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Updated compilation of information on the mitigation benefits of actions, initiatives and options to enhance mitigation ambition

Technical paper

Addendum

Technical examination process to unlock mitigation potential for raising pre-2020 ambition through carbon dioxide capture, use and storage

Summary

This updated technical paper compiles information on the mitigation and sustainable development benefits of actions, initiatives and options to enhance mitigation ambition, with a focus on the thematic areas of land use, urban environments, carbon dioxide capture, use and storage, and non-carbon dioxide greenhouse gas emissions. Information for the update was provided in literature, submissions from Parties and observer organizations, and at the technical expert meetings held during the sessions of the Ad Hoc Working Group on the Durban Platform for Enhanced Action held in June and October 2014 in Bonn, Germany. The technical paper builds upon the previous version of the technical paper, contained in document FCCC/TP/2014/3 and its addendum FCCC/TP/2014/3/Add.1.

This technical paper consists of the main document and four addenda. The addenda are focused on mitigation action in the thematic areas of land use, urban environments, carbon dioxide capture, use and storage, and non-carbon dioxide greenhouse gas emissions. The addenda elaborate on mitigation potential, progress, benefits, costs and barriers, as well as on good practice policies, key opportunities and options for catalysing action in these four thematic areas.

Contents

I. Introduction

1. This update of the technical paper on mitigation benefits of actions, initiatives and options to enhance mitigation ambition was requested by the Ad Hoc Working Group on the Durban Platform for Enhanced Action (ADP) at the third part of its second session.[1] The first and second versions of this technical paper were published on 28 May and 30 October 2013, respectively, and are contained in documents FCCC/TP/2013/4 and FCCC/TP/2013/8 and Add.1 and 2.

2. This update of the technical paper comprises five parts: the main text, contained in document FCCC/TP/2014/13, and four addenda, contained in documents FCCC/TP/2014/13/Add.1–4. The main text contains a summary of the main findings, substantiated by the more detailed information provided in the addenda, which capture the content of the discussions that took place at the technical expert meetings (TEMs) on land use, urban environments, carbon dioxide capture, use and storage (CCUS) and non-carbon dioxide (non-CO_2) greenhouse gas (GHG) emissions, held in June and October 2014 in Bonn, Germany, during the fifth and sixth parts of the second session of the ADP.[2]

3. This addendum covers the discussions on CCUS and consists of two parts focusing on mitigation potential, progress, benefits, costs and barriers; and practices, policies and actions to unlock mitigation potential in relation to CCUS.

II. Technical summary on carbon dioxide capture, use and storage

A. Mitigation potential, progress, benefits, costs and barriers

4. Carbon dioxide capture and storage (CCS) is considered as an important potential carbon dioxide mitigation option. Large point sources, in particular, in the power and several energy-intensive sectors (e.g. oil and natural gas refining/upgrading, chemical industry, iron and steel production, cement production and fertilizer production) form the largest potential for applying carbon dioxide capture (IPCC, 2005).[3] The origin of carbon dioxide can be fossil or biological. Various technology options are already in operation and/or under development to capture carbon dioxide, for example technologies such as those applied for many decades on an industrial scale in industries, including gas processing and ammonia production. Captured carbon dioxide often needs to be transported to the storage site. Transport of carbon dioxide can involve one or a combination of transport modes (e.g. truck, train, ship or pipeline).

5. Carbon dioxide storage, as discussed in this technical paper, refers to storage in geologic formations, which encompasses the injection of carbon dioxide into porous rocks that may hold or have held gas and/or liquids. Several types of storage are used and proposed, including: deep saline formations (aquifers); oil reservoirs, possibly with enhanced oil recovery (EOR); gas reservoirs, possibly with enhanced gas recovery; and deep unmineable coal seams combined with enhanced coal bed methane production.

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[1] FCCC/ADP/2013/3, paragraph 30(c)(ii).

[2] Detailed information on the TEMs held in June and October 2014, including the initial summaries of the discussions at the meetings, is available at <http://unfccc.int/bodies/awg/items/8171.php>, <http://unfccc.int/bodies/awg/items/8170.php>, <http://unfccc.int/bodies/awg/items/8421.php> and <http://unfccc.int/bodies/awg/items/8420.php>.

[3] The scope of this paper excludes the direct capture of carbon dioxide from the atmosphere.

6. Utilization of carbon dioxide, referred to as carbon dioxide capture, use and storage (CCUS), has been proposed as a possible alternative or complement to geologic storage of carbon dioxide. CCUS requires the identification and development of utilization options that maximize the economic value of the captured carbon dioxide and at the same time lead to permanent retention of carbon dioxide from the atmosphere.

7. The International Energy Agency (IEA) reports that many uses of carbon dioxide are known, although most remain at a small scale (IEA, 2013). Between 80 and 120 Mt CO_2 are sold commercially each year for a wide variety of applications. Both natural and industry-sourced carbon dioxide is used. The largest share is the use in enhanced hydrocarbon production, which amounts to over 60 Mt CO_2/year. Other potential uses of carbon dioxide include use in: synthetic fuel production;[4] agriculture for enhanced crop production or algae growth; and production of chemicals and plastics (IEA, 2013). The enhanced deployment of these uses and the successful development of a wider range of alternative uses will require further research and development (R&D).

8. CCS and CCUS should be considered as an element of an ultimate and necessary transition to net-zero emissions, as acknowledged by the participants at the TEM on CCUS.[5] Such transition requires a balanced portfolio of both distributed and centralized clean energy options influencing future energy production and the subsequent energy mixes, including energy efficiency, renewable energy and other non-fossil fuel energy sources. The specific role of CCS/CCUS within this broader transition to a low-carbon pathway results from its capacity to deliver timely and large-scale emissions reductions and a lowering of the total abatement cost and challenges through a more effective utilization of the existing and established asset base.

