CARBON CAPTURE AND STORAGE:

A vital low carbon technology that can deliver on economic development, | energy security, and climate goals

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1 Executive Summary

The global energy landscape is changing and policy makers have important choices to make. Energy markets are in transition with technology innovations tapping unconventional oil supplies, improving efficiency, and generating lower carbon electricity, but not at a rate fast enough to seriously address climate concerns. Energy investments are shifting from developed countries to emerging economies with rapid energy demand growth. Yet, reliance on fossil fuels continues. At present, around 80 per cent of the world's primary energy and 65 per cent of global electricity generation is supplied from fossil fuels and they are projected to dominate for decades. As part of a portfolio of low carbon emissions technologies, carbon capture and storage (CCS), a vital technology that can address large-scale cuts in carbon dioxide (CO_2) emissions from fossil fuel power plants and industrial facilities, can deliver on climate goals and in many countries simultaneously meet energy security and sustainable economic development goals. Given these potential benefits, policy makers must take urgent action to accelerate commercial deployment and build on the successes of the past two decades.

The global energy landscape is changing in many important and dynamic ways but fossil fuels, which currently supply around 80 per cent of the world's primary energy and 65 per cent of global electricity generation, are projected to dominate for decades.[1] Given this trend, it is improbable that climate goals can be met without carbon capture and storage (CCS)[2], a low carbon technology that can achieve deep cuts in carbon dioxide (CO_2) emissions from fossil fuel (coal, oil, natural gas) power generation.[3] CCS is also the only CO_2 mitigation option for achieving deep emission reductions from industrial sources such as cement manufacture, steel production, gas processing and refining.

The Intergovernmental Panel on Climate Change (IPCC) highlights that most climate models conclude that including CCS in the portfolio of climate mitigation technologies, along with other low carbon options, is an essential, cost effective approach to achieving ambitious carbon reduction goals.[4] Recent analysis also concludes that CCS is complementary to intermittent renewables and can increase renewable penetration and improve overall system performance, cost and reliability.[5] In addition to climate benefits, CCS enables nations to utilise their natural resources and optimise power systems, thus supporting economic

[1] (IEA, 2014)
[2] CCS refers to the full suite of technology options to separate, capture, transport, utilize and store CO_2 emissions from fossil fuel power plants and large industrial facilities. CCS and carbon capture, utilization and storage (CCUS) are referred to as CCS throughout this report.
[3] For coal-fired power plants without CCS, increased efficiency is the most cost effective method for CO_2 emissions reduction. Compared to average emissions from the existing coal based fleet, high efficiency, low emissions (HELE) plants (supercritical or ultra supercritical) can achieve up to 35 per cent CO_2 reductions without significant cost of electricity increases (Beer, 2009).
[4] The 2009 Copenhagen Accord agreed to limit global warming to 2 degrees Celsius above pre-industrial levels. The IPCC finds that in order to achieve this goal, a portfolio of technologies, including CCS, along with behaviour changes, are needed (IPCC, 2014). Furthermore, in 2005, the IPCC released a special report recognizing CCS as a major climate change mitigation technology (IPCC, 2005) that resulted in the acceptance of CCS as a major climate change mitigation option and inclusion of CCS in various greenhouse gas reduction scenarios.
[5] (van den Broek, et. al, 2015)

development and energy security goals.

Recognising the multiple advantages of CCS, in 2008 global leaders from the Group of Eight (G8) committed to broad CCS deployment by 2020. This vision mobilised global action among CCS project developers, technology providers and governments that resulted in advances in the research and development (R&D) arena, legal and regulatory frameworks, public engagement and large-scale[6] commercial demonstrations. Yet, policy action and investment has not been enough to overcome market barriers and the G8 goal will not be realised.[7]

Today, there are 14 large-scale CCS projects in operation (one in the power sector) and eight under construction (two in the power sector). Of these 22 projects, 11 out of the 14 in operation and five out of the eight under construction utilise CO_2 for enhanced oil recovery (EOR)[8], while deep saline reservoir storage accounts for six of the 22 projects with three in operation and three under construction. There are another 11 projects in advanced planning (seven in the power sector) and a further 12 projects in the early planning stage.[9]

The current portfolio of large-scale CCS projects reflects, in part, policies initiated close to a decade ago. Since 2007, total CCS investment has been around $13 billion[10] compared to roughly $1,800 billion for renewable power generation technologies over the same timeframe.[11] This substantial funding difference, in part, reflects that CCS has not been afforded sufficient policy support, especially when viewed in terms of its relative ability to achieve deep CO_2 emissions reductions.

Over the past decade – since the release of the IPCC S*pecial Report on Carbon Dioxide Capture and Storage* – CCS has been accepted as a major climate change mitigation option and included in every major greenhouse gas (GHG) reduction scenario. While there have been important CCS policy advances, especially with regard to legal and regulatory framework developments, acceptance of CCS as a clean energy technology in the low carbon portfolio has not translated broadly enough into the policy arena. Many jurisdictions do not afford CCS policy parity – an equitable level of consideration, recognition and support mechanisms – along-side other low-carbon technologies. The degree of support levels for low carbon technologies can be debated, but affording CCS the same type of mechanisms that other low carbon options receive will be a critical step towards advancing the most cost effective climate mitigation path.

This paper calls for recognition of CCS in the low carbon technology portfolio, and policy parity to help enable CCS to deliver on its contribution to carbon emissions reduction while also providing for energy security and sustainable economic development. A number of recommendations for policy makers are

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[6] Large-scale integrated CCS projects (LSIPs) are defined as projects involving the capture, transport, and storage of CO_2 at a scale of at least 800,000 tonnes of CO_2 annually for a coal-based power plant or at least 400,000 tonnes of CO_2 annually for other emissions-intensive industrial facilities (including natural gas-based power generation). For more detail see: ttps://www.globalccsinstitute.com/projects/large-scale-ccs-projects-definitions

[7] See G8 Hokkaido Toyako Summit Leaders Declaration, Hokkaido Toyako, 8 July 2008: www.mofa.go.jp/policy/economy/summit/2008/doc/doc080714__en.html. Also, reporting on progress toward the G8 goal (IEA/CSLF, 2010).

[8] CO_2-EOR involves injecting CO_2 into deep wells to increase oil production in depleted reservoirs. The process is a closed loop system so any CO_2 that is produced with the oil is separated, reinjected and stored in the reservoir rock.

[9] See the Global CCS Institute: https://www.globalccsinstitute.com/projects/large-scale-ccs-projects

[10] (Bloomberg New Energy Finance, 2015)

[11] (Frankfurt School-UNEP Centre/Bloomberg New Energy Finance, 2015)

included, which build on previous recommendations on the agendas of major international energy governance organisations including the G8, Group of Twenty (G20), United Nations (UN), Major Economies Forum (MEF), Clean Energy Ministerial (CEM), Carbon Sequestration Leadership Forum (CSLF), and Asia Pacific Economic Cooperation (APEC). It is also important to highlight that the ENGO Network on CCS[12] – an organisation comprised of 11 leading ENGOs from around the world – has issued recommendations to policy makers in support of CCS deployment.[13,14]

These organisations are critical to help set global leadership but national governments must ultimately implement policies that enable CCS deployment in different market conditions. It is important to recognise that a number of countries have taken initial steps to support CCS technologies through various policy interventions.[15] However, given the relatively early stage of technology deployment, policy makers must take further action to address barriers and facilitate the creation of CCS markets that can give rise to an industry with global reach. Suggested recommendations for policy makers to consider include:

- Recognise CCS as a vital low carbon technology within the full portfolio of low carbon technologies, including renewables and energy efficiency, that should be deployed to address carbon emissions reduction according to each country's sustainable economic development, environmental, energy supply and security priorities
- Incorporate into energy policy and planning credible projections that fossil fuels will continue to dominate over the next few decades, and that CCS – a vital low carbon technology that can significantly reduce CO_2 emissions from fossil fuel power generation and large industrial facilities *and* complement intermittent renewables to increase renewable penetration and improve overall system performance, cost and reliability – should be commercialised because it offers a least cost pathway to meet CO_2 emission reduction goals, when included in the portfolio of low carbon technologies
- Provide policy parity – an equitable level of consideration, recognition and support mechanisms – for CCS along-side other low-carbon technologies
- Mobilise private investment in CCS by offering an effective suite of financial incentives such as grants, loans, tax credits, capacity payments, and "green bonds", and establish public-private partnerships that include both cost and risk sharing
- Provide financial resources that support international collaboration, knowledge sharing and training opportunities to enable CCS demonstration projects in developing countries. Governments should also strengthen development bank funding through the World Bank CCS Trust Fund and the Asian Development Bank (ADB) CCS Trust Fund[16]

[12] Established in 2011, the ENGO (Environmental Nongovernmental Organisation) Network on CCS supports safe and effective CCS deployment as a timely mitigation tool for combating climate change. See http://www.engonetwork.org/index.html
[13] (GCCSI, 2014)
[14] (ENGO Network on CCS, 2012)
[15] The Global CCS Institute compares and reports on levels of national policy support to drive domestic action on CCS through its CCS Policy Indicator (GCCSI, 2015a).
[16] The World Bank CCS Trust Fund and ADB CCS Trust Fund were both established in 2009 to build CCS capacity in emerging economies. The World Bank currently supports CCS activities in South Africa and Mexico.

