An International Commitment to CCS: Priority Actions to Enable CCS Deployment

Coal Industry Advisory Board Submission to the International Energy Agency

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The views expressed in this paper are those of the Coal Industry Advisory Board (CIAB) to the International Energy Agency (IEA). The sole purpose of this paper is to advise the IEA secretariat in accordance with the role of the CIAB. This paper draws on the experiences of CIAB members based on their involvement in the design, funding, construction, and operation of CCS projects and energy infrastructure projects worldwide. The views do not necessarily reflect the views or policy of the IEA Secretariat or of its individual member countries.

Foreword

Seamus French
Coal Industry Advisory Board (CIAB) Chairman

Deployment of carbon capture and storage (CCS) is critical if we are to meet our climate change goals. This is because under a 2°C scenario fossil fuels will continue to make up 68% of the total primary energy demand in 2030, and 58% in 2040 (IEA, 2016). The most cost-effective way to manage the carbon emissions from fossil fuels is CCS. Without CCS, reaching the goal will be 138% more expensive (IPCC, 2014).

The Paris Agreement is even more ambitious and aims to hold any increase in global temperatures to well below 2°C. According to the IEA Energy Technology Perspectives (2017), 37% of any additional reduction in emissions will need to come from CCS, making CCS even more critical.

There is already governmental recognition of the importance of CCS, with 10 out of 162 countries currently including CCS in their National Determined Contributions (NDCs), representing 33% of global emissions. If we include member countries of the Carbon Sequestration Leadership Forum and countries, such as the United States, that are actively pursuing CCS, the percentage of global emissions covered rises to 70%. However, despite this, not enough progress is being made. Government and industry need to work together to deliver the required 200-fold increase in CCS deployment by 2030.

In 2016, the Coal Industry Advisory Board (CIAB) outlined the coal industry's recommendations on the policies that will support the growth of CCS, namely, policies that 1) stimulate market uptake, 2) support CCS project development, 3) enable CCS project funding and 4) advance next-generation CCS technologies.

These were based on industry experiences of CCS projects, including the Boundary Dam and Petra Nova operations.

This report builds on these recommendations by examining a specific suite of policies and incentives that would stimulate the private sector and government to reach the required deployment rate. It focuses on the United States, the United Kingdom, Australia and the People's Republic of China – key countries with regards to their overall emissions and that also provide policy lessons for other governments.

The case studies show the following:

- Governments have been very effective at building the regulatory and technology knowledge to advance CCS. Examples are the Global CCS Institute and the United Kingdom-China Clean Energy Partnership. There have also been effective programmes to facilitate the characterisation of geological resources, with the United States and Australian governments in particular being leaders in this area.
- CO_2 transportation infrastructure planning has been relatively limited. This is a key factor in influencing investment decisions by industry. China has strong potential to become a leader in lower-cost CCS, in particular through enhanced hydrocarbon recovery. However, it currently lacks the infrastructure to transport carbon from sources to sinks.

- Industry and governments have been able to collaborate effectively on a variety of pilot-scale projects. Government support for commercial-scale demonstrations, however, has been weak. A policy change in the United Kingdom has had a particularly strong impact, inhibiting the development of two CCS commercial-scale projects there; White Rose and Peterhead. In contrast, examples in the United States show that the most successful projects to date have had the benefit of government contributing capital combined with policies that support operating expenditure cost recovery and sufficient revenue streams.
- Policy continuity and international awareness of the criticality of CCS are required to encourage long-term investment and the right forms of international finance. The investment policies of international financial institutions and multilateral institutions need to include the capability to fund CCS projects. The governments of the United States, China and the United Kingdom have an important role to play in advocating this. The IEA also has a key voice to communicate this message. Under the right circumstances, industry has and will continue to invest significantly.
- As with all developing technologies, government co-funding and support for research, development and demonstration (RD&D) is critical in order to reduce risks and bring costs down. Industry also has a strong role to play in funding RD&D to complement international research, with the Australian COAL21 fund providing a potential structure to replicate.

Our case-study countries have shown that under persistent austerity and policy uncertainty, a productive alternative is to focus on smaller-scale, easily replicable CCS units that do not carry similar risk levels. The industry can echo success in the renewables sector by learning by doing and through introducing greater efficiencies into each innovation cycle. However, as with renewables, success will depend on the right policy framework.

Industry needs to support government to:

a) **Deliver compelling messages that CCS is an essential technology** to achieving a low-carbon energy future at the lowest possible cost.

b) **Implement incentive-based policies** that enable CCS deployment.

c) **Distribute technology-demonstration funding** among low-carbon energy alternatives to demonstrate each technology at a commercial-scale.

d) **Implement international public-private collaboration on CCS projects** with equitable cost sharing.

e) **Distribute R&D funding, with parity among low-carbon energy alternatives** (i.e. renewables, CCS, and nuclear), **low-carbon industrial processing** (e.g. steel, liquefied natural gas [LNG] and cement manufacturing with CCS) and **focus CCS R&D more strategically**.

Industry supports the IEA's work to develop a map of policy options that drive new projects and bring down the costs of new technology. Ultimately, government and industry need to work together to develop projects that distribute risk and cost in a way that is consistent with the level of public and private benefit achieved.

The examples of the United States, the United Kingdom, Australia and the People's Republic of China show that commercial-scale projects of first-generation CCS technology can work. Deployment of the next generation of projects will require governments to put well-designed policies in place, public and private banks to finance well-designed projects, and industry to drive project development and technical innovation.

This paper has been written by members of the CIAB, drawing on our experiences in CCS projects around the world, to outline policies and incentives that could provide the underpinning for future successful projects.

An International Commitment to CCS: **Priority Actions to Enable CCS Deployment**

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The CIAB is a group of high-level executives from coal-related enterprises, established by the International Energy Agency Governing Board in July 1979 to provide advice to the IEA from an industry perspective on matters relating to coal. The views expressed are those of the CIAB. The sole purpose of this paper is to advise the IEA Secretariat in accordance with the role of the CIAB. This paper draws on the experiences of CIAB members based on their involvement in the design, funding, construction, and operation of CCS projects and energy-infrastructure projects worldwide. This paper does not necessarily represent the views of the IEA or the acknowledged contributors.

Introduction

Most major countries have committed themselves to the ambitious goal of a low-carbon energy future in order to address climate change concerns. CCS is essential to the lowest-cost pathway to this goal. IEA data shows that, without CCS, achieving ambitious climate goals becomes unaffordable and thus most likely unattainable.

The Intergovernmental Panel on Climate Change's (IPCC's) 5th Assessment Report (IPCC, 2014) examined the cost of transforming the global energy system to an emissions outcome consistent with the stabilisation of atmospheric carbon dioxide (CO_2) concentration at 450 parts per million (ppm) (achieving a 2°C goal)[1]. From the IPCC's assessment, some compelling conclusions can be made:

- The majority of the energy-economic models employed in the 5th Assessment Report cannot achieve a 2°C goal without the deployment of CCS.
- The lowest-cost approach to achieving a 2°C goal involves the deployment of a diverse portfolio of low-carbon technologies, including CCS, wind, solar, biomass and nuclear, alongside overall greater energy efficiency.
- Strikingly, CCS is the single most influential class of technology for reducing the cost of achieving a 2°C goal, given its broad applicability to electricity generation, synthetic-fuel production, industrial processes, and bioenergy.
- Without CCS, the cost of achieving a 2°C goal increases by a mean estimate of 138%. This increase in cost equates to ~3% of cumulative global GDP for the rest of the century.
- Limiting wind, solar, or phasing out nuclear has considerably less impact on the total cost of achieving a 2°C goal (IPCC, 2014b). Thus, among the major low-carbon technologies, CCS has the greatest leverage in terms of controlling cost.

The Paris Agreement commits signatory countries to pursuing efforts aimed at limiting temperature increases to well below 2°C. That is, holding the increase in the global average temperature to well below 2°C and pursuing efforts to limit the temperature increase to 1.5°C (UN, 2015). The more ambitious the goal, the greater the role for CCS (IEA, 2017). As a result, under the Paris Agreement, CCS would have even greater economic value than that previously estimated by the IPCC for a 2°C goal.

It makes economic sense for there to be an international commitment to CCS that rivals the scale of commitment that countries have made to renewables. In 2016, the CIAB reviewed successful and unsuccessful global CCS projects and CCS policy mechanisms in order to identify policy-related lessons learnt and best practices (CIAB, 2016). The CIAB then recommended a portfolio of policies that would be effective in facilitating CCS investment and in supporting an international commitment to CCS. The policies the CIAB recommended were targeted towards four objectives: stimulating CCS market uptake; supporting CCS project development; enabling capital investment in CCS projects; and advancing next-generation CCS technologies.

[1] The IPCC specifically evaluated stabilisation of atmospheric concentrations of carbon dioxide at 450 parts per million (ppm). This stabilisation target is approximately equivalent to limiting global average temperature rise to 2°C.

1. Stimulate CCS Market Uptake. Achieving a low-carbon future requires deployment of CCS technologies and substantial capital investment. If government policies are put in place that enable investment capital to earn a market-based rate of return, investment capital will flow. As deployment becomes more widespread, cost reductions and performance improvements will inevitably arise from the private-sector competition between technology suppliers. As costs are reduced, and performance improves, deployment will increase.

2. Support CCS Project Development. The public benefits resulting from emissions reductions, and the economic benefits of commercial-scale CCS projects, are extremely large in a low-carbon future. CCS projects currently need to navigate a development process that is often complex and which typically takes three to seven years. Policies should be designed to financially de-risk and accelerate project development so that CCS projects have the maximum opportunity for success. Furthermore, the public sector has a critical role to play in the planning and development of geologic storage infrastructure and trunk pipelines. The combination of these actions would allow the associated public benefits of CCS to be realised as quickly as possible.

3. Enable Capital Investment [2]. Public policy has the ability to improve project economics and access to investment capital. Policies should enable investors to achieve an appropriate risk-weighted return on investment to unlock investment from public and private banks, as well as equity investors. Low-carbon renewables have seen a global surge in market penetration, and a related reduction in cost, owing in large part to policies that improve project economics and access to investment capital. If CCS is to see a similar global surge in market penetration, a policy-support framework for CCS is required – just as one was required for renewables.

