ROADMAP FOR CARBON CAPTURE AND STORAGE DEMONSTRATION AND DEPLOYMENT IN THE PEOPLE'S REPUBLIC OF CHINA

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ASIAN DEVELOPMENT BANK

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CONTENTS

FIGURES

TABLES

BOXES

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The Roadmap for Carbon Capture and Storage Demonstration and Deployment in the People's Republic of China (PRC) Project was led by the Department of Climate Change, National Development and Reform Commission (NDRC) of the PRC, managed by the Asian Development Bank (ADB), and cofinanced by ADB's Carbon Capture and Storage Fund under the Clean Energy Financing Partnership Facility.[1]

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FOREWORD

Balancing sustained economic growth with energy security and environmental and climate change constraints is a common but difficult challenge confronted by many developing countries in the Asia Pacific region. This challenge gets amplified for large economies which are also heavily dependent on fossil fuels. The People's Republic of China (PRC) as the largest energy consumer in the world, 90% of which is fossil fuel-based, faces the enormous task to transform its energy mix to a low-emission and low-carbon mix to achieve its goal of continued prosperity, social development and ecological security towards an Ecological Civilization (Shengtai Wenming).

The PRC has launched many commendable initiatives in an effort to peak out its carbon dioxide (CO_2) emissions by 2030. Its current policy suite prioritizes accelerated energy efficiency improvement, rapid deployment of renewable energy, and larger share of low-carbon, low-emission natural gas and nuclear in the mix. But coal, which has underpinned the PRC's rapid economic growth over the past quarter of a century, is still expected to supply more than two-thirds of its energy needs compared to the global average of 24%. Coal is not only the most carbon-intensive fossil fuel causing the largest increase in CO_2 emissions but is also the main contributor to the poor air quality prevalent over a large part of the PRC.

The "new normal" economic growth paradigm in the PRC with greater emphasis on quality of growth with environmental friendliness has brought renewed attention on continued use of coal in the business as usual case. Nonetheless, large new capacity of coal-based power generation and industrial plants is still expected to meet incremental energy demand for the next 20–25 years. These new plants are expected to be most efficient and low-emission at par with the best available technology in the world. But they will still cause an increase in absolute CO_2 emissions. Thus, the need to urgently demonstrate and timely deploy carbon capture and storage (CCS), the only near-commercial technology currently available to cut up to 90% CO_2 emissions from coal-based plants, becomes an urgent policy imperative for the PRC.

It is with this backdrop, that Asian Development Bank (ADB) has been assisting the PRC since 2009 through a set of technical assistance projects, to analyze issues, identify the strategic fit of CCS in the existing portfolio of low carbon technologies, and strengthen capacity to overcome key barriers and develop readiness to bring forward CCS demonstration and deployment. The Roadmap for CCS Demonstration and Deployment in the PRC described in this report is a direct result of these analyses and presents a possible pathway with practical and specific policy actions to achieve these outcomes. It has identified unique low-cost opportunities for CCS demonstration during the 13th Five-Year Plan (2016–2020). But recognizing that many crucial barriers remain to be overcome, such as excessive energy penalty, high capital costs, perceived and real technical risks, weak CO_2 off-take agreement regime, it has recommended a gradual dual track approach of large-scale demonstration in low-cost opportunities utilizing captured CO_2 (CCUS) and parallel intensive research efforts to overcome remaining cost and energy penalty hurdles.

Combating climate change needs a robust portfolio of high impact low-carbon technologies to effectively address the emerging challenges. In our assessment, the CCS (or CCUS) technology is an integral part of such a portfolio. ADB has already created a CCS Fund with current contributions from the Global Carbon Capture and Storage Institute and the Government of the United Kingdom to help prepare its developing member countries for CCS demonstration. I believe that the Roadmap in this report is a practical and sound approach to move forward with CCS in the PRC. I can reiterate ADB's continued commitment to provide assistance in leveraging more knowledge and innovative financing for this purpose.

Ayumi Konishi
Director General
East Asia Department

FOREWORD

The 13th Five-Year Plan (2016–2020) is a crucial period for building a moderately prosperous society as defined by the 18th National Congress of the Communist Party of China and also a crucial period for the People's Republic of China (PRC) to actively respond to climate change and propel green and low-carbon development.

Widespread and continuous smog continues to afflict many parts of the PRC, arousing public concern and underlining the need to actively address climate change and to pursue a green, low-carbon economy. The Government of the PRC is acutely aware of the problem of climate change and issued the *2014–2015 Action Plan for Energy Conservation, Emissions Reduction and Low Carbon Development* in May 2014. It commits to cutting carbon dioxide (CO_2) emissions per unit of GDP by 4% in 2014 and 3.5% in 2015. The PRC's National Plan on *Climate Change for 2014–2020* was issued in September 2014 and identifies the guiding principles, main goals, roadmap, key targets, and policy directions necessary to address climate change.

The government's 2014 Report *China's Policies and Actions on Climate Change* provides details about how the government wants to (i) mitigate climate change by adjusting the industrial structure, conserving energy and improving energy efficiency, optimizing the energy structure, controlling emission from non-energy activity, and increasing carbon sink; (ii) pursue climate change adaptation in the fields of infrastructure, agriculture, water resources, coastal areas, ecosystem, and public health; (iii) develop low-carbon pilot projects; and (iv) build capability by promoting relevant legislation on climate change, strengthening major strategic studies and plan formulation, improving relevant policy systems for climate change, strengthening scientific support for addressing climate change, and steadily setting up relevant statistics and accounting systems.

The government dedicated tremendous efforts to reverting from a carbon intensive growth path during the 11th plan through increasing energy efficiency, controlling greenhouse gas emissions, adjusting the country's industrial structure, saving energy, optimizing the energy structure, increasing carbon sinks, adapting to climate change and intensifying capability building. Looking ahead to 2020, ambitious targets have been set for reducing carbon intensity (CO_2 emissions per unit of GDP) by 40%–45% compared to 2005 levels and an increase of the share of renewable energy sources in the energy generation mix to 15%.

The government continues to proactively collaborate with international organizations and financial institutions to achieve these targets. Starting in 2012, the Department of Climate Change of the National Development and Reform Commission carried out the Project for elaborating the *Roadmap for Carbon Capture and Storage (CCS) Demonstration and Deployment in the PRC* with the support of the Asian Development Bank (ADB). In the absence of a national plan for CCS demonstration and deployment, the Roadmap was developed to outline technical, legal, policy, financial and public engagement solutions that need to be implemented to move CCS from today's early demonstration projects to full-scale commercialization. For its formulation, we engaged some of the most valued domestic experts on climate change, economic modelling, CCS technology, CO_2 storage and CO_2-enhanced hydrocarbon recovery technology from the Administrative Center for China's Agenda 21, Chinese Academy of Sciences, Tsinghua University, and Dalian University of Technology. The national experts were supported by a group of international experts whose responsibility was to share international experiences on formulation of roadmaps, and the promotion of CCS technology in the full spectrum of aspects.

The Roadmap informs decision makers on a scientific basis about the PRC's readiness to use this innovative technology as well as about the urgency to expand its deployment at a rapid scale to meet priority emission reduction targets in the short, medium and long-term. It is a practical document as it recommends specific actions during the period of the 13th plan, and beyond 2020, as part of a phased approach to implement CCS in the context of the PRC.

The Roadmap is designed to be a living document and will be updated regularly to incorporate innovations and address new developments under the guidance of the National Center for Strategy and International Cooperation on Climate Change. The government appreciated the strong support of ADB for the formulation of the Roadmap and would welcome ADB's continued assistance on CCS development.

Gao Li
Deputy Director General
Department of Climate Change
National Development and Reform Commission

KEY MESSAGES

- **Carbon capture and storage (CCS) demonstration and deployment is essential for cost-effective climate change mitigation**. The economy of the People's Republic of China (PRC) is highly coal intensive. Despite recent vigorous efforts by the country to limit coal in its energy mix, coal is expected to remain a dominant fuel in the foreseeable future. CCS is now the only available technology that can cut up to 90% of carbon dioxide (CO_2) emissions from large industrial processes and power plants based on coal and other fossil fuels. Without CCS, the cost of meeting the country's anticipated long-term climate change mitigation objectives would be about 25% higher. CCS is also the only option for reducing CO_2 emissions in carbon-intensive coal–chemical, steel, cement, and refinery plants. Early demonstration of CCS in the PRC now will allow its timely and cost-effective deployment in the next 10–15 years.

- **The PRC can benefit from international experiences.** International CCS roadmaps share a common vision: the accelerated development and deployment of CCS technologies over the next 10–15 years. Countries such as Australia, Canada, Norway, the United Kingdom (UK), and the United States (US) have specific programs and policies supporting CCS demonstration projects. Globally, there are 14 large-scale CCS projects in operation, and eight others are under construction. Combined, these 22 projects will capture and store about 40 million tons of CO_2 per year. These early projects present significant opportunities to learn by sharing knowledge and practical experiences in planning and executing large-scale demonstration projects.

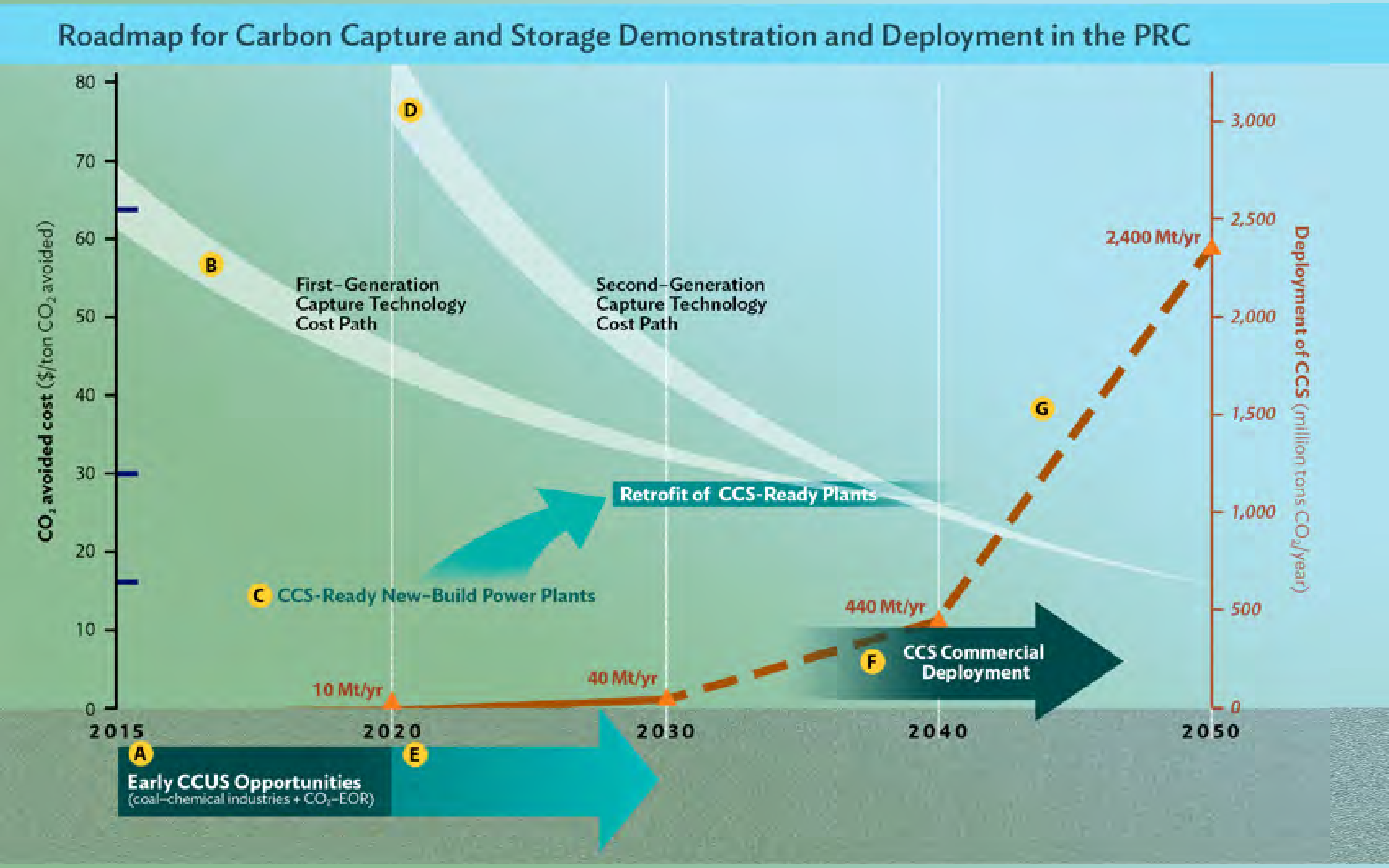
- **Unique low-cost CCS demonstration opportunities exist in the PRC.** Over the past decade, the Government of the PRC has built its capacity across the CCS chain through research, development, the construction of nine pilot projects, and extensive international cooperation. It has reached an adequate level of readiness to construct large-scale CCS demonstration projects. Moreover, the PRC has a large number of coal–chemical plants in which CO_2 capture is a low-cost (less than $20/ton) possibility. Many of its coal–chemical plants are also in the vicinity of oil fields amenable to CO_2- enhanced oil recovery (CO_2–EOR). The CO_2–EOR allows CO_2 storage and production of incremental oil, thereby providing a revenue stream. Thus, the PRC has the unique opportunity to demonstrate CCS at low cost.

- **CCS demonstration faces formidable challenges in the absence of targeted support.** CCS is a complex but proven technology that has been in commercial operation for decades especially in the oil and gas industries. Higher incremental capital costs, parasitic energy and water consumption to capture CO_2 from large industrial and power plants, and lack of proven CO_2 off-take arrangements to transport and store it in suitable storage sites (depleted oil and gas fields) are key barriers that have delayed or prevented CCS demonstration in the PRC and elsewhere. In the absence of an adequate price for carbon and targeted incentives to offset higher capital investments and parasitic energy loss, there is hardly any economic driver for CCS. Wider CCS demonstration offers significant opportunities for large reduction in the capital costs and energy loss, up to 50% following the demonstration of 10 to 20 gigawatt-scale power plants. But the early stage demonstration projects will need financial support, enabling policies, and an appropriate regulatory framework to cover associated risks.

- **Current low oil prices may have temporarily reduced incentives for CO_2–EOR, but fundamental drivers for CO_2–EOR in the PRC remain strong.** The recent sharp decline in oil prices may have a direct impact on the CO_2 off-take price any oil producer may be willing to pay for CO_2–EOR. Typically, oil producers pay about a quarter of the crude oil prices per ton for the injected CO_2. Nonetheless, the PRC imports more than half of its oil consumption and about 70% of its domestic oil production comes from nine large oil fields, which are all mature and are facing or will soon face a decline in production. In some oil fields, water flooding is no longer effective in maintaining oil production levels. Introducing CO_2–EOR is thus inevitable to maintain the economic viability of oil fields. To deploy CO_2–EOR in these oil fields, it is essential to undertake early stage demonstration and pilot testing. To overcome the lack of interest under the current oil prices, however, the government will not only need to incentivize industries to capture and transport CO_2, but also oil companies to conduct CO_2–EOR.

- **A phased approach to CCS demonstration and deployment is needed.** This Roadmap recommends a phased approach to overcome the described early-stage challenges by first targeting low-cost CCS applications in coal–chemical plants with CO_2–EOR. This will prove the feasibility of the CO_2 off-take arrangement and provide much-needed confidence in the CCS application. In parallel, intensive research and development activities including limited CCS application in coal-based power plants could bring down the capture costs and provide new insights and experiences. This will stimulate further research to drive down the capture costs. This dual-track approach of accelerated demonstration and more intensified research and development of capture technologies until the year 2025 can pave the way for wider deployment of cost-competitive CCS from 2030 onward.

Figure 1: Proposed CCS Roadmap for the PRC



CCS = carbon capture and storage, CCUS = carbon capture, utilization, and storage, CO_2 = carbon dioxide, CO_2–EOR = carbon dioxide–enhanced oil recovery, Mt/yr = million tons per year, PRC = People's Republic of China.

Key Policy Actions to Implement the CCS Roadmap

2015–2020

- CCUS and CO_2–EOR target of 10–20 million CO_2 captured and stored and 30 million barrels of incremental oil produced through CO_2–EOR announced and included in the 13th Five-Year Plan.
- CCUS enabling policies announced, including (i) Carbon Capture and Storage–Ready policy, (ii) CO_2–EOR policy, and (iii) standard CO_2 off–take agreement.
- Incentive program for CCUS demonstration projects adopted, including (i) payment of fixed subsidy per ton of CO_2 captured for CO_2 supplier, and per ton of CO_2 stored for oil company, (ii) tax credits given to oil companies applying CO_2–EOR technology, and (iii) capital grants to support projects moving to final investment decision stage.
- National carbon market established to provide additional funding for CCS projects.
- Existing environmental regulations expanded to CCUS projects and CCUS approval process clarified.
- Public awareness strengthened through targeted programs.
- First-generation CCS demonstration program assessed, strategy adjusted, and support program implemented.

2021–2030

- Second-generation CCUS targets announced.
- More market-based incentives for coal–chemical projects introduced, such as carbon tax, CO_2 emission caps, etc.
- Incentive program for coal-fired power plants introduced.
- Comprehensive CCS regulatory framework put in place.

Beyond 2030

- Economic and regulatory incentives for CCUS deployment in coal-fired power generation sector strengthened.

Roadmap Activities

2015–2020

A 5–10 large-scale projects in coal–chemical sector with CO_2–EOR selected and implemented. 1–3 coal-fired power plants selected for demonstration to overcome technical barriers and concerns.

B Largest contribution of first generation technologies to the cost reduction curve in coal-fired power plants.

C Planned mega coal-fired power plants in Inner Mongolia, Ningxia, Shaanxi, Xinjiang, etc., are constructed CCS-Ready.

2021–2030

D Largest contribution of second-generation technologies to the cost reduction in coal-fired power plants.

E Commercial deployment in coal–chemical industry and demonstration phase for wider CCS application.

Beyond 2030

F Capture cost reduction and carbon price reach a level to trigger wider application of CCS.

G **The Projected CCS Deployment Path**

The CCS deployment level attained is highly uncertain and will depend on (i) the degree of cost reduction achieved; (ii) the costs of CCS relative to alternative low-carbon technologies, including nuclear and renewables; and (iii) gain in capture efficiencies.

The projected CCS deployment path will lead to a cumulative avoidance of CO_2 emissions of (i) 10–20 MtCO_2 by 2020, (ii) 160 MtCO_2 by 2030, and (iii) 15 GtCO_2 by 2050.

ABBREVIATIONS

ADB	–	Asian Development Bank
CCS	–	carbon capture and storage
CEP	–	continued-efforts policy
CNY	-	yuan
CO_2	–	carbon dioxide
CO_2–EOR	–	carbon dioxide–enhanced oil recovery
EOR	-	enhanced oil recovery
FEED	–	front-end engineering design
$GtCO_2$	–	gigatons of carbon dioxide
GW	–	gigawatt
GCCSI	-	Global Carbon Capture and Storage Institute
IGCC	–	integrated gasification combined cycle
km	–	kilometer
LCOE	–	levelized cost of electricity
$MtCO_2$	–	million tons of carbon dioxide
NDRC	–	National Development and Reform Commission
NH_3	–	ammonia
PRC	–	People's Republic of China
RD&D	–	research, development, and demonstration
t	–	ton
US	–	United States

NOTE

In this report, "$" refers to US dollars.

(PHOTO CREDIT: CHINA HUANENG GROUP)

Tianjin Integrated Gasification Combined Cycle Power Plant of China Huaneng Group—the PRC's first-of-its-kind.

I. INTRODUCTION

1. Carbon dioxide (CO_2) emissions from fossil fuel combustion account for the largest share of greenhouse gas emissions by far. In the People's Republic of China (PRC), CO_2 emissions have risen in tandem with its rapid economic growth for the past three decades due to its carbon-intensive coal dominated energy mix. Accelerated efforts to rein in growing CO_2 emissions in the PRC, the world's largest energy consumer and largest emitter of CO_2, are of paramount importance to global climate change mitigation efforts.

2. Consistent with its aim to peak out CO_2 emissions by 2030, the Government of the PRC 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 the PRC 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. Carbon capture and storage (CCS) is the only currently available technology that can cut up to 90% of CO_2 emissions from coal-fired power plants and industries.

3. Many studies have highlighted CCS as an essential part of a portfolio of technologies that are required to achieve cost-effective long-term CO_2 mitigation. Yet, many perceived and real risks and barriers are delaying CCS demonstration and deployment, risking the attainment of CO_2 mitigation objectives.

4. Since the 11th Five-Year Plan (2005–2010), the government has invested more than CNY3 billion in CCS research and development. Nine pilot projects have been implemented, and many large-scale demonstration projects are at various stages of development. A number of roadmaps focusing on various individual aspects of CCS have been published, but a national plan for CCS demonstration and deployment is yet to be drafted.

5. This CCS Roadmap for the PRC aims to provide clear links between early-stage CCS demonstrations, phased scale-up, and the achievement of the PRC's emission reduction objectives. The Roadmap is
   (i) **scientific and manageable:** It is based on a detailed and practical assessment of CCS technology relevant to the PRC, the status and pace of economic development, and the status of infrastructure for CCS deployment;
   (ii) **comprehensive:** It integrates strategic climate change objectives, emission reduction targets and, technological innovation across government and industry;
   (iii) **flexible:** It is able to respond to uncertainties in both future technology and policy, both domestically and internationally; and
   (iv) **inclusive:** It incorporates research, development, and demonstration (RD&D) programs and goals necessary for deployment, and maps the interests of stakeholders critical to successful implementation.

II. CARBON CAPTURE AND STORAGE: AN ESSENTIAL CLIMATE CHANGE MITIGATION TECHNOLOGY FOR THE PEOPLE'S REPUBLIC OF CHINA

6. The coal-dominated power generation and industrial sectors provide a compelling case for the early demonstration of CCS in view of the government's commitment to climate change mitigation. Since 2006, the PRC has made significant progress in increasing the share of renewable energy, improving energy efficiency, and retiring more than 70 gigawatts (GW) of small, inefficient power plants as well as obsolete production capacity in energy-intensive sectors. With continued economic growth, coal consumption increased by 44% since 2006 to 2.4 billion tons (t) of coal equivalent in 2013. It represents half of the world's consumption of coal. Consequently, CO_2 emissions grew by about 34% over the same period, reaching 8.3 gigatons of CO_2 ($GtCO_2$) by 2010 (World Bank 2014).

