# 近零排放
# NEAR ZERO EMISSIONS

2013/12 试刊号

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中英（广东）CCUS 中心
UK-China (Guangdong) CCUS Centre

英国驻广州总领事馆

# 英国驻广州总领事馆低碳事业在广东

英国驻广州总领事馆致力于支持华南区的低碳经济转型，推动英国与华南在低碳政策、商业、科技等领域的双边合作。在过去几年中，我们与广东省的政府部门、企业、研究机构以及社会团体密切合作，共同开发和支持了一批有影响力的低碳项目活动，包括高层对话、政策研究、技术交流、机制体制研究、贸易投资等，实质性的推动中英低碳合作。

## 气候变化与能源处

英国驻广州总领事馆气候变化与能源处成立于2008年，标志着英国政府开始加大与中国在气候变化和能源方面的合作。我处与英国驻华使馆，及英国驻上海，重庆，香港领事馆的气候变化与能源处联合组成英国驻中国气候变化与能源网络。在华南地区，我们的工作覆盖了广东，湖南，海南，福建，广西和江西6省。在我处的促成下，广东省发展和改革委员会与英国能源与气候变化部于2013年9月签署低碳发展合作联合声明，确立了英国于华南在低碳合作上的又一里程碑。

## 中英合作项目

我们的工作重点之一是开发，管理和评估由英国外交部繁荣项目基金 (Prosperity Fund) 资助的合作项目。在该基金的资助下，中英双方专家共同努力，贡献了一系列已经应用于当地低碳经济发展的研究成果。例如广东省低碳发展路线图、企业能耗管理工具、广东省碳交易重点行业配额分配机制等。其中，我们从2009年开始支持的广东省CCS研究项目成果表明广东有丰富的二氧化碳海上封存潜力和早期示范机会，推动了中英(广东)CCUS中心的成立。展望未来，气候变化与能源处将着眼于扩大和深化这些项目在华南地区的影响。

了解更多，请联系英国驻广州总领事馆气候变化与能源处林珊，邮箱 phyla.lin@fco.gov.uk

British
Consulate-General
Guangzhou

# The British Consulate–General in Guangzhou and the Low Carbon Agenda

The British Consulate–General in Guangzhou is committed to support the shift to a low carbon economy in Guangdong and promote UK–China collaboration on low carbon policies, business engagement as well as science and innovation. In recent years, the Consulate has worked closely with the Guangdong Government and other stakeholders including research institutes, Non–Governmental Organisations (NGOs) and the business community in order to advance bilateral cooperation between the UK and Guangdong. This cooperation comes in many forms but has principally included high level exchange visits and cooperation on a range of projects aimed at helping Guangdong's low carbon transition.

## The Climate Change and Energy Team (CCE)

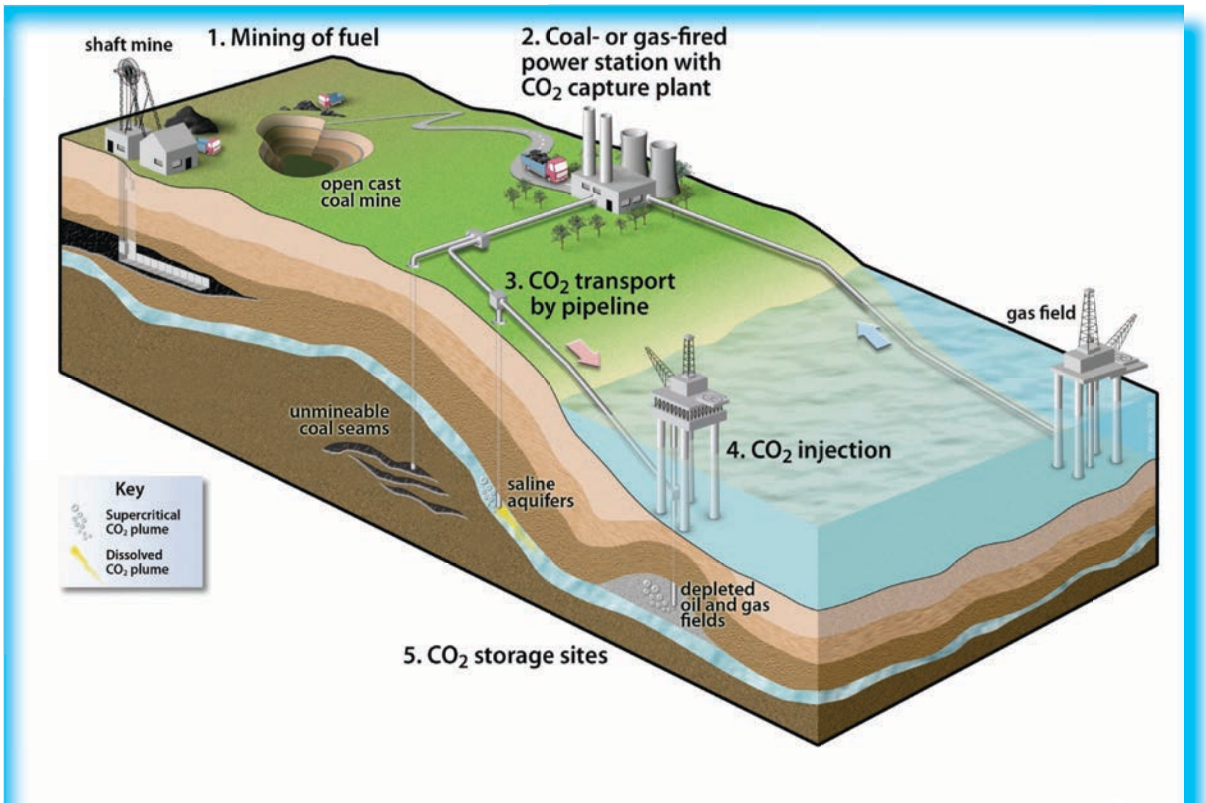
The Climate Change and Energy Team was established in 2008 to develop cooperation between the UK and the Southern Chinese provinces of Guangdong, Hunan, Hainan, Fujian, Guangxi and Jiangxi. The CCE Team in Guangzhou is part of the UK Climate Change and Energy Network in China. The network covers Beijing as well as the Consulates in Shanghai, Chongqing and Hong Kong. Over the years, the team has developed a wide range of low carbon workstreams with Guangdong partners.
This was recently highlighted when the Guangdong Development and Reform Commission signed a Low Carbon Development Joint Statement with the UK Department of Energy and Climate Change. This agreement, will ensure cooperation strengthens further in the years ahead.

## Deliverables

One of our priorities is to identify, develop, and monitor various projects that are funded through the UK FCO Prosperity Fund. Drawn from UK and International experience, and tailored to Guangdong and China's particular needs, our project work aims to provide practical policy recommendations, as well as technical solutions to support Guangdong's low carbon development. In recent years this has included the Guangdong Low Carbon Development Roadmap, Energy Management Toolkits for companies, and Guangdong ETS Allowance Allocation Plan for Key Sectors. In 2009, one of our projects aimed to develop a CCS Roadmap for Guangdong. The project revealed large $CO_2$ offshore storage capacity in Guangdong and indentified early demonstration opportunities which has led to the launch of UK–China (Guangdong) CCUS Centre.

For further information, please contact Phyla Lin at phyla.lin@fco.gov.uk.

封面图片描述：广州华润热电有限公司 Cover Picture: Guangzhou China Resources Power Thermal Power Company
封面图片来源：华润电力，2013 Source: China Resources Power, 2013



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# 为了发展

广东省发展和改革委员会副主任
中国民主促进会广东省委副主委　鲁修禄

鲁修禄

发展仍是解决我国所有问题的关键，这是《中共中央关于全面深化改革若干重大问题的决定》所强调的重大战略判断。改革是为了发展，把生态文明提升到五位一体的高度也是为了发展。那是因为中国还需要发展，而发展却遇到了前所未有的、不容回避的环境挑战，遇到了发展路径的瓶颈制约。不改革难以再发展，不凸显生态文明不能再发展。

广东依靠灵活政策实现了30多年的高速发展，GDP总量引领全国十多年，但是广东的人均GDP水平仍大大低于发达国家，基本公共服务仍处于较低水平。因此，发展仍是广东今后的第一要务。面对广东人口大省、资源消费大省的省情，广东省委、省政府一直致力于可持续发展的探索和创新，致力于生态美丽广东的实践。通过强力推动产业结构调整、推进区域协调发展、大力优化能源结构、落实节能减碳各项措施及开展碳排放权交易试点等，努力完成国家要求的能源强度、碳强度和排放物下降的约束性指标，广东的努力和探索为未来的发展提供了“正能量”。

推动能源生产和消费革命是建设生态文明、实现低碳发展的根本途径和关键着力点，是广东突破资源环境制约，实现可持续发展的根本途径和战略选择。近年，城市内涝、雾霾等环境污染问题再次突显，大幅度降低GDP的能源强度和碳强度，努力实现近零排放正逐步成为广东政府、企业、社会的广泛共识。广东一次能源消费中煤炭比重占48.7%，化石能源比重达83.6%的现实，使CCUS作为全球最重要的减排技术之一成为广东发展的现实需要，在广东电力、水泥等企业中已形成共识，并有了积极的响应。

CCUS离我们并不遥远，它已是广东满足能源消费需求，同时保障生态环境和发展的现实需要。要让这种需求成为广泛应用的技术，需要我们就近零排放技术在政策法规、技术标准、项目示范、产业化模式、集成服务、安全保障以及成本降低等各方面作更多、更深入的研究和更大、更积极的努力。

“中英（广东）CCUS促进与学术交流中心”的成立，为广东打造了一个开放的、交流合作和产业促进平台，凝聚了合作方参与者的心血和智慧。她的成立和成功运行，将为实现近零排放的理念，为广东可持续发展注入强大力量。我们相信，一个繁荣富裕的广东天是蓝的，水是清的，山是绿的。发展带给广东人民的不会是危害，只会是幸福！

# Towards Development

Deputy Director of Guangdong Development and Reform Commission
Deputy Director, Guangdong Provincial Committee, China Association for Promoting Democracy
Lu Xiulu

Lu Xiulu

Development still holds the key to resolve all issues in China, and this was highlighted as a major strategy in “Decision on Major Issues Concerning Comprehensively Deepening Reforms”. Reform is carried out to facilitate ‘development’, and highlighting ecologically motivation in the “Five-in-One” development strategy also aims for ‘development’. Because China still needs ‘development’, but China is now confronted with unprecedented and unavoidable environmental challenges and bottlenecks in the path of development. China's development will halt without reform; China's development will halt without a focus on creating an ecological civilization.

With rapid development in the past 30 years based on flexible policies, Guangdong's total GDP has led the country for more than a decade. However, the per capita GDP is well behind that of developed countries, and the basic public services are still at relatively low level. Consequently development is still at the top priority for Guangdong Province. Under the new scenario of a large, resource-consuming population, Guangdong provincial party committee and Guangdong provincial government dedicating to sustainable development exploration and innovation, creating an ecological civilization. Guangdong is achieving the national obligatory targets of energy intensity, carbon intensity and emission reductions by (i) promoting industrial restructuring, (ii)balancing development between regions, (iii) optimizing energy structure, (iv) implementing energy conservation and carbon reduction measures, and (v) demonstrating a carbon emission trading scheme. The efforts and exploration carried out by Guangdong Province will provide ‘positive energy’ towards future development.

Promoting the revolution in energy production and consumption is a critical pathway and a strategic choice for an ecological civilization to take to break resource and environmental constraints and allow sustainable development in Guangdong Province. Inland inundation and haze caused by environmental pollution have recently become prominent in urban areas. The Guangdong Government, enterprises and society are gradually reaching broad consensus on the need to reduce the energy and carbon intensity of the provincial GDP and to strive for near-zero emissions. Of Guangdong's total energy consumption, coal contributes to 48.7% of primary energy and fossil fuel contributes to 83.6%, thus CCUS as one of the world's most significant emission reduction technologies, is essential for Guangdong's development. This consensus is acknowledged by enterprises within many sectors including power, cement.

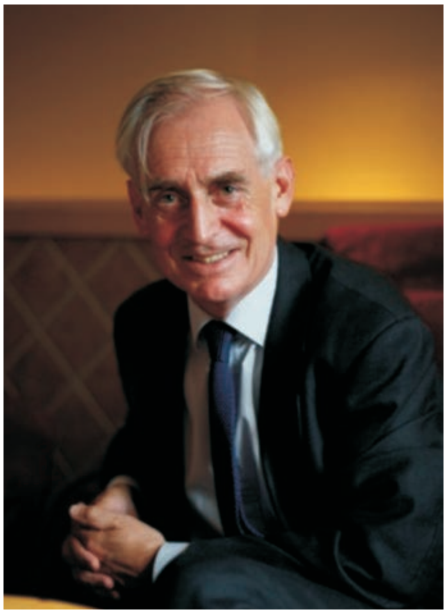
CCUS is not far away from us. Guangdong Province can achieve CCUS to satisfy demand for energy consumption and allow environmental friendly development. To enable CCUS technologies to be widely applied, more in-depth studies and greater effort on ‘Near Zero Emission Technology’ are required on policies and regulations, technical standards, project demonstrations, industrialization patterns, integrated services, safety control and cost reductions.

The establishment of “UK-China (Guangdong) CCUS Industry Promotion and Academic Collaboration Centre” provides an open platform to promote CCUS exchange, cooperation and industrial development, and symbolizes the hard work and intelligence of all cooperating parties. The successful establishment and operation of this Centre will give a strong impetus to realizing Guangdong's concepts of near-zero emissions and sustainable development. A thriving and prosperous Guangdong will enjoy clearer sky, greener land, cleaner water and a better environment for development. Let development benefit the people in Guangdong!

# 《近零排放》杂志序言

英国驻广州总领事馆总领事 摩根

2013 年 12 月 10 日



英国驻广州总领事馆总领事 摩根

近零排放！我想首先为这个令人振奋的名字而喝彩。近零排放代表着一种可持续的发展模式。包括英国在内的许多国家，正在积极探索这种发展模式。更让我欣喜的是，广东也在朝着这个方向迈进。作为中国改革开放的先锋，广东勇于开展研发，并探索新的政策，来创造一个近零排放的未来，相当令人鼓舞。

大家都知道，碳捕集与封存 (CCS) 技术是实现近零排放的重要手段。这种技术有潜力实现大规模的减排，从而给我们的经济发展“脱碳”。因此，我一直都全力支持英国驻广州总领事馆气候变化和能源处的努力，非常高兴看到他们坚持不懈地支持广东探索和发展 CCS 技术。

在英国，我们也在竭尽全力加速 CCS 技术的商业化进程。

今（2013）年 12 月 9 日，英国政府 10 亿英镑的 CCS 商业化项目宣布斥资数千万英镑支持名为“白玫瑰”的全规模碳捕集与封存清洁煤电厂项目，为超过 63 万家庭提供清洁电力。如果这个大规模、一体化的项目能够顺利运作，将可能进一步降低 CCS 技术的成本，进一步缩短商业化 CCS 技术的距离。正如英国能源与气候变化部部长爱德华·戴维 (Edward Davey) 所说：“英国能够站在发展碳捕集与封存技术的前沿，这令我无比自豪。CCS 不仅是我们应对气候变化的关键手段，而且将为开展 CCS 项目的地区乃至全英国带来不可估量的经济效益。”我们相信，CCS 技术和低碳发展也为英国和广东创造了实质性的合作机会。

今 (2013) 年 9 月，我有幸陪同广东省省长朱小丹先生访问了英国。访问期间，朱省长见证了广东省发展和改革委员会与英国能源与气候变化部签署了关于低碳发展合作的联合声明。一项关于成立中英( 广东 )碳捕集、利用与封存研究中心的谅解备忘录也同时签署。我认为，这不是我们工作的终点，而是一个起点，一个里程碑：一个建立长久合作关系的里程碑。

因此，我谨对与我们携手推动 CCS 技术，以及更多低碳领域中英合作的广东的同仁们表达诚挚的感谢！我也相信，《近零排放》杂志将为我们实现共同的低碳梦想贡献一份力量！

# Preface for Near Zero Emissions Magazine

Alastair Morgan

Consul General, British Consulate General in Guangzhou
10 December 2013

Alastair Morgan

Near Zero Emissions! I should perhaps begin by applauding those that chose such an inspiring name. Near Zero Emissions represents a sustainable development model which generates economic growth without damaging the environment.  It is a model which many countries, including the UK are exploring and I am delighted to see it now gaining support here in Guangdong. Given Guangdong's history and role as China's pioneering province, it is hugely encouraging to see the province commit to R&D as well as the necessary policy reform to pave the way to a Near Zero Emissions future.

In order to make progress on this agenda, it is right that we focus on Carbon Capture and Storage (CCS).  It is a technology that offers real potential to significantly reduce emissions and help decarbonise the world. I am therefore particularly pleased that, for a number of years, the Consulate's Climate Change and Energy team have been working with provincial stakeholders to help identify and support opportunities to move this forward in Guangdong.

In the UK, we are also making good progress in commercialising this technology. On 9 December 2013, the UK's £1bn Carbon Capture and Storage Commercialisation Programme announced its multi–million pound FEED study funding to support the White Rose project, a state–of–the–art coal power plant with full CCS that will be able to provide clean electricity to more than 630,000 homes. This is important because if this large scale integrated project become operational, the technology will move further down the cost–curve, bringing us closer to realistic commercial deployment. As our Secretary of State for Energy and Climate Change, Edward Davey said: “I'm proud that the UK is at the forefront of developing Carbon Capture and Storage – which could be a game–changer in tackling climate change and provide a huge economic advantage not just to this region, but to the whole country.” We believe that this, along with the wider low carbon agenda offers a real cooperation opportunity for both the UK and Guangdong.

In September this year, I had the honour to accompany Governor Zhu Xiaodan on his visit to the UK. During the visit, Governor Zhu witnessed the signing of a low carbon cooperation agreement between the Guangdong Development and Reform Commission and the UK Department of Energy and Climate Change. A MoU on establishing a UK–China (Guangdong) CCUS Centre  was also signed between UK and Guangdong institutes. This is of course not the culmination of our work but rather a milestone on a relationship that has a long way to go.

I would therefore like to express my sincere thanks to our partners in Guangdong that continue to work with us to move CCS and the broader low carbon agenda forward. I am sure Near Zero Emissions magazine will have a role to play in helping achieve our shared objectives.

# 中心主任寄语

中英（广东）CCUS 产业促进与学术交流中心主任 罗必雄

中心主任 罗必雄

节能减排是深化改革、改进民生、构建社会主义和谐社会的重大举措。

长期以来，我国政府非常重视节能减排和环境保护工作，取得了卓有成效的成绩。但也应该看到，随着工业化的高速发展，人类活动导致的排放对环境的破坏愈来愈严重。为更有力地推进节能减排工作，9 月 27 日，在广东省省长朱小丹和英国能源与气候变化部副部长 Gregory Barker 的见证下，我作为广东省电力设计研究院院长代表广东省低碳技术与产业研究中心（GDLRC）与英国碳捕集与封存研究中心（UKCCSRC）、苏格兰碳捕集与封存中心（SCCS）和清洁化石能源发展研究所（CFEDI）在英国伦敦兰卡斯特宫共同签署了中英脱碳合作协议，并由上述 4 家单位组建成立中英（广东）CCUS 产业促进与学术交流中心。中英双方承诺并计划在脱碳技术及产业化方面开展广泛、深入的合作。

不久前，国家发展和改革委员会副主任解振华代表中国在联合国气候变化华沙会议高级别会议上作出正式承诺“确保实现到 2020 年碳强度比 2005 年下降 40%–45% 的行动目标”，节能减排低碳环保已成为各国政府和组织对我们共同生存的地球环境保护的郑重承诺。

为积极响应政府号召，搭建低碳技术交流、实施的平台，推动我省节能减排低碳工作深入开展，我中心特编辑出版《近零排放》期刊。此刊将陆续收集国内外节能减排的相关政策、低碳技术相关论文及工程案例、低碳技术领域最新信息报道等，希望《近零排放》成为全国企业节能减排低碳工作相互交流、彼此探讨、共同发展的载体。让绿色、循环、低碳发展理念深入人心。

# A Message from the Director of the UK-China (Guangdong) CCUS Centre

Director of UK-China (Guangdong) CCUS Industry Promotion and Academic Collaboration Centre Mr Bixiong LUO

LUO Bixiong

Energy conservation and emissions reduction are major measures needed to strengthen reform, improve the livelihood of the people, and build a harmonious socialist society.

For a long time, the Chinese Government has attached great importance to the work of energy conservation, emissions reduction and environmental protection, and has achieved significant results. However, it is evident that, with rapid industrialization, emissions from human activities cause more and more serious damage to the environment. In order to boost more effectively the work of energy conservation and emissions reduction, as president of Guangdong Electric Power Design Institute (GEDI) and representing the Guangdong Low-carbon Technology and Industry Research Centre (GDLRC), on September 27th I signed the UK-China CCUS Cooperation Agreement. were the UK Carbon Capture and Storage Research Centre (UKCCSRC), the Scottish Carbon Capture and Storage (SCCS) and the Clean Fossil Energy Development Institute (CFEDI). The signing, which took place at Lancaster House in London, was witnessed by Governor Zhu Xiaodan of Guangdong Province, People's Republic of China, and Minister Gregory Barker of the UK's Department of Energy and Climate Change (DECC). At the same time the above four institutions founded the UK-China (Guangdong) CCUS Industry Promotion and Academic Collaboration Centre. Both China and the UK have committed and are planning to co-operate extensively and in depth to promote technology to decarbonize industry.

Mr Xie Zhenhua, deputy director of National Development and Reform Commission, made a formal commitment to ensure the realization of the goal of “reducing carbon intensity by 40%-45% below the level of 2005 in 2020” in the Warsaw High Level Meeting of the UN Climate Change Conference. Energy conservation and emissions reduction, low-carbon development and environmental protection have become firm commitments by governments and organizations around the world to the global environment in which we are living.

Actively responding to the Chinese government's appeal, the UK-China (Guangdong) CCUS Industry Promotion and Academic Collaboration Centre is launching the Near Zero Emission magazine to provide a platform for the exchange and implementation of low-carbon technologies as well as conduct in-depth analysis on energy saving, emissions reduction and low-carbon development. This magazine will publish policies related to energy saving and emission reduction from home and abroad, together with papers, engineering projects and the latest news relating to low-carbon technologies. It is expected to become a platform for domestic enterprises to exchange and investigate information as well as make joint progress on energy saving and emissions reduction. Let the concepts of green development, recycling and low carbon development take root in every citizen's mind.

# 编者的话

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李佳博士（右）和邓广义副总工（左）在英国伦敦 Lancaster 宫合影
照片来源：杨晖，2013

气候变化是全人类共同面对的一大挑战，要实现联合国制定的控制气候变化在 2 摄氏度以内的目标，如果不上 CCUS 等近零排放技术，现在已探明的化石燃料只有不到四分之一能够燃烧和排放。与此同时，包括中国在内的许多发展中国家还面临着迅速工业化带来的严重环境污染的灾难，能源供应安全担忧，和能源价格承受能力问题。在中国和印度等主要新兴经济体，以化石能源为主的能源结构中，要解决上述问题，迫切需要发展，示范和应用近零排放技术，迅速寻找产业化路径和成本下降的路径。在近零排放技术的产业链中，碳捕集，利用与封存技术（CCUS）是实现二氧化碳近零排放的最重要但也最挑战的技术。借此中英（广东）CCUS 中心成立之际，本期将重点回顾 2013 年 CCUS 在世界的发展，以及该技术在中国的项目应用，和在广东的示范和产业发展机会。本期也同时介绍中国水泥行业清洁生产的一个重要技术选项。

全球主要国家对应对气候变化还没达成一致协议，CCUS 技术在 2013 年还是取得不少积极的进展。在 CCUS 政策推动方面，国际能源署发布了最新的碳捕集与封存技术路线图；中国国家发展与改革委员会发布了《关于推动碳捕集、利用和封存试验示范的通知》；美国财政部发布了修改后的技术指导方针建议发展中国家新建燃煤电厂需要实施 CCS 技术，否则不能取得多边机构在内的公共融资。在项目进展方面。在示范项目方面，世界上第一个商业规模燃烧后二氧化碳捕集与封存的项目 Boundary Dam 项目已经接近竣工、英国的‘白玫瑰’项目顺利得到政府支持进入前端工程设计阶段、世界上最大的二氧化碳注入设施——澳大利亚的 Gorgon 项目正在往前推进。与此同时，在中国和南非等发展中国家新增的大型一体化 CCUS 项目正在为 CCUS 的推广树立榜样和信心。

同时，中英，中美也签订的合作谅解备忘录，合作开发和推广创新型碳捕集、利用与封存技术；而世界银行，亚洲开发银行在中国的项目也在积极进行实现知识转让；目前，中国目前有 12 个处于各发展规划阶段的大型一体化 CCUS 项目，比 2010 年的 5 个大幅增加，数目仅次于美国。

而我们近零排放杂志也将从本期启航，成为一个新的信息渠道和讨论平台，不断为来自各界各位专家，同行提供丰富的近零排放技术信息，政策变化，示范项目，增进企业，专家和政府相互交流。在此，预祝各位在 2014 年工作顺利，身体健康，万事如意！

# Editors’ Thoughts

Dr LI Jia (University of Edinburgh)
Ms DENG Guangyi（China Energy Construction Group Guangdong Electric Power Design Institute)

Jia LI (right) and Guangyi DENG (left) at Lancaster House, London
Source: Hui YANG, 2013

Climate Change is a major challenge for human society. Without CCS technologies, only one quarter of the world's current fossil fuel reserves can be burned and emitted to the atmosphere if we are to limit the rise in global temperatures to 2 degrees centigrade. At the same time, developing countries, including China, are facing severe environmental pollution problems, concerns over energy security, and energy price affordability issues along with rapid industrialisation. In major emerging economies such as China and India, whose energy structures are dominated by fossil fuel, it is essential to develop, demonstrate and deploy near zero emission technologies to help solve the above challenges. We also need to seek a pathway to reduce the cost of, and industrialise, these technologies. Within the near zero emission industry chain, carbon capture, utilisation and storage (CCUS) is an important but most challenging technology. The UK-China (Guangdong) CCUS Centre will be established on December 2013, and in this current issue, we are taking the opportunity to review the development of CCUS technologies during 2013, their application in China, and the potential opportunities in Guangdong for demonstration and industrial development. At the same time, we also introduce a clean production option for the cement sector.

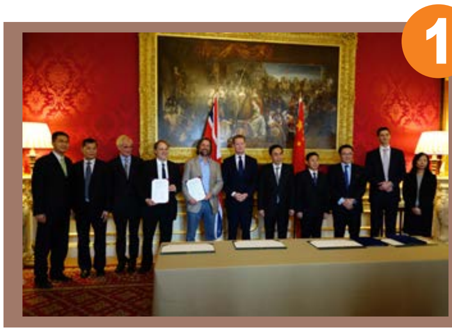
Although major economies have not yet reached a durable global agreement to combat climate change, CCUS technologies made progress in 2013. From the policy perspective, the new version of the IEA CCS Roadmap laid the foundation for this exciting year, and in the US, a revised technical guidance released by the Treasury Department pointed out that the US Government would no longer support the public financing of new coal plants without CCS. From the project side, the Canadian Sask Power Boundary Dam project is nearing the completion of construction,and the UK White Rose project enters the FEED stage. China's progress is particularly noteworthy. The Chinese government ministry, the National Development and Reform Commission issued a “Notice on Promoting Carbon Capture, Utilisation and Storage Pilot and Demonstration”. This notice clearly confirms governmental support for research, development and deployment of CCS.

In the meanwhile, China and the UK, and China and the US have signed MOUs to develop innovative CCUS technology. Projects funded by the World Bank and Asian Development Bank in China are progressing well and transferring knowledge. 12 projects spread across all stages of development planning are progressing in China, a significant increase compared to the 5 in 2010, ranking China second only to the United States in the number of extant CCUS projects.

Looking forward to 2014, we hope the progress on CCS can be accelerated and experiences and lessons will be learned from the various demonstration projects. Starting with this issue, we are aiming continuously to deliver comprehensive near zero emission information provided by experts to peers. Finally we would like to take this opportunity to wish everyone a very Merry Christmas and a Happy New Year!

# 中英（广东）CCUS 中心活动剪影

1



广东省省长朱小丹与英国能源及气候变化部 Gregory Barker 副部长与中英 CCUS 团队在有关 CCUS 合作备忘录签约后合影　照片来源：杨晖，2013

Guangdong Provincial Governor Mr Xiaodan ZHU and UK Department of Energy and Climate Change Minister Mr Gregory Barker MP and UK–China CCUS Team at Lancaster House at the CCUS MoU Signature

Photo Source: Hui YANG, 2013

2

广东省省长朱小丹与英国能源及气候变化部 Gregory Barker 副部长在伦敦兰卡斯特宫亲切交谈，由广东省政府秘书长李锋（左一），兰卡斯特大学环境学院院长 Kevin Jones （左二），广东省外办吴雅丽（左三）等陪同　照片来源：杨晖，2013

Guangdong Provincial Governor Mr Xiaodan ZHU and UK Department of Energy and Climate Change Minister Mr Gregory Barker MP discuss at the garden of Lancaster House in London，with Secretary General of Guangdong provincial government Mr Feng LI (Left One), Lancaster University Environment Centre Director Prof Kevin Jones (Left two) and Guangdong Provincial Foreign Office, Ms Wu Ya Li (Left three). Photo Source: Hui YANG, 2013

3

广东省政府发改委，科技厅和财政厅官员和广东 CCUS 成员，与 CCS 协会主席在英国能源与气候变化部开会后合影　照片来源：梁希，2013

Guangdong government officials, Guangdong CCUS Team and CCS Association chair meeting at UK Department of Energy and Climate Change Photo Source: Xi LIANG, 2013

4

广东省发改委官员，英国驻广州领事馆官员，苏格兰发展局官员，广东 CCUS 项目成员，与华润电力和佛山公控同事在爱丁堡大学老学院座谈会后合影　照片来源：杨晖，2013

Guangdong DRC, BCG, Scottish Enterprise, GDCCUS Project, China Resources Power and Foshan Utilities Colleagues meeting at University of Edinburgh Old College　Photo Source: Hui YANG, 2013

5

苏格兰 CCS 中心主任 Stuart Haszeldine 教授与报告者在中心年会后合影 Photo Source: Brian McIntyre, 2013

Scottish CCS Centre Director Prof Stuart Haszeldine and Speakers at SCCS Annual Conference　照片来源：Brian McIntyre, 2013

# 活动剪影

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广东省发改委，英国驻广州领事馆，中英（广东）CCUS 中心，华润电力，与佛山公控同事在苏格兰 CCS 中心会议期间合影　照片来源：杨晖，2013

Guangdong DRC, British Consulate General in Guangzhou, UK-China (Guangdong) CCUS Centre, China Resources Power and Foshan Utilities Officials Photo at Scottish CCS Industrial $CO_2$ Capture Conference

Photo Source: Hui YANG, 2013

7

广东 CCS 预留项目成员参加延长油田 CCUS 项目研讨会后合影

照片来源：周蒂，2013

Guangdong CCS Readiness Project Team at Yanchang Oil Field CCUS Project Workshop　Photo Source: Di ZHOU, 2013

8

广东省发改委官员，英国驻广州领事馆官员，广东 CCUS 项目成员，与华润电力和佛山公控同事访问英国 CCS 中心中试基地

照片来源：杨晖，2013

Guangdong DRC, BCG, UK-China CCUS Centre project, China Resources Power and Foshan Utilities Colleagues Visit UKCCSRC PACT Facilities Photo Source: Hui YANG, 2013

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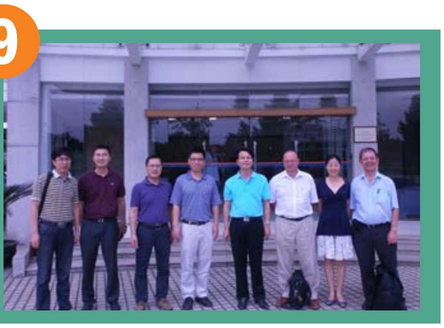
英国豪顿集团，爱丁堡大学，与中科院南海海洋所同事在粤堡水泥厂座谈会后合影　照片来源：梁希，2013

Howden Group, University of Edinburgh and Chinese Academy of Sciences Colleagues meeting at Yuebao Cement Plant

Photo Source: Xi LIANG, 2013



10

英国驻广州领事馆官员，广东 CCUS 项目成员，与豪顿集团成员访问中海石油惠州炼化二期项目组　照片来源：梁希，2013

British Consulate General in Guangzhou, Guangdong CCUS Team, and Howden Group　Photo Source: Xi LIANG, 2013

# 近零排放
NEAR ZERO EMISSIONS

**2013/12 试刊号**

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British Consulate–General Guangzhou

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# 新闻回顾

## 1. 欧洲委员会发布对 2030 的 CCS 政策选择咨询

2013 年 3 月

欧洲委员会三月底在一份政策文件中表示，较低的二氧化碳价格，阻碍了碳捕集与封存商业化，让该技术难以迅速得到应用。

在该文件中建议的主要方案包括强制性的电厂排放性能标准、可交易的 CCS 证书以及国家层面的战略规划。

对该草案唯一主要的变更，是增加了关于“对确保在欧盟进行充分的 CCS 示范项目而解决主要障碍”的问题。一位发言人表示，支持 CCS 的非政府组织贝罗那基金会对增加的该问题表示欢迎，因为该问题有助于“评估欧盟 NER300 计划出了什么差错”。因为第一轮 NER300 资助计划没有实现资助任何的 CCS 项目的目标。而该政策选项的咨询结果将在 2013 年年底公布。

## 2. 全球碳捕集与封存研究院北京办事处成立

2013 年 3 月

全球碳捕集与封存研究院三月在北京开办了一个办事处，凸显了中国在 CCS 技术开发方面起到的重要作用。

全球碳捕集与封存研究院由澳大利亚政府创办，帮助碳密集型经济体加快开发 CCS 技术，并在全世界范围内向政府和项目支持者收集和传播专业知识。

资源与能源部长、议员 Martin Ferguson 表示，“该新办公室将使该研究院能够与其中国地区的会员进一步增强联系。中国占全球能源使用预计增长的最大份额，到 2035 年其需求将增长到 60%”。而“通过该研究院在中国的工作学到的和分享的经验教训将有助于来自世界各地，包括澳大利亚的政府和项目支持者加快 CCS 技术的推广。”

全球碳捕集与封存研究院还在欧洲、北美和日本拥有办事处。

该研究院有一个来自世界各地 368 个政府、行业组织、非政府组织和研究组织为基础的国际会员资格。该研究院的会员涵盖超过 80% 的来自能源和工业源的世界二氧化碳排放。

全球碳捕集与封存研究院启动仪式，图片来源：北京青年报 ,2013

图片描述：2013 年 7 月，澳大利亚碳捕集与封存研究院与延长石油签订合作备忘录
图片来源：延长石油，2013

除了对该研究院的支持外，澳大利亚政府正通过一系列措施中投资 20 多亿美元，以帮助开发低排放技术，其中包括 CCS 计划。

北京办事处在开业四个月后，成功促成了碳捕集与封存研究院与延长石油的重要合作。

## 3. 英国 10 亿英镑 CCS 竞标计划宣布两个优选项目

2013 年 3 月

英国 10 亿英镑的碳捕集与封存商业化计划竞标在三月宣布了两个优先竞标者。它们是位于苏格兰阿伯丁郡的 Peterhead 项目和位于英格兰约克郡的白玫瑰项目。能源与气候变化部部长 Edward Davey 在公布后说：“今天的公告使我们在更接近一种碳捕集与封存工业上推进了重大一步——一个将有助于减少碳排放并创造数千工作机会的行业。” “这两个项目是主要的基础设施项目，可能价值 70 亿英镑，在未来几年可以支持数千建筑岗位。”

“我们有四个优秀的投标，我感谢它们每一个投标的努力工作。我们现在将马上工作以推进我们首选的两个项目，同时确保我们继续向纳税人提供最大可能的价值。”

能源大臣 John Hayes 说：“为使我们拥有具备成本竞争力的 CCS 行业的目标，我们正在迅速行动——这些项目只是开始。在去年我们已经证明了在英国 CCS 行业有旺盛的投资欲望，能提供工作和投资机会。我的目的是除了这两个项目外与工业合作，以确保在本年代末我有更多的 CCS 项目——由我们对能源市场正在做出的创新改变支持，以鼓励在低碳电力方面的投资。我非常高兴这两个项目为我们提供机会以确保燃煤和燃气发电能够显著降低我们的碳排。”

这两个优选的项目的详情：

- 位于苏格兰阿伯丁郡的 Peterhead 项目——采用燃烧后捕集捕集技术，分离位于 Peterhead 燃气电厂大约 90% 的二氧化碳，并将二氧化碳运输并封存到北海的一个枯竭气田。该项目由壳牌公司和苏格兰南部电力（SSE）公司牵头。
- 位于英格兰约克郡的白玫瑰项目——捕集位于北约克郡 Drax 电力公司准备建设的高效富氧燃烧燃煤发电厂，捕集 90% 的二氧化碳，再将二氧化碳运输并封存进北海南部的一个咸水层。该项目由阿尔斯通公司、

Drax 电力公司和英国国家电网公司牵头。

这两个优选项目是自去年 10 月，与入选自最初 8 个项目中的四个项目一段密集的商业谈判之后，被挑选出来的。英国政府目前正与这两个首选项目进行讨论，以确认进行前端工程设计研究的条款，该研究将持续大约 18 个月。政府将在 2015 年初作出有关以上两个项目的最终投资决策。其余的两个竞标者——Captain 清洁能源项目和蒂赛德低碳项目——将被指定为后备项目。

## 4. 国家发展改革委关于推动碳捕集、利用和封存试验示范的通知

2013 年 4 月

国家发改委气候司发出通知，推动碳捕集、利用和封存（CCS）试验示范工作。该通知提出，要实施一批碳捕集、利用和封存试验示范项目，探索建立相关政策激励机制，加快相关标准规范的制定。

发改委目前认识到，中国碳捕集、利用和封存各环节的技术研发已取得显著进展，但仍然存在成本和能耗高、长期安全性和可靠性有待验证等问题，开展试验示范既有助于通过实践来解决该技术发展中存在的各种问题，也是该技术走向规模化和商业化应用、发挥其大规模温室气体减排潜力的必经环节。国家发改委气候司同时要求各地、各部门加强对碳捕集、利用和封存试验示范的支持和引导。

通知提出，近期将从 6 个方面来推动碳捕集、利用和封存的试验示范工作：一是结合碳捕集和封存各工艺环节实际情况，开展相关的试验示范项目。鼓励在煤化工、油气等行业开展对高纯度二氧化碳排放源进行捕集的示范项目；加强对二氧化碳天然气藏（田）开采的管理，严格限制以利用为目的的二氧化碳气藏（田）开发，逐步关停现有气田，推动捕集所获的二氧化碳实现多方式、多渠道的资源化利用；在二氧化碳排放集中地区加强二氧化碳封存潜力评价与选址工作；建立不同行业间的协调合作机制，加强二氧化碳捕集点（供应方）与封存地（需求方）的匹配和衔接。二是开展碳捕集、利用和封存示范项目和基地建设。优先支持成本较低、规模适度、有行业和地区特色、拥有自主知识产权的半流程及全流程示范项目，并组织建立重点示范项目清单和项目库。三是探索建立相关政策激励机制，落实现行有关税收扶持政策，不断拓宽资金渠道。四是加强相关战略研究和规划制定，在摸清电力、煤炭及煤化工、石油石化、天然气等行业温室气体排放基本情况的基础上进一步明确政策需求和导向。五是推动相关标准规范的制定。六是加强能力建设和国际合作。

推动碳捕集、利用和封存试验示范已经是“十二五”控制温室气体排放工作的一项重点任务。据了解，国务院此前印发的《“十二五”控制温室气体排放工作方案》明确要求，在火电、煤化工、油气、钢铁等行业中开展碳捕集试验项目，建设二氧化碳捕集、驱油、封存一体化示范工程。

## 5. 中美两国同意建设“几个大规模的”碳捕集示范项目

2013 年 7 月

中国国务委员杨洁篪、国务卿约翰・克里，中国国务院副总理汪洋和美国财政部长 Jack Lew 在华盛顿举行的美中战略经济对话开幕式后握手

美国和中国达成一致协议将采取一系列其他措施，共同控制中美两个污染大国的温室气体排放。

两国高官于星期三举行会晤，把目光瞄准五个方面——从最基本的提高建筑能效到官员认为的能推动发电站碳捕集技术发展的前沿方法。

拥护者认为碳捕集是一项能在长期内解决全球变暖问题的重要技术，但高昂的成本和尚需通过更多大型示

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范项目检验成为阻碍其发展的主要因素。在达成的协议中，中美两国同意建设“几个大规模的”碳捕集示范项目，以求克服阻力，在更大范围内利用这项技术。

“中国和美国是世界上两大重要的经济体，也是温室气体排放得最多的国家…携手合作…有益而无害”美国气候变化事务特使托德•斯特恩说，“这并不是突然改变国际协定，相反这反映了积极的一面。”

## 6. 澳大利新任总理欲废止碳税，而全球最大CCS 项目将照常进行

2013 年 9 月

澳大利亚当选总理 Tony Abbott 承诺废除碳税以提升经济竞争力，但该国仍然继续开展世界上最雄心勃勃的碳捕集与封存项目。

雪佛龙公司将从 2014 或 2015 年开始向地下 2.5 千米深处注入 1.2 亿吨增压的超临界二氧化碳，这也是大型 Gorgon 液化天然气项目的一部分。

Gorgon 油田的天然气源中伴生二氧化碳的含量达 14%，必须把这些碳分离出来并将其安全的处理才能液化提纯的甲烷，再进行出售。

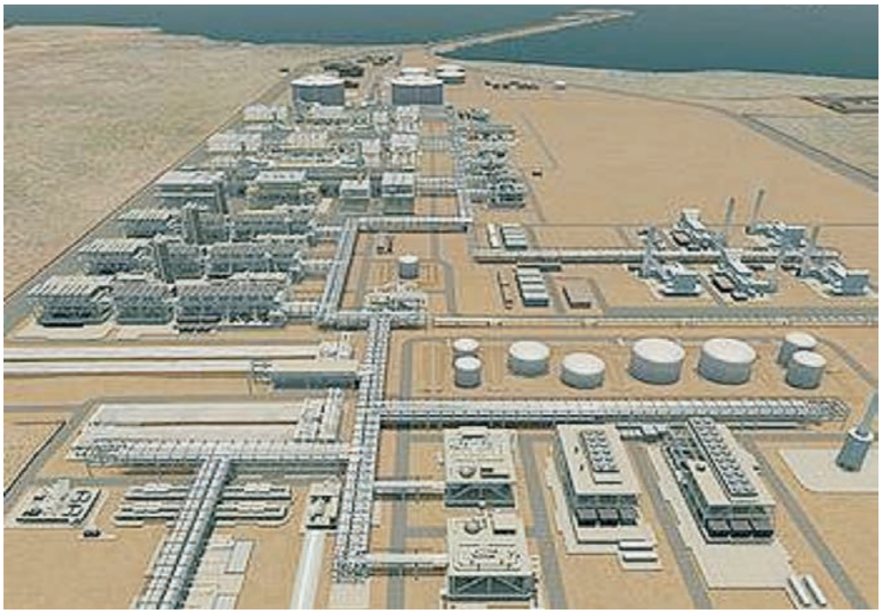
根据 2009 年州和联邦政府都通过的一个雄心勃勃的项目，雪佛龙公司将向临近西澳大利亚州海岸的巴罗岛地下咸水层注入二氧化碳。

雪佛龙公司投入 20 亿美元建造世界上最大的二氧化碳注入设施，年封存量将能达到 300 万吨以上，这让其成为迄今为止全世界最大的二氧化碳封存项目，同时为研究二氧化碳被注入到咸水层后在地下的活动情况提供了绝佳的机会。

长期义务与保障

巴罗岛是一级自然保护区，而二

图片描述：澳大利亚 Barrow 岛正在建设的 Gorgon 项目 LNG 输出站
图片来源：悉尼先驱晨报 ,2013



图片描述：Gorgon 项目效果图；图片来源：韩国现代集团，2013

在建设中的 Gorgon 项目 ；图片来源：雪佛龙，2013

氧化碳在浓度只有 7–15% 时，对人类也是致命的。因此，雪佛龙公司进行了大量的地震探测和钻孔观察，评估蓄水层的封存能力，确保不会发生碳泄漏。

公司还承诺利用 4 维地震探测法监测二氧化碳烟羽从初始注入井扩散时在地下的运动轨迹。雪佛龙公司与其合资伙伴将共同承担项目进行过程中以及停止二氧化碳注入后的 15 年内因泄漏或其他损失所产生的费用。而联邦及西澳大利亚州政府已经同意承担任何更长期的义务。

联邦和州的保障能保护合资伙伴免于承担因在封存点停止运营后第三方索赔损失引起的任何普通法律责任。

这一保障实现的前提条件是，在停止注入二氧化碳后的 15 年或更长时间内，对封存起来的二氧化碳的监测和建模要持续进行，直到州和联邦政府都认可二氧化碳气体已被安全封存。

根据 Baker & McKenzie 法律事务所准备的数据分析，这项前提条件至少要到 75 年之后才会生效。

至关重要的资源

与大多数项目将二氧化碳注入枯竭油气田不同，Gorgon 项目将向咸水层注入二氧化碳，为大规模咸水层二氧化碳注入提供了很好的示范。

美国能源部将咸水层作为所有能从实质上改善气候环境的规模的 CCS 项目的重要封存地。

仅美国的咸水层就能封存 1.6 至 20 万亿吨二氧化碳，而不可开采的煤储层只能封存 600 到 1200 亿吨，枯竭油气田的封存量也只有 1200 亿吨。

二氧化碳被封存至咸水层后在地下的活动状况还鲜为人知。

Gorgon 项目即使正在面对澳大利亚气候变化政策的不确定性，澳大利亚政府也将赞助这一全球目前最大的 CCS 项目，帮助其成功地将二氧化碳封存到地下。

## 7. 英中宣布合作开发创新性碳捕集、利用与封存技术

2013 年 9 月

中英科学家和工程师将深化合作，为创新型碳捕集、利用与封存（CCUS）技术的研发与示范创造条件。

九月底，英国碳捕集与封存研究中心（UKCCSRC）、苏格兰碳捕集与封存中心（SCCS）、广东省电力设计院广东低碳技术与工业研究中心（GDLRC）和清洁化石能源发展研究所（CFEDI）在广东省省长朱小丹及英国能源与气候变化部部长 Gregory Barker 见证下在伦敦兰卡斯特宫共同签署了一份为期十年的合作谅解备忘录。

这一协议将推动中英（广东）CCUS 中心的建立，该 CCUS 中心促进中英两国的研发和产业化合作，为地方和地区政府提出建议，并为各参与方知识交流创造条件。双方计划迅速采取行动，可能在三到五年内在中国示范 CCUS 技术。

图片描述：英国能源与气候变化部副部长 Gregory Barker 与广东省省长朱小丹见证中英机构签署 CCUS 合作备忘录
图片来源：爱丁堡大学，2013

图片描述：中英机构签署 CCUS 合作备忘录后合影
图片来源：爱丁堡大学，2013

Gregory Barker 部长和朱小丹省长还共同签署了一份联合声明，保证中英两国在低碳技术开发方面的合作，包括 CCS 技术。

非常巧的是，这些协议的签署和政府间气候变化专门委员会一份进一步报告的发布发生在同一周，该报告确定人类活动、温室气体与气候变化之间存在明显的联系。

英国碳捕集与封存研究中心主任 Jon Gibbins 教授说，“英国有良好的 CCS 研发基础，通过与中国的合作，我们能进一步推动和促进这一缓解气候变化的重要技术的商业化进程。气候变化是一个需要全球合作的全球性难题，这项计划将有助于建立更牢固的合作关系。”

