# Recent studies and publications on the status, need and potential of Carbon Capture and Storage (CCS) and negative $CO_2$ emissions – *a selection*

**By: Wim Turkenburg,** *1 december 2015*

**01. Global Energy Assessment – 2012-06-11 – 'Toward a Sustainable Future'**
*"Major Changes in Fossil Energy Systems are Essential and Feasible: Transformation toward decarbonized and clean energy systems requires fundamental changes in fossil fuel use, which dominates the current energy landscape. This is feasible with known technologies.*
- *$CO_2$ capture and storage (CCS), which is beginning to be used, is key. Expanding CCS will require reducing its costs, supporting scale-up, assuring carbon storage integrity and environmental compatibility, and securing approval of storage sites.*
- *Growing roles for natural gas, the least carbon-intensive and cleanest fossil fuel, are feasible, including for shale gas, if related environmental issues are properly addressed.*
- *Co-processing of biomass and coal or natural gas with CCS, using known technologies, is important for co-producing electricity and low-carbon liquid fuels for transportation and for clean cooking. Adding CCS to such coproduction plants is less costly than for plants that make only electricity. Strong policies, including effective pricing of greenhouse gas emissions, will be needed to fundamentally change the fossil energy system."*

**02. European Commission – 2013-03-17 – 'On the Future of Carbon Capture and Storage in Europe'**
*"The EU is committed to an overall greenhouse gas emissions reduction of at least 80% by 2050. Nonetheless, fossil fuels are likely to continue to be used in Europe's power generation as well as in industrial processes for decades to come. Therefore, the 2050 target can only be achieved if the emissions from fossil fuel combustion are eliminated from the system, and here CCS may have an essential role to play, as a technology that is able to significantly reduce CO2 emissions from the use of fossil fuels in both the power and industrial sectors. CCS can also be applied in conjunction with the production of transport fuels, particularly for the production of alternative fuels like hydrogen from fossil sources.*
*CCS is normally considered in conjunction with fossil fuel combustion, but it can also be used to capture biogenic carbon from the use of biomass (Bio-CCS). Bio-CCS application can range from capturing CO2 from biomass co-firing and biomass-fired power plants to biofuel production processes. However, the technical feasibility of biomass-CCS value chain has still to be demonstrated on a large scale.*
*IEA analysis suggests that without CCS, capital costs – in the power sector - to reach the greenhouse gas targets required for a maximum 2 degree rise in global temperatures might increase by as much as 40%.*
*The role of CCS in cost efficient climate mitigation has been illustrated in the 2050 Energy Roadmap in which all of the scenarios imply the use of CCS. In 3 of the 5 decarbonisation scenarios that were elaborated, CCS was applied to more than 20% of Europe's electricity mix by 2050. The 'diversified supply technology scenario' of the 2050 Energy Roadmap shows that by 2035 a total of 32 GW of CCS could be installed, rising to around 190 GW by 2050."*

**03. IPCC – 2014-03-13 – 'Climate Change 2014 Synthesis Report – Summary for Policymakers'**
*"(…) Overshoot scenarios typically rely on the availability and widespread deployment of bioenergy with carbon dioxide capture and storage (BECCS) and afforestation in the second half of the century. The availability and scale of these and other CDR technologies and methods are uncertain and CDR technologies are, to varying degrees, associated with challenges and risks. CDR is also prevalent in*

*many scenarios without overshoot to compensate for residual emissions from sectors where mitigation is more expensive (high confidence).*
*In the absence or under limited availability of mitigation technologies (such as bioenergy, CCS and their combination BECCS, nuclear, wind/solar), mitigation costs can increase substantially depending on the technology considered. Delaying additional mitigation increases mitigation costs in the medium to long term. (…) Many models could not limit likely warming to below 2°C if bioenergy, CCS and their combination (BECCS) are limited (high confidence)."*

**04. UNEP – 2014-11-15 – The Emissions Gap Report 2015**
*In the scenario database from the IPCC, all least cost 2020 scenarios assume that net negative Carbon dioxide emissions are needed at some point during this century to stay within the 2 °C limit. (…) Negative carbon dioxide emissions, the active removal of carbon dioxide from the atmosphere, can be achieved by several means. These include afforestation or reforestation, carbon dioxide storage in combination with direct-air-capture, and BECCS. BECCS is an often applied measure in model-based studies because of its attractive costs and high potential. But the viability of large-scale BECCS deployment depends on overcoming some critical barriers."*

**05. IEA – 2015-04-24 – 'Tracking Clean Energy Progress 2015'**
*"Significant milestone for carbon capture and storage (CCS) was reached with the opening of the first commercial-scale coal-fired power plant (CFPP) with $CO_2$ capture in October 2014. Further projects are being built in the United States, Canada, Australia, Saudi Arabia and the United Arab Emirates. The number of projects in development, however, is lower than required to meet the 2DS targets. Given the importance of CCS in a low-carbon future, there will need to be a substantial increase in investment in research and development (R&D), storage resources, and projects now to ensure it is widely available in the coming decades."*

