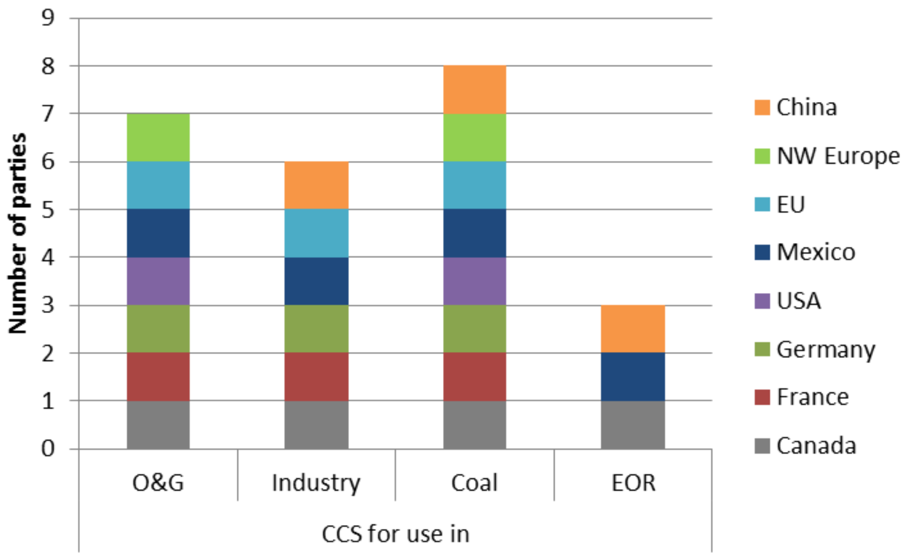
Table 2: Main points of interest from NDCs that mention CCS

Topic included in NDC	Number of Countries	Countries	Comments
R&D or technological needs	4	China, Iran, Malawi, Saudi Arabia	China and Saudi Arabia aim to invest in R&D, while Iran says CCS could address its technological needs. Malawi needs better technology to install CCS.
Investment required	3	Iran, Malawi, South Africa	All three countries state that investment is required for CCS to be successful
Cost of CCS	2	Iran, South Africa,	These two countries attempt to estimate the cost needed to install CCS in their country, US$0.45 billion for South Africa, whilst Iran estimate up to US$52.5 billion for their 6 plans to be introduced, but do not mention an individual CCS cost
Importance of CCS for tackling Climate Change	3	Egypt, Iran, Norway	Egypt claim CCS is essential, Iran state it has high potential, while Norway class CCS as a priority in their NDC.
Mention specific projects	3	Bahrain, Saudi Arabia, UAE	Bahrain: BAPCO Carbon Recovery Plan and GPIC Carbon recovery plan. Saudi Arabia: Enhanced Oil Recovery project. UAE: project relating to steel industry and enhanced oil recovery
Other benefits of CCS addressed	2	Saudi Arabia and UAE	Both these countries talk about the potential economic benefits and the opportunities for enhanced oil recovery
Aims to be leading countries for CCS	2	Saudi Arabia and UAE	Saudi Arabia wants to build the world's largest CCS plant, while UAE wants to build the region's first commercial-scale network for CCS
Minimal coverage of CCS	5	EU, Japan, Malawi, Mexico or Montenegro	These countries only mention CCS as an option within certain sectors or for mitigation without giving much further detail

The Paris Agreement calls for Parties to create a long-term plan, or a mid-century strategy (MCS)[1], looking at how their 2050 goals can be achieved. So far, only Benin, Canada, France, Germany, Mexico and the US have MCSs, though the U.S. has announced in June 2017 that it intends to withdraw from the Paris Agreement. However, other parties have produced similar style reports such as the EU Low Carbon Economy Roadmap for 2050. Since completion of this report, the UK and the Czech Republic have also submitted an official MCS. The UK's report supports commitments to CCS.

CCS is mentioned in all these MCSs except for the one from Benin. However, the uses for CCS in the plans to 2050 vary considerably, including for oil and gas, coal, EOR and industrial sectors such as chemicals, steel and cement.

Figure 1: Summary of the different uses of CCS in key countries' MCSs and roadmaps



In the above figure, NW Europe refers to data from a report published by the PBL Netherland Environment Assessment Agency which is covered in more detail in the main section of the report. This focuses on Belgium, Denmark, France, Germany, the Netherlands and the UK.

Despite CCS being mentioned in five of the six mid-century strategies as well as three roadmaps to 2050, only 4 of these documents use scenarios to model emission reductions up to 2050 which include CCS. Furthermore, only 3 documents quantify the reductions which could be achieved by CCS.

In addition, most countries or parties consider there to be barriers to CCS implementation in their MCSs, whether it is present challenges or those faced when scaling up in the future.

[1] All Mid-Century Strategies available at: https://unfccc.int/process/the-paris-agreement/long-term-strategies

GLOBAL SCENARIOS

The Deep Decarbonisation Pathways Project (DDPP) is a global research initiative looking at how countries can limit global temperature rise to 2 degrees.[1] With research teams in 16 countries responsible for 74% of global CO_2 emissions, these scenarios are well respected and are used by many of the countries, for example in Canada's MCS.

In contrast to many scenarios, the DDPP uses back casting methods to determine steps required to get to the 2050 target. Country reports were released in 2015, of which 13 of the 14 included CCS in their scenarios. Ten of the 13 reports included values for CCS.

Table 3: Values for the contribution of CCS in order to limit global temperature rise to 2 degrees in the DDPP individual country reports

Country	Findings on CCS
Australia	- Up to 21% of electricity supply with CCS in 2050 (9% gas, rest is coal) - CCS will capture 25-50% of emissions from non-energy sectors by 2050
Canada	- 23 Mt CO_2e captured and stored by 2050
China	- In 2050, CCUS is projected to annually remove 2737 Mt CO_2 (1867 Mt CO_2 from the power generation sector and 807 Mt CO_2 from industry emissions) - Accumulated CO_2 capture is approximately 27 Gt CO2 between 2010 and 2050
France	- By 2050, about 10 Mt CO_2 will be stored annually using CCS, equating to 20% of gas and 40% of coal consumed
Germany	- 57 Mt CO_2 captured from industrial sector in their 90% GHG reduction scenario by 2050
India	- 7099 to 9929 Mt CO_2 captured depending on the scenario (mainly coal) by 2050
Indonesia	- Power supply in 2050 in renewable and CCS scenario: 19% coal with CCS and 18% natural gas with CCS
Japan	- Decarbonisation in power sector "notably thanks to large deployment of CCS" approximately 97% reduction in carbon intensity of electricity from 2010 level by 2050
UK	- 318 Mt CO_2 captured between 2033 and 2050 in the industrial sector
US	- In the mixed scenario, 12.2% of electricity generation is from natural gas with CCS -In the high CCS scenario, 26.3% of the supply is from gas with CCS, 28.6% is from coal with CCS

The Joint Research Centre (JRC), a European Union academic consortium, published the Global Energy and Climate Outlook (GECO)[2], which assesses different countries' abilities to reduce emissions to stay within the 2 degree scenario. This paper estimated coal will fall to 10% of the global energy mix in 2050, most of which is associated with CCS, while total energy with CCS is 30%. This 30% includes all forms of CCS including biomass.

[1] DDPP report (2014) http://deepdecarbonization.org/wp-content/uploads/2015/12/DDPP_EXESUM-1.pdf

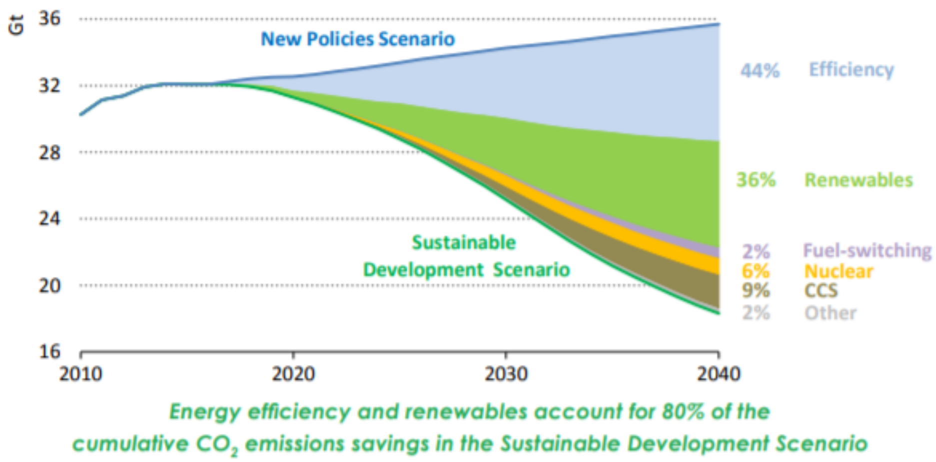
[2] GECO (2015) Road to Paris. https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/geco2015-global-energy-and-climate-outlook-road-paris-assessment-low-emission-levels-under

The International Energy Agency (IEA) sees a large role for CCS, accounting for 14% of emission reductions in the 2 degree scenario (2DS)[1] and 19% of reduction emissions in the BLUE Map scenario.[2] However, the IEA raises concerns about several barriers which need to be addressed for CCS to be able to store the 7000 Mt CO_2 required by 2050 in the 2DS. Expansion of the current global CCS network is required, including significant research and development, investment, and the backing of governments such as the implementation of laws and incentives.

In 2017, the IEA introduced a new scenario in their World Energy Outlook[3]: the Sustainable Development Scenario focuses on achieving aims relating to climate change, reducing air pollution and universal energy access security. Therefore, its main aim is not to prevent global surface temperature rise to two degrees, but it is useful to compare CCS contributions in this report. The other main scenario is the New Policies Scenario, which uses existing policies and announced intentions, which overall leads to a slight increase in CO_2 emissions by 2040.

CCS is projected to account for a further 9% of the cumulative reductions in emissions in the IEA Sustainable Development Scenario in comparison to the New Policies scenario. However a value for CCS reductions in the New Policies Scenario is not given. Therefore this scenario is excluded from the final conclusion that CCS accounts for more than 10% in all scenarios covered in this report, to reach the Paris Agreement 2 degree goal, as it is unclear what the total reductions from CCS would be.

Figure 2: Global CO_2 emissions reductions in the 2017 IEA New Policies and Sustainable Development Scenarios



[1] IEA (2017) Tracking Clean Energy Progress
http://www.iea.org/publications/freepublications/publication/TrackingCleanEnergyProgress2017.pdf

[2] The IEA uses a BLUE Map scenario, which reduces energy-related CO_2 emission by 50% by 2050 from 2010.

[3] IEA (2017) World Energy Outlook

The most recent MIT report: *Climate stabilisation at 2 degrees and net zero carbon emissions*[1], explores possible emission pathways to keep warming below 2 degrees. It focuses on different climate sensitivities: high, medium and low, equating to sensitivity of 4.5, 3.0 and 2.0 degrees C respectively.

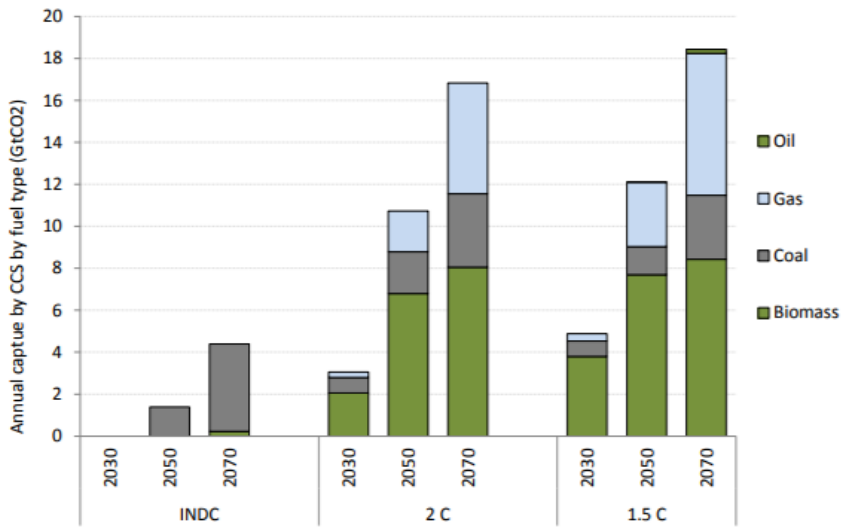
One reference to CCS in the MIT 2017 report is made in a comparison of global energy use, using Integrated Global System Model (IGSM) calculations using estimations for CCS technology costs from the MIT future of coal study from 2007. The 2017 MIT paper concludes that in comparison to the 2007 report on the future of coal, there is now an expected "reduced role for CCS and biomass" and an increased role of renewables (wind and solar), nuclear and energy efficiency. However, CCS could still supply up to 20% of energy use up to 2100.

The *Role of CCS in Meeting Climate Policy Targets*[2], commissioned by the Global CCS Institute (GCCSI) in 2017, looks at the importance of CCS in meeting GHG targets.

Research in this GCCSI report, focusing on the scenarios used in the IPCC 5th Assessment report, comments that "without large scale CCS, most models cannot produce pathways consistent with the 2°C goal".

Comparisons between the role of CCS for 2 degree, 1.5 degrees and INDC targets are shown in the figure below:

Figure 3: Annual carbon captured through CCS by fuel type, dependent on selected scenarios, for 2030, 2050 and 2070.



(From *The Role of CCS in meeting climate policy targets*, GCCSI 2017)

[1] Sokolov et al. (2017) Climate stabilisation at 2 degrees and net zero carbon emissions (MIT) https://globalchange.mit.edu/sites/default/files/MITJPSPGC_Rpt309.pdf

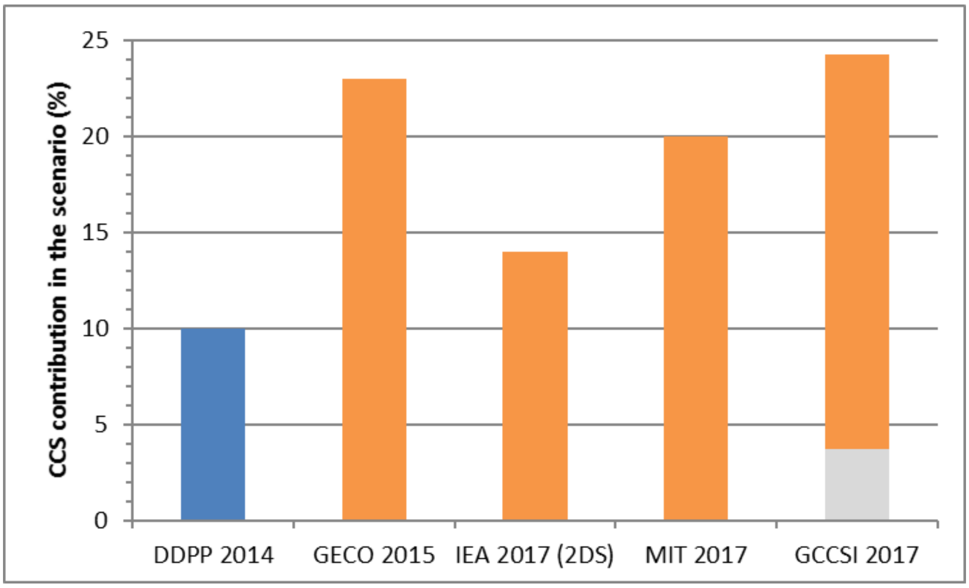
[2] GCCSI (2017) The role of CCS in meeting climate policy targets http://hub.globalccsinstitute.com/sites/default/files/publications/201833/report-role-ccs-meeting-climate.pdf

The GCCSI report concludes that the "risks of CCS not being available as part of a portfolio of mitigation options to address climate policy targets are greater than the risks associated with attempting to develop it".

Summary Observations re: CCS in Key Energy Scenarios

One of the main conclusions is that the five leading scenarios reviewed in this project include CCS, all of which estimate its contribution to reaching a 2 degree world as more than 10%, which means CCS has a sizeable role in emission reductions (see below).

Figure 4: ERM Summary: CCS contributions for the different scenarios to 2050*.



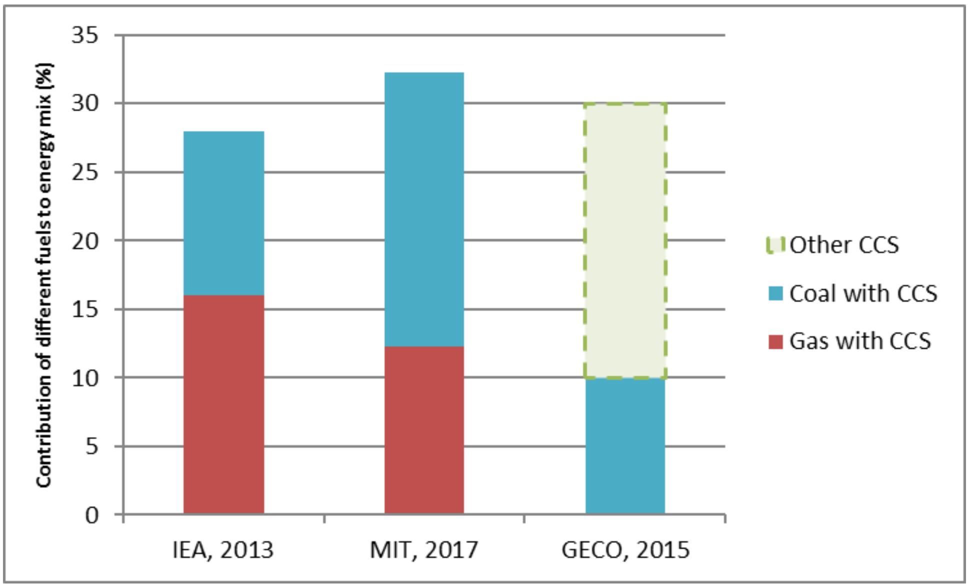
**Blue bar: electricity contribution, Orange bar: total emission reduction contribution, Grey bar: minimum reductions contribution from range of models*

In the DDPP report, CCS accounts for 10% of electricity capacity, whereas all the other scenarios state CCS contributions in relation to total emission reductions.

The MIT 2017 value here is taken from MIT's 'high optimism CCS scenario'. For the GECO 2015 report, this includes coal, gas and biomass usage. The values from different models in the GCCSI report range from 3.7% to 24.3%. The IEA 2017 Sustainable Development Scenario is not included in the figure as it is not a 2DS and no temperature rise is given, although it is expected to be in line with Paris Agreement objectives.

The next figure below compares the energy mix predicted for 2050 across different models. The IEA scenario suggests that the energy mix in 2050 would be comprised of 12% coal and 16% gas. The IEA comments that the future contribution of coal and gas in their scenario is only so high due to CCS.

Figure 5: ERM: Selected Global energy mix projections with CCS for 2050



The main findings from ERM's review of key energy scenarios include:

- The IEA 2DS expects CCS to account for 14% of carbon reductions against the reference transition scenario
- All scenarios which include a contribution from CCS to reach a 2 degree scenario, have it accounting for more than 10% which is a substantial role in the future.
- 13 of 14 DDPP country scenarios include CCS
- Current NDC commitments are not enough to reach a 2 degree world; there is an emission gap, which requires solutions which could include CCS

CCS IN THE PUBLIC DOMAIN

From ERM's assessment of a large number of publicly available sources on CCS (see section 3 of the main report), it is clear that most sources are in agreement that CCS will be required to play a pivotal role in the energy transition.

An outlier is the World Energy Council (WEC) World Energy Issue Monitor report[1], where it seems that the opinion about the role of CCS amongst energy leaders surveyed by WEC has been that CCS is decreasing in importance and its future is seen as uncertain.

[1] World Energy Council (2017) World Energy Issues Monitor: 2017 http://wec-italia.org/wp-content/uploads/2017/04/1.-World-Energy-Issues-Monitor-2017-Full-Report-v1-Embargoed.pdf

Across most of the sources reviewed there are several points seen as holding back CCS development (although the GCCSI does not see some of these as barriers, or disagrees on the numbers):

- CCS technology has been mature for some time, however large-scale projects to prove its application across the energy and industrial sectors, are few compared to earlier projections.