苏格兰碳捕集与封存中心主任、爱丁堡大学碳捕集与封存教授，英国皇家地质学院院士 Stuart Haszeldine 说，“中国的‘五年计划’正在为 CCS 做准备，因此广东省正准备一举超越所有的欧洲成就。这项及时的战略性协议将使来自苏格兰、英国和中国研究者在 CCS 技术上迅速取得实际进展的共同志向中团结起来。广东省是中国的一个产业创新大省。这份谅解备忘录使英国的研究人员和中国的工业能够进行人员和专业知识交流，以便能够在 2014 年中期作出投资的决定。”

广东电力设计院院长罗必雄说：“目前全世界均在关注低碳减排，中国也在为减排积极努力，并确定了减排目标，但中国作为发展中国家，也是能源消费大国，2012 年煤炭消费总量约达 37 亿吨，其中电力、冶金等行业占有较大的比例，尽管已在大力发展新能源产业，但燃煤发电仍将是主要的能源提供方式，在经济持续发展的同时控制并减少二氧化碳的排放，任务十分艰巨。广东省电力设计研究院（GEDI）作为以能源行业为主的国际化工程公司，长期致力于能源领域的设计和研究，致力于新能源的开发和推广应用。此次代表广东省低碳技术及产业研究中心与英国方面签订脱碳合作协议，将为双方进一步开展脱碳减排领域合作，提供良好的发展平台，中英双方将在互惠互利的基础上，通过积极开展相关合作，推动先进脱碳技术应用，促进脱碳产业发展，为世界环保减排事业的发展做出积极的贡献。同时也在此对广东省政府及发改委对脱碳工作的推动支持和英国 CCS 中心及爱丁堡大学等各方面所做卓有成效的工作表示感谢。”

“来自发电和其他固定排放源的温室气体和微粒污染是我们急速恶化的全球环境的一个主要驱动因素，正在影响我们和子孙后代。”清洁化石能源发展研究所董事长林有勤先生认为，“我希望在广东省和英国合作伙伴的帮助下，清洁化石能源发展研究所在促进中国和世界其他地区的清洁低碳能源方面能够做出重大突破。”

这份谅解备忘录建立在由英国外交及联邦事务部、能源与气候变化部和英国研究理事会赞助的广东省与英国之间耗时 5 年多的联合 CCUS 活动的基础之上。该谅解备忘录的签署方一致同意为中英（广东）CCUS 中心的发展提供建议和支持，这将推动广东省 CCUS 研究合作及技术的产业化和推动两国在 CCUS 和清洁煤技术的合作。

## 8. 挪威政府终止蒙斯塔德碳大型捕集项目计划，但继续研究和测试工作

2013 年 9 月

挪威巨头挪威国家石油公司开始终止其全规模的蒙斯塔德碳捕集项目（TCM），这一进程在挪威政府作出终止决定后就启动了。政府认为，该项目成本过高，且不值得为其带来的相关挑战去冒险。

2006 年，挪威国家石油公司与石油和能源部门签署了一份执行协议。按照协议，公司在 2009 年提交了一份在蒙斯塔德进行全规模碳捕集的总体规划。2012 年，挪威国家石油公司与合作伙伴 Gassnova 公司、荷兰皇家壳牌公司以及南非萨索尔公司共同建成了蒙斯塔德二氧化碳技术中心。

挪威国家石油公司现正力争顺利地终止蒙斯塔德碳捕集项目，而在此之前，该公司广泛开展了极具挑战性的碳捕集与封存工作。目前公司并未感到失落，而是计划将项目进行过程中所获得的经验运用到将来的 CCS 相关事业中。挪威国家石油公司还开发了一套测量和评估项目过程中排放量的工具箱。

通过多年的广泛研究，挪威国家石油公司已成为 CCS 领域的龙头企业。其中，斯莱普纳的碳封存项目（Sleipner）是世界上首个大型封存项目，也是首个大型海洋地质封存项目。公司的其他项目还包括位于阿尔及利亚因萨拉赫的全规模碳捕集与封存项目和挪威的斯诺赫维特气田项目。

挪威国家石油公司还参与了广泛的碳捕集技术发展研究项目，包括除了蒙斯塔德项目的其他封存项目。该公司在蒙斯塔德中心积累了广泛的知识，这些都激励公司须兼顾开发技术与降低成本。但项目的研究和中试工作将继续进行。

## 9. 重启欧洲CCS政治议程

2013年9月

2013年苏格兰CCS会议于昨日在英国爱丁堡举行。这一工作会议旨在为发掘北海二氧化碳运输和封存潜力并进一步推动欧盟减排目标的实现制定实际的行动方案。

Haszeldine教授说，“将现有的排放源和基础设施贯通起来能为北海碳封存提供机会，因为CCS将更快捷，方便，成本也会更低。二氧化碳海运的基础设施已无需再建造，所以我们可以建造一个港口枢纽连接各个排放源，在大型项目结束前就可证明封存是可行的。”

英国自由民主党在欧盟议会英格兰西北部议员，自由民主党在欧盟议会的环境事务发言人Chris Davies参加了此次会议，并发表了“重启欧洲CCS政治议程”的主题演讲。

目前，欧洲还没有针对CCS发展的政策，这与5年前的形势相去甚远，Davies说道。

他接着指出，“根本上来说，行业还没有可供参考的CCS投资财政案例。NER300投资计划太死板，融资水平也因此降低了。比如投资白玫瑰项目投资都会因此变得很棘手，因此后期需要比NER300首轮招标更高的灵活性。”

他还说，“不要低估政治障碍的影响力。官员们反对或者漠不关心CCS的发展；人民党政治否定气候政策；欧盟委员会行动拖沓；不幸的是，Hedegaard委员并没有很积极地支持CCS，而是更倾向于可再生能源。”

Davies表示，欧盟委员会发布了一份新的CCS倡议报告，鼓励成员国采取进一步行动，实现CCS的发展。

“委员会应要求其成员国上报其低碳经济计划及CCS在其中的作用，并接受委员会的详细审查。”他说，“成员国在现有法规的倾向性以及基础设施方面应作出进一步行动。”

欧共体能源理事会长建议，所有成员国都应准备一份CCS路线图。

Chris说：“欧盟需要恢复对CCS的重视，落实2020年的中期目标。让项目运行起来！我们能实现年封存量1000万吨的目标吗？”

“波兰希望CCS发展的所有资金都由欧盟赞助，这是不可能的，但一些催化资金可以推动项目的运行，“Chris接着补充，“CCS创新在短期内将需要欧盟更多的资助。接下来应在化石燃料电厂进行CCS认证。”

Chris说“大量的团体都支持发展可再生能源。支持CCS的团体在

图片描述：苏格兰CCS中心年会
图片来源：苏格兰CCS中心,2013

图片描述：苏格兰CCS中心年会后主要演讲者合影
图片来源：苏格兰CCS中心,2013

哪呢？辩论中也看不到煤炭、天然气和技术行业的身影。若要推动CCS发展，就必须有一个政治群体热心规划其前景并争取去实现它。”

## 10. 加拿大Aquistore封存项目完工

2013年10月

Aquistore项目—世界上第一个商业规模、从燃煤发电厂用燃烧后捕集方式，分离二氧化碳并封存的项目—已经完工并准备好要从伊斯特万附近的沙省电力公司边界大坝发电厂价值12.4亿美元的碳捕集与封存整合项目中购买二氧化碳。

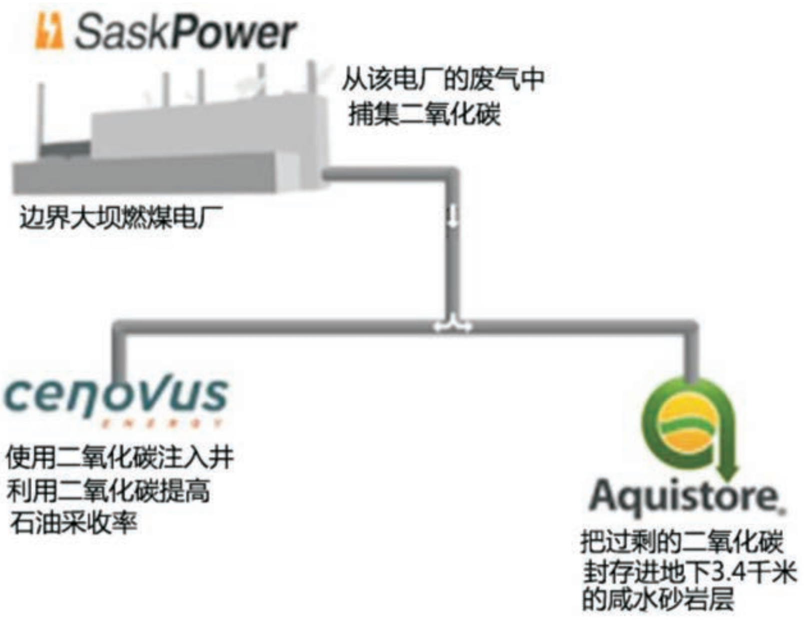
石油技术研究中心（PTRC）正着手将此项目交给沙省电力公司，公司将使用Aquistore项目每年封存100万吨来自边界大坝项目3号机组碳捕集装置的二氧化碳。

石油技术研究中心（PTRC）首席执行官Neil Wildgust承认此项目—里贾纳中心历史上最大的—是有着值得许多顶尖的、高成本的研发机构学习经验的项目。

“Aquistore项目是加拿大第一个工业二氧化碳深咸水层封存项目，“Wildgust说道，他于2011年9月以首席项目官的身份加入石油技术研究中心（PTRC），并于六月份Malcolm Wilson辞职之后成为首席执行官。他说：“这是非常重要的一个项目”。

事实上，Wildgust曾是英国国际能源署温室气体项目地质封存项目经理，他说，Aquistore项目曾是他进入石油技术研究中心（PTRC）的其中一个原因。“这是一个完全的整合项目，（碳捕集与封存）链的所有部分都整合在一起。Aquistore项目很小，但对整个（碳捕集与封存）项目链来说却很重要。”

Aquistore项目另外一个特殊的方面在于它拥有两个3440米的深井—是萨斯喀温彻省最深的井——一个井用于每天注射2000吨液体二氧化碳进入咸水层，另外一个井用于深层地质封存时监管、跟踪并测量二氧化碳。



图片描述：Aquistore项目结构
图片来源：CBC News,2013

漏的风险还是很低的。同样地，在那个区域不存在会渗透蓄水池的古老井孔。因此我们知道Aquistore将会成为非常安全的封存位置。

当然，深孔钻井是很昂贵的，其中风险不是项目设计者能预测的。“管理一个像这样的深层基建工程队与一个规模较小的非盈利性组织来说是巨大的挑战。这一路上我们学到了很多。”

他说：“我们将会将资产转让给沙省电力公司，资产转让得到的资金将帮助我们实现现在的财务规划，并能确保我们这个可行的研究项目继续向前发展。”

沙省电力公司发言人Tyler Hopson证实正在针对Aquistore项目资产价值进行磋商。但是Hopson说：“但是有关合同的条款和细节我们暂时还不能公开讨论。”

## 11. 南非推行碳捕集计划

2013年10月

尽管国际气候谈判和碳定价进展甚微，挪威也在近日决定撤下蒙斯塔德中心的全规模二氧化碳捕集项目，南非仍表示将继续探索碳捕集与封存技术能否成为减少该国碳排放的重要助力。

作为南非项目的支持者之一，挪威是世界碳捕集与封存技术研发的领导者，曾表示，尽管其已经决定停止备受瞩目的蒙斯塔德项目，在2020年之前该国仍将继续支持其全规模捕集装置的发展。

在十月于约翰内斯堡举行的南非第三届CCS会议上，南非能源部长Dikobe Ben Martins重申了政府对该技术以及南非碳捕集与封存中心工作的支持。该中心于2009年3月成立，主要进行碳捕集与封存的研发工作以

图片描述：南非能源部长 Dikobe Ben Martins 先生在 2013 年南非 CCS 会议上致词
图片来源：南非国家能源发展机构，2013

及建设在当地实现碳捕集与封存技术所必须的能力。

Martins 说道，政府依然认为，在能源结构越来越多样化之时，仍应继续利用该国丰富的煤炭资源。然而，政府也打算信守 Jacob Zuma 总统 2009 年在丹麦哥本哈根举行的联合国气候谈判会议上许下的分别于 2020 年和 2025 年将基准情景下的碳排放减少 34% 和 42% 的承诺，且其前提条件是发达国家给予南非财政和技术上的支持。

2012 年 5 月，南非内阁同意政府留出 1.97 亿兰特资金用于支持南非碳捕集与封存中心在 3 年内落实碳捕集与封存路线图的工作。

南非碳捕集与封存中心的主任 Brendan Beck 同时也是计划于 2017 年实施的二氧化碳封存中试项目的经理，他对蒙斯塔德项目的终止感到很失望。

然而，他指出，国际能源署的分析表明，只要化石燃料和碳密集型工业继续在能源构成中占据主导地位，碳捕集与封存技术就仍将是解决温室气体减排的重要方法。国际能源署认为，到 2050 年，碳捕集与封存技术可帮助完成当年碳减排量的 1/6 以及到 2050 年累积总减排量的 14% 的目标。

Beck 还强调，挪威、美国、澳大利亚及阿尔及利亚都在进行其他的项目，示范碳捕集与封存技术。“全球范围内正在进行的 5 个项目共封存了 500 多万吨二氧化碳。”

在南非实现陆上示范项目的计划的准备工作还在继续，但二氧化碳排放源和最终的封存地还有待确定。南非东部的祖鲁兰盆地以及东开普省的阿尔戈阿盆地的勘探工作也将继续进行。

由于南非的油气工业较不发达，因此与澳大利亚正在进行的类似计划相比，这次勘探可能会增加南非示范项目的资本成本。Beck 预计开发将需要 7000 到 8000 万兰特。

“我们还在解决成本的问题，这也要看具体的地点，“南非国家能源发展研究所的首席执行官 Kevin Nassiep 补充道。南非碳捕集与封存中心由南非国家能源发展研究所成立，该研究所是审查从可再生能源、能效到绿色交通及碳捕集与封存技术等有关能源的研发工作的国家机构。

融资计划也正在进行，而南非政府早已许下承诺，据称会给其他帮助兑现政府对碳捕集与封存技术承诺的潜在资助者给出重要的信号。

挪威驻南非大使 Kari Bjørnsgaard 给出保证，挪威会继续做其“坚定的合作伙伴”，并指出挪威石油与能源部承诺向南非的碳捕集与封存工作资助 2800 万兰特。世界银行的碳捕集与封存能力建设信托基金是另一潜在的后续资金来源。

但 Beck 强调，南非碳捕集与封存中心的推力不是“不惜一切代价”发展碳捕集与封存技术，而是了解该技术在南非的发展潜力。

## 12. 美国财政部建议开发银行不资助没有采用碳捕集与封存技术的新的燃煤发电厂

2013 年 10 月

美国财政部十月底发布了修改后的技术指导方针，以支持奥巴马总统《气候行动方案》的主要内容，宣布美国终止支持多边发展银行应对海外煤炭项目提供资金，除非是在非常特殊的情况下。

这份更新的指导文件旨在通过私人多边发展银行被纳入运营政策和部门战略中，私人多边发展银行是由许多国家创立的为发展目的提供财务支持的机构。这些机构包括世界银行、欧洲投资银行及亚洲开发银行等。正如《电力杂志》之前报告的那样，世界银行及欧洲投资银行已经制定他们自己的政策来减少对海外燃煤发电厂的投资。而亚洲开发银行的能源政策力图帮助那些看起来是世界大部分未来煤炭生产增长的国家的发展——比如中国、印度及越南，这些国家曾承诺优先资助能源效率提高项目及可再生能源项目，以便缓解化石燃料的需求、提高能源安全并减少温室气体的排放。

美国财政部星期二指出，修改后

图片描述：美国财政部
图片来源：美国财政部，2013

图片描述：世界银行标志
图片来源：世界银行，2013

图片描述：亚洲开发银行俯瞰图；
图片来源：亚洲开发银行，2013

的文件将代替 2009 年版本，以反映奥巴马总统在他 2013 年 6 月《气候行动方案》中的号召：结束美国政府对海外新的燃煤发电厂的公共融资支持，除非是在非常特殊的情况下。

此文件建议多边发展银行为能够满足电力需求的“零排放资源或低碳资源”移除障碍并建立需求，并号召有关部门提供政策贷款“促进低碳技术市场”，市场上目前的电力或燃料补贴偏都对碳捕集与封存减排技术不利。

这份财政部的文件建议多边发展银行在评估一个提议的未开发的或更新的燃煤发电项目之前要全面考虑零碳或低碳选择，如果可供选择的方案证明比拟议的煤炭项目更昂贵，号召多边发展银行帮助借款人确定外部筹款的公共或私人资本提供机构来承担成本。

最后，此文件为煤炭项目制定了评价标准。比如，即使项目的容量在原有的基础上缩减了，也必须使用“国际上最好的可行技术”来减少温室气体排放，正如通过“必达到预计需求特性所需的”发电量的大小及工作周期做出的判断一样。尽管大型一体化发电项目还不存在，但依然需要该项目采用碳捕集与封存技术。

世界上只有两个这样的项目在建设当中——位于密西西比州的南方电力公司肯珀县整体煤气化联合循环发电厂及加拿大边界大坝项目——尽管在 2014 年之前，没有一个项目的捕集部分将会完全运营。行业专家当下预测，使用一流的碳捕集与封存系统将使燃煤发电厂发电成本增加范围在 37% 至 76% 之间，天然气发电厂将增加 40%。

然而，该指导文件建议，只有燃煤项目显示出“克服国家经济发展上的绑定约束”，只要“实际上可行”，它就应该代替成为温室气体减排的“最可行技术”。

也就是说，按照财政部的说法，美国政府将不会支持新建燃煤电厂的公共融资，除非它们使用碳捕集与封存技术或者在世界最贫穷的国家没有其它经济可行的替代选择却有可利用的高效的煤炭技术。

# News Digest

## 1. European Commission Publishes CCS Policy Options Released by ENDS Europe, March 2013

The lack of a long-term business case for carbon capture and storage (CCS) because of low carbon allowance prices is the main reason the technology has not got off the ground, the European Commission said in a policy paper on March, 2013.

The major options suggested in the paper are the same as those in a draft version leaked in January. These include mandatory emissions performance standards for power plants, tradable CCS certificates and national strategies.

The only major change to the draft was the addition of a question on “the main obstacles to ensuring sufficient demonstration of CCS in the EU”. Pro-CCS NGO Bellona welcomed the addition of this question as it could help to “evaluate what went wrong with NER300”, a spokeswoman said. The first round of the NER300 funding scheme did not manage to support any CCS projects.

## 2. Global CCS Institute Opens Beijing Office

Global Carbon Capture and Storage Institute, press release, March2013

Launch Ceremony of GCCSI
Source: Beijing Youth, 2013

The Global Carbon Capture and Storage Institute (GCCSI) opened an office in Beijing on March 3rd, highlighting the important role that China plays in the development of low–emissions technologies.

Founded by the Australian Government, GCCSI helps carbon–intensive economies accelerate the uptake of CCS technologies, and collects and disseminates expertise to governments and project proponents all over the world.

Australian Minister for Resources and Energy, Martin Ferguson AM MP, said the new office will allow the Institute to enhance further its engagement with its members in the China region. "China accounts for the largest share of projected growth in global energy use, with its demand rising by 60 per cent by 2035," Minister Ferguson said. "The lessons learnt and shared by theInstitute through its work in China will help governments and project proponents from around the world, including Australia, to accelerate the deployment of CCS technologies."

The GCCSI also has regional offices in Europe, North America and Japan.

It has an international membership of 368 government, industry, non–government and research organisations from around the world.The Institute's membership covers more than 80 per cent of the world's $CO_2$ emissions from energy and industrial sources.

GCCSI and Yanchang Petroleum sign MoU
Source: Yanchang Petroleum, 2013

In addition to its support for the Institute, the Australian Government is investing over $2 billion in a range of measures to assist the development of low–emissions technologies, including the CCS Flagships programme.

## 3. Preferred Bidders Announced in UK's 1bn CCS Competition

UK Government press release, March 2013

The two preferred bidders in the UK's 1bn Carbon Capture and Storage Commercialisation Programme Competition were announced on 20March2013.They are the Peterhead Project in Aberdeenshire, Scotland, and the White Rose Project in Yorkshire, England.Secretary of State for Energy and Climate Change, Edward Davey said: " This announcement moves us a significant step closer to a Carbon Capture and Storage industry – an industry which will help reduce carbon emissions and create thousands of jobs.These two are major infrastructure projects potentially worth several billion pounds and could support thousands of construction jobs over the next few years.

"We had four excellent bids and I'd like to thank each one of them for their hard work. We will now be working swiftly to progress our preferred two, while making sure we continue to provide the best possible value to tax payers."

Energy Minister John Hayes said: "We are working quickly to our goal of a cost competitive CCS industry – and these projects are just the start. In the past year we have demonstrated there is significant appetite from industry to invest in UK CCS, providing jobs and investment opportunities. It is my intention to work with industry, beyond these two projects, to ensure we have further CCS projects by the end of the decade – supported by the innovative changes we are making to the energy market to encourage investment in low carbon electricity. I am also very pleased that these two projects offer us the opportunity to ensure that both gas and coal generation has a hugely reduced impact on our carbon emissions."

The two projects selected in detail:

Peterhead Project in Aberdeenshire, Scotland – a project which involves capturing around 90% of the carbon dioxide from part of the existing gas fired power station at Peterhead before transporting it and storing it in a depleted gas field beneath the North Sea. The project involves Shell and SSE.

White Rose Project in Yorkshire, England – a project which involves capturing 90% of the carbon dioxide from a new super-efficient coal-fired power station at the Drax site in North Yorkshire, before transporting and storing it in a saline aquifer beneath the southern North Sea. The project involves Alstom, Drax Power, BOC and National Grid.

The two preferred bidders were selected following a period of intensive commercial negotiations with four projects shortlisted from an original eight in October last year.

The Government will now undertake discussions with the two preferred bidders to agree terms by the summer for Front End Engineering Design studies, which will last approximately 18 months. A final investment decision will be taken by the Government in early 2015 on the construction of up to two projects. Captain Clean Energy and Teesside Low Carbon, the remaining two bidders with whom the Government has been in discussion, will to be appointed as reserve projects.

## 4. Notice by Chinese Government NDRC on Promoting CCUS Pilot and Demonstration

NDRC release, April 2013

The Climate Office of National Development Reform Commission (NDRC), the national policy unit in the Chinese Government for climate change activities, released this notice to promote the piloting and demonstration of Carbon Capture, Utilisation and Storage. The notice proposes to develop CCUS demonstration projects, explore and establish financial incentive mechanisms and promote CCUS standards and regulation.

The notice states that R&D in all components of CCUS has achieved significant progress, but there are still a number of challenges: the cost and energy penalty remain high,and the long-term safety and reliability need to be proved. Piloting and demonstrating CCUS technologies would not only solve these challenges through development and practice, but also pave the way for large-scale application and commercialisation – as an essential stage to achieve large-scale greenhouse gas reductions.All regions and all departments should strengthen support and guidance for piloting and demonstrating CCUS.

In the immediate term, CCUS pilots and demonstrations should be promoted by the following means:

1. Develop pilot and demonstration projects along the CCUS technology chain. Encourage $CO_2$ capture demonstration from coal, chemical and oil and gas industries with highly concentrated $CO_2$ sources, develop pilot and demonstration projects for pre-combustion, post-combustion, oxyfuel and other $CO_2$ capture pathways, strengthen the techno-economic comparison of different $CO_2$ capture technical pathways, and solve practical issues for developing a large-scale CCUS industry. Strengthen the management of natural $CO_2$ fields, strictly control gas field development for the purpose of utilising natural $CO_2$ sources, gradually close down all existing natural $CO_2$ source fields, and promote multiple mechanisms to utilise captured $CO_2$ to improve the economic performance of pilot and demonstration projects. Strengthen work on assessing $CO_2$ storage

sitesand identify clusters of concentrated $CO_2$ sources. Develop coordination mechanisms for different industries and sectors, strengthen $CO_2$ capture (supply side) and $CO_2$ storage (demand side) source – sink matching and linking.

2. Develop CCUS demonstration projects and a CCUS database. Give priority to integrated and semi-integrated projects with high demonstration value which suit national conditions, with lower cost, moderate scale, regional characteristics and locally-owned intellectual property. Organise a CCUS key demonstration project list and database.

3. Explore and establish financial incentive mechanisms. Study and explore mechanisms and financial incentives to promote the piloting and demonstration of CCUS, and implement a tax support policy.

4. Strengthen strategy and planning for CCUS development.Based on the understanding of emission characteristics for the various industrial sectors (electricity, coal, coal chemical, oil/petroleum, gas, steel, and cement), analyse how these industries could promote CCUS piloting and demonstration. Further identify policy and guidance requirements in medium and long term planning for CCUS and associated industries.

5. Promote CCUS standards and regulation.

6. Strengthen capacity building and international collaboration.

Promoting Carbon Capture, Utilisation and Storage Pilot and Demonstration is an important task in the 12th Five Year GHG control plan. The Plan's working programme published by the State Council clearly indicates the need to develop CCS pilot and demonstration programmes in thermal power, coal chemical, cement and steel industries.  It also stresses the need concurrently to develop anintegrated capture, enhanced oil recoveryand storage demonstration project, and to build up human resources, financial security and policy support.

## 5. US and China Agree on Climate Steps to Curb Emissions

The Washington Post news story, 11 July 2013

AFP/GETTY IMAGES – (from left to right) Chinese State Councilor Yang Jiechi, Secretary of State John Kerry,Chinese vice premier WANG Yang and Treasury Secretary Jack Lew shake hands after the opening session of the U.S. and China Strategic and Economic Dialogue in Washington.

The United States and China agreed in August to tighten pollution standards on heavy trucks, boost energy efficiency in buildings and take a series of other steps to curb greenhouse gas emissions in the world's top two polluting countries.

A working group of officials from the two nations was established in April, with orders from the top of both governments to intensify cooperation on global warming. Environmental activists say this holds immense potential because of the combined size and influence of the two nations — at a time when countries are struggling to agree on a global strategy.

Top officials from both sides met on 10th July and targeted five areas — from bread-and-butter steps, such as boosting building efficiency, to what officials said would be a leading-edge effort to improve the technology for capturing carbon as it is released from power plants.

Advocates say carbon capture is important for a long-term solution to global warming, but the cost and unproven nature of the technology are considered to be major hurdles.

Under the 10th July agreement, China and the United States consented to build “several large-scale” demonstration projects to try to “overcome barriers” to the wider use of carbon-capture technology.

Todd Stern, the US special envoy for climate change, said the aim of the working group's recommendations is not to commit either country to specific carbon reduction targets but to develop practical steps and policies to cut greenhouse pollution — such as the elimination of hydrofluorocarbons - which was agreed by President Obama and Chinese President Xi Jinpingin June in California.

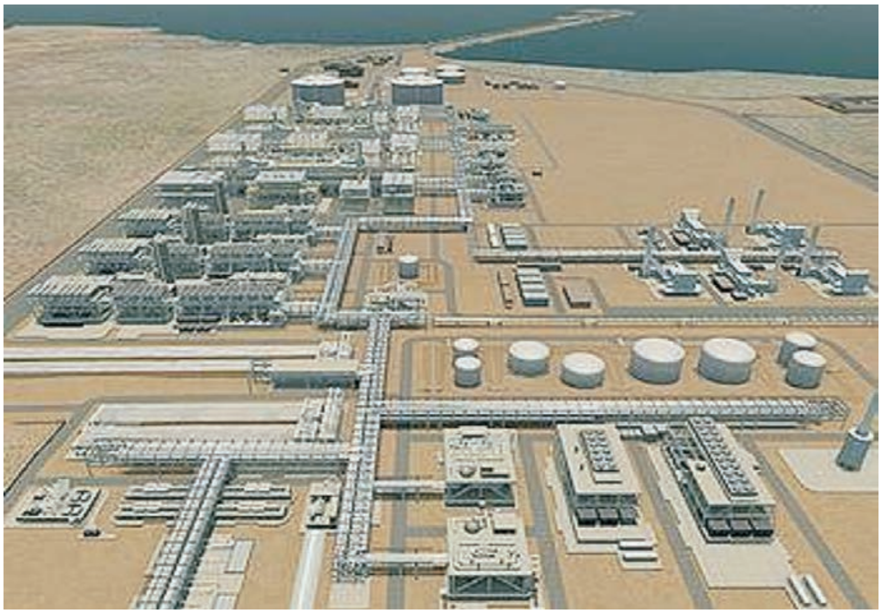
“China and the US are the two most important players. We are the largest emitters of greenhouse gases... working shoulder to shoulder ... is only a good thing, “Stern said.” It is not suddenly going to transform the [international] negotiation, but it will project something positive.”

## 6. World's Largest Carbon Capture Project Begins Even as Abbott Tax Repeal Looms

The Sydney Morning Herald news story, 16 September 2013

Prime Minister Tony Abbott has pledged to repeal the country's carbon tax to boost economic competitiveness, so it is ironic that Australia is about to host the world's most ambitious project for capturing carbon dioxide and storing it underground.

Gorgon LNG Termal in Construction, Barrow Island, Australia
Source: The Sydney Morning Herald, 2013



Australia Gorgon Project Gas Processing and LNG Terminal Montage
Source：Hyungdai Heavy Industries, 2013

Gorgon Project in Construction
Source: Chevron, 2013

Starting in 2014/15, Chevron will begin injecting 120 million tonnes of pressurised supercritical $CO_2$ 2.5 kilometres underground as part of its giant Gorgon LNG project.

Raw gas from the Gorgon field contains about 14 per cent $CO_2$, which must be separated out and safely disposed of before the methane is purified.

Under an ambitious programme agreed with the State and Federal Governments back in 2009, Chevron will inject the $CO_2$ into a saline aquifer beneath Barrow Island off the coast of Western Australia.

Chevron is spending $US2 billion on the world's largest $CO_2$-injection facility, which will store over 3 million tonnes per year, making it by far the world's largest $CO_2$ storage project, and creating a unique opportunity to study how injected $CO_2$ behaves underground in saline aquifers.

Long-term indemnity

Barrow Island is a Class A nature reserve and carbon dioxide is fatal to humans in concentrations as low as 7-15 per cent. So Chevron has conducted extensive seismic surveys and drilling to estimate the aquifer's storage capacity and ensure it will not leak.

The company has also promised to monitor the underground movement of the $CO_2$ plume as it spreads away from the initial injection wells using 4-dimensional seismic surveys.

Together with its joint venture partners, Chevron will be responsible for any costs associated with leaks and other damage during the lifetime of the project and for 15 years after $CO_2$ injection ceases.

However, the Federal and WA Governments have agreed to accept responsibility for any long-term liabilities.

Federal and State indemnities will protect the joint venture partners from any common law liability arising from third-party claims for loss or damage, suffered after the site closes.

The indemnity will only occur after continuous monitoring and modelling of the stored carbon dioxide for at least 15 years after injection ceases, and when both State and Federal Governments are satisfied the $CO_2$ has been stored safely.

The indemnity is not expected to be invoked for at least 75 years, according to an analysis prepared by law firm Baker & McKenzie.

Vital resource

Unlike most other projects, Gorgon will inject $CO_2$ into a saline aquifer rather than a depleted oil or gas field, providing an opportunity to test how $CO_2$ injections into a saline aquifer behave on a large scale.

The U.S. Department of Energy has identified saline aquifers as a vital storage resource if CCS is to be captured on anything like the scale that will make a difference to the climate.

In the United States alone, saline aquifers could store between 1.6 and 20 trillion tonnes of $CO_2$, compared with just 60-120 billion tonnes in unmineable coal seams and 120 billion tonnes in depleted oil and gas fields.

Little is known about how stored $CO_2$ behaves in saline aquifers.

But with Gorgon, Australia's Government will be sponsoring the world's largest and most ambitious attempt to lock $CO_2$ away safely underground, even as it tries to water down other elements of its climate change policy.

## 7. China and United Kingdom Announce Collaboration on Innovative Carbon Capture Utilisation and Storage Technology

September 2013

Scientists and engineers from China and the United Kingdom have formed a groundbreaking initiative that will pave the way for the research, development and demonstration of innovative carbon capture, utilisation and storage (CCUS) technologies.

CCUS MoU signed between UK and Guangdong Institutes witnessed by Gregory Barker, UK Department of Energy and Climate Change and Xiaodan ZHU, the governor of Guangdong.
Source: University of Edinburgh,2013

Photo after UK–Guangdong MoU signature
Source: UKCCSRC,2013

The UK Carbon Capture and Storage Research Centre (UKCCSRC), Scottish Carbon Capture and Storage (SCCS), Guangdong Low–carbon Technology and Industry Research Centre (GDLRC) and the Clean Fossil Energy Development Institute (CFEDI) signed the ten–year Memorandum of Understanding (MoU) this September at Lancaster House, in London, witnessed by Governor Zhu Xiaodan of Guangdong Province, China, and Minister Greg Barker of the UK's Department of Energy and Climate Change (DECC).

The agreement will lead to the establishment of an international CCUS network, which will promote joint research and development, provide advice for local and regional governments and develop ways to exchange knowledge. The partners plan to move rapidly towards demonstrating CCUS technologies in China, potentially within three to five years.

Minister Barker and Governor Xiaodan also concurrently signed a joint statement pledging collaboration on low carbon development, including CCS technology, between the UK and China.

The agreements come in the same week as the United Nations Intergovernmental Panel on Climate Change released a further report, which makes a clear link between human activities, greenhouse gas emissions and climate change.

CCUS refers to a range of technologies which could significantly reduce carbon emissions worldwide. $CO_2$ from power plants and industrial facilities can be captured and transported to underground storage sites where it can be geologically stored safely for millennia, thereby reducing emissions into the atmosphere. The $CO_2$ can also be used for enhanced oil recovery or locked up in stable materials. A commercial–scale CCUS industry will also create jobs and revenue, while retaining the existing workforce in the fossil fuel power sector.

“The UK has well–established research and development capacity in CCS, and by linking up with China we can further advance and promote the commercialisation of this important climate change mitigation technology,” said UKCCSRC Director, Professor Jon Gibbins. “Climate change is a global problem that requires global collaboration, and this initiative will help build stronger relationships.”

“Preparation for CCS is now in China's Five Year Plan, so Guangdong is preparing to surpass all European efforts with one leap. This strategic and timely agreement will unite researchers from Scotland, the rest of the UK and China in the shared ambition of making swift and practical progress on CCS technologies. Guangdong is a leading province for industrial innovation in China. This MoU enables UK researchers and Chinese industry to exchange staff and expertise, so that decisions can be made in mid 2014 to commence construction,” said Professor Stuart Haszeldine, SCCS Director, and

Professor of CCS at the University of Edinburgh.

BixiongLuo, President of GEDI, said: “Currently, the whole world is paying attention to carbon reduction, and China is working hard to reduce carbon and set a carbon reduction target. Although China is actively developing a new energy industry, electricity from coal will still dominate the energy system. GEDI, as an international engineering company, is dedicated to design and research in the energy sector, and promoting new energy development and deployment. The carbon capture agreement between GDLRC and UK parties will provide a platform for collaboration in carbon reduction, both promoting the CCS industry and contributing to global environmental business.”

The MoU builds on more than five years of joint CCUS activities between Guangdong and the UK, supported by the UK's Foreign & Commonwealth Office, DECC and Research Councils UK. The MoU signatories have agreed to advise and support the Guangdong International CCUS Industry and Academic Collaboration Promotion Network, which will promote CCUS research collaboration and technology industrialisation in the Guangdong Province of China.

## 8. Statoil Stops TCM on State Mandate and Learns Lessons for Future Endeavours

Zacks Equity Research news release, September 2013

Norwegian giant Statoil ASA is initiating the termination process of its full-scale carbon capture project at Mongstad (CCM) following the Norwegian Government's decision to discontinue it. The Government finds the project far too costly and the challenges associated with it not worth the risk.

In 2006, Statoil had signed an implementation agreement with the Ministry of Petroleum and Energy. In accordance with the agreement, in 2009 the company submitted a master plan for full-scale carbon capture at Mongstad. The Technology Centre at Mongstad was completed in 2012 by partners Statoil, Gassnova, Royal Dutch Shell plc and Sasol.

Statoil, which is now striving for a smooth termination of CCM, had worked extensively on the challenging technology of CCS. Instead of feeling let down, the company plans to use all the lessons learned in the process for its future endeavours relating to CCS. In the process Statoil has also developed a toolbox for measuring and evaluating emissions.

With years of extensive study, Statoil is among the leading companies working on CCS. The carbon storage project on Sleipner was the first large-scale storage project in the world. The other projects of the company include full-scale capture and storage at In Salah in Algeria and the Snohvit field in Norway.

Apart from its Mongstad activities,Statoil is also participating in extensive research projects relating to the development of carbon capture technology, including storage.

Statoil has gained immense knowledge at Mongstadwhich inspires it to develop the technology as well as reduce the costs involved.

## 9. Rebooting the Politics of CCS in Europe

SCCS news story, September 2013

Europe should take immediate action to push ahead with smaller-scale CCS projects “of inherent value” and move ahead of the politicians, conference delegates were told on 12th September.

CCS experts from across Europe gathered in Edinburgh for an interactive event aimed at driving forward the establishment of $CO_2$ storage sites beneath the North Sea, as a means of tackling the European Union's carbon emissions.

Delegates to the conference, hosted by SCCS, were given a “call to arms” by SCCS Director, Professor Stuart Haszeldine, who encouraged them to shake up EU policymakers with a set of practical actions to unlock the

North Sea's storage capacity.

Prof Haszeldine added: “EU policy focus so far has rightly been on decarbonisation, but has attempted only big, expensive power sector projects. However, 1.7 million jobs are in the industrial sectors, and these will need CCS too.”

He pointed out that steel and cement producers and refineries have significant emissions linked to their actual processes rather than fossil fuel use. Similarly, hydrogen production for ammonia already creates between six and seven million tonnes of $CO_2$ that could be made available for early storage projects.

He said: “The North Sea is the most important $CO_2$ storage region for the whole EU, so we propose that it is both possible and necessary to commence small injections of $CO_2$ as soon as possible, to transfer capability from science to industry and build confidence.”

Chris Davies MEP, one of the day's keynote speakers, urged delegates to lobby hard to keep CCS on the European Parliament's agenda or risk the consequences. He said: “Don't underestimate political barriers. Ministers show opposition or indifference, and populist politics deny climate change. There is an enormous lobby in favour of renewables. Where is support for CCS The coal, gas and technology sectors are absent from the debate.”

Scottish Energy Minister, Fergus Ewing, who also gave a keynote talk, said there was “a need to move from innovation and invention to creating a [CCS] industry”, adding: “Scotland has been a consistent supporter of CCS, and welcomes [the UK's Department of Energy and Climate Change's] efforts. But it is clear that an industry requires more than two projects.”

He reiterated the need for DECC to pursue a route to low-carbon electricity from CCS through its Contracts for Difference (CfD) scheme as part of the UK's Electricity Market Reform. He said that he hoped for “rapid progress on the Peterhead-Goldeneye and White Rose projects”. He added that the Captain Clean Energy project uses proven technology, has a very low risk, and is ready to commence as soon as the UK agrees CfD terms with no grant subsidy.

SCCS is now considering the results of detailed discussions held during the conference and was due to publish a recommendations report by mid-October, targeting EU policymakers.

## 10. Aquistore Project Complete

Leader-Post news release, September 2013

SCCS 2013 Annual Meeting
Source: SCCS, 2013

Group Photo in SCCS Annual Meeting
Source: SCCS,2013

Aquistore — the world's first commercial-scale, $CO_2$ storage project with post-combustion $CO_2$ from a coal-fired power plant — is completed and ready to receive $CO_2$ from SaskPower's $1.24 billion integrated CCSproject at Boundary Dam power station near Estevan, Canada.

The Petroleum Technology Research Centre (PTRC) is in the process of turning over the project to SaskPower, which will use Aquistore to store about one million tonnes a year of $CO_2$ from the carbon capture unit attached to Boundary's Unit 3.

Neil Wildgust, acting CEO of the PTRC, admitted the project — the biggest in the Regina-based Centre's history — was a big learning experience for the research institute and, like many first-of-a-kind projects, more expensive than expected.

"Aquistore will be Canada's first storage of industrial $CO_2$ in a deep saline aquifer," said Wildgust, who joined the PTRC as Chief Projects Officer in November 2011 and became acting CEO upon the retirement of Malcolm Wilson in June. "It's really an important project."

In fact, Wildgust, who was Project Manager for geological storage for the International Energy Agency Greenhouse Gas Programme in the U.K., said Aquistore was one of the reasons he joined the PTRC. "This is a fully integrated project, so all the parts of the CCS chain are together. And Aquistore is a small, but very important, part of that full CCS chain project."

Another unique aspect of the Aquistore project is its two 3,400-metre deep wells — the deepest ever drilled in Saskatchewan — one well to inject up to 2,000 tonnes per day of liquefied $CO_2$ into the saline aquifer and the other to monitor, track and measure the $CO_2$ while in deep geological storage.

"We' re a long way down. We have a lot of (geological) layers above the reservoir, so the chances of any leakage ... are very remote. Similarly, there are no old well bores in the area that penetrate the reservoir. So we always knew Aquistore was going to be a very secure storage location."

Of course, deep well drilling is expensive and subject to "surprises" not anticipated by the project's designers. "To be in charge of a major infrastructure project like this was a major challenge for a relatively small, not-for-profit research organization. We learned a lot along the way."

"We will transfer the assets over to SaskPower, "he said." The money that we will be paid for the transfer of the assets will see us through our financial commitments now and make sure we have a viable research project moving forward."

SaskPower spokesman Tyler Hopson confirmed negotiations are underway to determine the value of the Aquistore assets. But "the terms or details of the contract aren't something we can talk about publicly just yet," Hopson said, adding an announcement was to be expected this Fall.

## 11. South Africa Pushing Ahead with Carbon-Capture Plans Despite Global Headwinds

Source: Mining Weekly, October 2013

South Africa has indicated that it will continue to explore whether CCS can play a meaningful role in helping it to reduce the country's carbon footprint notwithstanding limited progress in international climate negotiations and carbon pricing, as well as Norway's recent decision to pull back from the development of full-scale $CO_2$ capture at Mongstad.

Norway, which is also a supporter of the South Africa programme, is a leader in CCS research and development and has indicated that it continues to support the development of a full-scale capture facility in Norway by 2020, despite the decision to discontinue the high-profile Mongstad project.

Speaking at South Africa's third CCS conference in Johannesburg on 3rd October, Energy Minister Dikobe Ben Martins reiterated the Government's support for the technology, as well as for the work being done by the South African Centre for Carbon Capture and Storage (SACCCS). The Centre was established in March 2009 to conduct research and development and to build the necessary capacity to implement CCS locally.

Martins said that the Government remained of the view that the country's abundant coal resources should continue to be exploited as part of an increasingly diversified energy mix. However, it also intended honouring the commitment made by President Jacob Zuma at the United Nations climate negotiations in Copenhagen, Denmark, in 2009, where South Africa pledged to reduce its business-as-usual emissions by 34% by 2020 and by 42% by 2025 – a commitment premised, though, on South Africa receiving financial and technological support from developed countries.

South Africa has set aside R197million over a three-year period to support SACCCS in implementing the CCS roadmap that was endorsed by Cabinet in May 2012.

SACCCS's Brendan Beck, who is also the manager for the proposed $CO_2$ storage pilot project that is due for implementation in 2017, described the discontinuation of the Mongstad project as “disappointing”.

However, he pointed to International Energy Agency (IEA) analysis showing that CCS would remain a critical greenhouse-gas reduction solution for as long as fossil fuels and carbon-intensive industries continue to occupy a dominant position in the energy mix. The IEA believes CCS could contribute one-sixth of total $CO_2$ emission reductions required by 2050, and 14% of the cumulative emissions reductions through to 2050.

Beck also stressed that other projects were under way in Norway, the US, Australia and Algeria, where the technology was being demonstrated. “There are five projects operating in the world that have stored over 5-million tons of $CO_2$.”

Therefore preparations werecontinuing on a plan to implement an onshore pilot plant in South Africa, with the $CO_2$ source and the eventual storage sites yet to be determined. Further exploration would be pursued in the Zululand Basin, on the eastern side of South Africa, and the AlgoaBasin, in the Eastern Cape.

Owing to South Africa's relatively undeveloped oil and gas industry, this exploration is likely to increase the capital cost of the South Africa pilot project when compared with similar initiatives under way in Australia. Beck estimates that between $70-million and $80-million will be required for the development.

“We are still working on the costing, which is also site-specific,” South African National Energy Development Institute (Sanedi) CEO Kevin Nassiep added. The SACCCS falls under the aegis of Sanedi, the State agency responsible for overseeing energy-related research and development in fields as diverse as renewable energy and energy efficiency, through to green transport and CCS.

Work was also under way on a funding plan, with the financial pledge already made by the South African Government which provides an important signal to other potential funders of South Africa's commitment to CCS.

Norwegian Ambassador to South Africa Kari Bjørnsgaard offered assurances that Norway would remain a “strong partner” and noted that the Norwegian Ministry of Petroleum and Energy had pledged R28million to the Country's CCS activities. The World Bank's CCS Capacity Building Trust Fund was another likely source of additional funding.

But Beck stressed that the thrust at SACCCS was not to pursue the solution “at any cost”, but rather to understand the potential for CCS in South Africa.

Minister of Energy Mr Dikobe Ben Martins giving the opening address at the CCS Conference 2013
Source: The Royal Norwegian Embassy in Petoria, 2013

## 12. US Treasury Dept. Advises Development Banks Not to Fund New Coal Plants without CCS

Source: Sonal Patel, Power Magazine, October 2013

A revised technical guidance released by the U.S. Treasury Department in October to bolster a key facet of President Obama's Climate Action Plan declares an end to U.S. support for multilateral development bank (MDB) funding for new overseas coal projects except in “narrowly defined circumstances”.

The updated guidance document is designed to be incorporated into the operational policies and sector strategies by individual MDBs, which are institutions created by a group of countries to provide financing for development purposes. Examples of MDBs include the World Bank, the European Investment Bank (EIB), and the Asian Development Bank (ADB). As Power Magazine had previously reported, the World Bank and the EIB have instituted their own policies to cut funding for oversees coal–fired power plants. The ADB, whose energy policy seeks to aid development in countries slated to see the world's most future coal generation growth—such as China, India, and Vietnam–has pledged to prioritize energy efficiency improvements and renewable energy projects to ease growth in fossil fuel demand, improve energy security, and reduce emissions of greenhouse gases.

The Treasury Department said on the 29th October that the revised document will replace a 2009 version to reflect the President's call in his June 2013 Climate Action Plan to end U.S. Government support of public financing of new overseascoal plants except in “very

US Treasury Department
Source: US Treasury, 2013

The World Bank Logo
Source: The World Bank, 2013

Asian Development Bank Headquarter
Source: ADB, 2013

limited” circumstances.

It advises MDBs to “remove barriers to, and build demand for,” zero- or low-carbon resources that meet power needs and calls for institutions to provide policy loans “to level the playing field” where existing electricity or fuel subsidies bias investment decisions against those resources.

Those calls presumably apply only to renewable generation, because both the World Bank and the ADB clearly state in their energy policies that they will not be involved in financing nuclear power generation. “Nuclear plants are thus uneconomic,” says the World Bank in its Environmental Assessment Source Book, “because at present and projected costs they are unlikely to be the least-cost alternative. There is also evidence that the cost figures usually cited by suppliers are substantially underestimated and often fail to take adequately into account waste disposal, decommissioning, and other environmental costs.” The EIB says it would consider financing a nuclear project, but only if it is economically, financially, and technically viable.