7. The energy mix continues to be dominated by coal, which is the main pillar of the PRC's energy security, because it is cheap and abundantly available in the country. Fossil-fuel combustion accounts for more than 80% of CO_2 emissions in the PRC. Coal has a 75% share of these fossil fuels. More than 70% of the total installed power generation capacity and 80% of generated electricity depends on coal. Although the PRC is the largest solar and wind market in the world and the use of natural gas is increasing rapidly, only small gradual change is expected in the fuel mix for power generation in the medium term. The current coal-fired power plant capacity of about 800 GW is projected to increase to about 1,250 GW by 2030. This will cause the single largest increase in CO_2 emissions in the PRC and in the world in the absence of any CCS.

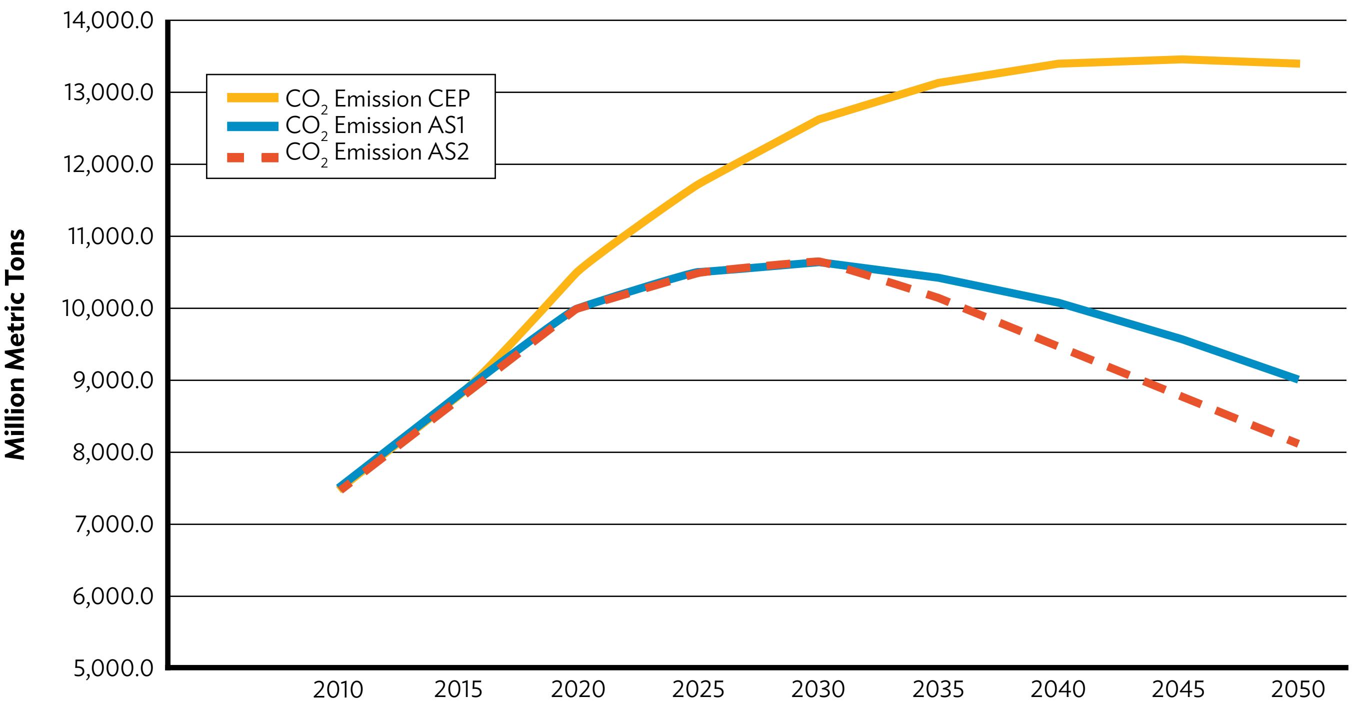
8. Economic modelling was used to assess the fit of CCS in the PRC's climate change mitigation endeavors.[2] Two alternative scenarios that allow the PRC's CO_2 emissions to peak in 2030 are compared with a continued-efforts policy (CEP) scenario. The CEP represents an annual reduction of carbon intensity of 3% from 2016 to 2050. One alternative scenario (AS1) assumes an annual reduction in carbon intensity of 4% from 2016 to 2050 while the other alternative scenario (AS2) assumes an annual carbon intensity reduction of 4% during 2016–2030 and 4.5% during 2031–2050, respectively. AS2 is a more accelerated effort scenario and also serves as a sensitivity analysis of CCS applications in the power sector.

9. Figure 2 (on page 3) shows the CO_2 emission trajectory under each scenario. CO_2 emission growth would continue to remain strong in the CEP scenario (though at a more gradual rate than in the past), with CO_2 emissions likely to peak by 2050 at around 13.4 $GtCO_2$ per year. In both alternative scenarios (AS1 and AS2), energy-related CO_2 emissions are expected to peak by 2030 at about 10.6 $GtCO_2$. In the long-term, the scenarios would reach a CO_2 emission level of 9.0 $GtCO_2$ and 8.1 $GtCO_2$ by 2050.

2 Two complementary modeling frameworks are used—a general equilibrium model, C-GEM of Tsinghua University and a technology detailed energy system optimization, bottom-up model, MESSAGE, of the International Institute of Applied Systems Analysis (IIASA). The general equilibrium model is used to identify the macroeconomic impact of climate mitigation efforts; the energy system optimization model, to identify specific implications of applying CCS in various energy subsectors. Note that the CCS potential for power generation in this report is primarily based on estimates by the C-GEM model. The additional potential for CCS in the liquids/chemical sector is based on the IIASA MESSAGE model.

10. CCS is projected to play an important role in achieving a cost-effective reduction in CO_2 emission through a shift from the CEP scenario to either of the two other scenarios. The C-GEM model was used to project CO_2 emissions reductions from CCS in the power generation sector. In addition, the energy system optimization model MESSAGE indicates that significant additional CO_2 emission reductions can be achieved in the coal–chemical, petrochemical, and other industrial sectors. By 2030, CCS is thus projected to contribute about 40 million tons of carbon dioxide ($MtCO_2$) in emission reductions per year, predominantly in the coal–chemical sector. By 2040 and 2050, CCS can contribute up to 238 $MtCO_2$ and 1,428 $MtCO_2$ in emission reductions per year in the power sector, respectively. The share of coal-fired power plants with CCS is projected to reach 6% in 2040 and 56% in 2050, respectively. In addition, the potential for carbon capture, utilization, and storage (CCUS) in the coal–chemical sector is estimated to be about 200 $MtCO_2$ per year by 2040 and 900 $MtCO_2$ by 2050. Combined with CO_2-enhanced oil recovery (CO_2–EOR), the coal–chemical sector may therefore provide the possibility to reduce emissions below the levels shown in Figure 2 below.

Figure 2: Carbon Dioxide Emission Trajectories in the PRC across Several Climate Policy Scenario Variants from the C-GEM Model



AS1 = alternative scenario, AS2 = alternative scenario, CCS = carbon capture and storage, CEP = continued-efforts policy, CO_2 = carbon dioxide.
Source: ADB (2014b).

11. The actual level of deployment is highly uncertain and will depend on (i) the degree of technological innovation and the cost reduction achieved, in particular by 2020; (ii) the costs of CCS relative to those of other alternative low-carbon technologies, including nuclear and renewable energy; and (iii) the achievement of better capture efficiencies.

(PHOTO CREDIT: SHENHUA GROUP)

Scale model of Shenhua Group's 100,000 ton CCS demonstration project

12. The key conclusions from the economic analysis prepared for this Roadmap is that (i) CCS is an essential part of a cost-effective CO_2 abatement strategy for the PRC; (ii) early demonstration of CCS during the 13th Five-Year Plan period is important to realize essential learning effects, and (iii) substantial CO_2 emission reductions can be achieved through CCS in the coal–chemical sector, the power sector, and to a significantly lesser extent in other industrial sectors such as cement, iron and steel.

III. READINESS TO LAUNCH CCS DEMONSTRATION IN THE THIRTEENTH FIVE-YEAR PLAN

13. The following describes the current state of readiness for CCS in the PRC, key criteria for selecting early-stage demonstration projects, and steps that can be taken to reduce the costs and risks of such projects.

A. CCS Research and Development and CCS Pilot Activities

14. More than CNY3 billion has been invested in CCS reserch in the PRC since 2008. Since the 10th plan period (2001–2005), the Government of the PRC has engaged in RD&D activities for CCS.[3] These activities are focused on emissions reduction potential from different CO_2 capture technologies, CO_2–EOR and geological storage, and different options for CO_2 use and transformation. Government investment in CCS pilot projects under national science and technology plans has been the only domestic financial support mechanism available so far in the PRC.

15. By 2014, nine pilot projects, mainly in the power and the coal–chemical sectors, were implemented. Several of them, with a capture capacity of more than 100,000 t per year, were built in recent years. A 100,000 t per year saline aquifer storage demonstration project and a 40,000 t per year capture and CO_2–EOR coal-fired power plant demonstration project are ongoing.

16. Several industry partnerships have been formed for the advancement and development of technologies with intellectual property rights. The Shenhua Group is collaborating with a number of universities, research institutes, and technology and equipment providers on the development of oxy-fuel combustion CCS; China Huaneng Group has a collaborative research network for precombustion CCS; and PetroChina and other oil companies are working together to push forward technologies for CO_2–EOR. In August 2014, key stakeholders including the China Huaneng Group and PetroChina jointly founded a CCS Alliance.

17. As a result, the capacity has been built and strengthened over a wide range of technologies across the CCS process chain, as well as on policy and regulatory aspects of CCS development. To maintain the momentum, there is a need to identify and establish commercial-scale demonstration projects to
    (i) establish the technology, including process integration and optimization, at a scale that is large enough to allow subsequent plants to be built with confidence at full commercial capacity;
    (ii) prove that CCS works and is safe, thereby building public confidence; and
    (iii) accelerate technology development in order to gain experience that will lead to cost reduction in full-scale commercial plants.

18. A number of commercial-scale demonstration projects are in various stages of development (GCCSI 2014). A list of possible coal-based CCS demonstration projects has been compiled from available information (Appendix 1). Listed are several possible projects that qualify as large-scale integrated projects. Others are smaller but within the broad range that might be worthwhile taking forward as agreed by the National Development and Reform Commission (NDRC) and the Asian Development Bank (ADB).

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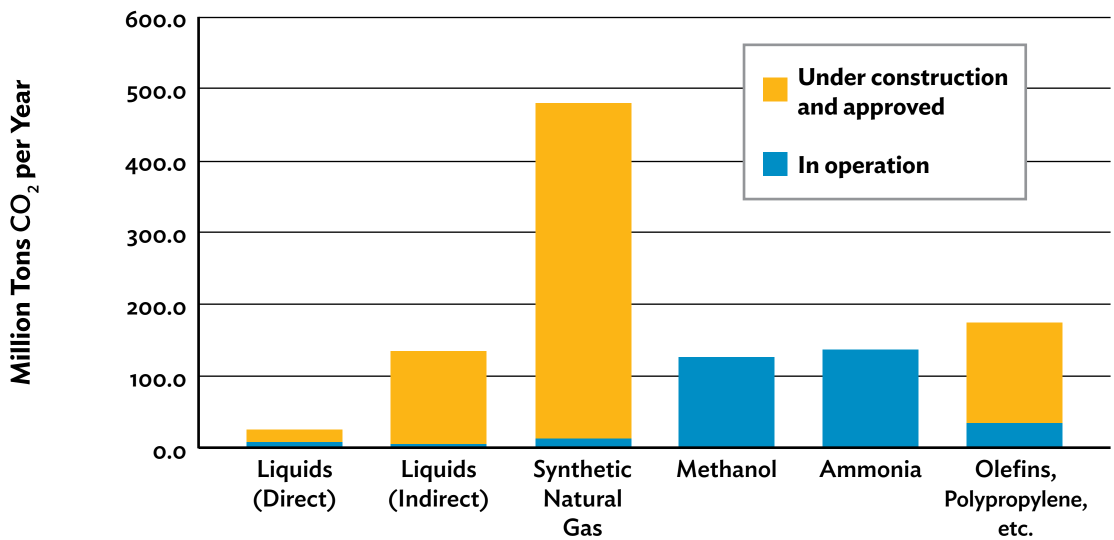
3 Through its National Basic Research (973) and National High-Tech Research and Development (863) programs, as well as the National Science and Technology Support Program and other science projects.

B. Coal–Chemical Plants: A Cost-Effective Early-Opportunity Approach

19. Coal–chemical plants are strategically important for the PRC's energy security. But their carbon and environmental footprints are significantly larger than that of coal-fired power plants. The conversion of coal to synthetic natural gas is a common coal–chemical process widely used in the PRC. If synthetic natural gas produced from coal is used to generate electricity, its life-cycle CO_2 emissions would be 36%–82% higher than those of pulverized coal-fired power (Yang and Jackson 2013). Liquid fuels produced synthetically from coal emit about twice to thrice as much CO_2 as conventional liquid or gaseous fuels derived from crude oil.

20. The coal–chemical industry is a very significant industrial sector in the PRC. Coal gasification primarily produces ammonia, methanol, olefins, and synthetic natural gas. In 2013, about 170–200 non-power coal gasification plants were in operation or under construction emitting nearly 300 $MtCO_2$ per year. Total emissions are projected to grow to more than 1 $GtCO_2$ per year by 2020. In particular, emissions from plants producing synthetic natural gas from coal are projected to reach nearly 500 $MtCO_2$ per year (Figure 3). Coal–chemical plants tend to operate on a large scale, with annual CO_2 emissions per site ranging from 0.5 $MtCO_2$ to more than 2 $MtCO_2$. Most of the coal–chemical projects are in the Midwest region of the PRC, which comprises the autonomous regions of Xinjiang Uyghur and Inner Mongolia, and the provinces of Ningxia, Shaanxi, and Shanxi.

Figure 3: Projected CO_2 Emissions from Coal–Chemical Plants, in Operation or Under Construction and Approved



Sources: China Petroleum and Chemical Industry Federation database; ADB (2014d).

21. Coal–chemical plants offer a unique opportunity to deliver low-cost CCS. In these plants, CO_2 is separated as part of the coal–chemical production process, resulting in a high-purity CO_2 stream at high pressure. This CO_2 requires only minor purification and compression to liquefy before transportation. Thus, the incremental capital and operating costs of CCS are relatively small: the addition of carbon capture will increase capital cost by 1%–1.3%, and the output cost factoring in the energy penalty for operating the compressors, by about 7.5%–8%. The analysis of coal-to-methanol plant prepared for this Roadmap showed that (i) even at modest carbon prices of CNY50, it is economical to invest in CCS; and (ii) when combined with CO_2–EOR, CCS in coal chemical plants results in near-zero cost if oil operators pay a reasonable price (about CNY100/t) for the CO_2.

C. Carbon Dioxide Utilization for Enhanced Oil Recovery

22. Injecting CO_2 to improve the recovery of oil from a depleted oil well is a proven process commonly known as CO_2–EOR. Since most of the injected CO_2 will be permanently isolated from the atmosphere, this approach is recognized as effective in mitigating CO_2 emissions. The process of capturing CO_2 from an industrial plant, liquefying it, and transporting it for use in an oil field is called CCUS technology.

23. CO_2–EOR can create a revenue stream through the sale of incrementally produced crude oil to partially offset the costs of establishing a CCS chain of capture, transport, injection, and storage. CO_2–EOR has been used for more than 30 years, primarily in the US. During that time, more than 1 $GtCO_2$ has been injected into geological reservoirs (GCCSI 2013). National oil companies in the PRC understand CO_2–EOR well because of trial operations in the PRC and, for some, because of their offshore operations in North America. However, CO_2–EOR technologies applied widely in the US will need to be adapted to suit the geological structure in the PRC.

24. The key determining factor for the economic viability of a CO_2–EOR project is the cost per ton of CO_2 delivered versus the revenue from incremental oil production. The main advantage of CO_2–EOR is that it is generally less risky than new exploration projects. Large reserves associated with its application can be booked at their initial value, and oil production from CO_2–EOR can provide sustained cash flow for extended periods of time (GCCSI 2013).

D. Storage Potential and Regional Priority Areas for CCS Demonstration

25. CO_2 storage capacity potential estimates for the PRC remain highly uncertain to date because of a lack of (i) consistent evaluation models and a standardized assessment methodology, (ii) comprehensive data, and (iii) integrity of data regarding the properties of subsurface geological properties. Most studies have used a range of approaches and data sets of variable size and quality, resulting in varying storage capacity estimates. Nonetheless, current academic research confirms that the geological formations of the PRC have sufficient potential to store the projected levels of captured CO_2 in the near, medium, and long-term as described below.

26. In the near to medium term, it is expected that CO_2 will mainly be stored as part of CO_2–EOR activities. In the medium to long-term, storage will mainly use saline aquifers. For this Roadmap, the storage capacity potential of saline aquifers, oil fields, and gas fields in the PRC's 23 main onshore basins and nine main offshore basins was reviewed and assessed. When the stratigraphic and solubility method is used, the storage potential of saline aquifers onshore is estimated to be 1,300 $GtCO_2$, that of saline aquifers offshore 573 $GtCO_2$, and the combined storage potential of about 1,900 $GtCO_2$. The oil- and gas-bearing basins in the PRC can be divided into 14 main regions, including 216 oil fields. According to Shen, Liao, and Liu (2009), the theoretical CO_2 storage capacity in the onshore oil reservoirs is 3.78 $GtCO_2$ and the effective capacity is about 2 $GtCO_2$ (Shen, Liao, and Liu 2009; Shen 2010). Sun and Chen (2012) assess the theoretical storage potential of geological storage in onshore oil reservoirs of the PRC at depths of more than 800 meters to be about 5 $GtCO_2$. Liu et al. (2012) estimate the theoretical storage potential in gas fields to be 30 $GtCO_2$.

27. Cumulative CO_2 storage is projected to reach 160 $MtCO_2$ by 2030 and 15 $GtCO_2$ by 2050. Thus, the current storage potential in oil and gas fields and particularly in saline aquifers exceeds by a large margin the projected deployment levels and does not represent a constraint on CCS deployment. However, the assessment also shows that the PRC will have to move to CO_2 storage in saline aquifers in the medium term. As those technologies are still at an early stage of development and their demonstration is time consuming, pilot testing has to commence as soon as possible. Appendix 1 shows the location of coal–chemical plants across the Eastern, North eastern, and Northern PRC and the locations of priority CO_2 emission sources and storage sinks.

E. Potential Early-Stage Demonstration Projects

28. For reasons explained earlier, the first CCS demonstration projects in the PRC are expected to be with CO_2–EOR in the coal-chemical sector. Such projects will also need to meet several key criteria. The projects should
    (i) comprise a large-scale coal–chemical process that will provide a high-purity CO_2 source, not less than 100,000 t per year and preferably close to or in excess of 1 $MtCO_2$ per year;
    (ii) be able to demonstrate that CO_2–EOR is technically feasible;
    (iii) provide a CO_2 source and CO_2–EOR location close enough to guarantee economic feasibility; and
    (iv) include the design and implementation of a comprehensive monitoring and verification program to confirm that injected CO_2 will remain stored in the oil field.

29. Since the power sector offers the largest scope for applying CCS, projects with a high level of readiness and in close proximity to a proven CO_2–EOR site should be prioritized for CCS demonstration. Additional selection criteria are low-cost capture and the credibility of project proponents.

30. As part of the Roadmap exercise, CCS demonstration projects under development were screened on the basis of publicly available information. This resulted in a preliminary short list of projects as shown in Appendix 2. The assessment focused on projects that might offer low-cost application opportunities in the PRC. Several coal–chemical projects are included, all with partial or total CO_2–EOR. The basin has a large number of potential storage sites and is also a large energy and chemical base that can provide adequate sources of high-concentration CO_2.

31. One particular region stands out as an early-stage demonstration area. The Ordos Basin region has a high concentration of many coal–chemical plants in close proximity to oil and gas fields amenable to CO_2–EOR. Several large state-owned enterprises are considering large scale demonstration projects in this region. The region has an opportunity to establish an interprovincial cluster of CCS projects with a CO_2 pipeline network around the Ordos Basin oil fields. The pipeline will allow pumping up to 5–10 million t of captured CO_2 per year from coal-fired power plants as well as from coal–chemical plants covering Gansu, Ningxia, and Shanxi provinces. Appendix 2 also shows the location of short-listed projects in the Ordos Basin.

F. CCS-Ready Approach to Future CCS Retrofit

32. To satisfy estimated electricity demand growth in the PRC until 2030, total power generation capacity will increase to about 2,300 GW, with coal expected to provide 1,000-1,200 GW, or nearly half of the total increase. Most of this additional capacity will be built in the next 5–10 years. The new coal-based power plants will be among the largest and most efficient in the world but would still cause an increase in absolute CO_2 emissions. Unless the new plants have specifically kept provisions for future CO_2 capture retrofit and are sited within a reasonable distance of a storage site, they run the risk of becoming stranded assets when unabated coal plants can no longer operate, a highly plausible scenario post 2030 or so. A CCS-Ready design would avoid such risks and allow greater flexibility in the degree and timing of CCS deployment.

(PHOTO CREDIT: SASKPOWER

Boundary Dam Carbon Capture and Storage Project

33. The PRC is shifting the construction of new coal-fired power plants to its Northwestern and Western provinces. The plants will be built in Inner Mongolia, Ningxia, and Xinjiang with a total output of 68 GW of power. The state grid will invest $500 billion in the construction of ultra-high-voltage network to transport the electricity to the east. These power plants will all have nearly identical generating unit design and could be built close to favorable storage sites. They are ideal candidates for CCS-Ready designs. Appendix 3 includes a policy note on the CCS-Ready Policy for the PRC, outlining the rationale, the challenges, and specific recommendations.

IV. WIDER DEMONSTRATION, INNOVATION, AND KNOWLEDGE SHARING TO OVERCOME EARLY-STAGE CHALLENGES

34. Even at this early stage, CCS is cost competitive with other low-emission technologies like solar photovoltaic and offshore wind with regard to the levelized cost of electricity (LCOE) (Section II of Appendix 4 provides financial analysis of prototype CCS projects in the PRC). There is considerable potential for CCS demonstration to drive down costs in the future. However, while none of the individual CCS components—capture, transport, and storage—is complicated, the integration of all components into the entire project chain is complex. Each CCS project is capital intensive and faces major policy, technical, financial, and commercial challenges.