- Costs are currently too high on the whole, especially given low carbon prices. This could be mitigated by financial incentives, and any such support policies should be stable and long term.

- Regulation, e.g. on coal sector emissions, would support CCS deployment if retrofitting is to become more common or more plants that are CCS ready are to be built.

Carbon pricing could serve as an effective policy for enabling investment in CCS and could serve to create a more level playing field with other low-carbon technology options.

Successful operational projects have typically benefitted from project-specific policy and financial support – there are lessons to be learned from these cases:

- Responsibility and accountability across the value chain will have to be more clearly defined to reduce risk premiums.

- Support for CCS will likely have to come from the national government level in the first instance, addressing some of the barriers above, before the private sector will become interested again.

Overall the various leading energy scenarios cited in this report, all conclude that current commitments are not enough and more must be done in order to increase our chances of meeting the 2 degree goal. This should leave an opportunity for CCS, especially with the high level of fossil fuel reliance predicted to continue into the future.

At the same time, the share of CCS's contribution to the transition to a low-carbon energy mix has gone down somewhat when the latest scenarios are compared to earlier scenarios, and energy sector leaders surveyed by WEC expect CCS to play a lesser role from their view of today's energy trends.

The challenge suggested by ERM's findings, and an area potentially ripe for further analysis, is how to 'square the circle' of CCS still needing to provide an estimated 10%+ of the projected GHG reductions required by 2050 in a 2 degree pathway when energy executives surveyed by WEC are not optimistic about CCS.

1 SECTION 1: INTRODUCTION

1.1 BACKGROUND AND OBJECTIVE

This report has been prepared by ERM for the Policy and Incentives Working Group of the oil & gas industry Carbon Capture Project (CCP4) whose current member companies are BP, Chevron and Petrobras.

The objective of this report is to evaluate the current situation regarding the role of carbon capture and storage (CCS) in the energy transition, namely:

- What impetus is created for CCS by the ambition to reduce global greenhouse gas (GHG) emissions under the Paris Agreement?
- How is CCS treated in the leading scenarios and analyses related to the transition over time to a low-carbon energy mix?
- To what extent do government plans and policies serve to support the role of CCS in the energy transition (or downplay the role of CCS)?
- What sorts of actions could help CCS achieve its long-term potential to contribute to the energy transition and the Paris Agreement ambition?

1.2 CONTEXT AND DRIVERS

The Paris Agreement sets a goal to maintain a global temperature rise this century to well below 2°C above pre-industrial levels and sets an ambition target' to limit the temperature increase even further to 1.5 degrees Celsius. To date, 144 Parties have ratified the Paris Agreement and set an initial GHG reduction commitment. The Paris Agreement entered into force in November 2016.

The Paris Agreement also calls for Parties to submit "long-term, mid-century low greenhouse gas emission development strategies" (or "Mid-Century Strategies") by 2018.

In addition, Parties to the Paris Agreement will "take stock" in 2018 of the collective efforts in relation to progress towards the goal set in the Paris Agreement and inform the preparation of future Nationally Determined Contributions (NDCs).

The informal 2018 global "stocktake," now called the Talanoa Dialogue, under the Paris Agreement is likely to conclude that the sum total of existing national commitments is inadequate to achieve the goal of 2 / 1.5°C and call for more concrete actions to curb GHG emissions.

The 'energy transition' is a widely-used term referring to the evolution of the global energy mix toward a low-carbon (activists would say near zero-carbon) footprint for the production, transformation, delivery and end-use of energy in all its forms and applications.

Studies by the IPCC, IEA and many others suggest that the share of fossil fuels in the global energy mix needs to be drastically reduced by 2050, which is the core challenge of the 'energy transition'. The IEA Energy Technology Perspectives (ETP) 2017, states that 65% of the global energy mix must be low-carbon energy sources in 2060 to reach a 2DS, with a reduction in carbon intensity of 78%.

Since fossil fuels dominate the energy mix today (>80% share), the NDC scenario of the IEA (based on measures countries committed to so far in NDCs under the Paris Agreement) suggests that the 2°C/450 ppm scenario will not be met because NDCs are insufficient to bend the fossil fuel demand curve.

The biggest challenge for the energy sector – both producers and consumers in both developed and developing countries – is to confront the reality of the dominant share of fossil fuels in today's energy mix and consider viable pathways for the transition over time to a more climate-friendly energy mix.

With the dominance of oil today in all modes of transport and the growing share of gas in power generation and petrochemicals, not to mention the many other end-uses for oil & gas, it is challenging to imagine in practical terms the low-carbon energy mix envisaged across all global energy scenarios. Logically, CCS should be central to the discussion of mitigating future GHG emissions from fossil fuels.

Thus, this report looks in some detail at current views on and projections for the role of CCS in the energy sector and what aspects need to be addressed for CCS to play a significant role in the energy transition.

1.3 REPORT STRUCTURE AND APPROACH

The report will first provide a comprehensive overview and assessment of the role of CCS in existing energy scenarios and government plans/strategies. This will focus on the specific instances where CCS has been included.

The report will also look at examples where CCS could make a significant contribution even if it was not mentioned specifically in national plans.

The report analyses the treatment of CCS in leading scenarios for the energy transition and in major studies of energy pathways in the public domain.

There is a discussion of the potential role of CCS projects under the Market Mechanisms provisions of the Paris Agreement.

The report compiles the main results from the above reviews and analyses and presents key findings to support ERM insights on the role of CCS in the energy transition.

Discussion is provided on possible actions that could be taken to support and enhance the role of CCS in the energy transition in light of the key findings and possible next steps are identified.

2 SECTION 2: CCS IN NDCs, MCSs, MBMs, ENERGY TRANSITION SCENARIOS

2.1 ROLE OF CCS IN NDCS THAT CITE CCS

Across the 163 parties which have submitted Nationally Determined Contributions (NDCs)[1] to the UNFCCC, only 13 countries and the European Union on behalf of its 28 member states, have mentioned Carbon Capture and Storage. These are: Bahrain, China, Egypt, Iran, Iraq, Japan, Malawi, Mexico, Montenegro, Norway, Saudi Arabia, South Africa, United Arab Emirates and the EU. The extent to which CCS is discussed varies considerably, from a mention as part of the scope, to its own section in the NDC. This is shown in Figure 6 for the 14 NDCs with the full details in Table 4.

Figure 6: The extent to which CCS is mentioned in the 12 countries NDCs

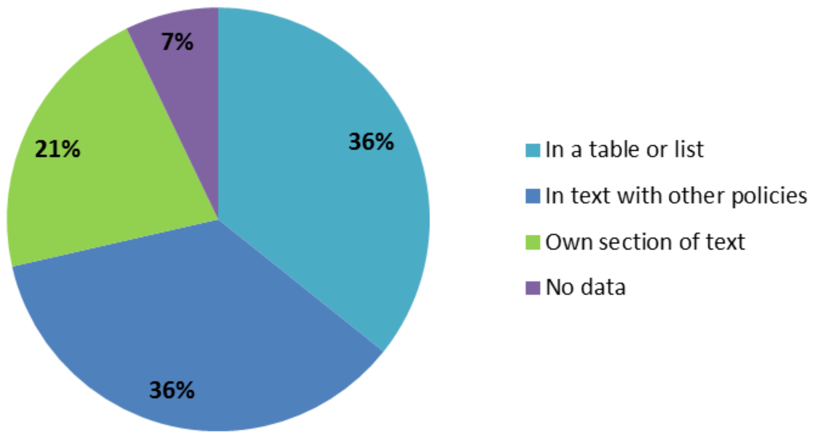


Table 4: The inclusion of CCS by different parties in their NDCs

Party	In table or list	In text with other policies	Own section of text	No data
Bahrain			✓	
China		✓		
Egypt		✓		
EU	✓			
Iran		✓		
Iraq				✓
Japan	✓			
Malawi	✓			
Mexico	✓			
Montenegro	✓			
Norway		✓		
Saudi Arabia			✓	
South Africa		✓		
UAE			✓	

[1] All countries NDCs available at http://www4.unfccc.int/ndcregistry/Pages/All.aspx

The EU, Japan, Malawi, Mexico and Montenegro have the least content on CCS, outlining it as a mitigation policy for the energy sector, as well as the agricultural sector for Malawi. Five of the 14 parties went a step further by including CCS in the main text of their NDC. China acknowledges it is an area which requires research and development along with other low-carbon and nuclear power technologies. Egypt categorises CCS as one of four "key technology-related requirements essential for transformation" to a low carbon economy. This is included alongside energy efficiency, co-utilisation of fossil fuels and biomass, and co-generation plants. Iran acknowledges its need for renewable and alternative energy sources as well as CCS due to its significant share in the energy sector, accounting for more than 90% of its economy.

Norway states that CO_2 capture and storage is a priority area for national climate policy, which indicates it has a high interest in its development but does not go into further detail. Finally, South Africa identifies CCS as a technology which could further reduce the country's emissions. It is the only country to address the potential economic cost of this, estimating a cost of US$0.45 billion for use at a coal-to-liquid plant, capturing 23 million metric tonnes (Mt) CO_2. However, of the five plans South Africa discussed the financial costs for CCS is the one they plan to invest the least in.

Out of the 14 parties, the three Middle East countries; Bahrain, Saudi Arabia and UAE, focused on CCS in more detail in their NDC. Bahrain has developed different plans and projects relating to carbon capture and storage. The first is the BAPCO (The Bahrain Petroleum Company) Carbon Recovery Plan which utilizes waste CO_2 from gas streams for industrial uses. There is also the Gulf Petrochemical Industries Company (GPIC) Carbon Recovery Project, which captures CO_2 for flue gases at the GPIC Methanol Plant.

Saudi Arabia takes a different approach looking for mitigation co-benefits from economic diversification, which includes CCS. Their ambitions are high, aiming to build the world's largest carbon capture and utilisation plant, to purify 1500 tonnes of CO_2 a day for use in petrochemical plants. In order to achieve this, there will be an enhanced oil recovery pilot project to assess the viability of CO_2 sequestration in oil reservoirs. Hoping to capture 40 million cubic feet of CO_2 a day to be injected into the Othmaniya oil reservoir, the plan also includes monitoring and surveillance. Saudi Arabia addresses CCS as a response to climate change, again focusing on research and development that will enhance economic competitiveness. Finally, UAE have similar ambitions to its neighbouring country, mentioning the development of a commercial scale network for CCS in its NDCs. The focus is capturing emissions from the steel manufacturing industry, to store in oil fields where it can also be used for enhanced oil recovery.

The one remaining party to include CCS in the NDC is Iraq; however, it is published in Arabic and no English version could be found. Therefore, it is unknown what level of ambition Iraq is aiming for in relation to CCS in the future.

Overall, the NDCs vary between countries; however, they are quite short documents, so it does not mean other countries are not considering CCS, which is why the research also reviewed other documents such as mid-century strategies. Moreover, the EU has a separate CCS policy[1] which is not mentioned within its NDC. Therefore, it is important to remember that countries may have more interest and focus on CCS than what is mentioned in their NDC. The main take away messages from the 14 parties' NDCs are summarised below.

Table 5: Main points of interest from the 12 parties' NDCs

Topic included in NDC	Number of Countries	Countries	Comments
R&D or technological needs	4	China, Iran, Malawi, Saudi Arabia	China and Saudi Arabia aim to invest in R&D, while Iran says CCS could address its technological needs. Malawi needs better technology to install CCS.
Investment required	3	Iran, Malawi, South Africa	All three countries state that investment is required for CCS to be successful
Cost of CCS	2	Iran, South Africa,	These two countries attempt to estimate the cost needed to install CCS in their country, US$0.45 billion for South Africa, whilst Iran estimate up to US$52.5 billion for their 6 plans to be introduced, but do not mention an individual CCS cost
Importance of CCS for tackling Climate Change	3	Egypt, Iran, Norway	Egypt claim CCS is essential, Iran state it has high potential, while Norway class CCS as a priority in their NDC.
Mention specific projects	3	Bahrain, Saudi Arabia, UAE	Bahrain: BAPCO Carbon Recovery Plan and GPIC Carbon recovery plan. Saudi Arabia: Enhanced Oil Recovery project. UAE: project relating to steel industry and enhanced oil recovery
Other benefits of CCS addressed	2	Saudi Arabia and UAE	Both these countries talk about the potential economic benefits and the opportunities for enhanced oil recovery
Aims to be leading countries for CCS	2	Saudi Arabia and UAE	Saudi Arabia wants to build the world's largest CCS plant, while UAE wants to build the region's first commercial-scale network for CCS
Minimal coverage of CCS	5	EU, Japan, Malawi, Mexico or Montenegro	These countries only mention CCS as an option within certain sectors or for mitigation without giving much further detail

2.2 *ROLE OF CCS IN COUNTRIES' MID-CENTURY STRATEGIES*

Under the UNFCCC Paris Agreement (COP21), Parties should strive to create a long-term plan, or a mid-century strategy (MCS), looking at emission reductions to 2050 and how their goals can be achieved. So far, only 6 countries have produced MCSs: Benin, Canada, France, Germany, Mexico and the United States. The extent to which these covered carbon capture and storage (CCS) is discussed below:

[1] EU CCS Directive on Geological Storage of Carbon Dioxide (2009) http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0114:0135:EN:PDF

2.2.1 *Submitted Mid-Century Strategies*

Canada MCS[1]

CCS is at an advanced stage of development in Canada, with a range of projects already in place. This includes the Boundary Dam project, which uses CCS at a coal-fired power station - the world's first commercial application of CCS in this way, which is estimated to reduce emissions by 1 Mt of CO_2 each year. Canada believes this project is key to understanding the economic, environmental and technical performance of CCS technology which could encourage countries to implement similar projects. The Alberta Carbon Trunk Line (ACTL) is another CCS project currently under development which captures and uses CO_2 emissions for enhanced oil recovery. It is expected that ACTL will support permanent storage of about 14.6 Mt of CO_2 per year at full capacity.

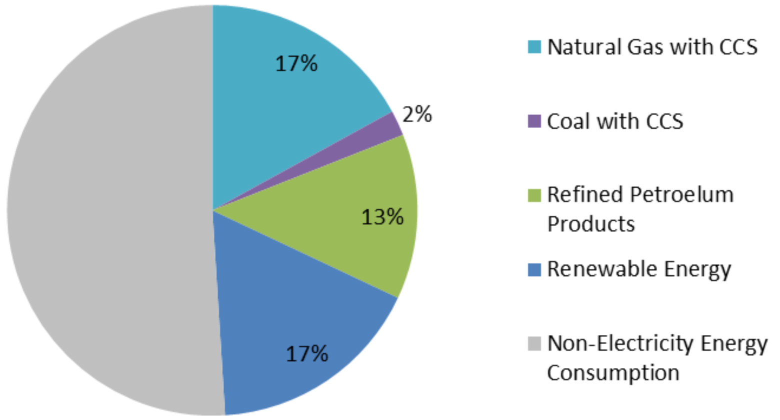
Canada views CCS as a viable option for preventing emissions to the atmosphere, with the "oil and gas sector able to make use of its proximity to geological reservoirs to store carbon emissions captured on site". They also believe there is the potential for emissions reduction through CCS in the iron and steel, pulp and paper, chemical and cement sectors. CCS is currently used to capture emissions from steam methane reformers.

Within Canada's MCS are a range of decarbonisation pathways to compare different methods to reach its mid-century goal of 80% reduction in emissions from 2005 levels. Most of these rely on currently available technologies. The different scenarios are: Deep Decarbonisation Pathways Project (DDPP) (high ambition) Trottier Energy Future Project (Current Tech and New tech) and Environment and Climate Change Canada (High Non-Emitting and High Demand Response). Only one scenario uses oil and gas CCS as a significant supplier of fuel use in 2050 (Fig. 7) which is the DDPP high ambition pathway.

In the analyses, "natural gas and coal with carbon capture and storage (CCS) technology is apparent throughout the projection period with natural gas generation with CCS as a significant proportion of electricity generation in 2050". The DDPP high ambition scenario estimates that electricity will generate 48% of total energy consumption in the country by 2050. It is expected 17% will come from natural gas with CCS, 2% from coal with CCS, 13% by refined petroleum products and the final 17% from renewable fuels (Fig.7). Alternatively, the Environmental and Climate Change Canada model estimates CCS could reduce greenhouse gas emissions in the energy sector by 23 Mt CO_2e (gross) by 2050.

[1] Canada's MCS http://unfccc.int/files/focus/long-term_strategies/application/pdf/can_low-ghg_strategy_red.pdf

Figure 7: DDPP high ambition scenario for electricity generation, which generates 48% of energy consumption.*



*Values may not total 48% due to rounding.

Canada's MCS says that "some barriers for deployment of CCS technology in these sectors remain, such as lack of economic capture technology and infrastructure to connect carbon source with sequestration formations" and that CCS "will require significant investments and pipeline network construction" as well as "more technological advances to make CCS economic".

Although Canada does not state which pathway it intends to follow, they do conclude that "much of the transformation can be achieved with existing technology, but innovation and significant investments in research, development, demonstration & deployment, and related infrastructure, will be fundamental to the transition".

Therefore, it is likely CCS will continue to play an important role in the Canadian energy sector, but it is expected to require further investment and research to develop and deploy the technologies in the future.

France MCS[1]

The French mid-century strategy focuses on a drastic decarbonisation, by a factor of 10, of the energy mix by 2050. In the long term, this relies on "significant deployment of carbon capture and storage systems by 2050", aiming to install across all fossil fuel power stations still in operation then. However, France does not quantify how significant the implementation of CCS will be. France acknowledges it must deploy CCS systems by 2050, but it will involve "taking account of the storage options available when choosing where to locate facilities". The point of cost is raised, with France aiming to make CCS economically viable through research and innovation, but there is no reference to any values or projections.

[1] France's MCS http://unfccc.int/files/focus/long-term_strategies/application/pdf/national_low_carbon_strategy_en.pdf

In their MCS they focus on the transition to a low-carbon industrial sector, which involves 4 steps. Listed in chronological order, CCS development and deployment is the final point to reduce GHG intensity for energy generation and industrial processes, which will occur "in the long term". There is a particular focus on CCS for the chemical industry as well with aim to introduce "carbon capture and storage (CCS) and carbon capture and use (CCU) technologies suitable for use in the chemical industry, hitting our target of an 85% reduction by 2050", which is a target for reducing the GHG intensity of energy production.

Overall, CCS is mentioned throughout the France mid-century strategy, but no figure or values are stated. With aims to implement by 2050, it may be a strategy to achieve the final reductions required to meet their target.

GERMANY MCS[1]

CCS is considered a "new technology" for Germany, which can be used to meet climate targets in the long term, in a "cost effective way"; however, the focus in their MCS is mainly around CCU. Germany considered the industrial sector "challenging in terms of reducing emissions" but there are "various options available". As an example, they suggest CO_2 emissions can be reduced using CCU and could be an option for a "circular carbon economy" in this sector. "If emissions are unavoidable, it may be necessary to lower them through long-term carbon capture and storage (CCS)". It is suggested this refers to the capture of any emissions produced using CCS, however, there is no definition of what Germany means by "unavoidable".

To achieve the reductions that Germany has committed to in the industry sector "will require defining further steps in implementation no later than 2020-2030", therefore Germany aims to commence "immediate major research and development work targeted to specific process innovations and to CCU". CCS is mentioned as having a "potential role" if it turns out to be "necessary and acceptable".

In general, Germany's focus is on CCU, with CCS a potential option if required. They also acknowledge research and development is required for both technologies. However, there are no projections for the size of the role CCU and CCS will play in Germany's reduction targets.

[1] Germany's MCS
http://unfccc.int/files/focus/long-term_strategies/application/pdf/national_low_carbon_strategy_en.pdf

MEXICO MCS[1]

To achieve a 50% reduction in emissions by 2050, models used by Mexico in their MCS "rely on energy efficiency improvement and the deployment of renewable energy" which includes gas or coal with CCS in some instances. One scenario to achieve this reduction target was through the DDPP which shows an "important role for natural gas CCS technology". However, there are no more details about the extent of CCS or the DDPP scenario pertaining to Mexico.