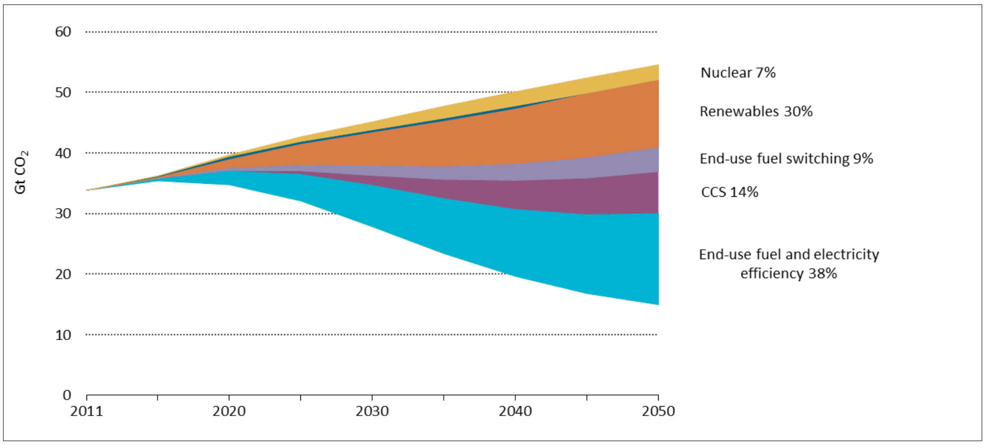
1. Mitigation potential and practices

9. CCS is an important mitigation option in the emissions scenarios prepared by the IPCC (IPCC, 2014). This is also the case in the most recent scenario prepared by IEA which aims for an 80 per cent probability of limiting the average global temperature increase to 2 °C (hereinafter referred to as the 2DG scenario) (IEA, 2014). This scenario estimates the need for a global deployment of CCS at a level capable of capturing 1.5 Gt CO_2 in 2030, increasing to 6.3 Gt CO_2 in 2050. In 2050, the power sector would be responsible for half of captured carbon dioxide and the various industry sectors for the other half. In total, CCS is estimated to contribute 14 per cent to emission reductions in the 2DG scenario by 2050. More details are provided in figures 1 and 2 below.

[4] For examples on CCU initiatives for production of chemicals and synthetic fuels see, inter alia, the ADP TEM on CCUS; presentation by Germany, 2014.

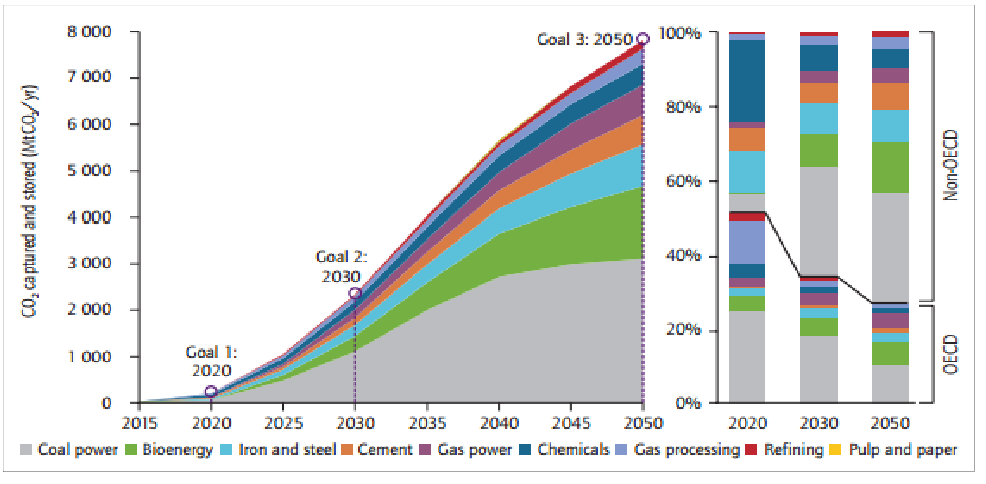
[5] Please note that there are occasions where only CCS is referred to in literature, while CCUS is not explicitly included or excluded. In this case the statement is solely attributed to CCS.

Figure 1
Contribution of technologies to annual emission reductions between the 6 °C scenario and the 2 °C scenario



Source: International Energy Agency. 2014. *Energy Technology Perspectives.*
Abbreviation: CCS = carbon dioxide capture and storage.

Figure 2
Carbon dioxide capture, use and storage applied in various sectors and regions in the 2 °C scenario between 2015 and 2050



Source: International Energy Agency. 2013. *Technology Roadmap Carbon Capture and Storage.*
Abbreviation: OECD = Organisation for Economic Co-operation and Development.

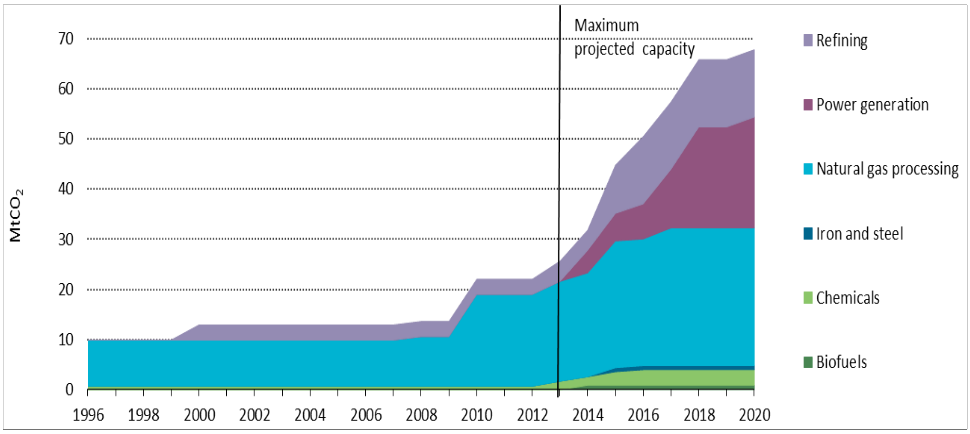
10. Likewise, the Intergovernmental Panel on Climate Change (IPCC) reports that many scenarios that reach concentrations of 430 to 580 ppm[6] CO_2 equivalent (CO_2 eq) by 2100 rely on technologies that attain negative emissions, namely carbon dioxide removal (CDR) technologies (IPCC, 2014). Bioenergy with CCS (BECCS) is an important CDR technology in many scenarios. The IPCC Fifth Assessment Report (AR5) highlights the role of BECCS in the second half of the twenty-first century. The economic potential of this technology is estimated in the range of 2–10 Gt CO_2/year.

[6] The majority of scenarios reaching long-term concentrations between 430 to 480 ppm CO_2 eq in 2100 are likely to keep temperature change below 2 °C over the course of the century relative to pre-industrial levels and are associated with peak concentrations below 530 ppm CO_2 eq.

11. In the context of assessing the long-term viability of CCS, consideration was given at the TEM on CCUS to the availability of appropriately characterised storage locations. In this regard, the IPCC estimates that the global storage capacity is in the range of 200–2,000 Gt CO_2. While noting this, participants at the TEM recognized that there is no single global standardized solution for carbon dioxide storage, and CCS/CCUS projects inevitably need to be tailored to local circumstances, and storage sites need to be selected with care. The current work of the International Standards Organization on establishing global standards for the design, construction, operation, environmental planning and management, risk management, quantification, monitoring and verification, and related activities of fully integrated CCS solutions was noted.