**06. World Energy Focus (WEC) – April 2015 – 'The Carbon Capture Conundrum'**
*"With fossil fuels expected to provide the bulk of the world's primary energy needs for the foreseeable future – despite the rapid rise of renewables – carbon capture and storage (CCS) is seen by many as an essential technology if we are to keep global warming within 2 degrees C limit that scientists recommend. However, though there are signs of progress, the widespread adaption of CCS still appears to be decades away. (…) The progress is a big worry, for three reasons. Firstly, despite the rise of renewables, long term energy outlooks published by the World Energy Council, the IEA, BP and others all agree that humankind will be relying on fossil fuels – coal, oil and natural gas – for most of its energy supply decades from now. Secondly, these organisations, along with the Intergovernmental Panel on Climate Change (IPCC), agree that limiting GHG emissions will be much more expensive without CCS. Thirdly, some go as far as to argue that, without CCS, limiting global warming to 2 degrees C will be impossible."*

**07. G7 – 2015-06-09 – 'Statement on Climate Change, Energy and Environment'**
*"The G7 has delivered a timely reminder on the need for a global roadmap to a low carbon economy through ongoing research and development in carbon capture, storage and re-use technologies. The G7 statement says all nations must do their part to achieve a low-carbon global economy in the long-term including developing and deploying innovative technologies (…) It is important to emphasise that decarbonisation and continued fossil fuel use are not mutually exclusive. The production of zero emissions electricity from coal is already happening. Using carbon capture and storage, the Boundary Dam power station in Canada is demonstrating that coal can produce affordable energy at virtually zero emissions. Importantly, the Intergovernmental Panel on Climate Change has forecast that a global solution to climate change without CCS will be 138 per cent more costly than other options."*

**08. IEA Greenhouse Gas R&D Programme – July 2015 – 'CCS Deployment in the Context of Regional Developments in Meeting Long-Term Climate Change Objectives'**

*"Meeting the long-term goal of the United Nations Framework Convention on Climate Change (UNFCCC) to limit global temperature rises to 2°C will require radical changes to energy systems over the coming decades. In this context, carbon capture and storage (CCS) represents a key mitigation option to achieve the envisaged emission reduction pathways in a cost efficient manner. Furthermore, CCS is currently the only technology that can enable deep cuts in $CO_2$ emissions, or even "negative" emissions, across fossil-based power generation and many carbon intensive industries. (…) CCS is an opportunity for many countries to reduce their greenhouse gas (GHG) emissions. A portfolio of CCS technologies is available, depending on $CO_2$ sources and availability of suitable storage sites. The relative importance of CCS within a country's portfolio of climate actions will vary according to national circumstances, e.g. reliance on fossil power generation, expected economic growth, presence of carbon intensive industries, storage availability, etc."*

**09. IDDRI study by 16 international leading research teams (including PBL) – 2015-10-15 – 'Beyond the Numbers: Understanding the Transformation Induced by INDCs' (MILES Report)**

*"The report investigates the risk of lock-in into high-carbon infrastructure. In the global INDC scenario, deployment of unabated fossil fuel is significantly higher than what would be seen in a 2°C scenario. (…) By 2030, unabated coal deployment is more than twice as high in the global INDC scenario developed for this paper than in the immediate 2°C scenario. However, the national and global INDC scenarios demonstrate little deployment of CCS, with a share of CCS in electricity generation of about 3% in 2030 for the USA, China, Japan and the EU. Yet, given the scale of fossil fuel infrastructure in 2030 under the INDC scenario, it seems that CCS will need to be a crucial technology for mitigation post-2030."*

**10. UK Committee on Climate Change – October 2015 – 'Power sector scenarios for the fifth carbon budget'**

*"Low-carbon options are likely to be cost-competitive. Several low-carbon options should reach maturity by or during the 2020s. If unabated gas-fired generation faces the full cost of its carbon emissions (i.e. a 'target-consistent' carbon price, estimated at £78/tonne in 2030), these options could be delivered without further subsidy, even when intermittent generation faces the full system costs it imposes. (The following) options represent good value investments for a society committed to climate targets (…): onshore wind and ground-mounted solar from the first half of the decade, and nuclear, offshore wind and potentially carbon capture and storage (CCS) in the second half of the decade. (…)*

*Our scenarios also include investments in less mature options – principally offshore wind and CCS – in the first half of the 2020s, when these will still need subsidies. These are required to drive down costs for competitive deployment from the second half of the decade.*