The Treasury Department's document also advises MDBs fully to consider zero- or low-carbon options before appraising a proposed greenfield or retrofit coal-fired power project, calling on MDBs to help borrowers identify public or private sources of external financing to cover costs if alternative portfolios prove more expensive than proposed coal projects.

Finally, it sets appraisal criteria for coal projects. For example, even if the project's capacity has been scaled back from its original proposal, it must use the “best internationally available technology” to reduce GHG emissions, as judged by the size and duty cycle of generating capacity that is “needed to meet projected demand characteristics.” This requires the project to deploy carbon capture and sequestration technology—though no large-scale power generation integrated projects yet exist.

Only two such projects are under construction worldwide—Southern Co.'s Kemper integrated gasification combined cycle power station in Mississippi and the Boundary Dam project in Canada—though neither project's capture portion of the plant will be fully operational until 2014. Industry experts currently estimate that using a first-of-a-kind CCS system increases the cost of power production at a coal plant from between 37% and 76%, and at a natural gas plant by 40%.

The guidance document advises, however, that only if a coal project shows it “overcomes binding constraints on national economic development,” should it be allowed to use “practically feasible” technology for reducing GHG emissions rather than “best available” technology

That means, according to the Treasury Department, the U.S. Government will not back public financing of new coal plants unless they use CCS, or the “most efficient coal technology available in the world's poorest countries in cases where no other economically feasible alternative exists.”

技术进展 .......>>>|

## 1. 中国 CCUS 技术研究进展

作者：中国 21 世纪议程管理中心 全球环境处 张九天

图片描述：张九天参与研讨会
图片来源：重庆市科学技术院，2013

碳捕集、利用与封存技术（CCUS）是指将二氧化碳从工业或其他排放源中分离出来，并运输到特点地点加以利用或封存，以实现被捕集 $CO_2$ 与大气的长期隔离。在众多温室气体减排技术方案中，CCUS 是一项新兴的，可以实现化石能源大规模低碳利用的技术。

气候变化是当今世界面临的最严峻挑战之一，关系到人类未来的生存与发展，发展碳捕集、利用与封存技术是应对气候变化挑战的需要，其战略意义不仅仅在于 CCUS 技术具有大规模温室气体减排的潜力，更重要的是它为我们提供了一种可能的战略性技术选择前景。

### 一、CCUS 技术的国际进展

为促进 CCUS 技术的发展与应用，欧盟、美国、澳大利亚等发达国家和地区均已启动大规模的计划推动 CCUS 技术的研发与示范，并在八国集团峰会（G8），二十国集团峰会（G20）、碳收集领导人论坛（CSLF）等框架下积极推动 CCUS 在全球范围的发展。

从示范项目来看，目前 CCUS 已经逐步开始发挥其减缓气候变化的作用。全球已建、在建和计划建设的 CCUS 项目（包括单一捕集、运输或封存环节项目和同时考虑捕集、运输与封存的全流程项目）超过 300 个，其中大型 CCS 全流程项目 65 个。在这 65 个全流程项目中，12 个处于“运行“状态，分别分布在美国、欧洲、加拿大等国家，并均与石油、天然气领域直接相关，规模都在百万吨以上，并已达到工业化的生产能力。

从国际 CCUS 工程实施经验看，各单个环节技术已具有相当的成熟度，基本可应用于任何排放二氧化碳的工艺或流程，目前最大的挑战是各技术要素的资本和运营成本，额外能耗，安全性以及大型示范项目的系统整合问题。同时，出于 CCUS 的经济性考虑，各国优先将 CCUS 应用于高浓度、高排放量的能源与工业部门，如电力部门、天然气加工厂，炼油厂等。

从政策动向来看，美国、欧盟、加拿大、英国、澳大利亚等发达国家均通过颁布 CCUS 技术发展路线图及战略规划，明确近期、中期、远期的技术方向和研发重点，设立跨部门的协调工作机制等措施加强国家层面技术政策的指导和宏观协调。政府投入不断加大，甚至将推动 CCUS 技术发展作为实现国内经济复苏的手段。重视跨行业、跨领域的 CCUS 合作平台的建设，加强知识与经验共享。不仅如此，各国在技术标准、法律法规、管理制度和规范以及公众接受度等各种技术应用“软环境”的建设上也在不断增强。

### 二、中国 CCUS 技术研究进展

近年来，中国对 CCUS 技术的发展给予了积极的关注，尽管起步较晚，中国 CCUS 技术发展取得了长足进步。在政府的指导下，企业、科研单位和高等院校共同参与下，已围绕 CCUS 相关理论、关键技术和配套政策的研究开展了很多工作，建立了一批专业研究队伍，取得了一些有自主知识产权的技术成果，成功开展了工业级技术示范。

（一）政策制定

目前，中国有多个技术政策文件，包括《国家中长期科学和技术发展规划纲要（2006–2020 年）》、《中国应对气候变化国家方案》、《中国应对气候变化科技专项行动》、《国家“十二五”科学和技术发展规划》、《“十二五”国家应对气候变化科技发展专项规划》、《“十二五”CCUS 科技发展专项规划》、《“十二五”控制温室气体排放工作方案》等均将 CCUS 技术列为重点发展的减缓气候变化技术，积极引导 CCUS 技术的研发与示范。

2011 年 9 月科技部完成了《中国碳捕集、利用与封存技术发展路线图》研究报告，该路线图较系统地评

估了我国 CCUS 技术发展现状，提出了我国 CCUS 技术发展的愿景和未来 20 年的技术发展目标。2013 年 4 月，国家发改委发布了《关于推动碳捕集、利用和封存试验示范的通知》，首次明确了 CCUS 产业未来商业化导向。同年科技部中国 21 世纪议程管理中心组织编写了《中国二氧化碳利用技术评估报告》，该报告紧密结合中国国情，系统评估了 $CO_2$ 利用技术在能源资源增采、经济发展、环境保护和二氧化碳减排等方面的巨大潜力和效益，为促进 $CO_2$ 资源化利用奠定了理论基础。

### （二）技术研发

近年来，中国政府在 CCUS 研发与示范方面的投入力度不断加大，支持范围也从侧重单一环节的技术研究和中试转向支持工业规模的全流程技术示范。

“十五”以来，国家基础研究（973）计划、国家高技术发展（863）计划、国家科技支撑计划等有关国家科技计划先后围绕 CCUS 技术减排潜力、$CO_2$ 捕集、$CO_2$ 生物转化利用、$CO_2$ 驱油和地质封存相关的基础研究、技术研发与示范等方面进行了较系统的部署，涉及不同种类的 $CO_2$ 排放源、不同的捕集技术方向、不同的 $CO_2$ 转化和利用模式等。国家重大科技专项“大型油气田及煤层气开发”围绕 $CO_2$ 驱油、驱煤层气技术研发与工程示范进行了部署。

经初步统计，仅“十一五”期间，相关国家科技计划和科技专项针对 CCUS 基础研究与技术开发部署项目共约 20 项，总经费超过 10 亿元，其中公共财政支持约 2 亿元。“十一五”期间，针对全流程技术示范的投入力度明显加强，仅 2011 年，相关国家科技计划和科技专项已部署项目约 10 项，总经费超过 20 亿元，其中公共财政支持超过 4 亿元。

政府支持的主要 CCUS 研发项目总体情况见下表。

表 1 中国政府支持的部分 CCUS 技术研发项目

| 项目名称 | 资助来源 / 渠道 | 执行时间 | 主要参与单位 |
|---|---|---|---|
| 温室气体提高石油采收率的资源化利用及地下埋存 | 973 计划 | 2006-2010 | 中国石油集团科学技术研究院、华中科技大学、中科院地质与地球物理研究所、中国石油大学（北京）等 |
| $CO_2$ 减排、储存与资源化利用的基础研究 |  | 2011-2015 | 中国石油集团科学技术研究院等 |
| $CO_2$ 的捕集与封存技术 | 863 计划 | 2008-2010 | 清华大学、华东理工大学、中科院地质与地球物理研究所等 |
| $CO_2$ 驱油提高石油采收率与封存关键技术研究 |  | 2009-2011 | 中国石油集团科学技术研究院、中国石油化工集团勘探开发研究院等 |
| 新型 $O_2/CO_2$ 循环燃烧设备研发与系统优化 |  | 2009-2011 | 华中科技大学等 |
| $CO_2$- 油藻 - 生物柴油关键技术研究 |  | 2009-2011 | 新奥集团、暨南大学等 |
| 基于 IGCC 的 $CO_2$ 捕集、利用与封存技术研究与示范 |  | 2011-2013 | 华能集团、清华大学、中科院热物理所等 |
| 超重力法 $CO_2$ 捕集纯化技术及应用示范 | 支撑计划 | 2008-2010 | 中石化胜利油田分公司、北京化工大学、北京工业大学、中国石油大学（华东）等 |
| 35MWth 富氧燃烧碳捕获关键技术、装备研发及工程示范 |  | 2011-2014 | 华中科技大学、东方电气集团、四川空分设备集团等 |
| 30 万吨煤制油工程高浓度 $CO_2$ 捕集与地质封存技术开发与示范 |  | 2011-2014 | 神华集团、北京低碳清洁能源研究所、中科院武汉岩土力学所等 |
| 高炉炼铁 $CO_2$ 减排与利用关键技术开发 |  | 2011-2014 | 中国金属学会、钢铁研究总院等 |
| 全国 $CO_2$ 地质储存潜力评价与示范工程 | 国土资源部 | 2010-2014 | 中国地质调查局、中科院武汉岩土力学所、北京大学等 |

表 1 中国政府支持的部分 CCUS 技术研发项目（续）

| 项目名称 | 资助来源 / 渠道 | 执行时间 | 主要参与单位 |
|---|---|---|---|
| 含 $CO_2$ 天然气藏安全开发与 $CO_2$ 利用技术 | “大型油气田及煤层气开发”重大专项 | 2008-2010 | 中国石油集团科学技术研究院、中石油吉林油田分公司等 |
| 松辽盆地含 $CO_2$ 火山岩气藏开发及利用示范工程 | | 2008-2010 | 中石油吉林油田分公司、中国石油集团科学技术研究院等 |
| $CO_2$ 驱油与埋存关键技术 | | 2011-2015 | 中国石油集团科学技术研究院、中石油吉林油田分公司等 |
| 松辽盆地 $CO_2$ 驱油与埋存技术示范工程 | | 2011-2015 | 中石油吉林油田分公司、中国石油集团科学技术研究院等 |
| 中联煤深煤层气开发技术试验项目 | | 2011-2015 | 中联煤层气公司等 |

中国 CCUS 技术研发活动覆盖整个 CCUS 产业链，并以政府指导，企业为主体实施，科研单位和高等院校共同参与的方式进行。经过近年来的努力，中国在 CCUS 技术链各环节都已具备一定的研发基础。但总体还处于研发和示范的初期阶段，各环节技术发展也很不平衡，相比国际先进水平我国整体上仍存在较大差距，尤其是在 $CO_2$ 驱油与地质封存相关理论、$CO_2$ 封存的监测、预警等核心技术，以及大规模 $CO_2$ 运输与封存工程经验等方面。

捕集方面，围绕低能耗吸收剂、不同技术路线捕集工艺等关键技术环节开展了一系列研究，已开发出可商业化应用的胺吸收剂，建成了燃煤电厂 $CO_2$ 捕集万吨级 / 年和 10 万吨级 / 年规模的工业示范；

运输方面，借鉴油气管输经验，开展了低压 $CO_2$ 运输工程应用，高压、低温和超临界 $CO_2$ 运输研究刚起步；

利用方面，围绕 $CO_2$ 驱油、驱煤层气、$CO_2$ 生物转化和化工合成等不同利用途径开展了理论和关键技术研究，已开展 $CO_2$ 驱油工业试验，建成微藻制生物柴油中试和小规模的 $CO_2$ 制可降解塑料生产线；

封存方面，已启动全国 $CO_2$ 地质储存潜力评价，初步结果表明，我国 $CO_2$ 地质储存主要空间类型为深部咸水层，潜力可观；工业规模咸水层封存示范已启动。

### （三）试点示范

近年来，中国企业积极开展 CCUS 研发与示范活动，在国家相关技术政策引导和各级政府及不同部门的支持配合下，已建成多个万吨以上级 $CO_2$ 捕集示范装置，最大捕集能力超过 10 万吨 / 年；开展了 $CO_2$ 驱油与封存先导试验，最大单独项目已控制封存 $CO_2$ 约 16.7 万吨；启动了 10 万吨 / 年级陆上咸水层 $CO_2$ 封存示范；建成 4 万吨规模的全流程燃煤电厂 $CO_2$ 捕集与驱油示范。此外，还有多个企业正在开展 CCUS 项目的前期筹备，这些筹备项目的捕集量多在 50 万吨 / 年以上，并将煤化工与 EOR 和地质封存相结合。有关工业试点和示范工程的总体情况见表 2。

表 2 CCUS 工业试点和示范工程的总体情况

| 序号 | 项目名称 | 规模 | 示范内容 | 现状 |
|---|---|---|---|---|
| 1 | 中石油吉林油田 $CO_2$-EOR 研究与示范 | S：10 万吨 / 年 | CCS-EOR | 2007 年投运 |
| 2 | 中科金龙 $CO_2$ 化工利用项目 | U：约 1 万吨 / 年 | 酒精厂 $CO_2$ 化工利用 | 2007 年投运 |
| 3 | 江苏姜堰化肥厂项目 | U：3.2 万吨 / 年 | 尿素生产 | 2007 年投运 |
| 4 | 华能北京热电厂 | C: 3000 吨 / 年 | 燃烧后捕集 + 利用 | 2008 年投运 |
| 5 | 中海油 $CO_2$ 制可降解塑料项目 | U: 2.1 千吨 | 天然气分离 $CO_2$ 化工利用 | 2009 年投运 |
| 6 | 华能集团上海石洞口捕集示范项目 | C：12 万吨 / 年 | 燃烧后捕集 | 2009 年投运 |
| 7 | 中电投重庆双槐电厂碳捕集示范项目 | C：1 万吨 / 年 | 燃烧后捕集 | 2010 年投运 |
| 8 | 中联煤利用 $CO_2$ 强化煤层气开采项目 | S: 试验级 | CCS-ECBM | 2010 年投运 |
| 9 | 中石化山东胜利油田示范项目 | S: 3.65 万吨 / 年 | 燃烧后捕集 + $CO_2$-EOR | 2010 年投运 |
| 10 | 中石油 CCS 项目 | C：2 万吨 / 年 | EOR | 2011 年投运 |
| 11 | 连云港清洁煤能源动力系统研究设施 | C：3 万吨 / 年 | 燃烧前捕集 | 2011 年投运 |
| 12 | 神华集团煤制油 $CO_2$ 捕集和示范封存 | C：10 万吨 / 年<br>S：约 10 万吨 / 年 | 煤液化厂捕集 + 咸水层 | 2011 年投运 |
| 13 | 华中科技大学 35MWt 富氧燃烧技术研究与示范 | C：5 万吨 / 年 | 富氧燃烧捕集 | 2011 年启动 |
| 14 | 国电集团天津北塘热电厂 | C：2 万吨 / 年 | 燃烧后捕集 + 利用 | 2012 年投运 |

表 2 CCUS 工业试点和示范工程的总体情况（续）

| 序号 | 项目名称 | 规模 | 示范内容 | 现状 |
|---|---|---|---|---|
| 15 | 新奥集团微藻固碳生物能源示范项目 | U：约 2 万吨 / 年 | 煤化工烟气生物利用 | 一期投产；二期在建；三期筹备 |
| 16 | 中国石化集团胜利油田捕集和驱油封存示范工程 | S: 100 万吨 / 年 | 燃烧后捕集 + $CO_2$-EOR | 在建（预计 2014 年投运） |
| 17 | 中石油吉林油田 $CO_2$-EOR 研究与示范 | S：80-100 万吨 / 年 | CCS-EOR | 在建（预计 2015 年投运） |
| 18 | 中国大唐集团 $CO_2$ 捕集和示范封存 | C：100 万吨 / 年 | 富氧燃烧 + 地质封存 +EOR | 在建（预计 2015 年投运） |
| 19 | 华能天津 IGCC 试验示范 | C：180 万吨 / 年 | 400MW IGCC GreenGen 示范发电 +EOR | 在建（预计 2016 年投运） |
| 20 | 中国华电 IGCC 项目 | - | IGCC | 在建 |
| 21 | 东莞电化 IGCC 项目 | - | IGCC | 在建 |

### （四）国际合作

近年来，在科技部等相关部门的领导下，国内高校、科研机构和企业与欧盟、澳大利亚、意大利、日本、美国等相关机构开展了广泛的科技交流与合作。通过国际合作，不仅加强了中国相关科研机构和企业的能力建设，形成了中国在 CCS 领域的核心研究团队，同时围绕捕集技术选择、技术经济性评价、封存潜力评估、源汇匹配等开展了探索性的研究工作。

目前，我国 CCUS 国际合作的内容是以技术交流和合作研究为主。到目前为止，中国 21 世纪议程管理中心牵头承担了中欧近零排放合作项目（Near Zero Emissions Coal, NZEC），第一期已经完成，第二期进入筛选示范工程的阶段；中澳二氧化碳地质封存能力建设项目（CAGS），第一期已经完成，第二期正在开始；已完成的中意二氧化碳捕集与封存技术合作项目（SICCS），主要工作集中在二氧化碳捕集方面。此外，其他政策研究项目包括，中欧 COACH 项目等。

表 3　部分国际合作项目的具体情况

| 项目名称 | 资助来源 | 执行时间 | 主要参与单位 |
|---|---|---|---|
| 中欧近零排放合作（NZEC）项目第一阶段 | 国家科技部、欧洲联盟、英国环境、食品与乡村事务部 | 2007-2009 | 中国 21 世纪议程管理中心、西安热工院、清华大学、中科院热物理所等 |
| 中欧近零排放合作（NZEC）项目第二阶段 | 欧洲联盟、英国、挪威 | 2013- | 中国 21 世纪议程管理中心、中国科学院武汉岩土力学研究所、华北电力大学、中科院工程热物理所、华中科技大学等 |
| 中美清洁能源研究中心 | 国家科技部、能源局、美国能源部 | 2010-2015 | 华中科技大学、清华大学、华能集团、中科院武汉岩土所等 |
| 中澳 $CO_2$ 地质封存（CAGS）合作项目 | 国家科技部、澳大利亚资源、能源与旅游部 | 2009-2011 | 中国 21 世纪议程管理中心、中国地质调查局、中科院武汉岩土力学研究所、清华大学等 |
| 中意 CCS 技术合作项目 | 国家科技部、意大利环境部 | 2010-2012 | 中国 21 世纪议程管理中心、华能集团、清华大学、 |
| 整体煤气化联合循环的低排放技术联合研究 China-USA | 国家科技部、美国能源部 | 2010-2012 | 中科院热物理所，大连化物所、等 |

## 三、结语

全球气候变化深刻影响着人类的生存和发展，是世界各国共同面临的重大挑战。各国只有采取有效的措施大幅度减少温室气体尤其是二氧化碳的排放，全球控制气候变化的目标才可能实现。过去十年里，CCUS 技术从一个鲜为人知的技术概念到矗立在大地上的众多工业规模示范项目，已经逐渐开始对减缓气候变化发挥作用。CCUS 技术在全球范围呈现着加速发展的态势。中国对 CCUS 技术亦给予了积极的关注和高度重视，在推动 CCUS 技术的研发和示范上已做了大量显著且有成效的工作。

# 2. 利用水泥窑协同处置城乡废弃物技术在中国推广应用的可行性分析

胡伟基，水泥行业专家，英国华威过程工程硕士

胡伟基

水泥工业协同处置城市废弃物是指利用水泥窑焚烧城市废弃物，实现废弃物减量化、资源化、无害化处理的一种水泥生产方式。发达国家利用水泥窑焚烧处理危险废物和城市生活垃圾已经有30多年的应用历史，并广泛认可这种方式环境安全、经济合理、技术可靠。

截至2010年底，全国设市城市和县城生活垃圾年清运量2.21亿吨，生活垃圾无害化处理率63.5%，其中设市城市77.9%，县城27.4%。我国生活垃圾处理方式从过去的简易填埋为主逐步转向以卫生填埋、焚烧为主，生物处理等多种技术协同处理的格局。近年来，随着中国城镇化的快速发展，生活垃圾等城乡废弃物激增，尽管中国在90年代末引进垃圾焚烧发电技术并逐步在国内推广，但由于处理能力仍相对不足，一些城市面临“垃圾围城”的困境，部分处理设施建设水平和运行质量不高，配套设施不齐全，存在污染隐患，对环境卫生和社会稳定造成了很大的压力。因此，找到科学合理处置城市废弃物的出路已经刻不容缓。

## 一、利用水泥窑处置废弃物的可行性

（一）利用水泥窑处置废弃物是国家重点鼓励的技术。国务院《关于印发循环经济发展战略及近期行动计划的通知》（国发〔2013〕5号，以下简称《通知》）提出，鼓励水泥窑协同资源化处理城市生活垃圾、污水厂污泥、危险废物、废塑料等废弃物，替代部分原料、燃料，推进水泥行业与相关行业、社会协同的循环链接。到2015年，水泥窑协同资源化处理废弃物生产线比例达10%。近期国家将选择100个利用水泥窑处置城乡废弃物项目开展试点工作。

（二）利用水泥窑处置废弃物是水泥产业结构调整、转型升级的需要。2012年全国水泥产量达21.84亿吨，产能利用率仅73.7%，行业产能严重过剩，造成资源严重浪费，严重影响行业效益。在水泥行业通过“减量置换”发展先进产能，推广利用水泥窑资源化处置废弃物，替代部分原料、燃料，推进行业节能降碳减排工作，实现真正减量化、资源化和无害化，可促进水泥行业的转型升级。据估算，如果全行业全面推广协同处置废弃物的技术，每年可处置废弃物达8亿吨，在不考虑区域布局的情况下，已可以满足全国生活垃圾处理的要求。

（三）利用水泥窑处置废弃物是实现无害化处置经济可靠的办法。用水泥窑处置废弃物在国外已有30多年成功运营的经验，我国通过引进吸收改良，目前已具备大范围推广的条件，可无害化处理生活垃圾、污水处理厂产生的污泥、危险废弃物和废塑料皮革等废弃物。

处置废弃物的方式主要有五种（见附表1），目前我国主要推广生活垃圾焚烧发电处理方式和利用水泥窑协同处置技术。与垃圾焚烧发电相比，利用水泥窑处理垃圾有明显的优势：

一是环境友好。水泥窑生产过程中窑内温度一般在1350 ~ 1650℃之间，能将二噁英等有害物彻底分解。同时处理后的废弃物成为水泥的成分，二次污染降到最低。

二是资源节约。废弃物热值在水泥窑内几乎可以全部用于煅烧熟料，替代煤效果明显。欧洲部分发达国家已实现了100%替代煤。由于国内的原生垃圾成分的特点，热值较低，但替代煤的效果仍相当可观。例如目前湖北华新水泥公司的技术，一条5000吨/日熟料的水泥生产线，最多可处理生活垃圾2000吨/日，替代煤约500吨/日，替代率可达到50%。

三是经济效益好。按照国内的经验，目前利用水泥窑无害化处理废弃物的成本已低于垃圾焚烧发电。

四是政府投入低产出大。利用现有水泥窑处理废弃物，政府只需按处理量给予补贴；垃圾焚烧厂虽然现在以 BOT 形式由企业投资为主，但政府对前期的土地等投入大，每年的补贴力度也相对较大。如利用现有的水泥窑改造，新增投资要约为垃圾发电投资的三分之一。而日产 5000 吨的水泥熟料生产线，每年缴纳的税金可超 1 亿元，有很好的经济效益。

此外，利用水泥窑协同处置城市废弃物还可替代部分水泥生产原料，减少天然矿物资源的消耗；大幅节约土地资源，减少城市垃圾填埋对土地的占用；在遵循相关法规和标准的前提下，可以充分保障环境安全，也避免了二次污染产生的社会矛盾。

综上所述，随着技术与实践的不断发展，水泥窑焚烧处置城市废弃物在环保效益、社会效益和经济效益方面都显示出了巨大优势，大力推动水泥工业处置城乡废弃物很有必要。

## 二、国内外水泥工业协同处置城乡废弃物的实践

### （一）发达国家已广泛应用

德国、瑞士、法国、英国、意大利、挪威、瑞典、美国、加拿大、日本等发达国家利用水泥窑焚烧处理危险废物和城市生活垃圾已经有 30 多年的应用历史，并广泛认可这种环境安全、经济合理、技术可靠的处理方式。发达国家已经建立起从废弃物产生源头到水泥厂处置的质量保证体系，既考虑污染物排放、又保证水泥和混凝土产品的质量，是基于产品全生命周期的体系。欧盟国家利用水泥窑处置废弃物的技术居世界前列，法规、标准已比较完备，如规定了可以在水泥厂处置的废弃物种类、水泥厂可处置废弃物的重金属最高含量限值、重金属在水泥熟料和成品中的最高含量限值，水泥窑焚烧危险废弃物的大气污染物排放标准等。

水泥工业主要将城市废弃物作为替代燃料处置。发达国家水泥工业均有较高的燃料替代比例，如美国是 25%、德国是 49.9%，荷兰是 92%、世界最高，欧洲水泥行业燃料替代率目前已超过 27%。发达国家有 2/3 的水泥厂使用替代燃料，可燃废物在水泥工业替代燃料中的比例平均达 20%。欧洲水泥协会明确规定将工业污泥和城镇生活用水处理厂污泥列入 14 类替代燃料中。瑞士水泥工业 2007 年替代燃料使用干化污泥达 5.7 万吨。德国水泥工业 2006 年处置污泥 23.8 万吨，是 2002 年的 59 倍。日本水泥工业 2008 年替代燃料使用湿污泥 303 万吨，水泥工业处置污泥量已占日本污泥产生量的 30%。韩国水泥工业 2007 年处置污泥 71.3 万吨。

### （二）国内利用水泥工业协同处置城乡废弃物方兴未艾

我国从 20 世纪 90 年代开始广泛开展利用水泥窑处置危险废弃物和城市生活垃圾的研究工作。近几年，我国水泥工业利用水泥窑协同处置城市废弃物有了积极的尝试，取得了显著成果，已逐步建立了一套协同处置的技术体系，但仍与发达国家差距较大。

北京水泥厂早在 1998 年就开始利用 1 条日产 2000 吨水泥熟料窑进行废弃物处置，主要对石油、化工、汽车、医药、冶金、建材行业及实验室等单位产生的危险废弃物进行安全处置。2005 年，专门兴建 1 条日产 3200 吨水泥熟料生产线协同处置危险废弃物。2009 年 10 月，建成设计每天处置 500 吨（含水 80%-85%）污泥的热干化预处理线，干化后的污泥在水泥熟料生产线焚烧处置，目前每天处置污泥已达 400 吨。

广州越堡水泥有限公司将 1 条日产 6000 吨水泥熟料生产线改造成日处理 600 吨（含水 80%）城市污泥的项目。自 2009 年 8 月投运以来，共处置了广州市生活污泥 29 万多吨。该处置系统运行可靠，操作简便，对污泥的适应性强。按照日处理 600 吨污泥的设计能力运行，该项目每年可节约标准煤 1.36 万吨，相当于减少二氧化碳排放 3.4 万吨；避免污泥填埋产生甲烷排放 5000 吨，相当于减少二氧化碳排放 10.5 万吨。

安徽海螺集团与日本川崎公司联合开发了水泥窑与气化炉相结合的城市垃圾处置技术，利用铜陵海螺水泥 2 条日产 5000 吨水泥熟料生产线，建设日处理生活垃圾 600 吨的协同处置项目。一期工程于 2010 年 4 月投运，日平均处理铜陵市产生的生活垃圾 230 吨。

华新水泥投资 6500 万元在湖北武穴工厂建设日处理 500 吨生活垃圾的生产线，2009 年 4 月建成投产。华新水泥秭归公司 2010 年 7 月建成利用水泥窑协同处置三峡库区漂浮物项目，设计日处理能力 1000 立方米，年处理能力达 30 万立方米。

除上述企业外，天津水泥股份有限公司、青海水泥有限责任公司、甘肃永登水泥有限公司、重庆拉法基瑞安（重庆南山）水泥有限公司、宁波富达股份有限公司、吉林亚泰水泥有限公司等企业也先后获得危险废物经营许可，利用水泥窑处置工业有毒、有害废弃物。处置的废弃物主要有化工油泥、石化污泥、金属加工业污泥、漆渣、废轮胎、电镀污泥、有毒化工废料、有毒土壤等，但处置规模相对较小，尚不能充分发挥水泥工业处置废弃物的潜力。

附表 1

废弃物处置方式比较

| 方式 | 优点 | 缺点 | 发展趋势 |
|---|---|---|---|
| 卫生填埋 | 短期成本较低，技术简单，适用经济不发达地区 | 占用大量的土地，需不断投入环保治理，否则易造成土壤和地下水的严重污染 | 仍在应用，经济发达但土地资源紧缺的地区不适用 |
| 生物堆肥 | 成本较低，可以在农业上使用 | 处理不当易导致重金属污染土壤和地下水体，引发食品和环境安全问题 | 适用生活垃圾管理水平较高的地区，但发达国家已经逐步淘汰 |
| 直接焚烧 | 能快速减量 | 成本较高，垃圾中的热量没有充分应用，烟气污染无法控制，飞灰难以处理 | 已经基本淘汰 |
| 焚烧发电 | 在减量的同时利用垃圾中的热量 | 投资较高，选址、环评困难，产生的烟气、灰渣需要二次处理 | 中国重点推广 |
| 利用水泥窑协同处理 | 完全无害化、资源化处置 | 新建水泥窑投资较高 | 中国重点推广 |

# 1. China CCUS Technology Development

Jiutian ZHANG, China's Agenda 21

ZHANG Jiutian speaks in a workshop
Source: Chongqing Academy of Science and Technology, 2013

CCUS technologies separate $CO_2$ from industrial or other sources and then transport it to specific sites for utilization or storage, thus preventing the captured $CO_2$ from entering the atmosphere. Among the many GHG emission reduction solutions, CCUS is a newly-developed technology that enables the continued large scale use of fossil fuels.

Climate change is one of the most severe global challenges which involve the future survival and development of the human race. The development of carbon capture, utilization and storage technologies is important for not only the reduction of GHG emissions in order to address climate change, but also to provide access to potential strategic technological solutions.

## 1. International Development of the CCUS Technology

To promote the development and deployment of CCUS, the EU, the United States, Australia and other developed countries have commenced large-scale projects to encourage the R&D and demonstration of CCUS technologies and actively promote global CCUS development under the framework of the G8, G20, CSLF, etc.

Currently, the CCUS demonstration projects are beginning to play their role in combating climate change. There are over 300 CCUS projects (including projects which cover a single process within the capture, transportation and storage chain as well as whole process CCUS projects) in operation, construction or planning, 65 of which are large-scale whole-process CCUS projects. 12 of these are oil and gas industrial scale projects that are “in operation” with a capacity of over 1Mt/year and distributed in the United States, Europe, and Canada.

Based on international CCUS engineering practice, individual processes within the $CO_2$ emission technology chain are relatively mature and capable of implementation. Currently, the greatest challenges are the capital and operational costs of the technologies, the additional energy consumption, safety issues and the system integration in large-scale demonstration projects. Meanwhile, each country has to consider the economics of this technology and apply CCUS technologies to the energy and industrial sectors, such as the power sector, natural gas process industry, and refineries, which emit large amounts of highly concentrated $CO_2$.

CCUS policy trend: the United States, Europe, Canada, the UK, Australia and other developed countries have defined their near, medium and long-term technical direction and research focus by releasing a CCUS technology development roadmap and strategic plan which establishes the inter-departmental coordination mechanism to strengthen the guidance of the relevant national government. Governments have increased investment in CCUS and are even using it to revive the domestic economy. More attention should be paid to the construction of cross–industry and cross–discipline CCUS collaboration platforms to increase knowledge and experience sharing. In addition, the countries should put more effort into building the “intangible infrastructure”, including technical standards, laws and regulations, management systems and public acceptance.

## 2 .The Development of CCUS Technology in China

In recent years, China has paid more attention to CCUS technology development. Despite the late start, the development of CCUS technology in China has made considerable progress in recent years. Under the guidance of the Government, enterprises, research institutes and universities have cooperated together, undertaken lots of work focusing on the study of CCUS–related theories, key technologies and supporting policies, established professional research teams, achieved many technology achievements with intellectual property rights of their own, and launched the successful demonstration of industrial scale $CO_2$ capture.

(1) Policy Making

Currently, there are several technical policy documents in China, including the National Medium– and Long–Term Program for Science and Technology Development (2006–2020), China's National Climate Change Program, China's Scientific and Technological Actions on Climate Change, and the National 12th Five–Year Plan on Science & Technology Development. All these documents list CCUS technology as a key technology to mitigate climate change, and actively guide the R&D and demonstration of CCUS technology.

In September 2011, China's Ministry of Science and Technology (MOST) completed the “Technology Roadmap of Carbon Capture, Utilisation, and Storage in China”. The Roadmap evaluates the CCUS technology development status in China, proposes the vision of CCUS technology development in China and targets technical development over the next 20 years. In April 2013, the NDRC issued the “Notice on Promoting Carbon Capture, Utilization and Storage Pilot and Demonstration”, and indicated for the first time the commercialization of CCUS technology in the future. Later in 2013, based on the national conditions in China, China's Agenda 21 Administrative Centre published China's “Carbon Dioxide Utilization Technology Assessment Report” which evaluated the great potential and benefit of $CO_2$ utilization technology on the recovery of energy resources, economic development, environment protection and carbon emission reduction, which laid a theoretical foundation for $CO_2$ resource utilization.

(2) Technical R&D

The Chinese Government has continually increased the CCUS R&D and demonstration funding in recent years. The range supported has been transformed from technical investigations and pilot scale test on a single link to industrial–scale full chain technical demonstration.

Since the tenth five–year plan, Chinese national science and technology programs – including the National Basic Research (973) Program, the National High Technology Development (863) Program, and National Key Technology R&D Program – have launched a series of projects targeted at developing CCUS technology. These cover strategic policy studies on the emission reduction potential of CCUS technologies, basic research and technology R&D on $CO_2$ capture, bio–conversion and utilization, $CO_2$–EOR and geologic storage, which involve different types of $CO_2$ emission sources, different capture technology paths, and different $CO_2$ conversion and utilisation modes. China has also deployed $CO_2$–EOR and $CO_2$–ECBM technical development and demonstration in the National Major Science and Technology Special Program for “the Development of Large–sized Oil & Gas Fields and Coal–bed Methane”.

Preliminary statistics show that about 20 research projects on the basic research and technology exploitation of CCUS have been deployed in the national science and technology programs during the period of the eleventh five–year plan. The total funding was above 1 billion RMB, including 0.2 billion RMB from public finance. The investment on full chain technical demonstration significantly increased during the period of the eleventh five–year plan. In 2011, 10 CCUS–related research projects were arranged in the national science and technology programs with total funding of 2 billion RMB, including the 0.4 billion RMB from public finance.

The research projects on CCUS supported by Government are as follows:

Table 1 List of Main CCUS Technology R&D Projects and International Cooperation Projects supported by Chinese Government

| Project Name | Funding Sources | Execution Time | Main Participating Organizations |
|---|---|---|---|
| Greenhouse Gas Enhanced Oil Recovery and Underground Storage | The National Basic Research Program (973) | 2006–2010 | Institute of S&T Research, PetroChina, Huazhong University of Science and Technology, Institute of Geology and Geophysics of the Chinese Academy of Sciences and China University Of Petroleum (Beijing), etc. |
| Basic Research of $CO_2$ Emission Reduction, Storage and Utilization | | 2011–2015 | Institute of S&T Research, PetroChina, etc. |
| The Capture and Storage Technology of $CO_2$ | National High Technology Development (863) Program | 2008–2010 | Tsinghua University, East China University of Technology<br>and Institute of Geology and Geophysics of Chinese<br>Academy of Sciences, etc. |
| Critical Technology Research on $CO_2$ Enhancing Oil Recovery and Storage | | 2009–2011 | Institute of S&T Research, PetroChina and Research<br>Institute of Exploration and Development, Petrochina, etc. |
| New O2/$CO_2$ Cycle Combustion Equipment R&D and System Optimization | | 2009–2011 | Huazhong University of Science and Technology, etc. |
| $CO_2$–algae– Biodiesel Critical Technology Research | | 2009–2011 | ENN Group, Jinan University, etc. |
| Research and Demonstration of $CO_2$ Capture, Utilization and Storage Based on Integrated Gasification Combined Cycle (IGCC) | | 2011–2013 | China Huaneng Group, Tsinghua University and Thermal<br>Physics Institute of Chinese Academy of Sciences, etc. |

Table 1 List of Main CCUS Technology R&D Projects and International Cooperation Projects supported by Chinese Government

| Project Name | Funding Sources | Execution Time | Main Participating Organizations |
|---|---|---|---|
| $CO_2$ Capture and Purification Technology with High-Gravity and Application Demonstration | The National Key Technology R&D Program (Key Technology Program) | 2008-2010 | Sinopec Shengli Oilfield Branch, Beijing University of Chemical Technology, Beijing University of Technology and China University of Petroleum (East China), etc. |
| Critical Technology, Equipment Research and Development and Engineering Demonstration of 35MWth Oxy-Combustion Carbon Capture | | 2011-2014 | Huazhong University of Science and Technology, Dongfang Electric Group and Sichuan Air Separation Equipment Group, etc. |
| Technology Development and Demonstration of 300,000 tonnes $CO_2$ Capture and Geologic Storage of High Concentrations $CO_2$ from Coal-to-liquid Project | | 2011-2014 | China Shenhua Group, Beijing Institute of Low-Carbon Clean Energy and Wuhan Institute of Rock and soil Mechanics of Chinese Academy of Sciences, etc. |
| Critical Technology Development and Demonstration of $CO_2$ Emission Reduction by Blast Furnace Iron Making | | 2011-2014 | Chinese Society of Metals and Iron and Steel Research Institute, etc. |
| The Nationwide $CO_2$ Geologic Storage Potential Assessment and Demonstration Project | The Ministry of Land and Resources | 2010-2014 | China Geologic Survey Bureau, Wuhan Institute of rock and soil mechanics of Chinese Academy of Sciences and Peking University, etc. |
| Safe Development of Natural Gas Reservoirs with $CO_2$ and $CO_2$ Utilization Technology | The National Major Science and Technology Program of "Large Oil and Gas Fields and Coal-bed Methane Development" (Major Project) | 2008-2010 | Institute of S & T Research, PetroChina and PetroChina Jilin Oilfield Branch, etc |
| the Development of Songliao Basin Volcanic Gas Reservoirs and $CO_2$ Utilization Demonstration Project | | 2008-2010 | PetroChina Jilin Oilfield Branch and Institute of S&T Research, PetroChina, etc. |
| Critical Technology of $CO_2$ EOR and Storage | | 2011-2015 | Institute of S&T Research, PetroChina and PetroChina Jilin Oilfield Branch, etc. |
| $CO_2$ EOR and Storage Technology Demonstration Project of Songliao Basin | | 2011-2015 | PetroChina Jilin Oilfield Branch and Institute of S&T Research, PetroChina, etc. |
| Technology on Deep Coal-bed Methane Development and its Application | | 2011-2015 | China United Coal-bed Methane Company, etc. |

Under the guidance of the Government, enterprises, research institutes and universities have cooperated together, undertaking many CCUS technology R&D projects that cover the whole chain of CCUS. Through these efforts in recent years, China has built a research foundation on each technical aspect of CCUS. However, there are relevant wide gaps in comparison with international advanced technology, especially on the relevant theory of $CO_2$–EOR and geological storage, the key technologies of $CO_2$ storage monitoring, early warning and engineering experiences on large–scale $CO_2$ transportation and geological storage.

Capture Technology: China has carried out series of researches on the key technologies of low energy consumption absorbents and capture technology using different technical routes, developed amine absorbers for commercial application, and set up several industrial scale $CO_2$ capture demonstration projects, with the largest capture capacity of 10,000 tonnes and 100,000 tonnes per year respectively at different power stations.

Transportation Technology: China has carried out engineering studies applicable to low–pressure $CO_2$ transport based on the experience of oil and gas transportation. Transportation investigations on high pressure, low temperature and supercritical $CO_2$ have started;

Utilisation Technology: China has carried out research on theory problems and the key technologies of $CO_2$–EOR, $CO_2$–ECBM, $CO_2$ biotransformation and chemical synthesis, and carried out industrial tests on $CO_2$–EOR, set up pilot projects on microalgae transformation to biodiesel and a small–scale production line of degradable plastic made from $CO_2$;

Storage Technology: China has started the assessment of the $CO_2$ geological storage capacity for the whole country. The preliminary results showed that the main large geological $CO_2$ storage capacity in China was in deep saline formations. The industrial scale storage demonstration project in saline formations is in operation.

(3) CCUS Demonstration Projects

Chinese enterprises have launched many R&D and demonstration activities in CCUS in recent years. They have set up several industrial–scale $CO_2$ capture demonstrations with the largest capture capacity over 100,000 tonnes per year; developed pilot–scale tests of CCS–EOR in which the cumulative injection volume of $CO_2$ has exceeded 167,000 tonnes; launched $CO_2$ storage demonstration in onshore saline aquifers of 100,000 tonnes per year; and established integrated a full–chain CCS–EOR demonstration at the scale of 40,000 tonnes per year on coal–fired power plants. In addition, many enterprises are preparing for CCUS projects with capture capacity of more than 500,000 t/a, which combine coal chemical, EOR and geological storage. Table 2 shows the status of CCUS pilot and demonstration projects in China.

Table 2 Status of CCUS Pilot and Demonstration Projects in China

| No. | Project Name | Scale | Demonstration Content | Status |
|---|---|---|---|---|
| 1 | $CO_2$–EOR Research and Demonstration, PetroChina Jilin Oil Field | S：about 100,000 t/a | CCS–EOR | Operational since 2007 |
| 2 | $CO_2$ Chemical Utilization Project of Zhongke Jinlong | U：about 10,000 t/a | Chemical Utilization of $CO_2$ in ethyl alcohol plant | Operational since 2007 |
| 3 | Jiangyan Fertilizer Plant | U：32,000 t/a | Urea Production | Operational since 2007 |
| 4 | Huaneng Beijing Thermal Power Plant | C: 3000 t/a | Post–Combustion + Utilization | Operational since 2008 |
| 5 | $CO_2$ manufacturing Biodegradable Plastic Project , CNOOC | U: 2,100 t/a | Chemical Utilization of $CO_2$ | Operational since 2009 |

Table 2 Status of CCUS Pilot and Demonstration Projects in China

| No. | Project Name | Scale | Demonstration Content | Status |
|---|---|---|---|---|
| 6 | Shanghai Shidongkou Carbon Capture Demonstration Project, Huaneng Group | C：120,000 t/a | Post–Combustion | Operational since 2009 |
| 7 | Chongqing Shuanghuai Power Plant Carbon Capture Demonstration, China Power Investment Group | C：10,000 t/a | Post–Combustion | Operational since 2010 |
| 8 | Zhonglian Coal utilization, $CO_2$–ECBM | S: Pilot–scale | CCS–ECBM | Operational since 2010 |
| 9 | Sinopec Shengli Oilfield CCS–EOR Demonstration | S: 36,500 t/a | Post–Combustion +$CO_2$–EOR | Operational since 2010 |
| 10 | CNPC CCS Project | C：20,000 t/a | EOR | Operational since 2011 |
| 11 | Lianyungang Clean Coal Energy Power System Research | C：30,000 t/a | Pre–Combustion Carbon Capture | Operational since 2011 |
| 12 | Shenhua Group Coal–To–Liquid CCS Demonstration | C：100,000 t/a<br>S：about 100,000 t/a | Capture form Coal Liquefaction Plants +Saline Storage | Operational since 2011 |
| 13 | Research and Demonstration of 35MWth Oxy–Combustion Carbon Capture, Huazhong University of Science and Technology | C：50,000 t/a | Oxy–Combustion Carbon Capture | Operational since 2011 |
| 14 | Tianjin Beitang Thermal Power Plant, China Guodian Corporation | C：20,000 t/a | Post–Combustion Carbon Capture +Utilization | Operational since 2012 |
| 15 | ENN Group Microalgae Bio–fuel Demonstration Project | U：about 20,000 t/a | Biological Utilization of $CO_2$ | the First Phase: Put into Production; the Second Phase: under Construction; the third Phase: under preparation |
| 16 | Sinopec Shengli Oil Field CCS–EOR Demonstration | S: 1Mt/a | Post–Combustion Carbon Capture +$CO_2$–EOR | under Construction （expected to be operational in 2014） |
| 17 | CNPC Jilin Oilfield $CO_2$–EOR Demonstration | S：0.8–1Mt/a | CCS–EOR | under Construction （expected to be operational in 2015） |
| 18 | China Datang Corporation $CO_2$ Capture and Storage Demonstration | C：1Mt/a | Oxy–Combustion Carbon Capture + Geological Storage + EOR | under Construction （expected to be operational in 2015） |
| 19 | Huaneng Group Tianjin IGCC Demonstration | C：1.8Mt/a | 400MW IGCC GreenGen Power generation Demonstration + EOR | under Construction （expected to be operational in 2016） |
| 20 | China Huadian Group IGCC Project | – | IGCC | under Construction |
| 21 | Dongguan Power Plant IGCC Project | – | IGCC | under Construction |

(4) International Corporations

Under the leadership of MOST and other related departments, China has actively and organized its research institutions and enterprises to participate in a series of bilateral and multilateral cooperation projects with the EU, USA, UK, Australia, Italy and Japan.

The CCUS international cooperation projects currently focus on technological exchange and research cooperation. Until now, China's Agenda 21 Administrative Centre has been in charge of the Near Zero Emissions Coal cooperative project, phase one of which has been completed, and phase two has commenced with the selection of demonstration projects. As to the China–Australia $CO_2$ Geological Storage capacity building project, phase one has been completed, and phase two is about to commence. The SICCS project has been completed, focusing on $CO_2$ capture. Other policy research projects include “COACH” etc.

Table 3 The Details of some International cooperation Projects

| Project Name | Funding Source | Execution Time | Major Organizations Involved |
|---|---|---|---|
| Phase one of the Near Zero Emissions Coal ( NZEC ) Project | MOST, EU, and The Department for Environment, Food and Rural Affairs | 2007–2009 | China's Agenda 21 Administrative Center, Xi'an Thermal Power Research Institute, Tsinghua University, Institute of Engineering Thermophysics, Chinese Academy of Sciences, and etc. |
| Phase two of the Near Zero Emissions Coal ( NZEC ) Project | EU, UK and Norway | 2013– | China's Agenda 21 Administrative Center, Wuhan Institute of rock and soil mechanics of Chinese Academy of Sciences, North China Electric Power University, Institute of Engineering Thermophysics, Chinese Academy of Sciences, HUST, and etc. |
| China–US Clean Energy Research Center | MOST, Bureau of Energy and DOE | 2010–2015 | HUST, Tsinghua University, Huaneng Group, Wuhan Institute of rock and soil mechanics of Chinese Academy of Sciences, and etc. |
| China–Australia $CO_2$ Geological Sequestration (CAGS) Cooperation Projects | MOST, Australian Department of Resources, Energy and Tourism | 2009–2011 | China's Agenda 21 Administrative Center, China Geological Survey, Wuhan Institute of rock and soil mechanics of Chinese Academy of Sciences, Tsinghua University and etc. |
| China–Italy CCS Technological Cooperation Projects | MOST and The Italian Ministry of Environment | 2010–2012 | China's Agenda 21 Administrative Center, Tsinghua University, and Huaneng Group |
| China–USA Joint Low Emission Technology Research on IGCC | MOST and DOE | 2010–2012 | Institute of Engineering Thermophysics, Chinese Academy of Sciences, Dalian Institute Of Chemical Physics and etc. |

## 3. Conclusions

Global climate change is a big challenge that could dramatically change the chances of survival and development of the human race. Effective greenhouse gas, especially carbon dioxide emission reduction methods must be adopted to mitigate climate change. The past ten years have seen CCUS technology developing from concept to industrial–scale demonstration projects and has begun to play an important role in combating climate change. The international development of CCUS is accelerating. China pays great attention to technology and has completed lots of significant and fruitful work on the research, development and demonstration of CCUS technology.