4. Advance Next-generation CCS Technologies. Governments have a key role to play in advancing next-generation technologies, as well as elements of CCS knowledge, that are 'pre-competitive' (i.e. public information), or for which market-based financial returns (e.g. storage-resource characterisation) are not yet identifiable. In particular, the parties to the Paris Agreement that committed to Mission Innovation, which includes a doubling in government clean-energy research and development (R&D) funding, should fulfil that pledge, and there should be dollar-for-dollar parity in R&D funding for CCS and renewables. Distinct from R&D, demonstration funding should be distributed across all low-carbon technologies (i.e. CCS, renewables and nuclear) based on the level of funding required to demonstrate first-of-a-kind technologies at a commercially relevant scale.

Specific policy mechanisms to address each of these four objectives are listed in Table 1 and described in detail in the CIAB's 2016 report (CIAB, 2016).

In addition, three essential communication and co-ordination actions were identified in the CIAB's 2016 report:

- **Advance a Positive CCS Narrative.** The economic development and prosperity of many countries depend on affordable and reliable energy and industrial products made possible by fossil fuels. This dependence will continue for the foreseeable future. A transition to a low-carbon energy future will be more successful if the messaging from senior political and industry leaders emphasises the economic importance of CCS in facilitating such a future.
- **Increase Intra- and Inter-governmental Co-ordination as well as the Effective Implementation of Government CCS Programmes.** Co-ordination that builds support for CCS, shares knowledge, and speeds the implementation of government CCS-related policies is essential.

[2] *The CIAB's previous report used the title "Enable Project Funding" to describe the third category of policy. The title has been changed to "Enable Capital Investment" to better reflect the intent of this category of policy.*

Existing government programmes that implement CCS policy have made notable progress, but implementing agencies must look ahead to the scale of CCS deployment required for a low-carbon future and, accordingly, accelerate the speed and scale of policy incentives. Business-as-usual implementation of government permitting, grants, guarantees, and other approvals will not suffice. Furthermore, although carbon capture is technically feasible at power plants and in industrial processes worldwide, there is considerable variability globally in geological resources available for storage. Governments need to recognise these differences, and co-ordinate infrastructure development if CCS is to be deployed widely.

- **Involve Inter-governmental Co-ordination on Carbon Markets that Enable CCS Deployment.** Carbon credits generated by CCS projects should be tradeable on an equal basis to carbon credits from other low-carbon technologies.

Building an International Commitment to CCS

An international commitment to CCS ultimately involves a sharing of responsibilities between the public and private sectors. If governments, in consultation with the private sector, implement well-designed policies and associated incentives, a market environment would be created where public and private banks would finance CCS projects, industry would drive a wave of CCS deployments, innovation would drive down the cost and commercial risk of CCS, and climate goals would be achieved at the lowest possible cost. It has been done before for renewables, and it can be done again for CCS.

Industry has also learnt that it is more effective to focus on smaller-scale, lower-cost projects with replicable scalable units that can incorporate innovations with relative ease. Implementation of a full suite of policies and incentives will likely require most of a decade – just as it did for renewable policies. There are, however, high-priority actions that can and should be taken with urgency if CCS deployment momentum is to build. In this report, the CIAB has selected four countries that could choose to take a leadership position on, and begin building an international commitment to, CCS. For each of these countries, the CIAB has identified what it believes would be high-priority actions for these countries to take. The selection of four countries is meant to illustrate what actions could be taken in different parts of the world to begin building an international commitment to CCS. It is not meant to suggest that only these countries should take leadership positions on CCS.

The four countries are: the United States, the United Kingdom, Australia and the People's Republic of China. China and the United States were selected as they are currently the largest CO_2 emitters, together comprising 44% of global emissions in 2015 (IEA, 2016). In addition, as the United States and China have different forms of government, and regulate their energy and industrial markets in different ways, there are likely to be some differences in what each regards as the priority actions to be taken. Despite the cancellation of the GBP 1 billion CCS competition for budgetary reasons in 2015, the United Kingdom was chosen as a focus because it continues to have a strong national-policy framework that could facilitate CCS deployment should budgetary pressures ease. Moreover, the United Kingdom's approach can serve as an excellent model for other countries. Finally, Australia was selected because it is the leading seaborne-coal exporting nation. It is already undertaking several unique CCS projects that can inform CCS deployment in other countries.

Stimulate Market Update	Power Purchase Agreements
	Product Purchase Agreements
	Policy Parity in Portfolio Standards
	Policy Parity in INDCs and Article 6 Carbon Markets
	Technology-Transfer Support
	Price on Carbon
Support Project Development	Project-Development Grants
	Streamlined Permitting
	Land-Rights Access
	Long-term CO_2 Liability Transfer
	Hub Transport/Storage Infrastructure
	Transport/Storage Safety Valve
Enable Capital Investment	Improve project economics • CAPEX buy-downs • Accelerated depreciation • Investment and production tax credits • CO_2 price stabilisation • CCS emissions trading
	Improve access to capital • Loan guarantees • Completion guarantees • Preferred bonds • Development-bank financing • Green Climate Fund
Advance Next-generation CCS Technologies	R&D Tax Credits
	R&D Grants
	Pilot- and Commercial-Scale Projects
	Storage-Resource Characterisation

Table 1. CCS Policies to Enable a Low-Carbon Energy Future

Priority Actions to Enable CCS Deployment in the United States

In 2016, fossil fuels provided 81% of energy consumption in the United States, (DOE EIA, 2017), where they are affordable and reliable. They underpin the generation of electricity, residential and commercial heating, industrial use, and transportation infrastructure. Given that the majority of economic activity relies upon fossil-fuel infrastructure, it is in the country's strategic interest to secure an orderly transition to a low-carbon energy future that incorporates CCS technology.

Current Status of CCS

The United States has been at the forefront of developing large-scale CCS projects, with nine large-scale projects in operation (GCCSI, 2016). Of particular note, the world's largest post-combustion capture project, Petra Nova, commenced commercial operations at a coal-fired power plant in Texas during 2017. These nine projects represent more than 50% of the world's operating CCS projects. Eight of them involve utilisation of the captured CO_2 in enhanced oil recovery (EOR). The remaining project involves dedicated geologic storage. While these projects represent a significant accomplishment, the prospects for the next wave of large-scale CCS projects is uncertain owing to recent structural factors, such as uncertainty regarding United States climate policy; reduced government co-funding for innovative CCS projects, which has shifted increased risk to industry when market-based returns at present do not justify carrying of such risk; and lower world oil prices, which have decreased the market value of CO_2 for use in EOR, and have reduced the financial incentive to capture CO_2.

As a consequence, short-term market conditions are driving private-sector investment away from investment in CCS and associated technologies that would reduce emissions at many coal-fired power plants, notwithstanding that development of such technologies is essential in a carbon-constrained world. These conditions could quickly turn more favourable with well-designed CCS policies. In the current political and market environment, CCS policies are only likely to be successful if they are incentive-based, rather than mandatory. Furthermore, and as has been achieved with renewables, such policies must also be well designed so that investors can earn a market-based return on their investment in CCS projects.

Most potential industrial applications for CCS (e.g. steel, cement, petrochemical processes) involve producing products that are sold on a free-market basis where being cost-competitive is a prerequisite. Therefore, unless carbon capture is essential to product quality (e.g. natural-gas purification), or provides offsetting revenue streams (e.g. CO_2 sales revenue), it will be too costly to implement. Consequently, incentives must be well designed in order to offset the incremental cost of CCS as well as any incremental commercial risk created by CCS (e.g. added process complexity or reduced process availability).

Although some segments of the electricity sector (e.g. industry self-generation for consumption and merchant-power generation) also operate on a free-market basis, a significant segment of US power generation is owned by rural electric co-operatives, municipalities, and regulated utilities. In the case of regulated utilities, there may be some mechanisms available for recovering a portion of the higher cost of CCS-enabled power generation if state governments (e.g. state public-utility commissions) approve cost recovery. In all cases, CCS deployment would expand if well-designed incentives were in place – much like wind deployment expanded substantially once incentives (e.g. the wind production tax credit) were made available.

With regard to CO_2 utilisation for EOR and CO_2 storage, private ownership constitutes a large portion of sub-surface storage and mineral rights in the United States – unlike in many countries, where governments own sub-surface rights. Frequently, however, sub-surface ownership has been separated from overlying surface ownership. In addition, governments (federal, state and local) and tribal nations are major property owners in many parts of the United States. For CCS policy to be effective, it must work effectively in all these property-ownership circumstances.

In the United States, there has been strong governmental commitment to renewable-electricity generation. This commitment, which takes the form of numerous state and federal policies, is successfully addressing market barriers and the added cost of renewables. The National Coal Council (NCC), an advisory body to the US Secretary of Energy, has evaluated the differences in federal incentives for renewable-electricity generation versus electricity generation with CCS. The differences are striking; as a result, the NCC has recommended that policy parity be created so that both low-carbon technologies (i.e. renewables and CCS) have an equal opportunity to advance in the marketplace (see Table 2) (NCC, 2015).

The Petra Nova carbon-capture system, including co-generation unit (left), at the WA Parish generating station (coal-fuelled units 6, 7 and 8 visible behind the system). (Image credit: NRG)

United States Renewable Electricity-generation Incentives vs CCS-enabled Fossil-fuel Electricity-generation Incentives

In its November 2015 report, "Leveling the Playing Field: Policy Parity for Capture Capture and Storage Technologies", the National Coal Council (NCC, 2015) evaluated incentives for renewable-electricity generation compared with CCS-enabled electricity generation.