- Enhance support for CCS in international climate financing mechanisms[17] and carbon markets such as the Green Climate Fund, the Technology Mechanism, and the Clean Development Mechanism (CDM)
- Recognise that CO_2 EOR operations utilising captured anthropogenic CO_2 improve the business case for CCS and offer a viable storage option when methods are implemented to quantify the amount of CO_2 stored
- Invest in CCS human capital through education and training programs, R&D, knowledge sharing, and international collaborations and exchanges
- Support the development of CCS legal and regulatory frameworks
- Maintain and elevate CCS on the agendas of high-level energy and climate change governance organisations including the G8, G20, UN, MEF, CSLF, and APEC, and advocate for sustained, high-level engagement and policy action at both national and international levels

[17] In April 2015 the World Bank, International Development Finance Club and Agence Francaise de Developpment agreed to a set of "Common Principles" for climate finance that could include CCS; however, further action is needed to broaden and establish CCS within viable financing mechanisms (World Bank, 2015a).

2 Energy and Economic Development

Investment and resources are shifting to emerging economies where significantly more energy is needed to support urbanisation, economic and infrastructure development, and improvements in health and living standards. Many developing countries have opportunities for renewable energy but also have considerable natural resources, including coal, oil and gas. A portfolio of low-carbon technologies is required to enable sustainable resource development that aligns with each nation's economic, social and environmental goals.

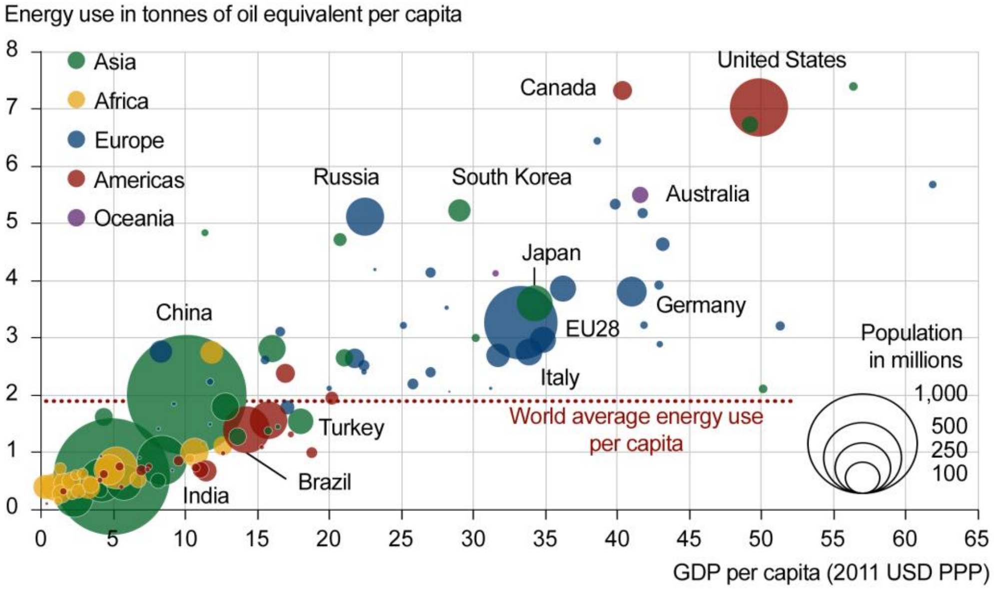
As economies develop, there is an identified link with energy usage.[18] Modern energy services are essential to economic activity, prosperity and human well-being; countries with higher per capita energy consumption enjoy higher living standards. In recent decades, electrification rates have improved steadily worldwide but population increases have offset part of this improvement.

Many emerging economies and regions are endowed with conventional and unconventional fossil fuels (hydro carbons that cannot be produced by conventional drilling, such as heavy oils, oil sands, oil shale, and tight sands). For example, Africa holds almost eight per cent of global oil reserves and vast deposits of shale oil and gas. Nearly one-fifth of the world's oil reserves are in Latin America, and parts of Asia, especially Indonesia, India and China, are home to abundant coal deposits. While renewable deployments are accelerating globally, it is likely that fossil fuels, notably coal – with its abundant supply and ability to provide reliable, affordable base-load power generation – will continue to be used to meet ongoing energy demand.[19] This reliance on fossil fuels in emerging economies creates challenges and opportunities for sustainable development through the incorporation of CCS as a low-carbon technology to address climate change.

As emerging economies continue on their development paths and strive for the same living standards as the developed world, per capita energy consumption is expected to grow dramatically in the next couple of decades. (Figure 1) This trend is being driven, in part, by rural-urban migration. Today, more than half of the world's population lives in cities and if trends continue, by 2050 that figure will jump to over 70 per cent.[20]

[18] (Carbonnier & Brugger 2013)
[19] (Fallows, 2010)
[20] (United Nations, 2014)

Figure 1: Per capita energy consumption and gross domestic product (GDP)[21]



Energy consumption per capita and GDP growth has historically been correlated. In developed countries, technology has largely enabled more energy efficiency per unit of GDP. However, in developing economies, GDP is growing along with per capita energy consumption. As more people gain access to energy fossil fuels are expected to be relied upon to meet a large part of growing energy demand, which calls for CCS to mitigate its impact.

Urbanisation presents considerable challenges but it also provides opportunities to upgrade and build out existing infrastructure where electrification rates are over 90 per cent.[22] Urban areas can also leverage population densities, technologies and economies of scale to improve electricity availability, reliability and affordability. It is likely that fossil fuel or nuclear base-load generation will continue to meet much of growing urban electricity demand and also provide back-up generation for intermittent renewable energy supplies, underscoring the importance of CCS to mitigate CO_2 emissions growth (and highlights its complementarity role in energy supply alongside other low-carbon technologies).

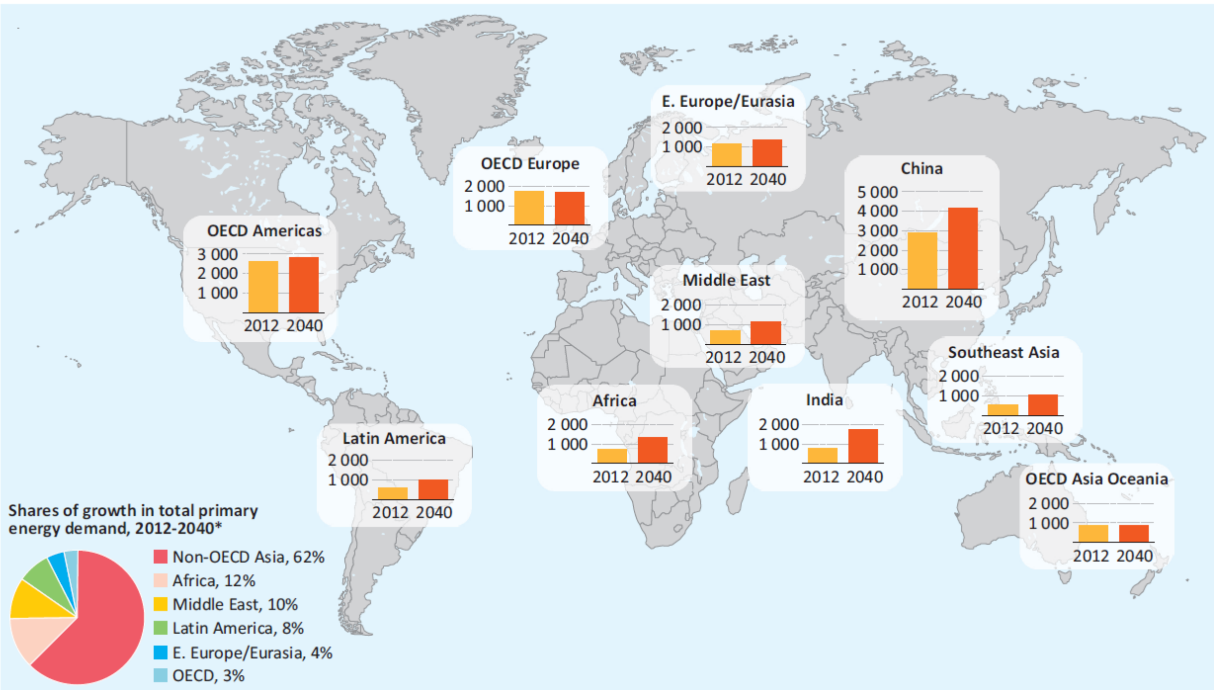
[21] (European Environmental Agency, 2015)
[22] See the International Energy Agency's Energy Access Database: http://www.worldenergyoutlook.org/resources/energydevelopment/energyaccessdatabase/