# 2. Feasibility Study on the Deployment and Application of Urban and Rural Waste Disposal Technology Based on Cement Kilns

Weiji HU, Cement Clean Technology Expert, Master in Process Technology and Business Management at University of Warwick

Weiji HU

Cement industry co-processing municipal waste is a method of producing cement by incinerating the waste in the cement kiln, thus achieving waste reduction, recycling, and bio-safe disposal. Developed countries have more than 30 year's experience in using cement kilns to incinerate hazardous and municipal solid wastes; and this method is widely recognized to be environmentally friendly, economically feasible, and technologically reliable.

By the end of 2010, the amount of municipal solid waste disposed of in China reached 221Mt. The average bio-safe disposal rate of the waste was 63.5%, with 77.9% and 27.4% in the cities and towns respectively. The main municipal solid waste disposal method in China is to transfer it from simple landfill to sanitary landfill and incineration. As urbanization has accelerated in recent years, the amount of municipal solid waste in China has increased hugely. Despite the introduction and deployment of waste incineration power generation technology at the end of 1990s, China's disposal capacity is far from sufficient. The low quality of the construction and operation of disposal facilities and the lack of supporting facilities lead to some "waste siege cities", and the hidden danger of pollution puts more pressure on sanitation and social stability. Consequently it is critically important to dispose of the municipal solid waste scientifically and appropriately.

## 1. The feasibility of cement kiln waste disposal

(1) Using cement kilns to dispose of municipal solid waste is a key technology encouraged by the National Government. The Notice on the Issuance of Circular Economy Development Strategy and Near-term Action Plan released by the State Council (ND〔2013〕No.5,stated clearly that the use of cement kilns to co-process municipal solid waste, sewage sludge, hazardous wastes, waste plastics and other wastes should be encouraged. This would have the effect of replacing some of the raw materials and fuels used by the cement industry, and strengthen the Circular Economy between the cement and other related industries. Recycling wastes using cement kilns could account for about 10% of the waste disposal by 2015. A hundred projects for the disposal of municipal solid waste in cement kilns were recently selected for national demonstration.

(2) Cement kiln municipal solid waste disposal is essential for the cement industry's industrial restructuring, transformation and upgrading. In 2012, the total production of cement nationwide reached 2.184Gt. The rate of capacity utilization only reached 73.7%, leading to a serious capacity surplus and waste of resources, which eventually will materially affect the industry's efficiency. The transformation and upgrading of cement industry can be realized by developing advanced capacity

through “replacement and reduction of capacity” , deploying cement kiln waste disposal technology, replacing some of the raw materials and fuels, and boosting industry energy conservation and emission reductions to realize capacity reduction and bio-safe reutilization of waste. It is estimated that annual cement kiln waste disposal can reach 800Mt once the technology is fully deployed in the industry. This can satisfy the whole country's need for solid waste disposal (though this doesn't take into account regional distribution issues).

(3) It is economically feasible to realize bio-safe disposal of the waste in cement kilns. The technology has more than 30 years of successful operation in developed countries. Once the technology is introduced and improved, China would be well positioned to deploy this technology widely and to realize bio-safe disposal of the municipal solid waste, sewage sludge, hazardous wastes, waste plastics and other wastes.

**There are mainly five ways to dispose the waste (see attached table 1). Currently, municipal solid waste incineration for power generation and cement kiln waste disposal are the two major technologies deployed in China, and the latter has some obvious advantages over the former**:

(1) t is environmentally friendly. During the production process, the temperature inside the cement kiln is generally between 1350-1650 ℃ , which can completely decompose TCDD and some other hazardous wastes. At the same time, the processed waste is recycled as cement, minimizing secondary pollution.

(2) It conserves resources. Almost all the waste calorific value in the cement kiln can be used for calcining clinker, which effectively replaces burning coal. Some European developed countries have realized 100% coal replacement. Although China's domestic waste has a low calorific value, there is still considerable scope to replace coal with waste. For example, Huaxin Cement Co., LTD in Hubei Province developed a technology that allows its 5000t/d clinker cement production line to dispose of 2000 tons of municipal solid waste per day, replacing 500 tons of coal, a replacement rate of 50%.

(3) It is cost effective. The national experience is that the cost of cement kiln waste disposal is lower than incinerating the waste for power generation.

(4) It is a small investment with a large return for the Government. By using existing cement kilns to dispose of waste, the Government only needs to grant subsidies according to the disposal capacity. Based on BOT, waste incineration plants are mainly built with private investment. However, the Government invests a lot in the land at the early stages, so subsidies can be quite large. For example, the new investment required to retrofit an existing cement kiln would be 1/3 the cost of converting power generating equipment to incinerate waste. At the same time the tax paid by a 5000t/d cement clinker production line is more than 100 million RMB, which makes the investment cost effective.

In addition, solid waste can replace part of the raw materials for cement production, thus reducing the consumption of natural mineral resources, saving land required for landfill, satisfying environmental laws and regulations, and avoiding social conflicts caused by secondary pollution.

In conclusion, with the progress being made in technologies and practices, cement kiln municipal solid waste disposal shows great economic, social, and environmental benefits. Cement kiln municipal solid waste disposal should therefore be promoted strongly.

## 2. Domestic and overseas practice in cement kiln municipal solid waste disposal

(1) Wide application in developed countries

Germany, Switzerland, France, Britain, Italy, Norway, Sweden, the United States, Canada, Japan, and other developed countries have used cement kilns to dispose of municipal solid waste and hazardous wastes for more than 30 years, and this method is widely recognized as being environmentally friendly, economically feasible, and technologically reliable. Those countries have established a quality assurance system which covers the whole range from sourcing the waste to cement disposal. The systems are based on product life cycle, and consider not only the emissions of pollutants but also the quality of cement and concrete products. The EU has world-leading cement kiln waste disposal technologies as well as comprehensive regulations and standards. For example, regulations set laws and standards for the types of waste that can be disposed of in the cement plant, the limits on the heavy metal content of the waste and of the cement clinker and finished products, and pollutant emissions.

The cement industry uses municipal solid waste as a substitute fuel. Developed countries have high fuel replacement ratios, with 25% in the USA, 49.9% in Germany, 92% in Netherlands (highest in the world), and over 27% in Europe as a whole. Two thirds of the cement plants in developed countries use substitute fuels, more than 20% of which are combustible waste. The European Cement Association (CEMBUREAU) explicitly includes industrial sludge and urban domestic water treatment plant sludge within 14 categories of substitute fuels. In 2007, the Swiss cement industry used 57,000 tons of dry sludge as substitute fuel. In 2006, the Germany cement industry disposed of 238,000 tons of sludge, 59 times greater than the amount in 2002. In 2008, the Japanese cement industry used 3.03 million tons of wet sludge as substitute fuel, representing 30% of Japan's total sludge discharge. And in 2007, 713,000 tons of sludge was disposed of by South Korea's cement industry.

(2) The rising trend of cement kiln municipal waste disposal in China

In the 1990s, extensive research work on cement kiln hazardous and municipal waste disposal began in China. In recent years, cement kiln municipal waste disposal has been actively trialed and significant achievements have been made in establishing a co-processing technical system. However, there is still a long way to go to catch up with the developed countries.

In 1998, Beijing Cement Plant began to use a 2000t/d cement clinker kiln to dispose of waste, with a special focus on the bio-safe disposal of hazardous waste from the petroleum, building materials, chemical, automobile, medicine, and metallurgy industries and laboratories. In 2005, a 3200t/d cement clinker production line was built specially to dispose of hazardous waste. In October 2009, a 500t/d sludge (containing 80%-85% of water) thermal drying pretreatment line was designed and built to dry the sludge for incineration in the cement clinker production line. It currently disposes of 400 tons of sludge per day.

Guangzhou New Cement Plant retrofitted a 6000t/d cement clinker production line to provide a 600t/d municipal sludge (80% water content) disposal program. Since it became operational in August 2009, the program has disposed more than 290,000 tons of municipal sludge in Guangzhou. This disposal system is reliable, easy to operate, and well-adapted to the sludge. When operating at its 600t/d designed capacity, the project can save about 13,600 tons of standard coal per year (which is equivalent to the emission reduction of 34,000 tons of $CO_2$) and save 5,000 tons of methane emissions from sludge landfill, (equivalent to 105,000 tons of $CO_2$ emissions).

Conch Group in An' hui Province, China, and Kawasaki in Japan jointly developed municipal waste disposal technology which incorporated a cement kiln and gasifier. A 600t/d municipal waste disposal program was built on Tongling Conch Cement's two 5000t/d cement clinker production line. The first phase entered into operation in April 2010, and it can dispose 230t/d of the municipal waste produced in Tongling.

Huaxin Cement invested 65 million RMB in a 500t/d municipal waste disposal line in its Wuxue Plant in Hubei Province. The disposal line began operating in April 2009. In July 2010, Huaxin Cement (Zigui) Limited Co. completed the construction of the Three Gorges Reservoir Region flotage disposal program with a designed capacity of 1000 $m^3$/d (or 300,000 $m^3$/a).

In addition to the companies mentioned above, Tianjin Cement Co., LTD., Qinghai Cement Co., LTD., Gansu Yongdeng Cement Co., LTD., Chongqing Lafarge Shui On (Chongqing Nanshan) Cement Co., LTD., Ningbo Fidelity Co., LTD., Jilin Yatai Cement Co., LTD and other companies successively obtained licenses for disposing of hazardous waste. They are using cement kilns to dispose of industrial toxic or hazardous waste, including sludge from the chemical, petrochemical, metal processing and electroplating industries, paint slag, waste tires, toxic soil, etc. at a relatively small scale which cannot fully demonstrate the potential of cement kiln waste disposal.

Attached Table 1

Figure 1 The comparison of waste disposal ways

| Mechanisms | Merits | Defects | Development Tendency |
|---|---|---|---|
| Sanitary Landfill | low short-run cost, simple, suitable for economically underdeveloped areas | occupy a lot of land, continuous investment in environmental protection, or it will cause severe contamination of soil and groundwater | still in the application, not suitable for developed areas without sufficient land resources |
| Biological Compost | relatively low cost, can be applied in agriculture | heavy metal pollution of soil and groundwater with misconduct, causes problems in food and environmental security | suitable for higher level of management in municipal waste, but has been weeded out gradually in developed countries |
| Direct Ignition | can reduce waste fast | relatively higher cost without using the waste heat fully, hard to handle the smoke pollution and fly ash | has been weeded out |
| Incineration Power Generation | use the heat while reducing waste | relatively higher investment, difficult to select sites and evaluate environment | key promotion in China |
| The Application Of Cement Kiln | fully harmless, recycling disposal | relatively higher investment to build new Cement Kiln | key promotion in China |

# 中国 CCUS 政策法规环境研究——现状与挑战

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二氧化碳捕集、利用与封存技术，作为一项新兴的 $CO_2$ 减排技术，迫切需要从法律与法规的角度对 CCUS 的法律地位、技术规范、减排效益评价等多方面进行明确和保障，从而加快其在全球范围内的认同、普及及其商业规模化的发展。

目前，欧盟、英国、美国等国家和地区均积极倡导 CCS 的制度化和规范化。欧盟 2007 年制定的 Directive/2009/31 是世界第一部关于 CCS 的详细立法；英国在两部能源法中均针对 CCS 作出了相应的规定；美国和澳大利亚也分别出台了《$CO_2$ 捕获、运输与封存指南》以规范 CCS 技术的实施。此外，国际能源署（IEA）制定的 CCS 技术路线图中也强调了制定相关政策、法规和标准的重要性。

对于中国而言，虽然 CCUS 技术的起步较晚，但中国政府对其给予了高度的关注并采取了积极的态度。自 2006 年以来，颁布了多个技术政策文件，包括《国家中长期科学和技术发展规划纲要（2006-2020 年）》、《中国应对气候变化国家方案》、《中国应对气候变化科技专项行动》、《国家“十二五”科学和技术发展规划》等，均将 CCUS 列为重点发展的减缓气候变化技术，2013 年 2 月国家科技部还发布了《“十二五”国家碳捕集利用与封存科技发展专项规划》，积极引导 CCUS 技术的研发与示范。然而，与发达国家和地区相比，中国对 CCUS 的规范管理仍处于起步阶段，还面临着项目管辖权难以划分、项目所有权和责任归属难以界定、缺乏统一的技术标准和激励机制等多方面的挑战，无法为 CCUS 尽快进入商业阶段提供必要的政策法规保障。因此，研究适用于中国的 CCUS 专门性政策、法规成为一项紧迫的任务。

我们根据中国的实际情况，结合欧盟、英国等国家和地区的先进经验分析，建议中国 CCUS 的立法和政策应重点关注以下问题：

（1）明确 CCUS 项目的行政管辖权

CCUS 是一项大型、长期、对环境具有潜在影响的项目，国内能源、环保、国土资源等部门均有权提出对 CCUS 项目的管辖权，极有可能出现多头管理的情况，从而造成项目审批难度加大、审批时间增长、审批环节增加等现象。需要通过立法明确 CCUS 项目的管辖权，并建立完善的项目申请和核准制度，以规范 CCUS 项目的实施和运行。

（2）确定 CCUS 项目的所有权和封存责任

CCUS 项目的所有权和责任归属问题涉及对土地使用权的可能影响、贸易和物权法对所有权的先行规定、可能与已有法律产生冲突的问题等。此外，在中国还有可能出现因为投资经营主体不同而造成的对封存有关的所有权范围界定的不同。因此，需要通过专门立法或者修改现有相关法规明确 CCUS 项目的所有权和责任，并建立起完善的、具有可操作性的责任承担制度和事故响应制度。其中，特别需要建立 $CO_2$ 封存责任体系，明确为 $CO_2$ 泄漏风险负责任的法律主体。

（3）建立统一的技术标准

CCUS 项目的建设与运营涉及技术转化与应用、经济效益、环境影响、减排效益等多方面的内容，需要建立一系列 CCUS 技术实施和监测标准，并修订现有的多个领域（油气、矿产、环境与土地领域等）的法律来保证项目的技术可行性、安全性和合法性。考虑到不同领域的利益，标准的制定过程将十分艰难。

（4）构建 $CO_2$ 捕集和封存激励机制及财税政策

由于 CCUS 是单纯的 $CO_2$ 减排技术，无论是发达国家还是中国，发展 CCUS 都存在着巨大的资金缺口，特别是在前期的研发和示范阶段，如何设计和制定激励政策和机制，调动利益相关方的积极性，将直接决定 CCUS 技术发展和应用的前景，包括税收减免、补贴、财政支持、低息贷款等形式。

（5）建立有效的公众参与和公众认同机制

目前，由于 CCUS 所呈现出的种种风险，其社会接受程度往往降低，来自公众的阻力成为一些国家发展 CCUS 的主要障碍。因此，需要建立 CCUS 风险管理制度和公众宣传体系，增加 CCUS 项目的透明度，提高公众对 CCUS 项目的参与度和认同度，避免可能出现的来自公众的阻力。

# CCUS Legal and Regulatory Study in China: Status and Challenges

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Carbon Capture, Utilisation and Storage (CCUS) is regarded as one of the most important technological paths for the in-depth implementation of greenhouse gas emission reductions. As an emerging $CO_2$ emission reduction technology, there is an urgent need to identify, guarantee and evaluate the legal status, technical specification and reduction benefits of CCUS in order to accelerate its identification, popularity and commercial-scale development globally.

The EU, UK, and US etc. currently are actively advocating the institutionalization and standardization of CCS. The Directive/2009/31 enacted by the EU in 2007 is the first detailed legislation on CCS. The UK made the corresponding provisions relevant to CCS in both its energy bills. The US and Australia unveiled their $CO_2$ Capture Transport and Storage Guidances respectively to specify the implementation of CCS. In addition, the CCS technology roadmap formulated by the IEA also emphasized the importance of enacting relevant policies, laws, regulations and standards.

In China, CCUS technology started relatively late, but the Chinese Government now pays it close attention and is positive towards it. Since 2006, the Chinese Government has issued multiple technology and policy documents, including the National Medium and Long-term Science and Technology Development Plan Outline (2006-2020), China's National Program on Climate Change, China's Science and Technology Specific Project on Climate Change, and the National “Twelfth Five-year” Science and Technology Development Plan etc. All of these focus on CCUS for the development of climate change mitigation technology. In February

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2013 MOST also issued the National Carbon Capture Utilization and Storage Technology Development Special Planning document within the “Twelfth five-year” plan to positively guide the R&D and demonstration of CCUS. However, China's standardized management for CCUS projects is still in the start-up phase, and faces various difficult challenges such as the division of jurisdiction over projects, the definition and attribution of project ownership and responsibility, and the lack of unified technical standards and incentive mechanisms etc. In addition, compared to the position in developed countries, insufficient necessary security policies and regulations have yet been provided to allow CCUS to enter into the commercial phase. Consequently the need to research the specialized CCUS policies and regulations which suit China has become pressing.

Taking into account the situation in China, combined with the advanced experience from the EU, the UK and other countries, China's CCUS legislation and policy should focus on the following questions:

### (1) Define the Jurisdiction over the Project

CCUS is a large-scale, long-term project that has potential influence on the environment, domestic energy supply, and land and resources etc. Many ministries have the right to claim jurisdiction over CCUS projects, leading to the likelihood of multiple management, resulting in problems such as increased difficulty, time and process for project examination and approval. There is a need to clarify the jurisdiction of CCUS projects through legislation and to establish fit-for-purpose project application and approval systems to standardize the implementation and operation of CCUS projects.

### (2) Define the Ownership and Responsibility of CCUS Projects

The problems of attribution of ownership and responsibility of CCUS projects could possibly influence land use rights and trade, and create conflicts with existing rules and laws of property ownership. Moreover, because in China project investors and operators may be different, ownership provisions for storage sites may be complex. Consequently there is a need to pass special legislation, or modify existing relevant laws and regulations to identify the ownership and responsibility of CCUS projects, and build up relevant and operable responsibility and incident response systems. Particular attention should be paid on establishing a $CO_2$ storage liabilities regulatory framework.

### (3) Establish Unified Technical Standards

The construction and operation of CCUS projects involves various elements such as technical transformation and application, economic benefit, environmental influence, emission reduction benefits etc. There is a need to build up a series of implementation and monitoring standards for CCUS, and to modify multiple areas (oil and gas, minerals, environment and land areas etc.) within existing laws to ensure the technical feasibility, security and legality of projects. Given the interests of different areas, the process of enacting the standards will be very difficult.

### (4) To Establish Incentive Mechanisms and Finance and Taxation Policies

Because CCUS is a purely $CO_2$ emission reduction technology, there exists a huge funding gap both in developed countries and in China to develop CCUS, especially at the early R&D and demonstration stages. How to design and formulate incentive policies and mechanisms and arouse the enthusiasm of stakeholders will decide directly the prospect of development and application of CCUS, including the forms of tax deduction and exemption, subsidies, financial support, low interest rate loans etc.

### (5) To Build up Effective Public Engagement and Public Acceptance Mechanisms

At present, because CCUS presents all kinds of risks, its level of social acceptance is usually very low, and resistance from the public could become the key barrier for some countries to develop CCUS. Hence, there is a need to build up a risk management and public information system for CCUS, to increase the transparency of CCUS projects, to improve public participation and acceptance for CCUS projects, and to avoid possible resistance from the public.

# 发展碳捕集，利用，与封存对广东的产业机会（上）[1]

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“碳捕集，利用，与封存（CCUS）会给传统化石能源行业，制造业，建造业，工程服务业和金融行业等产业带来显著的发展机会。尽管全球 CCUS 市场还没到达迅速增长阶段，但如果现在不及早准备逐步推动示范项目和相关产业发展的政策，将会失去发展 CCUS 相关产业和进入其供应链的机会。另一方面，发展 CCUS 产业不能‘守株待兔’等待市场的到了身边才行动’，大部分 CCUS 的相关技术和装备都在现有能源行业等非 CCUS 领域有广泛应用和市场。中国广东省有不少成功的装备制造和能源服务企业，相信他们能够与国内外企业合作为 CCUS 产业发展和成本下降做出贡献。”

## 1. 碳捕集，利用，与封存的介绍

碳捕集，利用与封存（CCUS）包括三个主要部分：(a) 二氧化碳捕集；(b) 二氧化碳运输；(c) 二氧化碳利用或封存（如图 1–1 所示）。CCUS 是唯一一项能够从化石燃料大幅度减排温室气体的技术，预计会为应对全球气候变化事业做出显著贡献。根据国际能源署 2011 年蓝图情景预测，碳捕集与封存将在 2050 年前贡献 19% 的（在 1990 至 2050 年间）所需温室气体减排（如图 1–2 描绘）。

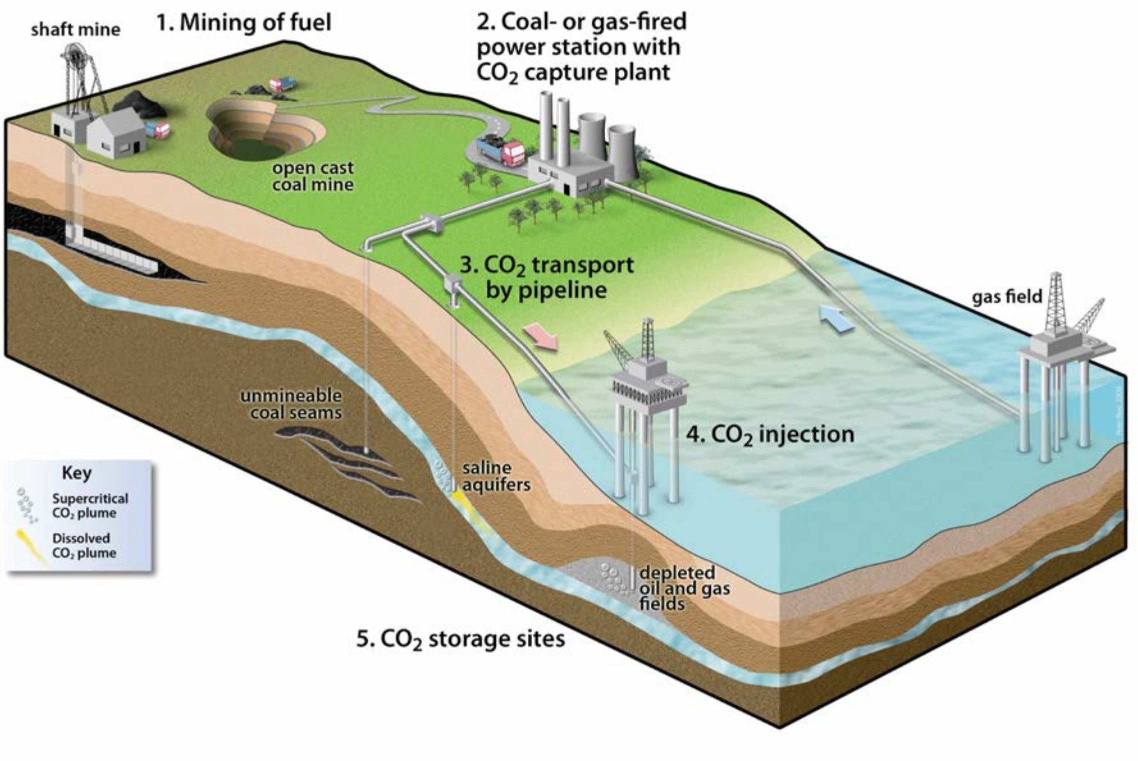

图 1–1 碳捕集与封存流程图（苏格兰 CCS 中心，2010）

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[1] The second part will be published in the next issue. 第二部分将在下一期出版

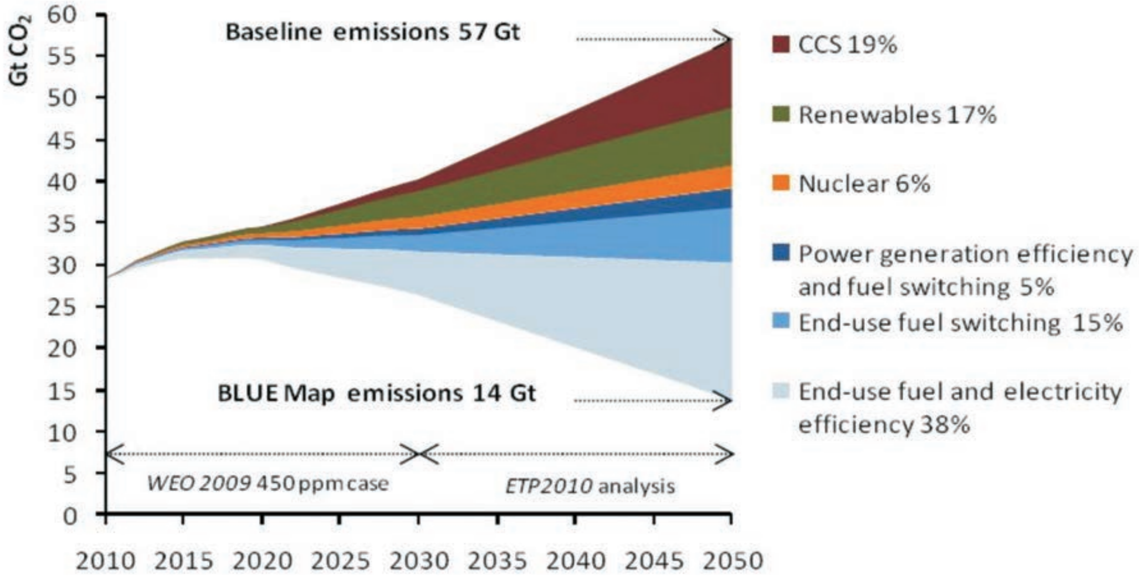

图 1–2 国际能源署 2011 年预测碳捕集与封存技术将为 2050 年前减排二氧化碳贡献 19%，从而实现蓝图情景

国际能源署温室气体中心（2012：1）预计全球 CCUS 项目将在 2030 年达到 850 个，并在 2050 年增长至 3400 个。如图 3–1 描绘，化工行业 CCUS 有较多低成本机会，将在 2020 年前成熟，而 2030 年大部分 CCUS 项目可能会位于发展中国家（国际能源总署，2013：22）。苏格兰 CCS 中心（2012：20）预测英国北海中部每年能够封存 5 亿吨二氧化碳，相当于欧盟在 2007 年 25% 的电厂及工业碳排放总量。

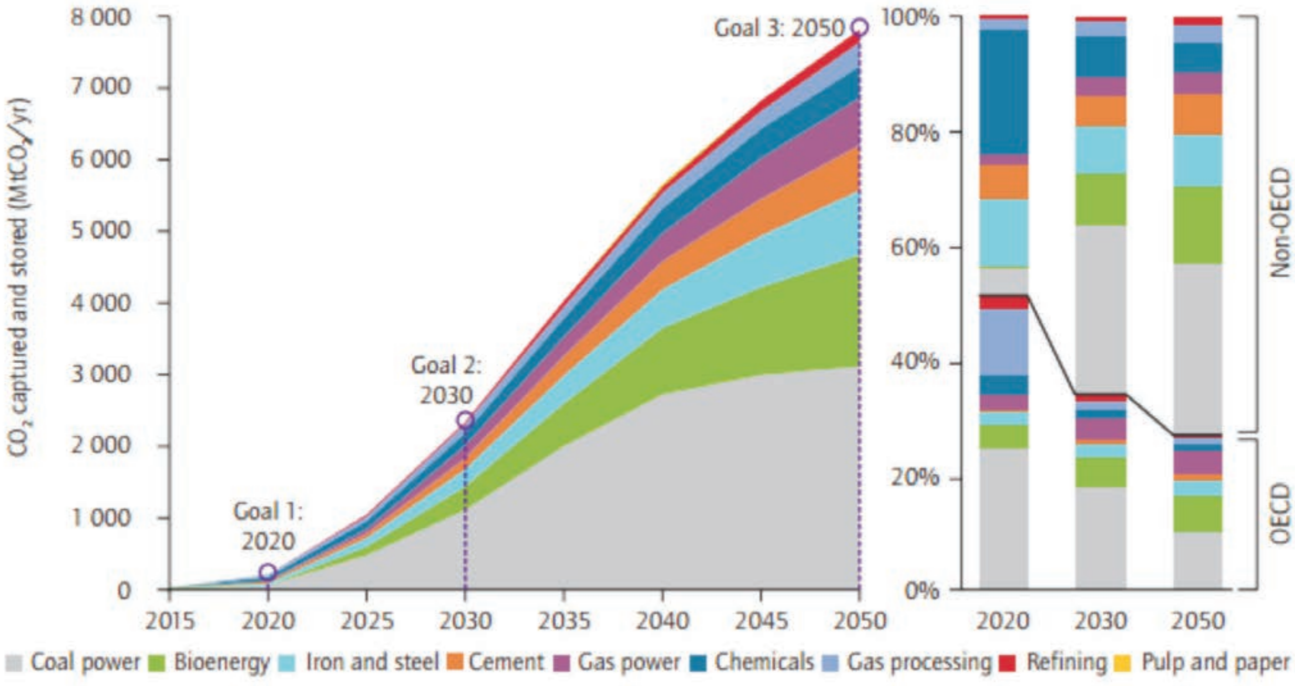

图 1–3 预计电力和工业行业内的 CCUS 活动（国际能源总署，2013：22）

## 2. 潜在 CCUS 供应链带来的商业机会

预计 2030 年前 CCUS 和相关清洁煤技术每年会为英国经济创造 20 至 40 亿英镑，和 7 万至 10 万个额外就业职位。

CCUS 供应链对与建设一体化 CCUS 项目非常重要 – 大型 CCUS 项目将会是非常复杂的和需要商业合作和合同关系（英国能源与气候变化部，2012: 5）。英国能源与气候变化部委托 AEAT 公司 (2012) 的一项研究预计 2030 年前 CCUS 和相关清洁煤技术每年会为英国经济创造 20 至 40 亿英镑，和 7 万至 10 万个额外就业职位。英国能源与气候变化部（2012：5）预计英国 CCS 商业化示范项目将带来 6 大行业机会：

（a）在建设阶段供应设备和提供服务

（b）在运营阶段持续地服务

（c）项目退役与拆除

（d）为其他国家提供装备和服务

（e）为其他国家提供英国大陆架的封存机会

（f）为其他国家提供项目退役和拆除服务

为了促进 CCS 技术的发展，英国政府拨款十亿英镑资本金（约一百亿人民币），以及额外的电力市场改革措施促进设计，建设和运行大规模 CCS 项目（英国能源与气候变化部，2013）。CCS 供应链（如图 1-4）涵盖石油与天然气行业，电力行业，基础设施发展和建设，金融服务行业，延伸至原材料供应。目前的研究显示，创造一个 CCS 产业将会对英国经济产生显著的积极影响（Senior CCS 咨询公司：2010; 苏格兰 CCS 中心，2012: 5）。

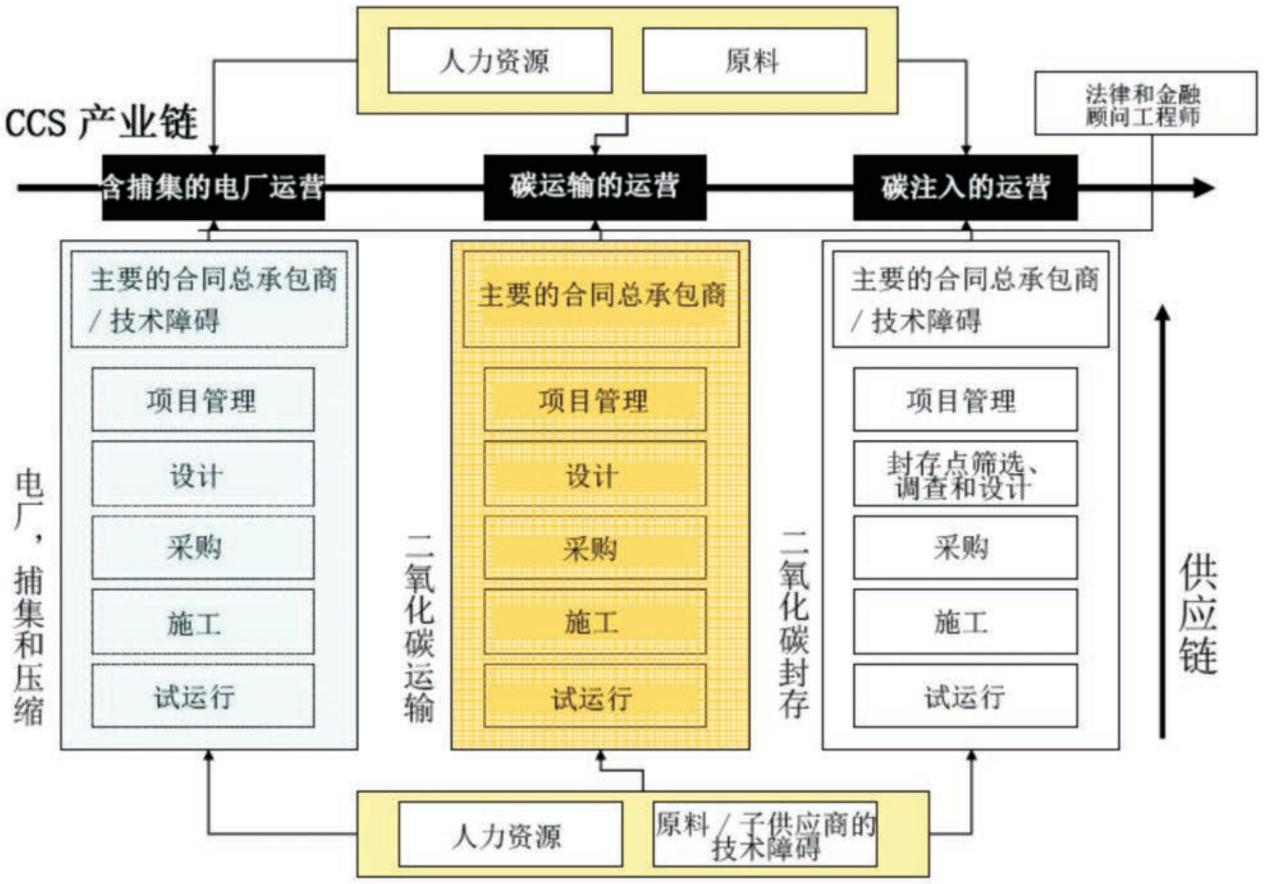

图 2-1 CCS 技术的供应链（国际能源总署温室气体中心，2012:4）

因为不同的技能，能力和商业模式，以及现有能源行业的结构，基础电厂和二氧化碳捕集模块通常在运输和封存部分之外，可能仅有少量大型能源公司可能有能力投资 CCUS 项目整个链条（例如壳牌集团）。二氧化碳运输和封存供应链预计与石油及天然气行业类似（Senior CCS 解决方案公司，2010: 8）。英国政府委托 Senior CCS 顾问公司（2010：8）的研究把英国二氧化碳运输和封存的产业链分成三部分：（a）运输和封存开发商；（b）主要的合同和顾问；（c）产品与服务供应商，子合同商和子供应商。这项研究提出了 CCUS 产业链在现有的石油及天然气行业基础上，衍生出 8 个新的领域（如表 2-1 所示）。

表 2-1 CO2 运输和封存环节为石油和天然气行业带来的新商业机会和技能需求

| 新的领域 | 潜在的商业活动 | CCUS 项目的生命周期阶段 | 潜在执行机构 |
|---|---|---|---|
| 封存地特性确认和模拟 | 提供封存地特性确认和模拟顾问 | 封存地开发 | 顾问公司，石油天然气公司，研究机构，和其他能源服务公司 |
| 检测技术 | 检测 $CO_2$ 在盆地的封存情况 | $CO_2$ 注入和注入后关闭环节 | 专业的能源服务公司 |
| $CO_2$ 井服务公司 | 为井监控和修复提供开发和执行系统 | 井开发和 $CO_2$ 注入 | 井服务公司 |
| 封存风险的评估 | 评估封存风险 | 从封存地开发的封存地关闭 | 顾问公司，油田和天然气公司，研究机构和其他能源服务公司 |
| 供应和分析井的材料 | 为开发和闭井提供材料 | 井开发，拆除和关闭 | 建设公司，工程顾问 |
| $CO_2$ 运输 | $CO_2$ 运输和管道开发，建设及运营 | 建设和 $CO_2$ 运输 | 管道建设商和运营商 |
| $CO_2$ 封存证书 / 认证 | 提供 $CO_2$ 封存活动的认证服务 | $CO_2$ 注入，闭井，闭井后服务 | 认证机构 |
| 金融机构和风险管理机构 | 提供融资，金融风险转移方案 | 项目全生命周期 | 银行，保险机构 |

如果 CCUS 沿着国际能源署 CCS 路线图的步伐发展（图 1-3），显著的装备和服务的机会将会出现。国际能源总署（2012：77-78）委托 Ecofys 公司研究列出了碳捕集过程内主要的装备需求（如图 2-2 所示）。

燃烧后捕集直接从化石燃料电厂，水泥厂，炼油厂，钢厂和其他工业排放源尾气分离 $CO_2$。燃烧后捕集包括四大主要的过程：（a）尾气预处理（包括深度的脱硫和脱硝）；（b）$CO_2$ 吸收；（c）$CO_2$ 解析；（d）$CO_2$ 加压。

脱硫和脱硝是成熟和商业运行的过程。中国和欧洲均有一些燃烧后捕集吸收和解析的中试装置但还没有大型，全规模运行的吸收塔，除了在建的加拿大 Sask 电力边界大坝项目。溶液市场由能耗和环境表现驱动，通常受专利保护。最终，很可能少量企业拥有的具有成本效益的先进溶液占领显著的全球市场份额。压缩系统的技术是成熟的，但很少供应商能够生产高压设备（IEA GHG, 2012: 22）而且杂质对压缩系统的影响会为设备运行带来挑战。

在燃烧前捕集过程，$CO_2$ 从合成气中分离（通过‘转换’过程），$CO_2$ 在燃烧之前捕集。燃烧前捕集主要包括四大部分:

（a）空气分离装置；（b）气化炉；（c）水煤气变换反应炉；（d）富氢燃气轮机。

大型空气分离装置的过程在工业上是成熟的，因为空分在钢铁，空气处理，化工 / 炼油，以及煤制油等领域已经得到广泛应用。全球主要有少数几家企业供应大型空分装置，例如 Air Product, Linde, Air Liquide, BOC, 和 Praxair. 中国在气化炉上需求很大，但目前气化炉的制造能力还比较有限。水煤气变换反应是一个成熟的过程，在煤化工行业有广泛应用，其核心技术是催化剂。富氢气轮机目前还不成熟，只有少数几家潜在供应商，如通用电气，西门子和阿尔斯通。

表 2-2 电厂碳捕集环节的主要设备需求（根据国际能源总署， 2012：77-78 基础上更新和修改）

| 捕集技术 | 捕集步骤 | 设备名称 | 技术状况 |
|---|---|---|---|
| 燃烧后 | 脱硫 | 吸收塔及换热器 | 成熟 |
|  | 脱硝 | 催化剂 | 成熟，但未来可能缺乏部分所需矿物 |
|  | 吸收 | 直冷换热设备的泵 | 成熟 |
|  |  | 烟气冷却室 | 成熟 |
|  |  | 胺溶液的泵 | 成熟 |
|  |  | 吸收塔 | 未成熟，在示范阶段 |
|  |  | 热交换器 | 成熟 |
|  |  | 氨吸收剂 | 未成熟，在示范阶段 |
|  | 吸附 | 固体吸附剂 | 未成熟 |
|  | 解析 | 解析塔 | 成熟 |
|  | 二氧化碳捕集 | 滤网 | 成熟 |
|  | 二氧化碳压缩设备 | 多级压缩器 | 成熟，但需要再考虑杂质 |
|  |  | 热交换器器 | 成熟 |
|  |  | 脱水设备 | 成熟 |
|  |  | 二氧化碳泵 | 成熟 |
| 燃烧前 | 空分设备 | 热交换器器 | 成熟 |
|  |  | 升压压缩机 | 成熟 |
|  | 气化 | 气化炉 | 成熟 |
|  | 气化 | 进料装置 | 未成熟，在示范阶段 |
|  | 气化 | 合成气滤网 | 成熟 |
|  | 变换 | 水煤气转换 | 成熟 |
|  | 合成气处理 | 催化剂 | 未成熟，在示范阶段 |
|  | 二氧化碳压缩设备 | 二氧化碳压缩机 | 成熟 |
|  | 脱硫 | 脱硫装置 | 成熟 |
|  | 燃烧 | 氢气轮机 | 未成熟 |
| 富氧燃烧 | 空分设备 | 热交换器器 | 成熟 |
|  |  | 升压压缩机 | 成熟 |
|  | 二氧化碳压缩纯化设备 | 二氧化碳压缩机 | 成熟 |
|  | 燃烧 | 余热蒸汽发生器 | 成熟 |
|  |  | （过热器 / 热交换器） |  |
|  |  | 锅炉 / 燃烧器 / 燃烧室 | 未成熟 |
|  |  | 酸冷凝器 | 未成熟 |
|  |  | 汽轮机 | 未成熟 |
|  |  | 蒸汽透平冷凝器 | 成熟 |
|  |  | 燃气轮机 | 未成熟 |
|  |  | 对富氧燃烧的先进气体处理设备 | 未成熟 |

富氧燃烧过程包括四个主要部分：（a）空气分离装置；（b）富氧锅炉；（c）先进的尾气处理装置；（d）压缩系统。在富氧燃烧过程，需要用空气分离装置取得高浓度二氧化碳（如 95% 以上），然后输入富氧锅炉。世界上有不少大型的富氧中试锅炉，如阿尔斯通在德国的实验基地和华中理工在武汉的富氧中试项目，但目前还没有大型全规模的富氧锅炉。煤炭与氧气及二氧化碳的混合气燃烧，如果氧气有较高的氧浓度，需要有更好的耐热材料来建造锅炉，而热交换系统和燃

烧系统也与传统锅炉不一样，来应付回流尾气可能带来的腐蚀作用。另一方面，先进的尾气处理系统需要减少碳氧化物，氧化硫，和氩气等杂质的影响，从而保证加压和运输过程。目前，富氧燃烧输出尾气处理，还没有成熟的市场，但一些大型气体处理公司正在积极开发现有的尾气处理项目（国际能源总署温室气体中心，2012：26）。开发先进的尾气处理装置需要取决于运输和封存对 $CO_2$ 气体质量的监管。

除了装备制造，创新也是开发高附加值 CCUS 产业的核心部分。大部分主要的 CCUS 知识产权由几家大的高碳企业控制，通常分布在化工，肥料，和提高石油采收率等产业（Chatham House, 2009: viii）。英国皇家国际事务研究所 (2009: 39) 统计了 20 大 CCUS 系统的专利持有机构，当中包括石油与天然气公司，设备制造上，化工企业，和专门的服务供应商( 图 3–2）。$CO_2$ 分离相关专利的申报在 1998 年后迅速上升，特别是在吸附剂和薄膜等先进技术领域。

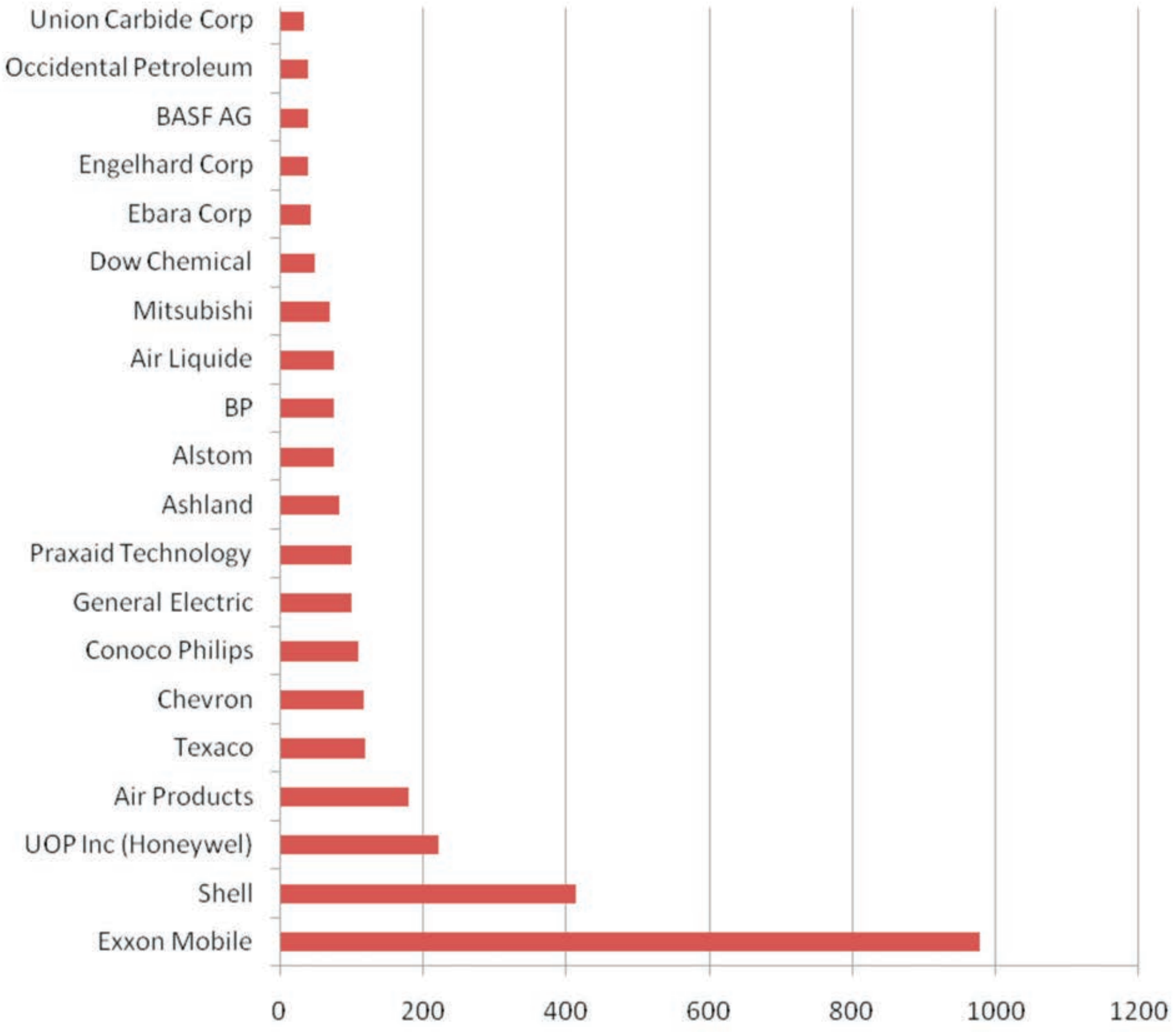

图 3–2 主要二氧化碳专利持有公司所持的专利数（英国皇家国际事务研究所 , 2009: 39)

目前还很难预计，CCUS 供应链什么时候会变得健全和成熟，并且在什么时候会开始进入快速的成本下降过程并为这一技术带来益处。但根据过去脱硫产业的经验，1970 年代，脱硫技术已经得到示范，但仍然存在很多技术和成本障碍，但没有妨碍其产业链随后 40 年的迅速发展。随着英国，德国和美国相关监管制度的健全，脱硫技术和产业链在 80 年代和 90 年代迅速发展，并在最近 15 年在中国得以广泛应用，成本大幅度下降。