INCENTIVE	RENEWABLES	CCS
DOE Budget (2012-2016)		
FY2016 (Requested)	$645 million	$224 million
FY2015	$456 million	$188 million
FY2014	$450 million	$200 million
FY2013	$480 million	$186 million
FY2012	$480 million	$182 million
Total DOE Budgets:	$2.5 billion	$980 million (CCS Demonstration: $0)
Tax Credits (2010-2014)		
Investment Tax Credit	$2.1 billion	$1 billion
Production Tax Credit	$7.6 billion	$0
ARRA §1603 Grants in Lieu of Credit	$7.6 billion	$0
Investment in Advanced Energy Property	$2.1 billion	$0
Accelerated Depreciation for Energy Property	$1.5 billion	$0
Total Revenue Cost	$37.3 billion	$1 billion
Other Federal Programmes		
Loan Guarantees (EPAct '05 §1703)	Yes ($13.9 billion)	Yes
Mandatory Purchase (Requirement (PURPA § 210	Yes	Yes
Clean Energy Credits (EPA, 111(d) Existing Power Plant Rule)	Yes	No
State Programmes		
Net Metering	44 States	0 States
Renewable Energy Standards	29 States	5 States (CCS applied to standard; 0)

Table 2. Incentives for Renewable Electricity vs CCS-enabled Electricity

Summary of Priority Actions

In contemplating the portfolio of policies the CIAB previously recommended all countries consider, and the current United States political and market environment, priority actions the US government could take to advance CCS technology include:

1. Enact pending federal legislation and take administrative action that stimulates market uptake of CCS, supports CCS project development and enables CCS capital investment.

2. Amend the United States policy position for development-bank financing such that it supports funding for CCS projects.

3. Expand efforts to advance next-generation CCS technologies, with a focus on cost-shared industrial-scale projects, as well as on strategic RD&D.

4. Advance the international dialogue on climate change and fully recognise that the continued use of fossil fuels, in combination with CCS technology, is essential to the lowest cost, low-carbon energy future.

These four actions by the federal government would keep the United States on a pathway to expanded CCS deployment and sustain its leadership position on CCS. These actions would also motivate state governments to adopt complementary policies and stimulate private-sector investment in CCS.

Explanation of Priority Actions

1. Enact federal legislation and take administrative action that stimulates market uptake of CCS, supports CCS project development and enables CCS capital investment

In the United States, there is substantial political support for CCS. This is particularly so when it is coupled with the utilisation of CO_2 in EOR. As a result, an opportunity exists for federal action in this regard, including the creation of economic incentives, regulatory streamlining, increased accessibility to federal-controlled land, and the creation of a long-term-liability management framework. All of these actions would incentivise CCS deployment. Examples of specific legislative or administrative actions that could be taken include:

- Authorise refundable tax credits for the utilisation of captured CO_2 in EOR or for geologic storage. Specifically, the 45Q reforms should increase the tax credit for CO_2 storage to a minimum of USD 50/ton, and the tax credit for CO_2-EOR to a minimum of USD 35/ton, as well as increase the aggregate cap and period of availability for the existing 45Q credits.
- Authorise refundable investment- and production-tax credits for CCS projects, including associated efficiency upgrades.
- As part of national infrastructure investment legislation, provide federal funding for cost-shared CCS-related projects, including CO_2-pipeline infrastructure that connects areas with multiple CO_2 sources to areas suitable for EOR operations and storage.
- Through legislation [and/]or administrative action, provide the Department of Energy (DOE) with the direction and authority to issue cost-shared pre-construction CCS-project development grants in order to increase the number of CCS projects in the development pipeline.
- Develop an expedited process for federal agencies to make federal land rights available for CO_2 storage, CO_2-enabled EOR, and CO_2-pipeline routing.
- Through legislation, create a process for the assumption of long-term CO_2 liability for storage sites that have met federally-mandated storage-permit closure requirements.
- Provide loan-guarantee authority, specifically for CCS projects, to the DOE at a level that is equivalent to that provided to renewables.
- Authorise the DOE to provide completion and performance guarantees on CCS projects, which would facilitate private-sector capital investment in first-of-a-kind CCS projects.

2. Amend the United States policy position for development-bank financing such that it supports funding for CCS projects

The United States has an opportunity to shape the policy of the World Bank and other development banks of which it is a member, such as the Asian Development Bank (ADB), to ensure bank policies treat CCS technology on a par with other low-carbon electricity-generation technologies. Considering the many benefits, the incremental costs associated with building high-efficiency coal-fired power plants with emission controls that are CCS-ready, CCS-enabled power plants, and CO_2-transport and -storage infrastructure should be supported by the World Bank and other development banks. The United States should also join in with other bank member countries with similar policy interests in shaping development-bank policies.

3. Expand efforts to advance next-generation CCS technologies, with a focus on industrial-scale demonstrations, as well as on strategic RD&D.

In the United States, the DOE's traditional role in the development of next-generation technology is principally in co-funding technology RD&D projects. These are funded through an annual funding process. Over a recent five-year period, funding for CCS averaged approximately USD 200 million per annum. For the same five-year period, appropriations for renewables averaged approximately USD 500 million per annum. As part of 2008 economic stimulus funding, CCS received USD 2.4 billion, whereas renewables received USD 17 billion in appropriated funding.

Particularly in light of the greater economic leverage that CCS provides relative to other low-carbon technologies in achieving long-term climate goals, there should be parity between RD&D funding for renewables and CCS. RD&D should focus on transformative technology (e.g. novel, low-cost capture or energy-conversion technologies), and on pre-competitive RD&D where there is not a clear line of sight to private-sector financial returns (e.g. basin-level geologic characterisation).

Demonstration funding should be distributed across low-carbon technologies proportional to the scale and cost of projects required to demonstrate commercial viability. As a general rule, CCS-technology demonstrations need to be larger in scale (e.g. 50-500 MW or 1 Mtpa of CO_2 per annum) than demonstrations for some other low-carbon technologies.

4. Advance the international dialogue on climate change concerns; ensuring that the dialogue and any future formal agreements fully recognise that the continued use of fossil fuels, with CCS technology, is essential to the lowest cost low-carbon energy future.

The cost of meeting emission limits associated with international climate goals is measured in tens of trillions of dollars. That cost more than doubles if CCS is not widely deployed. Yet, in recent international climate discussions, most countries did not mention CCS in their formal NDCs under the Paris Agreement. While the United States has announced its intention to withdraw from the Paris Agreement, the United States government has made it clear that it will continue participating in the international dialogue on climate change and developing CCS technology. The United States (public and private sectors) should drive forward a positive global message that "an international commitment to CCS" is a prerequisite to United States participation in any future formal agreements on climate change.

Outcomes

Adopting these recommendations and the associated policies before 2020 would:

- Create an incentive-based market environment where the private sector can bring forward substantial CCS deployment investment.
- Advance the United States' ability to meet its energy needs through the use of domestic low-carbon energy, while simultaneously addressing environmental concerns.
- Advance technology that can significantly reduce CO_2 emissions from steel manufacturing, cement production, natural gas-fired power generation, and other industrial processes.
- Facilitate the development of CCS-enabled bioenergy, including biomass co-firing of coal-fired power plants.
- Increase the United States' energy- and clean-energy-technology exports.

Priority Actions to Enable CCS Deployment in the United Kingdom

The 2008 Climate Change Act not only committed the United Kingdom to reduce emissions by at least 80% from 1990 levels by 2050, but also established an independent, statutory body known as the Committee on Climate Change (CCC) to advise the government on setting and meeting emission-reduction targets. The CCC's 2015 report concludes:

Carbon capture and storage (CCS) is likely to be a crucial part of the least cost path to decarbonisation in the [United Kingdom], and globally..... CCS also has a crucial role in decarbonising heavy industry where there are limited options, and in the longer term would help to maximise the emissions reduction obtained from scarce supplies of sustainable bioenergy as well as opening up other decarbonisation pathways (CCC, 2015).

In 2016, the government approved the CCC's fifth carbon budget, covering 2028 to 2032, with a legally binding emission limit of 1,725 $MtCO_2e$. The latest carbon budget expects deployment of CCS by 2025, with rapid uptake from the 2030s (UKCCSRC, 2016). Modelling by the Energy Technologies Institute (ETI), a public-private partnership between global energy and engineering companies and the government, indicates that delaying CCS deployment would incur a cost of around GBP 1 billion to GBP 2 billion per year from 2020 onwards. Furthermore, removing CCS as a technology option would raise the cost of meeting the 2050 target by more than 2% of gross domestic product (GDP) every year. It was also noted that models considering alternative generation sources, including energy storage, could not adequately meet electricity demand 24 hours per day, 365 days per year (UKCCSRC, 2016).

Current Status of CCS

Successive governments have therefore delivered policies that have attempted to develop CCS. The most notable of these has been the CCS Commercialisation Programme announced in 2012. GBP 1 billion of capital funding was to be made available for two preferred bidders: White Rose (a coal oxy-fuel project) in Yorkshire, and Peterhead (a gas project) in Aberdeenshire. In addition to the capital funding, policy support would provide operational revenue through 'Contracts for Differences' – a subsidy that had worked to bring renewable technologies through to greater commercialisation in the UK.

Despite appearing in the Conservative government's election manifesto of 2015 (Conservative Party, 2015), the Chancellor's 2015 Autumn Statement withdrew the availability of the GBP 1 billion capital budget for the competition. The decision resulted in both projects failing to continue to the next stage of development. A report by the National Audit Office following the decision highlighted concern in investor confidence owing to the lack of long-term policy commitment and financial concerns, particularly in the context of wider austerity. Equally, the report noted that many stakeholders continued to regard CCS as 'critically important to the UK achieving its decarbonisation target' (NAO, 2017).

Although the funding withdrawal resulted in a failure of 'full chain' CCS to advance – from generation to storage – it was noted in a report prepared for the CCC that the commercialisation programme created opportunities for rapid deployment if appropriate support were put into place. These assets included: 'well characterised storage ready for development, a detailed appraisal of capture technologies and costs and a significant body of knowledge around the creation of successful commercial arrangements for CCS' (Poyry, 2016).

Similarly, the report also noted that the United Kingdom possesses some of the best potential sites for carbon storage in Europe (Poyry, 2016), with surveys suggesting CO_2 offshore-storage potential of 78 billion tonnes (Deloitte, 2016). The exceptionally large capacity of storage provides opportunities not just for local industries, but also as an export-earning industry taking CO_2 from across Europe. According to the Zero Emissions Platform, exporting capacity has the potential to support GBP 1 trillion in pan-European savings (Poyry, 2016), further enhancing the United Kingdom economy's existing low-carbon credentials.