*CCS is very important for reducing emissions across the economy and could almost halve the cost of meeting the 2050 target in the Climate Change Act."*

**11. UK Committee on Climate Change – November 2015 – 'The Fifth Carbon Budget – the next step towards a low-carbon economy'**

*"<u>Carbon capture and storage (CCS</u>) is very important in meeting the 2050 target at least cost, given its potential to reduce emissions across heavy industry, the power sector and perhaps with bioenergy, as well as opening up new decarbonisation pathways (e.g. based on hydrogen). Estimates by the Committee and by the Energy Technologies Institute (ETI) indicate that the costs of meeting the UK's 2050 target could almost double without CCS. At the global level the IPCC has estimated that its absence could increase costs by over 100%.*

*<u>Sustainable bioenergy</u> can play an important role. However, there are limits to the sustainable supply (e.g. this could provide around 10% of primary energy in 2050), so its role must be supplementary to*

*other measures. Bioenergy should be allocated to options where it has the largest impact on reducing emissions. Our analysis indicates that use should preferentially be with CCS and/or displacing coal, with further potential for use where alternative low-carbon options are not available (e.g. aviation). The Committee's estimates of sustainable bioenergy supply suggest that use with CCS would provide an extra emissions reduction of around 20 $MtCO_2e$/year relative to use of the same quantity of bioenergy to displace gas in heat for industry and buildings."*

**12. Global CCS Institute (GCCSI) – 2015-11-18 – 'Global Status of CCS 2015 – Summary report'**

*"CCS is a cost-effective technology for achieving large emissions reductions, as evidenced by updated Institute analysis released in July 2015. And with SaskPower stating that cost reductions of up to 30 percent are achievable on the next project, further strong gains are available to the next generation of projects. 2016 and 2017 promise to be trailblazing years for CCS with seven large-scale CCS projects due to come on stream. Importantly, these will show CCS in action in many different countries including the United States (US), Canada, the United Arab Emirates (UAE) and Australia, as well as across many industrial sectors. It will take the number of large-scale projects in operation to 22 – three times as many as at the start of the decade. But this number of projects is dwarfed by the thousands required by the middle of this century to meet international climate targets. While CCS has made great progress this decade, it is abundantly clear that we must sharply accelerate its deployment. (…)"*

*"Urgent action is required to accelerate CCS. Enhanced policy support is key to accelerating CCS deployment. Key findings of the report are:*

- *Commercialising CCS is not a technical challenge; policy and regulatory enhancements are key to incentivising investment in CCS.*
- *Since 2007, total CCS investment has been less than US$20 billion compared to around 100 times that amount for renewable energy technologies over the same timeframe.*
- *This substantial funding difference reflects, in part, that CCS has not been afforded sufficient policy support, especially when viewed in terms of its ability to achieve deep $CO_2$ emissions reductions.*
- *Effective policies that will accelerate deployment of CCS must be implemented this decade.*
- *In the lead up to COP 21, the vital role of CCS in national and regional strategies to address climate change must be reinforced.*
- *Key projects in advanced planning that are very close to making a final investment decision must get across the finish line so benefits can flow.*
- *Application of the principle of 'policy parity' can strengthen the foundations for widespread deployment by an equitable level of consideration, recognition and support being given to CCS compared to other low-carbon technologies.*
- *Specific areas in the application of this principle include:*
    - *Predictable and enduring policy arrangements that support a positive business case*
    - *Extending CCS law and regulation across the globe*
    - *Incentivising storage site selection to support project development*
    - *Continuing research & development to reduce costs."*

**13. Nature (the international weekly journal of science) – 2015-11-25 – 'Editorial'**

*"Limiting the temperature rise to 2 °C will be difficult. Barring premature retirement of much of the existing fossil-fuel infrastructure, the only way to get there will be to overshoot the target and then bring atmospheric carbon dioxide concentrations back down later in the century. Unless engineers figure out a simple way to pull $CO_2$ out of the atmosphere, this probably means deploying bioenergy at massive scales, capturing the $CO_2$ that is emitted during energy production and pumping it underground."*

**14. Global CCS Institute (GCCSI) – 2015-11-30 – 'The CO2degrees Challenge has reached China'**

*"China is a leading country for CCS project development with nine of the world's 45 Large Scale Integrated CCS projects in the pipeline. Public awareness and understanding of CCS will be an influencing factor throughout the lifecycle of these projects. For this reason the Global CCS Institute, in partnership with the Ministry of Science and Technology (MOST) of the People's Republic of China and The Administrative Centre for China's Agenda 21, undertook China's first official CO2degrees Education workshop. The CO2degrees resource provides educational activities and hands-on experiments about energy, climate change, $CO_2$ and CCS that can be incorporated into existing curriculum."*