## 3. 对广东低碳化转型和产业发展带来的机会

> 化石能源的储备将在不久的将来面临两个选项：留在地底下或者执行 CCUS 技术。

为了防止气候变化带来危险的海平面上升，热浪，干旱等灾难，稳定气温上升在 2 摄氏度内是国际上认可的目标，同时也被联合国气候变化委员会专家确认，作为全球的碳预算。联合国气候变化委员会（IPCC）第五份评估报告要求全球温室气体排放不超过 1 万亿公吨，然而一半以上的温室气体已经被排放。为了实现这个目标，化石能源的储备只有两个选项：留在地底下或者执行 CCUS 技术。

中国是在全球应对气候变化工作上占有重要地位。中国从 2010 年开始低碳示范省份和城市规划。广东作为经济最发达的省份之一，在温室气体排放减排主动承担更大的责任，因此承诺了一个比全国温室气体减排的指标更高的减排量。在第十二个五年计划内，广东需要降底 14.8% 的二氧化硫和 16.9% 的氮氧化物排放量，并且减少 18% 的 GDP 能耗，和 19.5% 的单位 GDP 二氧化碳量，显著高于全国的平均目标。广东作为中国一个低碳试点省份，正在积极示范先进低碳技术和发展碳市场。

为了执行广东省的低碳战略，广东发展及改革委员会执行了一系列的战略，包括（a）启动一个十二五低碳规划，（b）制定温室气体清单，（c）成立省级低碳试点城市和低碳示范小区，以及（d）完成为碳排放试点的准备工作。此外，广东与先进经济体紧密联系，寻找低碳发展的机会，包括与英国在碳市场和碳捕集技术方面进行合作（英国下议院能源与气候变化委员会，2012: 11–13, 26–27）。

在 2012 年，中国进口了 2.89 亿吨煤，相当于 7% 的总消费量，而广东作为中国最大的煤炭进口省份，从海外市场进口了 6800 万吨煤，相当于广东 40% 的年度消耗量（广东省发改委，2013）。尽管广东在核电装机比其他省份明显要高（图 3–1），新的核电装机在广东的低碳战略有重要地位（Yet et al, 2011），火电依然贡献了广东 80% 的电力生产（国家统计局，2013）（表 3–1 列出部分火电运营企业）。如果煤炭能够实现近零排放，并清洁地转化为电能或天然气，将会在未来成为广东省的主要的能源来源。

除了环境保护和低碳发展，广东省政府把‘产业升级’作为一个重要的发展重点。在 2010 年广东制定了形成先进产业体系的计划（广东省政府，2010），其中一项目标将低碳作为一个战略的新型产业。为了执行产业升级发展计划，广东省制定了一个产业发展指引目录，计划开发了“500 强先进项目”的计划，涉及超过 1 万亿人民币的投资。其中，500 强项目内有大量项目属能源和环保领域。清洁煤（包括，碳捕集，封存与煤炭气化）在产业发展指引目录中被考虑为其中一个重要领域（广东省政府，2010）。

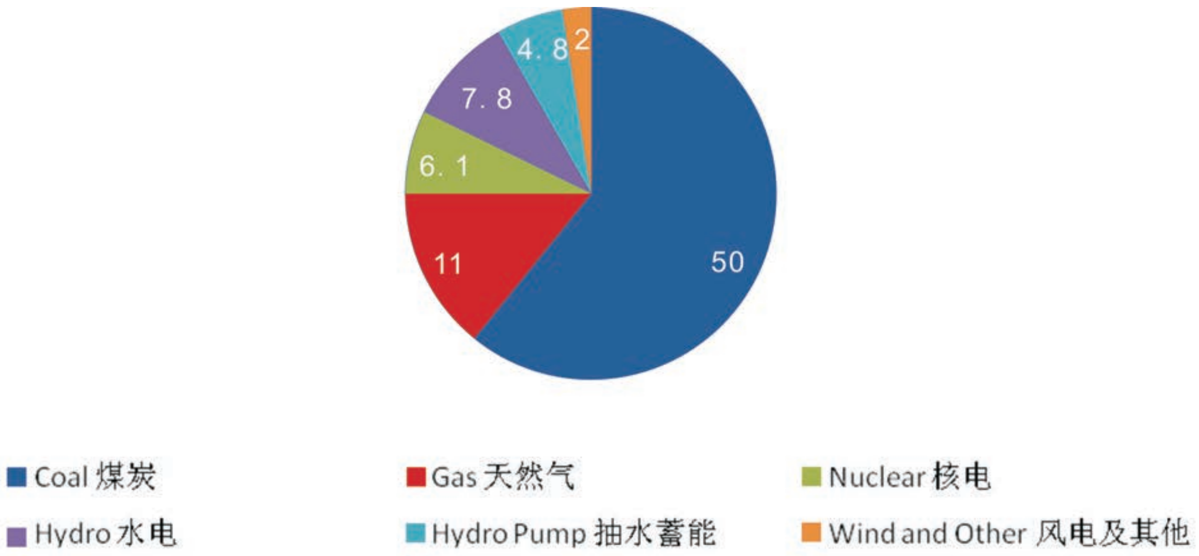

图 3–1 广东省 2012 年底发电装机容量结构（单位：GW，百万千瓦）

水泥与炼油行业在广东产业中占有重要地位。广东省有四个大型的石化基地：广州，惠州，湛江，茂名和揭阳，和大量的现代水泥生产线（如表 3-1 所示）。广东水泥和炼油厂，与电力行业和造纸行业已经被纳入碳排放交易试点体系内，面对减排二氧化碳和传统污染物的双重压力。

表 3-1 广东省内部分主要发电，炼油和水泥企业一览

| 企业名称 | 相关业务 | 生产基地或总部 |
|---|---|---|
| 中石化 | 炼油 | 广州，茂名，湛江 |
| 中石油 | 炼油 | 揭阳 |
| 中海油 | 炼油 | 惠州 |
| 华润水泥 | 水泥 | 罗定，阳春等 |
| 海螺水泥 | 水泥 | 英德，江门，佛山，清远 |
| 惠州罗佛山水泥集团 | 水泥 | 惠州 |
| 广东塔牌集团 | 水泥 | 惠州，梅州 |
| 广州越秀水泥 | 水泥 | 广州 |
| 惠州光大水泥 | 水泥 | 惠州 |
| 广东亨达利水泥 | 水泥 | 云浮 |
| 广英水泥 | 水泥 | 清远 |
| 英金水泥 | 水泥 | 英德 |
| 广州石井水泥 | 水泥 | 广州 |
| 英马水泥 | 水泥 | 英德 |
| 广东英德南山水泥厂 | 水泥 | 英德 |
| 粤电集团 | 发电 | 广州 |
| 深圳能源 | 发电 | 深圳 |
| 国华电力 | 发电 | 广州 |
| 华能集团广东分公司 | 发电 | 广州 |
| 珠江投资集团 | 发电 | 广州 |
| 华润电力 | 发电 | 深圳 |
| 广州发展集团 | 发电 | 广州 |
| 佛山公用事业控股 | 发电 | 佛山 |

因为 CCUS 行业仍处于发展初期，全球还没有形成 CCUS 的产业机会，但大量的制造企业可能参与到全球 CCUS 的供应链，如图 3-2 所示，部分广东企业可能为 CCUS 产业链作出贡献。下一期本栏将讨论广东省政府和企业应该如何发挥优势，与国内外企业合作，为产业发展和成本下降做出贡献。

图 3-2 广东省内可能对中国及全球 CCUS 产业链贡献的部分制造企业和设备供应商

| 企业 | 地点 | 潜在贡献 | 产业链环节 |
|---|---|---|---|
| 广州广重集团 | 广州 | 锅炉，压缩容器，背压式蒸汽轮机 | 捕集 |
| 东方电机（广州）重工 | 广州 | 蒸汽发生器，再热器，非能动热交换器 | 捕集 |
| 科达机电 | 佛山 | 循环硫化床，气化炉，锅炉，泵 | 捕集 |
| 豪顿华广州办事处 | 广州 | 供应压缩机，热交换器，引风机，鼓分机 | 捕集 |
| 梅塞尔工业气体公司 | 佛山 | 供应空气分离系统 | 捕集 |
| 中集安瑞科 | 深圳 | 热交换器，锅炉塔，气体压缩系统，气化炉制造，低温储运设备、石化装置工程总承包 | 捕集与运输 |
| 广州资源设备 | 广州 | 供应压缩机，鼓风机 | 捕集 |
| 广州维通工业气体 | 广州 | 空气分离，空气预热系统 | 捕集 |
| 中国能源建设广东电力设计研究院 | 广州 | 热电厂设计，总包 | 捕集 |
| 中国能源建设广东火电工程总公司 | 广州 | 热电厂设计，总包 | 捕集 |
| 中国能源建设集团广东省电力第一工程局 | 广州 | 热电厂建设，总包 | 捕集 |
| 广东天然气管网有限公司 | 广州 | $CO_2$ 管道开发和建设 | 运输 |
| 华南特种气体研究所有限公司 | 佛山 | 气体处理和加压站 | 运输 |
| 中海油能源发展（广州） | 广州 | 石油勘探与开发 | 运输与封存 |
| 中海油南海东部石油公司 | 深圳 | 石油开采和开发 | 运输及封存 |
| 深圳赤湾基地 | 深圳 | 海洋工程服务 | 运输及封存 |
| 中船广船国际 | 广州 | 海洋工程 | 封存 |
| 中船广州黄埔造船厂 | 广州 | 开井设备，封存项目总包 | 封存 |
| 中船澄西船舶修造公司 | 广州 | 海洋工程，油井开采船 | 封存 |
| 中远船务工程 | 广州及东莞 | 海洋工程，油井开采 | 封存 |
| 深圳远东石油钻采工程公司 | 深圳 | 油井开采 | 封存 |

参考文献祥见英文部分（65 页）

# Potential Economic Benefits of Developing a Carbon Capture, Utilisation and Storage (CCUS) Industry in Guangdong (Part I)

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> “Carbon Capture, Utilisation and Storage (CCUS) could bring in significant opportunities for energy, manufacturing, construction, engineering services, and financial service industries. The global CCUS market has not yet achieved a stage of rapid growth and therefore seizing the opportunities for industry will require early preparation of enabling policy frameworks and the development of CCUS demonstration projects. On the other hand, we cannot wait for this to happen before developing the CCUS industry and indeed most of the technology and equipment required already has applications in non-CCUS related industries.”

## 1.Introduction to Carbon Capture, Utilisation and Storage (CCUS)

Carbon Capture, Utilisation and Storage (CCUS) includes three components: (a) $CO_2$ Capture; (b) $CO_2$ Transport; (c) $CO_2$ storage and utilisation (Figure 1-1). CCUS is the only option to achieve a deep cut of greenhouse gas emission from fossil fuel, is estimated to make significant contribution to global climate change business. According to the International Energy Agency (IEA) 2011 blue map scenario, CCUS will contribute 19% of the required greenhouse gas mitigation effort from 1990 to 2050 (as illustrated in Figure 1-2).

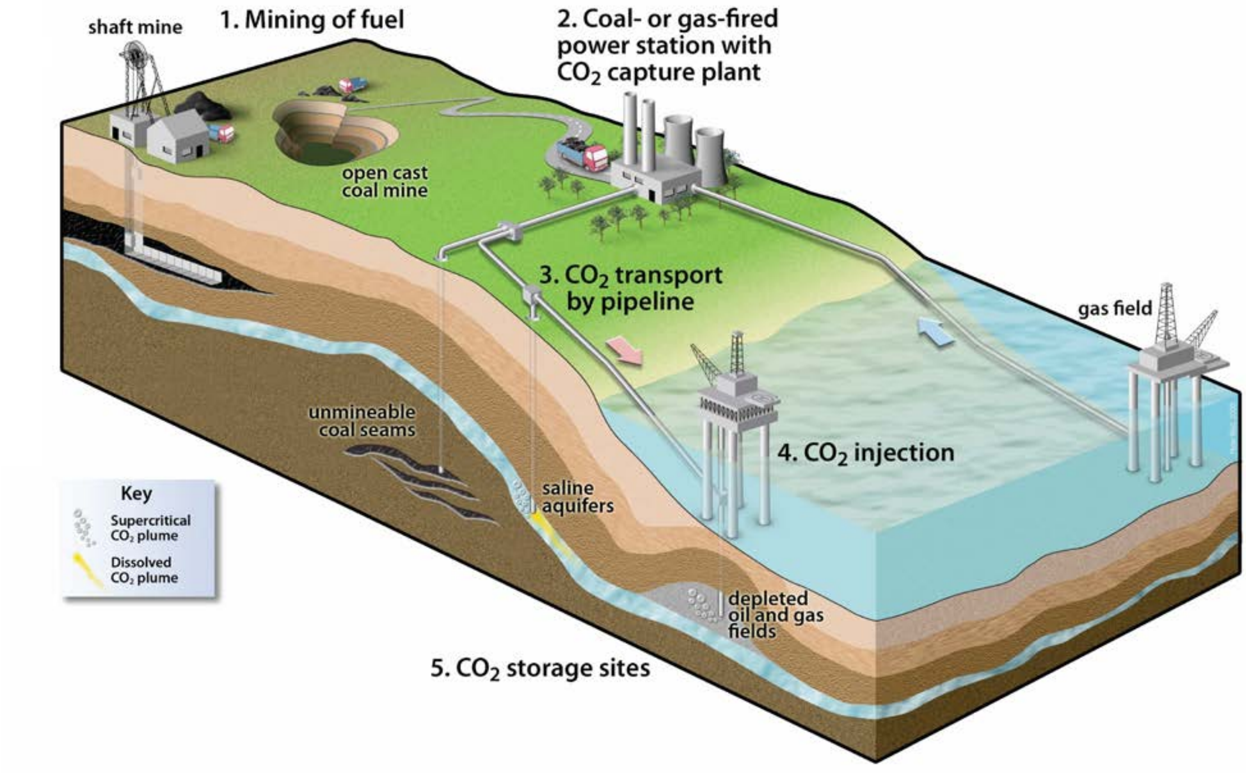

Figure 1-1 Schematic Diagram of Carbon Capture and Storage (SCCS, 2010)

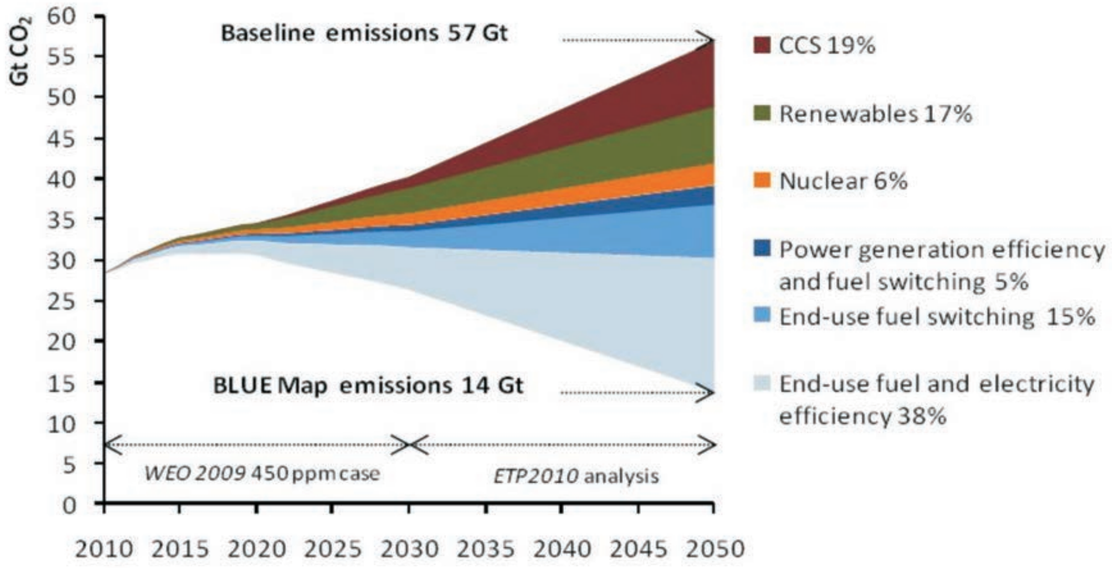

Figure 1–2 IEA (2011) Blue Map Scenario Projects that CCS can contribute 19% of the mitigation effort required to $CO_2$ in the atmosphere below 450ppm

The global CCUS market is estimated to achieve 850 installations by 2030 and 3400 installations by 2050 (IEA GHG, 2012: 1). Figure 1–3 below shows that in 2020 CCUS in the chemical industry will already be commercially viable due to a number of low cost opportunities and the size of the opportunity would be equivalent to that of the coal power industry. The figure also shows that the majority of CCUS projects are likely to be located in non–OECD countries by 2030 (IEA, 2013: 22).

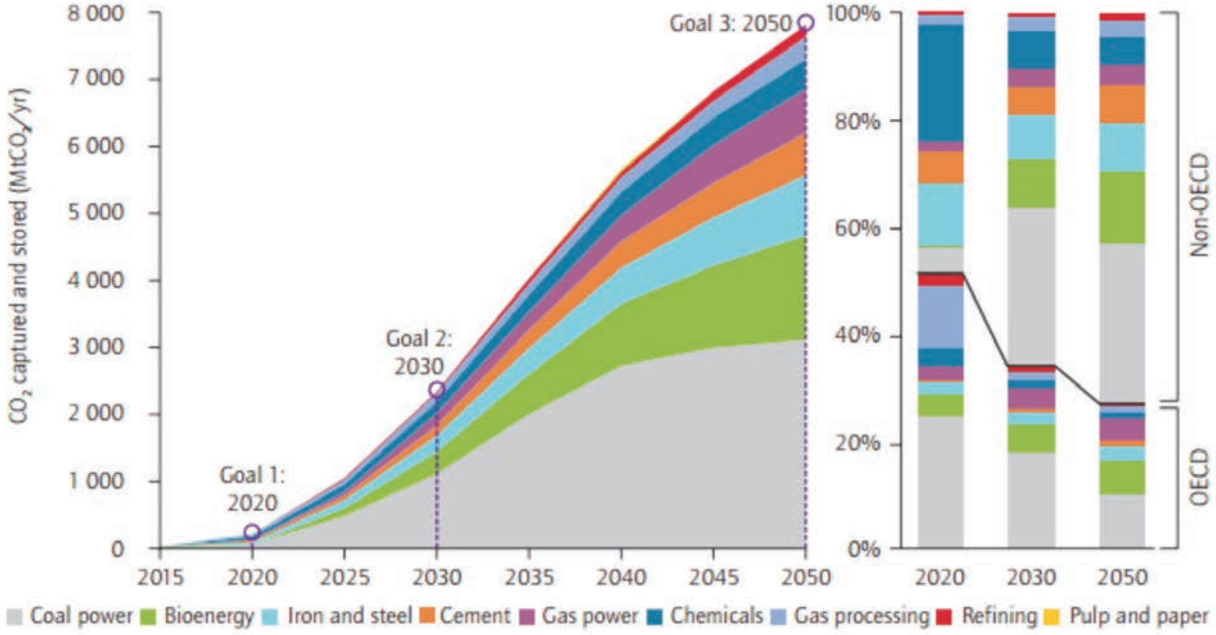

Figure 1–3 Estimated CCUS Activities in the Power and Industrial Sectors (IEA, 2013: 22)

## 2. Commercial Opportunities from a Potential CCUS Supply Chain

CCUS and related clean coal technologies will add £2 to 4 billion economic valueand 70,000 to 100,000 jobs to the UK economy each year by 2030.

For constructing integrated CCUS projects the supply chain is critical. Large–scale CCUS projects are complex and require a large number of business and contractual relationships (DECC, 2012: 5). There has been a great deal of work done in the UK to understand this and this work also serves as a good illustration for industry outside the UK. A study commissioned by the UK DECC and implemented by AEAT (2012) estimated that CCUS and related clean coal technologies would add ￡2 to 4 billion economic valueand 70,000 to 100,000 jobs to the UK economy each year by 2030. DECC (2012: 5) has also elaborated six specific areas of opportunity that would be brought about for UK businesses through the UK CCS Commercialisation Programme, including:

(a) Supply of equipment and services at the construction stage

(b) On–going services during operation

(c) Decommissioning

(d) Supply of equipment and services to other countries

(e) Supply of storage capacity to other countries on the UK Continental Shelf (UKCS)

(f) Providing decommissioning services to other countries

To accelerate the development of CCUS technologies, the UK Government allocated £1 billion capital funding with additional electricity market reform measures to support the design, construction and operation of large–scale CCS projects (DECC, 2013). The CCUS supply chain (Figure 1–4) covers the oil and gas, power generation, infrastructure development and construction, and financial service sectors. Existing studies found the creation of a CCUS industry would provide significant economic opportunities for the UK (SCCSL, 2010; SCCS, 2012: 5).

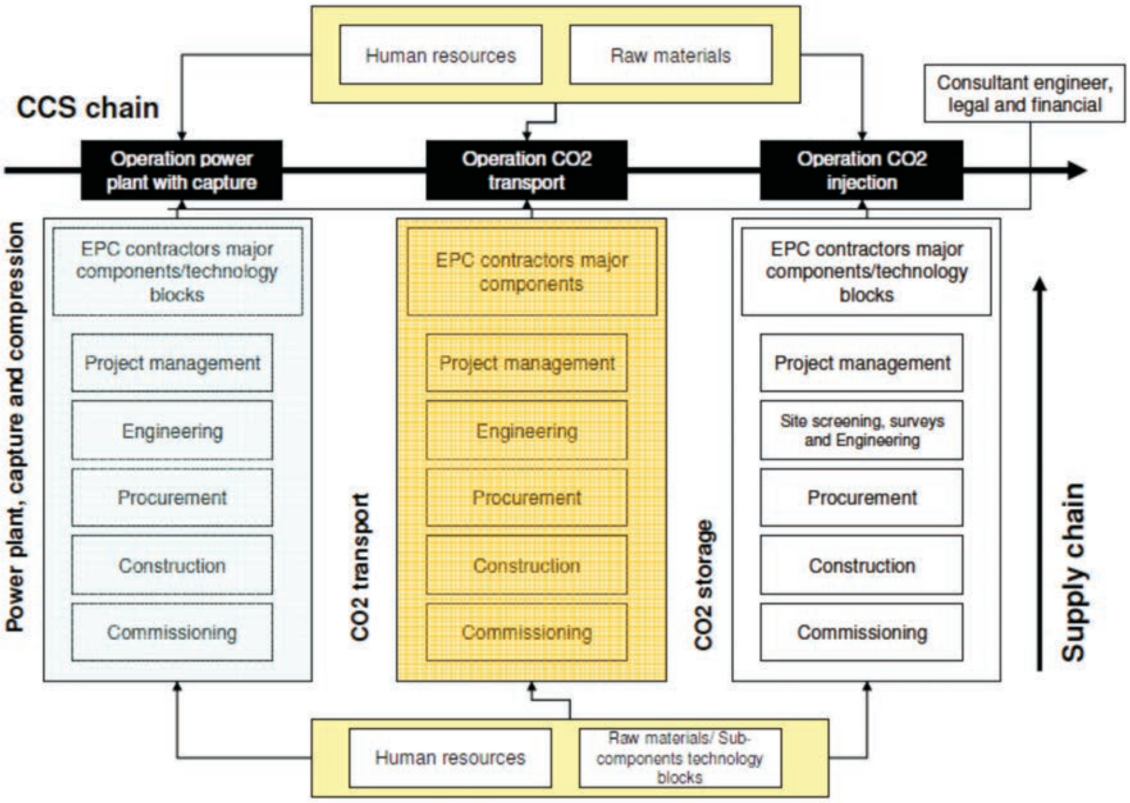

图 2–1 CCS 技术的供应链（IEA GHG, 2012:4）

Because the CCUS supply chain covers such diverse business specialisms (power plant operation and $CO_2$ capture, $CO_2$ transportation infrastructure and geological storage) with each requiring different skills, capabilities and business models, the components of the supply chain are generally separate businesses. The power plant/industrial facility is usually managed with the $CO_2$ capture component and separated from the $CO_2$ transport and storage. In some cases, the larger energy conglomerates may have the capacity to invest across the entire chain (such as Shell) (SCCSC, 2010: 3). The $CO_2$ transport and storage supply chain is expected to be similar to that of the oil and gas industry (SCCSC, 2010: 8). A study commissioned by DECC implemented by SCCSC (2010: 8) divided the potential UK $CO_2$ Transport and Storage Supply Chain into three different tiers: (a) Transport and Storage Developers; (b) Main Contractors and Consultants; (c) Product & Services Suppliers, Components Sub–contractors & Sub–suppliers. The study also identified eight new areas in the CCUS supply chain in addition to the current business models and technical capacity in the oil and gas sector (Table 2–1).

Table 2–1 New business activities and skills required in the $CO_2$ transport and storage chain compared to the oil and gas supply chain (modified based on SCCSC (2010: 9)

| Specific New Areas | Potential Business Activities | Lifecycle Stage of CCUS Projects | Possible Implementation Agencies |
|---|---|---|---|
| Site Characterisation and Modelling | Provide site characterisation and modelling consultancy | Site Development | Consultancy Firms, Oil and Gas Companies, Research Institutes and other energy service companies |
| Monitoring Technology | Monitor $CO_2$ storage in the reservoir | $CO_2$ Injection and post–closure | Specialised energy service companies |
| $CO_2$ Well Services | Develop and implement systems for well monitoring and remediation | Well Development, $CO_2$ Injection | Well Services Companies |
| Storage Risk Assessment | Evaluate storage risk | From site development to site closure | Consultancy Firms, Oil and Gas Companies, Research Institutes and other energy service companies |
| Supply and Analysis of Well Material | Provide material for development and closure | Well development Decommissioning and well closure | Construction Company; engineering consultant |
| $CO_2$ Transportation | $CO_2$ Shipping and Pipeline development, construction and operation | Construction and $CO_2$ Transportation | Pipeline Constructor and Operator |
| $CO_2$ storage certification | Provide verification services for $CO_2$ storage activities | $CO_2$ Injection, closure and post–closure | Classification Agency |
| Financing and Risk Management | Provide financing and financial risk transfer solutions | The whole lifecycle | Banks, Insurance firms |

If CCUS is deployed at the pace suggested by the IEA CCS roadmap (Figure 1-3), significant new business opportunities would arise. The IEA GHG (2012: 77-78) study by Ecofys listed the potential major equipment required in the capture process (Tables 2-2).

Post-combustion capture can be applied to separate $CO_2$ from flue gases from fossil fuel thermal power, cement, refinery and steel plants and other industrial installations. There are four major processes in post-combustion capture: (a) pre-treatment of flue gas (incl. deSOx and deNOx); (b) $CO_2$ absorber; (c) $CO_2$ Stripper; (d) $CO_2$ compression unit.

DeSOx and DeNOx are mature and commercially proven processes. There are pilot scale post-combustion $CO_2$ absorption and stripper towers installed in China and Europe but there is not yet a large scale $CO_2$ absorption tower installed in the world apart from the Sask Power Boundary Dam project in construction. The solvent market is highly driven by energy consumption and environmental performance, and usually shielded by patents. It is likely that a handful of the most cost-effective advanced solvents owned by a limited number of parties will capture a significant proportion of the global market. The compression unit technology is mature but very few suppliers can deliver high pressure units (IEA GHG, 2012: 22) and challenges exist in managing the impact of impurities on the compression equipment.

In pre-combustion capture $CO_2$ is separated (or "shifted") from syngas and the $CO_2$ is captured prior to the combustion process. There are four major components in the pre-combustion process: (a) air separation units; (b) gasifier; (c) water gas shift reactor; and (d) hydrogen rich gas turbine.

The air separation unit (ASU) process is mature in the industry as ASUs have been widely applied in iron and steel, gas processing, chemical/refinery and coal to liquid areas. Suppliers of large ASUs are concentrated around a few international key suppliers, such as Air Product, Linde, Air Liquide, BOC, and Praxair. China has the highest demand for gasifiers, but there is still limited capacity in gasifier manufacturing in China. The water gas shift reaction is a mature process in the coal-chemical industry and the core technology is the catalyst. The hydrogen rich gas turbine is a less mature component within the pre-combustion capture process, with only very few potential suppliers, such as GE, MHI, Siemens and Alstom.

Table 2-2 Major Equipment Required in the three Major Power Plant $CO_2$ Capture Process (updated and revised based on IEA GHG, 2012: 77-78)

| Capture Technology | Process Step | Equipment Name | Technology Status |
|---|---|---|---|
| Post-combustion | DeSOx | Absorber / Heat Exchanger | Mature |
| | DeNox | Catalysts | Mature but potentially lack of mineral resource |
| | Scrubber/absorber | Pumps for Direct Contact Coolers | Mature |
| | Scrubber/absorber | Flue Gas Cooler | Mature |
| | Scrubber/absorber | Amine Pumps | Mature |
| | Scrubber/absorber | Absorption Towers | Immature (Demonstration) |
| | Scrubber/absorber | Heat Exchangers | Mature |
| | Scrubber/absorber | Solvents(e.g. Amines) | Immature (Pilot and Demonstration) |
| | Adsorbtion | Solid Sorbent | Immature |
| | Stripper | Stripper | Mature |
| | $CO_2$ Capture - other | Filters | Mature |
| | $CO_2$ Compression | $CO_2$ Compressor (multistage) | Mature (but depend on impurities) |
| | $CO_2$ Compression | Heat Exchangers | Mature |
| | $CO_2$ Compression | Dehydration | Mature |
| | $CO_2$ Compression | $CO_2$ Pumps | Mature |

Table 2-2 Major Equipment Required in the three Major Power Plant $CO_2$ Capture Process (updated and revised based on IEA GHG, 2012: 77-78)

| Capture Technology | Process Step | Equipment Name | Technology Status |
|---|---|---|---|
| Pre-combustion | Air Separation Unit | Heat Exchanger | Mature |
| | Air Separation Unit | Booster Compressor | Mature |
| | Gasifier | Gasifier | Mature |
| | Gasifier | Feeding System | Immature |
| | Gasifier | Syngas Filters | Mature |
| | Shift | Water Shift Reactor | Mature |
| | Syngas Gas Treatment | Catalysts | Immature |
| | $CO_2$ Compression | $CO_2$ Compressor | Mature |
| | Sulphur Recovery | Sulphur Recovery Unit | Mature |
| | Conversion / Combustion | Hydrogen Rich Gas Turbine | Immature |
| Oxyfuel | Air Separation Unit | Heat Exchanger | Mature |
| | Air Separation Unit | Booster Compressor | Mature |
| | $CO_2$ Compression | $CO_2$ Compressor | Mature |
| | Combustion | Heat Recovery Steam Generator (superheater/heat exchangers) | Mature |
| | Combustion | Boiler/burner/combustor | Immature |
| | Combustion | Acid Condenser | Immature |
| | Combustion | Steam Turbines | Immature |
| | Combustion | Steam Condensor | |
| | Combustion | Gas Turbines | Immature |
| | Combustion | Advanced Fuel Gas Treatment Oxyfuel | Immature |

The oxyfuel combustion process includes four major components: (a) air separation unit; (b) oxyfuel boilers; (c) advanced flue gas treatment; and (d) compression unit. In the oxyfuel combustion process, high purity $O_2$ (e.g. 95% or above) needs to be separated by the air separation unit and then fed into the oxyfuel boiler. There are large pilot scale oxyfuel boilers in the world, such as Alstom and Huazhong University of Science and Technology pilot plant, but there is still no full-scale oxy-boiler. The higher oxygen content in combustion requires the use of high temperature resistant materials while the heat exchanger and burners need to be different from conventional boilers, in order to combat the corrosive impact of the higher percentage of recycled flue gas. The advanced flue gas treatment unit aims to reduce NOx, SOx and Ar impurity levels before compression and transportation. There are currently no mature markets for advanced flue gas treatment for oxyfuel, but a few large payers (such as Linde, Air Products, Doosan Babck, BOC) are actively developing processes building on their existing experiences in other flue gas treatment projects (IEA GHG, 2012: 26). The development of advanced flue gas treatment facilities also depends on the regulation of $CO_2$ gas quality for transportation and injection.

Apart from equipment supplies, innovation is a core element in developing a high-value added CCUS industry. A majority of key knowledge assets needed for CCUS are controlled by high-carbon companies, usually originated from applications in the petrochemical, fertilizer and enhanced oil-recovery (EOR) industries (Chatham House, 2009: viii). Chatham House (2009: 39) identifies 20 top patent holders in carbon capture and storage (CCS) systems, incl. oil and gas companies, equipment manufacturers, chemical companies, and specialised service providers (Figure 3-2). The rate of filing of $CO_2$ separation-related patents has risen rapidly since 1998 with a focus on sorbents and membranes.

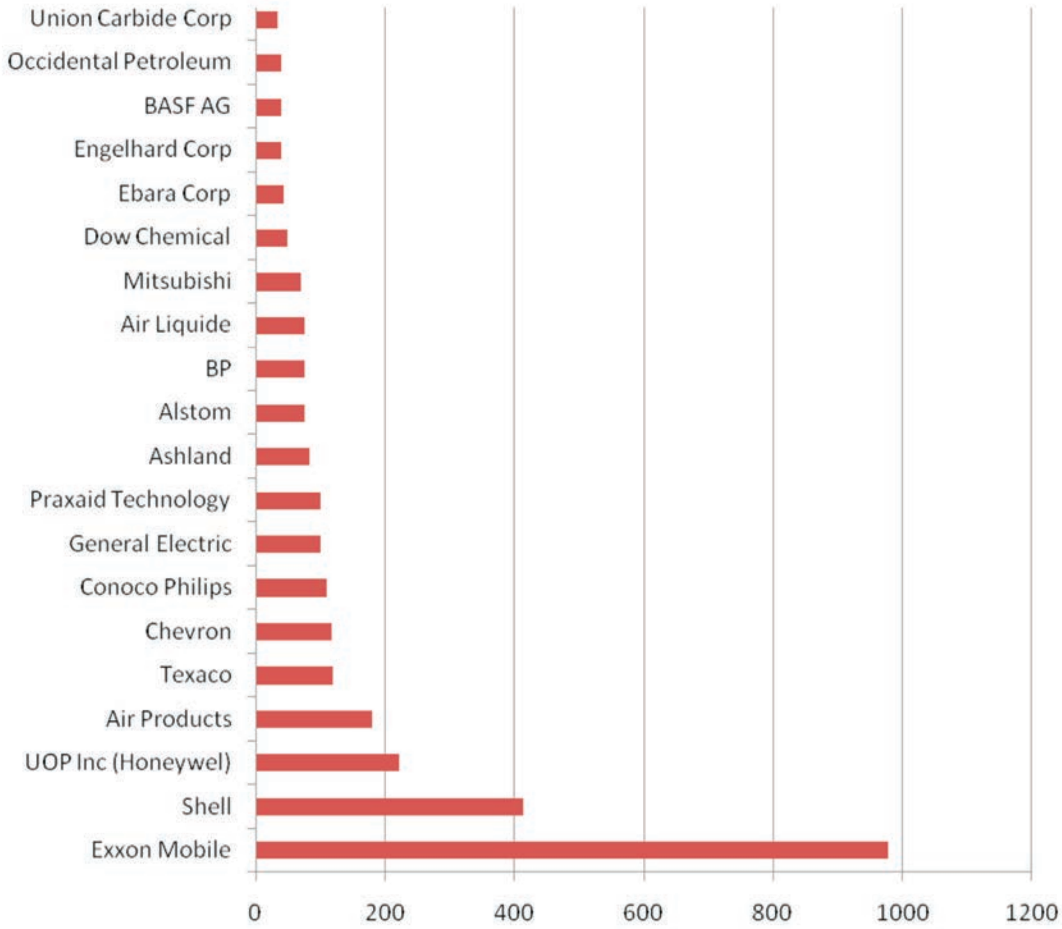

Figure 3-2 Top Patent Holders in Carbon Capture (Chatham House, 2009: 39)

It is hard to estimate when the CCUS supply chain will start to mature and the technology will benefit from the cost reduction process (i.e. learning by doing). However, according to the history of Flue Gas Desulphurisation (FGD), FGD technology was demonstrated in 1970s but is still facing many technical and cost barriers. Despite this, the development of a FGD supply chain hasn't been hindered in the last four decades. With FGD regulations in place in the UK, Germany and US, FGD technologies and supply chain were developed rapidly in the 1980s and 1990s, and the cost was further reduced significantly when it was applied in China in the last 15 years.

## 3. Opportunities for Guangdong in Decarbonisation and Industry

In order to the internationally agreed target, to contain global warming to within 2 degrees, known fossil fuel reserves will soon face only two options: either be left in the ground or they must be exploited alongside the implementation of CCUS.

The challenge to avoid dangerous climate change and to contain global warming to within 2 degrees, which is the internationally agreed target to avoid dangerous sea level rise, heatwaves, droughts and so on has for the first time ever been quantified by international scientists at the IPCC in terms of a global carbon budget. The IPCC Fifth Assessment report calls for global greenhouse gas emissions not to exceed 1000 Gigatonnes of carbon, more than half of which has already been emitted. In order to achieve this, known fossil fuel reserves must either be left in the ground or they must only be exploited alongside the implementation of CCUS.

China is central to global efforts to tackle the climate change challenge and has also sought to constrain the use of fossil fuels by introducing regional caps on the consumption of coal. The challenge for China will therefore be to constrain the use of coal and associated carbon emissions whilst at the same time continuing to promote growth across the economy. Again CCUS is a key technology that can support all of these objectives. China has already started to pilot low-carbon development at provincial and municipal levels from 2010. Guangdong, being one of the most developed provinces in China, has been shouldering a greater responsibility in greenhouse gas emissions reduction and therefore must meet higher standards than the national average. In the 12th Five-year Plan, Guangdong is required to reduce $SO_2$ by 14.8%, nitrogen oxides by 16.9% and to lower energy and $CO_2$ intensity by 18% and 19.5% respectively, significantly higher than the national targets[1]. Guangdong, as a low-carbon pilot province[2] in China, has been actively pioneering low-carbon technologies and a carbon market.

The Guangdong Development and Reform Commission (GD DRC) has implemented a number of provincial low carbon strategies, including (a) launching a low-carbon 12th FYP (twelfth five year plan, 2010-2015), (b) formulating a greenhouse gas inventory database, (c) establishing provincial low-carbon pilot cities and low carbon demonstration communities, and (d) completing the preparation for an emission trading pilot. In addition, Guangdong is closely collaborating with advanced economies to capture low-carbon development opportunities, for example, linking with the United Kingdom for capacity building in carbon markets and carbon capture, utilisation and storage (CCUS) (ECCC, 2012: 11-13, 26-27).

In 2012, China imported 289 million tonnes of coal, accounting for 7% of total consumption while Guangdong, as the largest coal importer in China, purchased 68 million tonne of coal from the overseas market, accounting for 40% of its annual consumption (GDDRC, 2013). Even though Guangdong has a relatively high nuclear capacity in China, the province's low carbon reduction goal (Ye et al, 2011) still hasthermal power contributing 80% of electricity production (NBSC, 2013) (Table 3-1 lists some major thermal power companies). Coal, if it can achieve near zero emissions through converting into gas and electricity via a clean pathway, will likely continue to be the backbone of the energy source in the Province in the near future.

Aside from environment protection and low carbon development, the Guangdong Provincial Government places ‘industry upgrade’ as a key development priority. In 2010, the Province formulated a development plan for establishing an advanced industry system (GD, 2010), with the aim of developing strategic emerging industries with particular attention towards a low-carbon industry. To implement the ‘industry upgrade’ development plan, the Province formulated an industry development guidance category and prioritised an implementation plan to develop the ‘top 500 projects of advanced industry’, with a total investment of over 1 trillion Yuan (approx. £100 billion sterling). Out of those projects in the energy sector, clean coal (incl. carbon capture and storage and coal gasification) is considered as one of the priority areas in the industry development category (GD, 2010).

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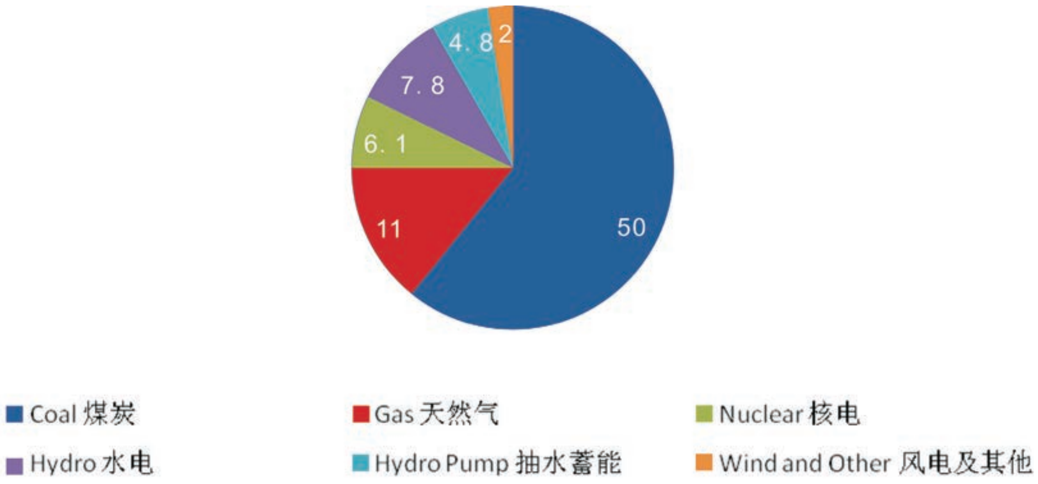
[1] The national target is 8% of reduction in $SO_2$, 10% of reduction of nitrogen oxides, 16% reduction of energy intensity, and 17% reduction of $CO_2$ intensity (per GDP).

[2] The first round of low carbon pilot provinces in China, launched in 2010, includes Guangdong, Liaoning, Hubei, Shaanxi and Yunnan.



The cement and refinery sectors also play an important role in the industry in Guangdong and all of which have associated opportunities in CCUS. Guangdong has five large refinery complexes with a total capacity of above 60 million tone per year: Guangzhou, Huizhou, Zhanjiang, Maoming and Jieyang and a large number of modern cement plants (Table 3-1). The cement and refinery plants in Guangdong are included in the pilot emission trading scheme, under pressure to reduce both carbon emissions and conventional pollutants.

Table 3-1: List of Major Refinery and Cement Companies in Guangdong and Estimated Carbon Emissions

| Company Name | Relevant Business | Plant Location or Company Headquarter (HQ) |
|---|---|---|
| SINOPEC | Refinery | Guangzhou, Maoming, Zhanjiang |
| CNPC | Refinery | Jieyang |
| CNOOC | Refinery | Huizhou |
| China Resources Cement | Cement | Luoding, Yangchun |
| Conch Cement | Cement | Yingde, Jiangmen, Foshan, Qingyuan |
| Huizhou Luofushan Cement Group | Cement | Huizhou |
| Guangdong Tapai Group | Cement | Huizhou, Meizhou |
| Guangzhou Yuexiu Cement | Cement | Guangzhou |
| Huizhou Guangda Cement | Cement | Huizhou |
| Guangdong Hengdali Cement | Cement | Yunfu |
| Guangying Cement | Cement | Qingyuan |
| Yingjin Cement | Cement | Yingde |
| Guangzhou Shijing Cement | Cement | Guangzhou |
| Yingma Cement | Cement | Yingde |
| Guangdong Yingde Nanshan Cement Plant | Cement | Yingde |
| Yudean Group | Power Generation | Guangzhou |
| Shenzhen Energy | Power Generation | Shenzhen |
| Guohua Power (Guangdong) | Power Generation | Guangzhou |
| Huaneng Group (Guangdong) | Power Generation | Guangzhou |
| Pearl River Investment | Power Generation | Guangzhou |
| China Resources Power | Power Generation | Shenzhen |
| Guangzhou Development Group | Power Generation | Guangzhou |
| Foshan Utilities Holding | Power Generation | Foshan |

Although there is not yet a manufacturing base for CCUS and CCUS is still at a very early stage, a large number of existing Guangdong enterprises have potential opportunities to join the global CCUS supply chain, as shown in Table 3-2. The next step is to discuss how the Government and industry in Guangdong can build on local advantages, collaborate with domestic and foreign companies, and contribute to the industry development and cost reduction of carbon capture, utilisation and storage in order to be able to take full advantage of the CCUS market as it evolves.

Table 3-2 Potential Manufacturers and Suppliers in Guangdong that May Contribute to the CCUS Supply Chain

| Company | Location | Potential Contribution | Chain Component |
|---|---|---|---|
| Guangzhou Guangzhong Enterprise Group Corp | Guangzhou | Boiler, pressurized vessels, back pressure steam turbine | Capture |
| Dongfang Electric (Guangzhou) Heavy Machinery | Guangzhou | Steam generator, reheater, residual heat exchanger | Capture |
| Keda Industrial | Foshan | Fluidized Bed Combustion, Gasification, Boiler, Pump | Capture |
| Howden Hua Guangzhou Office | Guangzhou | Supply Compressor, Heat Exchanger, ID and FD Fan | Capture |
| Messer Gas Company | Foshan | Air Separation Unit | Capture |
| CIMC Enric | Shenzhen | Heat exchanger, boiler tower, gas compressor, gasifier manufacturing, low temperature transport and storage equipment, chemical plant EPC | Capture & Transportation |
| Guangzhou Resource Equipment Complete Set Engineering | Guangzhou | Supply Compressor, FD Fan | Capture |
| Guangzhou Weiton Industrial Gas Technology | Guangzhou | Air Separation Unit, Air Pre-heater | Capture |
| Guangdong Electric Power Design Institute | Guangzhou | Thermal Power Plant Design, EPC | Capture |
| Guandgong Power Engineering Corp. | Guangzhou | Thermal Power Plant Design, EPC | Capture |
| Guangdong Electric Power First Engineering Bureau | Guangzhou | Thermal Power Plant Design, EPC | Capture |
| Guangdong Natural Gas Grid Company | Guangzhou | $CO_2$ Pipeline Development and Construction | Transportation |
| South China Special Gas Institute | Foshan | Gas Processing and Pipeline Substation | Transportation |
| CNOOC Energy Development (Guangzhou) | Guangzhou | Oil Exploration and Development | Transportation and Storage |
| CNOOC Nanhai East Oil Company | Shenzhen | Oil Exploration and Development | Transportation and Storage |
| Shenzhen Chiwan Base | Shenzhen | Offshore Engineering Service | Transportation and Storage |
| CSSC Guangzhou Shipyard International | Guangzhou | Offshore Engineering | Storage |
| CSSC Guangzhou Huangpu Shipbuilding | Guangzhou | Well Drilling Equipment, Storage Project EPC | Storage |
| CSSC Chengxi Shipyard | Guangzhou | Offshore Engineering, Well Drilling Ship | Storage |
| COSCO Shipyard Group | Guangzhou & Dongguan | Offshore Engineering, Well Drilling Ship | Storage |
| Shenzhen Far East Oil Drilling Engineering LTD | Shenzhen | Well Drilling | Storage |

## References （参考文献）

AEAT (AEA Technology plc，AEA技术公司), 2012. Assessing the Domestic Supply Chain Barriers to the Commercial Deployment of Carbon Capture and Storage within the Power Sector. https://www.gov.uk/government/publications/assessing-the-domestic-supply-chain-barriers-to-the-commercial-deployment-of-carbon-capture-and-storage-within-the-power-sector (accessed 20/Aug/2013)

DECC (UK Department of Energy and Climate Change，英国能源与气候变化部), 2010. UK Carbon Capture and Storage (CCS) Commercial Scale Demonstration Programme. Delivering Projects 2-4 (Further Information) https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/47995/1075-uk-ccs-commercialscale-demonstration-programme-fu.pdf

DECC (UK Department of Energy and Climate Change，英国能源与气候变化部), 2012. CCS Roadmap: Skills and supply chain. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48321/4903-ccs-roadmap--skills-and-supply-chain.pdf (accessed 5/Aug/2013)

DECC, (UK Department of Energy and Climate Change，英国能源与气候变化部), 2013. UK carbon capture and storage: government funding and support. https://www.gov.uk/uk-carbon-capture-and-storage-government-funding-and-support (accessed 4/Nov/2013)

ECCC (House of Commons Energy and Climate Change Committee, United Kingdom，英国下议院能源及气候变化委员会), 2012. Low-carbon Growth Links with China. http://www.publications.parliament.uk/pa/cm201213/cmselect/cmenergy/529/529.pdf (accessed 2/Nov/2013)

GD (People's Government of Guangdong Province, China，广东省人民政府), 2010. Notice of Planning for Guangdong Province Modern Industry System (广东省现代产业体系建设总体规划通知). GD [2010] 54 Document.