35. **Policy and regulatory challenges.** The NDRC, the National Energy Administration, the Ministry of Science and Technology, the Ministry of Environmental Protection, the Ministry of Land and Resources, and the Ministry of Industry and Information Technology promote various stages of CCS development. However, there is currently no comprehensive national plan, policy, or regulatory framework to facilitate CCS demonstration.
    (i) There is no formal permitting process for CCS projects in the PRC. Potential analogues from the authorization process for thermal power generation, oil and gas pipelines, and oil and gas field development may provide a solution. It has been reported that about 50 clearances or permits are required before the construction of a power plant can begin. CCS storage, clearing, and approval is also expected to be wide ranging and needs to be tested for different storage types, provinces, and settings. To facilitate the implementation of early-stage demonstration projects, it would be helpful if the central government would lead the approval of first-mover projects and work toward an integrated approval process.
    (ii) Explicit regulations for CCS technical and environmental management standards are still lacking. They are required to normalize operations and clarify the liability regarding different aspects of CCS projects to protect the interests of society and the environment. Wider CCS deployment will require specific standards for storage site selection, storage site characterization, environmental impact assessment, and long-term liability. For example, a specialized amendment to the law on requirements and standards of environmental impact assessments could address CCS-specific issues. Sharing knowledge and experience regarding policy frameworks with other CCS countries is important for progress on this agenda.
    (iii) International experience in addressing liability issues of CCS projects has resulted in a variety of approaches. The liability provisions cover transfer of liabilities, certain future liabilities (such as well closure and monitoring activities), and contingent liability (such as environmental impact, cost of CO_2 emission allowances, and remediation cost during a CO_2 leakage event). A takeover of long-term liability for early-stage demonstration projects has been adopted in other countries, notably the US. Such a balanced approach is essential while formulating regulatory needs. Otherwise, excessive regulations may become barriers to early large-scale CCS projects.
    (iv) There has been little public engagement or discussion about CCS and actions to provide related basic knowledge of CCS in the public domain are very limited. No specific regulations have been developed to address information disclosure and public engagement in CCS projects. This lack of information can lead to public apathy regarding CCS, and low levels of public participation in public hearings regarding CCS projects. Inadequate or poor communication can also lead to strong opposition against CCS projects, as has occurred in Germany, the Netherlands, and the US.

36. While technologies for the capture of CO_2 from natural gas processing have been well developed and proven over many years in the petrochemical industry, they have yet to be demonstrated more widely at commercial scale in power plants and in other industrial sectors. International experiences in CCS most relevant for the PRC is very limited. To date, there is one large-scale CCS project applying postcombustion CO_2 capture in operation in the coal-fired power sector in Canada. A precombustion CCS project and a number of other CCS projects in the industrial sector are scheduled to be commissioned in the US by 2016. As none of the currently available capture technologies are assessed to be superior to others, the selection of CO_2 capture technologies for the PRC will depend on several factors, including economic performance, sustainability, reliability, and opportunities to transfer technology and intellectual property rights.

37. **Economic and financial factors.** High costs constitute a major challenge at this early stage of demonstration and deployment.
    (i) High up-front capital investment and higher operating costs for additional energy and water are a result of applying CCS. For this Roadmap, an analysis of the cost impact of alternative first-generation capture technologies on LCOE in the PRC context was undertaken. The analysis shows that (a) LCOE of coal-fired power plants with CCS is cost competitive with that of solar photovoltaic or offshore wind, and (b) CCS combined with CO_2–EOR is the more competitive technology.
    (ii) It is unlikely that costs will come down significantly unless these technologies are demonstrated at a wider scale and are improved further. In addition, intensive research and development efforts in second-generation carbon capture technologies can also lead to major reductions in capital cost and energy penalty as compared with currently available first-generation technologies. A collaborative research approach and international knowledge sharing could accelerate the achievement of cost reductions.
    (iii) CCS demonstration projects must overcome the commercial viability gap between high up-front capital costs and associated incremental operating costs, and lack of additional revenues. Theoretically, revenues can be secured from the industrial production and sale of captured CO_2 for enhanced hydrocarbon recovery or from excess emission allowances (CO_2 avoided) where a market exists. Other forms of CO_2 utilization that do not sequester CO_2 permanently from the release into the atmosphere, cannot be considered as CCS. To date, there is neither a market for CO_2 nor an established price for CO_2 in the PRC. Any business cooperation between CO_2 emitter and user needs to be negotiated individually. Also, the national carbon market is still being developed. For early-stage demonstration projects, the commercial viability gap needs to be covered by an appropriate mix of fiscal and financial support measures from the government. Appendix 4 describes and recommends an adequate mix of such measures.
    (iv) CCS projects are perceived by financiers as high-risk projects with notable technical, market, legal, and regulatory risks. A survey prepared for this Roadmap showed that because the risks involved in such projects, financing terms may deteriorate, leading to an increase of more than 75% in LCOE. The government could facilitate first-mover projects, thereby advancing CCS demonstration and support effective de-risking of such projects. Appendix 4 describes and recommends a role for the government in developing an appropriate risk allocation methodology.

38. **Sustainability** refers to environmental safety issues as well as to the additional energy and water consumption required to implement the CO_2 capture technology, and the impact of any additional pollutant emissions created as a result.
    (i) The long-term safety and integrity of CO_2 storage is linked to the risk of leakage from storage sites. The safety and environmental impact of geological storage related to the risk of CO_2 release falls into two broad categories (IPCC 2005): global effects resulting from the release of stored CO_2 into the atmosphere, and the local environmental and safety impact. Significant leakage from storage sites would reduce the effectiveness and sustainability of CCS as an emission reduction option. Geological storage safety and potential leakage hazards, and mechanisms by which CO_2 can be released have to be studied extensively for each project. Also, each project needs to have a coverage for long-term liability risks.
    (ii) The water footprint of CCS represents a challenge. A recent study concluded that because of (a) increasing water demand, (b) limited water supplies, and (c) poor water quality due to widespread pollution, water scarcity may be one of the greatest development challenges facing the PRC over the next 10–15 years (Zhang and Crooks 2012). In particular, the Northwestern and Western regions of the PRC may have to deal with severe water shortages. Power stations use significant quantities of water primarily for cooling, and current technologies for capturing CO_2 add to that cooling requirement. Therefore, alternative cooling approaches that reduce the water requirement, such as air-cooled condensers, are important features of technology development.
    (iii) The impact of CCS on local air pollution has been discussed in a large body of international literature. The conclusions are: (a) CCS will reduce particulate matter (PM_{10}) emissions by around 50% because of the low emission factors for CCS-equipped power plants; (b) nitrogen oxides (NO_x) and sulfur dioxide (SO_2) emissions are significantly reduced because only very low levels of these chemicals are compatible with the capture solvent and potential corrosion issues within the CCS system have to be avoided; and (c) ammonia (NH_3) emissions are the only instance in which an increase in direct emissions compared with the non-CCS scenario has been anticipated. However, the projected increase of NH_3 emissions is relatively small in comparison with the present level of NH_3 emissions from the agriculture sector.

39. **Reliability** entails assessing the maturity of involved technologies and the challenges and risks to widespread deployment. First-generation capture technologies include precombustion, oxy-fuel, and postcombustion capture. While commercially available in some small-scale industrial applications, at their current state of development these technologies are not ready for widespread deployment in coal-fired power plants. At present, all three major CO_2 capture technology options appear to have opportunities to reach commercial deployment. There is no clear winner among the three technologies, as discussed briefly below.
    (i) **Postcombustion capture** uses chemical solvents such as amines to separate CO_2 from flue-gas streams, and is a commercially available, mature technology. However, the technology is yet to be fully demonstrated in power-plant application, and it is highly energy intensive. The recently completed Boundary Dam project uses this technology and will provide valuable lessons and practical experience in coal-based power plant applications. The postcombustion approach is relatively easy to retrofit. Postcombustion capture plants have proven to be highly reliable, with high availability. Moreover, the energy penalty has reduced by over 50% over the past decades through better heat integration and use of improved solvents.

(PHOTO CREDIT: SHAANXI YANCHANG PETROLEUM (GROUP))

Yanchang Petroleum Corporation's CO_2-EOR demonstration project

(ii) **Oxy-fuel capture** involves burning fossil fuels in a recycled flue-gas stream enriched with oxygen. This process delivers a high-concentration CO_2 stream and eliminates the need for a capture plant. Oxy-fuel technology remains at the development stage, with the focus firmly on coal-fired power plants. A large-scale power plant with oxy-fuel capture is expected to be constructed in the UK in the next few years.

(iii) **Precombustion capture** involves the partial conversion of hydrocarbon fuels into a mixture of hydrogen and carbon monoxide (or syngas), followed by a shift conversion of carbon monoxide with steam to produce hydrogen for combustion and CO_2 for separation. Precombustion capture and power generation using integrated gasification combined-cycle (IGCC) technology has potentially lower capture cost than postcombustion capture but is not suitable for retrofitting. The Kemper County IGCC project with CCS is likely to be put in operation in 2016 in the US, thus further validating precombustion capture in an IGCC power plant setting. This CO_2 capture technology is expected to be applied widely in the medium to long-term in the PRC in polygeneration applications combining coal-chemical production and power generation.

40. **Technology transfer and intellectual property rights.** CCS consists of a combination of different technologies along the process chain. Most CCS technology patent owners are in developed countries and view the establishment of a technology transfer mechanism as a key driver for successful commercial deployment and rapid cost reduction in the PRC (Liu and Liang 2011). NDRC also highlights the importance of knowledge transfer (NDRC 2013). A successful technology transfer process may require financing mechanisms and provisions for intellectual property rights holders. International cooperation is particularly important to jointly achieve the cost reductions of first- and second-generation technologies.

CO_2 injection well of Shengli Oil Field's CO_2–EOR pilot project

(PHOTO CREDIT: SINOPEC SHENGLI OIL FIELD)

V. RECOMMENDED PHASED APPROACH TO THE DEPLOYMENT OF CARBON CAPTURE, AND STORAGE IN THE PEOPLE'S REPUBLIC OF CHINA

41. The analysis prepared for this Roadmap showed that widespread commercial deployment of CCS technologies in the PRC could take about 10–15 years. For this commercial deployment to happen, demonstrating large-scale CCS projects now is critical.

42. This Roadmap has been divided into three phases: the near term describes the 13th Five-Year Plan period, the medium term covers the period between 2020 and 2030, and the long-term refers to the period after 2030. It combines recommended strategy and technology development paths for CCS development with practical policy and regulatory recommendations. The following sections provide specific objectives, strategies, and policy recommendations for these three phases: (i) the 13th plan period (2016–2020); (ii) the expansion phase (2020–2030); and (iii) the commercialization phase (2030–2050).

43. This Roadmap has a number of features to guide CCS implementation. It
    (i) combines a long-term strategy with clear and practical short-term actions that can kick-start CCS demonstration within the 13th plan;
    (ii) focuses on bottom–up approaches to assess readiness before scaling up demonstration, and it acknowledges the importance of successful near-term demonstration that is crucial for any medium- to longer-term uptake of CCS;
    (iii) ensures flexibility in fuel choices for the low-carbon, low-emission development path of the PRC;
    (iv) aspires to be a practical roadmap that can help in gradually overcoming the formidable challenges at this early development stage of a complex technology, to be refined and improved as implementation progresses; and
    (v) suggests targeting a cumulative storage of 10–20 $MtCO_2$ by 2020, 160 $MtCO_2$ by 2030, and 15 $GtCO_2$ by 2050.

44. The cumulative cost of implementing this Roadmap depends critically on the mix of demonstration projects and the scale of projects, and on assumptions regarding the development of other low-emission technologies. The cumulative cost of supporting a buildup of up to 10 large-scale demonstration projects in the coal–chemical sector combined with EOR is expected to range from cost neutral up to CNY6 billion while storing a maximum of 100 $MtCO_2$. If each project captures 90% of the CO_2 emissions on average, the cumulative sequestration from the power sector would be in the order of 95 Mt of CO_2 by 2030 at an average cost of around CNY150/t. Assuming that electricity prices reflect marginal production costs, the impact of such deployment on electricity pricing will be negligible.

A. Recommendations for the Thirteenth Five-Year Plan (2016–2020)

45. **Integrate CCS into the portfolio of low-carbon technologies and set CCS specific targets.** CCS should be fully integrated into the portfolio of low-carbon technologies. The PRC has successfully used targets to speed up the development of renewable energy capacity and energy efficiency improvements. To make necessary experiences and realize essential cost reduction, a critical mass of demonstration projects need to be realized during the 13th plan period. For the 13th plan, the recommended target should therefore consist of implementing 5–10 CCS demonstration projects in the coal–chemical sector and 1–3 projects in the power generation sector by 2020, with a cumulative storage of 10–20 $MtCO_2$ and an incremental oil production of 30–60 million barrels through CO_2–EOR.

46. **Prioritize early-stage demonstration of low-cost capture with CO_2-EOR.** The need for low-cost capture at the early stage cannot be emphasized enough. Coal–chemical plants with CO_2–EOR should be prioritized. In addition, coal–chemical plants going into operation from 2017 onward should be required to assess the feasibility of demonstrating CCS. Large and efficient coal-fired power plants close to a proven CO_2–EOR site should be closely tracked and, where feasible, should demonstrate CCS on a limited basis, i.e., there should be flexibility for plants to try CO_2 capture with EOR of 0.5 $MtCO_2$ per year upward.

47. **Select and endorse priority regions.** The Ordos Basin, the Songliao Basin in Northeastern PRC, the Jungar Basin in Northwestern PRC, and the Tarim Basin in Western PRC all have oil fields that are amenable to CO_2–EOR operations and are therefore good candidate regions. These regions are home to a large number of major coal–chemical plants, which offer low-cost CO_2 capture options and a source for large volumes of inexpensive CO_2 supply. By endorsing these regions as priority regions in the plan, the government can accelerate the demonstration of CCS projects at scale.

48. **Develop and adopt a CO_2–EOR policy.** The government should facilitate the proliferation of CO_2–EOR projects by announcing a CO_2–EOR policy and publishing a standard CO_2 off-take agreement. A specific support policy should accompany the CO_2–EOR policy. A specific CO_2–EOR policy note is included in Appendix 5 of this Roadmap.

49. **Develop and adopt a CCS-Ready policy.** The government should pave the way for CCS demonstration and deployment in the power sector by announcing a CCS-Ready Policy for this sector. A specific policy note with concrete practical recommendations is attached to this Roadmap (Appendix 3). Key recommendations are as follows:
    (i) The government should define CCS-Ready criteria. The large-scale CCS-Ready demonstration project under construction in Guangdong should be used to further refine proposed CCS-Ready criteria and standards.
    (ii) CCS-Ready assessments should be included as a standard component of any new power plant feasibility study. NDRC should have the authority to review and approve these studies.
    (iii) Instead of requiring all power plants to be made CCS-Ready in the near term, it is recommended that the government consider the following:
        (a) The large coal-fired power plants base like the one to be established in Xinjiang Province, should be made capture ready and located in the vicinity of the Junggar Basin or Tarim Basin (up to 200 km) to allow later retrofitting of the power plants with CCS.
        (b) Newly planned supercritical and ultra-supercritical coal-fired power plants within 200 km of a known storage site should be made CCS-Ready.

50. **Provide fiscal and financial support for first-mover projects.** Like many other countries that are moving ahead with CCS demonstration projects, the PRC will need to provide first-mover projects with fiscal and financial support to overcome economic barriers. When more such projects are undertaken, costs will come down, the risk profile will improve substantially, and less direct support will be required. A specific note on how to structure the business model as well as fiscal and financial support measures is included in Appendix 4 of this Roadmap. The following measures should be considered for early-mover projects that advance to construction or completion within the 13th Five-Year Plan period:

(i) **Provide grant support for upstream feasibility assessment.** Front-end engineering design (FEED) studies for early-mover projects can cost up to tens of millions of dollars, even with the CO_2–EOR storage option. The government can seek grant support for flagship projects from multilateral development banks like ADB.

(ii) **Provide loan guarantees for funding from international finance institutions.** The government should support early-mover projects by providing loan guarantees and access to low-cost financing from multilateral development banks. Given the substantial incremental investment required—usually $500 million for the capture facility alone—the government should allow substantial amounts of concessional loan funding or cofinancing by multilateral development banks and similar domestic financial institutions, such as the China Development Bank.

(iii) **Provide tax credits to owners of CO_2 capture equipment.** Reductions in value-added tax and income tax have proven effective in supporting the development of renewable energy in the PRC. Equivalent tax credits should be extended to CCS.

(iv) **Provide a fixed-price program of funding support** to close expected commerciality gaps and provide some revenue certainty, such as a contract based on the CO_2 bank model, which would pay the CO_2 emitter for capturing the CO_2, whether or not the CO_2–EOR or storage operator actually stores the CO_2, or separate agreements with CO_2–EOR operators to support their use of CO_2 in enhanced hydrocarbon recovery (see Appendix 4).

(v) **Recognize incremental oil produced from CO_2–EOR operations as unconventional oil.** Early-mover CO_2–EOR projects that use and effectively store anthropogenic CO_2 should become eligible for subsidies that the government provides for other forms of unconventional hydrocarbons, such as shale gas or coal-bed methane.

(vi) **Provide project support based on payment for CO_2 stored.** At this stage, the government should provide first-mover projects with financial support based on the CO_2 volume successfully stored. Financial analysis prepared for this Roadmap estimated the required financial support for CO_2 stored at about CNY100/t-CNY120/t. If payment for CO_2 of around CNY100/t–CNY120/t is required, government support of CNY60/t–CNY70/t should be considered.

(vii) **Provide a selective financial risk backstop** through a public–private risk-sharing model, as described in Appendix 4.

51. **Formalize the selection of early-stage demonstration projects from a short list.** It is recommended that the government establish an independent panel of industrial experts to work with project developers in gathering the process-related data necessary to assess project viability using key project selection criteria. A robust and transparent selection process could produce a short list of projects from which the more attractive options could be subjected to a FEED study. Once the study is completed and provided there are acceptable results and a financing plan, the government will be able to take well-informed decisions about bankable demonstration projects that can be taken forward. Appendix 4 also describes the proposed project selection process.

52. **Develop a CO_2 storage liability framework.** For early-demonstration projects, the government may take the postclosure liability risk. A more sophisticated regime could then be considered that might include a levy based on CNY/t of CO_2 stored to act as insurance against possible future leakage problems.

53. **Support storage capacity assessment.** The characterization process is costly and time consuming and entails considerable exploration risk, while providing no guarantee of a revenue stream, even if successful. In order for geologic sequestration of CO_2 to be cost competitive with low-emission alternatives, operators of pure CO_2 storage sites are likely to achieve only a low, regulated return for acting as site operator. This could be incompatible with the costs and risks of storage characterization. In this respect, the operator of a CO_2 well has a business investment model unlike that of an investor in a hydrocarbon production well, for whom exploration costs and risks are expected to be offset by high operating profits generated from commodity sales. It is therefore proposed that the government begin the process of a comprehensive storage characterization during the 13th plan period so that sufficient storage can be fully reported at the beginning of Phase 2.

54. **Intensify further RD&D.** The continuation and strengthening of current RD&D support is indispensable for achieving and advancing technology innovation. In the near term, the focus is on research and demonstration of CCS technologies, specifically in the power sector, which has the potential to be the lowest-cost option over the long-term. A research mechanism should promote RD&D, direct investment, a specialized public trust fund for CCS (shaped like similar international CCS public and trust funds focusing on the Clean Development Mechanism), and international cooperation.

55. **Adopt crucial standards and norms for monitoring, reporting, quantification, and verification.** Appropriate greenhouse gas accounting rules should be established to accurately award net emission reductions that are achieved through CCS with CO_2–EOR. In principle, these accounting rules should apply the same criteria as would be applied to a "pure" storage project to ensure equal treatment. The PRC cochairs the development of international standards for CCS under ISO/TC 265, and announcements have been made regarding the development of national standards and environmental oversight. These efforts should be strengthened to promote their early adoption. Standards could first be implemented and tested in pilot and demonstration projects before becoming mandatory for all projects. While environmental regulation should be enforced, the government may choose not to impose penalties for failure to achieve more permanent storage for projects developed before 2020 or thereabouts. This would encourage first-mover projects.

56. **Strengthen public awareness and engagement.** The general public should be educated about the benefits and risks of CCS. The government could require each demonstration project that receives support from the government to contribute to public awareness building. Local communities living in the vicinity of a CCS demonstration project should be consulted with and be made aware of the risks related to environment, health, and safety of the project.

57. **Create a transparent institutional framework.** The roles and responsibilities of relevant regulatory authorities need to be spelled out clearly, and the permitting requirements for CCS projects need to be established early to allow developers to conceptualize projects. It is recommended that CCS regulations be integrated with existing approval processes to avoid additional administrative burden.

B. Recommendations for the Expansion Phase (2020–2030)

58. **Focus on demonstration and commercialization of CCS technologies with relatively high scalability to drive down costs as rapidly as possible.** Given the long-term relevance of CCS projects in the power sector, the government should encourage up to 15–20 large-scale coal-fired power plant demonstration projects of about 1 $MtCO_2$ per year. For early-demonstration projects in the power sector, the government could establish a support program consisting of revenue support, such as feed-in tariff, relief from resource taxes, or contract-for-difference (CfD) for early-demonstration projects.[4] These could be cofunded by the government, the industrial project owner, and international financial institutions, including ADB, and supported with revenue from auctions under the emerging national emission trading scheme. Similar to the support for solar and wind technologies, the incremental cost of a relatively small number of projects would be spread across the overall electricity system.

59. **Support the development of CO_2 pipeline infrastructure.** As the PRC moves into the 14th plan period, a common CO_2 pipeline network could help reduce integration issues and facilitate the buildup of a cluster of CCS projects. The government may consider developing and financing the CO_2 pipeline network. The network operator should be an independent operator offering open access to CO_2 capture plants through a common set of CO_2 off-take agreements. This will strengthen investor confidence, improve economies of scale, and provide the CO_2 supplier and oil field operators with operating flexibility. A similar approach for constructing a high-voltage transmission line in support of wind-farm megaprojects has worked well in the PRC. The CO_2 pipeline network could be organized as a fully state-owned enterprise or as a public–private venture.

60. **Reinforce regulations and support policies.** Over the 14th and 15th plan periods, regulations, support policies, and technical standards for CCS projects and CO_2–EOR operations will need further refinement. A more complete policy framework will need to be established to further encourage CO_2 capture from coal-fired power plants aimed at scaling up CO_2 emission reduction. The following conditions and policies are deemed appropriate for this stage:
    (i) technical and management standards as implemented at the preliminary stage;
    (ii) incentive policies, such as feed-in tariffs, direct tax credits, specialized public and trust fund for CCS (focused on developing a domestic CCS trust fund), participation in an emission trading scheme, a fixed-price policy, loan guarantees, international cooperation, and a certification system for CCS; and
    (iii) public engagement through the disclosure of basic information about CCS projects by both government and CCS project management, and the establishment of efficient public engagement platforms for public participation.