12. During the TEM on CCUS, the Global CCS Institute reported a total of 55 large-scale CCS projects that are in different stages of development.[7] Out of the 55 projects, globally there are 22 "active" CCS projects, including 12 operational and 10 under construction, with cumulative expected carbon dioxide capture of 40 Mt CO_2/year by 2017. Possible progress in relation to large-scale CCS projects is forecast by IEA in figure 3 below, where total captured carbon dioxide is estimated to amount to almost 70 Mt CO_2/year by 2020 if sufficient support is provided and financial investment decisions to proceed are made. The total amount of carbon dioxide captured and stored, conditional on this support, could amount to 50 Mt CO_2/year by 2020 (IEA, 2014).

Figure 3
Large-scale carbon dioxide capture projects



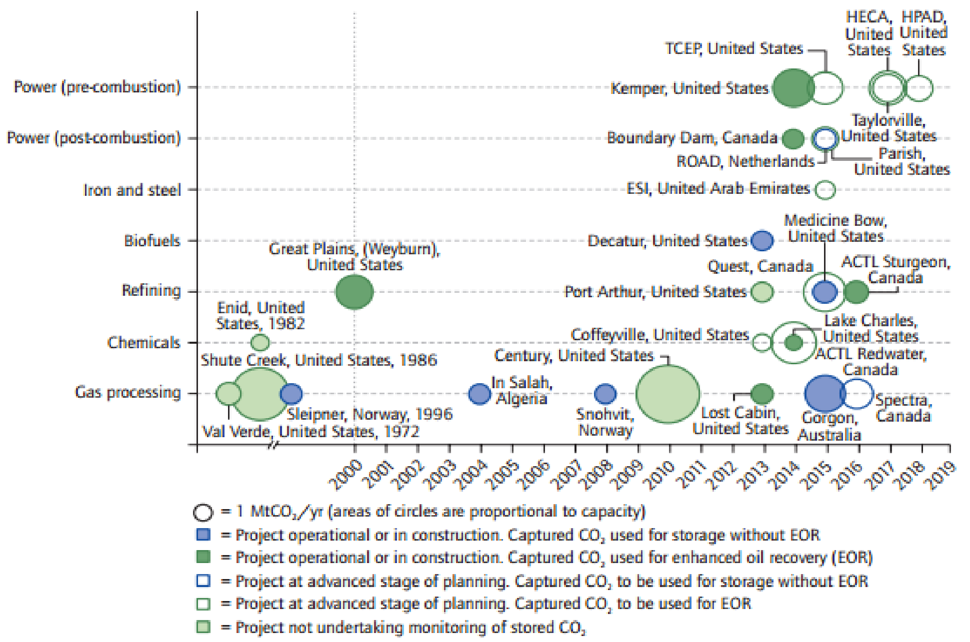
Source: International Energy Agency. 2014. *Tracking Clean Energy Progress.*

13. The active and planned large-scale CCS projects have been mapped by IEA and the Global CCS Institute including detailed information on size, sector and estimated start date (see figure 4 below). As shown in figure 4, carbon dioxide capture from oil and gas processing dominates the current demonstration projects, for example the Sleipner project in Norway. IEA notes that use of carbon dioxide for enhanced hydrocarbon (i.e. oil or gas) recovery is an important economic driver for active and planned projects (IEA, 2013). Several of these projects were discussed during the TEM on CCUS (see the spotlight box 1 below).

[7] ADP TEM on CCUS; presentation by the Global CCS Institute, October 2014.

Figure 4

Large-scale carbon dioxide capture and storage projects in operation, under construction or at an advanced stage of planning as at the end of 2012, by sector, storage type, capture potential and actual or estimated start date



Note: "Large-scale integrated projects" are defined as projects involving capture, transport and storage of CO_2 at a scale of at least 800 000 tonnes (t) annually for a coal-fired power station and 400 000 t annually for other emissions-intensive industrial facilities. All projects using CO_2 for EOR that are not yet operational are presumed to undertake monitoring in a way that is sufficient to provide confidence that injected CO_2 is permanently retained. Other noteworthy projects that are scheduled to enter operation in 2017 or after include FutureGen 2.0 in the United States, and the White Rose and Peterhead projects in the United Kingdom. These have not yet reached the Define lifecycle stage in accordance with the Global CCS Institute Asset Lifecycle Model.

Source: based on data from the Global CCS Institute (2013).

Source: International Energy Agency. 2013. Technology Roadmap Carbon Capture and Storage.

Abbreviations: ACTL= Alberta Carbon Trunk Line, HECA= Hydrogen Energy California Project, HPAD = Hydrogen Power Abu Dhabi, ROAD = Rotterdam Opslag en Afvang Demonstratieproject, TCEP = Texas Clean Energy Project.

14. Over the last 10 years, governments and industry have committed over USD 26 billion for R&D, and scaling-up deployment (GEA, 2012; IPCC, 2014). This has resulted in significant development of technological, operational and human capacity, ready to be deployed at a larger scale.

15. Experience exists with all of the components of integrated[8] CCS/CCUS projects, which are in use in various parts of the fossil-fuel energy chain. Importantly, the world's first large-scale CCS (with EOR) project[9] at a coal-fired power station has recently started operation in Saskatchewan, Canada (see spotlight box 1 below). Despite the progress, many applications of CCS/CCUS are currently still in the pre-commercial phase, with commercial uptake of the technology expected to occur after 2020. The transport of carbon dioxide is the most mature part of the CCS/CCUS chain, while storage of carbon dioxide

[8] Integrated CCUS projects are defined as projects that involve the capture, transport and storage of carbon dioxide.

[9] ADP TEM on CCUS; presentation by SaskPower, October 2014.

has seen major developments in terms of building human and technological capacity in the last decade.[10]

16. Several examples of CCS/CCUS projects in different stages of development were shared during the TEM on CCUS. Spotlight box 1 below provides detailed information on some of the projects, including the main drivers of project development.

Spotlight box 1

The Sleipner project in Norway[a]

Sleipner was the world's first commercial carbon dioxide storage project. The carbon dioxide is removed from the produced hydrocarbons at an offshore platform before being pumped back into the ground (a deep saline reservoir 800–1,000 metres below the sea floor) and the hydrocarbons are piped to land. It has been operational since 1996 and has resulted in storage of 0.9 Mt CO_2/year, amounting to 15 Mt CO_2 in total.

The project was driven by a carbon tax introduced in Norway in 1991 to incentivize increased efficiency and reduced flaring from oil and gas production. This created economic incentives to store carbon dioxide.