GDDRC (Guangdong Development and Reform Commission，广东省发展及改革委员会), 2013. Development Status: 2013. Chapter 3 Industrial Economics, Section 6 Energy Industry. http://www.gddpc.gov.cn/fzgk_3313/2013/201310/t20131031_226430.htm (accessed 7/Nov/2013)

IEA (国际能源总署), 2013. Technology Roadmap: Carbon Capture and Storage. http://www.iea.org/publications/freepublications/publication/TechnologyRoadmapCarbonCaptureandStorage.pdf (accessed 19/Nov/2013)

NBSC （National Bureau of Statistics of China，国家统计局），2013. Provincial Annual Data. http://data.stats.gov.cn/workspace/index?m=fsnd (accessed 2/Nov/2013)

SCCS (Scottish CCS，苏格兰CCS中心), 2012. Central North Sea – $CO_2$ Storage Hub: Enabling CCS Deployment in the UK and Europe.

SCCSL (Senior CCS Solutions Ltd，Senior CCS解决方案公司), 2010. $CO_2$ Storage in the UK – Industry Potential. Prepared for UK Department of Energy and Climate Change. http://www.ukccsrc.ac.uk/system/files/10D512.pdf (accessed 7/Sep/2013)

# 项目概览

## 1. 广东省 CCUS 可行性与发展路线图研究

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### 一、前言

碳捕集、利用与封存（Carbon Capture, utilization, and Storage，简称 CCUS）是一种将大规模点源排放的 $CO_2$ 捕集起来加以利用或永久封存到深部地层，以实现化石能源使用的大规模 $CO_2$ 减排的新兴技术（IPCC，2005），被认为是进行温室气体深度减排、实现全球 2050 年较 1990 年至少减排 50% 目标最重要的技术之一（IPCC，2007）。

为了分析广东省发展 CCUS 的可行性和前景，在英国外交及联邦事务部和澳大利亚全球碳捕集与封存研究院的资助下，由七个中英单位联合，于 2010 年 4 月至 2013 年 3 月开展了“广东省发展 CCUS 可行性研究”（GDCCUSR）项目。首个 CCUS 发展路线图建议。

### 二、广东省发展 CCUS 可行性研究的总体结论

CCUS 技术是广东省实现低碳发展的需要。对广东省能源结构和碳排放的研究表明，未来到 2030 年，在广东省能源消费结构中煤炭等化石能源仍将占据主导地位，燃煤火电产生的 $CO_2$ 排放也仍将是全省碳排放的主要来源。因此，未来广东省要想实现低碳发展必须充分考虑如何大力发展 CCUS 技术，只有这样才能在使用化石能源的同时也实现 $CO_2$ 的大量减排。对广东省水泥、石化、钢铁中的大型 $CO_2$ 排放源来说，也需要通过发展 CCUS 来实现深度减排。

CCUS 的成本竞争力将随着碳市场的发展而提高。预测在 2020 年以后，广东省发展 CCUS 等新型的减排技术的需求将大大增加。如从炼油厂的高浓度排放源捕集和利用枯竭油气田的设备进行封存的一些早期机会，可能会在随着碳市场的建立而开始具备成本竞争力。2030 年前后，碳减排目标趋于严格，国家有可能通过碳税或者碳交易等市场手段赋予碳减排合理的价格。我们对电力系统的技术经济模拟表明，在碳价达到每吨二氧化碳 200–350 元时，应用 CCUS 技术的燃煤发电（尤其是超超临界煤电 +CCUS）将具备成本竞争力，将开始进入商业化发展阶段。

广东省近海具有足够的 $CO_2$ 封存潜力。被捕集的 $CO_2$ 必须被永久安全地封存到地下深处才能发挥减排的效果。我们的评估表明，广东省陆上沉积盆地小、封存条件差，而且工农业发达、人口稠密，不利于 $CO_2$ 封存。但近海的珠江口盆地有巨大的 $CO_2$ 有效封存容量，仅水深小于 300 米区域的封存容量就足以封存广东省数百年大规模点源排放的 $CO_2$，而且封存地质条件良好。广东省的大规模 $CO_2$ 点源（燃煤电厂、石化和钢铁企业等）大多分布在沿海，与珠江口盆地内的潜在封存场地的距离在 120~300 公里之内，源汇匹配条件较好。因此，离岸地质封存将是广东省实现 $CO_2$ 封存的主要形式。

CCUS 会带来产业发展的机会。CCUS 已于 2013 年被国家发改委确

定为“战略性新兴产业”之一，它在捕集、运输和封存三个环节的工程化示范及商业化部署将带动一系列产业的发展，如装备制造、吸附剂化工、陆上和海底管线制造和铺设、海洋工程、以及相应的金融和服务产业等。

虽然数据表明能够被利用的 $CO_2$ 只占排放量的很小一部分（0.5~2%）(IPCC, 2005)，从经济效益的角度出发还是应该优先考虑对捕集的 $CO_2$ 进行利用。广东省的 $CO_2$ 资源化利用有以下有利方向：在海岸带发展养殖海藻炼油，发展多种 $CO_2$ 高效利用化工技术和产业，发展用 $CO_2$ 充注提高地热采收率等。

CCUS 的技术研发和政策环境建设需要从现在就开始。由于 CCUS 项目的技术链、产业价值链较长，需要在关键技术与装备、工程设计和施工、长期封存效果的验证、环境影响评估、风险防御和处理、运行与监管机制以及资金筹措等方面准备充分后方可大规模实施。因此，为了在 2030 年前后能够实现 CCUS 的商业化发展，广东省需要从现在就开始加强对 CCUS 的相关研发和政策环境建设，力争尽早将 CCUS 的发展计划纳入到省级低碳发展的措施和规划之中。

对新建燃煤电厂应该尽快实施 CCUS 预留（CCUSR）。CCUS 预留是一个设计概念，即将新建火电厂等高碳排放工业设施设计成将来一旦需要时便很容易被改造成有 CCUS 能力的方式。由于预测在 2030 年以后才会出现 CCUS 的大规模商业化运行，对 2030 年以前的新建燃煤电厂应该实行 CCUSR。本项目对广东一个超超临界粉煤电厂的模拟表明，CCUSR 能以很小建厂投入增量（< 0.5%）换取将来改装碳捕集时的成本的极大降低，更重要的是避免了碳锁定效应。

广东省开展 CCUS 的早期机会在石化行业高浓度 $CO_2$ 的捕集和离岸枯竭油气田的封存。

图 1　广东省 CCUS 发展路线图总图

石化行业制氢过程所产生的高浓度 $CO_2$ 将有利于实现低成本捕集。广东省石化工业发展很快，其目前的 $CO_2$ 排放占全省工业排放的 8%，预计到 2020 年将增加到 16%，居工业排放的首位，因此有很大的 $CO_2$ 捕集潜力。

广东省近海的珠江口盆地有一批已开采油气田，其中有些已临近枯竭。在油气采完以后其设备（平台、钻井、管线等）有可能被利用于进行 $CO_2$ 充注，从而降低 $CO_2$ 离岸封存的成本，同时也扩大了油气田的利用领域，延长了其利用时间，在实施碳价后还会产生一定的经济效益。

## 三、广东省发展 CCUS 路线图

广东省 CCUS 发展路线图的编制旨在为广东省从现在到 2030 年 CCUS 技术发展提供在技术和经济上可行的实施意见。该路线图包括一个总路线图（图 1）以及分别针对 $CO_2$ 捕集、运输、利用和封存各环节的子路线图。

总路线图主要时间节点如下：

● 2014 年前出台大型新建燃煤电厂的 CCUS 预留政策；

● 2015 年 CCUS 纳入广东省“十三五”低碳发展规划；

● 2025 年燃煤电厂全流程 CCUS 示范工程投入运行；

● 2030 年 CCUS 开始进入商业化规模；

● 从现在开始逐步建立 CCUS 发展所需的政策、法规和能力。

## 四、广东省发展 CCUS 的行动建议

1. $CO_2$ 捕集

（1）石化行业的高浓度 $CO_2$ 捕集：广东省开展 $CO_2$ 捕集的早期机会是石化工业的制氢过程所产生的高浓度 $CO_2$ 气体。应尽快开展化工行业所排放的高浓度 $CO_2$ 气体的资源调查、捕集技术优选和经济性评估，并开始 $CO_2$ 捕集示范项目的设计和建设，以保证 2020 年首个示范项目投入运营，2025 年开始建设规模化全流程 CCUS 项目。

（2）电力行业的 $CO_2$ 捕集：电力部门是广东省未来通过实施 CCUS 实现 $CO_2$ 深度减排的重点行业。研究表明超超临界发电 +CCUS 具有最大的成本优势，而燃烧后捕集技术是最适合广东省电力现状而因而应用范围较广的 $CO_2$ 捕集技术。由于捕集是 CCUS 链条中成本最高的环节，国内外在新型吸收剂、大型化和降能耗、降成本等方面已经开展了大量研发工作。广东省可将重点放在对最适于本省情况的捕集技术以及最能带来产业化前景的配套技术的选择和应用方面。到 2025 年形成电厂全流程 CCUS 示范项目，到 2030 年电厂 CCUS 项目达到初步商业化规模。

（3）新建电厂的 CCUS 预留设计：为了在 2030 年前后实现向 CCUS 大规模应用的低成本顺利过渡，并有效预防新建电厂的“碳锁定”效应，广东省应最晚在 2014 年出台大型新建燃煤电厂二氧化碳捕集与封存预留（CCUSR）的相关政策或法规，使 CCUSR 设计成为新建燃煤电厂获得政府批准的有利因素。到 2015 年完成一个 CCUSR 示范电厂的设计，并确保 2015 年以后所有新建燃煤电厂都实现 CCUSR。

（4）其他捕集技术的研发：广东省应发挥人才优势，通过低碳专项和科研基金等方式鼓励和支持目前尚处于研发阶段的电力部门以及水泥、钢铁等重点排放行业的 $CO_2$ 捕集技术的研发，争取有所创新和突破。

2. $CO_2$ 运输

（1）管道运输：管道运输是实现大规模和长时期 $CO_2$ 运输的有效方式。广东省应进行陆上和海域 $CO_2$ 运输网络的统一规划和优化设计，同时配合 CCUS 项目的进展开展与封存项目相匹配的管道建设，逐步形成能适应 CCUS 发展的陆上与离岸 $CO_2$ 运输管网。

（2）海洋船运：海洋船运是广东省 CCUS 早期示范阶段的可选 $CO_2$ 运输方式，需要以 LNG 运输船为参考来比较租船、改造和造船的各种方案。

3. $CO_2$ 封存和利用

（1）$CO_2$ 利用：应开展潜力调查，明确 $CO_2$ 的利用的重点行业和地区以及可利用的 $CO_2$ 总量，以指导 $CO_2$ 利用产业的发展，并有助于了解 $CO_2$ 地质封存的需求总量。应根据广东省的自然条件和产业优势，可重点进行 $CO_2$ 化工利用、养藻炼油等高效利用技术的研发，提高效率和降低成本。争取到 2020 年在技术研发上有所突破，到 2030 年形成 $CO_2$ 高效利用产业。

（2）离岸枯竭油气田 $CO_2$ 封存：离岸地质封存将是广东省实现 $CO_2$ 封存的主要形式，南海北部珠江口盆地有充足的封存潜力，但面临着海上工程成本高昂的主要障碍。因此，利用珠江口盆地枯竭油气田的设备以降低封存成本是 $CO_2$ 离岸地质封存的首选。当务之急是开展对近枯竭油气田的调查，选出在枯竭后其设备还可用于实施 $CO_2$ 封存的油气田。这项任务的完成必须比油气田枯竭超前若干年，以便有足够时间进行封存工程的设计和立项。

（3）离岸咸水层 $CO_2$ 封存：由于珠江口盆地内枯竭油气田的 $CO_2$ 地质封存容量有限，咸水层 $CO_2$ 封存将是将来 CCUS 规模化运营时的必

须选择。需要尽快开展珠江口盆地咸水层的潜在封存场地的普查，查明一批可达到商业规模封存能力的封存场地及其点群；在2015年开始对优选咸水层封存场地进行详查和评价；在2020年开始封存项目的设计和立项；在2025年开始封存项目的施工；到2030年基本满足本省化工行业和电力部门$CO_2$封存的需求。

## 五、广东省发展 CCUS 的政策建议

根据国内外经验，CCUS的发展一般经历两个阶段：第一阶段是研发和示范工程，主要依靠政府的资金投入和政策激励以及开展国际合作；第二阶段是大规模商业应用，主要依靠在成熟碳价系统基础上的市场机制运作。目前广东省CCUS发展处于第一阶段的初期，发挥政府的作用是关键性的。为此，应加强CCUS相关政策、法规的研究，设立专门的财政激励政策、技术标准政策、安全法规、金融机制等。

### 1. 广东省减排目标相关政策

广东省今后若干五年计划的碳强度下降目标和碳减排目标的确定以及重点耗能企业排放配额制度的建立，将对CCUS等新兴低碳技术的发展规划和部署起关键性的指导作用。应尽早将CCUS的发展计划纳入到省级低碳发展的规划和工作方案中。

### 2. 财政支持和激励政策

由于CCUS技术使煤成为能实现$CO_2$近零排放的清洁能源，应该对CCUS采取与其它清洁能源（如可再生能源、核能）类似的政策激励。特别在CCUS的研发和示范工程阶段，应加强政府对CCUSR的研发在立项和资金上的支持，以及对CCUS示范项目的财政支持，并制定减免税、低息贷款等财政激励政策，鼓励企业等利益相关者的资金投入。

### 3. 市场机制相关政策

广东省应借鉴他国经验教训，制定和不断完善碳排放交易或碳税、合同电价等已经在一些西方国家实行的制度，并根据本省的实际作出制度上的创新，使这些制度在CCUS的发展初期能起到促进作用，在成熟期能达到完全支持CCUS的商业化运行。

### 4. CCUS 预留的政策和标准

需要尽快（最晚2014年）制定新建燃煤电厂实施$CO_2$捕集、利用和封存预留（CCUSR）的激励政策，以避免“碳锁定”效应。

### 5. 技术相关政策和标准

需要依据国内外和本省的经验，制定CCUS工程及其各环节必须遵照执行的技术规范和标准，包括离岸封存的风险监测、控制和事故处理等，以保证CCUS工程的安全建设和运行。

### 6. 公众认知和能力建设相关政策和措施

需要采取措施鼓励有助于CCUS信息传播、知识普及、人才培养和能力建设的活动，如协会、网络、媒体宣传、定期或不定期的研讨会、学习班等，提高政府、企业、公众等利益相关方对CCUS的认知度与接受度。

### 7. 加强国内外合作和交流相关政策和措施

应制定政策和采取措施，鼓励国内外同行及利益相关者进行广泛的经验交流和技术合作，推动与发达国家和地区在CCUS研发、学术交流和技术引进等方面的合作，鼓励为广东省CCUS示范工程争取国际资助。

# 2. 百万千瓦超超临界机组碳捕集预留方案研究：华润海丰电厂案例分析

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**通过对华润海丰电 3 号、4 号 2×1000MW 机组二氧化碳捕集预留方案进行研究，广东省电力设计院与爱丁堡大学的研究团队在过去六个月的研究中，提出了二氧化碳捕集预留应考虑和关注的因素，以及对项目投资和发电厂系统性能的影响，给出了二氧化碳捕集装置工程投资及运行费用。二氧化碳捕集预留可以较低的成本有效减小新建电厂的“碳锁定”效应，让电厂在 25 年的设计生命周期具备二氧化碳捕集的选择权。广东省作为低碳试点省份，建议广东省政府应尽早并积极开展电厂二氧化碳捕集预留技术的示范和应用、制定新建电厂二氧化碳捕集预留的相关政策。**

## 前言

二氧化碳捕集和封存（简称 CCS）在未来 10 ~ 20 年内是最可能大大减少 $CO_2$ 排放有效和最具前景的技术。该技术的实施，有望实现化石能源使用的 $CO_2$ 近零排放，有效的降低 $CO_2$ 温室气体等的排放物的对人类的影响。 但由于目前 CCS 在技术、经济、政策法律、监管等诸多方面存在一定的障碍，还无法广泛地实现商业化大规模的发展，为避免新建电厂的“碳锁定”效应，减少现阶段未来实施 CCS 的成本和风险，CCS 预留（CCS Ready, CCSR）而得以应用来保持碳捕集与封存改装的选项开放。

为了分析广东省发展二氧化碳捕集和封存技术的可行性及前景，中国能源建设集团广东省电力设计研究院联合英国爱丁堡大学、中国科学院南海海洋所等单位于 2013 年 7 月开展了“广东省二氧化碳捕集预留方案研究”课题。我们依托华润海丰电厂 3、4 号燃煤机组（2×1000MW）进行了预留二氧化碳捕集装置的可行性研究，对电厂预留二氧化碳捕集装置方案的可行性、安全性、经济性和对机组性能影响等方面进行了分析和探讨，为中国燃煤火电厂未来实施二氧化碳捕集预留提供了有价值的参考技术路线。

## 一、华润海丰电厂情况简介

华润海丰电厂总规划容量为 4×1000MW+4×1000MW 机组，分期建设。一期 1、2 号机组为 2×1000 MW 超超临界燃煤发电机组，项目已于 2012 年 11 月开工建设，目前正在建设之中，两台机组计划于 2014 年 12 月前投产。一期 3、4 号机组亦采用 2×1000MW 超超临界燃煤发电机组，目前处于项目可行性研究阶段。本课题就是对 3 号、4 号 2×1000MW 机组二氧化碳捕集预留进行研究。

## 二、预留二氧化碳捕集工艺系统设计原则

1）二氧化碳捕集装置的处理容量

处理烟气量是单台 1000MW 机组锅炉最大负荷（BMCR）工况下 100%（干基）烟气量，烟气量为 3,252,839$Nm^3/h$（干态）；二氧化碳去除率为 90%；二氧化碳脱除能力为 791.5t/h，两台机组年二氧化碳捕集量约 1000 万吨。

2）采用燃烧后二氧化碳捕获技术，以乙醇胺（MEA）作为二氧化碳脱除系统的吸收剂；

3）配备烟气旁路系统；

4）预留的二氧化碳捕集系统年利用小时数按 6500h 考虑。

## 三、预留二氧化碳捕集装置需要关注的因素

### 1. 发电厂厂址选择

发电厂的厂址位置是确定选取何种二氧化碳捕集与封存技术的关键因素，在电厂厂址选择方面，预留二氧化碳捕集装置的发电厂除了需要考虑常规发电厂（未预留二氧化碳捕集装置）选址需要关注的问题外，还应该重点关注以下问题：

一是需要将电厂设置在与二氧化碳埋存点及其它的二氧化碳用户位置较近的区域；这将有利于运输并减少运输成本。

二是考虑设置在与其它现有或即

将建设碳捕集装置较近的位置；这样能共用二氧化碳输送管道，降低二氧化碳的运输费用。

与常规未预留二氧化碳捕集装置的燃煤电厂相比，预留碳捕集装置的燃煤电厂可行性研究中需要重点考虑如下因素。

1）二氧化碳运输问题。如何通过管道运输二氧化碳至埋存点，包括运输的安全性和共用二氧化碳管道（或）船舶运输到沿海地点的可行性。

2）与二氧化碳运输和胺溶液的处理相关的健康和安全问题。

华润海丰电厂位于广东省汕尾市海丰县小漠镇境内（如图一所示），为典型的滨海电厂，电厂面朝南海。根据有关研究显示南海北部珠江口盆地具有足够的二氧化碳封存潜力。海丰电厂距离此封存点位置不远，在二氧化碳捕集封存上有明显的地理优势。

图 1 华润海丰电厂地理位置

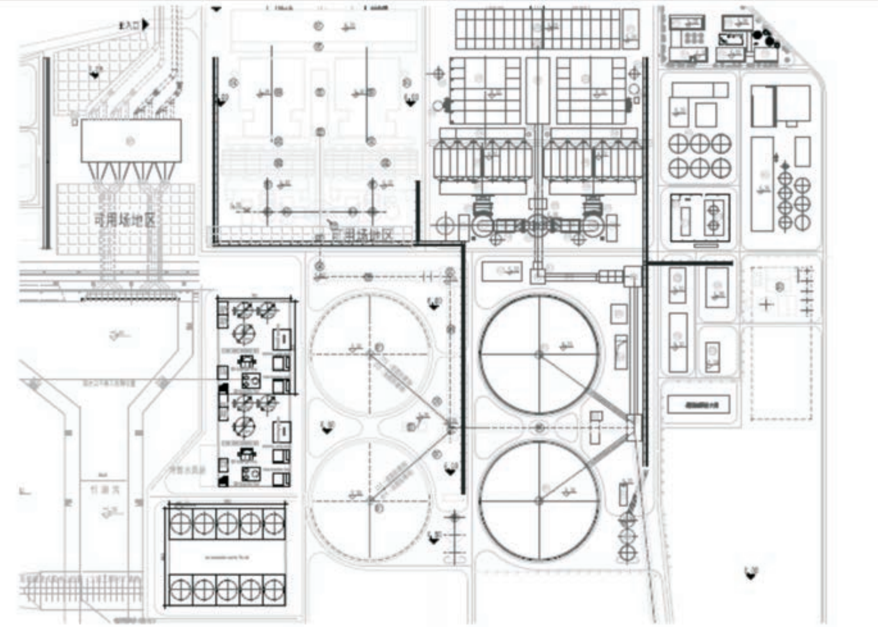

图 2　华润海丰电厂的布局图

2. 空间要求

需在电厂合适的位置对增加的二氧化碳预留装置进行配置，以便未来能安装二氧化碳捕集装置。此外，电厂内其它辅助系统也应该满足二氧化碳捕集装置的改造的空间和接口要求（如冷却水、辅助电力配置等等）。预留二氧化碳捕集装置的电厂需要考虑如下系统安装空间和位置。

二氧化碳捕集装置；

锅炉系统扩建和改建工程(例如，在引风机和胺溶液吸收塔之间安装烟道需要的空间）；

汽机系统扩建和改造工程（例如在汽机房中，需预留为安装大量供至胺溶液吸收塔的低压蒸汽管道所需要的空间）；

电厂辅助系统的扩展和加建，以满足未来安装二氧化碳捕集装置的相关要求；

为增加运输车辆留足空间（如考虑胺溶液的运输)；

需考虑二氧化碳捕集和处理的危险性与可操作性的空间管理要求。此外，还需考虑各个子系统与设备之间的安全间距要求。

华润海丰电厂 3、4 号机组已预留的二氧化碳捕集装置可分为两块区域：分别为吸收区域和加压区域。单套碳捕集装置的总占地 13000 $m^2$，其中 3 号机组吸收区域位于烟囱的南侧的空地上，面积约为 7000 $m^2$（东西长 87.5m，南北宽 80m）；4 号机组吸收区域位于 3 号机组吸收区域的南侧，面积与 3 号机组相当。两台机

组对应的加压区位于吸收区域的南侧，面积 12000 $m^2$( 东西长 100m，南北宽 120m )。随着二氧化碳捕集技术的不断发展，在下阶段项目真正实施时，二氧化碳捕集装置占地面积有可能随着技术的进步而大幅减少。

## 四、 预留二氧化碳捕集装置工程投资及运行费用预测

### 1. 工程投资

如表 1 所示，华润海丰电厂一期 3 号 1000MW 超超临界燃煤发电机组预计需要 0.7% 至 1.5% 额外资本开支来进行捕集预留投资。若应用目前最佳技术进行燃烧后捕集，改造工程，资本成本将会比原来不考虑上二氧化碳捕集装置的电厂建设投资增加约 26%-40% 左右，增加的资本投资中主要含有二氧化碳捕集装置安装费用及现有机组相关系统改造费用。

表 1 安装二氧化碳捕集装置对机组投资影响

| 项目 | 单位 | 不预留二氧化碳捕集装置的常规燃煤发电厂 | 预计捕集预留所需要投资 | 预留二氧化碳捕集装置燃煤发电厂改装投资 |
|---|---|---|---|---|
| 额外静态投资 | % | 基准 | 0.7% - 1.5% | +26%-40% |
| 单位造价 | 元 /kW | 3689 | 26 至 55 /kW | 959-1476 |

### 2. 运行成本

根据工程情况初步分析，华润海丰电厂一期 3 号、4 号 2×1000MW 超超临界燃煤发电机组的安装二氧化碳捕捉装置后，电厂脱除二氧化碳的运行成本约为 275 元 /t$CO_2$，该项费用包含了人力成本、管理成本、维护成本以及运行过程中厂用电、化学消耗品、污水处理等费用。

## 五、结论

由于目前燃煤火电厂燃烧后二氧化碳捕集技术仍处于中型试验和示范阶段，目前全球还没有百万机组容量的实际脱碳工程应用业绩，因此，本课题仅为理论上的初步研究成果，其目的是对未来大容量火电厂实施二氧化碳捕集预留方案的可行性进行了论证，并就其技术路线给出了参考性的建议。

以胺溶液为吸收剂的燃烧后捕集技术是目前火力发电厂最成熟的一种脱碳方案。但目前此技术还存在能耗高及一次性投资大等问题，需要在日后重点对新型吸收剂和大型化、低能耗等方面做进一步研究，也有价值研发出更先进的工艺和更科学的替代技术，实现二氧化碳捕集技术更加高效、环保和节能，同时投资和占地最少。

二氧化碳捕集预留可以较低的成本有效减小新建电厂的“碳锁定”效应，因此是实现二氧化碳捕集的平稳过渡，是低成本、无风险的技术和政策选择。广东省政府应积极开展电厂二氧化碳捕集预留技术的示范和应用，开发电厂二氧化碳捕集预留示范项目，并起草大型新建电厂二氧化碳捕集预留的相关政策。

作为 $CO_2$ 排放的大户，电力行业是未来实施二氧化碳捕集的重点。因此，广东省应尽快完成电厂燃烧后捕集技术示范项目的立项和设计，为我省火电厂二氧化碳捕集技术的大型化、工程化应用探索经验和奠定基础，推动我国在温室气体减排领域的技术进步。

下一期将讨论碳捕集改造的技术经济性和可能的改造技术发展。

# 1. CCUS Feasibility And a Development Roadmap For Guangdong

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## 1. Introduction

Carbon Capture, Utilization, and Storage (CCUS) is a technology to separate the $CO_2$ generated from energy and industry emission sources, and utilise or store it in deep geological formations in order to reduce emissions of $CO_2$ to atmosphere. It is one of the most important technologies to make a deeper cut in the greenhouse gas emissions from the use of fossil fuels and to achieve the global target of emission reduction of least 50% below 1990 levels by 2050 (IPCC, 2007).

In order to study the prospect and roadmap of developing CCUS in Guangdong Province, the project "Feasibility Study of Developing CCS-Readiness in Guangdong Province" (GDCCSR) was conducted from April 2010 to March 2013. The project was implemented by seven institutions in China and UK, and funded by the UK Government Foreign & Commonwealth Office and Global Carbon Capture and Storage Institute (GCCSI). This paper reports the key findings and the draft roadmap from the GDCCSR project.

## 2. Key findings on CCUS feasibility in Guangdong Province

### 2.1) CCUS is essential for the low-carbon development in Guangdong Province

Modelling based on the provincial energy structure and carbon emissions suggested that the dominance of fossil-fuelled energy in the Province will not change radically before 2030, and that $CO_2$ from coal-fired power stations will remain the largest source of greenhouse gas emissions. This determines that the application of CCUS would be necessary in order to achieve large-scale emission reductions. CCUS is also likely to be needed for deep cuts in $CO_2$ emissions from the large point sources in cement, petrochemical, and steel industries.

### 2.2) The cost-competitiveness of CCUS is growing with the development of a carbon market

After 2020, the demand for new carbon reduction techniques, including CCUS, will increase. The early opportunities for CCUS, such as $CO_2$ capture from hydrogen production and $CO_2$ storage using existing infrastructure in depleted oil and gas fields, might start to be cost competitive once a carbon market is in place. By 2030, carbon reduction targets are likely to be more rigorous, and the carbon price may reflect carbon taxes in the carbon market. Modelling of the power sector suggests that, when the carbon prices increase to the level of 200 to 350 RMB per tonne $CO_2$, CCUS in power generation, especially in ultra-supercritical pulverised coal-fired power plants (USCPC), will be cost competitive relative to conventional coal-fired power without CCUS.

### 2.3) Large $CO_2$ storage capacity exists offshore of Guangdong Province

$CO_2$ capture cannot materially reduce $CO_2$ emissions unless large quantities of the captured $CO_2$ are stored safely underground. Assessment shows that the onshore storage capacity is limited in Guangdong Province. The dense population and heavy land use make onshore $CO_2$ storage less attractive. However in the northern South China Sea offshore Guangdong Province there is very large effective $CO_2$ storage capacity, sufficient to store over one hundred years of the $CO_2$ emitted from the large point sources in Guangdong Province. As large point sources of $CO_2$ emissions (coal-fired power, petrochemical, and steel plants) in Guangdong are distributed mostly along the coast, the source-sink matching to the prospective offshore storage areas is within 120 to 300 km. Thus offshore underground $CO_2$ storage is the practical choice in Guangdong Province.

2.4) CCUS will bring business opportunities to Guangdong

In 2013, CCUS was listed as "emerging industries of strategic importance" by the State Council of China. The CCUS demonstration and commercialization in Guangdong will bring or accelerate the development of a number of industries, such as equipment manufacturing, chemical absorbents, onshore and offshore pipelines, marine engineering, as well as associated financial and other services.

Although data shows that the amount of $CO_2$ which can be utilised is only a small fraction of the total anthropogenic $CO_2$ emissions (IPCC, 2005), the utilisation of captured $CO_2$ should be considered as a priority from the economic perspective. In Guangdong Province the opportunities for $CO_2$ utilisation reside in a number of fields: the algae cultivation and algae-fuel production in the coastal zone, the $CO_2$ utilised by chemical industries, and the application of $CO_2$ enhanced geothermal recovery.

2.5) Technical research and policy building for CCS should start now

Because CCUS projects have long supply and value chains, significant lead time will be needed for developing large scale projects. In order to realize the commercialized operation of CCS by 2030, preparatory work, technical research and policy building for CCUS should start now. CCUS should be included as soon as possible in the low-carbon development plan of Guangdong Province, accompanied by necessary support measures, action plans, and incentive policies.

2.6) CCUS-ready for new coal-fired power plants should be introduced as soon as possible

CCUS-ready (or CCUSR) is the concept of designing a large-scale power or industrial facility so that it can be retrofitted with CCUS technology when the necessary regulatory and economic drivers are in place. As commercialized CCUS development is expected to start around 2030, before then all new coal-fired power plants should be designed to be CCUS-ready. Modelling of an ultra-supercritical pulverized coal power plant (USCPC) in Guangdong Province has indicated that a small incremental (i.e. 0.5 to 3%) capital investment in CCUSR can not only prevent the "carbon lock in" effect, but also bring a large saving in any future retrofitting of capture equipment. Thus CCUS-ready is a "no-regrets" policy choice to ensure a smooth and less-expensive transition toward CCUS-equipped fossil-fuelled plants.

2.7) Early opportunities of CCUS in Guangdong are provided by $CO_2$ capture in the petrochemical industry and storage in depleted offshore oil fields

The high-purity $CO_2$ flow produced from hydrogen production in the petrochemical industry will enable cost-effective $CO_2$ capture. The petrochemical industry in Guangdong is developing rapidly. It was the second largest industrial $CO_2$ emitter in China (8% of the total industrial emissions) in 2010 and is projected to be the largest source of $CO_2$ emissions in the industry sector in 2020 (16% of the total industrial emissions). Thus there are good potentially cost-effective opportunities for large-scale and low-cost $CO_2$ capture in the petrochemical industry in Guangdong Province.

In the offshore Pearl River Mouth Basin there are a number of producing oil fields, some of which are close to depletion. If after depletion the infrastructure (such as platforms, wells, and pipelines, etc.) can be used for

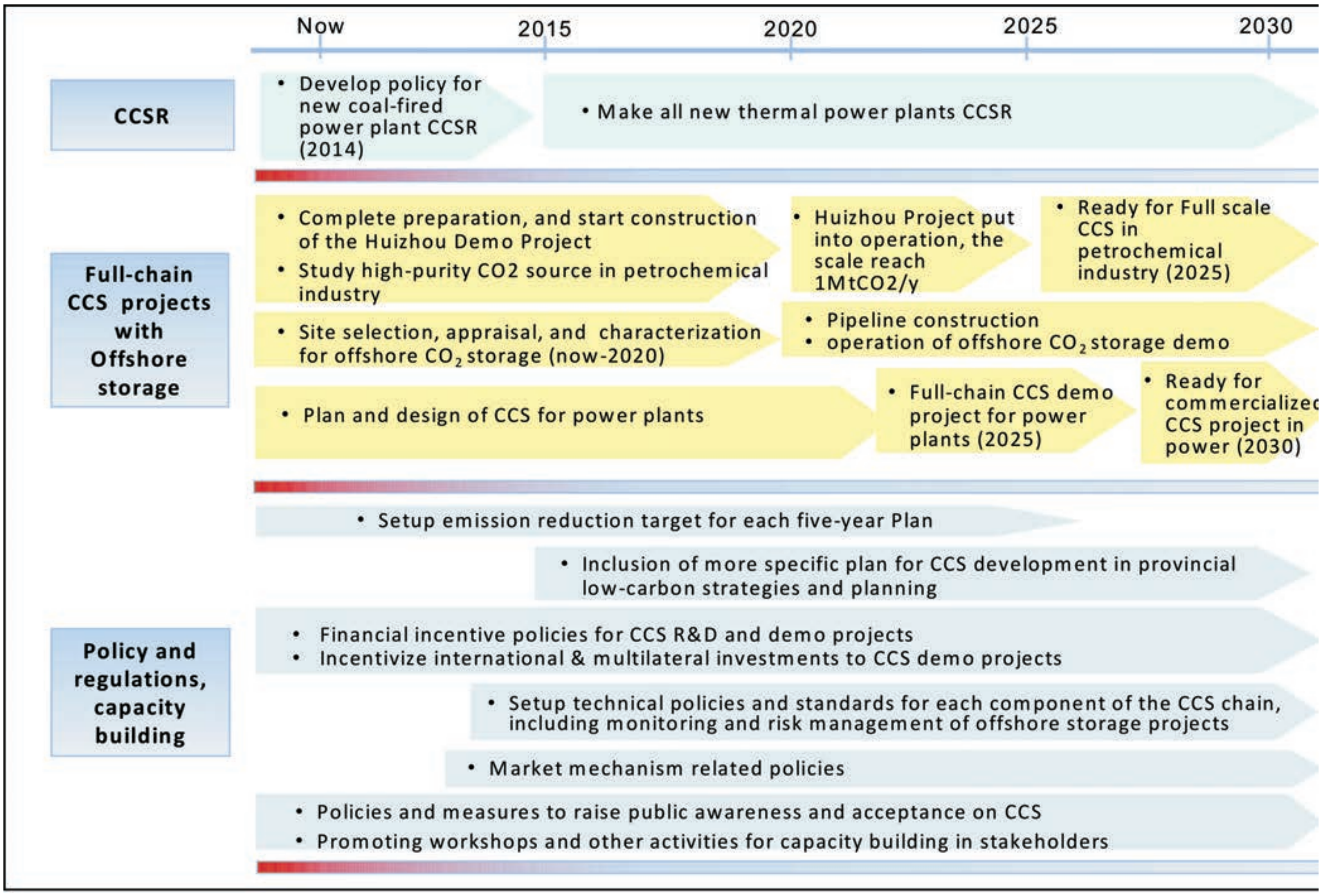

Figure 1 The General CCUS Development Roadmap for Guangdong Province

$CO_2$ injection, the cost of offshore $CO_2$ storage can be significantly reduced.

## 3. The proposed CCUS Development Roadmap for Guangdong Province

The CCUS Development Roadmap for Guangdong Province was proposed as a guide to a technically feasible and economically affordable CCUS development in the Province from now to 2030. The roadmap includes a general roadmap (Figure 1) and a number of individual component roadmaps for $CO_2$ capture, transport, storage and utilization, respectively.

The major milestones for the proposed roadmap are as follows:

- CCUS-ready policy for all new coal-fired power plants by 2014;
- CCUS included in the low-carbon action plan of the 13th Five-Year Plan of Guangdong Province in 2015;
- Operation of a full chain CCUS Huizhou Demonstration Project by 2020;
- Operation of full chain CCUS demonstration on a coal-fired power plant by 2025;
- Start of commercialized CCUS development in Guangdong Province around 2030;
- Building policies, regulations, and capacities for the CCUS development in Guangdong Province.

4. Suggested actions for CCUS development in Guangdong Province

4.1) $CO_2$ Capture

a. $CO_2$ capture in the petrochemical industry: Early opportunities for $CO_2$ capture in Guangdong exist in the capture of high-purity $CO_2$ sources from hydrogen production in the petrochemical industry. A study should be started soon to locate and quantify the resources of high-purity $CO_2$ sources in the Province. A feasibility study for a demonstration project should start as soon as possible to ensure that the first project can be in operation in 2020, and a full-chain CCUS project (i.e. including capture, transport, and utilization/storage) can start by 2025.

b. $CO_2$ capture in the power sector: The power sector is the major sector for a deep cut in $CO_2$ emissions through CCUS. Research indicates that capturing $CO_2$ from a USCPC plant has the highest cost advantage, and that post-combustion capture would be the technique with the largest application potential in the Province. Intensive research and development in new absorbents, system configurations, and large scale demonstrations have taken place worldwide. Guangdong should focus on the application of capture techniques most suitable for CCUS projects in the Province, and also prioritise techniques which might bring business opportunities to the Province. A full-chain CCUS demonstration project in the power sector should be in operation by 2025, allowing the deployment of commercial scale CCUS power plants by 2030.

c. CCUS-ready policy for new coal-fired power plants: Policies or regulations for new CCUS-ready coal-fired power plants should be implemented by 2014 to prevent carbon lock in and to ensure a smooth and lower-cost transfer to retrofitting CCS after 2030. New plants which are CCUS-ready should be given priorities by Government in the authorization process. By 2015 the design of the first CCUS-ready demonstration project should be implemented, and all the new coal-fired power plants must have CCUS-ready design after 2015.

d. Other capture techniques: Guangdong Province should encourage and support CCUS related research and development through low-carbon development funds to strive for innovation and breakthrough.

4.2) $CO_2$ transportation

a. Pipeline transportation: Pipeline transportation of $CO_2$ is the most effective method for large-scale, long-distance, and long-term $CO_2$ transportation. Guangdong should make an integrated design of an onshore and offshore pipeline network, and start pipeline infrastructure construction according to the pace of CCUS development.

b. Ship transportation: Shipping might be a viable option for $CO_2$ transportation in the early demonstration stage for Guangdong. LNG, LPG and existing smaller $CO_2$ ships may be referenced to compare the relative advantages of ship charter and ship modification.

4.3) $CO_2$ utilization and storage

a. $CO_2$ utilization: Investigation is needed to clarify the potential of $CO_2$ utilisation in Guangdong Province by major industries and other users, and to understand the total amount of $CO_2$ which can be utilised. This will be useful for planning not only the $CO_2$ utilisation industry but also for $CO_2$ storage. Given its natural conditions and industrial advantages, Guangdong should focus on high-efficiency $CO_2$ utilisation in the chemical industry, and $CO_2$ algae cultivation and algae-fuel production. It should try to achieve a technical breakthrough by 2020, and to form a $CO_2$ utilisation industry by 2030.

b. $CO_2$ storage in offshore depleted oil fields: For offshore $CO_2$ storage the main obstacle is the high engineering cost. The use of the existing infrastructures of depleted offshore oil fields may offset the cost. It is urgent to identify those oil fields whose infrastructure may be used for $CO_2$ injection. This must be completed several years before the field depletion in order to leave sufficient time for preparing the storage project.

c. $CO_2$ storage in offshore saline formations: The storage capacity in oil fields is limited. $CO_2$ storage in saline formations is the inevitable choice when the CCUS development reaches a large scale. A survey in the Pearl River Mouth basin is needed to locate potential storage sites in saline formations which meet the requirements of large-scale $CO_2$ storage. The characterization of selected sites should start in 2015, the design and commencement of an offshore storage demonstration project should start in 2020, and commercial storage operations should start between 2025 and 2030 to meet the requirements of CCUS development in Guangdong Province.

4.4) Demonstration of offshore storage.

The “Demonstration project of Huizhou refinery coal–to–hydrogen $CO_2$ capture and offshore depleted oil field storage” (the Huizhou Demonstration Project) is expected to be a low–cost full–chain CCUS demonstration project. The pre–feasibility study of the Huizhou Demonstration Project should start now, so that the project may be setup and start construction in 2015, and begin operation in 2020 at the scale of one million tonnes of $CO_2$ per year. The Huizhou Demonstration Project will be the first CCUS demonstration project with offshore storage in China. It will be a flagship project in the low–carbon development of Guangdong Province. It will also serve as an example for other areas in the world, including southeast China where the offshore $CO_2$ storage is crucial for CCUS development.

## 5. Policy Suggestions for CCUS development in Guangdong Province

The development of CCUS consists of two stages: the stage of research and demonstration and the stage of commercial implementation. In the first stage progressing CCUS relies mainly on the incentive policies and financial support from government and international cooperation; while in the second stage market mechanisms may play a major role. At the present, Guangdong Province is at the beginning of the first stage, thus the Government should play a crucial role through financial support and targeted policy incentive.

5.1) Policies on an emission reduction target: A target of carbon reduction for the Province and emission quotas for major industries should be set up in line with the subsequent Five–Year Plans. These will guide the research and development of emerging low–carbon technologies such as CCUS. CCUS should be included as soon as possible in the low–carbon development plan of the Province.

5.2) Policies on financial incentives: Because CCUS can transform coal into a clean energy with near zero emission of $CO_2$ and other pollutants, it should be entitled to the incentive policies that have already been applied to other clean energies such as renewables and nuclear. In recent years Government financial support should be enhanced for CCUS R & D and especially for early demonstration projects.

5.3) Policies on market mechanism: Regulations on carbon markets, carbon tax, and low–carbon electricity contract pricing mechanisms have been introduced in some western countries. CCUS has been included in the Clean Development Mechanism (CDM). In Guangdong the market mechanism should be designed to accelerate the CCUS research and demonstration and to support CCUS commercialization.

5.4) CCUS–ready policy and standards: The policy for new coal–fired power plant to be designed with CCUS–ready should be implemented by 2014 to prevent the “carbon lock–in” effect.

5.5) Technical standards and regulation: Technical standards and regulatory frameworks for each segment of the CCUS chain should be developed based on the learning process from CCUS demonstrations and other developments in China and abroad.

5.6) Programs on public awareness and capacity building: Programs and activities to encourage CCUS–awareness and capacity building should be set up, such as networking, websites, media communications, as well as regular and special workshops.

5.7) Enhance international and domestic exchange and collaboration: Policies and measures should be introduced to enhance the exchange and collaboration on CCUS among experts and domestic and international stakeholders. Collaboration with developed countries should be enhanced in CCUS knowledge sharing, technology transfer, and financial investment on CCUS R&D and demonstration in Guangdong Province.

# 2. Making 1GW Ultra–supercritical Coal–fired Power Plant $CO_2$ Capture Ready: A CCR Case Study for a China Resources Power 2x1GW ultra–supercritical power plant

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*Through a preliminary $CO_2$ capture ready (CCR) study on the China Resources Power Unit 3 and Unit 4 2x1GW project, the team from Guangdong Electric Power Design Institute (GEDI) and the University of Edinburgh (UoE) have identified key criteria and issues to consider for $CO_2$ capture and the impacts on project investment and plant performance and proposed the necessary investment in engineering and operational expenditure. CCR avoids the'carbon lock-in' effect with minimal cost, and gives power plants an option to capture $CO_2$ within their 30 years lifetime. We would recommend that Guangdong, as a low-carbon pilot province, should pioneer CCR demonstration and deployment and formulate CCR policy for new build power plants.*

## 1. Introduction

$CO_2$ Capture and Storage (CCS) is the most promising technology to achieve significant reductions in $CO_2$ emissions within the next two decades. Retrofitting a CCR plant could achieve near zero emissions from the use of fossil fuel and hence reduce to a large extent the impact of its greenhouse gas production on the climate. Due to the current barriers in technical, economic and legal and regulatory aspects, CCS is currently difficult to deploy widely at commercial scale. However, in order to reduce the costs and risks of implementing CCSR in the future, CCS Ready should be deployed to keep CCS retrofit options open.

To investigate the techno–economic prospects of deploying CCS technologies in Guangdong Province, in July 2013, GEDI, working closely with UoE, the China Energy Construction Group, and the South China Sea Institute of Oceanology in the Chinese Academy of Sciences (SCSIO), commenced work on the $CO_2$ Capture Ready project. This was based on a case study of China Resources Power's (CRP) 2 x 1GW ultra–supercritical pulverized coal (USCPC) power plant, in order to understand the technological feasibility, safety, and economic aspects of $CO_2$ Capture Ready, the impact of CCR provisions on the base plants and to develop a potential technical reference pathway for implementing CCR in coal–fired power plants in China.

The CRP Haifeng Project has 8GW total planned capacity, with a Phase 1 and Phase 2 (both 4x1GW), built on a staged approach. Construction started on the first 2GW (Phase 1 Units 1 and 2) of the USCPC project in November 2012. These two units will start operation in December 2014. Units 3 and 4 in Phase one will also use 2x1GW USCPC units, and are currently at the feasibility study stage. The project aims to investigate incorporating CCR provisions in Units 3 and 4.

## 2. CCR basic design principles assumed for this project

The following high-level design assumptions were made for the CCR design exercise:

2.1) $CO_2$ Capture Plant Capacity: The total volume (dry basis) of flue gas treated from one single 1GW unit at the boiler maximum continuous rating (BMCR) is 3.25 million $Nm^3$/hour. The assumed $CO_2$ capture rate is 90%, and the capture capacity is 791.5 tonne/hour, resulting in the two units capturing approximately 10 million tonnes $CO_2$ per year.

2.2) Adopt post-combustion capture technology, using amine (MEA) as the $CO_2$ capture solvent for a conceptual retrofit study.

2,3) Provide a flue gas by-pass system to allow operation without CCS;

2.4) Consider that the $CO_2$ capture system will operate an average of 6500 hours per year.

## 3. Required plant location considerations for CCR

Plant location is a key factor for deploying CCS technologies. In addition to the more obvious criteria for choosing the location of the base plant (e.g. water access, local population density), the following factors should also be considered:

3.1) Proximity of $CO_2$ emitter and storage site, to ease transportation and to reduce $CO_2$ transportation costs.

3.2) Co-location with existing and prospective $CO_2$ capture plants, to utilize infrastructure and to reduce transportation costs

Compared to plants that are not CCS ready, planning for capture ready coal-fired power plants should therefore take into account the following criteria:

3.3) $CO_2$ transportation issues: how to transport $CO_2$ to storage site, - including transportation safety and infrastructure sharing.