Mexico has set a wide range of aims to achieve their reduction target, two of which refer to CCS.

- "To continue exploring carbon capture and sequestration (CCS) technologies aimed at the implementation of projects. This will include the possibility of using CCS for enhanced hydrocarbon recovery".
- "To promote highly efficient technologies, fuel substitution, industrial process redesign, and CO_2 capture technologies in energy-intensive industries such as cement, steel, petroleum, chemical, and petrochemical industries"

This shows that Mexico has good intentions to implement CCS in the future in a range of sectors as well as enhanced oil recovery (EOR).

USA MCS[2]

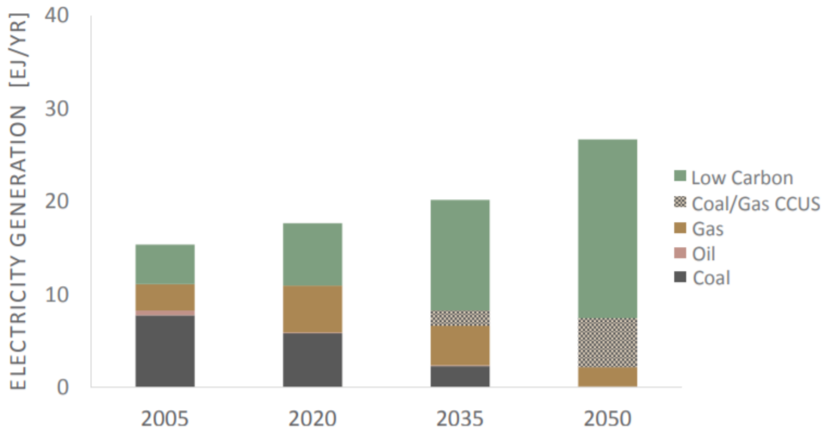
A mid-century strategy was released by the previous Administration of the U.S., but the current Administration announced on June 1, 2017 that it intends to withdraw from the Paris Agreement as soon as November 2020. To meet the USA's reduction target, authors of the previous Administration strategy used a mid-century strategy benchmark scenario, which is referenced throughout their MCS. For the energy sector, the aim was to replace nearly all fossil fuel electricity production with renewables, nuclear and fossil fuels or bioenergy with carbon capture, utilization and storage (CCUS) by 2050.

The benchmark scenario includes 55% renewables, 17% nuclear and 20% CCUS with fossil fuels (Fig. 8). Furthermore, "nearly all fossil fuel power plants without CCUS are phased out by 2050" in the MCS benchmark scenario.

[1] Mexico's MCS http://unfccc.int/files/focus/longterm_strategies/application/pdf/mexico_mcs_final_cop22nov16_red.pdf

[2] USA's MCS http://unfccc.int/files/focus/long-term_strategies/application/pdf/mid_century_strategy_report-final_red.pdf

Figure 8: Electricity supply in the MCS benchmark scenario



(From the USA MCS)

In their MCS, the USA states that "CCUS technology can significantly reduce or eliminate emissions from coal or natural gas plants" however "it is not widely used in the United States today due to high costs and the lack of sufficient market incentives". Despite this, progress is expected on the first power plant with CCUS in the USA.

Analysis by US Department of Energy for the MCS indicated that "without further innovation and additional policies that drive down emissions, over half of U.S. electricity generation in 2040 will come from fossil fuels without CCUS". This highlights how important additional actions in terms of investment and research are to implement CCUS on the scale needed to achieve their MCS benchmark scenario.

To address this, the USA MCS tests a 'No CCUS' scenario, showing how decarbonisation could be achieved without this technology. This contingency plan relies on 30% increased production from solar and wind technology, and nuclear generation increases by over 60 percent. This scenario achieves 80% reduction by 2050 by a "greater emphasis on enhancing the land carbon sink to produce negative emissions" as well as a "more rapid phase-out of coal and natural gas". Compared to the MCS Benchmark scenario, coal and natural gas use in the 'No CCUS' scenario are 97 and 28 percent lower, respectively, in 2050.

There are also many references to incorporating CCUS technology with biomass to achieve negative emissions, or bio-energy with CCS (BECCS). However, the USA states "the success of the MCS is therefore not contingent upon the successful emergence of BECCS or any other single technology" which is why they have created a scenario without CCUS as well as without carbon removal using bio-energy.

Overall, the USA MCS aims to incorporate CCUS in the future to decarbonise the energy sector but acknowledges that technology needs to be developed to be used on a commercial scale, and further incentives will be required.

BENIN MCS[1]

After translating the Benin MCS, there were no references found to CCS.

2.2.2 *Other national plans/strategies up to 2050*

EU Low Carbon Economy Roadmap for 2050[2]

Despite not submitting an official MCS, the EU has published a low carbon economy roadmap for 2050. Its target is at least an 80% reduction in emissions by 2050, which analysis shows is almost impossible without a 95-100% decarbonisation of the power sector. To address this, the EU aims to achieve almost full decarbonisation of the power sector using renewables, nuclear and CCS as well as increased transmission and distribution investments to minimise losses. It is important to note in the main 3 pathways tested in this roadmap, CCS for power generation was required to meet the emission reduction target, while all other pathways include CCS to reduce other industrial emissions.

In order to achieve this, the EU states there will be a requirement for further research and development as well as new technologies, including "CO_2 transport infrastructure" across parts of Europe. However, "the quantity of long-term storage capacity that will be feasible for CCS" is a concern for the EU. However, it does not expand or justify why there are concerns with storage capacity.

The results from the scenarios used for the EU roadmap suggest CCS is required to meet their reduction target, but the percentage of reductions which will result from CCS is not quantified. Therefore, it is important the EU address their concerns regarding research and infrastructure in order to make CCS a viable option.

Climate and Energy Roadmaps toward 2050 in north-western Europe[3].

A report by the PBL Netherland Environment Assessment Agency looks at roadmaps up to 2050 to address climate change which at the time in 2012 were being produced by Belgium, Denmark, France, Germany, the Netherland and the UK. Belgium, Germany, the Netherlands and the UK "assign CCS as an essential element of a future low-carbon energy system". However, the main applications mentioned are "energy- intensive industries (such as steel production) and the combination with biomass". The report mentions that in these countries, "CCS might also allow coal- and gas-fired power plants to play an important role in their future low carbon energy systems".

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[1] Benin's MCS http://unfccc.int/files/focus/long-term_strategies/application/pdf/benin_long-term_strategy.pdf

[2] EU's roadmap http://unfccc.int/files/focus/long-term_strategies/application/pdf/benin_long-term_strategy.pdf

[3] PBL Netherland Environment Assessment Agency (2012) Climate and Energy Roadmaps toward 2050 in north-western Europe http://www.pbl.nl/sites/default/files/cms/publicaties/PBL_2012_Climate-and-Energy-Roadmaps_500269001.pdf

The conclusion is that "carbon capture and storage (CCS) does not receive much attention". Reasons for this include set-backs when introducing CCS demonstration plants in the UK and the Netherlands. Investment also plays an important role with the UK unable to find an "interested investor". "Public resistance" was the set-back faced in the Netherlands, as the CCS project would have been in a densely populated area.

China CCS Roadmap[1]

The People's Republic of China produced a CCS demonstration and deployment roadmap in 2015. The main focus of CCS is for coal, which is the dominant fuel in China. CCS is seen as the "only available technology that can cut up to 90% of carbon dioxide emissions from large industrial processes and power plants based on coal and other fossil fuels". CCS is also seen as the only option to reduce China's emissions from their coal-chemical, steel, cement and refinery plants.

EOR is also mentioned in the roadmap. Currently China imports more than half its oil, but 70% of domestic production comes from nine large oil fields which are facing decline. CO_2-EOR is "inevitable to maintain the economic viability of oil fields". To "overcome the lack of interest under the current oil prices" it is expected that incentives from the government will be needed for industries and oil companies to conduct CO_2-EOR.

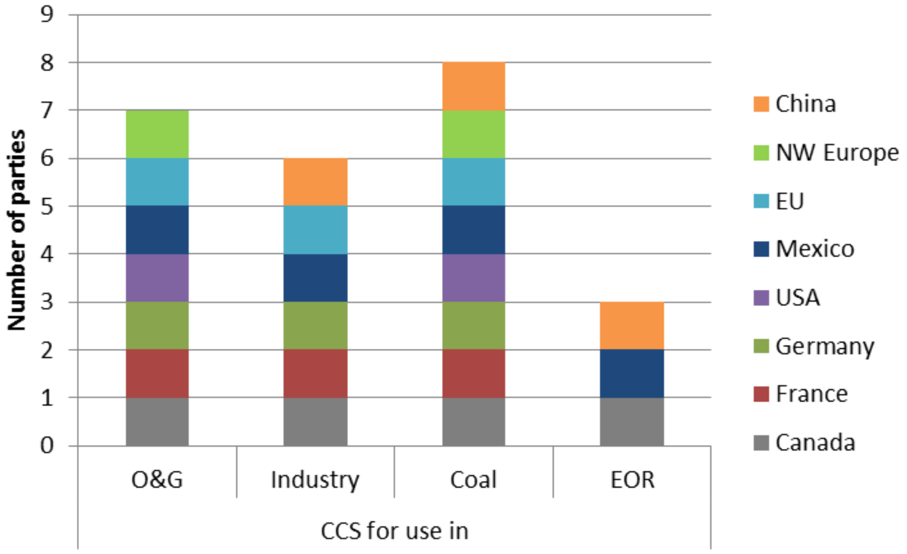
By 2030, CCS is expected to result in 40 Mt CO_2 a year in emission reductions, predominantly from the coal-chemical sector. Beyond 2030, it is expected that "capture cost reduction and carbon pricing" (outlined in the roadmap) will reach a level to trigger wider application of CCS. Overall CCS policy in China focuses on coal, but the option to diversify in the future is addressed depending on the country's energy mix.

2.2.3 *Comparison of the role of CCS across different strategies/plans*

CCS is mentioned in all the documents except for the MCS from Benin. However, the uses for CCS in the plans to 2050 vary considerably, including for oil and gas, coal, EOR and industrial sectors such as chemicals, steel and cement (Fig. 9).

[1] Asia Development Bank (2015) Roadmap for carbon capture and storage demonstration and deployment in the People's Republic of China https://www.adb.org/sites/default/files/publication/175347/roadmap-ccs-prc.pdf

Figure 9: Summary of the different uses of CCS in the different MCSs and roadmaps



Despite CCS being mentioned in five of six of MCSs and three roadmaps to 2050, only 4 of these documents use scenarios to model emission reductions up to 2050 which include CCS. Furthermore, only 3 documents quantify the reductions which could be achieved by CCS. In addition, most countries or parties consider there to be barriers to CCS implementation, whether present challenges or those faced when scaling up in the future (Table 6).

Table 6: In depth analyses of CCS and the barriers parties face

	Used Scenarios	Values for CCS	Barriers
Canada	✓	Reduction of 23 Mt CO_2e by 2050, 17% energy production in 2050 from gas CCS and 2% from coal CCS	Investment, Infrastructure
France			Investment, R&D
Germany			R&D
USA	✓	Reduction of 40 Mt CO_2e by 2030	Investment, R&D
Mexico	✓		R&D
Benin			
EU	✓		Investment, R&D
NW Europe			Investment, Public opinion
China		20% energy production from fossil fuel usage with CCS	

2.3 ROLE OF CCS IN NDCS THAT COULD BENEFIT FROM CCS

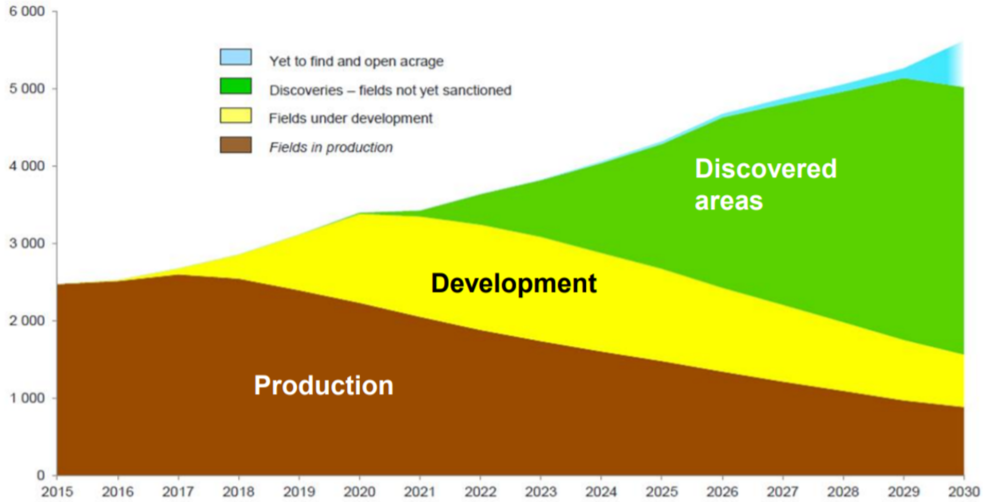
This sub-section looks at countries who have not mentioned CCS in their NDC. By focusing on oil and gas countries, it is possible to consider how CCS might help them achieve their GHG reduction targets as well as their oil and gas production goals.

2.3.1 Brazil

Target: 37% reduction in GHG emissions below 2005 by 2025 and 43% by 2030 (absolute reduction)[1]

For a country currently undergoing rapid development, Brazil's target is quite ambitious, as well as being one of the few countries which has set an absolute target. To achieve this target, Brazil's strategy is to suppress illegal deforestation and enhance carbon sinks through forest restoration and preservation policies[2], increase the participation of renewables in the energy mix from 40% to 45% by 2030, and pursue an indicative target to improve energy efficiency in 2030 by 10%[3].

Figure 10: Future Brazilian production of oil and natural gas in million barrels a day[4]



(From the Outlook for Oil and Gas in Brazil, 2017)

It is expected that Brazil will require further action to meet their NDC target, and with their O&G sector expected to develop (Fig. 10), CCS is an area which could help Brazil reduce its emissions. Furthermore, it could be used for industrial processes, in line with the "low carbon infrastructure" and "clean technology" referenced in the NDC.

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[1] Brazil's NDC http://www4.unfccc.int/submissions/INDC/Published%20Documents/Brazil/1/BRAZIL%20iNDC%20english%20FINAL.pdf

[2] Brazilian Forest Code reform and implementation

[3] Through industry sector partnerships and innovation programs

[4] IBP (2017) The outlook for oil and gas in Brazil http://www.thedialogue.org/wp-content/uploads/2017/05/Camargo-Presentation-The-Dialogue-Outlook-for-OG-in-Brazil-05-2017.pdf

The Brazilian government recently released a technical paper containing the marginal abatement costs and recommendations for two mitigation policy scenarios considered in the NDC and now under discussion with society for implementation and finance of the plan[1].

The document considers one scenario with more business as usual, low carbon mitigation options (low carbon scenario - LC) and other with options enhanced by more innovative but still feasible low carbon options (low carbon + innovation scenario – LC +I). In the LC + I scenario, CCS is one of the technologies considered. The document stated a high potential for CCS as long as more investment is provided for this technology to be commercially available.

In the LC+I scenarios, the study considered wider adoption of CCS from 2030 in some sectors such as bio-CCS on ethanol plants (2030) and the cement industry (2035). This wide adoption scenario for CCS assumes the following policies are in place in Brazil:

- Incentives for imports of certain key components for the technology
- Available Finance, throughout R&D agencies to implement pilot units of higher scale
- Carbon pricing in place from 2025 onwards
- More research to test into finer scale the impacts of CO2 storage on geological reservoirs and CO_2 transportation networks
- Creation of a new regulatory framework for CCS
- Capacity building, training programs and knowledge
- Transparency and engagement with society and learning from international experiences

The report forms the basis for the Brazilian NDC proposal and implementation process, shaping policies and the finance demand for its implementation. The estimated mitigation potential for CCS mentioned in the study is 218 MMtCO/year with carbon price signals up to U$50 and 761.2 MMtCO2/year considering a price signal of U$116. The specific policies and incentives that would support the achievement of these potential across a range of GHG emissions intensive industries were not mentioned in the study by the Brazilian government (MCTI 2017).

2.3.2 *Indonesia*

Target: 26% reduction in GHG emissions compared to BAU by 2020, increasing up to 41% with international support[2]

Combustion of fossil fuels accounts for approximately 19% of Indonesia's total emissions, whilst the energy sector accounted for 34.9% of emissions in 2016.

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[1] MCTI Opções de Mitigação

[2] Indonesia's NDC
http://www4.unfccc.int/ndcregistry/PublishedDocuments/Indonesia%20First/First%20NDC%20Indonesia_submitted%20to%20UNFCCC%20Set_November%20%202016.pdf

In their NDC, there is reference to a national energy policy with the following main ambitions for the primary energy supply mix:

- New and renewable energy at least 23% in 2025 and at least 31% in 2050
- Oil should be less than 25% in 2025 and less than 20% in 2050
- Coal should be minimum 30% in 2025 and minimum 25% in 2050
- Gas should be minimum 22% in 2025 and minimum 24% in 2050

This shows that Indonesia is expecting a growth in renewables and gas supply, and a reduction in oil and coal.

CAT[1] ranked Indonesia's progress as insufficient. Firstly, their NDC is not ambitious enough, with emissions expected to increase between now and 2030, whereas they should be stabilizing if not declining by this point to align with the Paris Agreement goals.

Indonesia is planning to construct new coal-fired power plants, to meet rapidly increasing electricity demands, which is likely to "bind them to this carbon-intensive technology for many decades". In order to reach the energy policy mentioned in the NDC, CCS could be used to reduce emissions from coal power, as well as for the expected increase in gas power.

2.3.3 *Malaysia*

Target: Reduction of GHG emissions intensity of GDP by 45% by 2030 relative to 2005, with 35% being unconditional, and further 10% relying on climate finance, technology transfer and capacity building from developed countries[2]

Malaysia's target is intensity based, so could still result in an absolute emissions increase, although this style of target is typical for developing countries. The energy sector accounted for 76% of emissions in 2011, with natural gas supply 45% of the energy mix[3]. Their NDC focuses on reducing emissions intensity but does not cover renewables[4]. This would suggest that expanding their energy sector is still a key goal for Malaysia, and CCS could allow them to be energy intensive whilst decreasing their carbon intensity.

[1] Climate Action Tracker (2017) Indonesia http://climateactiontracker.org/countries/indonesia.html

[2] Malaysia's NDC http://www4.unfccc.int/Submissions/INDC/Published%20Documents/Malaysia/1/INDC%20Malaysia%20Final%2027%20November%202015%20Revised%20Final%20UNFCCC.pdf

[3] Malaysia Biennial Update report to UNFCCC https://unfccc.int/files/national_reports/non-annex_i_parties/biennial_update_reports/application/pdf/malbur1.pdf

[4] Amponin and Evans (2016) Assessing the intended nationally determined contributions of ADB developing members https://www.adb.org/sites/default/files/publication/189882/sdwp-044.pdf

2.3.4 Russia

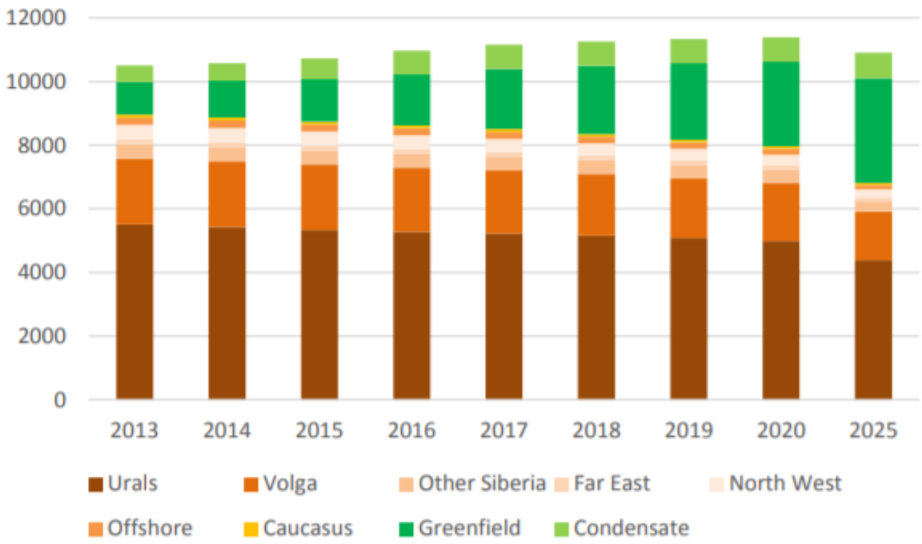
Target: Limit GHG emissions to 70-75% of 1990 levels by 2030 (equivalent to a 25-30% reduction), dependent on absorbing capacity of forests[1].