The Boundary Dam project in Canada[b]

This is the world's first power station with large-scale post-combustion capture, which was inaugurated in October 2014. The 110 MW retrofit of SaskPower's Boundary Dam coal-fired power plant in Saskatchewan, Canada, is designed to store around 1 Mt CO_2/year. The captured carbon dioxide will be injected into nearby oilfields, where it will also be used to enhance oil recovery. The main drivers of this project are federal and provincial government support (240 million Canadian dollars in 2008) and revenues from enhanced oil recovery.

The Quest project[c]

The Quest Carbon Capture and Storage Project expects to begin operation in 2015 and will reduce CO_2 emissions from Shell's oil sands operations by more than 1 Mt CO_2/year, by capturing carbon dioxide from crude oil processing and permanently storing it deep underground. The main drivers of this project are government funding and revenues from greenhouse gas credits (e.g. carbon tax).

CCUS demonstration projects in the United States of America[d]

Almost a dozen CCUS demonstration projects in different stages of development were presented during the TEM on CCUS, including projects capturing carbon dioxide from power production, hydrogen and methanol production, industry and agricultural processing (ethanol production). The captured carbon dioxide ranges from 1 to 4.5 Mt CO_2/year. Various applications of the captured and transported carbon dioxide are foreseen, including storage in saline reservoirs, storage in combination with enhanced oil recovery and use of carbon dioxide for the production of urea/urea ammonium nitrate. The main drivers of these projects are government funding, tax credits and revenues from enhanced oil recovery.

The Masdar–ADNOC CCUS project in the United Arab Emirates[e]

The presentation made by the United Arab Emirates showed that CCUS can also be seen as an element of a holistic sustainable development strategy where carbon dioxide capture solutions in the iron and steel sector and storage solutions in combination with enhanced hydrocarbon recovery are developed through public–private partnerships. The project captures 0.8 Mt CO_2/year at a steel plant from where

[10] ADP TEM on CCUS; presentation by the International Energy Agency, 2014.

it is transported by pipeline to oilfields for enhanced hydrocarbon recovery. Commissioning is expected in the first quarter of 2016. The main drivers of the project are the revenues from enhanced hydrocarbon recovery.

CCU projects in Germany[f]

Germany presented two CCU projects from the German R&D Programme for CO_2 Utilization. The first, the Dream Production project, is expected to launch the first carbon dioxide-based polyols on the market, used for the production of polyurethane foam, which would most likely be used for mattress production. The second, the Sunfire project, entails the production of liquid fuels from carbon dioxide and water using renewable energy. The main driver of the projects is government funding.

Sources:
[a] ADP TEM on CCUS; presentation by Statoil, October 2014. More details are available at: <https://sequestration.mit.edu/tools/projects/sleipner.html>.
[b] ADP TEM on CCUS; presentation by SaskPower, October 2014. More details are available at http://www.saskpowerccs.com/ccs-projects/boundary-dam-carbon-capture-project/carbon-capture-project/>.
[c] ADP TEM on CCUS; presentation by Shell, October 2014.
[d] ADP TEM on CCUS; presentation by ADM, October 2014.
[e] ADP TEM on CCUS; presentation by the United Arab Emirates, October 2014.
[f] ADP TEM on CCUS; presentation by Germany, October 2014.

17. The IPCC AR5 assesses that the total cost of climate mitigation[11] would amount to 1–4 per cent of gross domestic product in 2030 (2–6 per cent in 2050 and 2–12 per cent in 2100). This assessment is based on scenarios that include CCS as a mitigation option. Failure to deploy the mitigation potential of CCS would increase the costs by 29 per cent to 297 per cent (an average of 138 per cent). The IPCC scenarios show an important role for CCS applied to both fossil and bioenergy sources. This is confirmed by studies conducted by IEA and the International Institute for Applied Systems Analysis (Global Energy Assessment (GEA), 2012) which also show that both the total investment cost (IEA, 2012, 2014) and the cost of emission reduction are higher (GEA, 2012) when CCS is excluded from the list of mitigation options.

2. Barriers to mitigation action in relation to land use

18. The IPCC AR5 acknowledges that mitigation policy may have an impact on devaluing the natural resource endowments of fossil-fuel exporting countries, and notes that CCS technology may help to mitigate such impact (IPCC, 2014).

19. IEA reports that CCS could act as an asset-protection strategy for those industries that have large investments in fossil fuels (IEA, 2013a, 2013b). More specifically, less than one third of proven reserves of fossil fuels can be consumed prior to 2050, unless CCS technology is widely deployed.

20. Costs of CCS differ significantly per project, location and application. In the literature, a range of estimates are reported (GEA, 2012). The costs of carbon dioxide capture for nth-of-a-kind[12] plants range from about USD 30/t CO_2 avoided to USD 100/t CO_2 avoided. The heterogeneity and complexity of industrial sources have a strong impact

[11] The IPCC estimates that reaching 430–480 ppm CO_2 eq by 2100 would entail global consumption losses relative to a scenario without mitigation. The majority of scenarios reaching long-term concentrations between 430 and 480 ppm CO_2 eq in 2100 are likely to keep temperature change below 2 °C over the course of the twenty-first century relative to pre-industrial levels.

[12] First-of-a-kind plants are expected to cost significantly more, with estimates in the range of USD 100–150/t CO_2. GEA, 2012.

on the range of the cost and potential application of CCUS. The IPCC AR5 forecasts zero emissions-intensity levels in the industry sector requiring CCS technologies which are associated with mitigation costs in the range of USD 50–150/t CO_2 eq. Low-cost opportunities exist in industry sectors where the purer streams of carbon dioxide emitted can be captured at relatively low cost.