Figure 1 The geographical location of CRP Haifeng Project

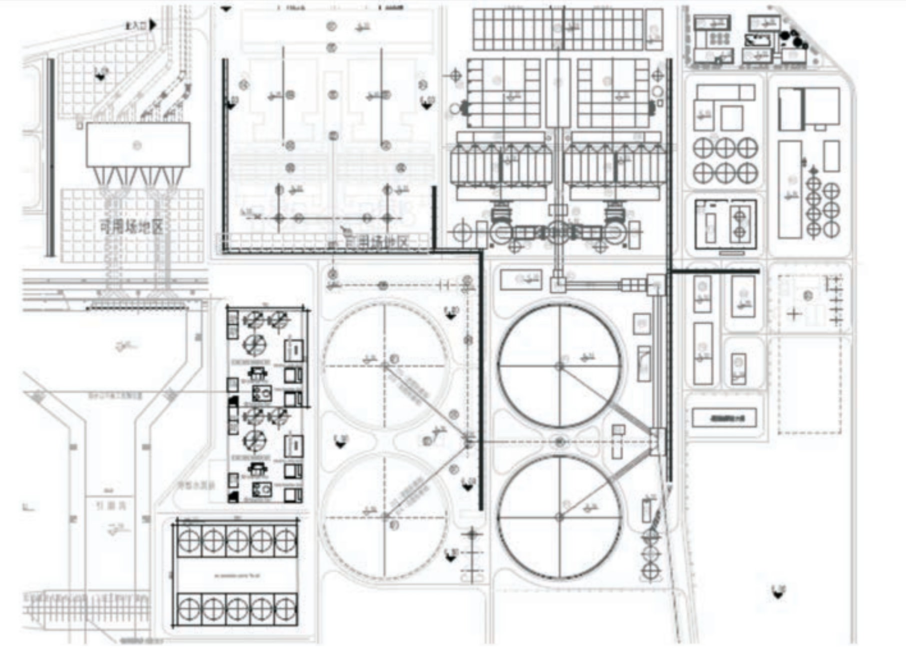


Figure 2 Layout of CRP Haifeng Power Project

3.4) Health and safety issues related to $CO_2$ transportation and amine treatment.

As illustrated in Figure 1, the CRP Haifeng project is located on the coast in Xiaomao town in Shanwei. According to a recent study on the $CO_2$ storage potential in the Pearl River Mouth Basin in the South China Sea, the CRP Haifeng project is not far away from potential storage sites, giving the location obvious geographical advantages.

## 4. Space requirement

Space has been allocated in the CCR design for the following purposes:

4.1) $CO_2$ Capture Plant: Boiler expansion and retrofit project (e.g. reserved space between induced draft fan and amine absorption tower for flue gas pipe)

4.2) Steam turbine system expansion and retrofit (e.g. space should be reserved for extracting low-pressure steam to pipe to the amine absorption tower);

4.3) Power auxiliary system expansion, to satisfy the future energy requirements of $CO_2$ captures facilities;

4.4) Power auxiliary system expansion, to satisfy the future energy requirements of $CO_2$ compression facilities;

4.5) Access space for vehicle transport (e.g. amine transportation vehicles);

4.6) Separation space In addition to the operational space for $CO_2$ capture and processing and considering the potential hazards, sufficient safety space must be allowed between different modules.

The CRP Haifeng project (Units 3 and 4) has reserved space in two blocks for the $CO_2$ capture and $CO_2$ compression areas respectively. The area allowed for $CO_2$ capture is 13,000 $m^2$; while the $CO_2$ compression area is approximately 12,000 $m^2$. As $CO_2$ capture technologies are developed, the required space for $CO_2$ capture could be significantly reduced.

## 5. Estimated costs for CCR and $CO_2$ capture retrofit

5.1) Capital Cost

CRP Haifeng Phase 1 Unit 3 1GW USCPC coal-fired plant is estimated to require 0.7% to 1.5% extra capital investment for the addition of CCR (as shown in Table 1), and would need an extra 26% to 40% capital cost for future retrofit based on the current state-of-art post-combustion capture technology. The incremental cost would include $CO_2$ capture plant capital cost and the required retrofit engineering.

Table 1 Estimated Capital Cost for CCR and CCS Retrofit

| Item | 单位 | Conventional Coal-fired Power Plant without CCR | Extra Investment for CCR | Extra Investment for $CO_2$ Capture Retrofit |
|---|---|---|---|---|
| Extra Static Investment Cost | % | Benchmark | 0.7% - 1.5% | +26%-40% |
| Unit Cost | CNY/kW | 3689 (or GBP368.9/kW) | 26 to 55 /kW (or GBP 2.6 to 5.5/kW) | 959 -1476(or GBP 95.9/kW) |

5.2) Operational Cost

According to the current preliminary analysis, the operational cost of CRP phase 1 (Units 3 and 4) plant would be CNY 225-300/t$CO_2$, incl. labour, management, and maintenance costs and the required auxiliary electricity, chemical consumables and pollution treatment.

## 6. Conclusions

Because coal-fired power plant post-combustion capture technologies are still in the pilot and demonstration phases, $CO_2$ capture has not yet been applied to a 1GW unit. This study provides some preliminary analysis for a $CO_2$ capture ready case study of a large-scale coal-fired power plant.

Amine based post-combustion capture is currently the most developed capture option. However, this technology involves a relatively high energy penalty and significant investment. It is important to study and improve solvents and reduce the energy penalty and understand the impact of technology scale-up. It is also valuable to study more advanced processes and alternative technologies, to achieve more efficient, cheaper and, environmentally friendly goals, and to reduce land and investment requirements.

$CO_2$ capture ready could avoid the ‘carbon lock-in’ effect with minimal cost, and help achieve a $CO_2$ capture transition in the future. It is therefore a low cost, risk-free technical and policy option. We suggest that the Guangdong Provincial Government actively demonstrate and apply $CO_2$ capture ready, and draft large-scale $CO_2$ capture ready policy.

The Guangdong Provincial Government should prioritise project design and authorize demonstration of CCR on coal-fired post combustion power generation (the largest industrial emitter of $CO_2$ in the Province) in order to contribute to the large-scale deployment of CCS, and promote further the effort to advance technologies for greenhouse gas emissions reduction.

The next issue will discuss the techno-economic performance of $CO_2$ capture retrofit and possible retrofit technology developments.

# 企业风采 · · · · · · 〉〉

## 1. 豪顿集团参与的项目

王健，豪顿区域业务拓展经理，wang.jian@howden.com.cn
Richard Smith, 豪顿集团新兴工艺商业发展经理 , Richard.smith@howden.com

豪顿集团与豪顿华工程有限公司很高兴参与和支持广东－英国CCS研究中心。

豪顿集团是由苏格兰工程师詹姆斯・豪顿创立的，从1882年开始公司致力于强制通风系统以及在锅炉中使用的换热系统的生产和研发。豪顿作为全球最权威的空气和烟气处理专家，其产品在发电、水泥、金属冶炼和石化等行业中被广泛使用。

把创新理念商业化始终是豪顿战略发展的一个关键要素，在20世纪30年代英国伦敦修建的世界上第一座使用烟气脱硫系统的电厂中，豪顿就提供过HOWDEN-ICI烟气净化装置。

如今，豪顿的许多业务与由环保方面的要求和法律规定所推动的重大项目和工艺流程有关，例如：

硫氧化物排放，烟气脱硫系统（FGD）

氮氧化物排放，烟气脱硝系统（SCR）

低硫燃料，硫磺分离系统（SRU）

工业革命以来化石燃料燃烧产生的二氧化碳已经被认为是造成全球气候变化的一个主要因素，因此也提出了远超出之前所有控制排放规模的挑战。

豪顿积极主动地与主要的技术供应商一起在国际上参与了各种各样的碳捕集开发项目，包括燃烧后吸收技术、燃烧前/整体煤气化联合循环技术以及富氧燃烧技术。

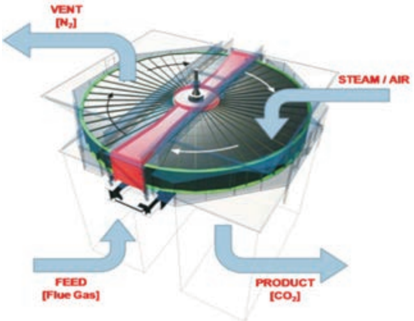
Karlshamn 项目 联合循环燃气轮机结合燃烧后捕集 瑞典

Ferrybridge 项目 传统燃煤电厂结合燃烧后捕集 英国

东莞项目 整体煤气化联合循环 中国

华电项目 传统燃煤电厂结合燃烧后捕集 中国

Kemper County 整体煤气化联合循环（585兆瓦） 美国



认识到在工艺中减少复杂性、能源消耗以及地面空间的必要性，豪顿与Inventys热技术公司合作，正在开发“下一代”Veloxotherm$^{TM}$变温吸附技术，该技术会采用豪顿已经被广泛使用的大直径，低阻力回转式热交换器技术。（参阅单独的文章页面#）

豪顿华工程有限公司（HHEL）成立于1994年，在中国近十几年大规范能源发展和工业建设期间，一直是大型工业风机、换热器以及压缩机的一个主要制造商和供应商。豪顿华工程有限公司已经发展成为一个年产值17.5亿元人民币、雇佣1000多人的公司，主要为中国市场设计和制造豪顿品质的产品。

认识到中国在全球“清洁能源”技术开发中的重要性以及所蕴含的机遇，豪顿集团已经任命王健先生（邮箱：wang.jian@howden.com.cn）为豪顿区域业务拓展经理，他将在豪顿华工程有限公司履职，并为设计院、承包商和客户提供支持。

更多信息请浏览：www.howden.com

## 2. 华能集团的 CCS 项目简介

作者：中国华能集团清洁能源技术研究院有限公司捕集工艺与设备技术研究所所长 刘练波

刘练波所长

目前，电厂 $CO_2$ 捕集技术路线主要有 3 种：燃烧后脱碳、燃烧前脱碳及富氧燃烧技术。燃烧后烟气 $CO_2$ 捕集技术适合传统燃煤电厂，最有可能在近期实现商业化示范，但能耗较高；基于整体煤气化联合循环（IGCC）的燃烧前捕集技术可以获得最低的捕集能耗，但 IGCC 电厂投资成本高、系统复杂；富氧燃烧技术在我国仍处于实验室和中试研究阶段。

中国华能集团公司于 2008 年奥运会前夕在华能北京热电厂建成投产了我国首座燃煤电厂烟气 $CO_2$ 捕集试验示范系统，回收 $CO_2$ 能力为每年 3000 吨。采用华能集团自主知识产权的燃烧后 $CO_2$ 捕集技术——从 $CO_2$ 浓度为 13% 左右的烟气中捕集出浓度超过 99% 的 $CO_2$，再经过精制系统，最终生产出食品级 $CO_2$ 产品，实现了二氧化碳的利用，该系统目前是世界上同类装置在燃煤电厂中运行时间最长的。该项目的实施，为我国燃烧后捕集技术积累了大量的运行和实验数据，培养了一批从设计到运行的人才队伍。

在此基础上，2009 年底，华能集团又在上海石洞口第二电厂建成规模更大的 $CO_2$ 捕集系统，捕集能力达到了 12 万吨 / 年。该系统与欧美国家正在运行或计划的几个项目相比，投资成本大大低于国际水平，能耗与国际先进水平相当。

除了燃烧后捕集，华能集团还在开展燃烧前捕集技术的研究和示范工作。华能天津 IGCC 示范电站于 2009 年正式开工，并于 2012 年建成投产。这是我国首座 IGCC 示范电站，也是华能集团倡导的“绿色煤电”计划第一阶段任务内容。以此为依托，

北京高碑店 3000 吨 / 年二氧化碳捕集装置

上海石洞口 120,000 吨 / 年二氧化碳捕集装置

天津 IGCC 电厂

北京燃气二氧化碳捕集系统

热功率 20MW 的绿色煤电实验室目前正在建设中，其中包括一套捕集规模为 6~10 万吨 / 年的燃烧前二氧化碳捕集系统，捕集后的二氧化碳将提纯、压缩液化后用于驱油及地质封存。该装置建成后，将成为我国开展燃烧前 $CO_2$ 捕集技术研发的重要平台。

以上项目均是针对燃煤机组的烟气或合成气二氧化碳捕集，近年来，随着环境指标的提高，国内外越来越多的发电机组采用天然气联合循环发电（NGCC），这对发展低成本 $CO_2$ 捕集技术提出了新的挑战和要求。基于燃气机组烟气的特点，借鉴煤电碳捕集的经验，华能集团清洁能源技术研究院开发了燃气烟气二氧化碳捕集成套技术，于 2012 年建成了我国首套燃气机组烟气 $CO_2$ 捕集示范工程，目前已经圆满完成 4000 小时连续示范运行，各项指标均达到设计要求，捕集率及能耗指标与燃煤二氧化碳捕集相当，溶剂消耗大大降低。这是我国在 $CO_2$ 捕集技术领域取得的又一重大突破，弥补了我国在燃气机组 $CO_2$ 捕集领域的空白，使得我国在该技术领域的研究达到国际先进水平。

以上项目的开展，不仅使我国在燃烧后捕集技术领域走在世界前列，在燃烧前捕集技术方面紧跟国际先进水平，也展示了我国应对气候变化的实际行动，增加了我国在国际交往和气候变化谈判中的砝码。华能 $CO_2$ 捕集技术及装置已成为展示我国应对气候变化实际行动的重要窗口。

# 3. 神华 CCS 示范项目工程实践与探索

作者： 神华集团煤制油化工公司 王永胜

## 1. 项目概况

2008 年神华集团建成的世界上首套百万吨级煤直接液化示范工程，核心技术采用了神华集团开发、具有自主知识产权的煤直接液化工艺技术。随着神华煤制油化工的示范与发展，神华在煤炭转化方面走在在世界的前列，大量温室气体的排放也引起了集团的高度重视，经多年调研后于 2009 年神华集团在神华煤制油分公司附近进行 10 万吨 / 年二氧化碳深部咸水层封存的示范研究。截止到 2013 年 11 月 25 日神华 CCS 实现连续注入目前已经注入约 17 万吨，并取得了完整的地质详细资料以及完整的注入、监测数据，为后期 CCS 封存机理的研究和封存风险的评价奠定了基础。

神华 CCS 示范项目在国内是首次将二氧化碳注入到深部咸水层，以实现二氧化碳永久性封存的科研探索项目，是国内乃至亚洲第一个实现从捕集、输送、到盐水层封存全流程的 CCS 示范工程。

## 2. 神华 CCS 项目技术特点

### 2.1 高浓度二氧化碳排放源

神华 CCS 示范项目的 $CO_2$ 源是来自煤制氢低温甲醇洗尾气 $CO_2$ 含量高达 88%（v）左右，对在煤化工集中地区开展CCS具有典型示范意义。

### 2.2 封存区具有陆地咸水层封存潜力大、风险小等典型特性

神华 CCS 封存地点所在的鄂尔多斯盆地是我国第二大沉积盆地。综合评价认为鄂尔多斯盆地局部地区存在有利的二氧化碳封存区，具备很好的封存潜力，据美国西弗吉尼亚大学评估，鄂尔多斯盆地咸水层可埋存二氧化碳 300 亿吨。

### 2.3 咸水层低孔低渗

通过对石千峰组储层，刘家沟组储层，和尚沟组储层等目标主力储层

神华项目的封存现场约距离捕集现场 15 公里。

神华项目的二氧化碳捕集设备

的分析，均为低孔隙率，低渗透率等典型特性。

### 2.4 完备的监测诊断系统

一口注入井，两口监测井的井位布置保证了对注入的有效监测。

生产注入监测：包括对原料气成分在线监测，对封存区注入工艺参数监测，对注入过程全井筒定期监测。。

环境监测：主要包括对深层地下水、承压水、地表水、土壤、空气以及地面变形等进行监测。

三维地震和 VSP 监测：通过地震以及模拟手段监测 $CO_2$ 在目标储层的运移情况。

数据平台及诊断系统：已经初步形成全流程的数据库，及生产注入诊断系统。

## 3. 神华 CCS 的工艺介绍

### 3.1 二氧化碳捕集单元

煤气化低温甲醇洗单元产生的二氧化碳尾气通过管道输送至二氧化碳捕集单元，CCS 示范工程捕集采用一步高压液化法，经过压缩、气液分离、净化、液化、精馏等工序生产出合格液体二氧化碳。

### 3.2 二氧化碳储存和输送单元

由捕集区的储罐、注入封存区的储罐、二氧化碳槽车、注入泵组成。

### 3.3 化碳注入封存单元：

由三口直井组成，一口为注入井、两口为监测井。液体二氧化碳经加压、加热后以超临界状态注入到咸水储层中，

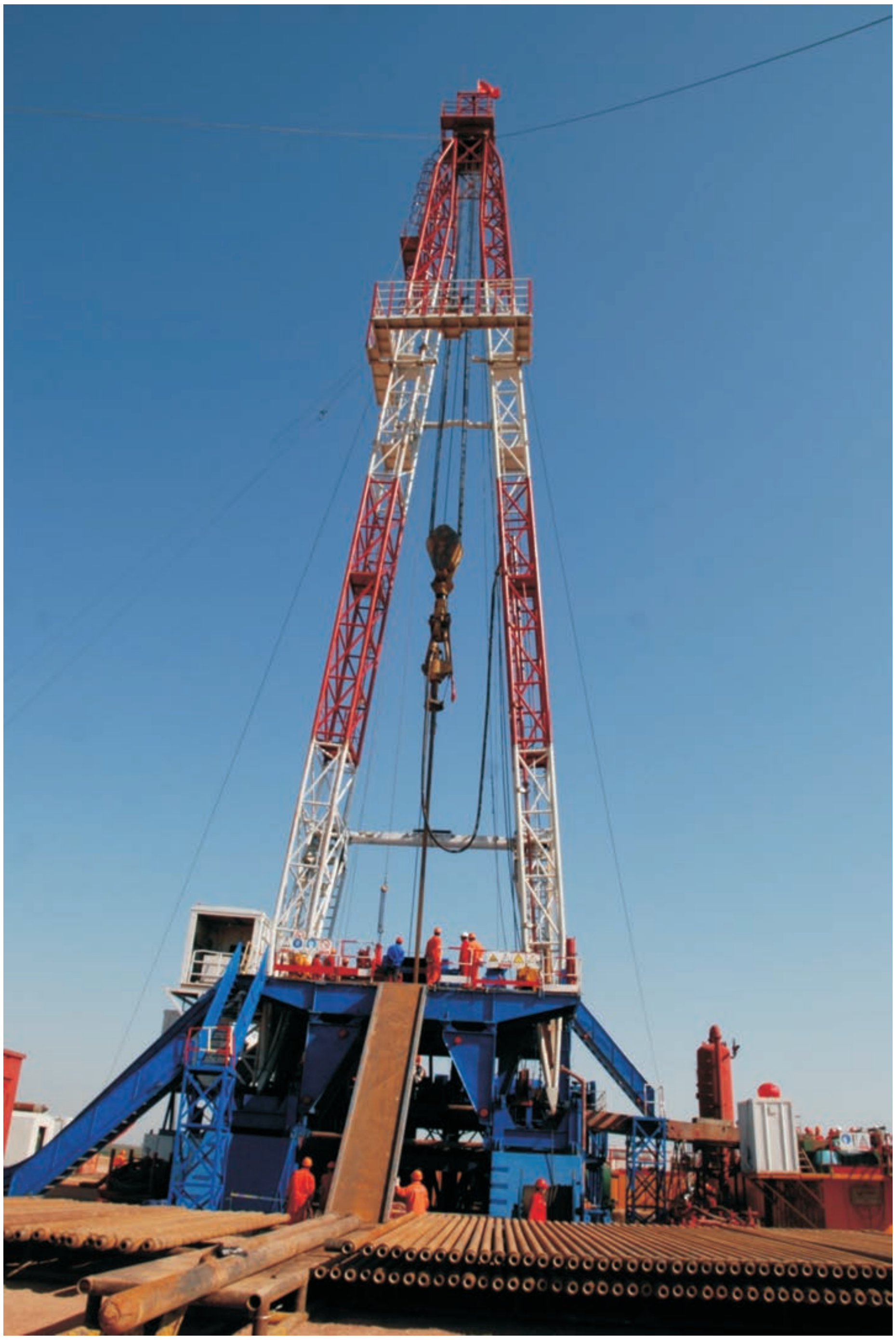
## 4 神华 CCS 取得的主要成果

(1) 首次确定了国内 CCS 咸水层封存项目封存目标区的选址办法

(2) 该项目是针对低孔隙度、低渗透性咸水层二氧化碳封存的首次探索，为此首次将压裂增渗引入了咸水层封存，是符合我国国情的重要探索。

(3) 该项目实现在灰岩中的二氧化碳封存，是首次非常重要的探索，对于扩大 CCS 的应用范围，为鄂尔多斯盆地其他排放源的二氧化碳封存提供新的解决方案。

(4) 该项目开创性的实施了多层分层注入、多层统注、分层监测注入方案。为我国规模化、工业化实施 CCS 探索最佳注入方案。



神华二氧化碳钻井施工现场

# 4. 中石化胜利油田大规模燃煤电厂烟气 $CO_2$ 捕集、输送、驱油封存全流程项目

资助机构：国家“十二五”科技支撑计划（2012BAC24B00）

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二氧化碳驱油与封存技术（$CO_2$-EOR）被认为是保障化石能源使用安全、应对全球气候变化和控制温室气体排放的重要途径之一。中石化胜利油田结合自身的科研、人才、基础设施等优势，拟建成50-100万吨/年燃煤电厂烟气二氧化碳捕集、输送与驱油封存全流程示范工程。2013年在 $CO_2$ 捕集、输送、驱油封存三个环节上均开展了丰富的前期研究工作：对国际主流烟气 $CO_2$ 捕集技术进行了工艺比选；对大规模、长距离 $CO_2$ 管输技术进行了研究；初步确定2个封存示范区。

## 1. 前言

温室气体的过量排放造成全球范围内气候变暖，这已成为当今最为显著的环境问题之一。按照京都议定书规定和哥本哈根国际环境会议要求，每个国家都有二氧化碳（$CO_2$）减排义务，$CO_2$ 减排已经成为全球关注的重大问题。结合全球碳减排需要及低渗透油藏开发需求，依托胜利油田油藏资源和胜利电厂烟道气 $CO_2$ 资源，拟开展“胜利油田燃煤电厂烟气二氧化碳捕集、输送与驱油封存全流程示范工程”项目，进行 $CO_2$ 大规模减排的同时实现 $CO_2$ 资源化利用，为全球碳减排提供宝贵技术经验和经济、环保、可持续发展的新途径。

## 2. 胜利油田开展 $CO_2$ 捕集、输送、驱油封存全流程项目的优势

### 2.1 承担多项与碳捕集、驱油封存技术相关的科研课题

自2007年以来，中石化胜利油田开展了 $CO_2$ 捕集及驱油封存技术攻关，承担了近十项国家与省部级CCUS科研课题（其中国家科技支撑计划项目2项，国资委示范工程1项，中石化总公司科研课题6项），申报专利20余项，发表论文40余篇。通过技术攻关和现场应用，建设运行了100吨/天燃煤电厂烟气 $CO_2$ 捕集纯化及驱油封存全流程先导工程，形成了燃煤电厂烟气 $CO_2$ 捕集、驱油与封存（CCUS）全流程技术，获得了大量的生产实验数据，取得了良好效果，为实施100万吨/年 $CO_2$ 捕集及驱油封存示范工程提供了技术支撑。

### 2.2 拥有适宜的 $CO_2$ 气源及丰富的低渗透油藏区域

中国石化胜利油田具有自备燃煤电厂——胜利发电厂，电厂装机容量总共为1640MW，年燃煤量约为410万吨，全年 $CO_2$ 排放量达700-900万吨，为 $CO_2$ 捕集提供了充足的气源；同时，胜利油区适合 $CO_2$ 驱油的低渗透油藏地质储量约为4.19×108t，$CO_2$ 封存需求总量将超过1.87×108t，具备开展大规模烟气 $CO_2$ 驱油封存的地质条件；能够实现燃煤电厂 $CO_2$ 捕集、输送、驱油封存全流程示范工程的应用。

### 2.3 实验室建设及丰富的人才资源

在实验室建设方面，申报单位已经建有 $CO_2$ 捕集、多相流腐蚀控制、油藏模拟、气驱采油、地面工艺处理等多个重点实验室，拥有 100 吨 / 天燃煤电厂烟气 $CO_2$ 捕集及高 89-1 块驱油封存全流程试验基地。在团队建设方面，项目研究组具有较强的技术力量，由油气集输、化学工程、油田化学、腐蚀防护、油藏工程、地质工程、采油工程、环境工程、热能工程等 10 余个专业的工程技术人员组成，多次承担和参加过国家级和省部级重大科研攻关课题，具有丰富的理论和实践经验。

### 2.4 广泛的国际合作与交流

在国内外合作交流方面，中国石化与国内外知名研究机构如加拿大 Saskpower、德国西门子、美国 PowerSpan、美国肯塔基大学应用能源研究中心等开展了广泛的合作与交流，并与清华大学、北京大学、中国科学院、中国石油大学、北京工业大学、华北电力大学、中国矿业大学等高校与研究机构共同开发应用 $CO_2$ 捕集、输送、驱油封存技术。

## 3. 大规模燃煤电厂烟气 $CO_2$ 捕集、输送、驱油封存全流程项目

胜利油田预期建成 50-100 万吨 / 年燃煤电厂烟气二氧化碳捕集、输送与驱油封存全流程示范工程，包括 $CO_2$ 捕集、管道输送、地质封存、驱油、采出液地面集输处理等工程内容，其中捕集及输送单元规模为 100 万吨 $CO_2$/ 年，$CO_2$ 捕集率 ⩾ 85%，产品 $CO_2$ 纯度 ⩾ 99.5%，再生能耗 ⩽ 2.7GJ/t$CO_2$；驱油、封存规模不小于 50 万吨 $CO_2$/ 年，$CO_2$ 驱示范区采收率提高 5% 以上，$CO_2$ 动态封存率达到 50% 以上。（动态封存率指一段时间内 $CO_2$ 总封存量与总注入量的比值）

该项目已于 2013 年启动，计划 2015 年动工建设，2017 年建成投产，并持续运行 15 年。针对大规模燃煤烟气 $CO_2$ 捕集、输送、驱油封存技术开发，截止到目前，胜利油田分公司已经对适合 $CO_2$ 封存的低渗透油区进行了勘探开发，初步确定了封存示范区，距离胜利电厂为 80km；同时对国际主流烟气 $CO_2$ 捕集技术进行了工艺比选，启动了 100 万吨 / 年 $CO_2$ 捕集纯化工程的前期研究工作；对大规模、长距离 $CO_2$ 管输技术进行了研究，确定了输送相态和输送压力，启动了年输送 $CO_2$ 100 万吨的 80km 管道的前期设计工作。

作者简介：刘海丽（1980 年 12 月）、女、硕士、高级工程师、主要从事二氧化碳捕集、利用及封存领域的研究，具体包括 $CO_2$ 捕集工艺的优化及 $CO_2$ 增强型地热系统的研究；中石化石油工程设计有限公司，山东省东营市济南路 49 号，0546-8551107，slsjylhl@163.com。

# 1. Howden's Involvement in CCS

Jian WANG, Howden Regional Business Development Manager, wang.jian@howden.com.cn
Richard SMITH, Howden Group Business Development Manager – Emerging Process, Richard.smith@howden.com

Richard Smith

Jian WANG

The Howden Group together with Howden Hua Engineering Ltd are pleased to be involved with and supporting the Guangdong – UK CCS Research Centre.

Since the development of the forced draft system with integral preheat for boilers in 1882, the company founded by Scottish Engineer James Howden has been at the forefront of air and gas handling, and engineering balance-of-plant equipment associated with power generation and other heavy industries including cement production, metals refining and petrochemical on a global scale.

Commercialisation of innovative concepts has continued to be a key element of Howden's strategic development which has included building the world's first FGD plants, and the Howden – ICI Gas Washer, in London during the 1930s.

Today, much of Howden's business is associated with major projects and processes driven by environmental initiatives and legislation. For example: –

SOx emissions, Flue Gas Desulphurisation (FGD)

NOx emissions, Selective Catalytic Reduction (SCR)

Low Sulphur Fuels, Sulphur Removal Units (SRU)

$CO_2$ produced from the combustion of fossil fuels since the Industrial Revolution is recognised as being the major factor contributing toward acknowledged global climate change, and represents a challenge for emission control at a scale way beyond all that has come before.

Being proactive, Howden is already involved internationally on various carbon capture development projects with key technology players incorporating post combustion absorption, pre combustion / integrated gasification combined cycle and oxy-fuel combustion technologies.

Karlshamn Gas Fired CCGT with PCC Sweden
Ferrybridge Conventional Coal Fired with PCC UK
Donguaan IGCC China

Hua Dian Conventional Coal Fired with PCC China

Kemper County IGCC (585MW) USA

Recognising the need for reduced complexity, energy consumption and ground space, Howden in collaboration with Inventys Thermal Technologies are developing "Next Generation" Veloxotherm™ Temperature Swing Adsorption technology which uses an adaptation of Howden's proven technology in large diameter rotating heat exchangers and low pressure loss.

Howden Hua Engineering Ltd (HHEL) was established in 1994 and has been a major manufacturer and supplier of heavy industrial fans, heaters and compressors during the energetic development and industrialisation of China in recent times. HHEL has grown to become a RMB 1.75Bn/year company, employing over 1000 people, designing and manufacturing Howden quality products primarily for the market within China.

For further information [www.howden.com](www.howden.com)

## 2. Huaneng CCS Demonstration Project Overview

Lianbo LIU, Director of the Capture Technology and Equipment Technology Research Institute, Huaneng Clean Energy Research Institute Co., Ltd.

Lianbo LIU

Currently, there are three main technical $CO_2$ capture routes for power plants: post-combustion decarbonisation, pre-combustion decarbonisation and oxy-fuel technologies. Pro-combustion flue gas $CO_2$ capture technology is suitable for traditional coal-fired power plants and the most likely to be realized in commercial demonstration in the near future. However, it has a relatively higher energy consumption. Pre-combustion capture technology based on Integrated Gasification Combined Cycle (IGCC) has the lowest capture energy consumption, but IGCC power plants have high investment costs and complex systems. Oxy-fuel technology is still at the laboratory and pilot study stages in China.

China Huaneng Group constructed and operated the first flue gas $CO_2$ capture test and demonstration system for coal - fired power plant – with 3,000 tons per year $CO_2$ recycling capacity – at its Beijing Thermal Power Plant on the eve of the 2008 Olympic Games. It adopted Huaneng Group's independent intellectual property rights for post-combustion $CO_2$ capture technology to capture $CO_2$ at 99% concentration from flue gases where the original concentration was 13%. It then further refined the $CO_2$ to use as food grade $CO_2$ products. The time the system has run at coal-fired power plants is currently the longest compared to similar equipment elsewhere in the world. The implementation of the project accumulated much operational and experimental data for post-combustion capture technology in China and cultivated a batch of talented teams from design to operation.

In addition, Huaneng Group completed a larger scale $CO_2$ capture system at Shanghai Shidongkou NO.2 Power Plant at the end of 2009, where the capture capacity reaches 0.12 million tons per year. The investment cost of the system is much smaller than the international level and its energy consumption is similar to several international advanced level projects at operational or planning stages in Europe and America.

Huaneng Group is also carrying out research and demonstration work for pre-combustion capture technology. Huaneng Tianjin IGCC Demonstration

Beijing Pilot $CO_2$ Capture Unit from Simulate CCGT Flue Gas

Shanghai Shidongkou 120,000 t/year $CO_2$ Capture Unit

Tianjin IGCC Power Plant

Power Plant formally started construction in 2009 and was put into operation in 2012. It is the first IGCC demonstration power plant in China, as well as fulfilling part of the mission of the first stage of the GreenGen plan advocated by the Huaneng Group. To further this plan, the GreenGen laboratory with 20MW thermal power is under construction, which will include a pre–combustion $CO_2$ capture system of 60,000–100,000 tons per year capacity. After purification, compression and liquidation, the captured $CO_2$ will be used for flooding oil fields and geological storage. When completed, the unit will be the important platform for China to research and develop pre–combustion $CO_2$ capture technology.

The above projects are all aimed at either capturing $CO_2$ from the flue gas of coal–fired units or producing synthesis gas. In recent years, as environmental constraints increase, more and more generator units in China and abroad have adopted Natural Gas Combined Cycle (NGCC) systems to generate electricity. This throws up new challenges and requirements for developing low–cost $CO_2$ capture technology. Huaneng Group Clean Energy Technology Institute has developed a complete gas–fired flue gas $CO_2$ capture technology based on the characteristics of a gas–fired unit and in 2012 has used the experience from coal–fired carbon capture as a reference to complete the first flue gas $CO_2$ capture demonstration project for gas–fired units in China. Currently, the project has satisfactorily demonstrated 4,000 hours of continuous operation and all the indexes meet the design requirements. The capture rate and energy consumption indices are similar to those of coal–fired $CO_2$ capture plant, and the solvent consumption is significantly reduced. It is another important breakthrough in $CO_2$ capture technology, making up for the lack of gas–fired $CO_2$ capture in China, and making the study in this field in China reach international advanced levels.

The implementation of the above projects not only allows China to lead the world in post–combustion capture technology and to keep up with international advanced levels in pre–combustion capture technology, but also demonstrates China's practical actions to tackle climate change, and increases China's weight in climate change negotiations and international communications. Huaneng Group's $CO_2$ capture technologies and facilities have become important windows for China to demonstrate its practical actions to tackle climate change.

# 3. Engineering Practice and Exploration of Shenhua CCS Demonstration Project

Yongsheng Wang, China Shenhua Coal To Liquid and Chemical Co., LTD.

In 2008, Shenhua Group successfully constructed the world's first 1MT/year large-scale direct liquefaction demonstration plant using its own direct liquefaction technology with independent intellectual property rights. With the demonstration and development of coal to liquid chemical engineering, Shenhua Group owns the leading-edge coal conversion technologies. Shenhua also pays great attention to the increasing amount of GHG emissions. In 2009, after years of research, Shenhua Group demonstrated the 100,000t/y deep saline $CO_2$ storage project near the Shenhua Coal to Liquids Company. The Group has completed the continuous injection of 170,000t of $CO_2$, and obtained detailed geological information and injection and monitoring data which has laid a solid foundation for future CCS storage mechanism studies and storage risk assessments.

Shenhua Coal to Liquid CCS Project $CO_2$ Storage Site, 15km from Capture Plant

Shenhua developed the first CCS demonstration project to inject $CO_2$ into deep saline formations to realize permanent storage in China, as well as to implement fully the process of capture, transportation and saline storage in China or even Asia.

## 2. Technical Characteristics of Shenhua CCS Demonstration Project

### 2.1 High Concentration $CO_2$ Emission Source

This project uses $CO_2$ from coal to hydrogen rectisol flue gas with a concentration of around 88%, which sets an example for CCS implementation in areas where coal chemical industries are concentrated.

### 2.2 The Storage Site Is Featured by Great Saline Storage Potential and Low Risk

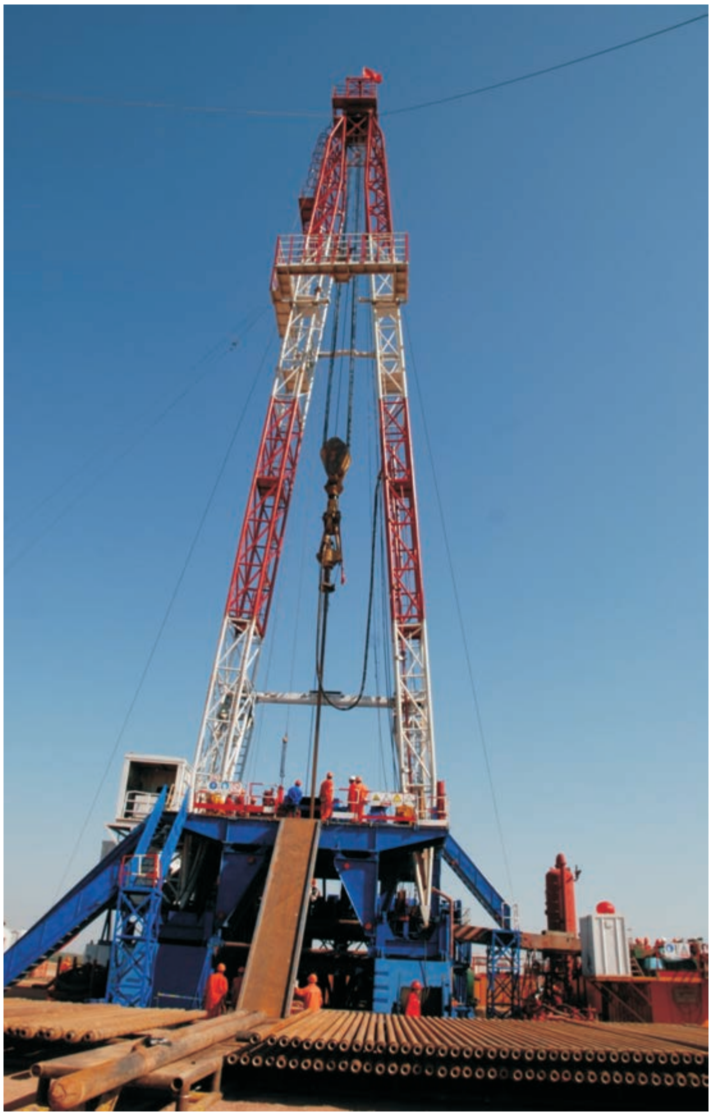
The storage site of Shenhua's CCS Project is located in China's second largest sedimentary basin-the Ordos Basin. According to an assessment by West Virginia University (USA), some parts in the Ordos Basin are favourable $CO_2$ storage sites. The saline formation in this basin has a potential storage capacity of 30Gt.

Shenhua Coal-to Liquid CCS Project $CO_2$ Capture Plant

### 2.3 Low Porosity and Permeability in the Saline Formation

An analysis of the reservoir in Shiqianfeng Group, Liujiagou Group and Heshanggou Group shows that the saline formations in these sites are characterized by low porosity and permeability.

### 2.4 Complete Monitoring and Identification System



Shenhua Coal to Liquid CCS Project $CO_2$ Storage Well Drilling Site

The effective monitoring of the injection of $CO_2$ is ensured by placing two monitoring wells with each injection well.

Injection Monitoring: monitoring of feed gas composition and technological parameters of injection at storage sites, and regular monitoring of the wellbore during the injection.

Environmental Monitoring: mainly including the monitoring of deep phreatic water, confined water, surface water, soil, air and ground deformation.

3D–seismic and VSP Monitoring: monitoring the $CO_2$ movement in the targeted reservoir by seismic and simulation tools.

Data Platform and Identification System: initially establishing the complete flow database and the system for production, injection and identification.

## 3.The Technology Process of the Shenhua CCS Demonstration Project

### 3.1 $CO_2$ Capture Unit

The $CO_2$ flue gas from the coal to hydrogen rectisol process will be transported through a pipeline to the $CO_2$ capture unit. This project will adopt one–step liquefaction under high pressure and produces high quality liquid carbon dioxide by compression, gas–liquid separation, purification, liquefaction and distillation.

### 3.2 $CO_2$ Storage and Transportation Unit

This unit combines the storage tanks in the capture and storage units, the $CO_2$ tank car and the injection pump.

### 3.3 $CO_2$ Injection and Storage Unit

This unit includes three plumb shafts, one of which is the injection well, and the others monitoring wells. After being pressurized and heated, the liquid $CO_2$ will be injected into the saline reservoir in a super–critical state.

## 4.Major Achievements of Shenhua CCS Demonstration Project

（1）Indentifying for the first time methods for selecting CCS saline storage sites in China.

（2）This project is a first–of–its–kind exploration of $CO_2$ storage in a saline formation with a low porosity and permeability. Consequently, anatonosis by fracture is introduced in saline storage, which is tailored to the conditions in China.

（3）This project realizes $CO_2$ storage in a limestone formation, which is also a ground–breaking exploration that expands the implementation of CCS technologies and provides new solutions for the storage of $CO_2$ from other sources in the Ordos Basin.

（4）The Shenhua CCS Project pioneers multi–layer hierarchical injection, multi–layer unified injection and layered monitoring injection, which is an exploration of the best injection options for large and industrial scale CCS projects.

# 4. Sinopec CCUS Project: Whole-chain Project of Capture, Transportation, Enhanced Oil Recovery, and Sequestration of $CO_2$ in Shengli Coal-fired Power Plant

Funding Agencies：National Key Technology R&D Program (NO. 2012BAC24A00)

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Carbon dioxide enhanced oil recovery and sequestration ($CO_2$-EOR) is considered to be one of the important technologies to guarantee the safe use of fossil energy, to address global climate change, and to control greenhouse gas emissions. Sinopec Shengli oilfield has plans to build a whole-chain project (0.5-1 million tons $CO_2$/year) of capture, transportation, enhanced oil recovery, and sequestration of $CO_2$ produced by Shengli coal-fired power plant. This project has carried out some primary research on the whole stage process such as capture, transportation and enhanced oil recovery, including development and optimization of the process of large-scale $CO_2$ capture from power plant, schemes for pipeline transport of $CO_2$ , and has chosen two preliminary $CO_2$-flooding areas.

## 1. Introduction

Climate change is one of the most significant threats facing the world today. Avoiding the worst consequences of climate change will require large cuts in global greenhouse gas emissions which will impact international society strongly. The United Nations Climate Change Conference 2009 in Copenhagen emphasized that the increase in global temperature should be limited to below 2 degrees Celsius to combat climate change. Each country has its own obligation to mitigate greenhouses which has become a global issue. A whole-chain project of capture, transportation, enhanced oil recovery, and sequestration of $CO_2$ in Shengli Coal-fired Power Plant is planned to be carried out based on $CO_2$ mitigation and sequestration in a low permeability reservoir in Shengli Oilfield using $CO_2$ sourced from Shengli coal-fired power plant, which will achieve $CO_2$ utilization and mitigation, and provide new methods for environmental protection, and economic and sustainable development.

## 2. Advantages of the whole-chain project in Shengli oilfield

### 2.1 Corresponding research projects in $CO_2$ capture and $CO_2$-EOR

Since 2007, Shengli Oilfield has made great improvements in the technology of CCS-EOR, and undertaken nine national and provincial research projects including two projects funded by National Science and Technology Ministry, one demonstration project funded by the State-owned Assets Supervision and Administration Commission, and 6 projects funded by Sinopec. It has applied for more than 20 patents and published more than 40 papers. Based on the technical researches and pilot tests, a whole-chain demonstration with 100 t/d capacity of $CO_2$ capture, transportation, enhanced oil recovery, and sequestration has been built, which will provide technical experience and support for the large-scale demonstration (1 million tons/year $CO_2$).

### 2.2 $CO_2$ gas source and injection area

Sinopec Shengli Oilfield owns a coal-fired power plant------Shengli Plant, with the installed capacity of 1640MW, burning about 4.1 million tons of coal per annum. As a result, its annual $CO_2$ emission is approximately 7-9 million tons, providing an abundant $CO_2$ gas source. In addition, the total geological reserves of low permeability reservoirs suitable for $CO_2$-EOR in Shengli oilfield are 4.19 × 108 tons, providing a practical capacity for $CO_2$ gas sequestration of over 1.87 × 108 t. Therefore, the geological conditions in Shengli oilfield are suitable for conducting a large scale CCUS application.

### 2.3 Lab construction and research team with multiple majors

Sinopec Shengli Oilfield and collaborative partners have built different kinds of laboratories for $CO_2$ capture, corrosion control in multiphase flow conditions, reservoir simulation, gas flooding, oilfield surface technology, and a whole-chain demonstration. This whole-chain demonstration includes $CO_2$ capture from coal-fired power plant with 100 t/d capacity and G89-1 test platform of $CO_2$ flooding sequestration. In terms of team building, the project team contains engineers from various majors such as oil & gas gathering and processing, corrosion protection, and chemical, reservoir, geological, oil production, environmental, and energy engineering. The team has undertaken and participated in national and provincial research projects, and gained excellent theoretical and practical experiences.

### 2.4 International cooperation and communication

During cooperation at home and abroad, Sinopec has had extensive technical exchanges and cooperation with SaskPower, Siemens, PowerSpan, and Kentucky Applied Energy Research Center. Besides, Sinopec is developing CCUS technology in cooperation with many universities and research institutes such as Tsinghua University, Peking University, China Academy of Sciences, China University of Petroleum, Beijing University of Technology, North China Electric Power University, and China University of Mining and Technology.

## 3. Whole-chain Project of Capture, Transportation, Enhanced Oil Recovery, and Sequestration of $CO_2$ in Shengli Coal-fired Power Plant

The whole-chain project includes the processes of $CO_2$ capture, $CO_2$ transportation, geological sequestration, enhanced oil recovery, and produced liquid gathering and processing with a capacity expected to be 0.5-1.0 million tons $CO_2$/year. The $CO_2$ capture and transportation units will handle 1 million tons/year, with more than 85% capture efficiency, more than 99.5% purity, and less than 2.7 GJ/t$CO_2$ regeneration energy consumption. The enhanced oil recovery and sequestration units will handle 0.6 million tons/year, with more than 5% EOR efficiency, and more than 50% dynamic sequestration efficiency (which is defined as the ratio of a total mass of $CO_2$ sequestration to injection during a specific time).

The whole-chain project is expected to be launched in 2013 and completed in 2017. The expected operational period is 15 years. Shengli Oilfield has chosen two preliminary $CO_2$-flooding areas after the exploration and development of low permeability reservoirs. One area is for 1 million tons/year $CO_2$-EOR with flue gas from Shengli coal-fired power plant as its $CO_2$ source, and the pre-feasibility research on $CO_2$ capture has been started. The distance from Shengli Power Plant to the $CO_2$-flooding area is 80 kilometers. The other one is for 0.5 million tons/year $CO_2$-EOR with coal gas from Sinopec Qilu Petrochemical company as its $CO_2$ source, and the pre-feasibility research on $CO_2$ pipeline transportation has been started. Pipeline transportation technology has been investigated. The $CO_2$ phase and pressure has been primarily determined. The distance from Qilu Petrochemical Company to the $CO_2$-flooding area is also 80 kilometers.

# <<< 人物专访

## 1. Andrew Minchener描绘CCS和清洁煤在中国的发展前景

Dr Andrew Minchener, general manager of the IEA Clean Coal Centre.