A compelling case for the development of CCS in the United Kingdom remains. Looking ahead, it falls to government to devise a support framework, with industry input, that addresses barriers and market failures that have led to restrictions in the development of CCS. This will require a two-pronged approach, with early-stage development of transport- and storage infrastructure and incentive regimes in the United Kingdom and, secondly, complementary collaboration with partner countries, particularly in Asia, where fossil-fuel use is projected to continue to rise. The international element of CCS policy is especially critical as the United Kingdom seeks to negotiate its position outside of the European Union.

Summary of Priority Actions

In contemplating the portfolio of policies recommended for consideration by the CIAB (see Table 1) and the United Kingdom political and market environment, as described, priority actions for the United Kingdom include:

1. Develop a renewed CCS strategy that delivers transport and storage infrastructure.
2. Establish a transparent incentive regime, with the goal of storing a growing percentage of CO_2.
3. Increase funding for RD&D, particularly in the areas of cost reduction and improvements in existing technologies.
4. Advocate internationally for CCS:
   a. Enhance support for CCS in international forums, including financing opportunities.
   b. Promote deployment through dedicated international aid, and mobilise other donors to follow.

Explanation of Priority Actions

1. Develop a renewed CCS strategy that delivers transport and storage infrastructure

The cancellation of the Commercialisation Programme has left the UK without an explicit funding mechanism for developing CCS. Of equal concern, stakeholders involved in the competition were critical of the manner in which the competition was cancelled and suggested at an evidence session held by the House of Commons Energy and Climate Change Committee that it had significantly damaged investor confidence in the United Kingdom energy market (House of Commons, 2016).

The withdrawal of capital funding has set development back; however, the evidence continues to show a requirement for CCS in the near future. As such, an updated CCS strategy should be delivered as a matter of priority. The absorption of the Department of Energy and Climate Change into the new Department for Business, Energy and Industrial Strategy (BEIS) has the potential to provide greater opportunities for CCS deployment through closer co-ordination of climate, energy and industrial policy. An updated strategy is particularly important as the United Kingdom withdraws from the European Union, as it will send a signal of stability in the energy and climate change policy framework.

An updated CCS strategy should articulate realistic milestones against the carbon budget, be holistic (considering CCS for industry and energy), and detail a credible delivery plan. Industrial, social, geological and geographic elements must be considered. Rather than focusing on 'full chain' delivery, the BEIS should drive transport- and storage-enabling activities that focus on reducing the cost of deployment. In the recent past, market failures in infrastructure investment have been resolved through a mixture of public-private partnerships, with government providing fiscal incentives and market-creation mechanisms. Adopting this approach for CO_2 transportation and storage infrastructure would promote suitable risk allocation, reduce storage liabilities that would be unpalatable in the private sector, and ensure geographically appropriate infrastructure to allow clusters of potential sites to connect. For instance, government grants could be awarded through competitive procurement to encourage appraisal activity. This would provide vital cost and size data on storage sites that are, in turn, necessary prerequisites for private-sector stakeholders to develop sufficiently detailed proposals for evaluation by public-sector bodies, financiers and industry. Table 3 provides several other examples of government interventions that could comprise a CO_2-transportation and -storage framework to establish a United Kingdom CCS industry (Goldthorpe, 2016).

Intervention type	Intervention options
Financial incentives	• Direct revenues under carbon-penalty frameworks • Direct payments under low-carbon subsidy frameworks • Centralised funding models for transport and storage • Capital grants for storage characterisation • Purchase guarantee by government • Capacity payment by government
Tax breaks	• Cross-sector tax breaks • Sector-specific tax breaks (targeting hubs)
Market creation	• CO_2-storage liability aggregation • Options contracts for transport and storage • Leasing rounds for options over storage sites • Long-term storage-capacity auctions
Knowledge generation	• Public-engagement programme • RD&D on CO_2 storage and monitoring

Table 3. Example Intervention Options (Goldthrope, 2016)

2. Establish a transparent incentive regime, with the goal of storing a growing percentage of CO_2

In 2016, the government announced a consultation to "set out the proposals to close coal-fired power generation by 2025 – and restrict its use from 2023". The rationale for the decision was based on the carbon intensity of coal compared to other fuels, including natural gas. In reality, however, the CCC's modelled scenarios show that an average intensity below 100 gCO_2/kWh for all United Kingdom power generation by 2030 would be required to allow the United Kingdom to meet its legally binding 2050 emissions target. This remains four times lower than the carbon intensity of unabated gas in combined-cycle gas turbines (House of Commons 2016b). The only practical way to close this gap will be rapid CCS deployment on fossil-fuel and industrial applications.

Following the necessary regulatory and policy incentives that deliver transport and storage infrastructure, the government should develop policies that incentivise operators to sequester a growing percentage of the CO_2 associated with their activities, and designed to recognise the 100g CO_2/kWh 2030 target. Realisation of this outcome, however, will depend on a significantly enhanced incentive regime.

Generators and industrial emitters require transparency in the quantum and terms of the support framework for capturing CO_2. The proposed feed-in-tariff contract-for-difference (CfD) was cited as a particular strength of the cancelled competition. The CfD would have ensured that the projects received a long-term guaranteed price for every unit of electricity generated. Following the cancellation of the competition, uncertainty remains over the potential for CCS eligibility for future feed-in-tariff incentives. In the Spring Budget of 2017, the government announced that the Levy Control Framework, which includes the CfD policy, would be replaced by a new set of controls in the near future. It is vitally important that the updated policy include price-support mechanisms for CCS in order to guarantee sufficient returns to CCS plant operators and make projects bankable. BEIS must work to ensure that there is adequate consultation before developing any policy so as to take into account CCS stakeholder input, including particular emphasis on those involved in the White Rose and Peterhead projects and the lessons learnt there, as well as the inclusion of relevant stakeholders, such as the offshore oil and gas sector.

A well-developed incentive regime – with necessary transport and storage infrastructure – would effectively close the gap towards CCS commercialisation and ensure the United Kingdom meets its legislated carbon-reduction targets. A mature CCS industry could also broaden United Kingdom energy options, including near-zero-emissions gas and coal.

3. Increase funding for RD&D, particularly in the areas of cost reduction and improvements in existing technologies

As demonstrated with solar photovoltaics and wind, energy technology has developed along a relatively standard track: nascent technology costs are typically high; technological development and efficiencies are realised through RD&D; and costs fall through product innovation and efficient processes delivered through the learnings from RD&D, as well as economies of scale and learning through deployment. Evidence to date demonstrates that CCS is no different, given the barriers facing greater deployment are commercial and political, not technical.

CCS research in the United Kingdom has benefited from European Union funding, including Framework Programme 7, Horizon 2020, the NER 300 scheme and the European Energy Programme for Recovery. The impending exit of the United Kingdom from the European Union has created uncertainty regarding future European research allocations. The United Kingdom should seek continued RD&D co-operation with European partners post-Brexit. For example, the government should aim to remain a member of the European Research Council, while simultaneously raising domestic support.

Priority research should focus on identifying opportunities that can best deliver reduced costs and improve existing technologies. Core areas of research could include: net-negative emissions via biomass energy with CCS (BECCS), including co-firing with coal; next-generation capture technologies; and CO_2-utilisation EOR and niche applications in limited cases. To this end, the United Kingdom has a demonstrated record of delivery in CO_2-utilisation research. One notable example is Imperial College London's collaboration with Anglo-Indian firm Carbon Clean Solutions; a small-scale project that captures CO_2 emissions from a coal boiler and uses the CO_2 in products to produce a revenue stream. This technology was developed with GBP 4.2 million of seed funding from the United Kingdom government. Investing in CCS research and innovation both in the United Kingdom and abroad could be a significant enabler of future deployment.

4. Advocate internationally for CCS

A clear CCS strategy should also promote CCS internationally, linking United Kingdom CCS stakeholders with international markets to understand needs and advance deployment in other economies. In addition to boosting CCS deployment potential internationally, this would promote opportunities for the United Kingdom to become a service-sector specialist for CCS in areas in which the economy already leads, including finance, insurance, law, consulting and accounting support services. A recent study estimates United Kingdom low-carbon services have the potential to grow at annual rates of up to 15% in the period up to 2030 (Ricardo, 2017). CCS could play a significant part in this outcome.

a) The United Kingdom should enhance support for CCS in international forums, including financing opportunities

Given that CCS technology is at a relatively early stage of deployment, United Kingdom energy and climate policymakers should adopt stronger positions in international forums to address barriers and facilitate the expansion of CCS markets to promote the global potential for deployment. The United Kingdom should work to promote the role of CCS as a vital low-carbon technology, alongside other low-carbon technologies, through the influential role that it plays in key international institutions such as: the World Bank, the Asian Development Bank (ADB), the Asian Infrastructure Investment Bank (AIIB), the G20 and G7, the Clean Energy Ministerial, the Carbon Sequestration Leadership Forum, and the Global CCS Institute. As a matter of priority, the United Kingdom should make the case for a multilateral development fund assessment that considers the economic, environmental and energy-security importance of CCS through comparative analysis against other mitigation technologies.

Using the outcomes of this assessment as a basis, the UK should also seek to form a coalition to consider more diverse funding proposals, including special provision for CCS. To date, international financial initiatives, such as the Clean Technology Fund, have characterised CCS as being in the pre-commercial phase – thereby denying funding in favour of renewable and efficiency proposals. This has happened despite CCS operating at scale in 17 projects globally and its being identified as an eligible low-emission technology in the Clean Development Mechanism. Specific CCS-funding provisions could stimulate pilot or demonstration projects, as well as setting an important precedent among other delivery partners.

United Kingdom policymakers involved in climate and energy negotiations should seek opportunities to share knowledge with international counterparts, especially in finance and aid departments. Encouraging developing countries to identify a role for CCS in their NDCs and long-term climate-mitigation plans will promote opportunities for CCS pre-investment and enabling activities and ultimately strengthen its long-term deployment potential.