61. **Strengthen governance of storage sites after closure.** Rules should be established to govern site abandonment and long-term stewardship of injected and stored CO_2 as a result of CO_2–EOR operations for early-stage demonstration projects. Monitoring mechanisms and well status requirements for oil and gas reservoirs, particularly for CO_2–EOR, including the baseline conditions for

4 In a CfD, a power generator sells electricity at the underlying market price; government underwrites the difference between that price and a pre-agreed level. The contractual structure of this arrangement can allow the government to receive a rebate if the commercial price rises above the pre-agreed level.

CO_2 storage, should be clarified. The issue of jurisdictional responsibility for pure CO_2 storage in oil and gas reservoirs, with regard to national–subnational jurisdictions and organizational jurisdictions (environment versus development ministries or departments), must also be addressed.

62. **Continue support for RD&D.** By 2030, the primary objective will be cost reduction through technology innovation and replication. The energy penalty should be reduced significantly (potentially to below 5%), and technologies should be commercially competitive for large-scale deployment in a low-emission environment. Technologies such as chemical looping and poly-generation are expected to become commercially viable at that time.

63. **Updating of the CCS Roadmap.** To ensure the relevance of this Roadmap as a "living document" it will need to be adjusted for the 14th plan in 2019 and subsequent five-year plans in accordance with global and PRC-specific progress on CCS.

C. Recommendations for the Commercialization Phase (2030–2050)

64. Economy-wide and globally consistent climate change policies such as the national emissions trading scheme (to be operational from 2017) are expected to drive the commercial deployment of CCS and of all low-emission technologies. The government will need to monitor and address any market failures or barriers to effective and efficient deployment.

D. Next Steps

65. This Roadmap suggests a way forward for policy makers in the PRC to help the country achieve its long-term climate change objectives at lowest cost with the help of CCS technologies. Consulting with the widest possible range of stakeholders in the PRC can ensure support and adoption of the Roadmap. As with any other roadmap, immediate next steps are clearer and more specific than later ones. The Roadmap provides a long-term vision and charts out the direction in the long run. Specific policy actions will need to be adapted to emerging new circumstances over time, factoring in new information and identified lessons.

66. These next steps are recommended with regards to the Roadmap:
    (i) Publish this Roadmap and disseminate it to a wide group of stakeholders to mobilize support for its implementation.
    (ii) Initiate discussions with policy makers to secure endorsement of key findings and recommendations and include them in the PRC climate change policy framework.
    (iii) Set appropriate targets for immediate early-stage demonstration projects and later up-scaling within the policy framework recommended in this Roadmap.
    (iv) Initiate a process for the short-listing and selection of early-stage demonstration projects ready for FEED studies.
    (v) Develop a policy and regulatory framework using information from this Roadmap as input and considering the actual policy environment at the time. The framework needs to include arrangements for facilitating CO_2–EOR and to determine whether power plants being built from the start of the 13th plan should be required to be CCS-Ready.
    (vi) Learn from international experience (Appendix 6).

APPENDIXES

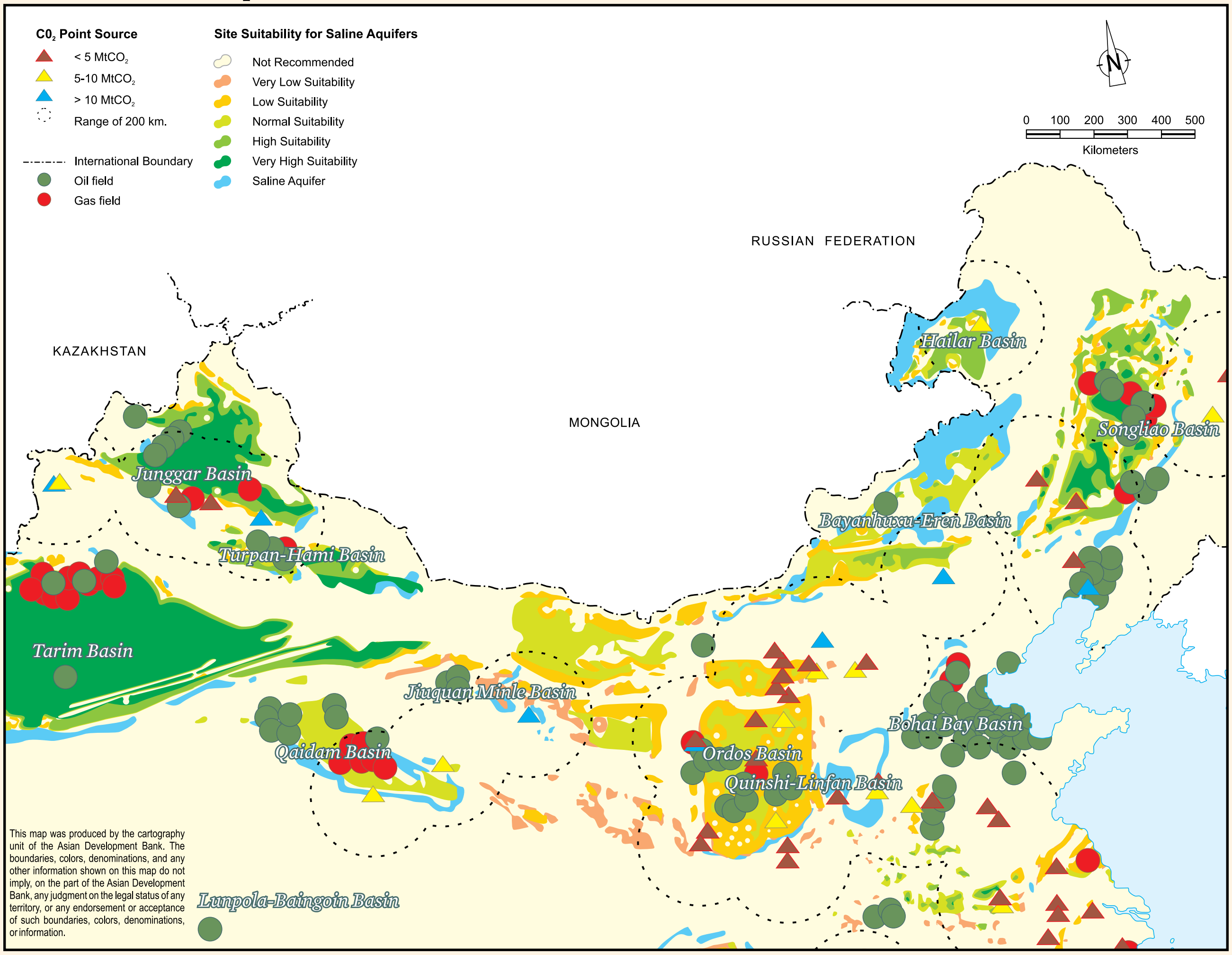
Appendix 1

Locations of Priority Carbon Dioxide Emission Sources and Storage Sinks in the People's Republic of China

1. Coal–chemical plants have been widely established across the Eastern, Northeastern, and Northern regions of the People's Republic of China (PRC). As sector rationalization takes hold, the location focus for new very large capacity units will be the Northern, Northwestern, and Western PRC, in particular the Inner Mongolia Autonomous Region, and the Ningxia, Shaanxi, and Xinjiang provinces. These provinces share the important Ordos Basin and many coal–chemical industries are located in these regions. Moreover, many opportunities for enhanced hydrocarbon recovery are available there in the near to medium term.

2. At the same time, mega coal-fired power plants are likely to be built in these regions to offset the shutting down of coal-fired power plants in the three key environmental areas of Beijing–Tianjin–Hebei, the Yangtze River delta, and the Pearl River delta. This will create opportunities for the demonstration carbon capture, utilization, and storage (CCUS), and the development of CCUS project clusters. Figure A1 gives a geographic overview and includes the large-scale CO_2 point sources, among them, the existing and future coal–chemical plants and power plants that are within 200 kilometers (km) of favorable storage sites.

Figure A1: Priority CO_2 Emission Sources and Storage Sinks in the PRC



CO_2= carbon dioxide km= kilometers, $MtCO_2$= million tons of carbon dioxide.
Source: ADB (2014d).

3. According to the source–sink matching situation, about 60% of large-scale point sources with high purity are within 200 km of favorable storage sites. Five areas can be considered priority areas, as shown in Table A1.

Table A1: Matching of Priority Basins and Storage Sinks in the PRC

Priority Area	Storage Sink
Ordos Basin[a]	Changqin oil field
Bohai Bay Basin[b]	Jidong, Shengli oil fields
Songliao Basin	Liaohe oil field
Jiangsu–Southern South Yellow Sea Basin	Jiangsu oil field
Xinjiang area	Qinghai, Tarim, Tuha oil fields

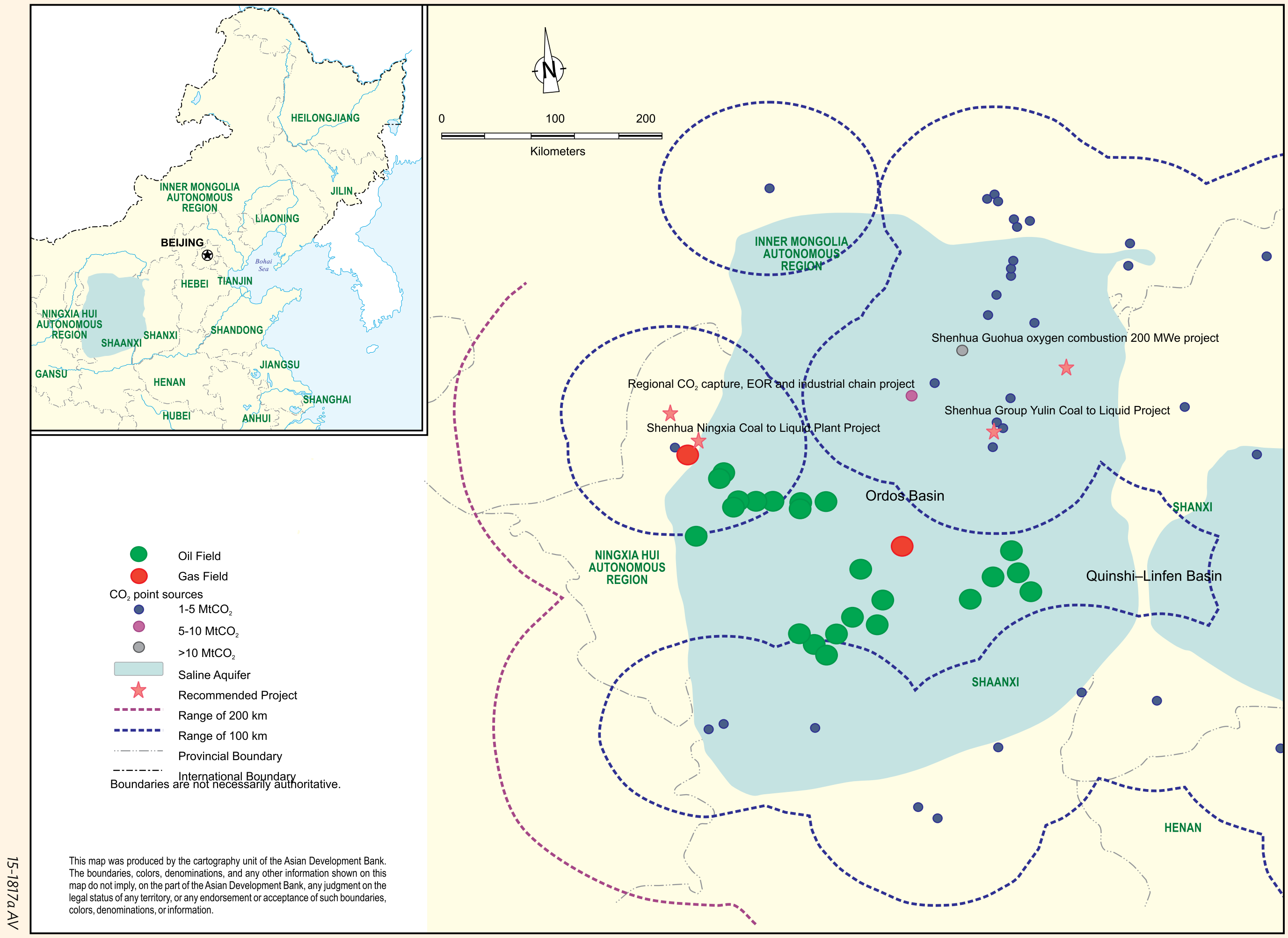
[a] Shaanxi Yulin, 2–3 million tons per year of planned storage in onshore oil or gas reservoirs; Ningxia, 2 million tons per year enhanced oil recovery planned; Ordos Basin, saline aquifer storage planned.
[b] Shengli oil field, enhanced oil recovery as primary storage option.
Source: ADB (2014d).

Appendix 2

Potential Early-Opportunity Carbon Capture, Utilization, and Storage Projects in the People's Republic of China

1. Figure A2 shows the location of potential early opportunity carbon capture, utilization, and storage (CCUS) projects in the Ordos Basin of the People's Republic of China (PRC). Table A2.1 lists the oil fields in the various priority CCUS areas and their distance to the nearest storage or utilization site.

Figure A2: Potential Early-Opportunity Projects in the Ordos Basin



km= kilometer, $MtCO_2$= million tons of carbon dioxide.
Source: ADB (2014d).

Table A2.1: Early-Opportunity CCUS Demonstration Projects in the PRC's Ordos Basin

Priority Area	Storage Sink	CO_2 Transportation Distance (km)
CCUS demo project of Yulin Energy and Chemical Group in Shaanxi Province	Jingan oil field	<50
	Ansai oil field	<50
	Yanchang oil field	150–200
	Huachi oil field	150–200
Yulin Coal-to-Liquid Project	Jingan oil field	150–200
	Ansai oil field	150–200
	Yanchang oil field	>200
Ningxia Coal to Liquid Plant Project	Lizhuangzi oil field	50–100
	Majiatan oil field	50–100
Regional CO_2 capture, EOR, and industrial chain project	Lizhuangzi oil field	50–100
	Majiatan oil field	50–100

CCUS = carbon capture, utilization, and storage; CO_2 = carbon dioxide; EOR = enhanced oil recovery; km = kilometer. PRC = People's Republic of China.
Source: ADB (2014e).

2. Table A2.2 lists potential early-stage demonstration projects in the power sector that either have reached a certain level of project readiness or are supported by key organizations, which allow them to materialize during the 13th Five-Year Plan period.

Table A2.2: Potential First-Mover Demonstration Projects in the PRC's Coal-Fired Power Sector

Project Name	Storage Site	CO_2 Transportation Distance (km)
200 MW Oxy-fuel Combustion Demonstration Project	Jingan oil field	>200
	Ansai oil field	>200
Shengli Oil Field Phase 2 Project	Songliao Basin	<50
Guandong Province Resources Power–China National Offshore Oil Corporation Project	Pearl River Mouth Basin	>200 (offshore)

CO_2 = carbon dioxide, km= kilometer, MW = megawatt, PRC = People's Republic of China.
Source: ADB (2014e).

Appendix 3

Carbon Capture and Storage-Ready Policy to Facilitate Future CCS Deployment in the People's Republic of China[1]

Key Messages

- Carbon capture and storage (CCS) is now the only proven technology that allows up to 90% reduction in carbon dioxide (CO_2) emissions from coal-fired power plants. The Asian Development Bank (ADB) supported Roadmap for Carbon Capture and Storage Demonstration and Deployment in the People's Republic of China (PRC) takes the view that large-scale CCS deployment is essential in achieving cost-effective CO_2 mitigation.

- CCS is still at an early stage of demonstration in the PRC because of the lack of economic drivers like an adequate price for carbon and the perceived risks associated with a complex technology. Early CCS demonstration is absolutely crucial and will most likely consist of a gradual learning process to build confidence in the technology before moving to the subsequent large-scale uptake.

- During this process of early demonstration and learning, a large stock of new coal-fired power plants with an estimated capacity of 100 gigawatts (GW) is likely to get built by 2020. If these new power plants are not made Carbon Capture and Storage-Ready, they will be constrained by high CO_2 emissions, which could put them at risk of becoming stranded assets in the future beyond 2030 or so.

- It is recommended that a new coal-fired power plant be mandated as CCS-Ready and that the following phased approach be adopted (i) in 2015, define CCS-Ready criteria, clarify approval and permitting authorities, and integrate the necessary additional regulations into the existing regulatory framework; (ii) from 2015 to 2016, stipulate that large power plants planned in the Northwestern and Western PRC be designed to be CCS-Ready; and (iii) stipulate that all new power plants to be constructed within 200 km of an oil field be designed to be CCSR.

- The introduction of a CCS-Ready policy is expected to increase capital costs of large coal power plants by less than 0.3%—an insignificant impact on the cost or financial performance of the CCS-Ready plant.

I. Introduction

1. CCS-Ready is a crucial policy imperative for the PRC to avoid locking its future coal-fired power plants into a high CO_2 emission trajectory, or putting them at risk of becoming stranded assets in a much anticipated carbon-constrained future. CCS-Ready is an effective way of ensuring low-carbon coal power deployment that can complement the PRC's current low-carbon development strategy, which is based on accelerated energy efficiency improvements, renewable energy, and nuclear power deployment.

1 This appendix was published as a stand-alone policy note as part of ADB's Observations and Recommendations publication series. It was submitted to the Government of the PRC in January 2015.

2. Coal use is expected to continue to dominate the power generation sector in the PRC.[2] In the next 15 years, an additional 400 GW of new power generation capacity is expected to be built. While these new coal-fired power plants will be some of the largest and most efficient in the world, resulting in reduced carbon intensity in the power sector, they will cause an annual increase of more than 2 gigatons of CO_2 emissions in absolute terms. This will undermine the PRC's efforts to develop a low-carbon energy system. Hence, achieving deep decarbonization while maintaining economic growth at desired levels makes a compelling case for the introduction of CCS into coal-fired power plants.

3. Adding CCS to coal-fired power plants increases capital investment costs by 25%–90% and operating expenditures by 5%–12%. A single project would typically cost between $500 million and $1 billion, depending on the size of the power plant. However, with continued research and CCS demonstration on 50 GW of coal-fired power plants, accounting for 5% or less of the PRC's current installed coal-fired generation capacity, these costs could be more than halved.

4. Existing power plants can potentially be fitted with CCS. However, retrofitting plants with CCS technology may prove technically and economically viable only if provisions have been made for that option at the design stage. Successful retrofitting requires (i) adequate space for an appropriate CO_2 capture technique that can be technically integrated with the power plant; (ii) a pipeline connected to the plant to carry the captured CO_2 from the source to a certified geological storage-ready site or a utilization location while avoiding areas of high population density; and (iii) one or more storage sites that are technically capable of, and commercially accessible for, geological storage of the captured CO_2 volumes.

5. This policy note examines major challenges and constraints of CCS-Ready. It provides recommendations for applying CCS-Ready as a means of ensuring the subsequent CCS retrofit of coal-fired power plants in the PRC.

II. Challenges and Constraints

A. Technical Challenges

6. **Need to define CCS-Ready criteria.** The Global Carbon Capture and Storage Institute (GCCSI) has established a comprehensive set of CCS-Ready criteria.[3] As GCCSI has stressed, these criteria will need to be adapted to a country's particular situation. The challenge is to strike the right balance between ensuring that the total costs of designing a plant CCS-Ready are minimized and establishing a credible CCS-Ready approach. Lower requirements allow a higher degree of design flexibility and limit the costs for developers at the design stage but also reduce the credibility of the CCS-Ready approach. However, developers in the PRC still lack critical information, such as details of locations and characteristics of suitable CO_2 storage sites and possible CO_2 pipeline locations.

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2 In 2013, energy intensity had improved by about 32% over the 2005 level. Coal-based power plants still supplied 80% of the PRC electricity in 2013, compared with less than 5% from wind and solar combined.

3 GCCSI. 2010. *Defining CCSR: an approach to an international definition.* Canberra. http://www.globalccsinstitute.com/publications/defining-ccs-ready-approach-international-definition

B. Policy and Regulatory Challenges

7. **Need for a regulatory framework for CCS-Ready.** The adoption of the CCS-Ready approach can be applied successfully only within a policy and regulatory framework that provides a thorough and widely recognized foundation for CCS-Ready plant requirements. For a power plant to be designated as CCS-Ready, it would have to be capture–ready, transport–ready, and storage–ready. All three components are interrelated and need to be integrated for the successful deployment of CCS.

8. **Absence of unified CCS-Ready regulations.** Some provinces in the PRC already appear to be applying various types of policies that could be broadly considered CCS-Ready. While such initiatives are commendable, no consistent approach has been adopted yet. It is important for the Government of the PRC to define and apply unified regulations. CCS-Ready requirements must be clearly spelled out and the baseline for assessments described in detail to make the approval process fair and transparent for project developers.

9. In the **absence of CCS-Ready related environmental, safety, and other government-defined standards,** developers cannot confidently establish CCS-Ready power plants.

C. Commercial Challenges

10. **Need for up-front investments in plant design.** Designing a CCS-Ready plant will involve up-front investments in additional space to allow for the future retrofitting of the plant and for additional engineering, cost estimate studies, and assessments of CO_2 transport and storage possibilities. Experience in the United Kingdom shows that the additional cost is less than 0.1% of the capital cost for a new 1,600 megawatt coal-fired power plant, and about 0.3% of the capital cost for a new 800 megawatt gas-fired power station. Available studies suggest a similar percentage of additional cost in the PRC.

11. **Lack of economic incentives.** To succeed, the implementation of a CCS-Ready approach must be policy driven, backed by the government, and include economic incentives to ensure the CCS retrofit of previously installed plants. Currently, economic incentives like a nationwide carbon price or a carbon tax have not yet been introduced.

III. Policy Recommendations

Thirteenth Five-Year Plan Period (2016–2020)

A. Addressing Technical Challenges

12. **Set CCS-Ready criteria.** Clear CCS-Ready criteria that address the various requirements for CO_2 capture–ready, transport–ready, and storage–ready power plants need to be established. A recent ADB study[4] suggests the following recommendations regarding such criteria, which could be adapted to suit conditions in the PRC.

4 ADB. 2014a. *Study on Carbon Capture and Storage on Natural Gas-Based Power Plants*. Consultant's Report. Manila (TA 8001-PRC).

(i) CO_2 capture–ready guidelines are recommended to

(a) give developers the freedom to choose their preferred CO_2 capture technology;

(b) identify key equipment for the CO_2 capture and compression plant in and integrate it into the design of the power plant;

(c) define a minimum percentage of CO_2 to be captured from the flue gas, which will determine the additional land footprint that must be secured to allow for the retrofit;

(d) require a plant design that will provide sufficient space to integrate the capture and compression plant as well as additional piping and access roads to these plant components;

(e) require developers to (1) review whether municipal regulations necessitate adjustments in the plant design to comply with a maximum height limit for the equipment; (2) assess additional water needs and ways of recycling the cleaned water; and (3) work with concerned authorities to ensure the allocation of additional water to the plant at the same time it is retrofitted with CCS—if additional water is not available through traditional means, techniques like coal drying and water production from underground sources should be evaluated;

(f) provide guidelines on the treatment of additional wastewater from the CO_2 capture plant; and

(g) ensure that additional risks from capturing CO_2 can be assessed.