Russia's NDC target is unambitious, but in line with their 2020 pledge. It is also conditional on the ability of Russia's forests to act as a carbon sink. Their NDC states it has "no plan to use international market mechanisms" and its target "does not create any obstacles for economic and social development". This shows how environmental concerns are a low priority for Russia.

CAT ranks Russia's commitment as critically insufficient, the lowest possible rating[2]. As one of the world's largest emitters and fossil fuel producers, Russia should be aiming for a more ambitious target. Their current commitment is in line with current policy projections, requiring no further action from Russia; however, this is not aligned with the Paris Agreement.

As more pressure is applied on large emitters, with Russia accounting for 5% of global emissions, it is likely Russia will be under international pressure to become more ambitious. With economic development a key priority, including continued oil and gas production (Fig. 11), CCS could offer an opportunity for Russia to continue to use fossil fuels, whilst decreasing their GHG emissions.

Figure 11: Projected oil projection in Russia to 2020[3]



(From the Russia Oil Production Outlook for 2020)

[1] Russia's NDC http://www4.unfccc.int/submissions/INDC/Published%20Documents/Russia/1/Russian%20Submission%20INDC_eng_rev1.doc

[2] Climate Action Tracker (2017) Russia http://climateactiontracker.org/countries/russianfederation.html

[3] Oxford Institute for Energy Studies (2017) Russia Oil Production Outlook to 2020 https://www.oxfordenergy.org/wpcms/wp-content/uploads/2017/02/Russian-Oil-Production-Outlook-to-2020-OIES-Energy-Insight.pdf

2.3.5 *Thailand*

Target: Reduction in GHG emissions by 20% in comparison to a BAU trajectory with a 2005 baseline, by 2030. This could increase to 25% with international assistance including technology development and transfer, financial resources and capacity building support[1]

In 2012, 73% of Thailand's emissions were from the energy sector, with 72% of electricity supply from natural gas in 2005 after a major shift away from oil. Within their NDC, Thailand aims to:

- Reduce energy intensity by 30% from 2010 to 2036
- 30% share in renewable energy by 2036
- 20% of power generation from renewable energy by 2036.

With only a small share estimated to come from renewable energy, Thailand is expected to still be predominantly relying on fossil fuels, particularly natural gas. In order to achieve their emission reductions, CCS could help achieve the remainder of Thailand's NDC commitment.

2.3.6 *Summary: Where CCS could be important in NDCs not mentioning CCS*

Overall, Brazil has the most ambitious NDC of these 5 countries; however, it is still rated as insufficient by the CAT for reaching a 2 degree scenario. Three of the 5 countries mention international support in order to set a more ambitious target, namely Indonesia, Malaysia and Thailand. This includes finance, technology and capacity building.

There is an opportunity for all these countries to introduce or further develop CCS, despite none of them mentioning it in their NDC. CCS should be particularly valuable as these countries are set to continue being global leaders in the oil and gas industry. Furthermore, CCS is a good alternative solution for those not willing or who cannot afford to promote renewable energy over fossil fuels, or to meet the emissions gap between renewables and their target.

2.4 *ROLE OF CCS IN ENERGY TRANSITION SCENARIOS*

In order to determine if the world is on track to achieve the two degree goal set in Paris 2015, various studies have been undertaken. Typically, these use different scenarios to predict emissions and temperature increase over a period of time.

From the results of these studies, it can be estimated if further action by countries is required. The extent to which CCS is included in these scenarios is summarized in this section, as well as the potential role CCS could play in meeting the two degree goal in scenarios which fall short.

[1] Thailand's NDC http://www4.unfccc.int/ndcregistry/PublishedDocuments/Thailand%20First/Thailand_INDC.pdf

2.4.1 *Deep Decarbonisation Pathways Project*

The Deep Decarbonisation Pathways Project (DDPP)[1], is a global research initiative looking at how countries can limit global temperature rise to 2 degrees. With research teams in 16 countries, which are responsible for 74% of global CO_2 emissions, these scenarios are well respected, and are used by many of the countries (e.g., Canada's MCS). In contrast to many scenarios, the DDPP uses back casting methods to determine steps required to get to the 2050 target.

Country reports[2] were released in 2015, of which 13 of the 14 included CCS in their scenarios. Of the 13, ten reports included values for CCS in their scenarios, as summarised in Table 7. Furthermore, CCS is expected to contribute reductions to 10% of electricity production capacity in 2050, with 362 GW from coal and 798 GW from natural gas[1].

Table 7: Values for the contribution of CCS in order to limit global temperature rise to 2 degrees in the DDPP individual country reports

Country	Findings on CCS
Australia	- Up to 21% of electricity supply with CCS in 2050 (9% gas, rest is coal) - CCS will capture 25-50% of emissions from non-energy sectors by 2050
Canada	- 23 Mt CO_2e captured and stored by 2050
China	- In 2050, CCUS is projected to annually remove 2737 Mt CO_2 (1867 Mt CO_2 from the power generation sector and 807 Mt CO_2 from industry emissions) - Accumulated CO2 capture is approximately 27 Gt CO2 between 2010 and 2050
France	- By 2050, about 10 Mt CO_2 will be stored annual using CCS, equating to 20% of gas and 40% of coal consumed
Germany	- 57 Mt CO_2 captured from industrial sector in their 90% GHG reduction scenario by 2050
India	- 7099 to 9929 Mt CO_2 captured depending on the scenario (mainly coal) by 2050
Indonesia	- Power supply in 2050 in renewable and CCS scenario: 19% coal with CCS and 18% natural gas with CCS
Japan	- Decarbonisation in power sector "notably thanks to large deployment of CCS" approximately 97% reduction in carbon intensity of electricity from 2010 level by 2050
UK	- 318 Mt CO_2 captured between 2033 and 2050 in the industrial sector
US	- In the mixed scenario, 12.2% of electricity generation is from natural gas with CCS -In the high CCS scenario, 26.3% of the supply is from gas with CCS, 28.6% is from coal with CCS

The findings from the country reports show CCS is expected to take some role in emission reductions, although the extent varies between countries. However, it is hard to compare as the different reports use different metrics, such as percentage of supply, or a value for the quantity of storage. Overall, the DDPP scenarios suggest that CCS is required in order to meet a 2 degree world.

[1] DDPP report (2014) http://deepdecarbonization.org/wp-content/uploads/2015/12/DDPP_EXESUM-1.pdf

[2] DDPP (2015) Country reports http://deepdecarbonization.org/countries/

2.4.2 *International Energy Agency – CCS publications*

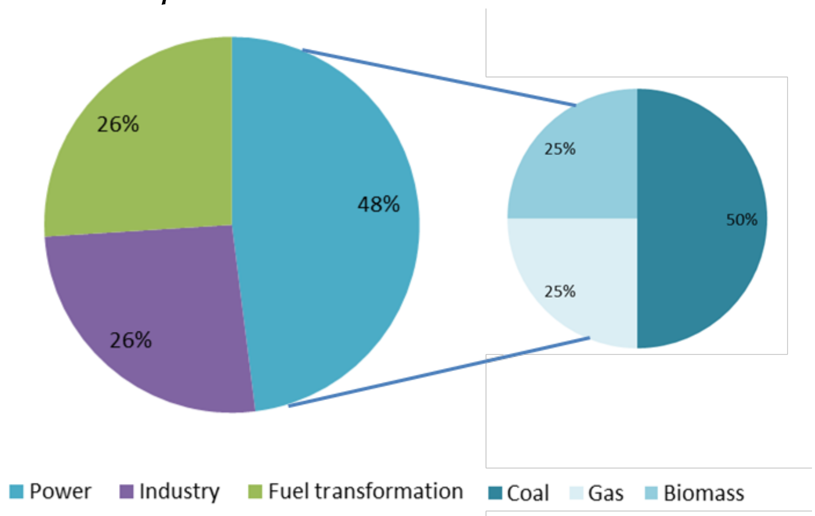
In the IEA 2 degree scenario (2DS) in 2013[1], CCS "could deliver a sixth (16.7%) of the total cumulative emission reductions needed by 2050", and 14% of emission reductions through 2050 against a business as usual scenario (6 degree scenario). This was reduced to 14% of emission reductions in the IEA 2DS in the IEA Tracking Clean Energy Perspectives[2] which is also modeled in the ETP 2017.

The 2DS is modelled to have a 50% chance of limiting temperature rise to 2 degree. The ETP also has a beyond 2 degrees scenario (B2DS) which has a 50% chance of limiting temperature rise to 1.75 degrees. CCS accounts for 32% of the additional emissions to achieve this more ambitious goal.

In the ETP 2 degree scenario[3], CCS is expected to store over 400 Mt CO_2 per year by 2025 and 142 Gt CO_2 by 2060. This is equivalent to 6.8 Gt CO_2 a year in 2060 across 3 main sectors (Fig 12). Within the power sector, CCS contributes 18% of reductions required in line with a 2DS, with 50% from coal and 25% each from gas and biomass.

However, CCS deployment is not currently in line with this trajectory, with only 17 large scale operational projects across the globe, capturing approximately 30 Mt CO_2 a year. Therefore, CCS would need to expand tenfold to be on track to meet the 2 degree pathway by 2025[4].

Figure 12: Total CCS contribution in the ETP 2DS (2017), split between the different sectors and power sub-sectors



[1] IEA (2013) Technology Roadmap: Carbon Capture and Storage https://www.iea.org/publications/freepublications/publication/technology-roadmap-carbon-capture-and-storage-2013.html

[2] IEA (2017) Tracking Clean Energy Progress http://www.iea.org/publications/freepublications/publication/TrackingCleanEnergyProgress2017.pdf

[3] IEA (2017) Energy Technology Perspectives

[4] IEA (2017) Tracking Progress: Carbon Capture and Storage http://www.iea.org/etp/tracking2017/carboncaptureandstorage/

To successfully achieve the ambitions of the IEA 2DS, the CCS roadmap identifies specific goals for CCS deployment:

1. "By 2020, the capture of CO_2 is successfully demonstrated in at least 30 projects across many sectors, including coal- and gas-fired power generation, gas processing, bioethanol, hydrogen production for chemicals and refining, and direct-reduced iron (DRI). This implies that all of the projects that are currently at an advanced stage of planning are realised and several additional projects are rapidly advanced, leading to over 50 Mt CO_2 safely and effectively stored per year."

2. "By 2030, CCS is routinely used to reduce emissions in power generation and industry, having been successfully demonstrated in industrial applications including cement manufacture, iron and steel blast furnaces, pulp and paper production, second-generation biofuels and heaters and crackers at refining and chemical sites. This level of activity will lead to the storage of over 2000 Mt CO_2/yr."

3. "By 2050, CCS is routinely used to reduce emissions from all applicable processes in power generation and industrial applications at sites around the world, with over 7000 Mt CO_2 annually stored in the process."

The IEA also comments on how critical "accelerated development" of CCS is by 2020 to reach 2 degree goals. In order to "scale-up CCS deployment" the IEA have identified 7 key actions to achieve by 2020, but they require "serious dedication by governments and industry, but are realistic and cover all three elements of the CCS process":

1. "Introduce financial support mechanisms for demonstration and early deployment of CCS to drive private financing of projects

2. Implement policies that encourage storage exploration, characterisation and development for CCS projects

3. Develop national laws and regulations as well as provisions for multilateral finance that effectively require new-build, base-load, fossil-fuel power generation capacity to be CCS-ready

4. Prove capture systems at pilot scale in industrial applications where CO_2 capture has not yet been demonstrated

5. Significantly increase efforts to improve understanding among the public and stakeholders of CCS technology and the importance of its deployment

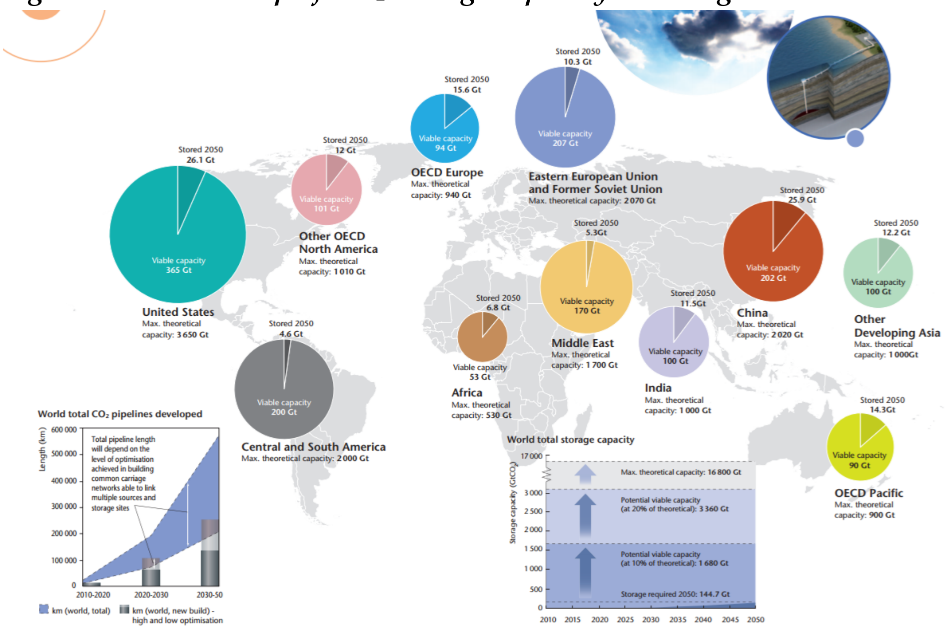
6. Reduce the cost of electricity from power plants equipped with capture through continued technology development and use of highest possible efficiency power generation cycles

7. Encourage efficient development of CO_2 transport infrastructure by anticipating locations of future demand centres and future volumes of CO_2"

To implement all of these actions, the roadmap predicts that an additional USD 2.5 to 3 trillion worth of investment will be required between 2010 and 2050, which equates to 6% of the overall investment to achieve a 50% reduction in GHG emissions by 2050[1].

The IEA roadmap for CCS also covers the potential for storage in the future, highlighting areas with large capacity and the extent to which they have been used (Fig. 13)

Figure 13: Global map of CO_2 storage capacity and usage



(From IEA Technology Roadmap: Carbon Capture and Storage (Foldout), 2013)

The IEA also uses a BLUE Map scenario[2], which reduces energy-related CO_2 emission by 50% by 2050 from 2010. This relies on CCS to capture 9.4 $GtCO_2$ with 55% from power generation, 21% from industry and 24% from fuel transformation. This accounts for 19% of the mitigation effort required. Plants equipped with CCS would account for 17% of power generation.

[1] IEA (2013) Carbon Capture and Storage roadmap (foldout)
https://www.iea.org/publications/freepublications/publication/CCS_roadmap_foldout.pdf

[2] IEA (2010) Energy Technology Perspectives
https://www.iea.org/publications/freepublications/publication/etp2010.pdf

The IEA overall predicts a large role for CCS, accounting for 14% of emission reductions in the 2 degree scenario and 19% of reduction emissions in the BLUE Map scenario. However, the IEA raises several barriers and concerns which need to be addressed for CCS to be able to store the 7000 Mt CO_2 required by 2050 in the 2DS. Expansion of the current global CCS network is required, including significant research and development, investment and the backing of governments including the implementation of laws and incentives.

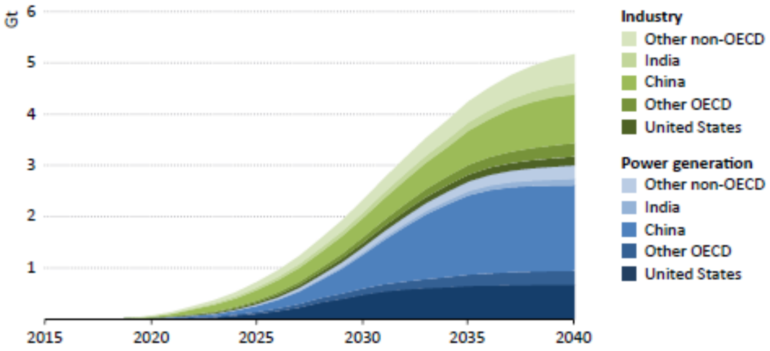
2.4.3 *IEA Report-Energy and Climate Change*

The IEA special report on Energy and Climate Change[1] looks at a few different scenarios. The main scenario is the 450 scenario, which looks at a 450 ppm concentration of CO_2 in the atmosphere and aligns with the 2DS. In the 450 scenario, "CCS becomes viable" and is "widely deployed in both the power and industrial sectors accounting for one-third of additional CO_2 reductions needed to put the world on track to 2 degrees". These "additional reductions" refer to the further 113 Gt CO_2 abatement required for the 450 scenario in comparison to the Bridge Scenario, which aims for a peak in global energy-related emissions by 2020.

In the energy sector, CCS adoption increases in the 2020s, significantly accelerating in the 2030s to capture 5.1 Gt CO_2 a year by 2040, in comparison to 52 Gt CO_2 in total between 2015 and 2040. To put this value in context, storage in 2040 would be almost triple India's energy sector emissions today. Without CCS, neither coal nor gas power plants could retain their significant market share, which is estimated in the 450 scenario (gas-fired generation accounts for 16% and coal accounts for 12% of total power generation in 2040). In industry, CCS captures more than 2 Gt in 2040 in the 450 scenario. This is led by the cement sector, accounting for half of that capture quantity, with nearly 500 Mt from the iron and steel sector and approximately 300 Mt CO_2 from the chemical sector. This requires approximately half of the global cement and steel production to be equipped with CCS in 2040. The level of CO_2 captured by sector and region can be seen in Figure 14.

[1] IEA (2015) Energy and Climate Change
https://www.iea.org/publications/freepublications/publication/WEO2015SpecialReportonEnergyandClimateChange.pdf

Figure 14: Projections for CO_2 captured in the 450 scenario for both power generation and industry.



Note: Industry includes the following sectors: steel, cement (energy- and process-related), chemicals and paper production; oil refining; coal-to-liquids, gas-to-liquids and natural gas processing.

(From the IEA report on Energy and Climate Change, 2015)

CCS deployment in the 450 scenario across both industrial and power sectors results in rapid expansion after 2025, "matching the pace of expansion seen in gas-fired capacity between 1990 and 2010". However, despite the high rate of deployment in the 450 scenario, the use of CCS is not implemented in all countries. For the energy sector, CCS plays an important part of mitigation actions in the USA and China, accounting for 80% of CCS installations, and to a lesser extent India and the Middle East. In the industrial sector, most of the capacity is in non-OECD countries including China, India, Russia and the Middle East, and less in the USA and parts of Europe. CCS is particularly important in sectors such as iron and steel as well as cement.

The report acknowledges the business case for CCS, with fuel consumption by CCS-equipped facilities creating revenues of $1.3 trillion for both gas and coal producers respectively from 2015 to 2040. Deploying CCS on a large scale will reduce costs and improve competitiveness as an abatement option in the power sector. However, in the near term, CCS is not competitive with coal-to-gas switching or wind power. Therefore, investment to build the growth in CCS is required, estimated at "a few billion dollars today, to about $70 billion in the 2020s per year, to $110 billion a year in the 2030s". Of this investment, approximately 60% up to 2040 goes to the power sector, the remainder to industry. Investment now needs to focus on R&D, mapping storage sites and other enabling factors. Furthermore, investments to date focus on sectors with manageable costs, for example natural gas or EOR. In the future, investments beyond these sectors will be required.