Large-scale deployment of CCS technologies will be dependent on encouraging the regulatory frameworks necessary for deployment and developing a group of experts that have familiarity and understanding of the technical feasibility of CCS. In practice, this will mean securing government buy-in; ensuring funding is in place for the full costs of projects; initiating public engagement to de-mystify CCS; and collaborating with key stakeholders to learn lessons from other projects.

b) Promote deployment through dedicated international aid and mobilise other donors to follow

In response to recommendations at the Third Clean Energy Ministerial, the United Kingdom government has been a leading contributor to CCS-enabling and pre-investment activities in developing countries. The United Kingdom channelled its GBP 60 million contribution through the ADB (GBP 35 million) and the World Bank (GBP 25 million). The most recent annual review of the investment noted the programme represented "value for money in terms of achieving objectives" (DECC, 2016). The report added "the potential reward of success is high – as the current evidence presents a clear case that CCS is a critical 'transformative' technology". Consistent with this view, the Programme's Annual Review identified the Roadmap for Carbon Capture and Storage Demonstration and Deployment in the People's Republic of China (ADB, 2015) as particularly notable, with its recommendations being considered for incorporation into medium- to long-term development plans.

Given this success, the government should seek to engage in mobilising greater levels of multilateral support for CCS knowledge-sharing, capacity development and, ultimately, project development. International financial institutions will remain the best avenue of delivery as they provide the best forum to promote returns to scale and a platform for the synthesis of experience. In addition to existing ADB and World Bank channels, the United Kingdom's recent accession to the AIIB provides further partnership opportunities for both donors and developing countries.

Moreover, mobilising higher levels of finance would be an early step in securing the forecasted USD 5 billion that will be required to support pre-investment and enabling activities through the World Bank CCS Trust Fund for the construction and operation of additional pilot-scale projects in developing countries (GCCSI, 2013).

Outcomes

Adopting the preceding recommendations will be vital to delivering the level of CCS infrastructure that will be required by 2030 in order to meet the 2050 emissions targets and climate goals mandated in the Climate Change Act. The implications of action are clear:

- CCS has the potential to bring significant decarbonisation opportunities to the power, industrial, heating and transport sectors which represent around 83% of the UK's total carbon dioxide emissions (House of Commons, 2017).
- According to the CCC, a 10-year delay to CCS deployment across the UK economy would significantly increase the cost of decarbonisation, with government projections suggesting an additional GBP 1 billion to GBP 2 billion cost per year in the 2020s, rising to between GBP 4 billion and GBP 5 billion per year in the 2040s (House of Commons, 2017).
- Forecasts suggest that a developed CCS sector could create between 15,000 and 30,000 jobs by 2030 (CCSA, 2014). In addition, CCS deployment in the industrial sector would secure the long-term future of carbon-intensive industries (e.g. steel, chemicals, and cement), particularly in areas of the UK which have suffered from deindustrialisation over recent decades. A developed CCS industry could be a driver of the UK government's 'Northern Powerhouse' and 'Industrial Strategy' initiatives.
- Maintain the UK's competitive advantage as a low-carbon economy. A recent report by the House of Commons Committee of Public Accounts detailed how the decision to cancel the CCS competition was reminiscent of the government's decision in the 1980s not to develop renewables (House of Commons, 2017). CCS presents a key opportunity area for technology stakeholders to act as effective low-carbon innovators, as well as in the high-value service sector, to develop niche capability.
- Promote a diversified and stable energy mix in the UK, including opportunities for fossil-fuel generation with emissions rates in line with mandated targets.

Priority Actions to Enable CCS Deployment in Australia

Fossil fuels are a major contributor to the Australian economy. They are an essential energy source for industry, underpin the generation of electricity and are the country's principal source of export revenue. Australia is the world's largest coal exporter and second largest LNG exporter; as such, it has the potential to be a global leader in the deployment of CCS.

CCS will become critical to Australia's export/use of fossil fuels and the jobs and investment they provide. It is the most viable technology to reduce emissions from the existing fossil-fuel-fired generation stock, locally and globally. It will also be required to help decarbonise energy-intensive industries that depend on the continued use of fossil fuels.

The current status of CCS

Australia has undertaken a range of CCS initiatives over the past decade. While investment has recently slowed, the country is still very active in CCS RD&D and project activities.

Australia has well-developed legislation for the secure geological storage of greenhouse gases in the offshore environment. A legislative framework for storage in the on-shore environment exists[3], but needs further development and/or testing to assess individual state needs, for example regarding pre- and post-injection monitoring.

Work to develop a basic knowledge of prospective CO_2-storage sites has been undertaken on a pre-competitive basis by the federal and state governments. This knowledge helps to inform government decisions on the release of suitable greenhouse-gas exploration acreage. More pre-competitive work is being undertaken in a number of basins and is designed to encourage take-up for commercial exploration and development under appropriate CCS legislation.

Australia, in collaboration with Japan, has successfully demonstrated oxy-fuel combustion technology with carbon capture, in a commercial operating environment at the Callide power station.

Australia is an active member of key multilateral forums for advancing CCS technologies, including the Global CCS Institute, the Carbon Sequestration Leadership Forum, and bilateral partnerships to advance the development and deployment of CCS. This helps ensure that Australia is efficiently and sensibly engaging in a co-ordinated global effort.

Australia is pursuing a number of CCS-enabling projects:

- In Western Australia, the Gorgon CO_2 Injection Project[4] will be the world's largest injection project permitted, injecting and storing approximately 3 Mt of CO_2 per year.
- In Queensland's Surat Basin, the Carbon Transport and Storage Company[5] (CTSCo) integrated CCS project is now at the front-end engineering and design (FEED) stage for a post-combustion capture plant with CO_2 injection. It is being led by industry, with additional government funding support. The complementary University of Queensland Surat Deep Aquifer Appraisal Project[6] is at the pre-competitive data-acquisition stage.

[3] *See: https://hub.globalccsinstitute.com/publications/offshore-CO_2-storage-legal-resources and https://hub.globalccsinstitute.com/publications/onshore-CO_2-storage-legal-resources.*
[4] *https://www.chevronaustralia.com/docs/default-source/default-document-library/fact-sheet-gorgon-CO_2-injection-project.pdf?sfvrsn=16*
[5] *http://ctsco.com.au/*

- In Victoria's Gippsland Basin, the CarbonNet project[7] is government-funded and is at the data-acquisition stage, with a view to encouraging private-sector participation and identifying commercial storage volumes.
- New South Wales' Darling Basin storage studies[8] involve government-funded exploration and pre-competitive data acquisition.
- Western Australia's South Perth Basin Southwest Hub[9] studies involve government-funded exploration and storage-reservoir definition.

Pilot post-combustion capture programmes have also been conducted at a number of power stations in Australia to assess the process on both brown and black coals and to optimise operating parameters. The behaviour of various sorbent systems has been monitored, along with other novel separation technologies such as membranes and adsorbents.

In addition, Australia hosts two internationally important research initiatives:

- Australian National Low Emissions Coal R&D: a national research and technical-services initiative to accelerate CCS deployment across several Australian CO_2-storage basins for large-scale demonstration of low-emission coal technologies; and
- Otway Pilot Storage: 65,000 tonnes of naturally occurring CO_2 has been compressed and transported two kilometres by pipeline and injected into a depleted gas reservoir; saline-formation storage experimentation is currently under way. The next phase will include validation of advanced monitoring- and storage-management processes and technologies.

Australian industry's funding model to advance low-emission coal technologies

In 2007, the Australian black-coal industry established the COAL21 initiative to generate funding for CCS and other low-emission coal technology (LECT) projects. COAL21 co-invests with other stakeholders (government, electricity generators, equipment suppliers and other investors), complementing similar international efforts. It is funded by a voluntary, equal levy on coal production. The COAL21 Fund has so far committed AUD 300 million to projects.

COAL21 and the Australian government jointly fund the AUD 150 million Australian National Low Emissions Coal R&D (ANLEC R&D) programme – a unique research initiative. ANLEC R&D's mission is to help reduce the investment risk associated with the demonstration of LECT in Australia, thereby accelerating the technology-development cycle. It provides independent and objective analysis, data and expertise to assist in fast-tracking the design, permitting and operation of LECT plant using Australian coals.

COAL21 also supports the CO_2CRC, which aims to develop CCS as a socially, technically and commercially viable option. Its AUD 100 million Otway Research Facility is one of the world's leading research and geo-sequestration demonstration projects involving injection, storage and monitoring of CO_2.

[6] *https://www.researchgate.net/project/CO_2-Storage-in-the-Surat-Basin-Deep-Aquifer-Appraisal-Project*
[7] *http://earthresources.vic.gov.au/earth-resources/victorias-earth-resources/carbon-storage/about-carbon-capture-and-storage/the-carbonnet-project*
[8] *http://www.resourcesandenergy.nsw.gov.au/energy-consumers/energy-sources/coal-innovation-nsw/research-projects/nsw-CO_2-storage-assessment-project*
[9] *http://www.dmp.wa.gov.au/South-West-Hub-CCS-1489.aspx*

Summary of Priority Actions

An aerial view of the Callide oxyfuel plant, Queensland, Australia (Image Credit: Callide Oxyfuel Project)

A key objective for Australia should be closing the gap between CO_2-reduction ambitions and current emissions.

Australia's NDC involves a reduction of 26% to 28% below 2005 levels by 2030. This can be seen as a first step, as it only extends to 2030 and CCS is not currently included. The Paris Agreement should provide fresh impetus to efforts in Australia and globally to deploy CCS. As NDCs are reviewable periodically, there is an opportunity for Australia to add further initiatives into its NDC over time. CCS is paramount if Australia is to achieve its ambitions in 2030, 2050 and beyond at the lowest-possible cost. The inclusion of CCS would also help ensure that the requisite CCS infrastructure becomes available over time, consistent with achieving the country's CO_2-reduction ambitions.