3 Global Energy Trends and Projections

Developing nations are driving energy demand growth and energy investments are shifting to these countries. Conventional fossil fuels continue to dominate primary global energy while renewables are growing and unconventional fossil fuels are becoming more accessible. Despite the changing energy mix, coal and natural gas-fired power plants are projected to supply 55 per cent of global electricity generation in 2040, underscoring the importance of CCS.

The global energy landscape is in the midst of the most dynamic phase the world has seen in over a century as world population continues to grow. Developing countries, with their rapidly increasing energy demand, are driving much of this change. (Figure 2) Developed economies are also driving change as they begin to replace aging infrastructure, reassess nuclear power, and address climate concerns by transitioning to less carbon-intensive energy[23]

Figure 2: Primary energy demand by region in the IEA New Policies Scenario (Mtoe)[24]



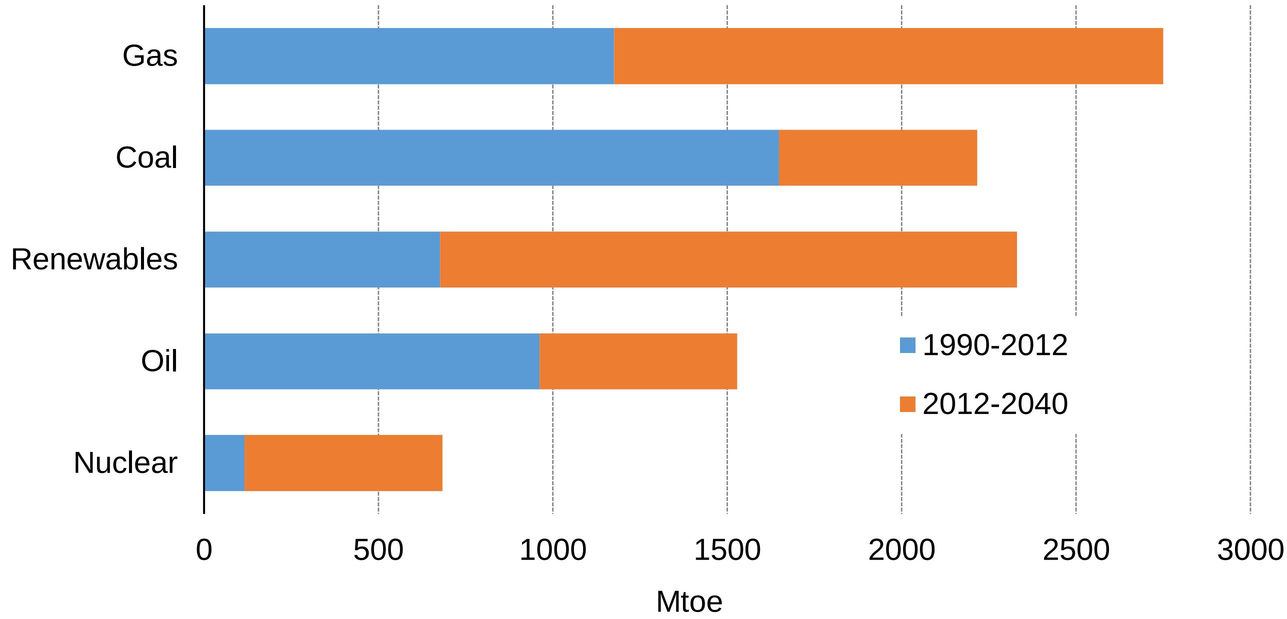
China accounts for more than 20 per cent of all global energy consumption, which has underpinned its tremendous economic growth. Other countries and regions, including India, Southeast Asia, the Middle East and parts of Africa and Latin America are seeing strong energy demand as their economies grow. Many of these regions have fossil fuel resources that are likely to be developed.

[23] (IEA, 2014a)
[24] (Ibid.)

There are important developments on the supply side too. Technology has unlocked production of unconventional fossil fuels from shale, a potential game changer in global energy markets.[25] The use of captured CO_2 for EOR has potential in many countries[26] and offers a business case for CCS.[27] Strong investments in solar photovoltaics and wind energy have begun to push costs down and increase deployment rates, and the world's first CCS project in the power sector was launched in 2014.[28]

Even with these dynamic developments, fundamental changes in global energy systems occur slowly. Today's share of fossil fuels in the global mix (82 per cent) is the same as it was 25 years ago. Despite substantial gains in renewable energy, fossil fuel use – according to the most internationally credible projections – will continue to grow and dominate the global energy picture for some time to come. For the past decade, the use of coal has increased more rapidly than other fuels and plays a central role in electricity generation as well as in cement manufacture and iron and steel production. The energy mix is changing, but fossil fuels are expected to supply around 75 per cent of projected primary energy demand in 2040. [29] (Figure 3)

Figure 3: Growth in total primary energy demand[30]



Fossil fuels provide about 82 per cent of the world's primary energy, which is roughly the same as it was 25 years ago. The energy mix is changing but fossil fuels are projected to supply most of the world's primary energy, around 75 per cent in 2040. Given this trend, it is improbable that climate targets can be met without CCS deployment.

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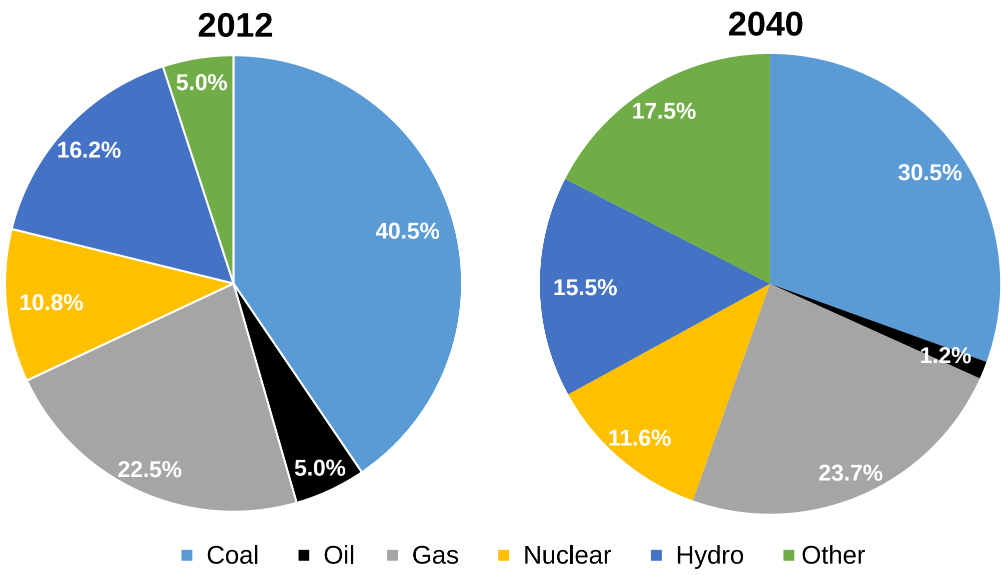
[25] (KPMG, 2011)
[26] (ARI, 2009)
[27] (Tomski, 2012)
[28] SaskPower's Boundary Dam Carbon Capture and Storage Project; (McCarthy, 2014)
[29] (IEA, 2014a)
[30] (Ibid.)