As well as an increase in investment, capacity of CCS needs to improve, estimated to increase from 20 GW a year in the 2020s to 50 GW a year in the 2030s. Global CCS capacity is expected to reach "740 GW in 2040, equivalent to 20% of fossil-fueled power generation at the time".

Despite an increase in the knowledge of CCS, the IEA estimated national level support is required for CCS to be adopted on a large scale. The report concludes that three types of actions can result in the level of CCS which is required:

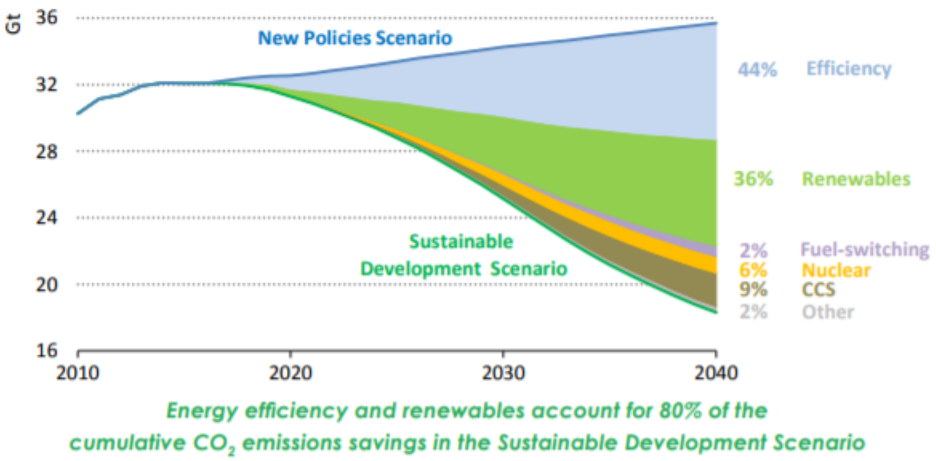
1) Regulatory incentives to promote large scale projects such as policies guaranteeing a reduction in cost, or access to climate funds
2) Continued R&D to improve technology, and address challenges in commercialisation
3) Policies to encourage exploration for and to develop CO_2 storage capacity as there are currently insufficient incentives.

2.4.4 *New Sustainable Development Scenario IEA WEO 2017*[1]

In 2017, the IEA introduced a new scenario in their World Energy Outlook report. The Sustainable Development Scenario focuses on achieving aims relating to climate change, reducing air pollution and universal energy access security. Therefore, its main aim is not to prevent global surface temperature rise to two degrees; however, it is useful to compare CCS contributions in this report. The other main scenario is the New Policies Scenario, which uses existing policies and announced intentions, which overall leads to a slight increase in CO_2 emissions by 2040.

Emission reductions between the New Policies scenario and the Sustainable Development Scenario see CCS accounting for 9% of the emissions reductions (Fig. 15). More than 60% of these reductions are from the power sector.

Figure 15: Global CO_2 emissions reductions in the New Policies and Sustainable Development Scenarios

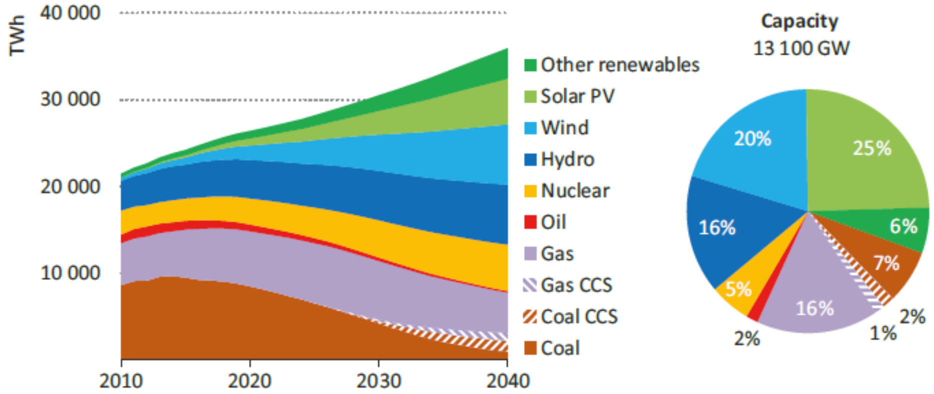


(From the WEO 2017)

[1] IEA (2017) World Energy Outlook

In the Sustainable Development Scenario, by 2040 power generation is mostly decarbonised with over 60% from renewables, 15% from nuclear power and CCS contributing 6%. Fossil fueled plants are progressively phased out, accounting for just 22% of total generation in 2040. Of this, almost 30% are equipped with CCS by 2040, reducing CO_2 emissions per unit of output by an order of magnitude. Overall CCS equipped power plants supply less than 1% of electricity supply in 2040 (Fig. 16)

Figure 16: Power generation in 2040 by source (left) and installed capacity (right) in the Sustainable Development Scenario



(From the IEA World Energy Outlook 2017)

Total energy sector CO_2 emissions in the Sustainable Development Scenario drop to approximately 18.5 Gt in 2040, roughly 50% the level of the New Policies Scenario. In the 2030s, the annual decline in emissions exceeds 3%, falling by over 650 Mt every year, with the largest contributions from energy efficiency and the use of renewables in power generation, heat and transport (biofuels). CCS accounts for just less than 10% of the emissions reductions in 2040, around a third of which stems from the use of gas with CCS in the power and industrial sectors. By 2040, there are 165 GW gas-fired CCS electricity plants worldwide, and around 10% of gas consumed in industry is in installations fitted with CCS. This accounts for around 7% of global gas-fired power capacity at that time, 85% of which is installed in the United States and China.

For industrial emission reductions, larger emission reductions in iron and steel production and cement can be achieved by using natural gas with CCS. However, in most cases it would be more economical to continue to use the current fuel source, often coal, and to equip it with CCS, rather than both to convert to the use of natural gas and to equip with CCS. Therefore, the uptake of natural gas fitted with CCS in the industrial sector is lower than for other fuels: 10% of industrial gas use is fitted with CCS in 2040 compared with around 20% for coal. The use of gas in iron and steel making is also impacted by increased recycling efforts.

Again, the IEA acknowledges that CCS faces a number of challenges, including additional investment which is unpopular as CCS does not directly generate any extra revenue. However, it can be used for EOR such as at Boundary Dam, Canada. Current progress on CCS is slow to date, and a bigger role for it in the future will depend on new financing and legal frameworks to help overcome the commercial and incentive obstacles that exist.

2.4.5 *MIT research on climate scenarios*

Massachusetts Institute of Technology (MIT) has done a range of work analysing the world's ability to keep global temperature rise below two degrees. The Energy and Climate Outlook report[1] from the joint programme on science and policy for global changes, uses INDCs and Copenhagen-Cancun commitments to assess if current targets will be enough to keep global temperature rise below 2 degrees. The main findings from the report include:

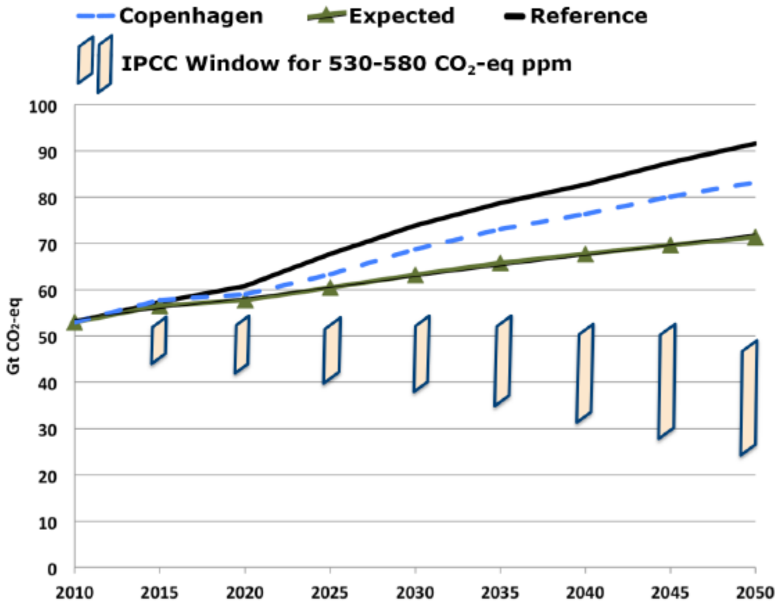
- Fossil fuels are still the largest source of GHG emissions
- Fossil fuels account for 75% of primary energy by 2050
- If no further policies are proposed and implemented, by 2030 the world will be within 5 years of hitting the cumulative emissions level where the IPCC estimates will result in there being a 50% change of limiting temperature rise to 2 degrees

The "Expectations for a new climate agreement"[2] report, which was released a year earlier had similar conclusions, suggesting the INDC commitments would not be sufficient to meet a 520-580 ppm scenario (Fig. 17).

[1] Reilly et al. (2015) Energy and Climate Outlook (MIT)
https://globalchange.mit.edu/sites/default/files/newsletters/files/2015%20Energy%20%26%20Climate%20Outlook.pdf

[2] Jacoby and Chen (2014) Expectations for a new climate Agreement (MIT)
https://globalchange.mit.edu/publication/15806

Figure 17: INDC modelled emission projections in comparison to the reference (BAU) scenario and the Copenhagen agreements, all of which exceed the IPCC window for 520-580 ppm CO_2



(From the MIT paper: Expectations for a new climate agreement, 2014)

In 2016, MIT released a new set of scenarios[1] in a report called "Scenarios of Global Change: integrated assessment of climate impacts". This used five different scenarios, outlined below, more than one of which uses CCS (Table 8).

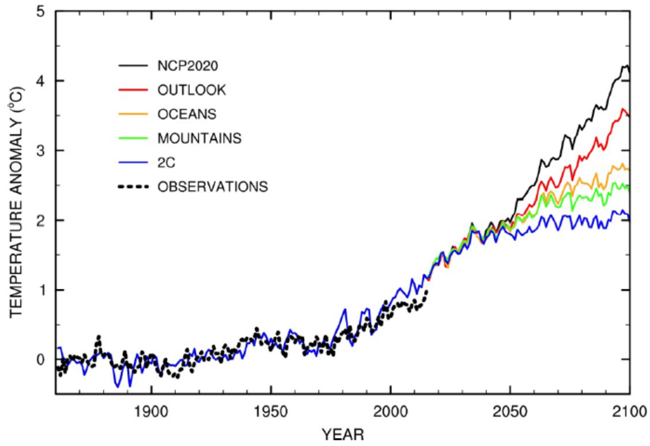
Table 8: Different scenarios used by MIT in their scenarios of global change report

Scenario	Description
NCP 2020	Copenhagen commitments through 2020 and no climate policy thereafter
Outlook	Derived from an assessment of COP-21 based on INDCs of major emitting countries
Oceans	Includes a large role for renewables and oil, and slow development of CCS
Mountains	Includes a large role from renewables after 2050, larger natural gas resources and accelerated development of CCS
2 degrees	Assumes a globally uniform carbon tax starting in 2020 that leads to a global temperature stabilization of 2 degrees above preindustrial times by 2100

The results show that only the 2 degree scenario limits warming to 2 degrees, with the mountains scenario being the second best option with warming of 2.44 degrees, and 2.7 degrees of warming for the oceans scenario. Outlook and NCP 2020 lead to warming of approximately 3.6 and 4 degrees, respectively, by 2100 (Fig. 18).

[1] Scenarios of Global Change: Integrated Assessment of Climate Impacts (2016) Paltsev et al. (MIT) https://globalchange.mit.edu/publication/16255

Figure 18: Global temperature rise up to 2100 from the 4 MIT scenarios



(From the MIT paper: Scenarios of Global Change, 2016)

Despite only the carbon tax scenario achieving 2 degrees, both the mountains and oceans scenarios "exhibit a substantial movement towards temperature stabilization". The contribution of a "substantial shift to renewable energy and deployment of CCS, availability of negative emission technology (e.g. biomass with CCS) and policies on non-CO_2 GHGs are valuable components of potential climate stablilisation pathways".

This would suggest more effort needs to be made to encourage these options to limit warming to 2 degrees.

Another MIT paper[1] from 2016 looks at the level of ambition required for countries in the MCSs so that emission reductions are in line with limiting warming to 2 degrees. Using the C-ROADS climate policy simulation model to generate more than 600 scenarios for the 15 countries and country groups, emission reductions are identified. It assumes nations meet or exceed their NDCs and rates of emissions decline beyond the NDC pledge point.

Scenarios for carbon reduction removal (CDR) are also included, which look at the impact of afforestation, agricultural soil carbon, bio-energy carbon capture, direct-air CCS and ocean uptake. Only scenarios achieving 1 Gt CO_2/year by 2050, or 6 Gt CO_2/year by 2100 are considered, and approximately half of the 600 scenarios consistent with warming below 2 degrees include CDR. The paper acknowledges that to limit warming to 2 degrees, it will require action from all countries. Table 9 shows the countries current commitment and baseline, and then the reduction required by 2050 to meet a 2 degree and a 1.5 degree scenario.

[1] Jones et al., (2016) Mid Century Strategies To Stay Within Paris Agreement Temperature Limits (MIT) https://d168d9ca7ixfvo.cloudfront.net/wp-content/uploads/2016/11/Mid-Century-Strategy-Pathways-16Nov16.pdf

Table 9: Current emission reductions countries have committed to, in comparison to the reductions expected to be required to minimise temperature increase to 2 degrees or 1.5 degrees.

Country or group of countries	Current commitments		Modelled scenarios		
	Current commitment reductions	Commitment baseline	Reduction by 2050 (2 degree scenario)	Reduction by 2050 (1.5 degree scenario)	Baseline for the models
USA	80% by 2050	2005	72-94%	88-94%	2005
EU	89-95% by 2050	1990	73-95%	89-95%	1990
Canada	30% by 2030	2005	86%	87-93%	2005
Australia	26% by 2030	2005	67-88%	86-88%	2005
Japan	26% by 2030	2013	66-94%	86-94%	2013
Russia	25% by 2030	1990	67-92%	86-92%	1990
S. Korea	37% from BAU		15-84%	64-84%	1990
Other developed countries*	26% by 2030	1990	76%	76-88%	2005
China	Achieve a peak no later than 2030		27%	64%	2005
Mexico	25% below BAU		27-87%	67-87%	2005
Brazil	37% by 2025 and 43% by 2030	2005	66-88%	85-88%	2005
India	33-35% by 2050	2005	Peak between 2025-2035	57%	2005
Indonesia	29% below BAU by 2030		31-38%	69-88%	2005
Other developing nations**	7.5% below BAU by 2030		Peak between 2025 and 2035	53-79%	1990

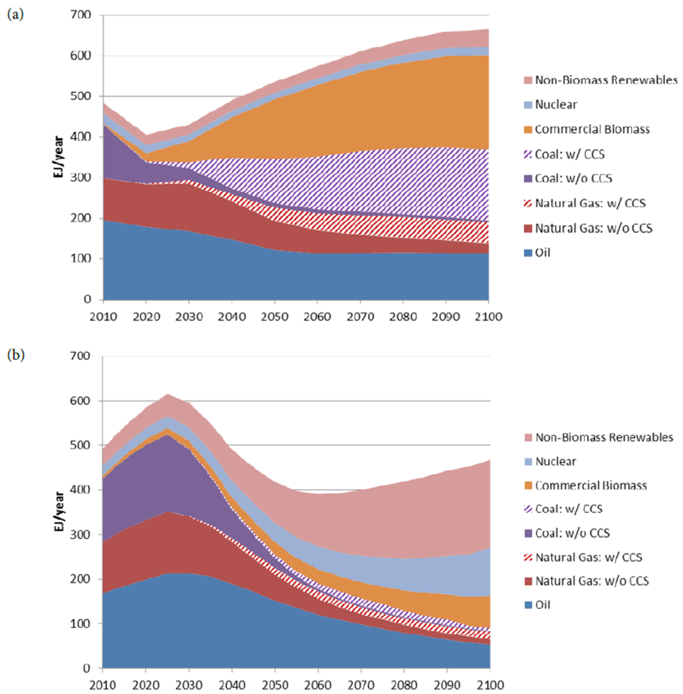
**= New Zealand, Albania, Bosnia & Herzegovina, Croatia, Macedonia, Slovenia, Armenia, Azerbaijan, Belarus, Georgia, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Ukraine, Uzbekistan (includes former Yugoslavia and fraction of former USSR).*
*** This grouping of nations includes all the nations that are not major emitters individually and part of the Major Economies Forum. Countries and regions that are part of this group include the Philippines, Thailand, Taiwan, the Middle East, much of Latin America, much of Africa, and over 20 small nations in Asia.*

Only the USA and the EU have set targets for 2050 out of the data available in 2015. It may be possible for the EU to reach a 1.5 degree scenario, whereas the US commitment is not enough for 1.5 degrees and is unlikely to achieve a 2 degree scenario.

Of the remaining countries, many who have set a 2030 target require approximately a doubling in their reduction target by 2050 when comparing this to the modelled emission reduction. This includes: Canada, Australia, Japan, Russia and other developed countries. This highlights a large level of effort is required from these countries, which would suggest they need to consider all possible options in the future, including CCS.

Finally, the most recent MIT report: *Climate stabilisation at 2 degrees and net zero carbon emissions*[1], explores possible emission pathways to keep warming below 2 degrees. It focuses on different climate sensitivities: high, medium and low, equating to sensitivity of 4.5, 3.0 and 2.0 degrees C, respectively. One reference to CCS is made in a comparison of global energy use, IGSM calculations using estimations for CCS technology costs from the MIT future of coal study from 2007. Figure 19 shows the energy use for medium climate sensitivity in two scenarios, a) optimistic view on CCS and b) optimistic view on renewables and energy efficiency.

Figure 19: Change in global energy use for scenarios (a) and (b) up to 2100



(From the MIT paper: Climate stabilisation at 2 degrees and net zero carbon emissions, 2017)

The paper concludes that in comparison to the 2007 report on the future of coal, there is now an expected "reduced role for CCS and biomass" and an increased role of renewables (wind and solar), nuclear and energy efficiency. However, CCS could still supply up to 20% of energy use up to 2100.

Overall, these conclusions prove that current commitments are not enough and more must be done in order to increase our chances of meeting the 2 degree goal. This leaves an opportunity for CCS, especially with the high level of fossil fuel reliance predicted in the future. However the most recent report suggests the role of renewables, nuclear and energy efficiency has increased while the importance of CCS has decreased.

[1] Sokolov et al. (2017) Climate stabilisation at 2 degrees and net zero carbon emissions (MIT) https://globalchange.mit.edu/sites/default/files/MITJPSPGC_Rpt309.pdf

2.4.6 *Global Energy and Climate Outlook (GECO) 2015*[1]

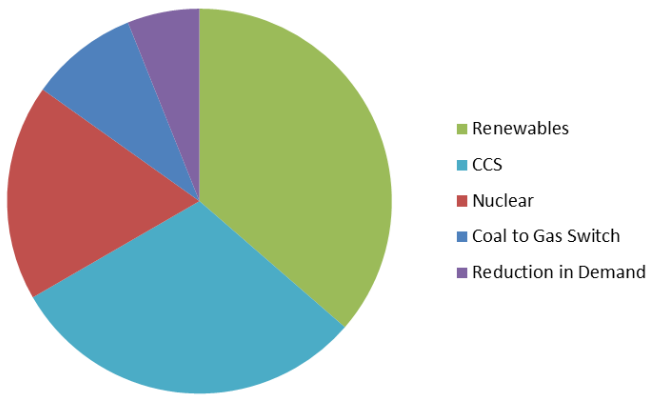
The Global Energy and Climate Outlook (GECO) is a technical report published by the Joint Research Centre (JRC) which is a European Union academic consortium. GECO 2015 assesses different countries' abilities to reduce emissions to stay within the 2 degree scenario. This uses POLES and GEM-E3 modelling, using 2020 pledges as a baseline. In the Global Mitigation scenario, all regions reduce their domestic emissions to stay below 2°C, with various profiles in 2020-2050 depending on the country's characteristics. For each country, the role CCS plays is evaluated; however, this includes CCS for coal, gas and biomass power plants.