(ii) CO_2 transport–ready guidelines are recommended to

(a) require the project developer to (1) choose the technology that guarantees safe transport of liquefied CO_2 from the power plant to minimize social health and environment risks; (2) identify a feasible transport route for the CO_2 to the envisaged utilization or storage site to avoid conflicts over rights-of-way on surface and subsurface land; and (3) establish key design parameters for the transport system, such as transport capacity, pipeline length, pressure, and operating temperature, taking into account the need to meet CO_2 quality specifications;

(b) encourage the developer to explore the option of a pipeline network that links various large CO_2 point sources to reduce unit costs;

(c) ensure that risks from potential low-probability, high-consequence pipeline failure events can be addressed; and

(d) complement the technical feasibility analysis for the power plant with a preliminary economic analysis for transport facilities.

(iii) CO_2 storage–ready guidelines are recommended to

(a) require the developer to identify geological locations that are commercially accessible and technically able to store the full volume of captured CO_2;

(b) provide guidelines on the selection of suitable formations for CO_2 injection and storage, including (1) adequate depth, (2) adequate confining layers, (3) adequate CO_2 storage capacity of formations, and (4) adequate location, avoiding close proximity to urban agglomerations or protected sites of historic or natural value;[5]

5 Footnote 4.

(c) require any conflicting surface and subsurface land uses at the storage site to be identified and addressed;
(d) complement the technical feasibility analysis for the power plant with a preliminary economic analysis for storage, taking into account third-party liability insurance and CO_2 monitoring and verification costs; and
(e) facilitate the preparation and publication of a comprehensive CO_2 storage atlas for the PRC.

B. Addressing Policy and Regulatory Challenges

13. In 2016, the government would need to clarify the roles and responsibilities of relevant regulatory authorities and establish permitting requirements as well as environmental regulations for CCS to allow developers to plan a future retrofit. It is recommended that CCS-Ready regulations be integrated with existing approval processes to avoid additional administrative burden.

14. After the initial regulatory measures, it is recommended that a selective CCS-Ready approach to be adopted in the power sector. The PRC intends to establish a series of mega-coal power bases in Xinjiang Uighur Autonomous Region, Inner Mongolia Autonomous Region, and Shaanxi and Ningxia provinces, with the objective of providing a total of 68 GW of power. It is recommended that these plants be made at least CO_2 capture–ready, with an identified transport route to nearby oil fields that will be suitable for enhanced oil recovery or storage. These coal-fired power plants of a certain capacity (at least 2 GW) should be within 200 kilometers of a major oil field or a known storage site.

15. Ensuring compliance is a necessary and important part of policy implementation. Methods for verifying compliance should be decided by the regulators and may cover the following: (i) CCS-Ready compliance for new plants at the design stage, after the plant has been built, and during plant operation; and (ii) review and planning of intended design changes in existing plants that comply with CCS-Ready requirements.

C. Addressing Commercial Challenges

16. Power plant developers should be allowed to recover additional costs for making a plant CCS-Ready by introducing an enhanced pricing mechanism for electricity from a CCS-Ready power plant. Such price increase will be almost negligible since the incremental capital investment is very small.

17. Developers of plants should be asked to maintain CCS-Ready planning documents for defined time periods and to report periodically on the CCS-Ready status of plants, for example, every 4 years.

Beyond the Thirteenth Five-Year Plan (2021–2030)

18. Some CCS-Ready plants are expected to be retrofitted with CCS much earlier than others. Such early CCS retrofitted plants will provide valuable lessons for the government when it formulates policies that require other plants to be retrofitted within a certain time frame.

19. Once the point is reached where a CCS-Ready plant needs to be retrofitted with CCS, the government will need to provide it with incentives within the power dispatch system by prioritizing it in the merit order of dispatch vis-à-vis coal-fired power plants without CCS. The additional capital investment for the CCS equipment would be better recovered through plant operation at base load, which would also provide the conditions best suited for CO_2 capture.

20. Depending on the identified lessons from introducing CCS-Ready into coal-fired power plants, the government could consider including CCS-Ready requirements in the approval process of industrial sectors like iron, steel, and cement, which consume significant quantities of coal and cannot readily use alternative fuels because of the nature of their production processes.

Appendix 4

Illustrative Financials, Financial Support, Business Structure and Project Selection to Facilitate the Demonstration of Early-Mover CCS Projects in the People's Republic of China

I. Introduction

1. The Roadmap for Carbon Capture and Storage (CCS) Demonstration and Deployment in the People's Republic of China (PRC) recommends the development of 5 to 10 early-stage opportunities in the coal–chemical sector and one to three projects in the power sector during the 13th Five-Year Plan period, 2016–2020. The successful implementation of these projects and their ability to advance the development of CCS in the PRC will depend not only on the choice of the technology or sector in which these projects will be implemented, but also on (i) the type of available fiscal and financial support mechanisms; (ii) the selected business structures and their implementation; and (iii) the process of selecting projects for support. This appendix contains financials of prototype CCS projects and recommendations on how the government should structure and support such early-stage demonstration projects, and it outlines a proposed project selection process. The recommendations (Table A4.1) draw on international experience and propose solutions that are adapted to the PRC context.

Table A4.1: Summary of Recommendations for Carbon Capture and Storage Demonstration Project Structuring, Support, and Selection

Item	Recommendation
Financial support measures	• Access to concessional finance through development bank loans • Access to tax concessions now available to new energy technologies • Fixed-price program of funding support to close expected commerciality gaps and to provide an element of revenue certainty • CO_2 transportation pipeline infrastructure by government • Storage characterization program undertaken by government to secure sufficient storage sites for Phase 2
Business structures	• Private sector assumption of technical and operational risks under build–own–operate model • Comprehensive government framework for addressing legal and regulatory risks • Partial underwriting by government of revenue and counterparty risks
Project selection	• Projects assessed against predefined criteria • Two-stage process with initial assessment based on pre-feasibility study documents • Final assessment based on project FEED studies • Capital grant support to be provided for pre-final investment decision FEED studies • Rolling selection process

CO_2= carbon dioxide, FEED= front end engineering and design.

2. These recommendations are examined in detail below. While this appendix provides high-level observations about the second phase of CCS roadmap implementation, lessons learned from early stage in CCS demonstration can be expected to shape the details of the implementation plans for the succeeding phase.

II. Illustrative Financials for Prototype Carbon Capture and Storage Projects

3. In order to examine the potential impact of financial support measures on CCS project viability, four generic CCS projects are considered, three power based and one coal-to-liquids facility:

    - Integrated Gas Combination Cycle (IGCC) Plant – 430 megawatts (MW);
    - Pulverized Coal Plant (PC) – 600 MW;
    - Oxy-fuel Combustion Plant – 200MW; and
    - Coal-to-Methanol Facility – 1,100 tons per day (methanol).

4. A dynamic discounted cash flow model has been developed in order to evaluate the impact of financial support mechanisms on the overall costs and revenues of CCS (including transport and storage) for each of the respective project scenarios. The model uses a Levelised Cost of Electricity (LCOE)[6] methodology, which indicates the price at which electricity (or methanol in the coal-to-liquids scenario) must be sold to make the project economically viable, while taking into account the full capital, operating and financing costs of building and operating each respective facility. The model is also capable of accommodating a selection of financing instruments (e.g. debt and equity from government, private investors or banks) and support mechanisms (e.g. capital cost subsidies, operating cash flow support and risk mitigation). A Debt Service Coverage Ratio (DSCR) constraint has also been incorporated to ensure that each respective project has sufficient cash flow to meet its debt service requirements.

5. **Reference Plant Technical Parameters and Cost Data.** The reference configuration is based on data acquired that details the respective IGCC, PC, oxy-fuel and coal-to-methanol facilities in the PRC. For the purpose of comparison for each technology "with" (called "w/CCS") and "without" CCS (called "No CCS") scenarios were developed. The "w/CCS" cases assume that 90% of produced carbon dioxide (CO_2) is captured and transported by pipeline 100 kilometers (km) for either long-term storage or for beneficial reuse in CO_2–enhanced oil recovery (EOR). Detailed reference plant technical parameters are shown in Table A4.2.

6 Levelised Cost of Electricity defined as the average price at which electricity generated in the plant under consideration would need to be sold over the projected project lifetime such that investors receive their expected returns (measured in $/MWh). This includes covering the capital expenditure,operating costs (fixed, variable and fuel costs), cost of CO_2 transport and storage, and the cost of capital (debt service and return to equity investors).

Table A4.2: Summary of Carbon Capture and Storage Reference Plant Technical Parameters

PLANT PROFILE	IGCC		Pulverized Coal		Oxy-fuel		Coal-to-Liquids	
	No CCS	w/ CCS	No CCS	w/ CCS	No CCS	w/ CCS	No CCS	w/ CCS
Gross Power Output (MW)	430	426	600	600	200	200		
Net Power Output (MW)	375	326	570	389	186	89		
Gross Methanol Output (Mt)							412,040	412,040
Net Plant HHV Efficiency / Rate	43.9%	35.9%	41%	28%			44.5%	44.5%
CO_2 Generated ($MtCO_2/yr$)	2.1	2.1	4.1	4.1	0.9	0.9	1.6	1.6
CO_2 Emitted ($MtCO_2/yr^2$)	2.1	0.2	4.1	0.4	0.9	0.1	1.6	0.16
CO_2 Captured ($MtCO_2/yr^2$)		1.9 r		3.7		0.8		1.4
Emission Intensity (tCO_2/MWh) or (tCO_2/t Methanol)	0.67	0.067	0.89	0.0089	0.92	0.0092	3.8	0.38
CAPEX								
Total Capital Cost (CNY Million)	3,698.3	4,229.4	2,778.8	3,417.0	946.6	1,153.1	2,358.2	2,539.5
OPEX								
Variable O&M (CNY/MWh)	0.15	0.15	0.15	0.15	0.62	0.60		
Fuel Costs (CNY/GJ)	21.87	21.87	21.87	21.87	21.87	21.87	21.87	21.87
Fixed O&M (CNY Million)	159.4	172.6	111.2	136.7	54.9	94.3	94.3	101.6
Macro & Other								
Inflation / Fuel Price Escalation	2%							
Tax Rate	25%							
Risk Free Rate	4.60% (10 year US Treasury-bill)							

CNY = yuan, CNY/GJ = yuan per giga-joule, CNY/MWh = yuan per megawatt-hour, CO_2 = carbon dioxide, HHV = higher heating value, MW = megawatt, Mt = million ton, $MtCO_2/yr$ = million ton of carbon dioxide per year, O&M = operation and maintenance, tCO_2/MWh = ton of carbon dioxide per megawatt-hour
Source: ADB (2014c).

6. **Transport and Storage Costs.** Table A4.3 below is summarizes capital and operating costs for transport and storage in the reference case scenario. It is assumed that at a distance of 100 km or less, no additional booster stations would be required. For both the base case w/CCS scenarios, it is assumed that each facility will capture 90% of its respective CO_2 emissions per year, and that captured emissions will be transported an injected into a saline aquifer for long-term storage.

Table A4.3: Transport and Storage Costs

Financing Scenarios	Capital Costs	Fixed / Variable O&M
Transport (14 inches 100km pipeline)	CNY 474.7 million	3%/0.025MWh/tCO_2
Storage (5 wells–Saline Aquifer)	CNY 434 million	10%

CNY = yuan, km = kilometers, MWh/tCO_2 = megawatt-hour per ton of carbon dioxide
Source: ADB (2014c).

7. **Base Case Financing Scenarios.** The "Base Case" financing scenario developed incorporates input from financial institutions and project proponents. The resulting LCOE for the underlying facilities was chosen as the reference for comparing various financial incentives.

8. While it is possible that some early CCS projects, particularly in non-power applications, will be financed through corporate balance sheet facilities, this analysis considers projects financed on a limited-recourse basis in order to separate corporate and project-specific effects. The Base Case structure seeks to optimize the cost of finance for each component of the chain and assumes that the Base Plant and Capture, Transport and Storage are financed as separate entities, reflecting their individual business models and risk profiles. Again, it is possible that an integrated project with a single lead developer may be financed on an overall basis.

9. Based on discussions with industry stakeholders, it has been assumed that a traditional power generation project with no CCS can be financed with up to 80% leverage. The real and perceived risks associated with early CCS projects, however, are likely to limit the leverage available with 70% leverage being indicated as a maximum. An interest rate of 6.5% for projects without CCS is consistent with the current lending environment in the PRC. For the purpose of this analysis, it is assumed that projects with CCS will be eligible for the 0.55% interest rate deduction, currently mandated for clean energy projects. In the Base Case, remaining financing is assumed to come from an equity contribution by the project developer. Discussions with various stakeholders indicate that projects would need to earn an Internal Rate of Return (IRR) on equity of 12% in order to attract investment, while the equivalent plant without CCS would require an equity return of approximately 9.5% (calculated as a 3% premium to the nominal debt interest rate). The analysis does not take into account any fees or transaction costs relating to sourcing financing as arranging fees for finance are not standard practice in the PRC. Financing scenarios are summarized in Table A4.4 below.

Table A4.4: Base Case Financing Scenarios

	Power		Coal-To-Liquids	
	No CCS	w/ CCS	No CCS	w/ CCS
Total Leverage	80%	70%	80%	70%
Interest Rate	6.5%	5.95%	6.5%	5.95%
Debt Tenor	18 years	12 years	18 years	12 years
Min. DSCR	1.4 times	1.6X	1.4X	1.6X
Return on Equity	9.5%	12%	9.5%	12%
WACC	5.41%	6.67%	5.41%	6.67%

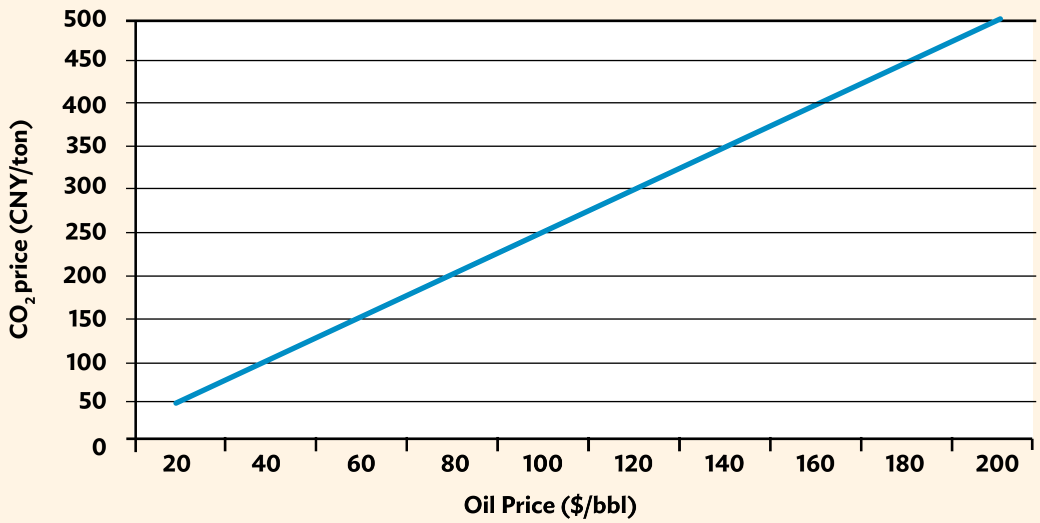
DSCR = debt service coverage ratio, WACC= weighted average cost of capital, w/ CCS = with carbon capture and storage
Source: ADB (2014c).

10. **CCS and LCOE.** The impact on LCOE due to changes in financial terms is significant. The deterioration of financing terms alone may lead to an increase in LCOE of more than 20%, compared to a project with access to finance at the same terms as a plant without CCS. This implies that to reduce LCOE for first-mover projects, the government could support them by supporting effective de-risking of such projects.

11. **Impact of CO_2–EOR on Base Case Costs.** CO_2–EOR is a 30-year-old practice used widely in the Permian Basin of Texas and the Gulf Coast region of the United States (US). CO_2–EOR is a tertiary stage of oil recovery whereby, under the right geological conditions, CO_2 can be injected into mature fields and result in significant volumes of incremental oil production. While conventional oil production practices can typically produce roughly 35-50% of an oil reservoir's original oil in place (OOIP), can yield an additional 5-17% of OOIP. CO_2–EOR in the PRC, many demonstration projects have utilized technologies of utilization of captured CO_2, such as PetroChina's CO_2–EOR Research and pilot Injection in Jilin Oilfield, China United Coalbed Methane Co. Enhanced Coal-Bed Methane Pilot Project, and Jinlong-CAS CO_2 utilization pilot in chemical production in Jiangsu.

12. While the market price for CO_2 utilized in EOR in the US is impacted by the prevalence of naturally occurring CO_2 sources, the price (in units of million cubic feet) is seen to be tied to roughly 2%-3% the price of oil, with most long-term contracts being written in the range of $20-30/ton of CO_2.[7] Consultations with statekolders on the PRC indicated that this relation would also hold in the PRC. The projected relationship is highlighted in Figure A4.1 below:

Figure A4.1: Estimated relationship between Oil Price and CO_2 Sale Price in the PRC

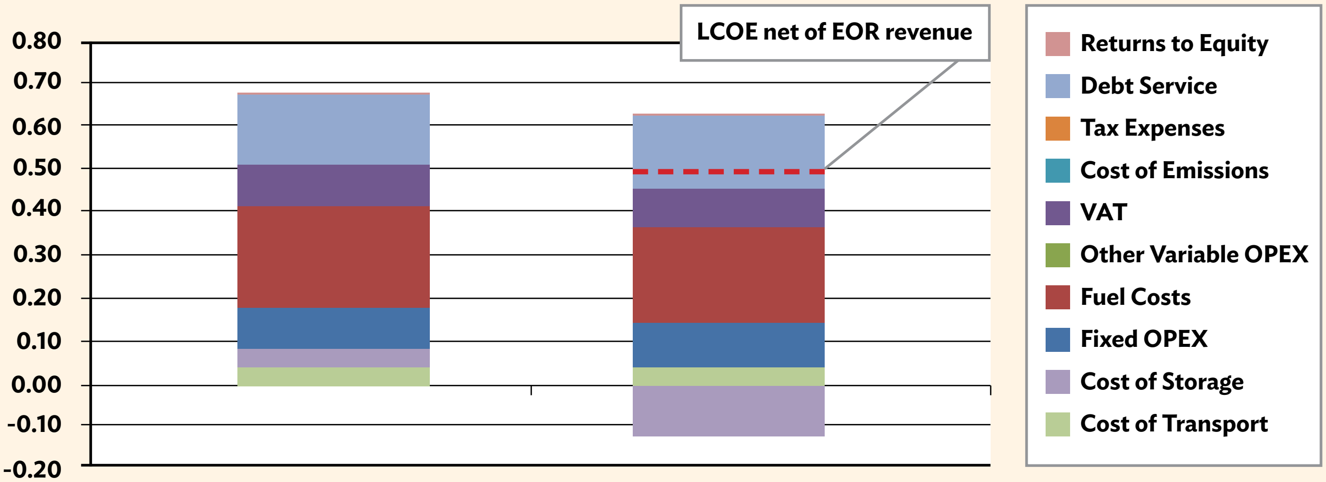


Source: ADB (2014c).

7 http://www.netl.doe.gov/energy-analyses/pubs/Storing%20CO2%20w%20EOR_FINAL.pdf

13. In early-mover CCS projects, project revenues from CO_2 sales can be used to offset capture costs. Figure A4.2 below shows the positive of year one cash flows, not only eliminating storage costs, but also providing a revenue stream to offset other costs.

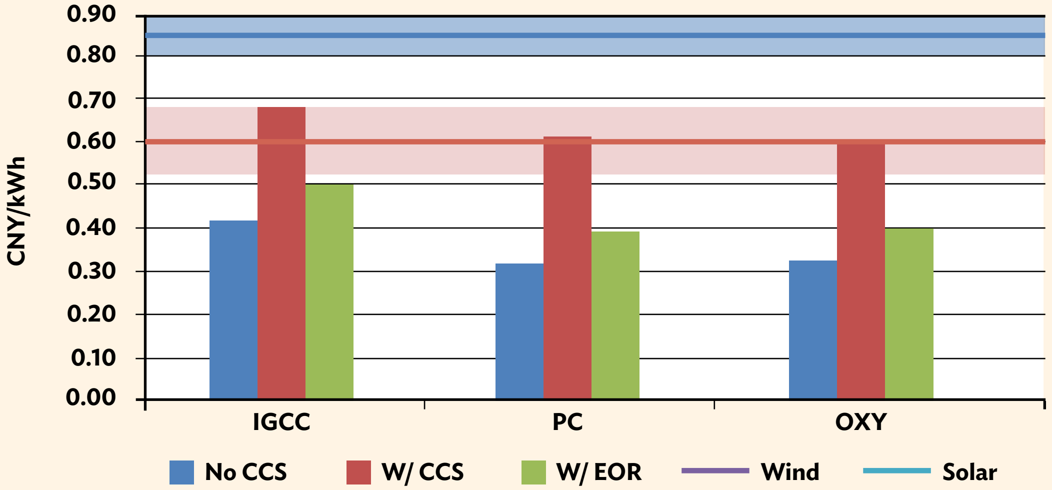
Figure A4.2: Potential impact of CO_2-EOR on Levelized Cost of Electricity for the Integrated Gasification Combined Cycle Technology with Carbon Capture and Storage



EOR = enhanced oil recovery, LCOE = levelized cost of electricity, OPEX = operating expenditure, VAT = value added tax
Note: CO_2–EOR assumes a CO_2 sales price of CNY120 per ton of CO_2
Source: Source: ADB (2014c).

14. **Benchmarking CCS against Alternative Technologies.** Figure A4.3 below shows the resulting LCOE of the reference scenarios benchmarked against existing revenue support measures currently offered for new power generation technologies in the PRC. These support measures, in the form of a feed-in-tariff for both wind and solar photovoltaic, and set at CNY0.6 per kilowatt-hour and CNY0.85 per kilowatt-hour respectively, can be considered as a proxy for revenue support in this analysis. As demonstrated below, the resulting LCOE of each of the respective reference case scenarios falls below or between the benchmarked feed-in-tariff levels.