In order to achieve this outcome, the following specific priority actions should be taken:

1. Implement additional policies to promote CCS investment by government and industry.

2. Promote and develop CCS-technology demonstration projects which are industrially-scalable.

3. Adopt an energy policy that is inclusive of low-emission coal technologies to ensure Australia's energy security.

Explanation of Priority Actions

1. Implement additional policies to promote CCS investment by government and industry

A national strategy is needed that draws Australia's CCS initiatives together, including[10]:

- Further CO_2 storage characterisation to assist in building investment-ready confidence in storage resources.
- Sufficient planning for strategic, large-scale CO_2-storage and pipeline infrastructure hubs and networks.
- Aligning national and state legal and regulatory frameworks, and stress-testing these (e.g. with the Global CCS Institute's Regulatory Test Toolkit[11]).
- Monitoring international CCS deployment to ensure Australia's activities complement these.
- Regular techno-economic assessments along the CCS value chain (e.g. to update carbon storage mapping).
- Securing continuing support through public engagement and integrated projects. To achieve this:
  - CCS should be included in a much broader campaign of education and engagement of the public around energy and the environment.
  - An industrially scalable CCS project will be necessary.

2. Promote and develop CCS technology-demonstration projects, which are industrially scalable

- An example of an industrially scalable project is the Surat Basin Hub proposal, which builds on the current CTSCo project[12]. Initially, the emphasis is on proving the viability of storing CO_2 in the

[10] Further details are provided in Greig (2016).
[11] https://www.globalccsinstitute.com/publications/carbon-capture-and-storage-regulatory-test-toolkit
[12] CTSCo's Integrated Surat Basin CCS Project is sequenced in up to four stages to deliver the lowest-risk and lowest-cost pathway to industrial-scale CCS deployment in the Basin.

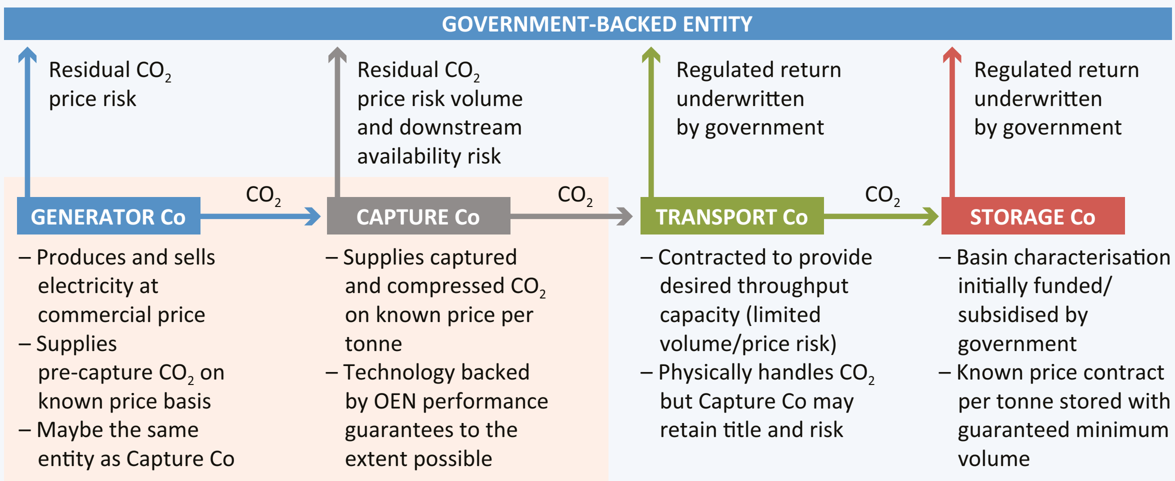
Surat Basin, while also increasing certainty in the most prospective areas for commercial-scale developments. In the future, a post-combustion capture-equipment module will be added to an existing coal-fired power plant in Queensland to capture a portion of the plant's emissions. The CO_2 will be transported to the Surat Basin. Subsequently, additional equipment modules could be added to the plant to capture larger volumes of CO_2. Looking further ahead, with three supercritical power stations and other industrial sources within 250 kilometres of Surat Basin reservoirs, other sources could ultimately be added to utilise Surat Basin storage. Initial testing of a single pulverised coal combustion (PCC) module reduces the cost of the project, while providing confidence that the technology can be deployed at full industrial scale.

- Similarly, the CTSCo storage site is at the 'shallow' northern end of the Surat Basin, where smaller amounts of injected CO_2 can be visualised and plume development monitored. The site could be used for a further 20 years of injection, if required. In the longer term, the deeper southern end of the basin shows excellent prospects for commercial-scale storage volumes.
- As with other low-emission technologies, governments have a role in supporting initiatives to allow CCS technologies to reach a commercial stage. This will necessitate significant public funds, with industry and other stakeholders being required to share in project costs.

3. Adopt an energy policy that is inclusive of low-emission coal technologies to assure Australia's energy security

- CCS must become available in Australia's energy mix so that future emissions reduction targets are delivered at the lowest economic cost without compromising energy security and reliability. Policy approaches should focus on lowering emissions by supporting CCS, high-efficiency low-emission (HELE) and other low-emission fossil-fuel, renewable and hybrid technologies. This will require an even-handed technologically agnostic approach to developing low-emission energy sources to ensure that sufficient, affordable and reliable baseload power is available.

A possible business model for incentives



A potential arrangement between corporate operators with four CCS components. The government would have risk-backstop arrangements with each company to support project returns. This crucially limits each company's exposure to the operational performance of other elements in the chain.

Source: Greig, 2016

Outcomes

By adopting the above actions, over the next 10 years Australia can realise a secure energy future built on the use of domestic fossil fuels enabled with CCS. Through joint government and industry efforts, Australia would be able to:

- Retrofit post-combustion technology to a Queensland power station; transport CO_2 from a Queensland power station and inject it into the Surat Basin; increase the understanding of the CO_2-storage capacity of the Surat Basin; and potentially develop a carbon capture use and storage (CCUS) industry in Queensland.
- Assess the CO_2-storage feasibility in the New South Wales Darling Basin.
- Develop Victoria's Gippsland Basin as an industrial CO_2-storage hub and remove and store CO_2 from various industrial sources, including hydrogen manufacture, CO_2 from Bass Strait natural gas production, and a post-combustion-capture retrofitted power station in the Latrobe Valley.
- Continue CCS RD&D at Victoria's Otway site, thereby reducing the cost and improving the reliability of CCS injection.
- Increase the understanding of vertical- and horizontal-migration-assisted trapping at Western Australia's South West Hub project, and potentially develop a CO_2-storage site in the Collie Basin.

Air separation units and associated pipes and vessels at the Callide oxyfuel plant, Queensland, Australia (Image Credit: Callide Oxyfuel Project)

Priority Actions to Enable CCS Deployment in the People's Republic of China

The energy sector in China is rapidly evolving. As part of this evolution, coal will remain a pillar of China's energy mix for the foreseeable future. The country has made significant progress in improving the environmental performance of its coal-fired power plants. China now has some of the strictest emissions standards in the world and is home to some of the most modern high-efficiency low-emission (HELE) power plants. In a similar vein, some inherent characteristics of the country's energy and industrial sectors could help China become a global leader in the deployment of CCS. First, there is evidence that the local cost structure of CCS in China has the potential to be lower relative to costs in other regions of the world. Secondly, the country is moving towards the development of a national emissions trading system to establish a market and price for CO_2. Finally, China is continuing to invest in research on early-stage concepts for CO_2 capture and conversion, as well as demonstration projects on various scales.

In considering the application of CCS to China's coal-fired power plants, there are sound reasons for optimism. Driven by efforts to improve air quality through reducing emissions, and also to improve energy efficiency, the country is increasingly moving towards a relatively young fleet of highly efficient plants with state-of-the-art emission controls as these modern plants replace older, less efficient ones. For example, government standards require that all new and existing power plant meet a 310 gce/kWh efficiency standard by 2020. If they are unable to do so, they will be retired. By comparison, no currently operating power plants in the United States meet this standard (Hart, 2017). The recent investment in these modern plants may also offer increased reassurance that the cost of CCS projects can be leveraged over many decades. Given the current knowledge of CO_2-storage opportunities, the IEA has stated that 385 GW of China's coal-fired power plants are within 250

Coal-to-liquids projects, such as this plant located in Ordos, could provide a low-cost source of CO_2 from which CCUS in China could be jump-started (Image credit: Shenhua Group) kilometres of suitable CO_2-storage opportunities, while 310 GW met the criteria for being "suitable for a retrofit" (IEA, 2016b). These numbers may grow with increased sub-surface exploration and as the country's coal-fired power-plant fleet continues to be upgraded.

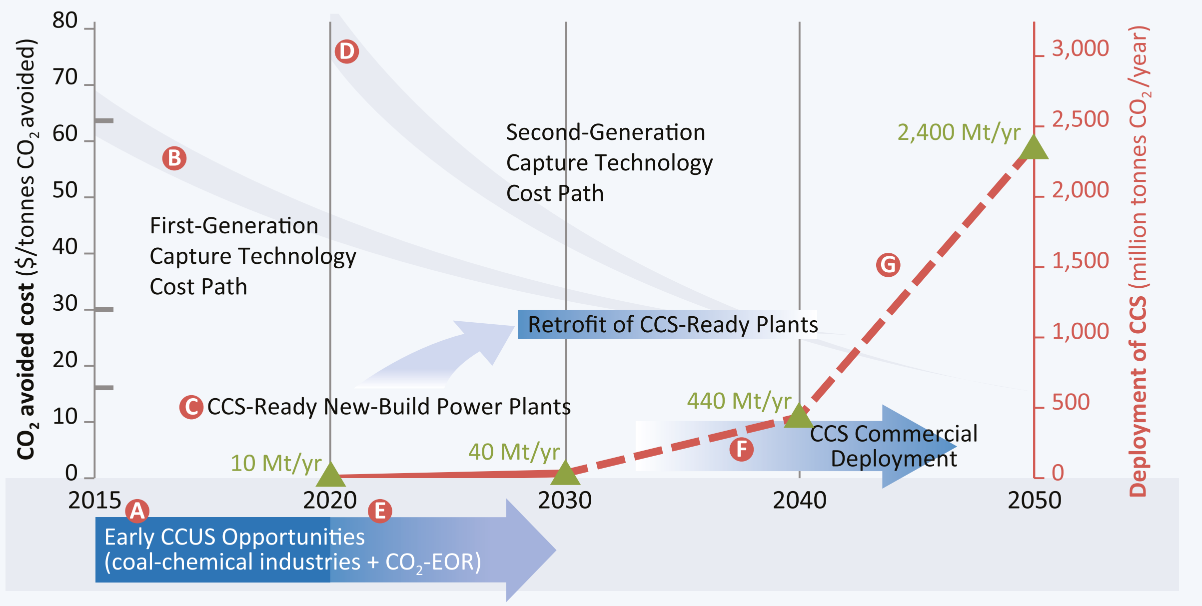
Moreover, the average reported costs from demonstrations of CO_2 capture from power plants in China are lower than those of corresponding demonstrations in other parts of the world – with estimates for post-combustion capture averaging about USD 34/tonne CO_2 compared to an estimate of USD 58.2/tonne CO_2 on a supercritical plant in the United States (Huang, 2010; Dave, 2011; Yan, 2011; Xang, 2016; Xu, 2013; NETL, 2015). There are multiple drivers responsible for this difference and, together, they create a commercial landscape that differs markedly from that of the West. Although China's infrastructure for CO_2 transport is underdeveloped, the capital-construction cost advantage that exists in China may reduce the costs of large-scale CCS relative to, for example, the United States.