21. In addition to the benefits outlined above, it was highlighted that the increasing range of options to deliver low-carbon energy allows Parties to maintain the diversity of energy supply options underpinning the security of energy supply.[13]

22. It was noted that the clean development mechanism (CDM) project regulations offer good practice administrative processes, through its CCS modalities and procedures, to address the trade-offs that were also identified and predominantly relate to health and safety, the environment and the economy, including:

(a) Health and safety concerns related to CCS/CCUS with regard to risks of carbon dioxide release connected to carbon dioxide transport and storage (GCCSI, GEA, 2012; IPCC, 2014; IEA, 2014). During the TEM, the long-term permanence and risks of carbon dioxide release were discussed and put forward as important aspects of existing or proposed regulatory frameworks and project implementation;

(b) The energy-efficiency losses (‘penalty’)[14] associated with carbon dioxide capture at power plants results in less energy being provided to the grid at the same input to the plant, which therefore has an impact on the cost of power provided to consumers. The energy penalty also affects environmental life cycle performance of CCS/CCUS, referred to by the IPCC as upstream and supply-chain activities (IPCC, 2014);

(c) Depending on the carbon dioxide capture technology and application, emissions to air (e.g. nitrogen oxides, ammonia, sulphur oxides, particulate matter and non-methane volatile organic compounds) are affected by CCUS technology (GEA, 2012). This may result in both co-benefits and trade-offs for local air quality;

(d) Water use and consumption patterns are also affected by the application of carbon dioxide capture (GEA, 2012). An increase in water use and consumption at power plants is expected due to the energy penalty and the water demand by the capture system, although the impact will be highly specific to the technology and site-specific conditions;

(e) As a consequence of increased fuel consumption, it is expected that waste streams such as bottom ash, fly ash, boiler slag and reclaimed waste will increase with the implementation of carbon dioxide capture (GEA, 2012).

23. Technical, social, economic, policy, organizational and political factors may limit deployment of CCS/CCUS if not adequately addressed. Key barriers include:

(a) The scale of the mitigation effort that will be agreed internationally and nationally, which can be an important barrier. CCS/CCUS is a policy-driven technology. The absence of adequate financial incentives (e.g. carbon price, carbon tax, or emissions cap-and-trade systems) and long-term confidence in policy frameworks weakens the development of a sound business case for CCS, whereas CCUS operations rely more on a market price for industrial carbon dioxide emissions and, in the case of enhanced hydrocarbon recovery, offtake prices of the resource being extracted;

[13] ADP TEM on CCUS; presentation by the United Kingdom of Great Britain and Northern Ireland, October 2014.

[14] In IEA’s CCS Road Map (2013), average energy penalties for adding carbon dioxide capture to power plants in OECD countries indicate that up to 34 per cent more primary energy is needed to deliver power to the grid compared to a similar power plant without capture.

(b) A low level of public financing. CCS/CCUS has still not attracted the funds needed for its development and deployment at the rate required. Extensive public funding is needed to implement large-scale demonstration projects and facilitate early deployment of the technology;

(c) The high upfront cost of infrastructure is a challenge, especially for small sources of carbon dioxide. Transport of carbon dioxide benefits from economies of scale and there may be a need to create the infrastructure, possibly using hubs, to ease capture and transportation;

(d) The high cost of finance. Risks and perceived risks related to CCS/CCUS projects can negatively affect access to finance and the cost of capital. Establishing a demonstration fleet of bankable CCS/CCUS projects would be a major driver for future projects;

(e) The lack of a regulatory framework. While many countries have implemented regulatory frameworks to ensure safe storage of carbon dioxide, significantly more progress is still needed in this regard, both at the national and international levels (e.g. cross-border arrangements). A clear regulatory environment is a prerequisite for Parties to invest in CCS/CCUS;

(f) The need for safe operational procedures and long-term liability inclusion in regulatory frameworks. Concerns about the operational safety and long-term integrity of carbon dioxide storage, as well as the risks related to transport and the required scaling-up of infrastructure, need to be managed and mitigated. Post-closure stewardship and management of liabilities is key to the deployment of CCS (IPCC, 2014);

(g) The technical complexity of system integration and clarity in cost estimates represent hurdles to the operationalization and financing of projects. Demonstration of new CCS/CCUS technologies are expected to improve energy consumption and help reduce costs;

(h) The most important limitations of CCUS are the potential scale and the uncertain contribution to climate change mitigation. The total demand for carbon dioxide for commercial use is currently limited compared to the total potential carbon dioxide that can be captured. Further, the net carbon dioxide avoidance and permanence of CO_2 emissions reduction are topics currently being examined by the research community and among CCUS stakeholders.

24. The success of large-scale CCS implementation will be affected by the way in which the uncertainties of public and private stakeholders are managed. Public support for CCS/CCUS is crucial for large-scale deployment. Today, the public and many stakeholders are largely unaware of CCS/CCUS technology. There is a need for improved understanding of CCS/CCUS technology by stakeholders engaged in the decision-making processes that grant projects their social licences to operate and better understanding of how stakeholders, including the public, can give expression to their views in the development of domestic regulatory frameworks, including the siting of individual projects (IEA, 2013).

B. Practices, policies and actions to unlock mitigation potential in relation to carbon dioxide capture, use and storage

25. It is critical, according to IEA (2013), that governments, industry, the research community and financial institutions work together to ensure the broad introduction of CCS by 2020, making it part of a sustainable future solution that takes fully into account economic development, energy security and environmental concerns. Based on the

experiences gained with global developments in CCS, lessons can be learned to develop and scale up CCS.

26. Localised circumstances greatly affect the potential and likelihood of CCS/CCUS deployment. Important examples are: geological resources, energy and industry systems, existing human and research capacity related to CCS/CCUS technologies, regulatory frameworks and market conditions. Given that localised circumstances are important and CCS is a policy-driven technology (noting that while CCUS may be less dependent on climate policies, it is highly dependent on the commercial prices of carbon and resources), commitment is needed from governments and other stakeholders to establish a complementary set of policies, actions and practices that fit the needs of a country or region and the phase of technology development.

27. To help conceptualize the different stages of CCS/CCUS development in a country, the Global CCS Institute offers a range of tools based upon practices, policies and actions conducted in the past (including such as CCS Development Lifecycle, Capacity Development Framework, Regulatory Development Toolkit and Public Engagement Toolkit). Also, IEA (2013) recognizes that the phase of development of a technology is important for policies and practices that facilitate the optimal development and deployment of CCS projects.

28. Various policy options, actions and technologies that can assist countries in addressing the challenges and removing the barriers faced in scaling up the deployment of CCS/CCUS were raised by the delegates and presenters at the TEM. The policy and technology options raised during the meeting include:

(a) A clear regulatory environment grounded in national policy priorities;

(b) Economic instruments that attach a price to carbon, such as a carbon tax or emissions trading systems;

(c) Regulatory instruments, for example emissions performance standards, direct regulatory requirements for CCS and/or a capacity to apply CCS in new industrial permits;

(d) Economies of scale to reduce finance and infrastructure costs; this includes sharing of infrastructure by different projects;

(e) Identification and engagement of key stakeholders;

(f) Support detailed mapping of point source emissions with geological storage sites and/or CCS/CCUS hubs;

(g) R&D policies.

29. The policy and technology options referred to above have been expanded upon and structured into three groups of policy options: (i) scoping and agenda-setting; (ii) strengthening institutional arrangements and legal and regulatory frameworks; and (iii) design and implementation of effective and multifaceted policy portfolios (see table 2 below).