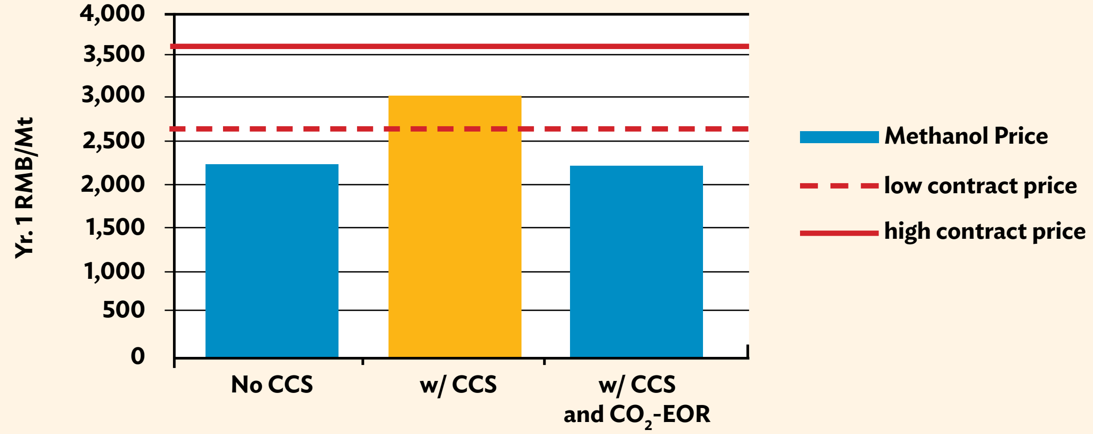
Figure A4.3: Benchmarking CCS against Alternative Power Generation Technologies



CNY/kWh = yuan per kilowatt-hour, IGCC= integrated gasification combined cycle, oxy = oxy-fuel combustion, PC=pulverized coal, Note: CO_2–EOR assumes a CO_2 sales price of CNY 120 per ton of CO_2
Source: ADB (2014c).

15. In the coal-to-methanol reference scenario, the levelized cost of methanol production is benchmarked against the 12 month monthly average Asian Posted Contract Price (APCP)[8] . As shown in Figure A4.4 reference costs fall firmly within or below the contract price range posted during the past 12 months.

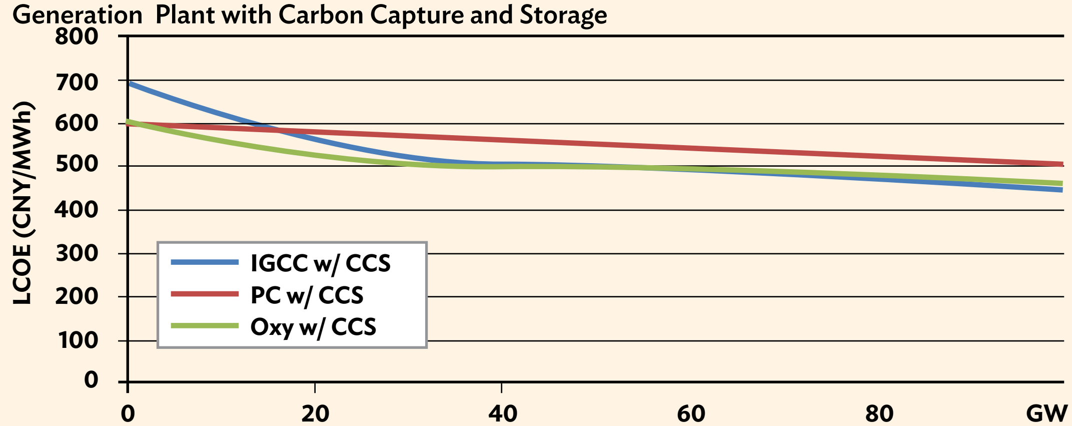
Figure A4.4: Benchmarking against 12-Months Average Regional Contract Price Trading Range



CCS = carbon capture and storage, CNY = yuan, CO_2–EOR = carbon dioxide–enhanced oil recovery
Note: CO_2–EOR assumes a CO_2 sales price of CNY120 per ton of CO_2
Source: ADB (2014c).

16. **Learning Curve.** For CCS to have a future as a meaningful emission reduction tool, it will need to become viable on a standalone basis without technology-specific government support policies. The potential volume of emissions that may be captured from point sources dwarfs that which may be utilized by the hydrocarbon extraction industries, meaning that long-term CCS scenarios should not assume a revenue stream from CO_2–EOR sales. Therefore, CCS investors will only deploy CCS at scale when they feel investment is warranted by their view on a carbon price trajectory or it is mandated by the government and the underlying plant is able to remain economically viable with the CCS cost penalty. Figure A4.5 below indicates that currently power produced by an IGCC plant with CCS is expected to be more expensive than an equivalent supercritical plant, but the relative immaturity of IGCC technologies presents opportunities for greater cost reduction as capacity builds out. As the potential volume of CO_2 to be stored through CCS is orders of magnitude larger than the potential opportunity of storage via CO_2–EOR and, therefore, the following charts do not assume any revenues from CO_2–EOR.

Figure A4.5: Evolution of Levelized Cost of Electricity in the People's Republic of China Generation Plant with Carbon Capture and Storage



CCS = carbon capture and storage, CNY/MWh = yuan per megawatt-hour, GW = gigawatt, IGCC = integrated gasification combined cycle, LCOE = levelized cost of electricity, PC = pulverized coal
Source: Source: ADB (2014c).

8 Methanex Monthly Average Regional Posted Contract Price History", September 2013-September 2014, https://www.methanex.com/our-business/pricing

III. Financial Support Measures

17. CO_2 capture in the power and coal–chemical sector adds to the energy costs and reduces the output of the emitting companies. The costs may be justifiable in the future in an increasingly carbon-constrained world, but a complementary set of support measures will be required to create a commercially justifiable business case for early-mover CCS project developers. As CCS project development becomes more common, fewer, less customized support measures will be required. Consequently, different sets of support structures are likely to be needed for the two phases of the demonstration and deployment program.

18. CO_2–EOR has proven to be an economically attractive means of CCS in the US, but the technology has not been widely tested in the PRC. To encourage domestic oil companies to participate in early-stage demonstration projects, it is proposed that CO_2–EOR field operators be required to pay a nominal fee of not more than CNY60/ton to receive CO_2 (Appendix 5 gives an overview of the key terms of such a CO_2 off-take arrangement). Without binding CO_2 emission constraints, this level of CO_2–EOR revenue may not be enough to ensure the viability of even relatively low-cost CCS projects in the coal–chemical sector, and for power projects, the commerciality gap is likely to be higher. Financial support in closing the commerciality gap can take a number of forms, including capital and revenue support mechanisms.

19. **Capital support.** Capital grants, typically released during project construction, are structured as a portion of capital expenditure, thus lowering the overall development costs of the project. Even if paid when construction milestones are reached, capital grants do not necessarily align with the investment goals of the government and the developer to sustain the long-term operation of the project. It is therefore recommended that capital grants make up a limited portion of overall financial support, and that other support measures that improve stakeholder alignment are given preference. Capital support may nonetheless be effective in the development phase, before the developer comes to a final investment decision to proceed with the project, as the developer's costs are significant at this stage and risks remain high.

20. **Repayable concessional finance.** This alternative capital support measure involves a form of repayable finance, such as a subordinated loan from the government or a development bank, offered at lower than commercial rates. Reducing the cost of finance by blending it with concessional funds lowers the overall cost of the project. At the same time, having to repay the loan motivates the developer to ensure the sound commercial operation of the project over the long-term.

21. **Tax incentives.** Early-mover CCS projects may also have access to government tax incentives that decrease their tax liability and strengthen their cash flow. Tax incentives available through existing support measures aimed at new energy technologies include reduced corporate income taxes, value-added tax exemptions and rebates, and other tax incentives based on the treatment of depreciation. Qualifying special equipment related to environmental protection, energy, or water conservation, as well as certain infrastructure assets, are allowed accelerated depreciation over a period of 10 years. Oil and gas produced via tertiary recovery technologies, including CO_2 flooding, currently benefit from a 30% exemption on the revised resource tax of 6% of sales pre-value-added tax.

22. **Revenue support.** Revenue support can be structured to fulfill either or both of two important functions: (i) give revenue certainty to project developers to make them confident regarding the volume of product they will be able to sell and the price at which they will be able to sell it; or (ii) provide financial support to reduce the commerciality gap. Revenue support is a "pay-for-performance" incentive. The project operator is encouraged to continue operating the project while retaining the operational risks. An adequate form of revenue support for early-stage demonstration projects in the PRC is considered to be a **fixed price** for each ton of CO_2 abated.[9] A fixed-price program could be used across several industries, with price negotiations on a case-by-case basis. Further, to assist in setting medium-term price expectations for the purchase of CO_2, the EOR operator could be provided with a fixed-price partial subsidy for the CO_2 stored.

23. **Recommended support mix during the 13th plan period.** The government is recommended to establish a mix of support mechanisms to meet the development needs of the early stage demonstration projects. The following measures should be made available to Phase 1 projects:
    (i) access to repayable concessional finance through development bank loans and the like;
    (ii) access to tax concessions now available to new energy technologies and tertiary hydrocarbon recovery;
    (iii) a fixed-price program of funding support to close expected commerciality gaps and to provide some revenue certainty, such as a contract based on the CO_2 bank model, which would pay the CO_2 emitter for capturing the CO_2–whether or not the EOR or storage operator actually stores the CO_2, or separate agreements with EOR operators to support their use of CO_2 in enhanced hydrocarbon recovery; and
    (iv) limited capital grant support for projects in the prefinal investment decision stage to support development activities such as front-end engineering design (FEED) studies and the process of obtaining regulatory approval.

24. **Specific support for transportation infrastructure.** First-mover projects require specific government support for the transportation of CO_2. Just as the government financed the construction of a high-voltage transmission line to transmit power from wind and solar generation sites in Gansu and Inner Mongolia provinces, the government should also finance the first CO_2 pipeline infrastructure. When selecting demonstration projects, the government should consider the project's potential contribution to a wider CCS network, given the likely emergence of CO_2 "hubs," where geographically proximate CO_2 emitters can store CO_2. Pipeline capacity may be oversized relative to initial transport volumes to optimize overall infrastructure costs. However, uncertainty over the scale and timing of additional CO_2 volumes may discourage project operators from underwriting oversized pipelines, thus requiring public sector support for the oversized infrastructure.

9 Other possible forms—such as a feed-in-tariff, offering generators a guaranteed price for power sold, or a contract for difference, under which the power generator or coal–chemical producer sells the product at the underlying commercial price and the government underwrites the difference between that price and a pre-agreed level—do not seem adequate in the PRC in the near term because early demonstration is focused on sectors other than the power sector. These forms of revenue support could lead to unnecessary government intervention in related commodity markets. Also, while regional trials of carbon pricing mechanisms are now under way, the lack of a permanent framework complicates the implementation of a contract for difference or a fixed price based on the price of carbon.

25. Constructing a dedicated transportation pipeline for projects requiring initial testing at about 100,000 tons before moving to full scale is unlikely to prove commercially rational at this stage; road transportation will have to be used instead. The cost of road transport will be part of a project's operating costs and must be considered when the overall level of government support needed for the project is determined.

26. **Recommended financial support measures in the medium term.** While coal–chemical projects may become commercially viable between 2021 and 2030 even without direct government support, the commerciality gap in the power sector is likely to remain. A CCS specific feed-in tariff, like the one currently in place for other low-emission technologies including wind and solar photovoltaic systems, could support the development of the most cost-effective projects. However, it is still too early to make final decisions on support measures for Phase 2.

III. Business Structures

27. **Key risks involved in CCS demonstration projects.** CCS projects can require significant capital investment, amortized over design operating lives of 20 years or more. As highlighted in the main Roadmap document, potential developers and financiers commonly view CCS projects as high-risk projects because of a number of factors:
    (i) **Technical risks.** While each of the components making up the CCS value chain has been established as a technically feasible technology, financiers continue to express concern about potential scale-up issues and the current limited experience in integrating these components at scale. During the early phases of commercial demonstration and deployment, sufficient commercial incentives need to be in place for entities to absorb these types of risks. Perceived technical risks can be resolved through demonstration at scale.
    (ii) **Legal and regulatory risks.** Investors require adequate and stable legal and regulatory frameworks to provide security in the forthcoming rollout of CCS. In the absence of greater certainty over the timing, completeness, and stringency of future policy frameworks and given their high absolute costs, risks, and complexities, the private industry cannot justify investments in large-scale CCS projects. In addition, the uncertainty or failure of emerging regimes to sufficiently address the issue of long-term storage liability continues to be a critical issue for CCS project proponents.
    (iii) **Counterparty risks.** CCS projects require harmonization of several unique businesses, often with different return expectations and operating cultures. While capture and compression are typically undertaken by a single entity or a joint venture, the transport and storage components may be operated by separate entities. The interdependence of the different CCS elements introduces the issue of counterparty risk, as a failure in one part of the chain may have a knock-on effect on the entire project. This includes CO_2 volume or deliverability risks, as well as credit risk. In view of the potential fragility of individual links in the chain and the distinct business profiles of the different project stakeholders, the appropriate allocation of risks and the establishment of adequate safeguards across the chain will be crucial to the success of integrated CCS projects.

28. In the case of a single developer CCS project, where the emitter also owns the transportation facilities as well as the oil field, each of these risks can be addressed separately. For projects with multiple equity stakeholders, the appropriate allocation of risks between parties and the provision of adequate safeguards remain fundamental challenges for CCS commercialization. For projects in which each proponent has a strong commercial or strategic rationale to participate, risk allocation is usually determined through commercial negotiations. For early-mover CCS projects, however, experience has shown that the level of commercial or strategic incentives may not be sufficient to persuade proponents to take on additional risks. While integrated projects led by a single developer may prove easier to deploy in the near term, the pool of suitable potential projects with sufficiently experienced developers that can adequately assess and hold risks across the CCS value chain is likely to be small and multi-developer projects may be required to ensure that the Phase 1 rollout targets are met.

29. **General structuring principles.** When structuring a greenfield or brownfield project, it is important to place risks with the party best placed to understand, price, and mitigate them. This principle holds true for projects involving technology risks or exposure to relatively immature regulatory regimes. The proposed business structures for CCS project development in the PRC are based on the key assumption that government will seek to minimize its level of involvement as well as an acknowledgment of the need for a level of public sector support for and involvement in early-mover projects to ensure their successful delivery. As the commercial drivers for CCS evolve, technology develops, and regulatory regimes mature, there should be less need for government support. Therefore, different business structures are likely to be required for the 13th plan period and for the broader rollout envisioned over the period 2021–2030.

30. **Storage characterization.** The characterization process is costly and time consuming and entails considerable exploration risk, while providing no guarantee of a revenue stream, even if successful. In order for geological sequestration of CO_2 to be cost competitive with low-emission alternatives, operators of pure CO_2 storage sites are likely to achieve only a low, regulated return for acting as site operator. This could be incompatible with the costs and risks of storage characterization. In this respect, the operator of a CO_2 well has a business investment model unlike that of an investor in a hydrocarbon production well, for whom exploration costs and risks are expected to be offset by high operating profits generated from commodity sales. It is therefore proposed that the government begins the process of a comprehensive storage characterization during the 13th plan period so that sufficient storage can be fully reported at the beginning of Phase 2.

31. **Demonstration program in the near term (phase 1).** Phase 1 of the CCS Roadmap calls for the demonstration of 5 to 10 projects based on concentrated emission streams of CO_2 from industrial sources (such as the coal–chemicals industry) and up to three more projects involving the collection of CO_2 from the stationary power generation sector, with each project collecting up to 1 million tons of carbon dioxide ($MtCO_2$) per year for CO_2–EOR use and storage or for geological sequestration in depleted oil reservoirs.

32. As neither CO_2 capture from coal–chemical sector sources nor the use of CO_2 flooding for CO_2–EOR has been widely undertaken in the PRC, project developers may need to phase the development to provide proof of concept at a scale of 100,000 tons of CO_2 per year before making a long-term commitment to a 1

$MtCO_2$ per year–scale project. Successful demonstration will depend not only on the choice of the technology and sector that would ensure the demonstration of CCS at low costs, but in particular on the structuring of the business model and the entities involved in its demonstration.

33. While technical scale-up risks in demonstrating CO_2 capture technologies at a scale of 1 $MtCO_2$ per year is a significant technical risk, the stability of long-term off-take agreements is of potentially greater concern to CO_2 emitters. Early-stage projects will most likely involve the sale of captured CO_2 to oil companies for CO_2-EOR under a long-term CO_2 offtake agreement. Such a long-term off-take agreement is inherently unstable. To overcome the risks of initial commercial relations, the government needs to work in partnership with project developers and shoulder some of the counterparty risks that project developers are unable to bear on their own.

34. Consistent with the principle that each party manages the risks that it is best placed to manage, it is proposed that, in general, capture, transport, and EOR or storage entities hold the bulk of the cost overrun, technical, and operating performance risks for their respective segments of the CCS chain. For projects with multiple equity stakeholders, the appropriate allocation of risks between parties and the provision of adequate safeguards remain fundamental challenges for CCS commercialization, as mentioned above. As shown in Table A4.5, there is a role for government in mitigating stakeholder interface and long-term containment risks in an integrated project.

Table A4.5: Allocating Risks between Counterparties

	Risk	Capture	Transport	EOR/Storage
Future	Technology obsolescence	Capture company	Transport company	EOR/Storage company
Cost	Operating performance shortfall	Capture company	Transport company	EOR/Storage company
	Cost of construction	Capture company	Transport company	EOR/Storage company
Interface	Interparty volume delivery	Government	Government	Government
	Counterparty life	Government	Government	Government
Environmental	Operating environmental risk	Capture company	Transport company	EOR/Storage company
	Long-term liability containment	n.a. (low)	n.a. (low)	Government
Finance	Debt and equity access and terms	Capture company	Transport company	EOR/Storage company
	Refinancing risk	Capture company	Transport company	EOR/Storage company

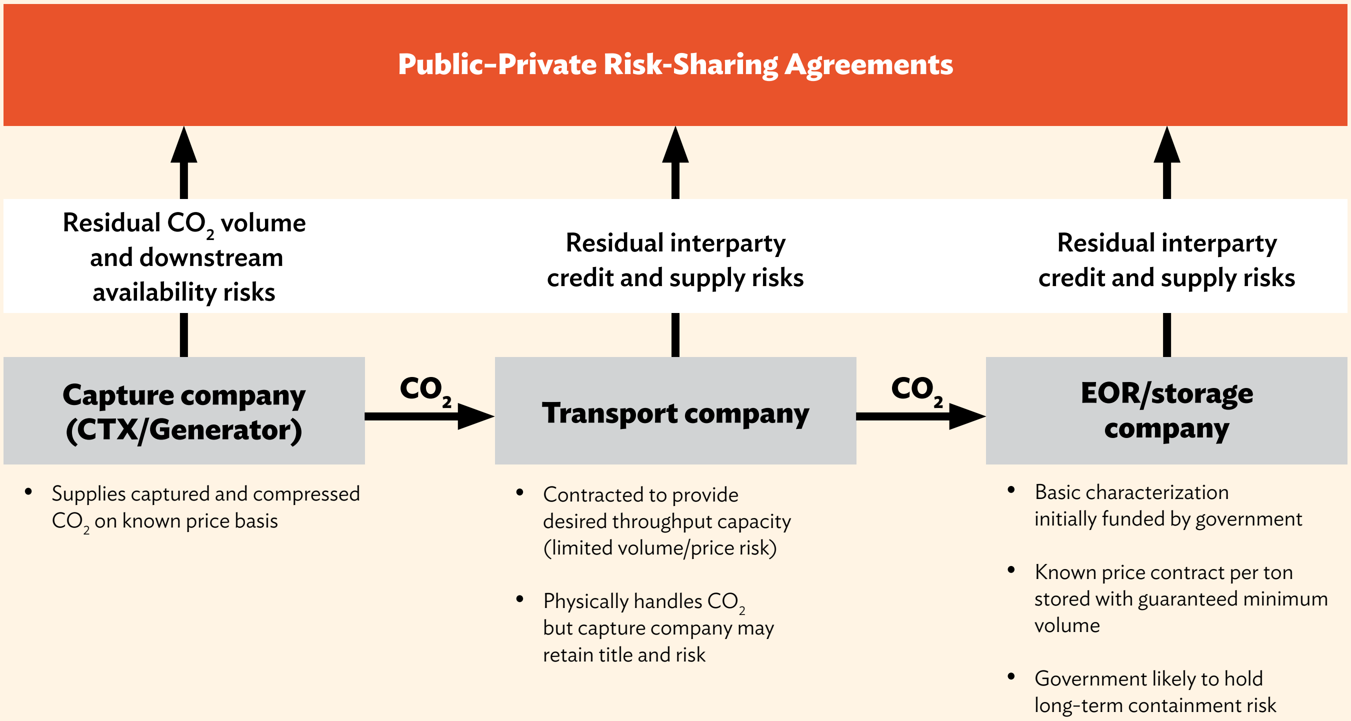
EOR = enhanced oil recovery.

35. To address these interface risks, the government should provide selective backstopping through a "public–private risk-sharing" model, similar to a build–own–operate agreement, where responsibility for capital investment and ongoing operations rests with the project developer, but revenue certainty is underwritten by the government.

36. During operations, the project proponents will interact directly and assume normal operating and interface risks, with the "public–private risk-sharing" agreements becoming active only when certain loss limits are breached. As a result, proponents for the various elements in the CCS chain are encouraged to cooperate in resolving commercial issues, while being protected from an unconstrained downside, particularly from risks they have no control over.

37. Figure A4.6 shows the conceptual relationship among corporate operators in a hypothetical integrated CCS project, with the government providing partial underwriting of counterparty risk. In terms of risk reduction, the government can have risk backstop arrangements with each of the separate operating companies to support project returns for adequate performance. These arrangements crucially limit each company's exposure to the operating performance of other elements in the chain. It should be noted that while the diagram illustrates a scenario in which each element is controlled by a separate entity, in reality a single entity could control several elements of the CCS chain.

Figure A4.6: Public–Private Risk-Sharing Agreements in an Integrated CCS Project



CCS = carbon capture and storage, CO_2 = carbon dioxide, CTX = coal–to–liquids/gas, EOR = enhanced oil recovery.

IV. Project Selection Process

38. The project selection process will be critical to the success of Phase 1 of the demonstration program. Before formally engaging with project developers, the government must establish a clear framework of objectives and constraints. In this regard, lessons can be learned from similar international projects. For example, the United Kingdom (UK) Government, following its decision not to proceed with a CCS demonstration project, undertook a review, which pointed out that a "lack of clarity regarding [the Department of Energy and Climate Change's] commercial position, particularly in relation to the sharing of risk and the project's overall financial envelope, meant that potential 'showstoppers' had not been identified and addressed early enough." The review recommended that future processes:
    (i) adopt a collaborative approach to the market, using early engagement to shape procurement, prepare the market for the proposals stage, and build confidence in the program;
    (ii) maintain procurement tempo, setting out a realistic and well-defined timetable to avoid extensions, which can increase procurement costs and make projects vulnerable to external events; and
    (iii) allocate risk where it can be most effectively managed and give a clear early signal of government's intended risk allocation following an assessment of market appetite.