China is also making progress in developing a market and price for CO_2. Regional pilot emissions-trading markets have been in operation since 2013, with average prices ranging from RMB 20 to 50/tonne CO_2 (approximately 3 to 8 USD/tonne CO_2) (Tanpaifang, 2017). A national market is set to start trading in 2017, with reductions of allowances currently scheduled to begin in 2020 (Zhao, 2016). The gap between carbon-trading prices and CCS costs is smaller in China than elsewhere in the world. CO_2 capture may be economical, or close to becoming economical, in the near term when performed at existing coal-to-chemical plants; this could represent an early opportunity for the development of CCS in China.

Current Status of CCS

To date, there have been several pilot-scale CCS projects in China. Recently, it was announced that the Yanchang CCUS project – a 400,000 tpa CCS project at a coal-to-chemicals facility – had commenced construction (GCCSI, 2017). A new round of smaller-scale demonstration projects is also planned; these aim to assist in reducing capture costs and in developing technologies that will meet the specific operating demands of China's power plants. As yet, China does not have operating large-scale demonstration projects ("large-scale" as defined by the GCCSI). The country, however, is host to more than a third (7 of 18) of the large-scale projects under earlier stages of development globally.

In 2015, the Department of Climate Change of the National Development and Reform Commission developed a Roadmap for Carbon Capture and Storage Demonstration and Deployment in the PRC with the support of the Asian Development Bank (ADB, 2015). This document highlights that the Chinese government values the contribution of CCS in meeting the country's climate change commitments – envisioning growing CCS deployment to 2,400 million tonnes of CO_2 per year by 2050 (see Figure 1).



CCS = carbon capture and storage, CCUS = carbon capture, utilisation, and storage, CO_2 = carbon dioxide, CO_2-EOR = carbon dioxide-enhanced oil recovery, Mt/yr = million tonnes per year, PRC = People's Republic of China

Figure 1. The Roadmap for CCS in China as published by the NDRC in collaboration with the ADB (ADB, 2015)

The role of CCS has been summarised well by the NDRC in its CCS roadmap (above):

Consistent with its aim to peak out CO_2 emissions by 2030, the Chinese government is implementing strong measures to transform its energy to a low-carbon mix. But coal is expected to remain a pillar of its energy security even in the long-term, with a large share in the energy mix. As a result, for China to move from its current CO_2 emission-reduction trajectory to a more ambitious one, CO_2 abatement from coal-based industrial production and power generation is crucial. CCS is the only currently available technology that can cut up to 90% of CO_2 emissions from coal-fired power plants and industries.

Summary of Priority Actions

1. Use high-purity CO_2 streams from coal-conversion facilities to explore potential CO_2-storage and -utilisation opportunities, especially enhanced hydrocarbon recovery.

2. Increase CCS research, development, and demonstration projects at coal-fired power plants and industrial facilities aimed at substantially reducing the costs of CCS implementation.

3. Assess the infrastructure needs, and associated costs, to develop a robust CCS industry in China.

4. Advocate for the inclusion of high-efficiency coal-fired power plants that have CCS, or are CCS-ready, in the portfolio-investment opportunities recognised by the AIIB.

Explanation of Proposed Priority Actions

1. Use high-purity CO_2 streams from coal-conversion facilities to explore potential CO_2-storage and -utilisation opportunities, especially enhanced hydrocarbon recovery

China has many coal-to-chemicals plants in which CO_2 capture costs are low (under USD 20/tonne CO_2), while a significant proportion of these costs may already have been incorporated into the operation of these facilities. Many of these plants are also within an acceptable proximity to oilfields that could benefit from CO_2 injection for EOR (CO_2-EOR) (ADB, 2015). The revenue resulting from incremental oil production could offset some or all of the costs for big CCS projects, making these projects a low-cost option for near-term, large-scale demonstration of CCS.

China has some particularly strong incentives for growing its nascent CO_2-EOR industry. The country imports more than half of the oil it consumes. In addition, its domestic oilfields are nearing or at maturity and are expected to decline in production in the near future. In some of these fields water flooding has already occurred and they are no longer viable in a scenario of low global crude oil prices. CO_2-EOR could help the country to ensure the continued economic viability of several of its large oilfields and improve its energy-security outlook.

Current low oil prices, however, do not provide sufficient incentive to advance CO_2-EOR demonstration projects – which are a necessary step – as the technology for these oilfields has not yet been demonstrated. State intervention and action, therefore, will be necessary to facilitate the realisation of low-cost CO_2-capture opportunities, build the necessary CO_2-transportation infrastructure, and demonstrate the viability of CO_2-EOR in the most suitable oilfields. These concerns notwithstanding, CO_2-EOR, using low-cost CO_2, represents a near-term opportunity that could jump-start CCS in China.

2. Increase CCS research, development, and demonstration projects at coal-fired power plants and industrial facilities

China is particularly well suited to advancing CCS rapidly. R&D is critical to reducing the costs of CCS technology and its deployment. The country's universities, government institutions, state-owned energy companies and other industrial players have extensive combined expertise on fossil-fuel power-generation technologies and coal conversion. Although CCS deployment has not yet begun in earnest in China, the country has invested about RMB 3 billion since the 11th Five-Year Plan (2005-2010) into CCS R&D, with nine pilot projects being in various stages of deployment. Growing this investment, in respect of both second-generation technologies and larger demonstration projects, is likely to bring down the costs associated with CCS deployment in China.

3. Assess the infrastructure needs, and associated costs, in developing a robust CCS industry in China

Because China lacks a mature and robust CO_2-EOR industry, it does not have at present the large-scale infrastructure needed to transport CO_2 from sources to sinks. In order to accelerate the widespread deployment of CCS, identifying the most-efficient and economic pipeline infrastructure is therefore critical. In addition, as new coal-fired power plants are being planned, it is essential to ensure that they will be CCS-ready, such as giving consideration of their proximity to CO_2 storage.

4. Advocate for inclusion of high-efficiency coal-fired power plants with CCS projects in the portfolio-investment opportunities recognised by the Asian Infrastructure Investment Bank (AIIB)

The AIIB has signalled that it will consider the inclusion of coal-fuelled projects in its investment portfolio. It has made it clear, however, that such funding would be contingent on using HELE technologies. In the near term, the AIIB could pave the road for future CCS deployment by supporting CCS-ready projects. As the costs involved are reduced, this would provide the possibility for widespread CCS deployment. In addition, there may be a limited number of cases that are likely to be principally focused around industrial sources of CO_2, rather than power production, where CCS costs may already be low; such projects could be considered for AIIB investment. China's support of investment in such projects would likely increase their uptake, thereby improving the outlook for CCS far beyond the country's borders.

Outcomes

Through enacting the proposed actions, China could rapidly advance CCS technology and become a global leader in its deployment. Specifically, China has the near-term opportunity to:

- Use CO_2, with minimal capture costs from industrial facilities, such as coal-to-chemicals facilities, to demonstrate CO_2 storage and/or use.
- Demonstrate CO_2 storage at increased scale, while also increasing knowledge of the sub-surface structure in optimal storage locations.
- Quantify the costs for CO_2 capture from coal-fired power plants in China (this has been the subject of academic studies to date, but has not yet been demonstrated at scale).

Shenhua's Ninghai Power Plant is an example of the relatively young fleet of HELE power plants that could be retrofitted with CO_2 capture (Image credit: Shenhua Group)

Conclusions

The cost of meeting emission limits associated with international climate goals is measured in tens of trillions of dollars. That cost more than doubles if CCS is not widely deployed.

Over the past decade, there have been some remarkable advancements that are propelling CCS technology and policies forward across industries. There have also been some notable project and policy shortfalls that are hindering progress.

If there continues to be an aspiration to transition to a low-carbon energy future, deployment of CCS technology is a prerequisite and must be expedited.