When evaluating emission reductions on a global scale, to maintain 2 degrees, CCS accounts for only 7% of total reductions in 2030 and becomes a more prominent mitigation option by 2050 accounting for 23% of total reductions. When focusing on the power sector, coal is expected to decrease to 10% of the energy mix by 2050, with a large proportion of this attributed to CCS. By 2050, the following reductions in emissions from the power sector come from:

- 6%: Reduction in demand
- 9%: Fossil fuel switch from coal to gas
- 18: Nuclear
- 36%: Renewables (8% biomass, 13% wind, 7% solar, 8% others)
- 30%: CCS

Overall, CCS is the largest single contributor (Fig. 20), but again this includes all forms of CCS, not just oil and gas.

Figure 20: Global energy mix for 2050 from GECO 2015 model



[1] GECO (2015) Road to Paris. https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/geco2015-global-energy-and-climate-outlook-road-paris-assessment-low-emission-levels-under

Despite the GECO report focusing on reductions to 2050, quantitative CCS reduction contributions are only given as values up to 2030, with some qualitative description for the decades beyond this. Modelled reductions as a result of CCS for each country or group of countries are summarised below in Table 10.

Table 10: GECO estimates for emissions reductions attributable to CCS up to 2030 ranked in descending order of absolute reductions in order to meet 2 degree scenario.

Country or group of countries	Percentage of predicted emission reduction in Power sector from CCS by 2030*	Absolute reductions from CCS in the Power sector (Mt CO_2e)
Global	7	1324.4
China	11	421.3
USA	11	92.4
EU	22	55.0
Russia	7	26.6
Japan	13	20.8
Mexico	25	17.5
South Africa	13	16.9
Rep. of Korea	16	14.4
Canada	15	13.5
India	2	9.6
Indonesia	9	8.1
Brazil	6	4.2

**All in comparison to a baseline using 2020 pledges. This means a 0% reduction does not mean CCS is not in use, but its contribution is no more than present.*

- For Brazil, CCS is marginal, and mainly is coal based with a move to biomass beyond 2030
- CCS becomes more significant beyond 2030 in China and Canada
- CCS in the Republic of Korea is mainly coal
- Mexico CCS is a combination of gas and coal CCS
- CCS in mainly biomass and coal in South Africa

These scenarios also show how CCS will play an important role in limiting temperature rise to 2 degrees, however it is difficult to compare when the contribution of the different types of CCS are not differentiated.

2.4.7 *The role of CCS in meeting climate policy targets*[1]

Commissioned by the Global CCS Institute in 2017, this report looks at the role and importance of CCS in meeting climate policy targets. WBGU, which are the scientific advisory council on global change to the German Federal Government, provide analyses of scenarios by global modeling studies (Table 11).

The probability of these scenarios exceeding 2 degrees, with or without CCS, is calculated. For 9 of the 14 scenarios, CCS is included, with the amount of CO_2 captured from 2000 to 2050 ranging from 59 to 310 Gt.

[1] GCCSI (2017) The role of CCS in meeting climate policy targets http://hub.globalccsinstitute.com/sites/default/files/publications/201833/report-role-ccs-meeting-climate.pdf

Table 11: Cumulative CO_2 emissions in selected scenarios reviewed by WBGU in 2011, including the contribution of CCS and the probability of exceeding 2 degrees

No.	Model, scenario name	Cumulative CO_2 emissions from fossil sources 2000–2049 [Gt CO_2]	Probability of exceeding 2°C without CCS [%]	CCS by 2050 [Gt CO_2]	of which bio-CCS [Gt CO_2]	Probability of exceeding 2°C with CCS [%]	Average growth rate of renewable energies 2010–2050 [%/year]	CO_2 prices [US$/t CO_2] 2030	2050
(1)	MESSAGE, GEA Efficiency	1,496	56	192	4,6	40	3	23	60$
(2)	MESSAGE, GEA Mix	1,391	47	92	4,6	40	3.5	67	177$
(3)	MESSAGE, GEA Supply	1,444	52	259	4,6	34	3.5	53	140$
(4)	IMAGE, RCP 3 PD	1,434	51	164	102	33	3	86	165
(5)	REMIND, RECIPE	1,455	51	77	35	43	4.4	22	92
(6)	REMIND, Adam	1,229	36	172	92	24	4.5	49	75
(7)	MERGE, ETL Adam	1,345	43	83	33	36	2,1	14	45
(8)	MARKAL, ETP Blue	?	?	59			3.6		
(9)	POLES, Adam	1,144	42	310	32	16	3.2	35	135
(10)	MESSAGE, WEC C1	1,138*	53				2		
(11)	MESAP, Energy [R]evolution 2008	?	?				3.7	30	50
(12)	MESAP, Energy [R]evolution 2010	1,107*	50				3.5	30	50
(13)	MESAP, Advanced Energy [R]evolution 2010	970*	38				4.1	30	50
(14)	WBGU	1,017*	41				4.8		

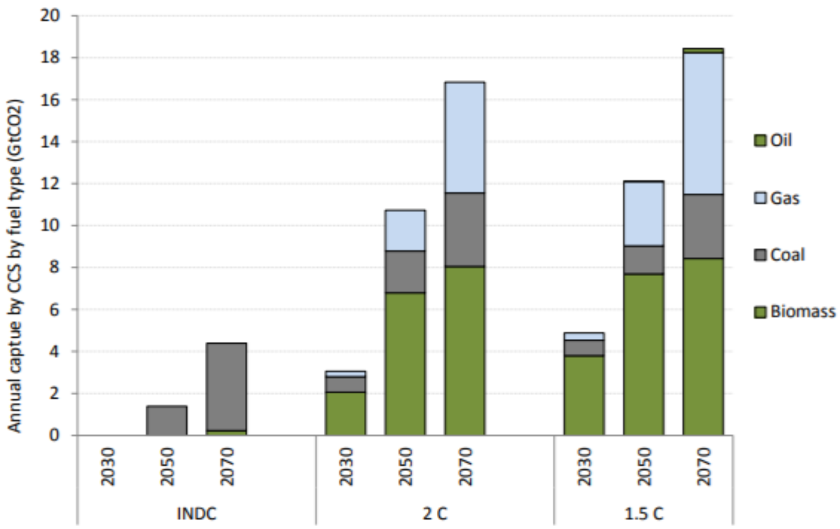
(From the Role of CCS in meeting climate policy targets, 2017)

Not all anthropogenic CO_2 emissions are included in the scenarios marked with a *. Non CO_2 GHGs and land-use emissions are not included. To include the shares which were not taken into account, corrective factors were used based on the contributions of these activities in 2005 to determine the probability of exceeding 2 degrees.

The probability of exceeding 2 degrees without CCS for these scenarios ranges from 36-56%, with only 2 scenarios including bio-CCS as more than 50% of CCS contribution. These models highlight the importance of CCS in meeting 2 degrees and demonstrate that CCS has been recognized by a wide range of sources as a potential solution to closing the emissions gap.

Other research in the report focusing on the scenarios used in the IPCC 5th Assessment report comments that "without large scale CCS, most models cannot produce pathways consistent with the 2°C goal". Comparisons between the role of CCS for 2 degree, 1.5 degrees and INDC targets are shown in Figure 21.

Figure 21: Annual carbon captured through CCS by fuel type, dependent on selected scenarios, for 2030, 2050 and 2070.



(From the Role of CCS in meeting climate policy targets, 2017)

Finally the report concludes that the "risks of CCS not being available as part of a portfolio of mitigation options to address climate policy targets are greater than the risks associated with attempting to develop it".

2.4.8 *Research analysing the NDCs against the 2DS*

The PBL Netherlands Environmental Assessment Agency climate pledge tool[1] looks at current commitments made by the world's governments. By analysing NDCs, it is estimated that the implementation of unconditional and conditional NDCs will leave an emissions gap of 13 and 11 Gt CO_2e, respectively, when aiming for a 2DS. Unconditional NDCs could result in a reduction in emissions of 6 Gt CO_2e by 2030, compared to PBL's business as usual scenario. However, the reductions could easily be less, with less than a third of countries studied in this tool on track to achieve their NDC targets.

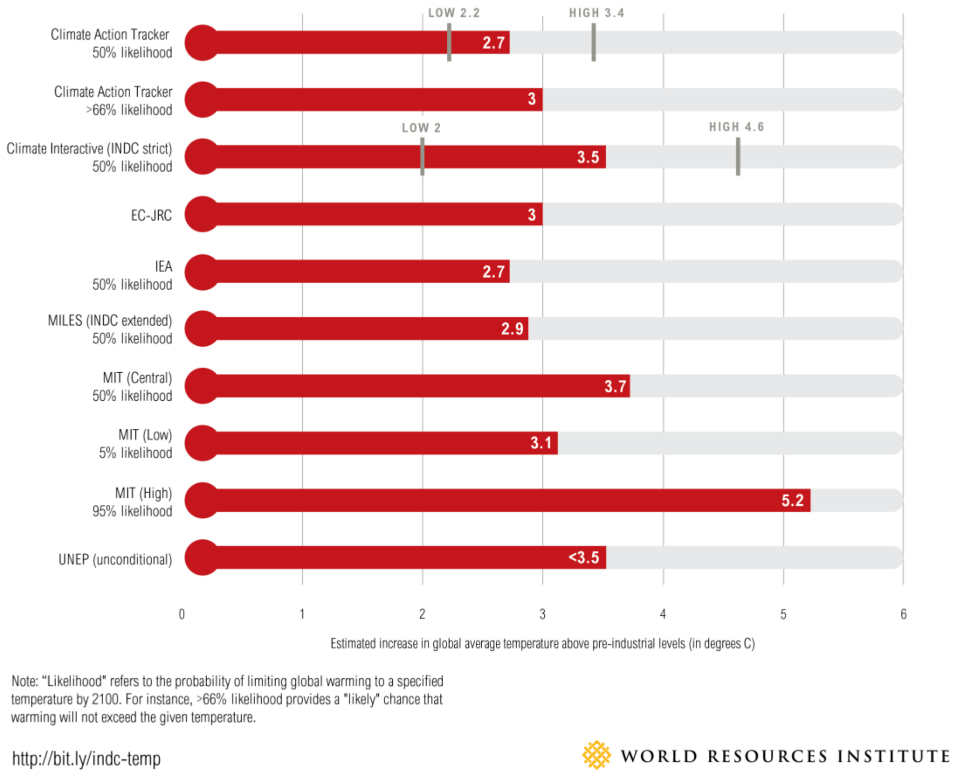
The Ecofys report "Pathways to Paris"[2] also analyses NDC commitments. They conclude that carbon sinks including CCS/CCU will need to be expanded if mitigation plans by 2030 are not strengthened. However, they do not quantify what expansion is needed.

[1] PBL climate pledge tool http://themasites.pbl.nl/climate-ndc-policies-tool/

[2] Ecofys (2016) Pathways to Paris http://www.energy-transitions.org/sites/default/files/20160426%20INDC%20analysis%20vF.pdf

A blog post by the World Resources Institute (WRI)[1] compares different energy scenarios and addresses why studies result in different estimates. Mainly, it is because they are created at different times, so include different data, such as later published INDCs. A range of assumptions also have to be made where there are data gaps; for example, countries aiming to reduce emissions in relation to GDP without specifying expected GDP growth. One of the most significant reasons for differences in studies is what is assumed after the target year of national plans, such as do they make further commitments, or continue on the same trajectory. The variation of changes resulting from NDC projections is shown in Figure 22.

Figure 22: Estimates of temperature rise for different studies which use NDC contributions



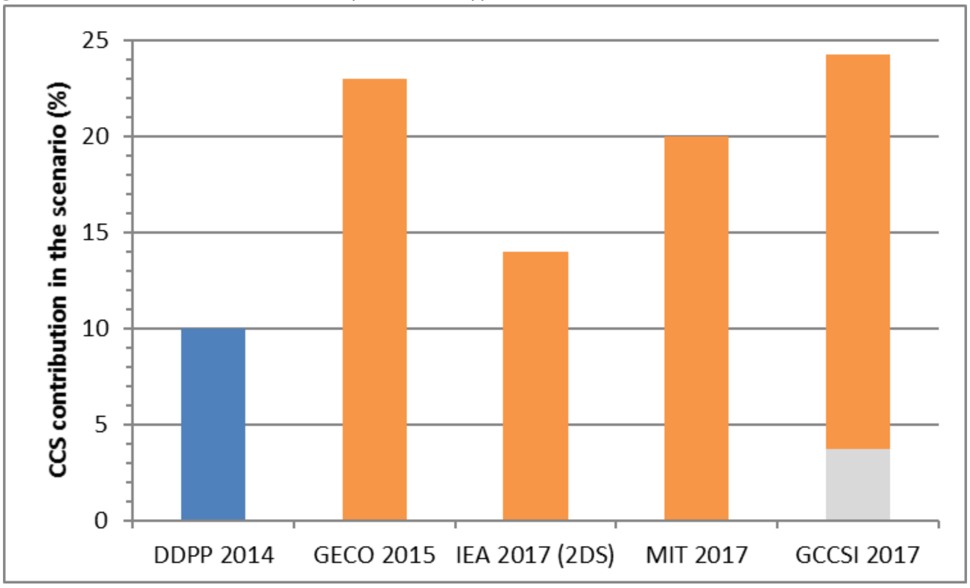
(From the WRI blog, 2015)

2.4.9 *Summary relating to CCS in leading energy transition scenarios*

One of the main conclusions is that the five leading scenarios reviewed in this project include CCS, all of which estimate its contribution to achieving a 2 degree target as more than 10%, which means CCS is projected to play a significant role in emission reductions (Fig. 23).

[1] WRI (2015) Why are INDC studies reaching different temperature estimates. http://www.wri.org/blog/2015/11/insider-why-are-indc-studies-reaching-different-temperature-estimates

Figure 23: CCS contributions for the different scenarios to 2050.*

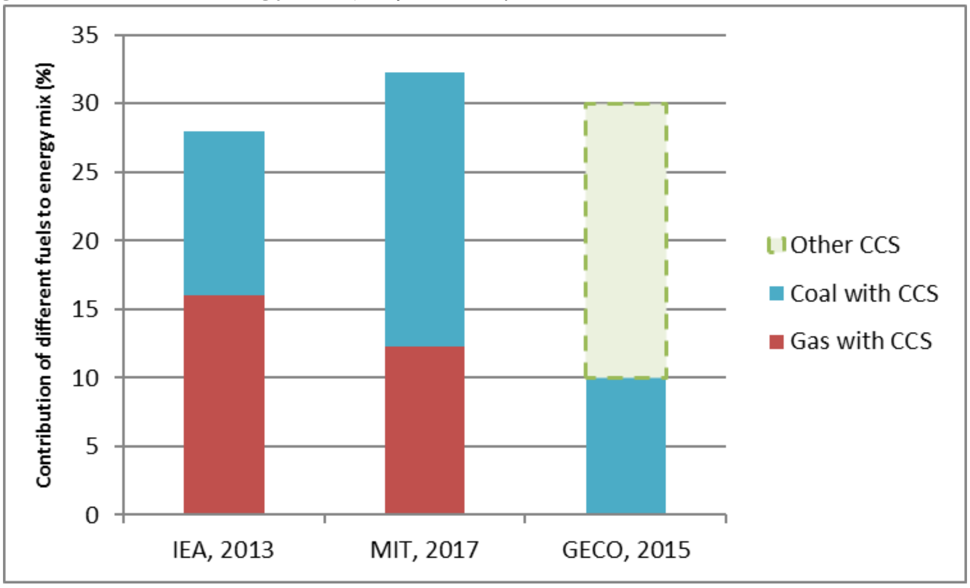


**Blue bar: electricity contribution, Orange bar: total emission reduction contribution, Grey bar: minimum reductions contribution from range of models*

In the DDPP report, CCS accounts for 10% of electricity capacity, whereas all the other scenarios state CCS contributions in relation to total emission reductions. The MIT 2017 value is estimated from Figure 19, which shows a high optimism CCS scenario. For the GECO 2015 report, this includes coal, gas and biomass usage. The values from different models in the GCCSI report range from 3.7% to 24.3%, excluding biomass CCS. The Sustainable Development Scenario accounts for 9% reduction to get from the New Policies scenario, but this is not included in the figure as it is not a 2DS and no temperature rise is given, although it is expected to be in line with Paris Agreement objectives.

Figure 24 compares the energy mix predicted for 2050 across different models. The IEA (2013) predicts that the energy mix in 2050 will comprise of 12% coal, and 16% gas. They comment that their contribution is only this high due to CCS, implying some of this energy generation is without CCS. The MIT (2017) values are estimated from a graphic. The GECO paper estimated coal will fall to 10% of the energy mix in 2050, most of which is associated CCS, while total energy consumption with CCS is 30%. Therefore, almost a third of CCS application is likely to be from coal generation. This 30% includes all forms of CCS including biomass.

Figure 24: Global energy mix projections for 2050



The main findings from this section include:

- The IEA 2DS expect CCS to account for 14% of carbon reductions against the reference transition scenario
- All scenarios which include a contribution from CCS to reach a 2 degree scenario, have CCS accounting for more than 10%; thereby CCS is expected to play a substantial role in the future.
- 13 of 14 DDPP country scenarios include CCS
- Current NDC commitments are not enough to reach a 2 degree goal; therefore, there is an emissions gap which requires solutions such as CCS.

2.5 *POSSIBLE ROLE OF CCS IN INTERNATIONAL MARKET MECHANISMS*

The Paris Agreement contains provisions that allow Parties under that Agreement to undertake 'Cooperative Approaches' under a framework set out in Article 6, paragraphs 2 and 4 for 'Market mechanisms' and paragraph 8 for 'Non-market approaches'. The modalities and procedures for these Market Mechanisms and Non-market approaches remain to be negotiated and elaborated in more detail. At the COP23 meeting in Bonn in November 2017, an approach was set out for negotiations under Article 6 to go forward. The main elements under Articles 6.2, 6.4 and 6.8 are supposed to be put together by March 2018 to produce a draft for negotiations in April-May 2018.

If Parties to the Paris Agreement do eventually agree to create and implement international market mechanisms with project-level recognition of avoided GHG emissions, that could be a vehicle to provide support for CCS projects.

3 SECTION 3: CCS CONTRIBUTION TO GHG GOALS IN PUBLIC DOMAIN STUDIES

This section is a review of what the main institutional commentators are saying about CCS in the public domain. The context is to review and assess the range of recent views and findings on CCS and the role it may play in the Energy Transition (Table 12).

Table 12: Sources covered with indicative summary of views on CCS in the Energy Transition

Organisation name	Sources	CCS context	Energy transition (Y/N)
World Bank	Several reports published by the WBG and in partnership with other bodies	Past technical assessment on deployment. Now in the context of low-carbon goals	Y
World Energy Council	Annual report on the main issues facing the energy industry; based on a survey of 1200 energy leaders	The importance of CCS has been steadily moving down the agenda and its future is perceived as uncertain	N
IEA	2016 summary report on the global status of the CCS industry and technological development	CCS is an important part of low-carbon scenarios for the IEA. Industry assessment and recommendations for improving its prospects	Y
OECD	Similar to the WB, some sector-specific reports, e.g. steel industry, but also more assessment of the possible low-carbon technologies available	Work on national & international policy alignment needed to stimulate CCS investment; CCS as probably the only option available to some industrial sectors for decarbonisation	Y
GCCSI	The Global Status of CCS: 2017	A clear advocate of CCS, at times overly so, but sets out the roles CCS can play in the energy transition	Y
CDP	A recent report on technology risks in CCS deployment	Acknowledges the role of CCS in scenarios and some of the key barriers to development	Y
UK Government	Clean Growth Strategy, 2017	The UK's CCS strategy is outlined. THE UK gov. clearly sees an important role for CCS in its low-carbon pathways and will put aside funds for investment. Clearly, larger scale demonstrations are necessary before deployment can go ahead	Y
BNEF	News article by Bloomberg New Energy Finance covering CCS and BHP Billiton's plans for developing CCS	Acknowledges the role of CCS in scenarios and how a private company can take some of the lead in CCS development	Y
MIT	2016 report on critical analysis of success factors for CCS projects. Many other reports available that cover technical development	Analyses a sample of global CCS projects and gives reasons for why some have failed or succeeded. In the context that CCS will be needed to meet emissions reduction goals	Y
Imperial College	Most reports cover technical development but one 2016 report assesses the challenges currently facing CCS commercialisation	Outlines some new approaches that could be taken to promote the deployment of CCS (as necessary to meet climate goals), with a focus on the UK	Y

3.1 WORLD BANK

The World Bank is an active commentator on CCS, has played a role in publicising the technology, and has commissioned several studies on CCS in the last decade. In 2011, the World Bank Group (WBG) published a formative report on CCS entitled *Carbon Capture and Storage in Developing Countries: A Perspective on Barriers to Deployment*[1]. The report was the first major effort of the WBG to contribute to a deeper understanding of CCS, its development, and financing.