30. **Scoping and agenda-setting**: An important basis for developing and deploying CCS/CCUS projects is to establish the technical potential of the technology in a certain country or region. Examples are the creation of storage atlases[15] and scenario studies that define the potential role of CCS/CCUS in the energy system and industry. Stakeholders

[15] North American Carbon Atlas Partnership published North American Carbon Storage Atlas 2012; the Carbon Storage Atlas of the Norwegian North Sea was published in 2011; the Queensland Carbon Dioxide Geological Storage Atlas was published as the first storage atlas of Australia.

(government, industry, research community, financiers) could collaborate to determine the business case of CCUS development and deployment and raise awareness among stakeholders with regard to the value chain of CCS/CCUS.

31. It should be further noted that the application of these policy options will differ according to a Party's choice as to whether to target carbon dioxide storage with or without use. While many policy options are applicable to both scenarios, the need for a clear regulatory framework is of greater importance when the captured carbon dioxide will be geologically stored and where CCUS claims net mitigation outcomes, and enhanced utilization options without geological storage will require significantly greater emphasis on R&D. The precise design of economic instruments should also take account of Parties' desire or otherwise to direct activity towards one or other of the scenarios.

32. Building CCS/CCUS expertise is key to any policy that aims to advance related activities in a country or region. Examples of expertise-building are the creation of national research, development and demonstration (RD&D) programmes to stimulate the creation and sharing of knowledge. Access to international research and knowledge-sharing initiatives is imperative to accelerate capacity-building in countries where CCS/CCUS development is currently in an early phase.

33. However, according to the IPCC AR5, the level of public R&D funding is relatively low compared with that for nuclear and renewable energy, and does not reflect the potential importance of CCS for the achievement of emission reductions, or even negative emissions through BECCS (IPCC, 2014).

34. To coordinate strategies and actions, CCS/CCUS technology road maps[16] is considered to be a good instrument to align stakeholders and provide a common understanding of the elements needed to progress CCS/CCUS development. To date, several national and international CCS/CCUS road maps have been published (see spotlight box 2 below). The creation of a common vision with stakeholders and agreeing on targets are policy options that may contribute to greater confidence in developing and deploying CCS/CCUS as a mitigation option.[17]

Spotlight box 2
Examples of CCS technology road maps

Global focus

- Technology Road Map (TRM), carbon capture and storage. IEA, International Energy Agency. 2010 and 2013. Available at: <http://www.iea.org/publications/freepublications/publication/CCSRoadmap2009.pdf>, <http://www.iea.org/publications/freepublications/publication/TechnologyRoadmapCarbonCaptureandStorage.pdf>,
- Carbon Sequestration Leadership Forum TRM 2011. Carbon Sequestration Leadership Forum. 2011. Available at: <http://www.cslforum.org/publications/documents/CSLF_Technology_Roadmap_2011.pdf>.

National/regional focus

[16] More details on technology road maps are reported in the "Background paper on Technology Roadmaps (TRMs)". Available at <http://unfccc.int/ttclear/misc_/StaticFiles/gnwoerk_static/TEC_documents/d06f20cd595a4caebbd0eb072544bcbb/e8afc9b923d04bc5aa5335b6bc2b975f.pdf>.

[17] ADP TEM on CCUS; presentation by IEA, October 2014.

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35. Stakeholder engagement is crucial in the acceptance of CCS technology. Enhanced transparency of information improves public and private decisions and can enhance public perception (IPCC, 2014). IEA therefore urges a significant increase in efforts to improve understanding among the public and stakeholders of CCS technology and the importance of its deployment (IEA, 2013).

36. **Strengthening institutional arrangements and legal and regulatory frameworks**: According to the IEA Road Map for CCS, there is a strong need for comprehensive and transparent regulatory frameworks for carbon dioxide storage (IEA, 2013). The primary function of such frameworks is to ensure that the storage of carbon dioxide is undertaken in a safe manner according to clear rules and best practices. Experience with the development of these frameworks is growing, but in many cases they need to be developed in parallel with the operation of the first major projects, incorporating lessons learned from these projects and ensuring that the concerns of local populations have been recognized and addressed. A predictable regulatory environment is needed at both the national and the international levels.

37. Long-term liability is an important aspect that needs to be addressed in regulatory frameworks. This includes well-defined responsibilities for the long-term reliability of geologic storage sites as they are an important prerequisite for successful CCS applications (IPCC, 2014).

38. Regulatory frameworks also include the establishment of clear and efficient permitting procedures for CCS/CCUS projects. Industry will only be able to undertake projects if the permitting processes and roles of the various relevant authorities are clear.

39. IEA (2013) suggests developing 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. The aim of building plants that are CCS-ready to allow for retrofitting[18] with CCS technology at a later date is to reduce the risk of stranded assets and 'carbon lock-in' of potentially inappropriate technologies in an environment of increasingly stringent carbon constraints. The key issues for CCS-ready plants are engineering in nature, inclusion of sufficient space, access for the additional facilities that would be required and the identification of reasonable transport route(s) and options for carbon dioxide storage (IEA, 2007). It should be noted that the carbon dioxide transport and geological storage components of CCS-ready policies are applicable more broadly to other sectoral CCS/CCUS applications than the just power sector.

40. Capacity-building at institutions for this purpose is needed and may be based on the experience gained with the development and deployment of existing CCS/CCUS projects. Best practices have been published and shared, and are publicly available; see, for example, the list of CCS/CCUS initiatives for knowledge- and technology-sharing in table 1 below.

Table 1
Specific examples of carbon dioxide capture, use and storage initiatives for knowledge- and technology-sharing, and capacity-building

Initiative	*Description*
Carbon Sequestration Leadership Forum	The Carbon Sequestration Leadership Forum (CSLF), established in 2003, is a ministerial-level international climate change initiative focused on the development of improved cost-effective technologies for the separation and capture of carbon dioxide for its transport and long-term safe storage. The mission of CSLF is to facilitate the development and deployment of such technologies via collaborative efforts that address key technical, economic and environmental obstacles. CSLF will also promote awareness and legal, regulatory, financial and institutional environments conducive to such technologies
Clean Energy Solutions Centre	The Clean Energy Solutions Centre, established in 2009, is an initiative of the Clean Energy Ministerial, a global forum to share best practices and promote policies and programmes that encourage and facilitate the transition to a global clean energy economy. The Clean Energy Solutions Centre also receives support from a unique partnership with UN-Energy, the United Nations inter-agency

[18] CCUS can be applied at new plants and on existing installed capacity: "In reality, the optimal degree of emission reduction will depend on the trade-offs between the amount of emission reduction and the cost of capture and age of the facility on which it is deployed. Partial capture may in some cases be more advantageous than striving for the largest emissions reductions possible from a particular facility. For example, a low cost and widely deployed retrofit technology that captures 50 per cent of the emissions from existing coal-fired power plants in China may be one of the most cost effective ways for near-term emission reductions. On the other hand, for a newly built power plant with integrated capture, emissions reductions of 90 per cent may be preferable." GEA, 2012.