In the electricity sector, presently coal accounts for the largest share of global electricity generation (41 per cent), followed by natural gas (22 per cent), hydro (16 per cent), nuclear (11 per cent), oil (5 per cent) and renewables (5 per cent) including geothermal, solar and wind. Coal- and natural gas-fired power plants will continue to dominate the power sector, and in 2040 are projected to have a combined share of 55 per cent of global electricity generation. China and India are expected to build almost 40 per cent of the world's capacity additions. In developed countries, 60 per cent of new generation will replace retired plants.[31] (Figure 4)

Figure 4: Global electricity generation by fuel type, 2012 and 2040 (New Policies Scenario)[32]



Coal powers more electricity generation than any other fuel; in 2012, it accounted for ~40 per cent with all fossil fuels ~65 per cent. In 2040, fossil fuels are expected to provide 55 per cent of global electricity generation. Industry accounts for roughly half of the projected global growth in electricity demand through 2040. CCS technologies are critical to meeting climate change goals because they offer an important solution to dramatically lower CO_2 emissions from both the industrial and power generation sectors.

Given these trends in global energy and electricity demand, energy investments are shifting to emerging economies and are estimated to reach a cumulative global total of US$40 trillion for energy supply to 2035, two-thirds in emerging economies.[33] Cumulative investment of $16.4 trillion is needed across the power sector with about 58 per cent for the construction of new or refurbished plants. While many countries are prioritizing renewable energy investments, fossil-fuel power plants are expected to account for almost 30 per cent of global power plant investments[34] offering an opportunity to deploy technologies that can improve efficiency, environmental performance and incorporate CCS to reduce CO_2 emissions.

[31] (Ibid.)
[32] (Ibid.)
[33] (IEA, 2014b)
[34] (Ibid.)

4 CCS in the Low Carbon Portfolio

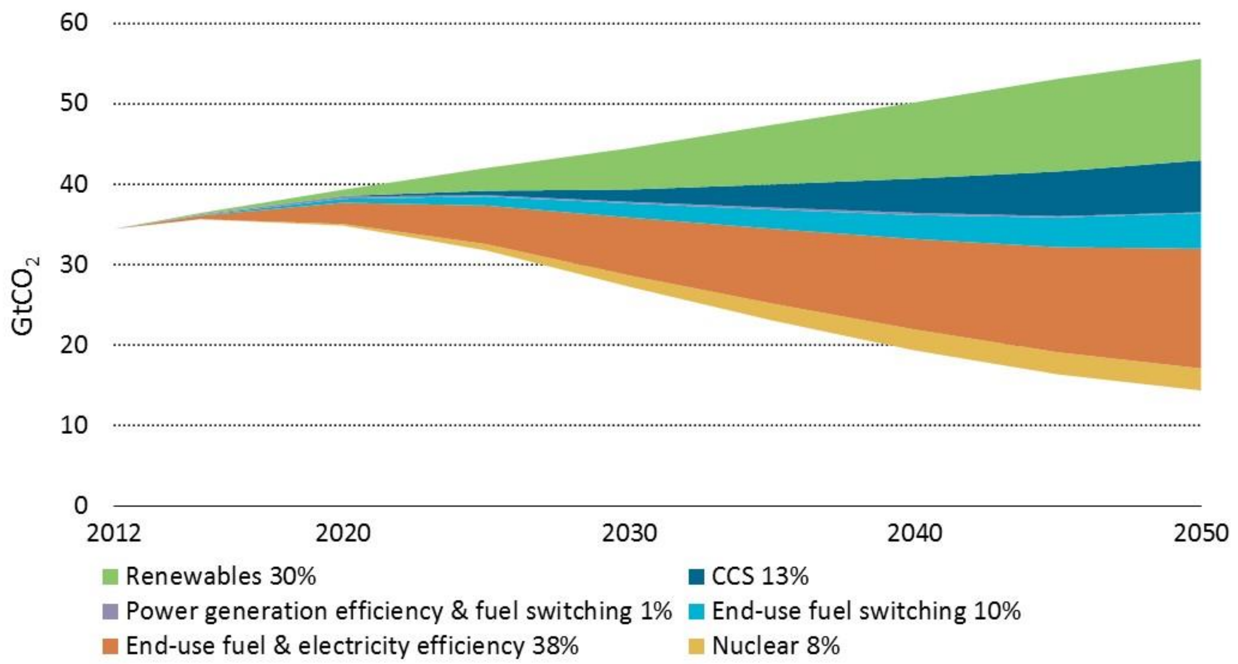
As countries maximise use of their natural resources, fossil fuels are projected to remain a large part of the energy mix even as renewables grow. Meaningful climate mitigation must include CCS, a vital low carbon technology that can achieve dramatic reductions in CO_2 emissions from fossil fuel power plants and large industrial facilities. Moreover, CCS is complementary to intermittent renewables and can increase renewable penetration and improve overall system performance, cost and reliability, enabling the least cost path to meet carbon emissions reduction goals. In some countries, captured CO_2 can be used to enhance oil production in declining oil fields or for the production of chemicals, fuels and building materials thus offering an energy security and business advantage in addition to a CO_2 mitigation benefit.

No single fuel source or power generation technology provides all the answers; they all have strengths and limitations relating to cost, reliability, accessibility, scale and environmental performance. Fossil fuels are abundant, accessible and affordable but have a larger CO_2 footprint than other options. Nuclear energy doesn't produce any CO_2 emissions yet has waste disposal challenges. Renewables such as wind and solar produce low carbon energy but electricity production is intermittent, difficult to scale, and often requires base-load back-up, or power generation that can quickly ramp up, to balance intermittency. Many of these challenges can be managed with a portfolio of low-carbon technologies that will vary according to each country's resource base, energy markets, strategic objectives, and economic development goals.

In terms of climate change mitigation, most credible studies recognise that all technologies have a role to play but differ on the mix. Modelling by the International Energy Agency (IEA) shows that CCS provides around 13 per cent of the cumulative emissions reductions required through 2050 in a 2°C world compared to 'business as usual'. [35] (Figure 5) This requires CCS not only in the power sector, but also to be broadly applied to large industrial facilities (cement, chemicals, refining, iron and steel, etc.) where there is no other available mitigation option to achieve deep decarbonisation. It is important to highlight that IEA's modelling also assumes significant efficiency improvements (38 per cent) and renewables growth (30 per cent). Recent analysis concludes that CCS is complementary to intermittent renewables and can increase renewable penetration and improve overall system performance, cost and reliability.[36]

[35] (IEA, 2015)
[36] (van den Broek, et. al, 2015)

Figure 5: Low carbon portfolio projected to achieve climate change goals[37]



Meeting ambitious climate change targets will require a portfolio of technology solutions that are currently more expensive than conventional options. CCS is a vital part of the mix because it can deliver dramatic emissions reductions from fossil-fuelled power generation and large industrial facilities. CCS is also complementary to intermittent renewables and can increase renewable penetration and improve overall system performance, cost and reliability.

In order for CCS to contribute its projected 13 per cent share to climate mitigation, the total CO_2 capture and storage rate must grow considerably from the current tens of megatonnes per year to approximately 6,000 million tonnes per year in 2050. While developed countries are largely responsible for historical anthropogenic CO_2 emissions, almost all new energy demand and CO_2 emissions growth is expected in developing economies. Under the IEA scenario, around 73 per cent of the cumulative CO_2 captured and stored needs to be achieved in developing countries[38] where national energy priorities such as improving energy access and reliability or developing natural resources, including fossil fuels, may take priority over climate change mitigation. CCS can support multiple objectives but given the higher costs and complexity relative to non-abated fossil fuel technologies, international collaborations and inclusion of CCS in climate- and CCS-specific financing mechanisms (e.g. The World Bank CCS Trust Fund, ADB CCS Trust Fund, Green Climate Fund, Clean Technology Fund, Technology Mechanism, and CDM) are essential to support projects in developing countries.[39][40]

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[37] (Ibid.)
[38] (Ibid.)
[39] At least 24 developing countries are engaged in CCS activity such as capacity development, pre-investment and planning activities, project development or operation. Most are early stage activities; however, several large-scale projects are advancing in Algeria, Brazil, China, Saudi Arabia, and the United Arab Emirates. (GCCSI, 2015b)
[40] (Alameda, et al, 2011)