The 2011 WBG report included case studies from another report: *Techno-economic assessment of carbon capture and storage deployment in power stations in the Southern African and Balkan regions*[2]. Key findings of that cited report are the modelled effects of imposing carbon taxation on the power, and related energy-systems of the two regions, for example:

- In the Southern African region, a carbon price of US$50 per ton CO_2 could make capturing and transporting CO_2 for storage from South Africa to depleted oil and gas fields in Mozambique economically feasible.

Another WBG report, published in June 2015, was *The Indonesia Carbon Capture Storage (CCS) Capacity Building Program: CCS for Coal-fired Power Plants in Indonesia*"[3]. This report considered the potential for retrofitting existing plant and assesses the potential for EOR at the two plants chosen in the study. The report found that CCS retrofitting would double the cost of electricity and decrease plant efficiency and output. The benefits were intangible without policy recognition and institutional support.

In 2015, the WBG blog[4] also featured a call from Eldar Sætre, President and CEO of Statoil, to governments around the world to put a price on carbon. Specifically, the blogpost advocates CCS and Statoil as a leader in the development of the technology. This is another example of the WBG advocating CCS in the public domain.

Since then, the WBG perspective on CCS has changed from being more technical-assessment themed, to focusing on the role of CCS in the energy transition.

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[1] Kulichenko and Ereira (2012) Carbon Capture and Storage in Developing Countries: A Perspective on Barriers to Deployment. https://elibrary.worldbank.org/doi/abs/10.1596/978-0-8213-9609-4

[2] Kulickenko (2011) Techno-economic assessment of carbon capture and storage deployment in power stations in the Southern African and Balkan regions. World Bank. http://siteresources.worldbank.org/INTENERGY2/Resources/4114191-1316103699379/Natalia_Kulichenko_CCS_model_Sept7-2011.pdf

[3] World Bank (2015) The Indonesia Carbon Capture Storage (CCS) Capacity Building Program: CCS for Coal-fired Power Plants in Indonesia http://documents.worldbank.org/curated/en/563781468284373788/pdf/FINAL-OK2-Jun-2415Cov-reduced-with-WB-cover.pdf

[4] Eldar Sætre (2015) World Bank blog, https://blogs.worldbank.org/taxonomy/term/13823

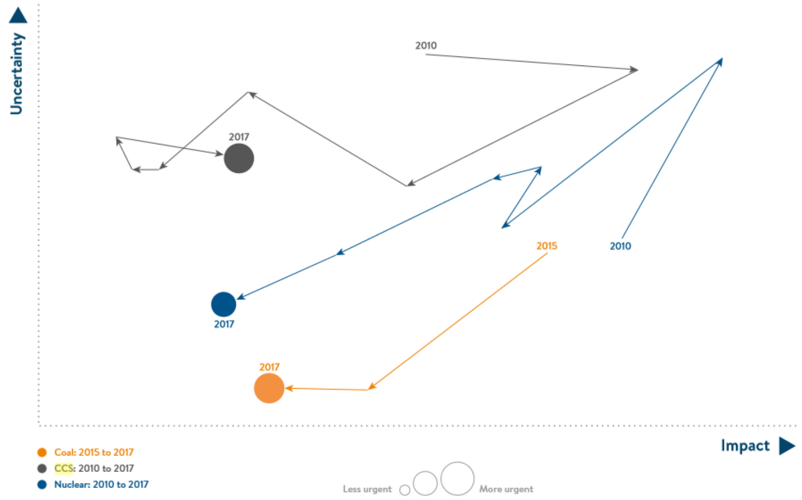
In 2017, the WBG published new directions for the WBG's Energy Sector (a section of the organisation) entitled: *Toward a Sustainable Energy Future for All*[1]. The report mentions CCS in the context of achieving sustainability goals, and specifically:

- Power plants with CCS technology can be highly water intensive – this can be a limiting factor;
- To date, carbon prices have been too low for long-term, low-carbon investment on a large scale;
- There has been little technological progress in CCS;
- As CCS is a critical area for meeting future sustainability goals, more technological breakthroughs are needed;
- The WBG will support the development of new clean energy technologies such as CCS. This may be through technical assistance, as with the CCS Capacity Building Trust Fund, launched in December 2009.

3.2 *WORLD ENERGY COUNCIL*

The World Energy Council (WEC) publishes an annual report called the *World Energy Issues Monitor*[2]. The report presents the results from a survey of 1200 energy leaders in over 90 countries. It asks the respondents to consider the issues facing the energy agenda and rank them in order of impact and certainty. Now in its eighth year in 2017, the last two years have seen CCS falling down the WEC agenda. CCS now occupies a perceived 'low impact' and 'uncertain' scoring on the agenda. Figure 25 shows the how the perception of CCS has changed since 2010. CCS has clearly slipped down the 'impact' scoring category.

Figure 25: CCS becoming a low impact issue



(From the WEC, *World Energy Issues Monitor*, 2017)

[1] World Bank (2017) Towards a Sustainable Future for All. http://documents.worldbank.org/curated/en/745601468160524040/pdf/795970SST0SecM00box377380B00PUBLIC0.pdf

[2] World Energy Council (2017) World Energy Issues Monitor: 2017 http://wec-italia.org/wp-content/uploads/2017/04/1.-World-Energy-Issues-Monitor-2017-Full-Report-v1-Embargoed.pdf

Since 2011, CCS has dropped down to one of the weakest signals in 2017 in terms of its anticipated future role. The WEC says that CCS is "acknowledged as an essential element of any low-carbon energy future, the latest global findings reinforce that expectations for CCS are very low in the current environment as the issue remains one of the lowest relative impact with a high degree of uncertainty".

What this suggests is that energy leaders in WEC are uncertain where CCS is headed and significant strides in the policy framework will be needed to stimulate the technological progression needed to garner support for CCS outside of EOR applications. However, North America is an outlier. CCS is perceived with a moderate impact there, perhaps because of more progress in recent years and a pipeline of projects.

3.3 IEA

In its 2016 report[1] *20 Years of Carbon Capture and Storage,* the IEA highlighted the technological progress made by industry since the start of the Sleipner CCS project offshore in Norway. The IEA also reiterates the necessity for CCS as a climate change mitigation technology in its own scenario analysis. The report serves as a proponent for CCS and admits that since 2009, CCS progress, at the pace the IEA deems necessary, has stalled. The report indicates where policy and regulation must change to stimulate further progress in the development of the technology. The challenges CCS faces are well known but must be addressed now to ensure climate goals are met.

In summary, this 2016 IEA CCS report suggests:

- Targeted policy support providing a financial incentive is needed, both now and for the long term.
- Where project specific factors and government policies have aligned, there are already operational projects. This is an indication that early adoption is possible but will take concerted effort at the project scale.
- Investment in CO_2 storage must be a priority as access to geological storage could be a significant barrier to widespread development.
- CCS is as important in industrial processes as it is in the power sector, e.g. for coal generation.
- More projects need to be developed now to pave the way for the future.
- More work is needed to educate the public about CCS to enhance acceptance.

CCS has been proven for 20 years and should now be developed with renewed urgency to meet the goals of the Paris Agreement. The IEA scenarios relevant to the Energy Transition are treated elsewhere in this report.

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[1] IEA (2016) 20 Years of Carbon Capture and Storage: Accelerating Future Deployment http://www.iea.org/publications/freepublications/publication/20-years-of-carbon-capture-and-storage.html

3.4 OECD

Under the umbrella of the Organisation for Economic Co-operation and Development (OECD), there is a lot of publicly available material that considers CCS. In most cases, CCS is mentioned as a technology that is crucial to meeting decarbonisation targets. Some of these reports are industry-sector or technology-specific, while others consider the role of CCS more generally. The points below summarise the OECD main conclusions regarding CCS:

3.4.1 *OECD in partnership with the Grantham Institute (2016/2017): A survey of key technological innovations for the low-carbon economy*[1]

This work summarises the main technological innovation priorities required to achieve deep decarbonisation consistent with meeting 2^{o}C and below. Technologies are identified that are crucial to achieving low-carbon goals but are not yet at commercial scale and so require more R&D, CCS being one of them.

- CCS is one of the few options for heavy industry such as steel, cement and chemicals to achieve low carbon processes.
- CCS technology has already been demonstrated commercially, but usually at the separate stages of the process, i.e. capture, injection, etc.
- A large-scale demonstration is urgently needed.

Cost estimates for CCS in power generation are estimated at around USD 43-80/tCO_2 (IEA, 2012). The application of CCS to industrial processes is less well developed and is generally more challenging but has the potential to be cheaper than CCS for power generation, the OECD says. Current cost estimates vary widely because each process and each site is unique and will therefore require bespoke equipment and plant design until there are more plants in operation. Current cost estimates range from USD 15-138/tCO_2 for cement and USD 51-64/tCO_2 for steel (Fennell et al., 2012).

3.4.2 *OECD (2015), Aligning Policies for a Low-carbon Economy*[2]

- The high cost of low-carbon technologies, such as CCS, will require a more stable price signal than the prices we currently see in modern electricity markets born out of sector liberalisation.
- Development forecasts show that this century most electricity capacity will be installed outside of the OECD. To be compatible with the IEA's 2DS, nine-tenths of coal plants will be built outside the OECD and will have to be fitted with CCS

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[1] Napp et al., (2016) A survey of key technological innovations for the low-carbon economy. http://www.oecd.org/environment/cc/g20-climate/collapsecontents/Imperial-College-London-innovation-for-the-low-carbon-economy.pdf

[2] OECD/IEA/NEA/ITF (2015) Aligning Policies for a Low-carbon Economy http://dx.doi.org/10.1787/9789264233294-en

3.4.3 *OECD (2015), Greening Steel: Innovation for Climate Change Mitigation in the Steel Sector*[1]

- The integration of CCS in iron and steel making processes is currently recognised as the only available way to enable the deeper carbon emissions reductions levels required to stabilise emissions.
- Because steel is a globally traded commodity, the level of carbon pricing that would make CCS economically attractive are politically and economically difficult to implement.

3.4.4 *OECD (2012), Energy and Climate Policy: Bending the Technological Trajectory*[2]

In the context of the global climate change debate, increased attention is being paid to international technology-oriented agreements, as a complement to emissions-based agreements. Such agreements can play a role in sharing of costs and knowledge. Researchers in countries which are members of the agreement are much more likely to co-operate with each other in the development of patented climate change mitigation technologies.

- This study finds that this effect varies by technology but has the greatest impact for CCS (83%)
- The analysis in the report suggests that, other things held constant, adherence to the International Technology Agreements would increase co-invention in non-member countries by more than 90% in the case of CCS.

3.5 *GLOBAL CCS INSTITUTE*

3.5.1 *The Global Status of CCS: 2017*[3]

This is a summary report of the state of the CCS industry by the GCCSI which is seen by many as an advocate for CCS. Interestingly, CCS is described as "the conduit to a new energy economy of hydrogen production, bioenergy and CO_2 re-use applications" (Brad Page, CEO, GCCSI). The report quotes the IEA number of 14% of cumulative emissions reductions needing to come from CCS applications if we are to achieve the targets of the Paris Agreement. CCS is described as "versatile, timely and utterly economic". According to the report, there is no challenge to CCS acceleration in terms of underground capacity. There are ample storage resources and the issue is actually above ground: "policy, funding and awareness". Figure 26 shows global storage resources according to the GCCSI.

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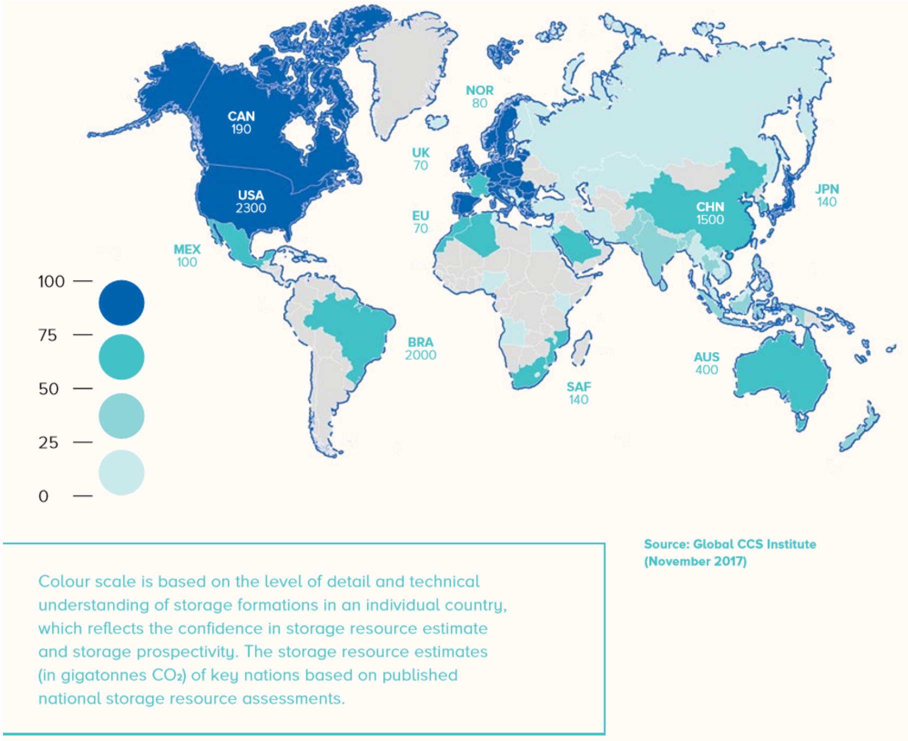
[1] OECD (2015) Greening Steel: Innovation for Climate Change Mitigation in the Steel Sector. http://www.oecd.org/sti/ind/Environmental-patents-steel.pdf

[2]OECD (2012) Energy and Climate Policy: Bending the Technological Trajectory http://www.oecd.org/env/consumption-innovation/energyandclimatepolicy.htm

[3] Global CCS Institute (2017) The Global Status of CCS: 2017 http://www.globalccsinstitute.com/sites/www.globalccsinstitute.com/files/uploads/global-status/1-0_4529_CCS_Global_Status_Book_layout-WAW_spreads.pdf

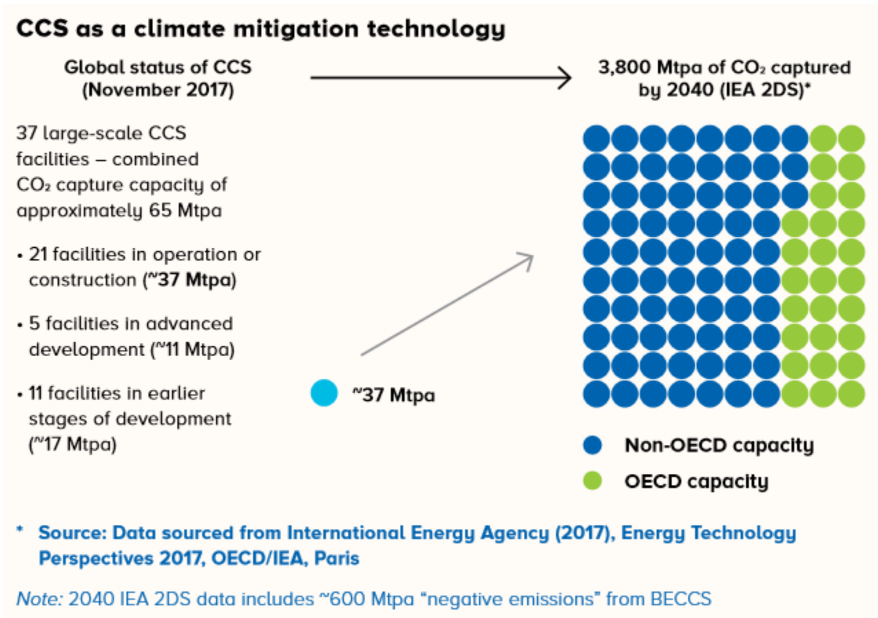
Figure 26: Global storage resources



(From the GCCSI, 2017)

In this report, CCS is a vital part of the energy transition and necessary to meet climate targets, as detailed in Figure 27.

Figure 27: CCS as a climate mitigation technology (GCCSI, p18)



(From the GCCSI, 2017)

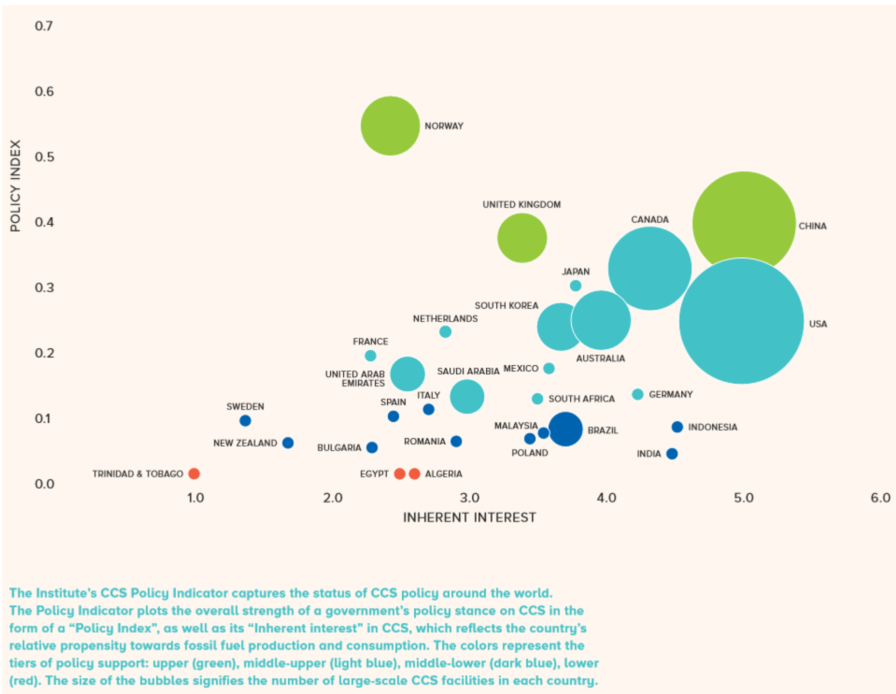
CCS is also put forward as having health benefits due to the removal of harmful pollutants and particulates causing poor air quality and "about 3 million premature deaths annually".

In terms of the 'new energy economy', CCS can solve the energy trilemma as it helps decarbonise, while also delivering reliability of supply and lowering costs. If deployed, CCS can create economy-wide employment growth, lower emissions from factories, and allows productive assets to stay open. The report also presents a vision for an integrated renewables and CCS low-carbon energy system.

According to the report, the future role of CCS is beginning to be better understood by policy makers. CCS must receive "policy parity" with renewables if Paris targets are to be met.

The GCCSI's Legal and Regulatory indicator found there had been little change in CCS legal and regulatory models worldwide. In fact, there has been little change in applicable countries (those with existing laws) since 2015. Figure 28 shows the state of national CCS policy against a country's need for CCS, i.e. does the country consume a lot of fossil fuels.

Figure 28: GCCSI Policy Indicator 2017: summary highlights (p37)



(From the GCCSI, 2017)

There is mention in the report of the developing 'rulebook' countries who are Parties to the Paris Agreement are designing.