Initiative	*Description*
	mechanism to scale up global clean energy use
Global Carbon Capture and Storage Institute	The Global Carbon Capture and Storage Institute, established in 2009, is an independent, not-for-profit company registered under the (Australian) Corporations Act 2001. The Institute accelerates the development, demonstration and deployment of carbon dioxide capture and storage (CCS) and carbon dioxide capture, use and storage (CCUS) globally through its knowledge-sharing activities, fact-based influential advice and advocacy, and work to create favourable conditions to implement CCUS
International Energy Agency International Low-Carbon Energy Technology Platform	The International Low-Carbon Energy Technology Platform (Tech Platform) is the International Energy Agency's tool for multilateral engagement on clean technologies between its member and partner countries, the business community and international organizations. Created by the G8 at the Aquila Summit in 2009, Tech Platform activities (including the one focusing on CCS, called IEA GHG) include sharing best practices for clean energy technologies, partnership-building and creation of technology-specific guidance on national road map development and implementation of projects
Clean Energy Dialogue	The United States of America–Canada Clean Energy Dialogue (CED) was launched in 2009 to enhance bilateral collaboration in the development of clean energy science and technologies to reduce greenhouse gases and combat climate change. CED is an important initiative in support of ongoing efforts towards building a low-carbon North American economy.
Zero Emission Fossil Fuel Power Plants	The European Technology Platform for Zero Emission Fossil Fuel Power Plants (ZEP) is a coalition of European utilities, petroleum companies, equipment suppliers, scientists, academics and environmental non-governmental organizations united in their support for CCS as a key technology for combating climate change. ZEP serves as an advisor to the European Union on the research, demonstration and deployment of CCS
South African Centre for Carbon Capture and Storage	The South African Centre for Carbon Capture and Storage (SACCCS) is the leading authority for CCS activities in South Africa. SACCCS undertakes CCS research and development and capacity-building (both human and technical) to attain a state of country readiness for the implementation of CCS in South Africa. SACCCS was established on 30 March 2009 as a division of the South African National Energy Development Institute.
European Industrial Initiative on carbon capture and storage	The strategic objective of the European Industrial Initiative on carbon capture and storage is to demonstrate the commercial viability of CCS technologies in an economic environment driven by the European Union Emissions Trading System, and, in particular, to enable the cost-competitive deployment of CCS technologies in coal-fired power plants by 2020–2025 and to further develop the technologies to allow for their subsequent widespread use in all carbon-intensive industrial sectors.
CO2GeoNet	CO2GeoNet is the European Network of Excellence on the Geological Storage of CO_2. Activities include research, training, scientific advice, and information and communication.
China–Australia Geological Storage	The China–Australia Geological Storage of CO_2 (CAGS) Project is a collaborative project that aims to accelerate the development and deployment of geological storage of carbon dioxide in China and Australia.
The 4-Kingdom	The 4-Kingdom CCS Initiative was developed by Saudi Arabia with

Initiative	*Description*
CCS Initiative	the participation of the Netherlands, Norway and the United Kingdom. It aims to address the issue of climate change and the importance of carbon dioxide capture and storage.
Smart CO_2 Transformation	Smart CO_2 Transformation (SCOT) is a collaborative European project (supported by the Seventh Framework Programme) in the area of carbon dioxide utilization aimed to define the strategic research and innovation agenda for Europe

41. **Design and implementation of effective and multifaceted policy portfolios**: The IPCC reports that CCS technologies applied in the power sector will only become competitive with their freely emitting (i.e. unabated) counterparts if the additional investment and operational costs associated with CCS technologies are compensated for by sufficiently high carbon prices and/or direct financial support. The provision of targeted technology-push instruments such as capital grants, investment tax credits, credit guarantees and/or insurance are considered to be suitable means to support the development and demonstration of nascent CCS technologies as long as they are in the early stages of development (IPCC, 2014).

42. Policies are required to improve the cost-competitiveness of CCS/CCUS compared to unabated technologies and to ensure investor confidence. For industries to embark on large-scale investments, policy instruments need to be clear and predictable in the long term. This requires a stable, long-term policy environment. Policies aimed at stimulating CCS/CCUS should take into account the need to maintain or reach a level playing field and should prevent international carbon leakage. These policies should also be developed in coordination with the development of safety regulations and permitting procedures that authorize underground storage and set clear requirements for its monitoring and safety.

43. The policies should be able to cope with the changing dynamics within the sector related to the development of alternative mitigation options and changes in the business case; for example: the increasing share of renewables; the changing position of nuclear energy; and fluctuations in natural gas, oil and coal prices.

44. Depending on the phase of CCS/CCUS development and the country specifics, several policy options are available and practised globally that stimulate or regulate the deployment of CCUS. These can be economic and financial instruments, but also regulating instruments, or a mix thereof.

45. Economic and financial instruments that could be applied to stimulate CCUS deployment and transfer include:

(a) Carbon tax: a carbon tax is a form of explicit carbon pricing directly linked to the level of CO_2 emissions (see spotlight box 1 above);

(b) Feebate: a carbon tax with an offset baseline. The tax (fee) applies to every unit of emissions above a set baseline, and tax credits (rebate) are issued if the emissions are below the baseline;

(c) Emissions trading scheme (ETS): a cap-and-trade system for emission allowances. Under the cap-and-trade principle, a cap is set on the total amount of GHGs that can be emitted by all participating installations. ‘Allowances’ for emissions are then auctioned off or allocated for free, and can subsequently be traded;

(d) Carbon price floor: a measure suggested in combination with carbon pricing (e.g. through an ETS) to set a minimum price for emission allowances;

(e) Feed-in tariffs: producers are paid a cost-based or premium price for the product (e.g. electricity) they produce;

(f) Contract for difference: this is a contract between two parties where one party (e.g. the government) will pay to the other (a project developer) the difference between a predetermined level for the carbon price and the actual carbon price;

(g) Government funding, grants and loan guarantees: often in the form of State investment and/or operation support, tax credits, loan guarantees or via a State-funded venture;

(h) RD&D programme and funding: government, private or joined support for the development of technology and building of human capacity;

(i) CCS/CCUS certificates: in a certificate system, a specific binding target is set for CCS/CCUS, while the market forces determine the price for the certificates to fulfil the scarcity.