While CCS is currently more expensive compared to unabated fossil fuel options, it can be cost competitive with other low carbon technologies provided policy treatment is on par with similar support mechanisms.[41] Moreover, the IEA, IPCC and others have concluded that CCS in the mitigation portfolio can offer the least cost, most economically sustainable path to achieve global CO_2 emissions reduction targets. For example, the IPCC highlights that most models conclude that without CCS (or with a considerable delay in its deployment), the world is unlikely to meet its 450 parts per million (ppm) CO_2 emissions reduction target and mitigation costs would increase by 138 per cent.[42] By comparison, limited availability of other technologies does not result in nearly as dramatic cost increases, for example, nuclear phase out leads to median cost increases of 7 per cent, and limited solar/wind, 6 per cent.[43] (Figure 6)

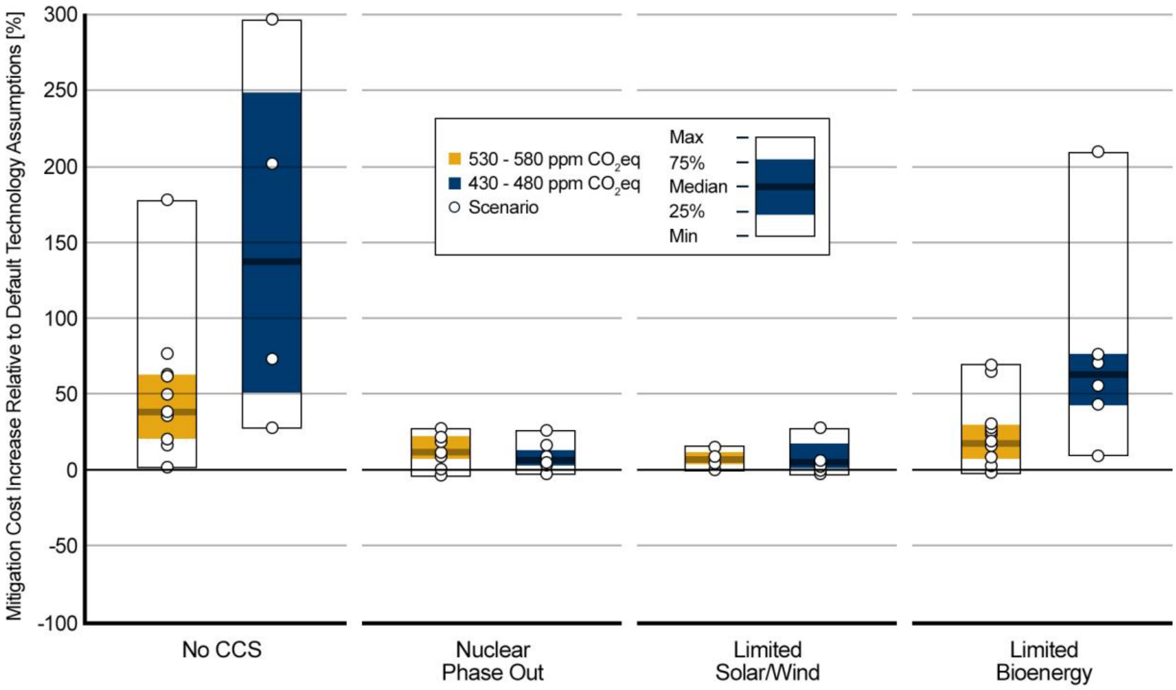
"*The IPCC Fifth Assessment Synthesis Report highlights that without CCS the cost of climate mitigation would increase by 138%. CCS therefore has a vital role to play as part of an economically sustainable route to deep emissions cuts. UNECE stands ready to develop and promote international standards required for the efficient achievement of CCS and CCUS*."

Christian Friis Bach, Executive Secretary, United National Economic Commission for Europe (UNECE)

While cost estimates vary, the message from scenario modelling of international energy and climate systems is clear: meeting global climate goals will be significantly more expensive without CCS. Furthermore, because CCS is complementary to intermittent renewables, it can increase renewable penetration and improve overall system performance, cost and reliability. Given current market conditions and the emerging status of CCS technologies, the benefits of CCS can only be realised when governments help mobilise private investment by implementing policies to support large-scale deployment.

[41] (Alstom, 2011); (NETL, 2010), The Global CCS Institute's analysis of US data in the NETL report demonstrates that CCS in the power sector is cost competitive when viewed through an appropriate policy lens (i.e. cost per tonne of CO_2 avoided. (GCCSI, 2015c)
[42] (IPCC, 2014)
[43] (Ibid.)

Figure 6: Climate change mitigation costs without CCS and other technologies[44]



The IPCC concluded that without CCS, costs to meet climate goals would be substantially more expensive, the median estimate being 138 per cent to meet a 430-480 ppm climate goal. By comparison, a phase-out of nuclear energy or limited wind and solar expansion would increase mitigation costs by 7 per cent and 6 per cent respectively. The IPCC also highlights that most climate change mitigation models recognise that without CCS (or with a considerable deployment delay), the world will fail to meet a CO_2 emissions reduction target of 450 ppm.

A number of prominent organisations have called on governments to take policy action to accelerate CCS deployment, including: G8, G20, Clean Energy Ministerial (CEM), Major Economies Forum (MEF), Carbon Sequestration Leadership Forum (CSLF), Asia Pacific Economic Cooperation (APEC), World Business Council for Sustainable Development (WBCSD), World Energy Council (WEC), the United Nations Economic Commission for Europe (UNECE), and the ENGO Network on CCS. Bodies of the United Nations Framework Convention on Climate Change (UNFCCC) also recognise the critical importance of CCS to achieve climate change goals.[45] (Box 1) These organisations have set the vision for CCS deployment and have outlined a number of policy recommendations, but a sustained, high-level commitment is needed at both national and international levels.

[44] (Ibid.)
[45] The Global CCS Institute is closely engaged with all aspects of the UNFCC process as they relate to CCS. See here for more detail: https://www.globalccsinstitute.com/insights/authors/JohnScowcroft/2015/06/02/unfccc-technology-and-finance-mechanisms

Box 1: Key international energy and climate governance organisations engaged in advancing CCS deployment

A number of leading global organisations have recognised the vital importance of CCS technologies and have called for policy action to advance deployment. However, national implementation has fallen short and a much more sustained, high-level commitment is needed at both national and international levels to help realise the significant contribution CCS can make to mitigate climate change and in many countries, enable an economic development and energy security advantage.

Group of Eight (G8): Heads of government from the top industrialized economies met at the Gleneagles Summit in 2005, a milestone for G8 engagement on energy and climate, that resulted in the *Gleneagles Plan of Action on Climate Change, Clean Energy and Sustainable Development.* The Plan included a request to the IEA and CSLF to make policy recommendations on accelerating CCS deployment. The organisations issued a progress report at the 2008 Hokkaido Toyako Summit leading to the G8 pledge to launch 20 projects by 2010 with broad deployment by 2020. G8 leaders affirmed this commitment at the 2009 L'Auila Summit; however, the global economic crisis shifted the G8 focus to security and political issues and the G20 became more actively engaged in energy and climate. (IEA/CSLF, 2010)

Group of Twenty (G20): The G20 was established after the 2008 global recession with a focus on "sustainable economic growth," that includes energy and climate. Reflecting some policy continuity with the G8, the 2009 Pittsburgh Summit endorsed the St Petersburg Principles on Global Energy Security, UNFCCC negotiations and the Copenhagen Accord, and established four energy working groups. The G20 has not yet advanced the full package of energy commitments agreed to by the G8, including specific pledges on CCS, and their energy focus is tied more narrowly to financial and economic stability and issues such as oil price volatility and energy market transparency. However, in May 2015, CCS was on the agenda of the G20 Energy Sustainability Working Group in Istanbul, Turkey, and the 2009 report, *Toward Global Green Recovery: Recommendations for Immediate G20 Action* includes a path for CCS. (Edenhofer and Stern, 2009)

Major Economies Forum on Energy and Climate (MEF): Formed in March 2009 with 17 participating economies, MEF facilitates dialogue among major developed and developing economies on climate change. In July 2009, MEF leaders identified the urgent need to develop and deploy transformational clean energy technologies including CCS. MEF's December 2009 report, *Technology Action Plan: Carbon Capture, Use and Storage,* includes support for the G8 commitment to launch 10 commercial-scale projects by 2010 and calls for four commercial-scale projects in developing countries. (MEF, 2009)

Clean Energy Ministerial (CEM): The CEM emerged from the MEF in 2009, with the aim to accelerate clean energy technologies; the CCUS Action Group was established within the CEM to create greater political momentum for CCUS deployment. In April 2011, Energy Ministers at CEM2 in Abu Dhabi endorsed seven CCUS recommendations. The CEM also issued the 2013 report, *Global Action to Advance Carbon Capture and Storage: A Focus on Industrial Applications* with recommendations for deployment in the industrial sector. In 2014, the Action Group fulfilled its mandate and reporting on CCS to the CEM was transferred to the CSLF. (CEM, 2013)

Carbon Sequestration Leadership Forum (CSLF): Established in 2003, the CSLF is a ministerial-level organisation with the mission to promote CCS development and deployment. The 5th meeting of ministers was held in November 2013, in Washington, DC and resulted in a ministerial communiqué that outlined seven key actions needed for CCS deployment. The communiqué stated that the next seven years are critically important for "creating the conditions for CCS to be ready for large-scale deployment by the end of the decade." (CSLF, 2013) The next CSLF Ministerial will be held in November 2015, in Saudi Arabia.