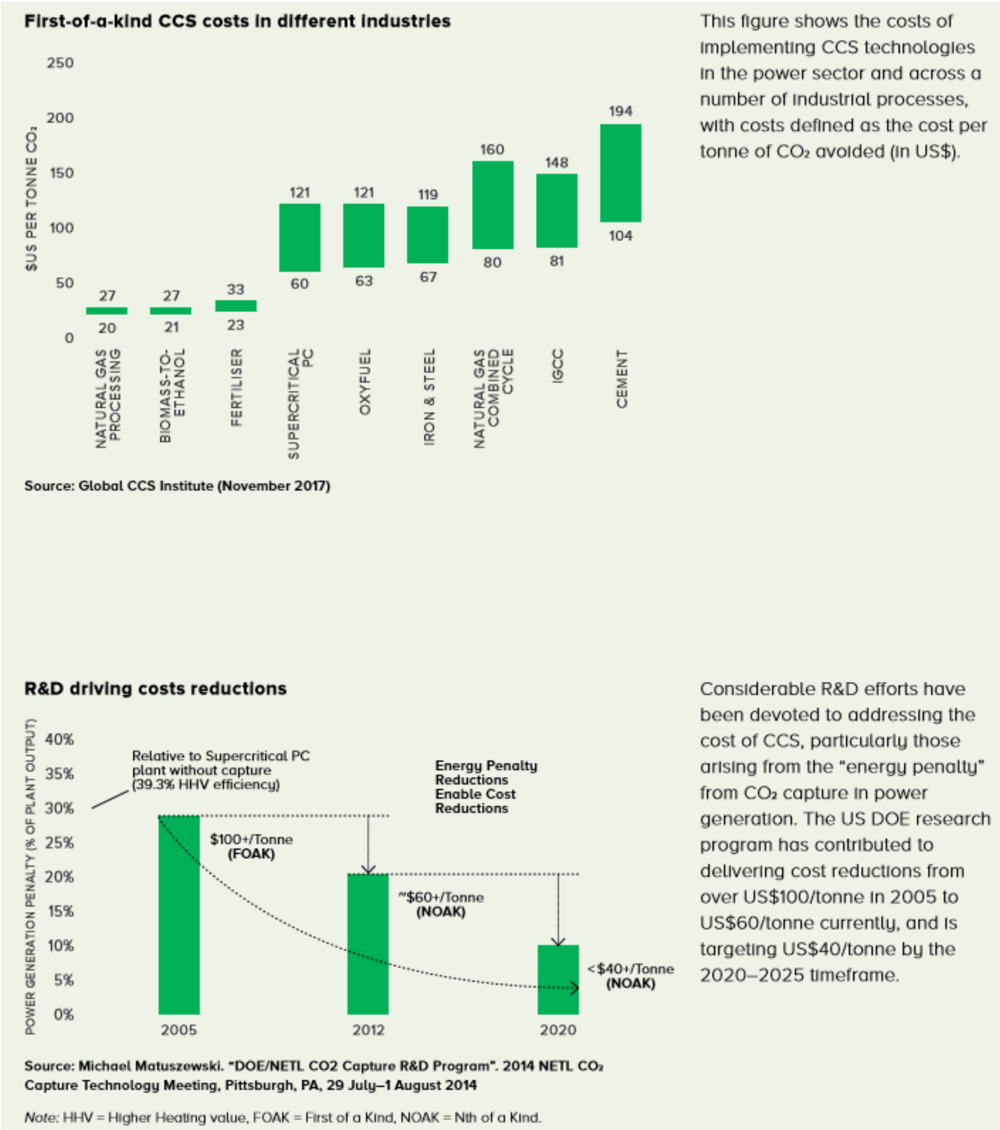
The report stresses that it is very important that countries remain neutral to the various climate change mitigation technologies that exist, and CCS should not be discriminated against.

CCS costs are discussed in some detail. Adding CCS to unabated power or industrial facilities "can result in additional costs of as low as 2% and up to 70% to the lifecycle or levelized unit cost of production".

This range is explained further on where it becomes clear that those facilities with lower costs already strip out CO_2 in the process, whereas power generation, steel and cement manufacturing incur much higher costs as stripping out the CO_2 is an additional process.

The report attests that CCS "has become just as, and in some cases, more competitive than other low-carbon technologies". Figure 29 shows CCS costs for first-time installations, and cost reductions due to R&D.

Figure 29: First-of-a-kind industrial CCS costs and R&D cost reductions (p46)



(From the GCCSI, 2017)

3.6 *CARBON DISCLOSURE PROJECT (CDP)*

In the CDP report, *Mind the CCS Gap: Carbon capture storage technology risks captivating business as usual – who will bear the cost of uncaptured carbon?*[1], CCS is described as a "set of technologies capable of delivering significant carbon emission reductions from the use of fossil fuels in power generation and in multiple industrial applications". Its role in the most popular scenarios is described as is its critical role in the modelling process. The report says that theoretically, CCS can be applied at scale, there is vast, available storage, and the infrastructure requirements are well known.

The report highlights the growing future presence of CCS in scenario analysis but the current low number of operating plants and stored volumes.

Other key 2017 findings from CDP are:

- In most cases, CCS is not commercial. Carbon prices of €65 to €215 per metric tonne would be needed to make it economic. However, this level of pricing is not expected to develop for years.
- Policy uncertainty in several areas is another hurdle. Clearer frameworks are needed, along with government financial support.
- There are discrepancies across industrial sectors: the chemical sector is more proactive in the CCS value chain; whereas the cement sector, a sector which uses CCS in many future scenarios, currently has no active CCS projects.
- Without CCS, it will be very challenging to meet climate goals. This is highlighted by the report's simple sensitivity analysis based on the IEA Beyond 2 Degree Scenario (B2DS).
    - In the power sector, renewables and nuclear would have to displace the gap left by CCS, and gas would replace all coal in scenarios.
    - The industrial sector would be even more challenged as some substitute technologies actually rely on CCS as well.
- Finally, the report recommends that CCS be "encouraged and forcefully pursued", and the current risk of projects' failure should be "hedged more credibly".

[1] CDP (2017) Mind the CCS Gap: Carbon capture storage technology risks captivating business as usual – who will bear the cost of uncaptured carbon? https://b8f65cb373b1b7b15feb-c70d8ead6ced550b4d987d7c03fcdd1d.ssl.cf3.rackcdn.com/cms/reports/documents/000/002/878/original/Mind-the-CCS-Gap-Report-EXEC_SUM.pdf?1512555344

3.7 *UK GOVERNMENT: UK CLEAN GROWTH STRATEGY, 2017*[1]

The UK government sets out a new approach to carbon capture usage and storage (CCUS). It wants the UK to become an international leader in CCUS and believes CCUS has the potential to reduce the cost of meeting the UK's 2050 emissions reduction target. It plans to collaborate with international partners and invest up to £100 million in CCUS and innovation, hoping to drive down costs.

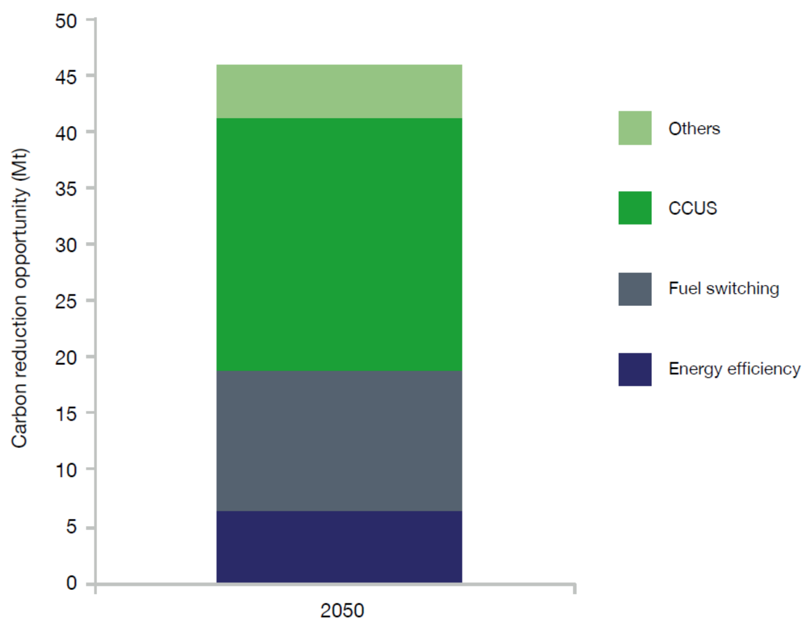
The government will work with industry to set up a new Ministerial-led CCUS Council. This will help develop the option of deploying CCUS at scale, while maximising economic opportunity.

The strategy includes three 'pathways to 2050' which outline potential options available to decarbonise the UK economy. In two of these, the Hydrogen pathway and the Emissions removal pathway, CCUS is expected to play an important role.

The government wants to position the UK at the forefront of GHG removal technology and will consider the scope of removing barriers and strengthening incentives for this to happen, including for CCUS.

Figure 30 highlights the options for reducing emissions across industry:

Figure 30: Carbon reduction opportunities across industry (2050)



(From the The Clean Growth Strategy, 2017)

[1] UK Government (2017) The Clean Growth Strategy: Leading the way to a low carbon future, https://www.gov.uk/government/publications/clean-growth-strategy

- CCUS is a potentially large economic opportunity for the UK because there is international consensus that CCUS will play an important future role in reducing emissions. The IEA estimates there will be a global CCUS market worth over £100 billion in the future.

- Despite UK government support and investment of £130 million in R&D since 2007, technological progress has been disappointing. A technical breakthrough to significantly lower costs has yet to occur and costs have been deemed too high for consumers.

- The government will convene a CCUS Cost Challenge Taskforce to develop a plan to reduce costs and this will become the foundation of deploying a CCUS pathway in **2018**. This will set out the steps necessary to reach the government's ambition of deploying CCUS at scale in the 2030s. This is subject to costs coming down sufficiently.

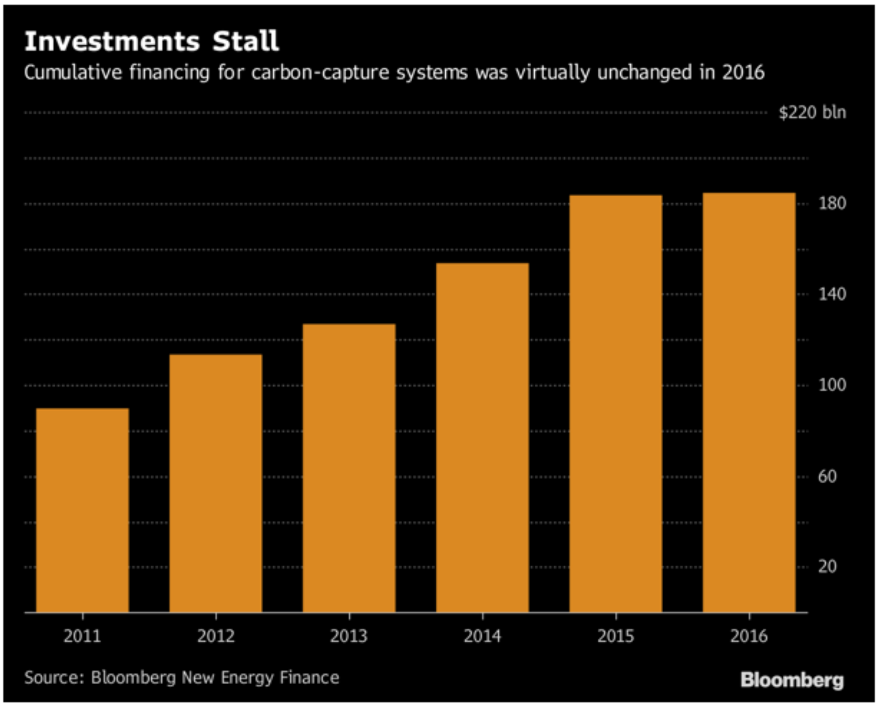
- The government will also continue to work internationally by working with public and private sector innovation bodies; developing closer working relations with countries who also harbour CCUS aspirations; investing a further £10 million in the UK's £60 million international CCS programme; organising an international CCUS conference in 2018.

- The UK government will also support and invest in UK-based CCUS technologies and companies, for example through the £4 million provided to Carbon Clean Solutions Ltd.

3.8 BLOOMBERG NEW ENERGY FINANCE (BNEF)[1]

A recent news article[2] outlines how CCS investment stalled in 2016, shown in Figure 31.

Figure 31: Cumulative global CCS financing



(From Bloomberg, 2017)

This BNEF article mentions that more than 2,000 CCS facilities will be needed by 2040 under IEA scenarios, with just 17 large-scale facilities operational now.

The article focuses on BHP Billiton's plans for achieving net zero GHG emissions in the second half of the century.

BHP has partnered with Peking University in China and this may help develop a pilot CCS project with a Chinese steel company. The company is also cooperating with SaskPower, a Canadian power producer, to build a CCS knowledge centre at its coal-with-CCS power plant.

BHP also started a research project in April 2017 with three top universities to assess the long-term storage of CO_2.

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[1] Bloomberg News, Bloomberg technology (2017) World's No. 1 Miner Sees Bigger Role for Carbon-Capture Systems https://about.bnef.com/blog/worlds-no-1-miner-sees-bigger-role-for-carbon-capture-systems/

[2] Bloomberg (2017) World's No. 1 Miner Sees Bigger Role for Carbon-Capture Systems (https://about.bnef.com/blog/worlds-no-1-miner-sees-bigger-role-for-carbon-capture-systems/)

3.9 *MASSACHUSETTS INSTITUTE OF TECHNOLOGY (MIT)*

MIT has a wealth of publicly available research documents with relevance to CCS and the Energy Transition[1]

Most recently published is the report *Lessons Learned from CCS Demonstration and Large Pilot Projects*[2]. This report analyses a selection of CCS projects in operation, under construction, or that have been abandoned – for a 'lessons learned' perspective:

- It deems that there have been 22 'successful' CCS projects, 21 of which occurred in areas with a significant oil and gas industry presence. EOR has clearly been very important to date, however this must change.
- Policies that could give CCS projects access to electricity markets would be beneficial.
- Regulatory drivers, such as those limiting emissions from coal-fired power plants, are needed for CCS project development.
- While government subsidy is necessary for most projects, over-reliance has led to four projects failing (in other words they were uneconomic or became an easy target, due to high cost, in a changing political environment): FutureGen and FutureGen 2.0 (US); Shell Peterhead and White Rose (UK); BP Peterhead (UK); Mongstad (Norway).
- Multiple financing components are necessary.
- CCS projects with shorter timeframes have been more successful and in general these characteristics help reduce project timelines: smaller scale; brownfield sites; minimise technical risks by developing technology at pilot scale; work with governments for a streamlined permitting process; avoid complicated business arrangements (Herzog (2016), p42).
- Much stronger political support and public acceptance is needed for CCS. Therefore advocating the role of CCS as complimentary to, rather than in competition with, renewables is important.

Similarly, Stanford University has a CCS research institute but most recent publications focus on technology development and scientific studies rather than the Energy Transition.

[1] MIT CCS search results http://energy.mit.edu/search/?q=CCS

[2] Herzog (2016) Lessons Learned from CCS Demonstration and Large Pilot Projects: An MIT Energy Initiative Working Paper http://energy.mit.edu/wp-content/uploads/2016/08/MITEI-WP-2016-06.pdf

3.10 *IMPERIAL COLLEGE LONDON*

On the whole, Imperial College publications generally focus on technical advancements in CCS technologies (and there are many).

Imperial gives credit to CCS as "a significant technologically ready tool for de-carbonising our current and future power and industrial sectors".

There are two research networks under the Imperial College umbrella exploring CCS technology and the role of CCS in the energy transition[1]

The most recent results of these networks were published in 2016: *Commercialisation of CCS – What needs to happen?*[2]. This is an assessment of the challenges facing the CCS industry and highlights some new approaches to development that could be tried. The section on costs says that one of the reasons for cancelling the UK CCS competition was perceived high costs.

CCS costs are compared to other forms of low-carbon generation that are lower cost now, although they are likely to increase system-wide costs in the future. Risk is highlighted as a barrier to the private sector developing CCS.

If some risk categories could be transferred to the public sector this could reduce project costs.

It is suggested that for a UK CCS industry to develop, a publicly-owned transport and storage company would have to be set up to mitigate risk in this area to the private developer.

3.11 *SUMMARY OF KEY POINTS FROM MAJOR STUDIES IN THE PUBLIC DOMAIN*

From this short assessment of the large number of publicly available sources on CCS, it is clear that most are in agreement that CCS will have to play a pivotal role in the energy transition. Many of the commentators here mention CCS in the context of the energy transition scenarios.

An outlier is the WEC where it seems that the opinion of CCS among energy leaders has been decreasing in importance and its future is seen as uncertain.

Across most of the sources reviewed there are several points seen as holding back CCS development (although the GCCSI does not see some of these as barriers, or disagrees on the numbers):

- CCS technology has been mature for some time, however large-scale projects to prove its application across the energy and industrial sectors, are few compared to earlier projections.

[1] CleanFAB website http://www.imperial.ac.uk/a-z-research/clean-fossil-and-bioenergy/

[2] Hackett (2016) Commercialisation of CCS – What needs to happen? http://industriamundum.com/wp-content/uploads/2016/12/IChemE-CCS-Commercialisation-L.-A.-Hackett-2016.pdf

- Costs are currently too high on the whole, especially given low carbon prices. This could be mitigated by financial incentives, and any such support policies should be stable and long term.

- Regulation, e.g. on coal sector emissions, would support CCS deployment if retrofitting is to become more common or more plants that are CCS ready are to be built.

Carbon pricing could serve as an effective policy for enabling investment in CCS and could serve to create a more level playing field with other low-carbon technology options.

Successful operational projects have typically benefitted from project-specific policy and financial support – there are lessons to be learned from these cases

- Responsibility and accountability across the value chain will have to be more clearly defined for risk premiums to reduce

- Support for CCS will likely have to come from the national government level in the first instance, addressing some of the barriers above, before the private sector will become interested again.

4 SECTION 4: FACILITATING CCS TO HELP MEET LONG-TERM REDUCTION GOALS

As elaborated above, this report found that the International Energy Agency, Massachusetts Institute of Technology, Intergovernmental Panel on Climate Change, Global CCS Institute, Deep Decarbonization Pathways Project, and others have all projected the need for CCS in order to achieve the Paris Agreement goals.

The contributions of CCS to scenarios that could successfully achieve the Paris Agreement goals range from 10 to 25 percent of the total GHG emissions response effort depicted in those scenarios.

On the whole, however, CCS is hardly mentioned or described in the discussion of potential policy developments by the nations of the world. Those handful of nations that do mention CCS do so with extensive discussion about barriers to investments in CCS projects including the cost of CCS, the lack of finance and the lack of implementation of government policies and incentives.

This points to the critical need for the rapid scale-up of CCS in the coming decades which has yet to begin. The pipeline of major CCS projects has dried up in recent years and no new significant CCS projects are being developed.

Further, because of costs and a range of issues from lack of policy framework, policy uncertainty, public perception, and potential long-term storage site stewardship issues, some business leaders in a World Energy Council survey have expressed negative sentiments about the prospect of deploying CCS.

These difficult challenges point to a fundamental gap between the ambitious goal of the Paris Agreement and the reality of deployment of CCS projects.

Despite these challenges, this report also points out that even if nations did not mention CCS in their nationally determined contributions or included CCS in a mid-century strategy, considering CCS as part of these future actions, especially as nations go through the every-five-year global stocktake, could still help these nations to analyse for and plan the conditions that would help in the future deployment of CCS to reduce emissions significantly.

Some of the possible ways to promote CCS as an energy transition solution may include, but will not be limited to:

- More information on CCS to address concerns of stakeholders and governments
- More analysis to address outstanding issues or lack of awareness regarding CCS
- More analysis and measures to address costs and benefits of CCS
  More analysis and measures to address reliability, permanence and storage potential of CCS