46. Regulatory instruments will not, in principle, reduce the cost of CCS, but will create a level playing field. Examples include:

(a) CCS/CCUS targets: a national target could be set for CCS/CCUS to be delivered within a defined period, for example by 2030. The target could for example prescribe a certain percentage of carbon dioxide that should be captured and stored;

(b) Mandatory CCS/CCUS for certain projects: also called a ‘command and control’ policy option by IEA (IEA, 2013). It regulates the mandatory application of CCS/CCUS for certain projects;

(c) Emissions performance: this standard sets a limit on the CO_2 emissions from a certain activity (e.g. kg CO_2/MWh electricity produced) (see the examples provided in table 2 below).

47. According to IEA, several national and subnational governments have already put in place policies to stimulate investments in CCS. There are examples of policies that are intended to ‘pull’ such investments by providing capital grants and support for RD&D (e.g. Canada, China, European Union, Japan, United Kingdom and United States of America), and examples of policies that intend to ‘push’ investments in CCS through performance requirements, direct regulation and high carbon prices (e.g. Canada, Norway and United Kingdom) (IEA, 2013).

Table 2
Policy options menu for carbon dioxide capture, use and storage

Select policy options	*Select specific examples*
Scoping and agenda-setting	
• Identify technical potential (e.g. storage atlas) • Investigate the potential role of CCS/CCUS in relation to energy systems and industry structure • Identify and engage key stakeholders • Raise awareness among governments and industry • Build CCS/CCUS expertise through RD&D and knowledge-sharing • Develop an action plan or road map with a (long-term) strategy for CCS/CCUS	• Storage atlases: North America, Norway, South Africa, United Kingdom • Leading countries and regions with advanced scoping and agenda-setting: Australia, Canada, China, European Union, Japan, Norway, Republic of Korea, United Arab Emirates, United States of America • Pre-competitive geological exploration data: Australia, China • Advancing countries or regions: Algeria, Botswana, Brazil, China, Egypt, India, Indonesia, Jordan, Kenya, Maghreb region, Malaysia, Mexico, Philippines, South Africa, Thailand, Trinidad and Tobago, Viet Nam • Examples of sectoral, national, regional or global road maps (see spotlight box 2 above)

Select policy options	Select specific examples
Strengthening institutional arrangements and legal and regulatory frameworks	
• Review existing legal and regulatory frameworks • Enhance knowledge-sharing in institutions with a clear role in legal and regulatory frameworks for CCS/CCUS • Implement frameworks that ensure safe and effective carbon dioxide capture, transport, storage and use • Ensure well-aligned permitting procedures for CCS/CCUS projects	• The International Energy Agency's CCS Review gathers contributions from national, regional, state and provincial governments, at all stages of CCS regulatory development • The Global CCS Institute has performed an extensive review of the permitting process of the (planned) CCS demonstration projects in the Netherlands and Romania, as well as in a number of developing countries[c] • The European Union's CCS directive is an example of Europe's strengthening of the regulatory framework for CCS • Review of legal and regulatory frameworks for nine developing economies: China, Chinese Taipei, Indonesia, Malaysia, Mexico, Philippines, Republic of Korea, Thailand and Viet Nam (Asia-Pacific Economic Cooperation, 2012)
Design and implementation of effective and multifaceted policy portfolios	
• R&D policy • Project demonstration support • Government provision of public goods or services (e.g. a common carrier infrastructure)	• Canada: the Alberta CCS Fund, the Clean Energy Fund, and the Climate Change and Emissions Management Fund • China: research programmes on utilization of carbon dioxide for enhanced oil recovery and geological storage, and a programme on technology research for carbon dioxide capture and storage • European Union: public R&D funding via framework programmes and Horizon 2020. Demonstration project funding via New Entrants' Reserve (NER) 300 (which was renewed in October 2014 re-named as the NER400) programme and European Energy Programme for Recovery • Norway has a State enterprise for development and deployment of CCS (Gassnova) • United Arab Emirates has a joint venture project funded by Abu Dhabi National Oil Company (ADNOC), the United Arab Emirates' State-owned oil company, and Masdar, a wholly owned subsidiary of the Abu Dhabi Government, which is owned by the Mubadala Development Company • United Kingdom: CCS commercialization programme and funding from the European Union • United States of America: Department of Energy's Industrial Carbon Capture and Storage Project (ICCS), the Clean Coal Power Initiative (CCPI) and the American Recovery and Reinvestment Act
• Financial instruments for the deployment of CCS/CCUS	• Public R&D funding, inter alia: Australia, Canada, Japan and the United States of America are together responsible for 75 per cent of cumulative public funding from 1974 to 2011 [d] • Canada: government funding and (State-dependent) carbon tax • Japan: government funding • European Union: European and national public funding; and emissions trading scheme • Norway: government funding and carbon tax • United Kingdom: government funding, emissions trading scheme and contract for difference • United States of America: loan guarantees, grants and tax credits
• Regulating instruments for the deployment of CCUS	• Canada: emissions performance standard (electricity performance standard for coal-fired electricity) • European Union: mandatory carbon dioxide capture readiness • United Kingdom: emissions performance standard • United States of America: emissions performance standard

Sources: International Energy Agency (IEA). 2013. *Detailed country RD&D budgets 1974–2011. IEA Energy Statistics – R&D Statistics*; Jonker T. 2013. *Permitting Process:Special Report on Getting a Carbon Capture and Storage Project Permitted.* Available at <http://www.globalccsinstitute.com/publications/permitting-process-special-report-getting-ccs-project-permitted>; The Global Carbon Capture and Storage (CCS) Institute. 2014. *Global Status of CCS 2014 Report*. Available at <http://www.globalccsinstitute.com/in-focus/global-status-ccs-2014>; <http://ec.europa.eu/clima/policies/lowcarbon/ccs/implementation/index_en.htm>.

Note: Many examples reference ongoing activities. The list is not exhaustive and the examples are for informational purposes only. A selection of policy options and examples highlighted during the Ad Hoc Working Group on the Durban Platform for Enhanced Action technical expert meeting on carbon dioxide capture, use and storage, held in October 2014, in submissions from Parties and in relevant technical literature. Detailed information on this meeting is available at <http://unfccc.int/bodies/awg/items/8421.php>.

Abbreviations: CCUS = carbon dioxide capture, use and storage, R&D = research and development, RD&D = research, development and demonstration.