Asia Pacific Economic Cooperation (APEC): APEC's Energy Working Group oversees five expert groups including the Expert Group on Clean Fossil Energy, which manages APEC's CCS agenda and supports CCS capacity development activities in APEC emerging economies. APEC has issued a number of CCS reports relating to CCS developments and opportunities in APEC emerging economies. (APEC, 2012)

United Nations Framework Convention on Climate Change (UNFCCC): The UNFCCC, the principal international negotiating forum on climate change, has engaged on CCS largely in the subsidiary body, Scientific and Technological Advice (SBSTA) and the Ad hoc Working Group, Long-term Cooperative Action Under the Convention (AWG-LCA). In 2011, CCS was included in the CDM under the UNFCCC's Kyoto Protocol. (UNFCCC, 2011)

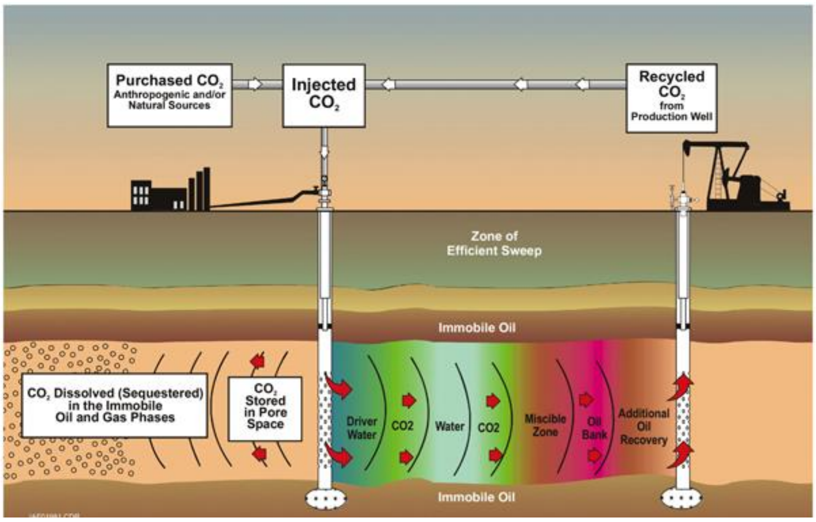
United National Economic Commission for Europe (UNECE): In November 2014, the UNECE issued recommendations to the UNFCCC on how CCUS-EOR should be treated in a Post-Kyoto Protocol Agreement. A key recommendation called for CO_2-EOR to be recognised as permanent storage based on established measurement, reporting and verification practices. (UNECE, 2014)

5 Global Status of CCS

Large-scale, integrated CCS has been successfully demonstrated for decades, mainly in the industrial sector, with one large-scale CCS power project currently in operation and two expected to come on-line in 2016. The portfolio of 22 large-scale CCS projects in operation or under construction around the world use first generation technology, integrated and scaled up for the first time, and includes projects that are the result of public and private investments initiated a decade or more ago. The technology is at a crossroad – it is established and well understood but has limited market opportunities in today's policy environment and like other low carbon technologies, it is more expensive compared to unabated fossil fuel options. Therefore, action from policy makers is required to help mobilise the public and private investments needed to accelerate deployment and realise the multiple benefits of the technology.

Individual CCS technology components have a long and successful track record in a number of industrial applications; but to be considered commercial as a CCS system, these different components need to be integrated, scaled up and demonstrated in different locations and technology configurations.[46] CO_2 capture has been applied to industrial processes and the food and beverage industry for almost 90 years[47] with the first installation on an industrial boiler in 1978.[48] The oil and gas industry has more than 40 years of operational experience with CO_2-EOR, and technologies for storage site selection, injection and monitoring are well developed. (Figure 7) There are also more than 4,039 miles (6,500 km) of CO_2 pipelines linked to EOR, mainly in the United States that have an excellent performance and safety record. This experience shows that CCS can be done.

Figure 7: CO_2-EOR / storage



[46] CCS is not one technology, rather it is a suite of technologies that are selected based on site specific considerations, e.g. type of industrial or power generation (pre- or post-combustion) application, proximity to a suitable storage site (EOR or deep saline reservoir), etc.
[47] (IPCC, 2005)
[48] (Herzog, 2015)

CO_2-EOR has over 40 years of operational experience and offers a near-term commercial CCS driver that results in carbon storage and oil produced with a lower carbon footprint. Injecting CO_2 into depleted oil fields can mobilise trapped oil to improve recovery. The injected CO_2 that is produced with the oil is "recycled" or separated and injected back into the reservoir in a closed-loop system. At the end of the project, essentially all of the injected CO_2 is stored in the reservoir rocks. In order for CO_2-EOR to provide permanent storage for the purpose of emissions reductions, the CO_2 must be man-made and operators must provide evidence through monitoring, verification and accounting methods that the CO_2 remains securely stored. The regulatory pathway and accounting methodologies to quantify the amount of CO_2 stored from EOR operations has been clarified or is under development in a number of jurisdictions including the United States, Canada, and Mexico.

The concept of implementing CCS technology for climate change mitigation with large-scale applications such as power plants emerged in the 1980s, and the primary technology challenges included scale-up, CCS system integration, and long-term CO_2 storage. Despite these challenges, considerable progress has been made over the past couple of decades to improve technical understanding and know-how through R&D, and pilot and large-scale demonstrations.[49] In 1992, the first international conference of scientists established the foundation for the emerging CCS expert community.[50] In 1996, the Sleipner Project was launched off the coast of Norway with CO_2 captured from Statoil's natural gas processing operations for injection into a deep saline formation deep beneath the sea floor. The project is on-going and has successfully stored over 15 million tonnes (Mt) of CO_2.[51]

Today, there are 14 large-scale CCS projects in operation and eight under construction. The total CO_2 capture capacity of these 22 projects is around 40 million tonnes per annum (Mtpa), roughly the equivalent to the CO_2 emissions of Switzerland. A number of these projects benefit from significant government support to offset high costs and operational risks; however, private investments generally constitute the large majority of capital costs. There are another 11 projects in advanced planning (the latter including seven in the power sector), and 12 projects in the early planning stage. The United States and Canada dominate in terms of overall project numbers and investment levels followed by China. (Figure 8)

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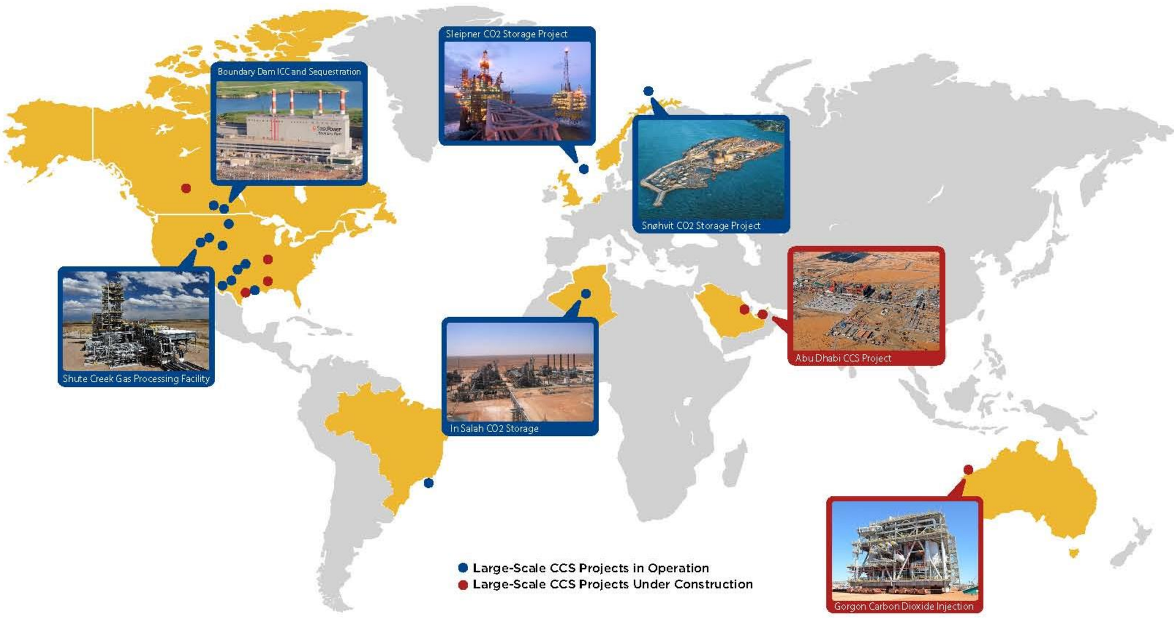
[49] The Global CCS Institute tracks the annual global status of large-scale integrated CCS projects: https://www.globalccsinstitute.com/projects/large-scale-ccs-projects. The CSLF tracks best practices and standards for various CCS technology components; the IEA Greenhouse Gas Programme maintains a number of technology networks that highlight technology developments and progress.