39. Clearly, while factors such as technical merit, level of support required, contribution to broader learning, and the like are very important, the program will ultimately be judged on the basis of whether the projects are actually built and operated as intended. Therefore, project "deliverability" will be a key assessment criterion. To enhance the deliverability of selected projects, the following suggestions are offered:
    (i) **Allow projects the option of incremental scale-up.** Hydrocarbon companies may need to test the suitability of their field geology for CO_2–EOR at 100,000 tons of CO_2 per year scale before committing to larger off-take volumes.
    (ii) **Optimize infrastructure rollout.** Depending on issues such as terrain and distance between emitter and EOR field, for projects requiring incremental scale-up, initial use of road-based CO_2 transport options can limit the need for dedicated, permanent infrastructure until a solid case can be made for such long-term infrastructure. Selecting projects with the potential to contribute to an infrastructure hub over the medium term may also assist in optimizing future unit infrastructure costs.

40. Larger state-owned enterprises are typically better placed to manage risks than smaller, independent operators, and are therefore expected to be involved in a majority of the demonstration projects. However, state-owned enterprises involvement is not expected to be a condition precedent to gaining access to government support.

41. To achieve an ambitious demonstration program, it is proposed that a formalized body (a "panel"), similar to the Australian Renewable Energy Agency (see Box A4.1), be formed to assess project proposals against predefined criteria and negotiate appropriate funding agreements within predefined guidelines

on a rolling basis. This agency could be attached to the Clean Development Mechanism Fund of the PRC. Projects will be assessed and given in-principle support on the basis of an initial submission, with final approval and support terms negotiated once developers have completed a full FEED study, received the necessary regulatory approvals, and met other conditions precedent. Assessment will occur on a rolling basis. Projects should not compete directly against one another and should be able to submit proposals when they are in a position to provide credible submissions. The US Department of Energy loan guarantee program works in a similar manner. The role of the panel in assessing the cost-competitiveness and risk profiles of project proposals will be especially critical in ensuring that value for money is achieved. The panel should therefore be adequately resourced.

Box A4.1: The Australian Renewable Energy Agency

The Australian Renewable Energy Agency (ARENA) was established in 2012 to help reduce the investment risk and hasten the commercialization of renewable-energy projects across the innovation chain through the deployment of an A$2.5 billion capital grant support program. ARENA took the place of a number of existing renewable-energy funding initiatives, including competitive-tender capital grant programs. ARENA runs a number of different programs and initiatives to make renewable-energy solutions more affordable and increase the amount of renewable-energy used in Australia.

ARENA has flexibility in the manner in which financial support is provided to successful projects. It has developed a general funding strategy and an investment plan, which are used as a framework for project assessment. An advisory panel has been established to guide the development and selection of projects and initiatives for funding by ARENA. While ARENA operates at arm's length from government, ministerial approval is required for the support of projects above specified limits.

For most programs, project proposals are received on a rolling basis,[10] although competitive tenders are sometimes applied where appropriate. Since its inception, ARENA has provided A$940 million in funding to support A$2.5 billion in project investment.

10 A standard competitive tender process with fixed timelines, like that organized in the UK, is likely to prove unsuitable because of a foreseen lack of competitive tension, even if a tender were held on a rolling basis.

Figure A4.7: Overview of the High-Level Project Selection Process

Initial Submission and Assessment	Final Assessment and Negotiation	Project Construction and Operation
• Developer submits pre-feasibility study and other relevant documentation • Panel determines in-principle support of project concept	• Developer submits detailed FEED study and approvals for panel assessment • Developer and panel negotiate mutually agreeable support package	• Project is constructed and operated • Developer undertakes project

FEED = front-end engineering design.

42. **Initial submission and assessment stage.** During the initial submission and assessment stage, the panel will be seeking to form an opinion regarding whether a proposed project is likely to meet the panel's predefined aims. A detailed prefeasibility study for the project will be central to the initial assessment, as it provides a high-level overview of the project, establishing an overall process concept in sufficient detail to determine likely process performance as well as a techno-economic assessment such that costing that is more specific than order-of-magnitude estimates can be arrived at. Within such a prefeasibility framework, it is possible to broadly identify the capital and operating costs that will be incurred should CCS be introduced. This will allow a preliminary assessment of whether such a project would be viable, and an initial estimate of the level of support required. Besides undergoing technical assessment, intended projects will also be required to show that they:
    (i) are consistent with the energy and environment strategic objectives of the PRC;
    (ii) have support from local government for the implementation of the proposed project;
    (iii) comprise a large-scale coal-based process that is representative of the technology used in the power, chemicals (including coal to liquids and gaseous fuels), iron and steel, or building sectors to which a CCS technique will be applied;
    (iv) include the whole technical chain of CO_2 capture, transport, and utilization or storage;
    (v) are developed sufficiently such that a FEED study will be able to start;
    (vi) are technically ready for capturing at least 85% CO_2 from the gas stream;
    (vii) have a utilization or storage level equal to or larger than 100,000 tons of CO_2, and preferably close to or in excess of 1 million tons of CO_2 per year;
    (viii) have a geological location identified and characterized to the extent that there is a reasonable expectation that the quantities of CO_2 captured over the life of the demonstration project can be adequately stored or used;
    (ix) include downstream heat recovery, if it is a power project, to improve overall process efficiency; and
    (x) have plans for a comprehensive monitoring and verification program for CO_2 storage, which will need to be applied also to EOR since a portion of the CO_2 remains within the reservoir.

43. Developer submissions will be assessed by the panel and prospective projects allowed to progress to a second stage of assessment and negotiation, for which some grant support may be given.

44. **Final assessment and negotiation stage.** For the panel to be in a position to make an informed decision on whether a particular project should be supported, the project developers must undertake a detailed FEED study, which corresponds to the point where very significant financial commitment needs to be made. To put the scale of this pre-project investment in context, the two FEED studies for the power generation–based projects that were funded by the UK Government in its first CCS competition amounted to about CNY400 million. A lesson learned from this experience is that it is essential for the government to bear a significant part of the financial burden of a FEED study to advance an early stage demonstration project to the final investment decision stage.

45. The FEED study provides verifiable means of justifying the technical CCS option for the demonstration project, including system definition, identification of key problems, and justification of proposed solutions. Among the items to be considered are the following:
    (i) **maturity of the demonstration project**, including operational scope, scale of input, readiness of the infrastructure and associated industrial facilities for project implementation, and availability of the necessary expertise, site, and equipment;
    (ii) **project innovativeness**, including technological sophistication, and compatibility or suitability for implementation in the PRC; and
    (iii) **availability of a comprehensive management plan**, including strategy and procedures to ensure full implementation of the project.

46. Preliminary but justifiable estimates of the impact of applying CCS to the industrial process will need to be provided with regard to the following:
    (i) process or cycle efficiency and the energy penalty per unit output; and
    (ii) investment and operational costs, including the equipment for each part of the CCS chain, extra land requirements, any characterization work for the CO_2 storage site, additional coal use, water use, manpower, waste products disposal, environmental permits, and monitoring and verification costs.

47. The estimates will provide support for the overall financial model and plan, including the total incremental cost of the demonstration and likely sources of financing. There will be a further need for the project owner to have a long-term operations plan for the plant with CCS integration when the project is completed.

48. The project developers should also make a commitment to provide non-intellectual property rights data and materials to facilitate project evaluation by external experts. This commitment should extend to the dissemination of such information and materials generated during the implementation of the project as part of a program of public awareness and acceptance, with emphasis on the monitoring and verification results for any CO_2 storage site (including EOR) within the project.

49. If the project submission satisfies the panel, the developers and the panel will negotiate a mutually acceptable funding and support package, consistent with panel guidelines.

Box A4.2: Parallels with Near Zero Emissions from Coal Project Phase 2

The People's Republic of China (PRC) has adopted an approach similar to that proposed in the PRC–European Union Near Zero Emissions from Coal (NZEC) Phase 2 collaborative project. The key difference is that NZEC project selection was undertaken through competitive tender. The NZEC project selection team, under the guidance of the Ministry of Science and Technology and comprising key national carbon capture and storage experts from well-regarded institutes and universities in the PRC, made a call for proposals, and then selected three potential coal-based power sector demonstration projects from the submissions. The developers of each of these three projects (major industrial organizations in the PRC) have received funding from the European Commission for small pre-feasibility studies. Once these studies are completed, the most appropriate proposal will be selected by the NZEC team to receive further significant funding from the European Commission for a front-end engineering design study.

50. **Illustrative process timeline.** A rolling assessment and selection process means that each project will follow an individual timetable; however, for illustration purposes Figure A4.8 shows how the first coal–chemical and power sector projects may progress. Because of their greater complexity, 1 $MtCO_2$ per year or more projects in the power sector are likely to have a longer development timeline than coal–chemical projects of similar scale. This may work to the advantage of the projects, allowing them to draw on lessons learned from the first coal–chemical projects, potentially reducing perceived business integration and off-take risks. Power sector projects that are able to supply CO_2 to EOR or storage reservoirs already receiving CO_2 from coal–chemical CCS projects will further benefit in this regard.

Figure A4.8: Illustrative Timeline for First CCS Projects in the Early Stage

ACTIVITY	2015		2016		2017		2018		2019		2020	
	H1	H2	H1	H2	H1	H2	H1	H2	H1	H2	H1	H2
Industrial CO_2 Sources												
Identification of potential projects		■	■									
Initial submissions and assessments				■								
FEED studies				■	■							
Project final investment decisions					■							
Project construction					■	■						
Project commissioning and operation							■	■	■	■	■	■
Project expansion (if not at 1 $MtCO_2$ per year scale initially)									■	■		
Expanded project operation										■	■	■
Power Sector CO_2 Sources												
Identification of potential projects		■	■									
Initial submissions and assessments				■								
FEED studies					■	■	■	■				
Final assessment and contract negotiation								■				
Project final investment decisions								■				
Project construction									■	■	■	■
Project commissioning and operation												■
Saline Aquifer Characterization												
Confirm saline aquifer storage reserves sufficient to meet Phase 2 CO_2 storage requirements	■	■	■	■	■	■	■	■	■	■	■	■

CCS = carbon capture and storage, CO_2= carbon dioxide, FEED= front-end engineering and design, H1 = first half of the year, H2 = second half of the year, $MtCO_2$ = million tons of carbon dioxide.

Appendix 5

Promoting Carbon Capture Utilization and Storage (CCUS) through Carbon Dioxide–Enhanced Oil Recovery (CO_2–EOR) in the People's Republic of China

Key Messages

- Injecting carbon dioxide (CO_2) to improve the recovery of oil from a depleted oil well is a proven process commonly known as carbon dioxide–enhanced oil recovery (CO_2–EOR). Since most of the injected CO_2 will be permanently isolated from the atmosphere, CO_2–EOR is recognized worldwide as an effective approach to mitigating CO_2 emissions. The process of capturing CO_2 from an industrial plant, liquefying it, and transporting it for use in an oil field is commonly called carbon capture, utilization, and storage (CCUS) technology. CO_2–EOR could simultaneously address the twin challenges of climate change and energy security in the People's Republic of China (PRC).

- Ongoing pilot projects and capacity development work have created a critical body of knowledge and readiness in the PRC to enable the large-scale demonstration of CCUS. However, some remaining technical challenges of CO_2–EOR, the absence of a policy and regulatory framework, and weak coordination between oil companies and industrial plants owners have inhibited CCUS and CO_2–EOR projects. As a result, none of the planned large-scale CCUS projects in the PRC has reached the investment stage so far.

- A phased approach is recommended to advance CCUS deployment in the PRC. During the first phase (2015–2020), the government could (i) adopt targets for both incremental oil production from CO_2–EOR and for CO_2 stored through CCUS; (ii) endorse priority regions for CCUS demonstration in locations that have been assessed to favor deployment of CCUS; (iii) establish a national program for CCUS demonstration; and (iv) expand existing environmental regulations to include CCUS projects. During the second phase (2020–2030), it is recommended that the government support the development of CCUS hubs with the establishment of a CO_2 pipeline network, and intensify support for CCUS deployment.

I. Introduction

1. Carbon dioxide–enhanced oil recovery (CO_2–EOR) is an effective strategy for low-cost carbon dioxide (CO_2) capture and an attractive early opportunity for testing and proving carbond dioxide, utilization and storage (CCUS) across the complete process chain. CCUS with CO_2–EOR is therefore widely regarded as a stepping stone toward wider CCUS deployment. It supports the building of a practical body of knowledge to move toward pure storage in deep saline aquifers. Rules and regulations for the injection of fluids into the subsurface are already in place, and could easily be adapted to CO_2 storage without any need for an entirely new framework.

2. CO_2–EOR has been practiced on a commercial scale in the United States (US) for the past 30 years. US oil fields yield about 250,000 barrels of oil per day, or 0.8 billion barrels per year—14% of the country's total oil production—by using CO_2–EOR. Each year more than 200 CO_2–EOR projects inject about 60 million tons of CO_2 in oil reservoirs. As per the US Carbon Sequestration Council's estimates, incremental oil production from CO_2–EOR could provide $210 billion in tax revenues to the federal and state governments and more than $12 trillion in overall economic benefits between 2012 and 2030.

3. The People's Republic of China (PRC) has been importing more than 50% of the oil it consumes yearly since 2007. About 70% of domestic oil production comes from nine large oil fields, all of which are mature and are already facing or will soon face a decline in production. In some oil fields, water flooding is no longer effective in maintaining oil production levels. EOR must therefore be introduced to stabilize or even increase production levels and maintain the economic viability of oil fields. Pilot projects have proved that for some oil fields CO_2–EOR is the most appropriate method. This suggests that the PRC has reached an adequate level of readiness to apply CO_2–EOR.

4. The current body of knowledge indicates that the introduction of CO_2-EOR could yield an extra 5%–17% of "original oil in place" (the amount of oil in a reservoir when the reservoir is first discovered) for different oil fields. Studies have estimated that CO_2–EOR could produce up to a theoretical maximum of 11 billion barrels of incremental oil in the PRC if deployed in all fields. At the same time it would avoid the release of 2–19 gigatons of carbon dioxide ($GtCO_2$). But uncertainties about how widely applicable CO_2–EOR may be in the PRC and about the potential scale of incremental oil and CO_2 utilization remain. Hence, large-scale demonstration and validation of CO_2–EOR and its potential role in CO_2 abatement in the PRC is essential at this stage.

II. Challenges for CO_2–EOR in the PRC

A. Policy and Regulatory Challenges

5. **Weak policy drivers delay CO_2–EOR applications.** While the government's National Program in response to Climate Change (2014-2020) recognizes CCUS as one of the key climate change mitigation technologies, the government has not yet adopted a national program with specific targets for its demonstration. In the absence of such targets and program, there is weak acceptance for demonstrating CO_2–EOR among oil companies who own mature oil fields. This low acceptance inhibits CO_2 off-take arrangements with industrial emitters thereby stalling CO_2–EOR demonstration at commercial scale and jeopardizing its further deployment.

6. **Lack of targeted incentives.** The government has not yet adopted any incentive mechanism that will pay either an industrial emitter directly for each ton of CO_2 that is captured or an oil company that will use the CO_2 from anthropogenic sources in EOR operations. Without suitable financial incentives, CCUS with CO_2-EOR is unlikely to be financially attractive.

7. **Additional monitoring, reporting, and verification liability.** Traditional EOR monitoring is designed to assess the efficiency of EOR and to deal with health and safety issues. A CCUS project qualifies as CO_2–EOR only if the injected and stored CO_2 is fully accounted for. This will require the following: (i) careful assessment of leakage and other risks before the injection activities start; (ii) establishment of monitoring, reporting, quantification and, verification protocols and compliance with such protocols during the operation of the CO_2–EOR project; and (iii) institution of postclosure monitoring protocols and stewardship, as well as long-term liability guarantees.

B. Commercial Challenges

8. **CO_2 price uncertainty.** Oil companies require a large and stable volume of CO_2 at an affordable, predictable cost for the CO_2–EOR operation to be sustainable. Operators of power plants and industrial plants that emit millions of tons of CO_2 each year hesitate to invest in facilities for CO_2 capture and transport to oil fields without an established market or price for CO_2 in the PRC. Because of this uncertainty, CCUS activities are languishing at pilotscale and are typically "capture-only" plants.

9. **Lack of CO_2 off-take agreements.** Industrial plant operators and petroleum companies have to commit to substantial up-front investments for the establishment of a CCUS project, the former in the capture and compression plant, and the latter in (i) drilling wells or reworking them to serve as either injectors or producers, (ii) installing CO_2 recycling plants and corrosion-resistant oil field production infrastructure, and (iii) laying CO_2 gathering and transportation pipelines. There are no standard CO_2 off-take agreements in the PRC and CO_2 suppliers and oil-field companies have no experience in negotiating their commercial relationship. The lack of CO_2 off-take agreements creates major commercial uncertainties about the availability of CO_2 and its price, and causes oil companies to delay or avoid the up-front investments in CO_2-EOR facilities.

10. **Mismatch between CO_2 emissions profile and use of CO_2 in EOR.** The source of emissions tends to generate CO_2 at a fairly constant rate unless the plant is

shut down for maintenance and production ceases. In contrast, the volume of CO_2 needed for a CO_2–EOR project changes over the project's lifetime. Relatively low quantities of CO_2 are required for initial assessments to test its suitability of the reservoir for CO_2–EOR. Then, a large quantity of CO_2 is needed to flood the reservoir. After several years of CO_2 injection and depending on the specific reservoir characteristics, the produced oil will contain CO_2, which has to be separated and reinjected back into the oil field. Thus, a gradually declining volume of fresh CO_2 will be needed. These changing needs will pose a challenge for a single plant–single oil field model. A matching large oil field with several oil wells and large sources of CO_2 emissions will have to be found for such CCUS projects. So far no province in the PRC in which such a cluster of CCUS projects could be built has been identified. As a result, CCUS projects with CO_2–EOR projects are likely to be scattered over various locations, each faced with the challenge of overcoming the described mismatch in CO_2 supply and demand.

11. **Additional investments in managing environmental and safety risks.** CO_2 sequestration must be properly accounted for to be considered as CCUS. The unintended release of CO_2 can also adversely affect ecosystems and human health across the CCUS project chain and at different stages of project operation. A developer will need to invest in stringent management plans, including hazard response planning and environmental safeguards. Specific monitoring and verification equipment must be procured for such a project. To date, the PRC oil companies have few environmental monitoring obligations and may not be willing to comply with such requirements.

C. Technical Challenges

12. **Low amenability of some oil fields to CO_2–EOR.** Some large oil fields in Eastern and Northeastern PRC are not amenable to CO_2–EOR operations because of reservoir characteristics or because of proximity to densely populated urban centers.

13. **Staged validation.** The PRC operators have been investigating CO_2–EOR for the past decades. They have achieved less than optimal results because the most effective CO_2–EOR techniques have not always been applied. A gradual approach is warranted to overcome technical complexities and uncertainties before the viability of a CO_2–EOR project is established. A phased validation and implementation process of CO_2–EOR is desirable. It could start with small injection tests in a few wells, followed by two phases of 1–3 years of scaling up before wider development. Such staged validation may affect the pace of CO_2–EOR uptake in the PRC.

14. **Lack of CO_2 transport infrastructure.** The PRC has no CO_2–EOR pipelines for transporting the CO_2 and no regulations and standards for constructing such pipelines. In the early stages of CCUS development, pipelines for large-scale CO_2 transport will consist of infrastructure built for other purposes without "open access." Initial investors in a dedicated pipeline have tried to minimize incremental cost by designing the pipeline specifically for its intended purpose, thereby limiting its accessibility to other potential future users (e.g., for CO_2 transport). The lack of CO_2 transport infrastructure further erodes the financial viability of early-stage CCUS projects.

III. Recommendations

Thirteenth Five-Year Plan Period (2016–2020)

15. In view of the above, there is a compelling case for the early demonstration of CO_2–EOR as a CCUS project during the 13th Plan period. It is recommended that the government announce specific measures during this period to create an adequate enabling environment for such early-stage projects.

A. Addressing Policy and Regulatory Challenges

16. **Set CCUS–specific targets.** The government should set an achievable target of 30–60 million barrels of incremental oil production through CO_2–EOR with cumulative storage of 10–20 million tons of CO_2 over the 13th plan period.

17. **Provide incentives EOR by qualifying incremental oil produced from CO_2–EOR operations as unconventional oil.** Early-mover CO_2–EOR operators that use and effectively store anthropogenic CO_2 should be eligible for fixed-price partial subsidies provided by the government for other forms of unconventional hydrocarbons, such as shale gas or coal-bed methane.

18. **Provide financial support for early-stage demonstration projects.** Like many other countries that have moved ahead with CCUS demonstration projects, the PRC will need to provide first-mover projects with financial support to overcome economic barriers like high risks and costs. When more such projects are undertaken, costs will come down, the risk profile will improve substantially, and less direct support will be required. For projects that advance to construction or completion within the 13th plan period, it is recommended that the government provide the following support mechanisms to promote these projects: (i) access to repayable concessional finance; (ii) access to tax concessions; (iii) a fixed-price program of funding support (see for instance, contracts based on the CO_2 bank model described in para. 20); and (iv) limited capital grants to support development activities such as front-end engineering design studies and the process of obtaining regulatory approval. Details of the financial support measures are included in Appendix 4 of this Roadmap.

19. **Adopt crucial standards and norms for monitoring, reporting, quantification, and verification.** Appropriate greenhouse gas accounting rules are necessary to accurately award net emission reductions from CO_2-EOR. The PRC co-chairs the development of international standards for CCUS under ISO/TC 265, and announcements have been made regarding the development of national standards and environmental oversight. These efforts should be strengthened to promote their early adoption. Standards could be first implemented and tested in pilot and demonstration projects before becoming mandatory for all projects.

20. **Strengthen postclosure governance of storage sites.** Rules should be established to govern site abandonment and long-term stewardship of CO_2 injected and stored as a result of CO_2–EOR operations. Monitoring and well status requirements, including the baseline conditions for CO_2 storage, should be clarified for oil and gas reservoirs, particularly for CO_2–EOR. The issue of jurisdictional responsibility for pure CO_2 storage in oil and gas reservoirs, with regard to national–subnational jurisdiction and to organizational jurisdiction (Ministry of Environmental Protection versus national energy administration), must also be addressed.