**15. Global CCS Institute (GCCSI) – 2015-11-30 – 'CCS Projects Overview'**

*"Globally, there are 15 large-scale CCS projects in operation, with a further seven under construction. The 22 projects in operation or under construction represent a doubling since the start of this decade. The total $CO_2$ capture capacity of these 22 projects is around 40 million tonnes per annum (Mtpa). There are another 11 large-scale CCS projects at the most advanced stage of development planning, the Concept Definition (or Define) stage, with a total $CO_2$ capture capacity of around 15 Mtpa. A further 12 large-scale CCS projects are in earlier stages of development planning (the Evaluate and Identify stages) and have a total $CO_2$ capture capacity of around 25 Mtpa.*

*Two large-scale CCS projects became operational in 2015:*

- *The Quest project, located in Alberta, Canada ($CO_2$ capture capacity of approximately 1 Mtpa) was launched in November 2015. The project, involving the manufacture of hydrogen for upgrading bitumen into synthetic crude oil, is North America's first large-scale CCS project to store $CO_2$ exclusively in a deep saline formation.*
- *The Uthmaniyah $CO_2$-EOR Demonstration Project, located in the Kingdom of Saudi Arabia was launched in July 2015. The project is capable of capturing around 0.8 Mtpa of $CO_2$ from the Hayiwah NGL (natural gas liquids) Recovery Plant.*

*Two more industrial CCS projects are expected to become operational in early 2016:*

- *The Illinois Industrial CCS Project ($CO_2$ capture capacity of 1 Mtpa) is located at the Archer Daniel Midlands corn-to-ethanol production facility in Decatur, Illinois (United States). The project, the world's first bio-CCS project at large scale, will be the first integrated CCS project in the United States to inject $CO_2$ into a deep saline formation at a scale of 1 Mtpa.*
- *The Abu Dhabi CCS Project ($CO_2$ capture capacity of 0.8 Mtpa), the world's first iron and steel project to apply CCS at large scale, will involve $CO_2$ capture from the direct reduced iron process used at the Emirates Steel plant in Abu Dhabi.*

*Large-scale CCS projects in the power sector are now a reality, demonstrated by:*

- *The world's first large-scale power sector CCS project – the Boundary Dam Carbon Capture and Storage Project in Canada ($CO_2$ capture capacity of 1 Mtpa) – becoming operational in October 2014.*
- *Commissioning activities on a new-build 582 megawatt (MW) power plant beginning at the Kemper County Energy Facility in Mississippi (United States, $CO_2$ capture capacity of 3 Mtpa) with $CO_2$ capture expected to commence around the middle of 2016.*
- *The Petra Nova Carbon Capture Project at the W.A. Parish power plant near Houston, Texas (US, $CO_2$ capture capacity of 1.4 Mtpa) entering construction in July 2014, with $CO_2$ capture anticipated by the end of 2016."*

**16. A.S. Brouwer, M. van den Boek, W. Zappa, W.C. Turkenburg, A. Faaij - 2016 - 'Least cost options for integrating intermittent renewables in low-carbon power systems', Applied Energy, Vol. 161 (2016) pp. 48-74**

*"Large power sector $CO_2$ emission reductions are needed to meet long-term climate change targets. Intermittent renewable energy sources (intermittent-RES) such as wind and solar PV can be a key component of the resulting low-carbon power systems. Their intermittency will require more flexibility from the rest of the power system to maintain system stability.*
*In this study, the efficacy of five complementary options to integrate intermittent-RES at the lowest cost is evaluated with the PLEXOS hourly power system simulation tool for Western Europe in the year 2050. Three scenarios to reduce $CO_2$ emissions by 96% and maintain system reliability are investigated: 40%, 60% and 80% of annual power generation by RES. This corresponds to 22%, 41% and 59% of annual power generation by intermittent-RES.*
*This study shows that higher penetration of RES will increase the total system costs: they increase by 12% between the 40% and 80% RES scenarios. Key drivers are the relatively high investment costs and integration costs of intermittent-RES.*
*It is found that total system costs can be reduced by: (1) Demand Response; (2) Natural gas-fired power plants (NGCC's) with and without Carbon Capture and Storage (CCS); (3) Increased interconnection capacity; (4) Curtailment.*
*Electricity storage increases total system costs in all scenarios. The charging costs and investment costs make storage relatively expensive, even projecting cost reductions of 40% for Compressed Air Energy Storage (CAES) and 70% for batteries compared to 2012. (…)*
*Only fossil-fuel fired power generators (i.c. NGCC's with CCS) can supply inter-seasonal flexibility. The Demand Response and storage technologies considered in this study lack the storage capacity to do this. Power storage that can provide inter-seasonal storage (e.g. hydrogen storage) is prohibitively expensive."*

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