[50] In 1992, the First International Conference on Carbon Dioxide Removal was held in Amsterdam, the Netherlands, which was followed the International Greenhouse Gas Control Technologies Conference (GHGT) conference series. Held every two years, GHGT is the principal international platform for CCS research. See: http://www.ghgt.info

[51] See: http://www.statoil.com/en/TechnologyInnovation/NewEnergy/Co2CaptureStorage/Pages/SleipnerVest.aspx

Figure 8: Locations of the 22 Large-scale CCS projects in operation and under construction



All 22 projects in operation or under construction use first generation CO_2 capture technologies that were previously available for industrial applications and are pioneer projects in demonstrating CCS integration at large-scale. Most of the projects separate CO_2 as part of normal operations, such as natural gas processing or fertiliser production, with the power sector accounting for only three of the 22 projects in operation or under construction. CCS with CO_2-EOR is the dominant storage option (11 out of the 14 in operation and five out of the eight under construction) while deep saline reservoir storage accounts for six of the 22 projects (three in operation and three under construction).

Absent strong climate policy, CO_2-EOR offers the most compelling business driver to advance CCS projects, primarily in North America where most CO_2-EOR has been implemented.[52] Outside North America, only a few CO_2-EOR projects are currently in operation. In Brazil, CO_2-EOR has been carried out by Petrobras since 1987, and the Lula CCS Project was launched in 2013. In the United Arab Emirates, the Abu Dhabi CCS project will use CO_2 captured from a steel plant and a number of CO_2-EOR pilot projects have been implemented in China with considerable focus on developing this potential. Assessments of the global CO_2-EOR and carbon storage potential estimate that the world's oil basins could produce nearly 1,300 billion barrels of oil from "next generation" CO_2-EOR technology and store 370 billion tonnes of CO_2 (equivalent to about 35 years' worth of 1,800 GW of coal-fired power plant emissions).[53]

Revenue from CO_2 sales for EOR improves CCS project economics and helps reduce financial risk. CO_2-EOR with captured CO_2 also lowers the emissions footprint of the produced oil and offers a storage opportunity when methods are implemented to quantify the amount of CO_2 stored. Growth in CO_2-EOR production is limited by the availability of reliable, affordable CO_2 and in many countries, the supporting

[52] (Tomski, 2012)
[53] (ARI, 2009)

infrastructure to deliver it to suitable fields. Also, in the context of CO_2-EOR systems, oil and carbon prices are linked, which can impact CCS projects – when oil prices are high, projects can bear a slightly higher cost for captured CO_2; however, when oil prices are low, the expense of CO_2 can make EOR economically less feasible. In order to overcome these barriers, CO_2 capture costs must be reduced through technology breakthroughs and / or incentives.

CCS for electric power or polygeneration (flexible facilities designed to coproduce electricity and other products such as fertiliser, chemicals, transportation fuels, etc) have had some significant recent developments, mainly linked to CO_2-EOR. (Table 1) In October 2014, the world's first large-scale CCS power project was launched at the coal-fired Production Unit No.3 at the Boundary Dam Power Station in Saskatchewan, Canada. The capture plant has the capacity to capture around 1 Mtpa of CO_2 emissions when fully operational.[54] The world's second CCS power plant retrofit at a 240 MW coal-fired unit is expected to come on line by the end of 2016 at the NRG W.A. Parish power plant in Texas, United States with a capture capacity of 1.4 Mtpa. The project is also implementing a CO_2 monitoring plan to track and account for carbon storage.[55] Also in 2016, Southern Company's Kemper County Energy Facility in Mississippi, United States, will come on stream; at full capacity the facility will be able to capture approximately 3.0 Mtpa or 65 per cent of its CO_2 from a newly built 582 MW Integrated Gasification Combined Cycle (IGCC) coal-based power plant making its emissions profile nominally equivalent to a natural gas combined cycle unit.[56]

[54] The SaskPower Boundary Dam CCS Project was largely motivated by Canada's 2012 update to the Environmental Protection Act that requires new coal plants to meet an emissions limit of 420 tonnes of CO_2 emitted per GWh of electricity produced, which also applies to existing plants when they turn 40 years old (Canadian Ministry of Environment, 2012). SaskPower had a choice to implement CCS or strand the asset. See http://www.saskpowerccs.com
[55] The Petra Nova WA Parish CCS Project is a joint venture between NRG and JX Nippon Oil & Gas Exploration. See http://www.nrg.com/business/carbon-360/projects/wa-parish-ccs-project/
[56] See http://www.mississippipower.com/about-energy/plants/kemper-county-energy-facility/

Table 1: Key large-scale power sector projects with CCS

Project name	Project proponent(s)	Location	Capture type	Primary storage type	Capture capacity (Mtpa)	Status & start date
Boundary Dam CCS Project	SaskPower	Saskatchewan, Canada	Post-combustion, retrofit to a coal-fired plant	Enhanced oil recovery	1.0	Operational since October 2014
Kemper County Energy Facility	Southern Company & Denbury Resources	Mississippi, United States	Pre-combustion, new build coal-fired plant	Enhanced oil recovery	3.0	Under construction, 2016 anticipated
Petra Nova Carbon Capture Project	Petra Nova Parish Holdings & Texas Coastal Ventures	Texas, United States	Post-combustion, retrofit to a coal-fired plant	Enhanced oil recovery	1.4	Under construction, 2016 anticipated
Sinopec Shengli Power Plant CCS Project	China Petrochemical Corporation (Sinopec)	Shandong Province, China	Post-combustion, new build coal-fired plant	Enhanced oil recovery	1.0	Advanced planning, 2018 anticipated
Texas Clean Energy Project	Summit Power Group, Kinder Morgan & Permian Basin oil producers	Texas, United States	Pre-combustion, new build coal-fired plant	Enhanced oil recovery	2.4*	Advanced planning, 2019 anticipated
ROAD	E.ON Benelux N.V. & GDF-SUEZ Energie Nederland N.V.	Zuid-Holland, the Netherlands	Post-combustion, retrofit to a coal and biomass-fired plant	Offshore depleted gas reservoir	1.1	Advanced planning, 2019-20 anticipated
Peterhead CCS Project	Shell U.K. Limited	Scotland, United Kingdom	Post-combustion, retrofit to a gas-fired plant	Offshore depleted gas reservoir	1.0	Advanced planning, 2019-20 anticipated
Don Valley Power Project	Sargas Power Yorkshire Limited & National Grid	South Yorkshire, United Kingdom	Pre-combustion, new build gas-fired plant	Offshore deep saline formation	1.5	Advanced planning, 2020 anticipated
Hydrogen Energy California Project (HECA)	SCS Energy LLC	California, United States	Pre-combustion, new build coal & pet-coke-fired plant	Under evaluation	2.7*	Advanced planning, 2020 anticipated
White Rose CCS Project	Capture Power Limited & National Grid	North Yorkshire, United Kingdom	Oxy-fuel combustion, new build coal-fired plant	Offshore deep saline formation	2.0	Advanced planning, 2020-21 anticipated

Global CCS Institute, October 2015

*Capture capacity is equivalent to amount of CO_2 available for injection

Capture is the most expensive element in the CCS chain for power generation applications, accounting for roughly 80 per cent of the total CCS project costs. A variety of capture technologies are in different stages of development and a number of studies show a wide range of capture costs for different technologies and power plant and industrial applications.[57] The additional cost of projects with CCS (compared to unabated projects) is often referred to as the “commercial gap” or “cost gap.”