By examining the CCS progress and opportunities in the United States, the United Kingdom, Australia and the People's Republic of China, some cross-cutting observations can be made:

- Governments have been very effective at building the technology and regulatory knowledge base to advance CCS. Capacity-building efforts (e.g. the formation of the Carbon Sequestration Leadership Forum, the Global CCS Institute, the United Kingdom-China Clean Energy Partnership, and the United States Department of Energy Regional Carbon Partnership) have helped inform and accelerate private-sector efforts to advance CCS projects.
- Governments have effectively supported efforts to advance basic characterisation of geologic resources. This recognises that geology is quite variable and that geological conditions differ widely between specific locations. Generally, it is difficult for industry to invest in geologic characterisation when there is not a project-specific motive. Given the long lead times associated with such characterisation, if governments are able to pre-screen and pre-qualify geologic resources, this would expedite future industry CCS projects.
- Projects related to CO_2-transportation infrastructure planning have been relatively limited. It is extremely difficult for industry to justify investment in core transport-infrastructure elements (e.g. trunk pipelines and seaborne port facilities) until incentive-based CCS policy is much more mature. Effective joint planning by government and industry can lead to more efficient investment by both.
- Industry and governments have been able to collaborate effectively on a variety of pilot-scale projects. As new and improved CCS technologies emerge, there will be candidates for pilot-scale testing. The objective of CCS pilot-scale efforts should be to provide the cost and performance data that enables subsequent scale-up, the provision of performance guarantees by the technology providers, and the cost and performance certainty required to secure financing for commercial deployment.
- Over the past five years, austerity has substantially reduced government funding for commercial-scale demonstrations, which are essential to expediting CCS deployment. This represents a mismatch between ambitious carbon emissions-reduction goals (such as those agreed in the Paris Agreement) and adequate government co-funding to conduct demonstrations that are an essential stepping stone to achieving carbon emissions-reduction goals. This mismatch needs to be erased.
- The track-record of establishing government-industry partnerships to conduct commercial-scale demonstrations is mixed. Such projects are absolutely essential to achieving large-scale, widespread CCS deployment. The most successful projects to date have had the benefit of a

government capital-expenditure buy-down coupled with one or more of the following:
  - a policy mechanism that provides operating-expenditure cost recovery and an acceptable return on private capital expenditure
  - a single high-margin revenue stream (e.g. separated natural gas)
  - multiple low- to moderate-margin revenue streams (e.g. electricity and CO_2 offtake agreements).

  Projects which were highly advanced but ultimately stalled were found to have carried more risk (e.g. first-of-a-kind technology risk or project-on-project risk) than commercial markets could absorb, there was no policy mechanism to close the risk gap, and/or the projects ran into timing issues, particularly with respect to policy incentives and programme requirements not being aligned with project-development and financing requirements.

- Governments have successfully promoted and invested in low-carbon renewables. Given that CCS is the technology with the greatest leverage to minimise the cost of a low-carbon future, CCS should receive an equivalent level of governmental R&D support so that both these low-carbon technologies have an equal opportunity to advance in the marketplace.

- The advancement of CCS technologies would significantly benefit from governments using their influence to increase international awareness of the criticality of CCS, and to frame the policy of international financial institutions and multilateral institutions. The IEA is uniquely positioned to inform governments and financiers, including multilateral development banks, on the urgent need to expand investment in CCS across the globe if a low-carbon economy is to be achieved.

- Industry will invest significantly in CCS projects where it sees a financial return commensurate with the financial risk involved. To expedite CCS deployment, the public sector needs to fill the gap between the cost of early CCS projects and the cost and risk commercial markets can bear. This needs to be done within a supportive policy framework. Otherwise, the portfolio of new CCS projects will be limited and the aspirations of many governments to achieve a low-carbon future will be far more costly, if not forfeited. If the public sector can fill the gap on early CCS projects, industry is well-positioned to deliver the necessary technical expertise and substantial investment capital. As the technology matures, industry will be able to carry a greater and greater portion of the investment costs.

The CCS Conundrum

There is consensus among most major countries that the world must move towards a low-carbon energy future to address concerns related to climate change. For these countries, it is essential such a future is achieved cost-effectively and does not result in major economic disruption.

Advanced technology is well recognised as being one of the most effective elements in reducing emissions while simultaneously controlling costs. Developing advanced technologies, however, is neither easy nor free. The upfront investment needed for R&D, pilot-scale tests and commercial demonstrations to aggressively develop CCS is substantial and is likely to amount to tens of billions of dollars worldwide per year for at least a decade. Given that CCS could reduce the overall cost of achieving a low-carbon energy future by tens of *trillions* of dollars, the societal return on investment is relatively clear.

The conundrum is how to expedite CCS development when government cannot provide the trillions in investment capital to deploy CCS, while for most CCS R&D, demonstrations, and commercial-deployment projects there is not a clear pathway to achieve an acceptable return on investment.

A Way Forward

The solution to this conundrum is a public-private partnership that makes an international commitment to CCS. Making this commitment involves taking five initiating actions. If these actions are taken, this would unlock access to the trillions in investment capital that are required to transition to a low-carbon energy system. With access to capital and a supportive, incentive-based policy environment, the private sector can use its expertise to drive forward the wave of CCS deployments that is required to enable an orderly transition to a low-carbon future. The actions include:

1. Deliver compelling messages that CCS is an essential technology to achieving a low-carbon energy future at the lowest possible cost

Political and industry leaders need to use their respective communication platforms to reinforce in the strongest terms that CCS is an indispensable technology that supports the lowest-cost pathway to realising a low-carbon energy future. Climate agreements must recognise this fact and must incorporate an international commitment to CCS.

2. Implement incentive-based policies that enable CCS to deployment

There must be a concerted effort to put in place incentive-based CCS deployment policies by 2020, or as soon thereafter as practical. Well-designed policies could close the gap between the cost of early CCS projects and what the commercial marketplace can support. The types of incentives contemplated are documented in the CIAB's 2016 report entitled "Policies and Incentives to Enable a Low-Carbon Energy Future" (CIAB 2016). Parties to the Paris Agreement should include policy progress in their periodic review of NDCs as these policies will play a crucial role in helping countries achieve their ambitions to 2025, 2030, and beyond, at least cost.

3. Distribute technology demonstration funding among low-carbon energy alternatives to demonstrate each technology at a commercial scale

Governmental demonstration support for all low-carbon technologies should be sized to provide for commercial-scale demonstrations. For example, a new solar technology may require demonstration over a 1-10 MW range. However, new fossil-based CCS technology or nuclear demonstrations may require demonstration at the scale of 50 – 250 MW. There must be a renewed commitment to demonstration of all low-carbon technologies at commercial scale.

4. Implement international public-private collaboration on CCS projects, with the cost-sharing considering the relative public vs. private benefit.

Where there is a natural alignment of private and public interests, international collaborations involving CCS demonstrations, CCS R&D, and CCS infrastructure should be pursued. The Callide oxy-fuel project is a notable example that involved the Japanese and Australian governments, as well as the private sector. It helped lay the foundation for future, industrial-scale oxy-fuel projects and would not have been possible without an international public-private collaboration. With respect to CCS infrastructure, a possible future collaboration could be with a country with substantial CO_2 sources, but limited CO_2 -storage opportunities, in collaborating on CCS infrastructure planning (e.g. cross-border shipping or pipelining of CO_2) with a country with suitable geologic resources for CO_2 storage.

5. Distribute R&D funding, with parity among low-carbon energy alternatives (i.e. renewables, CCS, and nuclear), low-carbon industrial processing (e.g. steel, LNG and cement manufacturing with CCS), and focus CCS R&D more strategically

As CCS has greater financial leverage, relative to other low-carbon energy technologies, to reduce the cost of building a low-carbon energy future, it should receive an equal share of annual government R&D funding (not less as it now does). Furthermore, government CCS should be strategically focused. For example:

- **Emphasise transformative vs. incremental R&D**. Novel carbon capture and innovative energy-conversion technologies, that could ultimately be implemented at industrial scale and offer significant cost-reduction potential, would be two appropriate focus areas. Incremental improvements will take place in the marketplace and should not be a focus.
- **Enabling R&D.** In those cases where financial returns are unlikely to be directly realised by the private sector, there is a role for government. Examples of enabling CCS R&D include: basin-level geologic characterisation, understanding the geologic mechanisms of CO_2 storage, international collaborations, capacity-building, and CO_2-transport infrastructure planning and development.
- **R&D in support of industrial-scale demonstrations.** R&D that reduces the risk or decreases the cost of demonstration projects, in a timely manner, would be an appropriate focus of CCS R&D.

As described earlier in this report, actions that the United States, the United Kingdom, Australia and the People's Republic of China could take immediately were recommended. Those specific actions would be an immediate start towards full implementation of the five broader actions above. Certainly, it is recommended that other countries begin taking action now.

As a practical matter, if there are continued agreements and aspirations to transition to a low-carbon energy future, while at the same time limiting costs, then CCS would be a central component to achieving those goals; and governments, industry and other stakeholders should advance CCS by taking the actions recommended herein.

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Abbreviations, Acronyms, and Units of Measure

Abbreviations and acronyms

45Q	U.S. Code – Credit for Carbon Dioxide Sequestration
ADB	Asian Development Bank
AIIB	Asian Infrastructure Investment Bank
ANLEC	Australian National Low-Emission Coal program
BEECS	BiOmass energy with CCS
BEIS	Department for Business, Energy, and Industrial Strategy
CAPEX	Capital expenses
CCC	Committee on Climate Change
CCS	Carbon capture (utilisation) and storage
CCSA	Carbon Capture and Storage Association
CCUS	Carbon capture, utilisation, and storage
CfD	Contract for differences
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
CTCSo	Carbon Transport and Storage Company
CTL	Coal to liquids
DECC	(United Kingdom) Department of Energy and Climate Change
DOE	(United States) Department of Energy
EOR	Enhanced oil recovery
EPA	(United States) Environmental Protection Agency
FEED	Front-end engineering and design
GCCSI	Global Carbon Capture and Storage Institute
HELE	High efficiency, low-emission
IEA	International Energy Agency
INDC	Independent Nationally Determined Commitment
IPCC	Intergovernmental Panel on Climate Change
LECT	Low-emission-coal-technology
NCC	National Coal Council
NDC	Nationally Determined Commitment
NGO	Non-governmental organisation
OECD	Organisation for Economic Co-operation and Development
OPEX	Operating expense
PCC	Post-combustion capture
PRC	People's Republic of China
R&D	Research and development
RD&D	Research, development and demonstration
WEO	World Energy Outlook

Units of measure

AUD	Australian Dollar
EUR	Euro
GBP	British Pound
gce	Grams of coal equivalent
GW	Gigawatt
kW	Kilowatt
kWh	Kilowatt hour
MWe	Megawatt electric
MWh	Megawatt hour
Mt	Million tonnes
Mtpa	Million tonnes per annum
RMB	Chinese Yuan
Tonne	Metric ton
USD	United States Dollar