B. Addressing Commercial Challenges

21. **Prepare model off-take agreements.** There is currently no market and no established price for CO_2. Standard off-take agreements between petroleum companies and industrial plants are therefore essential. The government should adopt and publish a model CO_2 off-take contract (see box A5) similar to the standard natural gas off-take agreement published in February 2014. A CO_2 off-take agreement reduces the commercial risks for the petroleum company (off-taker) and the industrial plant (CO_2 supplier or seller) and ensures revenue flow for their investments. It ensures (i) a sufficient quantity of CO_2 for the petroleum company at a predictable price and the required "quality," and (ii) the revenue flow of the CO_2 project for the industrial plant. A standard off-take agreement should incorporate the following characteristics:
    (i) **Types of contract.** CO_2 off-take agreements can take the form of a take-or-pay, take-and-pay, or long-term sales contract. An innovative provision in some off-take agreements is the establishment of a CO_2 bank. At the most basic level, a take-or-pay contract requires the buyer either to purchase and take delivery of a specified quantity of CO_2, or to pay for the gas regardless of whether it takes delivery or not. A take-and-pay contract obliges the buyer to take and pay for the CO_2 or to pay for the CO_2 as if the buyer had taken it. Unlike a take-or-pay contract, a take-and-pay contract requires physical delivery of the CO_2. These types of contracts provide the seller with a high degree of confidence. At the same time, the seller must be able to ensure the timely delivery of CO_2 in the contractually specified quantity and quality.
    (ii) **CO_2 bank model.** Some CO_2 off-take agreements are concluded on the basis of a long-term sales agreement establishing a "CO_2 bank." This model is based on a monthly (or daily) minimum quantity and determines how the contracting parties will net out any oversupply, supply deficiency, or excess demand. An off-take agreement based on the CO_2 bank model specifies the rights and obligations of both parties in the event of (i) overage (a higher CO_2 off-take than the agreed minimum monthly volume); (ii) supply deficiency (supply below the agreed minimum monthly volume); and (iii) a shortfall in volume, an off-take of (CO_2 below the monthly minimum volume). This model is close to the rules prescribed in the standard natural gas contract stipulated by the National Energy Administration in February 2014 and therefore most suited to CO_2 off-take agreements in the PRC. The CO_2 bank effectively addresses the challenges faced by a buyer of accepting (i) all CO_2 from an industrial plant that produces CO_2 all day throughout the year; and (ii) potential fluctuations in the supply of the CO_2. The purpose of such a CO_2 bank is to net out shortfall, overage, and supply deficiency volumes over time. It allows the effective matching of supply and demand and stabilizes the revenue flow despite the different demand and supply profiles of buyer and seller.
    (iii) **Pricing.** The seller and the buyer may agree on either a fixed price or a formula driven price for the CO_2. In the US, the CO_2 price is often linked to the price of oil. In the PRC, the CO_2 price could be linked to the coal price. A fixed price has the advantage of establishing transparency and long-term predictability for both the seller and the buyer. A flexible, formula-driven price linked to oil prices emphasizes the affordability of CO_2 to the purchaser. Linking the price of CO_2 to the coal price would ensure that the energy penalty costs of the industrial plant are covered by the sale price of CO_2.

Box A5: Carbon Dioxide Off-Take Agreements For First-Mover Demonstration Projects in the PRC's Coal-Fired Power Sector: Template Structure and General Contents
Definitions. This section defines key terms used in the contract, including "carbon dioxide," "contract period," "annual period".
Commitments of buyer and seller. An off-take agreement should include a section which defines the scope of the contract to cover the sale of CO_2, the right of the seller to sell the CO_2 to other buyers, and the responsibility of the seller to transport the CO_2 to the delivery point. In off-take agreements observed in the US, a "no warranty" clause is often included in the scope, indicating that the seller will make a good faith, diligent effort to deliver the CO_2. Off-take agreements in the US usually allow off-takers to permanently suspend the contract with 60 days' notice to the seller. Some off-take agreements, however, also limit the buyer's purchase obligation to not purchase more than the daily contract quantity of CO_2.
Quantities. An off-take agreement should include a section which defines the quantities of CO_2 traded under the agreement. This section includes a take-or-pay clause or provisions based on the CO_2 bank model (paragraph 21 (iii) of this Appendix). In case an off-take agreement is based on a take-or-pay clause, the contract could obligate the buyer to take and pay a substantial share of the CO_2 traded under this agreement and at least 50% of the monthly or daily contract volume (or 50% of the CO_2 provided by the seller each day). The section on buyer and seller commitments includes information about the obligations or commitments of each party in case of a change in the planned supply of or demand for CO_2.
Prices, taxes, and excess royalties. Any off-take agreement will need to specify price determination mechanism. For example, the CO_2 price may be based on the previous period's price adjusted by a factor that reflects inflation, taxes, and other factors impacting the price of CO_2. The contract may also define a minimum price. Each party is responsible for paying the taxes associated with their ownership of the CO_2. A buyer who receives money associated with a tax credit, the buyer must pay the seller 50%. The reimbursement to the seller or buyer is applied monthly as part of normal payments. This section may also include a benefit sharing mechanism. For example, if the government supports CO_2-EOR through some form of a tax credit like in the US, this section may define how the tax credit is shared among both parties. A buyer who is exempted from paying the tax must give details of the exemption (certificate) to the seller.
Term. An off-take agreement should clearly define the term of the agreement. The contract takes effect on the date specified in the contract and stays effective until after the delivery of the total contract quantity of CO_2, unless the contract is terminated earlier. Standard CO_2 off-take agreements usually have a term of 15–20 years. This section usually also specifies the conditions for renewal or extension of the contract, as well as reasons for early termination.
Delivery point. In an off-take agreement it is very important that the delivery point is specified. The contract makes it clear that at that point CO_2 ownership is transferred when deliver is made. The location details identify the specific part of the pipeline and the meter station. Ownership of the CO_2 implies acceptance of the liability related to its ownership.

Quality. It is equally important that an off-take agreement specifies the quality of the CO_2 delivered, including technical specifications of the (i) CO_2 purity (usually 95–96 mole% minimum), (ii) the maximum allowed water vapor content; (ii) total inerts gases (including hydrogen sulfide), nitrogen, hydrocarbons, oxygen, and total sulfur; (usually 4–5 mole% maximum), (iv) temperature (usually 48–50°C); and (v) pressure of the CO_2 at the delivery point (a minimum and maximum range), which may directly affect the price of the CO_2. The seller should be made responsible for ensuring that monthly tests are conducted and the buyer may request additional tests once during a specified period. The seller is required to give the test results to the buyer and to give the buyer notice before scheduled tests to allow the buyer's representative to be present. If the CO_2 does not meet the quality specifications, the buyer is no longer obligated to purchase the CO_2. At that the seller decides whether to process the CO_2. If the seller decides that the CO_2 cannot be processed, then the buyer and seller will discuss alternatives. If an agreement is not reached within 3 months, then the buyer can reduce the daily contract quantity or terminate the contract.
Measurement. The measurement point should be clearly specified in the contract, and can be the same as the delivery point. The contract outlines the measurement procedure, including any conversions that will be made in the calculations. The measurement of pressure, temperature, and density is also specified. The contract specifies the standards that must be met (such as the American Petroleum Institute's published standards). Each month a sample of the CO_2 is subjected to compositional analysis, unless an online system allowing more frequent analysis is installed.
Measuring and test equipment. A contract typically specifies the ownership of an existing metering or measuring station and the equipment required by the buyer or seller for measurement (and fee allocation). The seller owns such equipment and takes responsibility for ensuring that the meters are in working order, but the buyer has the right to be present during testing. If the equipment does not accurately measure the volume of CO_2 (the discrepancy exceeds 1%), the seller corrects the charges. The buyer may request special tests at any time. If a meter is out of service, the amount of CO_2 delivered is estimated through an agreed method.
Accounting, billing and payment. The contract should include provisions for the accounting, billing and payment of CO_2 delivered. This section specifies the accounting and billing obligations of the CO_2 provider, and the payment obligations of the buyer. Normally, provisions would specify that the seller issues a monthly statement to the buyer giving the amount of CO_2 delivered the previous month, and the buyer is required to pay within 1–2 months after receiving an invoice. The contract may also provide for make-up rights, which entitle the buyer to receive CO_2 to make up for any CO_2 that was paid for but not received. These banked volumes are used as credit against obligations to take or pay (within a given year). Both the buyer and the seller have the right to conduct an audit to verify accuracy. If the buyer does not pay on time, the seller will charge interest. The seller should notify the buyer in writing about the failure to pay and if an additional 45 days pass, then the seller has the right to terminate the contract.

Force majeure: The contract should allow cancellation in case of unexpected events (such as natural disasters, strikes, wars, epidemics, landslides, lightning, earthquakes, or other industrial disturbances, etc.) that prevent the buyer or seller from fulfilling the contract terms. The buyer or the seller is required to inform the other party of the force majeure event. If the situation lasts longer than 6 months, the party that did not claim force majeure may terminate the contract.
Successors and assigns. The contract should specify that its terms are binding and extend to successors of the parties who signed the contract, even where an organization undergoes reorganization, merger, or consolidation.
Government regulation. The contract is subject to government regulations and the seller and buyer agree to comply with the law as part of the contract. The contract also specifies that the ability of the seller to deliver the CO_2 is subject to existing and future laws that affect the CO_2 pipeline.
Miscellaneous. The contract should further include any other relevant clauses specifying administrative procedures for the implementation of the contract.
Dispute resolution. The off-take agreement should specify procedures how conflicts between buyer and the seller after signing of the contract are agreed to be resolved.

22. **Select and endorse priority locations.** The Erdos Basin, the Songliao Basin in Northeastern PRC, the Jungar Basin in Northwestern PRC, and the Tarim Basin in Western PRC have oil fields that are amenable to CO_2–EOR operations. These locations are also home to a large number of major coal–chemical plants, which are low-cost CO_2 capture options and a source of large volumes of inexpensive CO_2 supply. They are also suitable for establishing CCUS clusters.

23. **Support the development of CO_2 pipeline infrastructure.** As the PRC moves into the 14th Five-Year Plan period, a common CO_2 pipeline could help reduce integration issues and facilitate the buildup of a cluster of CCUS projects. It is therefore recommended that the associated CO_2 pipeline network be developed and financed. The network operator should be an independent operator offering open access to CO_2 capture plants through a common set of CO_2 off-take agreements. This will strengthen investor confidence, improve economies of scale, and provide the CO_2 supplier and oil field operators with operating flexibility. A similar approach of constructing a high-voltage transmission line in support of wind-farm megaprojects has worked well in the PRC. The CO_2 pipeline network could be organized as a fully state-owned enterprise or as a public–private investment venture.

C. Addressing Technical Challenges

24. **Intensify pilot testing and large-scale demonstration.** Progress on the CO_2 emission reduction agenda depends essentially on implementing more pilot and demonstration projects. Research and development support for programs like the 863 and 973 programs should be strengthened.

25. **Establish a coordinated national program for CCUS demonstration.** Five to ten commercial-scale CCUS CO_2–EOR demonstration projects, each one capturing, using, and storing 1–2 million tons of CO_2 per year, should be selected as national flagship projects. These projects should receive national recognition, resources, and financial support. Upon successful completion, they will become knowledge-sharing platforms for similar projects across the country and beyond.

26. **Gradual and phased approach to CO_2–EOR development.** A gradual approach is warranted to overcome technical complexities and uncertainties before establishing the viability of CO_2–EOR. A phased validation and implementation process for CO_2–EOR is desirable. It can start with small injection tests in a few wells, followed by two phases of 1–3 years each, for scaling up before wider development.

Appendix 6

Learning from International Experience

1. Carbon capture and storage (CCS) roadmaps have already been developed by governments or their agencies for a number of countries including Australia, Canada, Japan, Malaysia, Poland, South Africa, the United Kingdom (UK), and the United States (US). International CCS roadmaps share a common vision—to accelerate the development and deployment of CCS technologies over the next 20 to 30 years. However, given their unique context, each nation (or international organization) chooses a distinct technology focus and development approaches. These roadmaps include key actions for CCS development and deployment. However, implementation is not always linked to the visions, goals, and plans of the original CCS roadmap. In some cases CCS roadmaps are not viewed as an official CCS development guidance. Some CCS roadmaps are contracted to research organizations with a main purpose to understand the CCS potential in their country. A number of roadmaps did not address the detailed status of technology in the respective country and therefore do not provide comprehensive technology plans for each stage of research, development, demonstration and deployment. None of these nations has directly tracked the actions proposed by these CCS roadmaps with national implementation. To be effective, this Roadmap aims to provide clear links between early-stage demonstrations, staged scalability, and the achievement of climate change objectives. It is expected to be included as part of the Government's Action Plan on Climate Change and tracked accordingly.

2. National governments worldwide have taken action to encourage the development and adoption of CCS technology. These actions span from investing in research, development and demonstration to establishing regulations and financial support mechanism for CCS demonstration and deployment. There are three basic types of CCS policies, as outlined in Box A6.1. For CCS to move from research and demonstration towards a widely-adopted technology, all three types of policies may ultimately be required.

Box A6.1: Types of Policies and Regulations Set Up in Various Countries to Support CCS Development and Deployment

Fiscal and Financial Support	Technical and Environmental Regulations	Regulations Promoting Efficient Public Engagement
Incentives for CCS • funds • specialized research support • direct investment • feed-in premium • tax credits • carbon tax • public trust fund **Financing** • emissions trading scheme • bonus allowances • fixed-price policy • loan guarantees **Mandatory measures** • emission performance standards • quotas • CCS certification system	• Technical standards for CCS and CO_2–EOR technologies • Standards for storage site selection and management • A whole-process monitoring mechanism • Environmental impact assessment requirements and standards • Regulations for permit application, verification, and issuance system • Post-closure stewardship regulations	• Public education regarding the benefits and risks of CCS • Mandatory disclosure of basic information about CCS projects from both government and the CCS projects • Efficient public engagement platforms (e.g., colloquiums between project managers and public representatives, public hearings, project publicity) • Contract for difference

CCS = carbon capture and storage; CO_2–EOR = carbon dioxide–enhanced oil recovery.
Source: ADB (2014b).

Table A6: Summary of International CCS Policy Actions[a]

Country or Region	Technical Standards or Environmental Regulatory Framework[b]	Economic Incentives or Requirements
Australia	• Offshore Petroleum and Greenhouse Gas Storage Regulations 2011 • Onshore regulated at state level	• A$23 per ton carbon price • A$1.68 billion in government funds for CCS Flagship Program
Canada	• Canadian Standards Association published CCS standards under Z741-12 • State-level regulations adopted in Saskatchewan and Pipelines Act (1998),[c] administered by Ministry of Energy and Resources	• Emission performance standard requiring new and old coal plants to be as efficient as natural gas plants; plants using 30% CCS can receive deferral • Public funding for demonstrations totaling Can$3 billion[d]
European Union	Directive 2009/31/EC on geological storage of carbon dioxide transposed by the following countries into national law: Czech Republic, Finland, France, Germany , Ireland, Italy, Netherlands, Poland, Romania, Spain, an the United Kingdom	• European Union emissions trading scheme • CCS funding planned under New Entrants Reserve and 79 projects applied; value estimated at €4–€5 billion • European Union Energy Programme for Recovery set aside €1 billion for CCS in Germany, Italy, Netherlands, Poland, Spain, and United Kingdom
Republic of Korea	Marine environment management law amended to allow carbon capture and ocean disposal[e]	Emissions trading scheme proposed
Norway	CCS-specific regulations still pending; draft regulations to be released simultaneously by Ministries of the Environment and Petroleum and Energy at some future date	• CCS requirement for natural gas developments (including future power plants) • CO_2 tax applied to offshore developments
South Africa	Regulatory gaps analyzed and regulatory development under way	
United Kingdom	• European Union Directive transposed • Energy Act (2011) allows reuse of existing pipelines and infrastructure for CCS	Under electricity market reform of July 2011: • Emission performance standards (new coal only with CCS) • Carbon price floor • Contract for difference • Proposed emission reduction targets for electricity sector
United States	"Class VI" regulations for geological storage developed by US Environmental Protection Agency under Underground Injection Control Program and finalized in 2010;[f] no projects permitted under the rule so far	• Federal funding for demonstrations ($5 billion) • Loan guarantee program (new $8 billion[g] program announced in 2014) • Tax credits for CO_2 storage ($10/ton for EOR and $20/ton for storage) • Proposed performance standards for new plants

CCS = carbon capture and storage, CO_2 = carbon dioxide, EOR = enhanced oil recovery.
[a] IEA (2011); IEA (2012a).
[b] IEA (2012a, 2012f)
[c] Government of Canada, Government of Alberta, Saskatchewan, and Government of British Columbia. 2012.
[d] IEA (2011).
[e] Federal Register (2010).
[f] https://lpo.energy.gov/category/in-the-news/ (accessed 10 April 2014).
Source: ADB (2014b).

Box A6.2 A case study of the UK's policy framework to support CCS as a good-practice example

CCS Policy Case Study (UK)

The United Kingdom (UK) has been recognized as having one of the most developed policy frameworks to support CCS (GCCSI 2013). The backdrop is a legally binding greenhouse gas emission reduction target of at least 80% by 2050 and participation in the emissions trading scheme of the European Union.

The five key areas of the UK's 2012 CCS Roadmap (DECC 2014) are:

- A £1 billion CCS Commercialisation Programme to support front-end engineering and design and construction costs for two projects; tailored low-carbon contracts for difference, subject to value for money; and arrangements tailored to individual projects, for government to share CCS-specific risks.
- Electricity market reform to bring forward investment in CCS and other low-carbon generation via contracts for difference.
- £125 Million Research and Development and Innovation Programme.
    - Regulations to address key barriers to commercialization:
        - no new coal power plants over 300 MW built without CCS;
        - a carbon price floor, which gives an economic incentive to reduce emissions from fossil-fuel power stations; and
        - the Emissions Performance Standard, which provides a regulatory backstop to the requirement of no new coal power plants without CCS.
    - International engagement and knowledge sharing:
        - allocation of up to £60 million to support the development of CCS technology in emerging markets through the Clean Energy Ministerial Carbon Capture, Use and Storage Action Group; and
        - in cooperation with the Asian Development Bank, use of £35 million of this funding to support CCS projects in the People's Republic of China and Indonesia.

The roadmap covers three phases of CCS development and deployment. Early-stage CCS projects are first-of-a-kind projects taken forward under the Commercialisation Programme. The government considers support for early-stage projects to be the quickest and most effective way of reducing the cost of CCS. The second phase of CCS projects is a transition phase between heavily state-supported early-stage demonstration and cost-competitive commercial projects. In the transition phase, projects could capture CO_2 emissions from power stations or energy-intensive industry. Project developers may also choose to exploit enhanced oil recovery techniques. By the third phase the government expects the CCS industry to have developed to a point where projects are fully commercial and can compete in the market on the basis of cost with other low-carbon technologies.

CCS = carbon capture and storage, CO_2 = carbon dioxide, MW = megawatt.

3. The common thread among all roadmaps has been stronger government financial and fiscal support for the first-generation CCS demonstration projects and assumption of long-term liability for stored CO_2 by the relevant jurisdiction. Box A6.1 summarizes the range and types of policies and regulations that have been established to support CCS development and deployment.

4. National governments worldwide have taken action to encourage the development and adoption of CCS technology. These actions span from investing in research, development and demonstration to establishing regulations and financial support mechanism for CCS demonstration and deployment. There are three basic types of CCS policies, as outlined in Box A6.1. For CCS to move from research and demonstration towards a widely-adopted technology, all three types of policies may ultimately be required.

5. While most countries have chosen to rely on existing environmental impact analysis laws for CCS, the requirements for public engagement outlined in these laws are likely to be further strengthened for a new technology like CCS, which carries uncertain public acceptance because of perceived risks. How CCS is communicated to the public and the extent to which communities hosting CCS projects are engaged in the planning and implementation (permitting, siting, long-term safety issues, etc.) will influence whether CCS is deployed and where. Effective engagement may help ease concerns and focus attention on the impact (positive and negative) associated with CCS. International best practices for engaging local communities in CCS projects have been published (WRI 2010).

6. Although environmental impact analysis laws provide a framework for evaluating the potential environmental impact associated with a planned project, several environmental challenges unique to CCS have prompted some countries, including the European Union countries and the US, to establish environmental regulatory frameworks specific to CCS. These unique environmental challenges include (i) buoyancy of CO_2 in the subsurface; (ii) potential induced seismicity associated with CO_2 injection; (iii) integration of capture, transport, and storage aspects of a project; (iv) uncertainty or insufficient knowledge of subsurface geology; (v) expected permanence of storage and need for long-term monitoring frameworks; and (vi) long-term liability.

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ON THE COVER

From left to right, and from the outermost circle going inward, the photos show the following:

1. PRC's first 3,000 ton per year post-combustion carbon capture pilot project at the Beijing Gaobeidian Power Plant of China Huaneng Group (Photo credit: China Huaneng Group)
2. Shanghai Shidongkou 120,000 ton per annum carbon capture industrial pilot project of China Huaneng Group (Photo credit: China Huaneng Group)
3. CO_2 injection well of Shengli Oil Field's CO_2–EOR pilot project (Photo credit: Sinopec Shengli Oil Field)
4. CO_2 injection site of Shengli Oil Field's CO_2–EOR pilot project (Photo credit: Sinopec Shengli Oil Field)
5. Carbon capture plant of Shenhua Group's 100,000 ton per year CCS industrial-scale pilot project (Photo credit: Shenhua Group)
6. Production well at Dagang Oil Field (Photo credit: Dagang Oil Field)
7. Storage site of Shenhua Group's 100,000-ton-per CCS industrial-scale pilot project (Photo credit: Shenhua Group)

Roadmap for Carbon Capture and Storage Demonstration and Deployment in the People's Republic of China

The People's Republic of China (PRC) is taking concerted efforts and making large investments to peak out its carbon dioxide (CO_2) emissions around 2030. While current efforts are prioritizing accelerated energy efficiency and rapid expansion of renewables and nuclear in the energy mix, the fossil fuel related CO_2 emissions are still expected to rise even under a "new normal" growth strategies in the PRC. This brings in renewed emphasis on carbon capture and storage (CCS), which is currently the only near-commercial technologies to make deep cuts (up to 90%) in CO_2 emissions from fossil fuel related power plants and industries. This report draws on relevant technical assistance from Asian Development Bank (ADB), consultants' reports, and the work of ADB staff to assess the potential, the barriers and the challenges in demonstrating and deploying CCS in the PRC. It identifies unique low cost opportunities, recommends a gradual two phase approach to CCS deployment in the PRC and, provides complementary suite of policy actions to enable it.

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