At this stage, best estimates suggest that current technology would impose an energy penalty[58] of about 30-40 per cent and the cost of electricity could increase around 80 per cent compared to conventional technologies (similar to other low-emission technologies). However, costs depend on a number of site-specific considerations, such as capture technology, pipeline access, distance to suitable storage site, etc. As noted, actual large-scale power sector CCS experience is currently limited to Boundary Dam and most CCS cost estimates are based on design studies with differing assumptions. Like most new technologies, first generation CCS projects are expected to be more expensive than later projects and evidence from other technologies suggests that costs will become better known and decline as experience is gained, learnings are incorporated and research and development advances.[59] In fact, recent operating experience at Boundary Dam has led SaskPower to indicate that a 25-30 per cent cost reduction can be achieved on its next CCS project.[60]

In addition to higher costs, CCS projects as first movers in early deployment also carry more risk than conventional technologies thus making it more difficult to secure commercial financing. Risks generally fall into four major areas: 1) technical and operating; 2) policy, legal and regulatory; 3) market and financial, and 4) public acceptance (Table 2). CCS projects need to navigate the range of risk issues before advancing to financial close, which can add to project timelines and costs. A government role at this stage is essential to cover higher-risk early capital and address key policy and regulatory risks to enable private capital to flow.

[57] Over 50 CCS studies have attempted to address the cost issue, but there are significant differences in underlying costing methods and key assumptions that present a wide range of cost estimates. Some differences can be attributed to CO_2-capture systems but the major source of variability is in the reference plant to which the capture technology is applied. CCS is also site-specific, and no single set of assumptions applies to all situations or parts of the world; therefore, it is difficult to accurately compare cost estimates among studies. Experience with building and operating plants will improve understanding of costs (Rubin, 2012)

[58] The “energy penalty” of CCS systems is often expressed as a percentage reduction in power plant output relative to the same plant without CCS.

[59] New technologies typically see cost reductions with broader deployment. For example, since the 1990s, technologies to reduce sulfur-dioxide emissions at power plants have come down more than fivefold and technologies for nitrogen-oxide emissions threefold.

[60] SaskPower, which is owned by the Province of Saskatchewan, has invested around CAN$1.4 billion in the refurbishment of Production Unit 3 (including associated CCS capture) with a capital grant from the government of Canada of CAN$240 million. As a first-of-a-kind system, SaskPower will harness its learnings and claims its next development could cost ~30% less (McCarthy, 2014).

Table 2: CCS risks and key financing challenges

Risk Type	Key Financing Challenges to be Addressed
Market & Financial	
Market (Electricity Off-take)	Variation in electricity price and demand, ability to secure premium for low carbon electricity similar to renewable energy technologies
Carbon Pricing	Carbon price volatility or lack of carbon price hinders financing
Operating / Business Structure	Multiple players along the CCS value chain with differing risk appetites and balance sheets
Fuel	Cost and availability fluctuations; low natural gas prices make CCS less competitive on coal
Interest Rates	Interest rate rise threatens financing terms and costs
Technical & Operating	
Capital Cost	CCS components plus energy penalty high relative to competing baseload
Operational & Maintenance Costs	Incremental operational costs associated with CO_2 capture – loss of electricity revenue or additional fuel costs, operational swings or unexpected down time due to CCS
Technology / Reliability	Long lead times for site selection and characterisation, integrated operating experience limited, possible technical performance issues that lead to excessive repairs and downtimes
Technology	Wellbore integrity is a prominent storage risk
Transport	Limited or lack of CO_2 transport infrastructure proves too costly or logistically difficult
Policy, Legal & Regulatory	
Carbon Pricing	Current prices too low to encourage sufficient investment, inclusion of CCS in offset markets limited, methodologies to account for CCS developed but not broadly adopted
Incentives	Incentives (grants, allowances, tax credits, etc.) inadequate for additional CCS costs and risks, which limits prospects for securing financing, especially debt
Storage Frameworks	Regulatory frameworks emerging but not fully clarified in many jurisdictions
Environmental	CO_2 leakage to the surface or groundwater
Long-term Stewardship	Lack of clarity about liability for long-term stewardship in some jurisdictions can hinder financing
Electricity Dispatch	Electricity rate regulation fails to offer dispatch preference or incentives on par with other low carbon technology options
Public Acceptance	
Public Acceptance	Public acceptance linked to the ability to secure permits and rate recovery; recognition of CCS as a low carbon technology

Risks will vary by project and region and sustained policy support is critical at various project stages to help advance projects to financial close. Depending on the project location, policy makers and regulators may provide different CCS incentives including: tax credits or exemptions; loan guarantees or low interest loans; grants; feed-in tariffs; “wires charges” on electric utility customers; bonus allowances or revenue from cap and trade programs. None of these incentives alone are sufficient to entirely address the magnitude of risks and the commercial gap, thus project developers typically blend various incentives in an effort to make projects bankable. In order to help mobilise private capital and continue CCS deployment momentum, policy makers must take action to offer a more robust suite of financing tools and public-private partnership models.

6 CCS Policy Recommendations

CCS is a vital low carbon technology that can address deep cuts in CO_2 emissions from fossil fuel power plants and large industrial facilities, which are needed to meet the world's ambitious carbon mitigation goals. Moreover, CCS is complementary to intermittent renewables and can increase renewable penetration and improve overall system performance, cost and reliability. In many countries, CCS is also consistent with economic development and energy security goals. Policy makers must take urgent action to advance CCS deployment.

Over the past decade, a number of high-level organisations including the G8, G20, UN, Major Economies Forum (MEF), Clean Energy Ministerial (CEM), Carbon Sequestration Leadership Forum (CSLF), Asia Pacific Economic Cooperation (APEC), and the ENGO Network on CCS have set the vision and issued recommendations to policy makers that outline what is needed to accelerate CCS deployment. A number of countries have taken important initial steps to support CCS technologies through various policy interventions. However, given the relatively early stage of technology deployment, policy makers must take further action to address barriers and facilitate the creation of CCS markets that can give rise to an industry with global reach. Recommendations for policy makers to consider include:

- Recognise CCS as a vital low carbon technology within the full portfolio of low carbon technologies, including renewables and energy efficiency, that should be deployed to address carbon emissions reduction according to each country's sustainable economic development, environmental, energy supply and security priorities
- Incorporate into energy policy and planning credible projections that fossil fuels will continue to dominate over the next few decades, and that CCS – a vital low carbon technology that can significantly reduce CO_2 emissions from fossil fuel power generation and large industrial facilities *and* complement intermittent renewables to increase renewable penetration and improve overall system performance, cost and reliability – should be commercialised because it offers a least cost pathway to meet CO_2 emission reduction goals, when included in the portfolio of low carbon technologies
- Provide policy parity – an equitable level of consideration, recognition and support mechanisms – for CCS along-side other low-carbon technologies
- Mobilise private investment in CCS by offering an effective suite of financial incentives such as grants, loans, tax credits, capacity payments, and "green bonds", and establish public-private partnerships that include both cost and risk sharing
- Provide financial resources that support international collaboration, knowledge sharing and training opportunities to enable CCS demonstration projects in developing countries. Governments should also strengthen development bank funding through the World Bank CCS Trust Fund and the ADB CCS Trust Fund
- Enhance support for CCS in international climate financing mechanisms and carbon markets such as the Green Climate Fund, the Technology Mechanism, and the CDM
- Recognise that CO_2 EOR operations utilising captured anthropogenic CO_2 improve the business case for CCS and offer a viable storage option when methods are implemented to quantify the amount of CO_2 stored
- Invest in CCS human capital through education and training programs, R&D, knowledge sharing, and international collaborations and exchanges
- Support the development of CCS legal and regulatory frameworks
- Maintain and elevate CCS on the agendas of high-level energy and climate change governance organisations including the G8, G20, UN, MEF, CSLF, and APEC, and advocate for sustained, high-level engagement and policy action at both national and international levels

Action by policy makers to implement these recommendations should be urgently taken and coordinated at the highest levels globally so that CCS can help meet the world's carbon mitigation goals, and in many countries also satisfy economic development and energy security goals.

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