荣获大英帝国最优秀勋章(OBE)的Andrew Minchener博士在煤炭行业拥有超过35年的工程和管理经验，并且在碳捕集与封存及清洁煤领域取得卓越的成就。Andrew长期以来在很多机构负责项目执行，包括国际能源署(IEA)清洁煤中心、亚洲开发银行、世界银行、英国能源与气候变化部以及欧洲委员会。Andrew最近被委任为IEA清洁煤中心的总经理。他一直领导多个在中国的CCS大型技术协助和开发研究合作项目。Andrew是一个多才多艺、成功的管理者和经验丰富的行业专家。

**问：Andrew，您好，您一直以来管理和完成了多个成功的研究和工业项目，请问您可以与我们分享哪个项目让您觉得最为吸引、振奋和难忘呢?**

Andrew：基于各种原因，所有在中国的项目都让我感到很印象深刻！然而，我想特别提到中国－英国煤炭利用近零排放(NZEC)项目，其构建了整个欧洲－中国合作活动的主要部分。我的工作是支持英国能源与气候变化部(DECC)设计、执行和宣传主要的CCS能力建设项目，涉及的人员包括对CCS充满热忱的英国团队以及由工业和学术界组成的一个范围广泛的中国利益相关者团队。在DECC和一个外部专家Paul Freund的支持下，我们用了很多时间预先了解中国科学技术部的政府官员，以确保我们全面理解他们的需求。这使我们可以设计一个有价值的工作计划，包括二氧化碳捕集的主要方面和二氧化碳地质封存选项特征化研究及各种各样系统选项的具体技术经济评估。我确信NZEC在中国推进CCSR方面扮演了一个重要的角色，其研发项目处于全球CCS活动的领先地位。

**问：很明显您在全世界清洁煤技术的开发和知识传授方面做出了突出贡献。在2012年，英国政府在新年受表彰人员名单中授予您大英帝国最优秀勋章(OBE)。据某些报告所说您已经在来个中国超过130次。请问您第一次访问中国是什么时候? 什么原因或信心促使你经常来到遥远的中国?**

Andrew：在温莎城堡的典礼上从女王陛下手中得到大英帝国最优秀勋章授奖是我极大的光荣。

我第一次访问中国是受到欧洲委员会的邀请来到哈尔滨锅炉工程学研究中心讲授清洁煤流化床培训项目。我每天工作6个小时进行演讲和教程，

每周六天，这是一个令人难忘及很有收获的经验。

我一直保持访问中国及在中国工作是因为这是一个工业化快速发展的国家，正在尝试在能源安全、环境影响以及经济竞争力方面取得平衡。现在包括建立低碳未来的需求，同时持续成为全世界最大型煤炭使用国。正如所有这些都在进行当中，而我感到能够协助中国在应对这些挑战和捉住这个机遇 方面做出正面的贡献。

**问：中国是最大型的煤炭消耗国，但是煤被认为是中国环境污染的主要来源。中国中央政府在 2013 年中已经宣布了 10 项措施来应对空气污染，并且在上个月发布了行动计划（2013 年 10 月）。中国某些地区开始考虑设置一个绝对的煤炭消耗上限。你认为中国最近政策改变情况对于煤炭行业来说是威胁还是机遇呢？中国将很快地从煤炭转型到天然气吗？**

Andrew：煤炭可以是空气污染的主要来源，尽管运输行业是也是一个主要的来源。中国正在进行重要的步骤来控制煤炭相关污染排放，对碳氧化物、硫氧化物 以及空中微粒采用非常严格的排放标准，以及强硬的驱使力来提高电力生产效率。这些使能源组成更多样化的措施非常重要，而气体扮演着重要的角色。然而，煤炭将必须维持作为主要的能源来源，因为政府确保落实更清洁和高效地利用煤炭等法规框架是至关重要的。

正在改变的政策环境对于未能认识到其改变的煤炭利用者来说将会是威胁，而对于认识到其改变的煤炭利用者来说是机遇。例如，我刚刚访问了上海外高桥 3 号发电厂，与总工程师冯伟忠及我非常好的朋友清华大学的毛健雄教授交流了一天。该发电厂是一个在 2008 年开始运行的 1000 兆瓦发电功率电厂，并且取得 42.7% 的年净效率（LHV 基准）。冯先生不辞劳苦地在 2012 年底前把其提高到了 44.4%，同时提高各种污染物控制系统的性能。他还有完善的计划在不需要先进材料开发的情况下提高电厂效率到 49%。

**问：请问您对于新兴的“煤制气”技术方向的技术和商业前景有什么看法呢？诸如合成天然气（SNG）和地下煤气化（UCG）？**

Andrew: 通过气化进行的煤转化能够转化煤炭为燃气和化学物质，并且提供途径来降低其转化排放（非温室气体）及降低对于进口石油和天然气的依赖。首先从能源安全的立场来看，中国确认了多样化的战略需求来生产石油化工产品，并且在建立煤气化技术来利用煤炭作为化学物质和燃料生产的原料方面已经走在世界前沿。这些活动首先专注于 用于化肥生产的氨生产，及生产甲醇作为可能的燃料或者作为诸如甲醚等材料的中间原料。这个计划继续保持其重要性，特别是存在主要的驱动力来建立煤到合成天然气流程，而看来各种各样的煤到油技术可能向前发展。然而，同样重要的是一直在进行的把煤气化应用于烯烃生产作为一种手段来建立较高附加价值的塑料盒纤维市场。除了这些扩展的和新的市场活动以外，还有其他煤到化工技术的持续评估，利用煤到乙二醇和煤到芳香剂的研究和开发正在进行当中。

就是说我们需要认识到煤到化工流程是水资源的大型使用者和可能成为二氧化碳排放的大型点源。因此，为了开发其可持续发展议程，中国国家发改委已要求集中审批新型煤转化项目，并且出台了了各种各样对于使用水、能效以及环境保护的限制，包括能够及时地应对二氧化碳排放的能力。在我的意见看来，中国为所有阶段的工业发展周期内的大规模煤到化工、气体和液态燃料开发提供了一个模型，。这展示了在示范中从技术角度上能够实现的程度，当技术成熟后，紧随的各种各样方案以确保可接受的经济表现 将成为主要的因素。

**问：英国在 1970 年前也经历了长期的空气污染。请问您认为中国应该在哪些主要技术领域尽快与英国合作开发清洁煤技术？**

Andrew: 英国主要城镇的空气污染 是由靠近人口集中地区而缺乏污染物控制系统的小型煤电厂及大部分使用煤来取暖的家庭用户所造成的。这些问题通过关闭小型发电厂及从煤转化为天然气作为家庭取暖和煮食得到解决，取代这些小型发电厂的是具备更好控制系统的大规模电厂。在人口高度集中的华东地区，从煤气转化为天然气作为取暖和煮食的家庭用户、引进燃气发电厂以及热电联合正在逐渐地增多。这从我看来假如能够建立起足够的气体源，在不久的将来会受益良多。

**问：CCS 是唯一能够从化石燃料燃烧中取得深度减排的技术。然而，看来目前全球 CCS 活动远远地落后于早期预计。请问您认为需要加快碳捕集与封存实现全球商业化的主要驱动力是什么？**

Andrew: 这些问题最终都不是技术问题。三个主要的二氧化碳捕集选项的任何一个都处于一个需要应用大规模 CCS 全链示范的阶段。这些问题正在为这些项目寻求足够的融资机制，并且需要建立一个适当的政策和法规框架来支持这些项目。

**问：中国公司已经开发了大量的**

**中试 CCS 项目。在 2013 年 4 月，中国国家发改委宣布了公告来支持 CCS 项目示范。请问您认为中国可能成为 CCS 方面的主要参与者，及可以很快实现第一个百万吨项目吗？鉴于您在煤和环境行业的丰富经验，请问您对中国政府在设计可行的 CCUS 示范项目有什么想法和建议吗?**

Andrew: 中国已经开发了世界领先的工业中试规模 CCS 项目，从一个技术和工程观点来看，这是一个可以开发商业模型的机遇。诸如亚洲开发银行等机构正在紧密地与中国国家发改委合作来试图推进那些寻求前端工程设计研究（FEED）的项目，特别是电力行业。欧洲委员会继续跟进中英近零排放（NZEC）项目，也正在企图资助一个类似的 FEED 研究。然而，先不谈论仍存在的融资问题。其他可能性需要考虑在煤到化工行业的示范，这在中国正在迅速地发展，无论在项目数量和单个项目的规模上看，与那些中等规模的煤电厂对比时那些来自大型设施的年度二氧化碳排放十分显著。正因此，许多这些电厂代表着示范的重要早期机遇， 以帮助中国建立起在 CCS 全链上的专业知识。在这些气化炉上示范 CCS 的好处是这些结果将适用于很多煤炭行业的整体技术开发，并且与燃煤发电厂的运行相比，项目可以在极低成本的情况下进行。这是因为二氧化碳已经作为一个浓缩气流被生产出来，因此 CCS 边际成本基本上等于二氧化碳的压缩、运输以及注入成本，大大地低于必须包括二氧化碳捕集在内的成本。

在中国不同的工业地点也有其他集群点。这代表着大量累积的二氧化碳排放点源，这与 发电行业和个别非发电选项对比，展现出以非常低的边际成本在中国示范一体化 CCS 网络的前景。也展现出利用二氧化碳提高石油采收率的前景，因此创造出将会降低示范项目净成本的收入流。

**问：成本和能源损耗仍是 CCS 技术开发的主要阻碍。据您所知和观察，请问是否存在第二代技术可能或者有希望降低成本和二氧化碳捕集的能源损耗?**

Andrew: 我不想挑选出一种或者数个技术看起来非常有前景。然而，重要的是记住所有新技术开始时是一个概念，那些被估计具有足够吸引力的能源效率和投资成本通常会得到支持。因此当概念得到发展，开发现实意味着可能的效率下降和可能的成本增加。最终这些概念必须被带进大规模的运行中，从而可以利用工程解决方案来处理出现的问题及计算出更为准确的整体成本预算。因此重要的是这些开发的资助机构需要在开发周期内保持他们的耐性。

**问：合作可以带来协同作用，及加快实现全球环境目标，但是某些西方公司或者研究机构通常觉得合作很困难或者有时在适应存在差异的中国工作文化和法律系统感到很失望。请问当您在中国第一次开始 CCS 和清洁煤 合作任务时有感到中西方之间存在的文化差异吗? 您有过不愉快的经历吗? 请问您对于在合作中如何处理文化差异及带领跨国文化团队方面有什么实践建议吗?**

Andrew: 回到 1980 年和 1990 年早期，曾存在巨大的文化差异，在构建团队时的主要要求曾是确保具备一个能够理解项目意图的优秀传译者。我很幸运当初与天津大学火力工程部门建立起了牢固的合作关系，我的朋友当时也帮我建立起桥梁。在早期的日子里充满了怀疑，我花了很多时间与合作双方进行谈话，尝试并确保促进双方的相互接纳。就是说原则仍然维持良好。就像我之前说的，中国－英国 NZEC 项目取得了成功，因为我们在准备阶段下了苦功来确保合作双方充分理解对方的观点，使我们可以建立一个属于所有参与的利益相关者项目。

**问：您明显拥有非常成功的职业生涯，植入我们所知您也是一个尽职的好父亲。请问您是怎样在非常繁忙的工作和国际旅游要求中平衡家庭和工作之间的关系? 您的孩子理解清洁煤的重要性吗?**

Andrew：这是一个非常困难的问题。我必须首先感谢非常理解我的妻子 Linda，她总是能认识到我工作的性质及其责任。我四个孩子知道我长期不在英国工作。他们也能清晰地理解能源在全世界范围内都是至关重要的，并且其利用在地区之间会有很大不同。此外他们理解确保可接受的能源安全和可接受的环境影响并且保留经济可竞争性的解决方案并不是许多著名评论员和政客所理解那样容易！

## 2. Bill Senior 谈中英近零排放合作

Bill Senior

Bill Senior 是一名专门从事碳捕集与封存的独立顾问。他毕业于牛津大学的地质学系。他曾受雇于欧洲委员会、英国政府、英国石油公司和多家咨询公司。他擅长 CCS 项目的开发，同时对地质封存以及政策 / 法规有深入的见解。他在 CCS 项目方面的经验有在英国、阿尔及利亚（In Salah 项目）以及中国（近零排放项目和广东项目）等。他是《政府间气候变化专门委员会（IPCC）CCS 专题报告》有关地质封存和经济学章节的第一作者。最近，他一直在参与《欧洲 CCS 指令》实施指导文件的准备工作，为能源与气候变化部评估英国地质封存的工业潜力，而且是能源与气候变化部有关目前英国 CCS 竞赛的顾问。

Bill 以前曾在英国石油公司的商业和技术部门履职 32 年，他的工作涵盖可替代能源、天然气的勘探和开采等方面。他曾是英国石油公司碳捕集与封存技术首位技术经理和其后的英国石油公司可替代能源公司的高级顾问。他在石油地质学和上游石油业务的早期职业经历为其在地质封存方面的专业知识打下了基础。在 G8 峰会和 2004—2006 年欧盟轮值主席国期间，Bill 还曾被借调到英国政府的国际气候变化小组。他曾在欧洲、美国、东南亚、中国和俄罗斯工作过。

**问：请问您是什么时候开始您的第一个碳捕集与封存任务的？在起草《政府间气候变化专门委员会 CCS 专题报告》方面您的角色是什么？**

我 2000 年第一次参与 CCS 时正在为英国石油公司在新加坡工作。英国石油公司对马来西亚近海的一些二氧化碳含量高的气田产生了兴趣，其天然气中的二氧化碳含量高达 35%， 因此我们决定考虑通过 CCS 和 EOR 结合来减少二氧化碳排放。我们早期的工作表明，当在附近油田进行 EOR 或在把二氧化碳重新注入这些气田时，从天然气利用膜分离二氧化碳应该是可行的。最终在我们解决这一挑战之前，英国石油公司出售了这些气田，而我作为 CCS 技术经理回到了英国。

有关《政府间气候变化专门委员会 CCS 专题报告》的工作开始于 2003 年在加拿大里贾纳市韦本油田附近举行的一次专家会议。我作为该报告《CCS 的封存与经济学》章节的第一作者受邀参加会议。与来自世界各地的顶尖专家一起工作是一项有趣的任务和机遇。每一个章节都有一组作者，而我在关于《封存》的章节遇到了我的朋友——来自中国南海海洋研究所的周蒂教授。关于诸如二氧化碳泄漏的可接受程度和封存能力的估值与估算等主要问题，封存专家之间进行了长时间的讨论和争论。以广泛的同行评议起草该报告是一个漫长、艰辛和细致的过程。然而，该专题报告的发布，在为 CCS 在减缓气候变化和获得 IPCC 与国际利益相关者认可的案例制作方面，是一个主要的里程碑。

**问：世界上很多现有的集成 CCS 项目是由陆地提高石油采收率（EOR）共同融资的。但是在世界范围内海上二氧化碳 EOR 项目似乎非常有限。请问您对海上二氧化碳 EOR 技术的潜力及其推广潜力持何种观点？**

虽然二氧化碳利用因为经济效益以及有潜力开采更多的石油而看上去似乎很有吸引力，但是二氧化碳 EOR 并没有在海上油气田中开始进行，因此考虑这种情况的原因十分重要。许多北海的油气田已经研究过二氧化碳 EOR，虽然一些运营商正在尝试，但是迄今为止毫无进展。许多挑战中的大部分与额外开采潜力、EOR 性能和选择、设施、转换成本、二氧化碳供应和经济状况有关。北海许多油气藏的地质特征非常好，意味着初采和水驱（通常称为二次开采）的采收率已经非常高。因此， EOR 可能开采的剩余的油就减少了。因为海上实施一种高成本的运营，并且可能需要大量的资金来安全地转化或代替这些可能已经使用了多达 30 年的基础设施

和油气井，来接通二氧化碳供应。所以，这一方案还有经济挑战。

除了利用二氧化碳以外，石油公司还有许多其他选择可用于提高石油采收率。这些包括混合气体注入、热气流注入、化学品注入以及低盐度水注入。自然地，石油公司将会分析哪一种对其油田最适合和最有吸引力，二氧化碳 EOR 必须与之竞争。在中国我了解到在渤海湾已经有了 EOR 的丰富经验，但是那是利用化学品，而不是二氧化碳。然而，如果二氧化碳供应可以作为 CCS 网络的一部分进行开发，二氧化碳 EOR 的经济性可能也会变得更有吸引力。

**问：似乎欧洲的 CCS 指令已经对开发大规模 CCS 项目制造了重大的技术和监管障碍，尤其在义务和责任管理方面。您对中国在开发二氧化碳封存债务框架有何建议?**

当该 CCS 指令在 2008 年引进时它曾是一个重大进步，因为它欧盟建立了安全封存监管框架。指导文件紧跟其后，并且在可能利用 CCS 的欧洲国家执行。关于封存后义务及法律责任如何处理、财政安全以及资产转移仍然存在忧虑。这些忧虑是关于法规如何在实践中解读和使用，这就是为什么真正的项目经验和实施法规至关重要的原因。即使那样，在我们最终停止注入并且关闭封存项目之前，可能需要数十年。这些问题还取决于将要使用的封存点的安全性和泄漏风险。尽管我知道在有相同的地质理解和地下风险评估的不同利益相关者之间存在沟通和理解问题，但我个人认为被很好塑造、监控和监管的封存点的潜在泄漏风险非常非常低。至于中国的监管网络，有机会学习其他司法管辖区的经验，然后制定出最适合自己的监管网络。

**问：请问您第一次访问中国是什么时候?您从英国 – 中国煤炭利用近零排放项目中取得的主要成果和经验是什么?这是一项艰苦的工作吗?**

我第一次访问中国是 1990 年，当时英国石油公司（BP）已经在和中国南海和渤海类似的离岸盆地开展上游石油气事业，而在诸如塔里木、准噶尔以及四川等陆上盆地给外国公司开放了新的机遇。这使我对于中国很多盆地的地质情况有了一定了解，这些盆地现在成为了二氧化碳封存的候选者。

煤炭利用近零排放的发起来自于 G8 会议和欧盟气候变化活动 2005，当时我暂时在英国环境部、食品与城乡事务部工作。其跟进了在 2005 年欧中峰会声明中领导人同意的“在中国通过碳捕集和封存开发与示范欧盟先进的近零排放煤炭利用技术。”包括在政治协议中的 CCS 概念曾是开创性的，我记得与中国国家发展与改革委员会和中国科技部的首个会议展开了讨论结合煤的 CCS 角色，确定了煤炭利用近零排放（NZEC）这个名称。

在执行 NZEC 和 COACH 等的项目时，在中国和欧洲赞助商和合作伙伴之间的协调曾遇到很多困难，但我很荣幸最后都得到解决。NZEC1 期是一个创新的项目，与中国分享欧洲和英国在 CCS 方面的经验。这有时被称为能力建设和合作。这展现出 CCS 结合煤可以大规模地在中国降低排放，并且展示了可行的捕集技术和封存选项。我希望这能帮助探索出 CCS 的进一步工作方向，目前 CCUS 在中国区的的进展使我感到很受鼓舞。

**问：中国政府在其 CCS 战略中已经强调了二氧化碳利用的重要性。除了 EOR 以外，请问您在其他二氧化碳地质利用方法上有什么见解吗?诸如二氧化碳煤层甲烷、页岩气水力压裂、二氧化碳恢复地下水资源。**

2010 年，中国某些二氧化碳提高煤层甲烷的中试测试得到了加拿大的支持，但我不清楚它有多成功及是否已经在扩大规模。在其他方面，当二氧化碳注入后的煤增大可以产生渗透性和注入性的损失。

页岩气水力压裂在美国已经是一个成熟行业，并且可能影响未来封存，虽然页岩气仍处于中国的早期阶段。但是对我来说不明确的是在水力压裂中的气体生产是否将会由于二氧化碳的注入而得到提高。结合数以千计钻井和迅速下降来促进二氧化碳注入的页岩气项目性质、以及废弃和断裂页岩区域将会是一个完整封存场地也是不明确的。加上我只看到很少的工业兴趣。但是页岩气和封存机遇可能重叠。项目开发者将需要理解与其他封存的潜在重叠，在钻井渗透的封存和在页岩气开采后的页岩封闭完整性的潜在影响。我还是感兴趣看到中国如何开发页岩气和应对其他诸如水资源可用性和环境风险的挑战。

总的来说，我对于这些二氧化碳利用能够在中国或者世界其他地区实现大规模减排的可能性并不是很乐观。这些观点很重要，我们不想给政策制定者一种能够简单快捷处理问题同时带来可观的经济效益的虚假希望。

**问：您为英国能源与气候变化部草拟了一份关于在英国开发二氧化碳封存工业的行业潜力和社会经济效益的重要方案。基于您作为广东 CCS 预留和 CCS 合作活动顾问的专业知识，请问您认为在广东南海地区具备相同的工业机遇吗?**

是的，我看到在英国的环境和广东之间有很多类似的地方。这两个国家在离岸盆地都具备极好的大规模地质封存潜力，因为地质特征很有利，并且拥有来自油气田的既有基础设施、井、数据和知识。在沿海上的主要排放点源也具备良好的潜力来开发集群和枢纽，分享能够减少交通和封存成本的基础设施。这能促使在两个国家的工业新机遇，尽管某些主要的参与者将会不同。例如发电厂拥有者和石油公司。有趣的是在中国一些将要参与进来的中国石油公司已经在英国的数个主要油田进行了投资，这些项目也包括了某些二氧化碳提高石油采收率和封存的候选者。

**问：在开发二氧化碳封存场地时存在较长的交付周期。请问您有什么意见给中国来确保在二氧化碳封存和基础设施建设的中长期能力要求，以避免排放锁定反应?**

没错。我可以用好几年时间来作定义、特征化研究和开发封存场地。这个速度可能决定着整体 CCS 项目的步伐。必须进行的新地震探查和开发新开采或者井钻探需要花费时间和金钱。这是因为我们需要不同的数据来定义油气田的特征，诸如盖层取样和测试。中国将需要尽早理解这些要求，并且将需要考虑怎样资助和执行这个至关重要的活动和怎样把工业参与尽早带进来。把 EOR 潜力和油气解除计划考虑在内也是必要的。

在未来 CCS 链的另一端，CCS 预留法规和工程应用对于避免新建发电厂和工业的碳锁定反应是必不可少的。这在广东的研究工作当中已经进行了探索。中国可以参考欧洲和英国在发电行业的 CCS 预留法规。

**问：大量的固定排放源位于中国沿海地区。请问您认为是否存在可能的国际融资机制给中国在离岸咸水层开发和运行结合二氧化碳封存的大规模 CCS 示范项目?**

在中国的很多排放源位于沿海地区，特别是在广东和其他南部省份。我看到这些与离岸封存机遇很吻合，诸如拥有比陆上封存潜力大得多的珠江盆地，并且封存将会远离人口密集地区。

国际气候变化谈判一直以来很在缓慢艰难中进行，这令人很失望，我不确定今年华沙会议上取得怎样的进展。带来的是关于清洁发展机制和未来国际政策法案及将如何应用于 CCS 的很多不确定性。国际谈判多年以来一直强调 CCS，我希望他们意识到其在减排的重要性。英国能源与气候变化部已经宣布了支持中国 CCS 的某些资助，希望这可能用在示范项目。

**问：这看来 CCS 的全球开发速度并未如预想中顺利。在欧洲，哪种必要的激励机制您相信可以促进大规模碳捕集和封存项目的投资?请问您认为二氧化碳封存认证系统比目前的激励框架更好吗?**

自从 2008 年的金融危机以来，CCS 示范和开发进展已经明显地受到阻碍，并没有我在欧盟、挪威以及澳大利亚（最近在政治变化后都遭受到倒退）时预期那样顺利。我们仍在英国利用示范计划缓慢地推进 CCS。在另一方面，我们感到很欣慰看到中国在 CCUS 方面的前进和其他项目在美国、加拿大以及巴西得到落实。但气候变化的问题并没有解决，而且在世界上还有很多极端气候事件发生，即使单独一个事件的发生不能完全地归结于气候变化。

从政策的角度看，政府通过资金补助和运行支持等来对大规模示范项目（和封存特征化研究）进行支持是必不可少的。展望未来 CCS 开发，正在制定的各种不同的政策和激励措施大部分仍需要进行验证和测试。我不是政策专家但也能观察到这种状况。

欧洲的排放交易系统碳价格已经完全收缩了，但我认为问题是以它之前的碳价格是否可以提供必要的长期信心来支持 CCS。同样的关注可能在清洁发展机制类型的方案。在挪威气体领域的 CCS 已被商业化，他们已经实施离岸排放的碳税很长一段时间了。可能影响电力行业 CCS 的新政策机制通过电力市场改革和美国排放表现标准正在英国出台。英国政策希望通过差异长期合约或者差价合约来对 CCS 开发提供长期支持。原则是差价合约会填补需要引进在既定技术投资的电力市场估计价格和长期电力估计价格之间的差异（执行价格）。

这些政策必然是复杂的，需要调整使其适应特定的市场和工业部门。我们必须记住我们需要为气候变化做点事情，因此我们需要 CCS 来限制未来排放。这需要工业和商业机遇。需要政治和政策给工业提供长期稳定的信心来投资 CCS 和开展将会带来竞争、成本下降和造福所有人的创新周期。

**问：除 CCS 以外，请问您有其他兴趣或者让您感到兴奋的业余活动吗?**

我想目前大部分的工作仍是在 CCS 方面，让我们所有人都行动起来是非常重要的。我两个孩子都在读大学，因此他们不常在身边，但是我也尝试抽出时间给其他兴趣爱好，比方说旅游、板球、品酒、爵士乐、学习萨克斯管和绘画。

# 1. Andrew Minchener: Vision on CCS and Clean Coal Development in China

Dr Andrew Minchener, general manager of the IEA Clean Coal Centre.

Dr Andrew Minchener OBE has over 35 years engineering and managerial experience in the coal industry, with significant achievements in carbon capture and storage and clean coal areas. Andrew has been working as project leads for a number of organisations, incl. IEA Clean Coal Centre, Asian Development Bank, the World Bank, UK Department of Energy and Climate Change and the European Commission. Andrew recently has been appointed as the general manager of IEA Clean Coal Centre. He has been led a number of major technical assistant and research collaboration projects in CCS in China. Andrew is both a versatile, successful manager and an experienced, knowledgeable industry expert.

**Q: hi, Andrew, having managed and completed a large number of successful research and industrial projects, could you share which project (s) do you feel most interesting, exciting and memorable?**

Andrew: All my projects in China have been memorable for various reasons! However, I would like to highlight the China-UK NZEC project, which formed a key part of the overall EU-China cooperation activity. My role was to support DECC in the design, implementation and dissemination of what became a major CCS capacity building project, involving a UK team of CCS enthusiasts who worked alongside a wide ranging team of Chinese stakeholders from industry and academia. With DECC and a fellow external expert, Paul Freund, we spent a lot of time upfront in getting to know the government officials from MOST to ensure that we fully understood their needs and aspirations. That allowed us to design a valuable work programme covering key aspects of $CO_2$ capture and the characterisation of geological storage options for $CO_2$ together with detailed techno-economic assessments of various system options. I am firmly of the view that the NZEC project played a major role in China taking forward the extensive CCS R, D&D programme that is at the forefront of global CCS activities.

**Q: You obviously have made significant contributions to the development and knowledge transfer of clean coal technologies in the world. In 2012, you have been recognised by the British government and awarded the Most Excellent Order of the British Empire (OBE) in the New Years honours List. Some report said you made over 130 missions to China. When did you first time visit for work in China? What are the key drivers or belief that motivates you to frequently travel to the far-east?**

Andrew: Receiving the OBE was a great honour, which I received from Her Majesty the Queen in a ceremony at Windsor Castle.

I first visited China on business when I was asked by the European Commission to provide and present a clean coal fluidised bed combustion training progamme at the

Harbin Boilers Engineering Research Centre. I gave lectures and led tutorials for six hours a day six days a week, which was an amazing and rewarding experience.

The reason that I keep visiting and working in China is because it is a country that is industrialising at a fast rate and is very much trying to balance energy security , environmental impact and economic competitiveness. This now includes the need to establish a lower carbon future while continuing to be the largest coal using country in the world. As such it is where it is all happening and somewhere where I feel that I can make a positive contribution to assist China in addressing its challenges and seizing its opportunities.

**Q: China is the largest coal consumer, but coal is considered as the main source of Chinese air pollution. The central government of China has announced 10 new measures to fight air pollution in mid-2013 and issued an action plan last month (Oct 2013). Some regions in China started to consider setting up an absolute cap for coal consumption. Do you think the recent changing policy environment in China would be a threat or an opportunity for the coal industry? Will China rapidly shift from coal to natural gas?**

Andrew: Coal can be a major source of air pollution although the transport sector is a major contributor too. China is taking important steps to control coal related pollutant emissions with very stringent emissions standards for NOx, SOx and particulates and a strong drive to increase efficiency of power generation. The measures to diversify the energy mix are important and gas has an important role to play. However, coal will remain have to remain the major energy source and so it is critical that the government ensures that there is a regulatory framework in place such that coal is used as cleanly and efficiently as possible.

The changing policy environment will be a threat to those coal users that do not recognise the changing circumstances in China and an opportunity to those who do. For example, I have just been to visit Waigaoqiao no.3 power plant in Shanghai and spent a day with the Chief Engineer Mr Feng Weizhong and with my very good friend Prof Mao Jianxiong of Tsinghua University. The plant is a USC 1000MWe unit that started operation in 2008 and achieved an annual net efficiency of 42.7% (LHV basis). Mr Feng has worked tirelessly to improve on that and has raised it to 44.4% by end 2012, while also improving the performance of the various pollutant control systems. He also has credible plans for a plant that could achieve 49% without the need for advanced materials development.

**Q: what is your view on the technical and commercial perspective of emerging ‘Coal to Gas’ technology pathways, such as coal synthetic natural gas (SNG) and underground coal gasification (UCG)?**

Andrew: Coal conversion via gasification can transform coal into both fuels and chemicals, and offers a means by which it can reduce both its conventional (non-GHG) emissions as well as its reliance on imported oil and natural gas. Initially, from an energy security standpoint, China identified a strategic need to diversify the means to produce petrochemical products and has taken a global lead in establishing gasification technology to use coal as a feedstock for chemicals and fuels production. Its efforts first focused on the production of ammonia for fertiliser production and methanol either as a possible fuel or as an intermediate feedstock for materials such as DME. This initiative continues to be important, and in particular there is a major drive to establish coal-to-SNG processes while it seems probable that the scale-up of various coal-to-oil technologies may move forward. However, equally importantly, there has been a move to apply coal gasification for the production of olefins as a means to establish higher value-added markets for plastics and fibres. Alongside these scale-up and new market activities, there is a continuing assessment of other coal-to-chemicals techniques, with research and development of coal-to-glycol and coal-to-aromatics processes under way.

That said, there is a need to recognise that coal to chemicals processes are large users of water and can be large point sources of $CO_2$ emissions. Consequently, in order to develop its sustainability agenda, the NDRC has demanded centralised approval for new coal conversion projects and has introduced various constraints regarding water use, energy efficiency and environmental protection, including the capability to be able to address $CO_2$ emissions in due course. In my opinion, China offers a template for large-scale coal-to-chemicals, gaseous and liquid fuels deployment, for all stages of the industrial development cycle. It has shown what can be achieved from a technical standpoint while demonstrating, as technology familiarisation has been achieved, that there are various routes that can then be followed to ensure acceptable economic performance becomes a key factor.

**Q: Britain also experienced a long period of air pollution before they were cleaned up in 1970s. Do you think there are some key technical areas should China collaborate with UK in developing clean coal technologies immediately?**

Andrew: The air pollution in the major cities and towns of the UK was caused by a combination of small coal power stations with inadequate pollutant control systems located close to large population areas and the fact that most households used coal for home heating. The problems were addressed by the closure of the small power plants, their replacement with larger units with better control systems, and the switch from coal to gas for home heating and cooking. In the densely populated regions of Eastern China there is an increasing switch to gas for cooking and heating and the introduction of gas fired power plants and CHP schemes. So its eems to be me that providing there are adequate gas sources established, you should see the benefits in the near future.

**Q: CCS is the only technology that could achieve a deep cut of carbon emissions from fossil fuel combustion. However, it seems that the current global CCS activities are far behind IEA's earlier estimate. What do you believe the key drivers needed to speed carbon capture and storage (CCS) to commercialisation globally?**

Andrew: The problems are ultimately not technical. Each of the main three $CO_2$ capture options are at a stage where a large scale CCS full chain demonstration should be implemented. The problems are finding an adequate financing mechanism for such projects, and the need to establish an adequate policy and regulatory framework to support such projects.

**Q: Chinese companies have developed a large number of pilot scale CCS projects. In April, 2013, NDRC announced a notice to support the demonstration of CCS projects. When do you think China could be a lead player and implement the first mega tonne project soon? Given your rich experiences in the coal and environment sector, do you have thoughts and suggestions for the Chinese government in designing potential CCUS demonstration programme.**

Andrew: China has developed some world leading industrial pilot scale CCS projects, and from a technical and engineering perspective is in a position to develop commercial prototype opportunities. Organisations such as the Asian Development Bank are working closely with the NDRC to try and move forward such projects by seeking to support FEED studies, especially in the power sector. The European Commission, in a follow-on to the NZEC project, is also seeking to fund a similar FFED study. However, beyond that stage the financing issue remains. The other possibility is to consider demonstrations in the coal to chemicals sector, which is growing rapidly at least in China, both in terms of the number of projects and the scale of the individual projects, with annual $CO_2$ emissions from the newer larger units comparable to those of a medium size coal power plan. As such, many of these sites represent important early opportunities for demonstration that will aid China in building up expertise on all aspects of the CCS chain. The attraction of demonstrating CCS on such gasifiers is that the results would be applicable to the overall development of the technology for many coal using sectors and projects could be undertaken at significantly lower costs compared to operations on a coal-fired power plant. This is because the $CO_2$ is already produced as a concentrated stream and so the CCS marginal costs are essentially those of $CO_2$ compression, transport and injection, which are much lower than those where $CO_2$

capture also has to be included.

There are also clusters of sites in various industrial locations within China. These represent cumulative large point sources for $CO_2$ release and offer the prospect for demonstrations of integrated CCS networks within China at significantly lower marginal costs compared to the power sector and to individual non–power options. There is also the prospect of using the $CO_2$ for EOR, thereby creating arevenuse stream that will lower the net cost of the demonstration project.

**Q: Cost and energy penalty are still a main barrier for the deployment of CCS technologies. Are there any second generation technologies, to your knowledge and perception, likely or promising in bringing down the cost and energy penalty of $CO_2$ capture?**

Andrew: I don't want to pick out one as several look very promising. However, it is important to remember that all new technologies start out as a concept and those with attractive enough guesstimates of energy efficiency and capital costs will often get supported. Then, as that concept is developed , the development realities mean that the probable efficiency goes down and the likely costs rise. Ultimately, these concepts have to be taken forward to a significant scale of operation whereby engineering solutions to the problems arising can be introduced and better estimates of the overall costs can be produced. So it is important for the funding agencies of such developments to keep their nerve during the c development cycle.

**Q: Collaboration could bring synergy and may accelerate the achievement of global environmental goals, but some western companies or research institutes usually found collaboration hard or sometimes frustrating in cope with Chinese working culture and legal system differences. How did you find the cultural differences between China and Europe when you started the first few collaborative assignments in CCS and clean coal? Did you have any bad experiences? Do you have any practical recommendations for dealing with cultural issues in collaboration and leading a cross–culture team?**

Andrew: Back in the 1980s and early 1990s, there was a major cultural gap and the key requirement in setting up a team was to ensure that you had a good interpreter who also understood the purpose of the project. I was fortunate to have built up a strong working relationship with the Thermal Engineering Department of Tsinghua University and my friends there were invaluable in helping to build bridges. In those early days there was suspicion and I spent a lot of time talking to both sides to try and ensure mutually acceptable way forward. That said, that principle still holds good. As I mentioned previously, the China–UK NZEC project was successful because we worked very hard at the preparatory stage to ensure that both sides understood the other's point of view and so that we could establish a programme that was owned by all the stakeholders involved.

**Q: you obviously have a very successful career, and as we know you are also a good father undertaking significant family obligations. How would you balance family and work with your very busy time schedule and international travel requirements? Do your children understand the importance of clean coal?**

Andrew: That is a difficult question to answer. I must first acknowledge my very understanding wife, Linda, who has always recognised the nature and consequent obligations for my work. My four children have always known that their father doesn't work in the UK so much. They also understand very clearly that energy is of critical importance worldwide and that its use varies enormously from region to region. Furthermore they appreciate that the solutions to ensuring acceptable energy security, with acceptable environmental impact while remaining economically competitive, are not as straightforward as many well–known commentators and politicians make out!

## 2. Bill Senior: Thoughts on UK–China Near Zero Emission Coal Collaboration

Bill Senior

Bill Senior is an independent consultant who specialises in Carbon Capture and Storage. He has worked for the European Commission, UK Government, BP and consultancies. His main expertise is in CCS project development, geological storage and policy/regulation. His experience with CCS projects has included various options in the UK, Algeria (In Salah) and China (NZEC and Guangdong). He was a Lead Author on the Intergovernmental Panel on Climate Change (IPCC) Special Report on CCS contributing to the chapters on geological storage and economics. More recently he has been involved in preparation of guidance documents for implementation of the European CCS Directive, a review of industry potential for geological storage in the UK for DECC and as an advisor to DECC on the current UK CCS Competition.

Previously Bill spent 32 years with BP in business and technology roles covering alternative energy, exploration and production and gas. He was BP's first technology manager for carbon capture and storage technology and subsequently a Senior Advisor in BP Alternative Energy. His earlier career experience in petroleum geology and upstream oil business underpins expertise in geological storage. Bill was also seconded to the UK government's International Climate Change team during the G8 and EU presidencies between 2004–2006. He has worked in Europe, USA, SE Asia, China and Russia. He has a degree in geology from Oxford University.

**Q: When did you start your first mission in carbon capture and storage (CCS)? What was your role in drafting the IPCC Special report on CCS?**

I first became involved in CCS in year 2000 while I was working for BP in Singapore. They BP had acquired an interest in some high $CO_2$ gasfields in offshore Malaysia with up to 35% $CO_2$ in the gas and we decided to look at the options for CCS and EOR to reduce $CO_2$ emissions. Our early work suggested that $CO_2$ capture from gas clean up membranes should be feasible with portential storage as EOR in nearby oilfields or re-injection within the gasfields. Ultimately BP sold up before we could solve the challenge and I moved back to UK as Technology Manager for CCS.

The work on the IPCC Special Report on CCS started in 2003 with an experts meeting in Regina Canada near the Weyburn site. I was invited to be a Lead Author contributing to the chapters on Storage and Economics of CCS. It was an interesting assignment and the opportunity to work alongside leading experts from around the World. Each chapter had a group of authors and I met my friend Prof. Zhou Di from SCSIO then on the Storage Chapter. There were long discussions and debates between Storage experts about major issues such as acceptable level of $CO_2$ leakage, storage capacity estimation and estimates. Drafting the report was a long, painstaking and careful process with extensive peer review. However the Special Report's publication was a major milestone in documenting the case for CCS in mitigating Climate Change and getting this recognised by IPCC and international stakeholders.

**Q: A large number of existing integrated CCS projects in the world are co-financed by $CO_2$ onshore Enhanced Oil Recovery (EOR). But it seems there is very limit offshore $CO_2$ EOR projects around the world. What is your view on the potential of offshore $CO_2$ EOR technologies and deployment potential?**

While $CO_2$ Utilisation appears attractive because of economic benefits and the potential to recover more oil, $CO_2$ EOR has not kicked off in offshore fields and it is important to look at the reasons for this. Many fields in the North Sea have been studied for $CO_2$ EOR but so far there is little progress although some operators are pursuing it. There are a number of challenges most of which relate to potential extra recovery, EOR performance and options, facilities, conversion costs, $CO_2$ supply and economics. In the North Sea the geological characteristics of many oil reservoirs are very good meaning that recovery factors are already high from primary recovery and water flooding (often called secondary recovery). Consequently remaining oil potential for EOR is reduced. There are also economic challenges because the offshore can be a high cost operating environment and extensive capital may be required to safely convert or replace the infrastructure and wells, which may be as up to 30 years old, and to connect with $CO_2$ supplies.

Finally there are many other options available to oil companies to enhance oil recovery apart from using $CO_2$. These include miscible gas, thermal, chemical and low salinity water injection. Naturally oil companies will investigate which is most suitable and attractive for their oilfields and $CO_2$ EOR will have to compete. In China I understand there is already extensive experience with EOR in Bohai Bay but that is using chemical polymers rather than $CO_2$. However if $CO_2$ supplies can be developed as part of CCS networks the economics of $CO_2$ EOR may also become more attractive.

**Q: It seems the CCS Directive in Europe has created significant technical and regulatory barriers for developing large-scale CCS projects, especially in the liabilities management. What would be your recommendations for China in developing a $CO_2$ storage liabilities framework?**

The CCS Directive was a major advance when it was introduced in 2008 as it establishes the regulatory framework for safe storage in the European Union. This was followed up by Guidance documents and transposition in the European countries where CCS may be used. There are still concerns about how storage liabilities will be handled, financial securities and transfer of assets. These concerns are about how regulations are interpreted and used in practise which is why real project experience and implementation of regulations is vitally important. Even then it may be decades before we eventually stop injecting and close down storage projects. These issues also depend on the security of the storage sites that will be used and the risks of leakage. Personally I think that potential leakage risk are very very low for sites that are well characterized, monitored and regulated although I know there are issues of communication and understanding between different stakeholders who may not have the same understanding of geology and subsurface risk assessment. Regarding regulatory frameworks China has the opportunity to learn from other jurisdictions experience and figure out what is best for itself.

**Q: When did your first visit to China? What are your key findings and takeaways from the UK-China Near Zero Emissions Coal (NZEC) project? Was that a hard work?**

I first visited China in the 1990s when BP was already involved in upstream oil and gas business in offshore basins like South China Sea and Bohai and there were new opportunities opening up for foreign companies in onshore basins such as Tarim, Junggar and Sichuan. This has given me an understanding of the geology of many basins in China which are now candidates for $CO_2$ storage.

The NZEC seed was planted as part of the G8 and EU Climate Change activities 2005 when I was on secondment to the UK Department of Environment, Food and Rural Affairs. It followed the EU-China Summit Declaration in 2005 where the leaders agreed to “develop and demonstrate in China and the EU advanced, near-zero emissions coal technology through carbon capture and storage.” Including the CCS concept in the political agreements was groundbreaking and I remember the initial meetings with NDRC and MOST when we started the discussions on the role of CCS with coal and coined the term NZEC, near-zero emissions coal.

Implementing NZEC and other projects such as COACH was not without its challenges in building alignment between Chinese and European sponsors and partners but I am glad we worked through them. NZEC Phase 1 was a groundbreaking project to share European and UK experience in CCS with China. This is sometimes called capacity building and collaboration. It showed that CCS with coal could help mitigate Climate Change on a large scale in China and showed that there are viable capture technologies and storage options. I hope this helped pave the way for further work on CCS and I am encouraged by how much is being done on CCUS in China.

**Q: The Chinese government has highlighted the importance of $CO_2$ Utilization in its CCS strategy. Apart from EOR, what is your view on the perspective of other $CO_2$ geological utilization methods, such as $CO_2$ enhanced coal bed methane, $CO_2$ for shale gas fracking, $CO_2$ to recover underground water resources?**

There were some pilot tests of $CO_2$ Enhanced Coal Bed Methane in China in 2010 supported by Canada but I don't know how successful these were and whether they are being scaled up. In other areas the swelling of coals when $CO_2$ is injected can result in loss of permeability and injectivity.

Shale Gas fracking is already a mature industry in USA and that well may impact future $CO_2$ storage, while shale gas is at an early stage in China.  But it is not clear to me that gas production during fracking will be enhanced by $CO_2$ injection. It is not clear that the nature of shale gas projects with thousands of wells and rapid decline lends itself to $CO_2$ injection, nor that depleted and fractured shale zones would be high integrity $CO_2$ storage sites. Plus I see little industry interest in linking $CO_2$ with shale gas. and storage opportunities may overlap. Project developers will therefore need to understand potential overlap with other storage and potential impact on storage of well penetrations and shale seal integrity after shale gas exploitation. I am nonetheless very interested to see how shale gas develops in China and how other challenges such as water availability and environmental risks are addressed. It would be good from a Climate Change perspective if coal to gas switching can be increased in China.

In summary therefore I am not so optimistic that $CO_2$ utilisation with these possibilities has large scale potential for reducing greenhouse gas emissions in China or other parts of the World. For all these ideas it is important that we don't give policymakers false hopes that there are easy quick fixes that come with attractive economic benefits.

**Q: You have drafted a significant piece of work for UK DECC on the industry potential and the social-economics benefits of developing the $CO_2$ Storage industry in the UK.Based on your knowledge as an advisor for Guangdong CCS readiness and CCS collaboration activities, do you think there are identical industry opportunities for Guangdong in the South China Sea?**

Yes, I see many similarities between the UK situation and Guangdong. In both cases there is excellent potential for large scale geological storage in offshore basins where the geological characteristics are very favourable and there is existing infrastructure, wells, data and knowledge from oil and gas operations. There are also major emissions sources along the coast with good potential to develop clusters and hubs and shared infrastructure that can reduce transport and storage costs. This can lead to new opportunities for industry in both regions although some of the main players will be different, i.e. the owners of power plants and oil companies. Interestingly some of the Chinese oil companies who will need to be involved in CCS in China have taken stakes in several of the major fields in UK, including some candidates for $CO_2$ EOR and Storage.

**Q: There is significant lead time in developing a $CO_2$ storage site.  What will be your suggestions for China to secure the medium-to-long-term capacity requirementsin $CO_2$ storage and infrastructure, and to avoid the emissions lock-in effect?**

That's right. It can take years to identify, characterise and develop a storage site. This may be the rate determining step for overall CCS projects.  Often new seismic and drilling new exploration or appraisal wells  is required which needs time and money. This is because we need different data to characterise storage from oil and gas fields, such as caprock sampling and testing. China will need to understand this requirement early on and will need to consider how to fund and implement this vital activity and how to get industry involved early. It is also necessary tofactor in any EOR potential and oil and gas decommissioning plans.

At the other end of future CCS chains, the application of CCS ready regulations and engineering is essential to avoid carbon lock-in effects in new power plant and industry. This has been looked at in the work on Guangdong. China can look at CCS-ready regulations in the power sector in Europe and UK.

**Q: A large amount of stationary emission sources are located along the coastal areas in China. Do you think there are possible international financing mechanisms for developing and operating large-scale CCS demonstration projects with $CO_2$ storage in offshore saline aquifer in China?**

Many emissions sources in China are along the coast particularly in Guangdong and other southern provinces. I see these lining up nicely with offshore storage opportunities like the Pearl River Basin where the storage potential is much better than on-land and storage would be away from densely populated areas.

The international Climate Change negotiations have been painfully slow which is disappointing. I am not sure how much progress was made in this year's meetings in Warsaw. Consequently there is a lot of uncertainty about CDM and future international policy instruments and how they will apply to CCS. The international negotiators have been addressing CCS for some years and I hope they realise it's importance in mitigation. Also UK's DECC has announced some funding to support CCS in China so hopefully this might be used for demonstration projects.

**Q: It seems the global deployment rate of CCS is not yet satisfied. In regard to Europe, what type of incentive scheme you believe essential in unlocking investments in large-scale Carbon Capture and Storage projects? Do you think a $CO_2$ storage certificate system could work better the current incentive framework?**

CCS demonstration and development progress has definitely suffered since the 2008 Financial Crisis and there hasn't been as much done as I hoped in the European Union, Norway and Australia(both have suffered recent set-backs after political changes). We are still moving forward slowly in the UK with the demonstration programme. On the other hand it is good to see China moving ahead with CCUS and other projects being implemented in USA, Canada and Brazil. But the problem of Climate Change hasn't gone away and there seem to be more and more extreme weather events around the world, even if individual events cannot be attributed conclusively to Climate Change.

In terms of policy, it is essential to provide government support to large scale demonstration projects (and storage characterisation) through capital grants and operational support,etc. Looking to future deployment of CCS there are different policies and incentives being setup most of which have yet to be tried and tested. I am not a policy expert but I can make a few observations.

In Europe the Emissions Trading Scheme carbon price has virtually collapsed but I think there is a question whether it would provide the necessary long-term confidence to support CCS at previous carbon prices. Similar concerns might apply to CDM type instruments. One area where CCS from gas has been commercial is in Norway, where there has been a carbon tax on offshore emissions for a long time. New policy mechanisms that may impact CCS in power are being introduced in UK through the Electricity Market Reform and USA's Emissions Performance Standards. The UK policy is intended to provide longterm support for CCS deployment through long term Contracts for Differences, or CFDs. The principle is that the CfD then pays the difference between an estimate of the market price for electricity and an estimate of the long term price needed to bring forward investment in a given technology (the ‘strike price’).

These policies are necessarily complex and need to be tailored to the specific market and industry sector. We must remember that we need to do something about Climate Change and therefore we need to limit future emissions and we need CCS. This then needs industry and commercial opportunities for them. Politics and policy needs to provide consistent long-term confidence for Industry to invest in CCS and start the innovation cycle that will bring competition, cost reduction and benefits to us all.

**Q: Apart from CCS, do you have any other interests or extra curricular activities that you feel excited by?**

Most of my work is still on CCS these days as I think it's important for us all to get it moving. My kids are both at university so they are not around so much but I have lots of other interests that I try to find time for such as travel, cricket, wine tasting, jazz, learning the saxophone and painting.