



Opportunities for early Carbon Capture Utilisation and Storage development in China

Strategies for harnessing cost-effective integrated Carbon Capture Utilisation and Storage (CCUS) project potential in Shaanxi Province.



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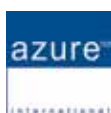
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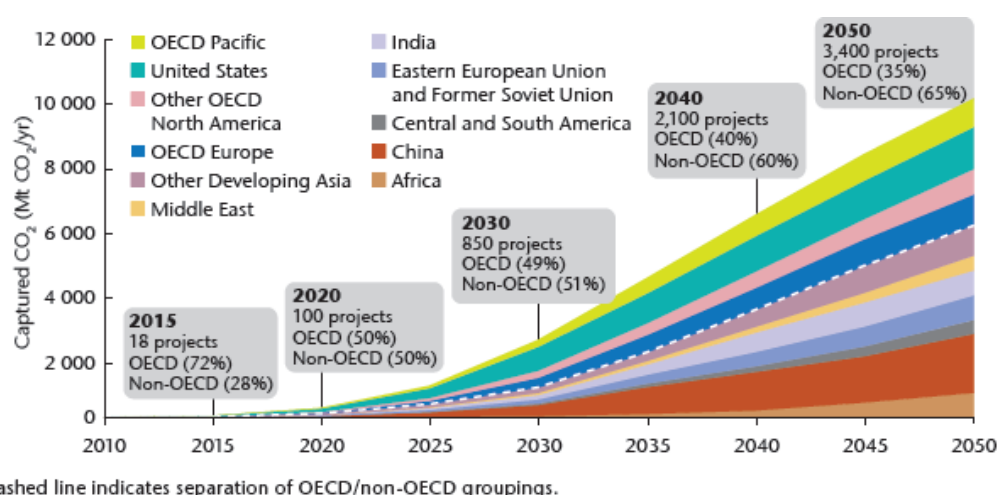
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1. Background and rationale

Carbon Capture Utilisation and Storage (CCUS) is a key technology to reduce China's carbon emissions, while satisfying its increasing demand for electricity and chemical products, and its continuous reliance on coal. According to the International Energy Agency (IEA), in order to prevent anthropogenic climate change increasing beyond 2°C, CO₂ emissions need to be reduced to 50% of 2005 levels by 2050. CCUS is a technology that must be utilised to mitigate one-fifth of the necessary emissions reductions in order to reach this target in the most economically efficient manner. IEA modeling suggests that by 2050, based on projected emissions growth China should be capturing 2.5 GtCO₂ each year by 2050 in order to contribute to this global challenge¹.

Figure 1 Required CO₂ capture by major countries and regions up to 2050.



Preliminary work on CCUS in China has focused on CCUS in the power sector. However, capture in the power sector is technically challenging, energy-intensive and expensive. Capture can be implemented at lower cost at large point sources of concentrated CO₂, such as in ammonia and methanol plants, coal-to-liquids facilities and hydrogen production processes. China has a large industrial base in these sectors, resulting in a significant CO₂ emission reduction potential through CCUS.

In recent years China has seen the development of Enhanced Oil Recovery (EOR) activities. EOR injects CO₂ in oil reservoirs to enhance production and prolong the life of the reservoir. EOR is widely applied in the United States and Canada and is in development in the Middle East. China has a large EOR potential and an EOR industry is emerging. CO₂ from nearby high-concentration point sources has a value

¹ IEA, 2009. Technology Roadmap – Carbon Capture and Storage. IEA Secretariat, Paris.

for EOR operations. This value can be used to develop early cost-effective CCUS projects involving industries where capture costs are relatively low.

To date a number of separate preliminary pilots for the capture and storage of CO₂ have been and are being undertaken in China. However, none of these pilots succeed in cost-effectively establishing a fully integrated CCUS chain.

Early demonstration of cost-effective CCUS potential in selected sectors can significantly advance CCUS development in China in selected industries, in time crossing over into other sectors, including power, as the technology and policy conditions mature.

Against this background, this international collaboration project identified cost-effective integrated CCUS opportunities in Shaanxi and developed recommendations to advance the implementation of these opportunities.

2. International CCUS developments and financing

The IEA/UNIDO have calculated that capture from high-purity industrial sources should account for 750 MtCO₂/yr globally by 2050. China is estimated to account for up to 120MtCO₂/yr or about 16% of this potential. The IEA/UNIDO further estimates that a total global investment of US\$220 billion is needed for high-purity CCUS, including transport and storage². Accordingly, the required investment for CCUS in China up to 2050 may be expected to be in the order of US\$35 billion.

In the meantime, international investment in CCUS demonstration projects, for example in the European Union, has diminished and development has slowed as a consequence of worsening global economic conditions and government finances since the 2008/2009 economic crisis. Financing options for CCUS under the United Nations Framework Convention on Climate Change process are currently limited. CCUS allowed in the Clean Development Mechanism (CDM), but there currently is limited demand of carbon credits resulting in a low carbon price and therefore a weak CCS investment incentive. Furthermore, the future of CDM in China is uncertain as China's economy grows and steps up its domestic and international commitments to mitigate greenhouse gas emissions.

Initial investment in CCUS demonstration projects in China and globally should therefore focus on integrated projects with strong business cases that show potential of economic returns, rather than adding cost to existing industries. However, it is likely that government and bi/multilateral donor funding will still be required to mitigate risks associated with such first-of-a-kind projects.

² IEA/UNIDO, 2011. Technology Roadmap – Carbon Capture and Storage in Industrial Applications. OECD/ International Energy Agency and the United Nations Industrial Development Organization.

3. China CCUS strategy and policies

China's CCUS policies have thus far primarily focused on research and to a more limited extent on demonstration. The National Medium- and Long-Term Program for Science and Technology Development (2006-2020) issued by the State Council in 2006 highlighted the development of efficient, clean and near-zero emission fossil energy utilization technologies as an important frontier technology. The subsequent National Climate Change Programme (2007-2010) adopted by the State Council in 2007 included CCUS as one of the key GHG mitigation technologies that should be developed. China's Scientific and Technological Actions on Climate Change of 2007, further emphasized CCUS as one of the key tasks in the development of GHG control technologies in China. In 2011 China with support from the ADB presented a study for a national CCUS roadmap. The study calls for a first 300 ktCO₂/annum full chain CCUS/EOR project to be implemented by 2015. It also recommends the prioritization of industrial high-purity CO₂ sources and EOR for initial full scale demonstration project development. China is currently starting work to develop an official CCUS roadmap.

In parallel the government has been encouraging the development of EOR technology with a view to enhancing oil reserves and improving China's energy security. In 2006, China's national Ministry of Science and Technology approved 'greenhouse gas-EOR resource utilisation and underground storage' supported by the 'National Key Basic Research Development Plan'. In 2007, China National Petroleum Corporation (CNPC) launched a major science and technology project 'greenhouse gas CO₂ resource utilisation and underground storage'. Also in 2007, CNPC launched a major pilot test 'Jilin Oilfield CO₂-EOR and CO₂ underground storage pilot test'. With these and other related actions China is aiming to quickly advance its technological capabilities in the field of EOR.

4. Status and plans for CCUS demonstration projects in China

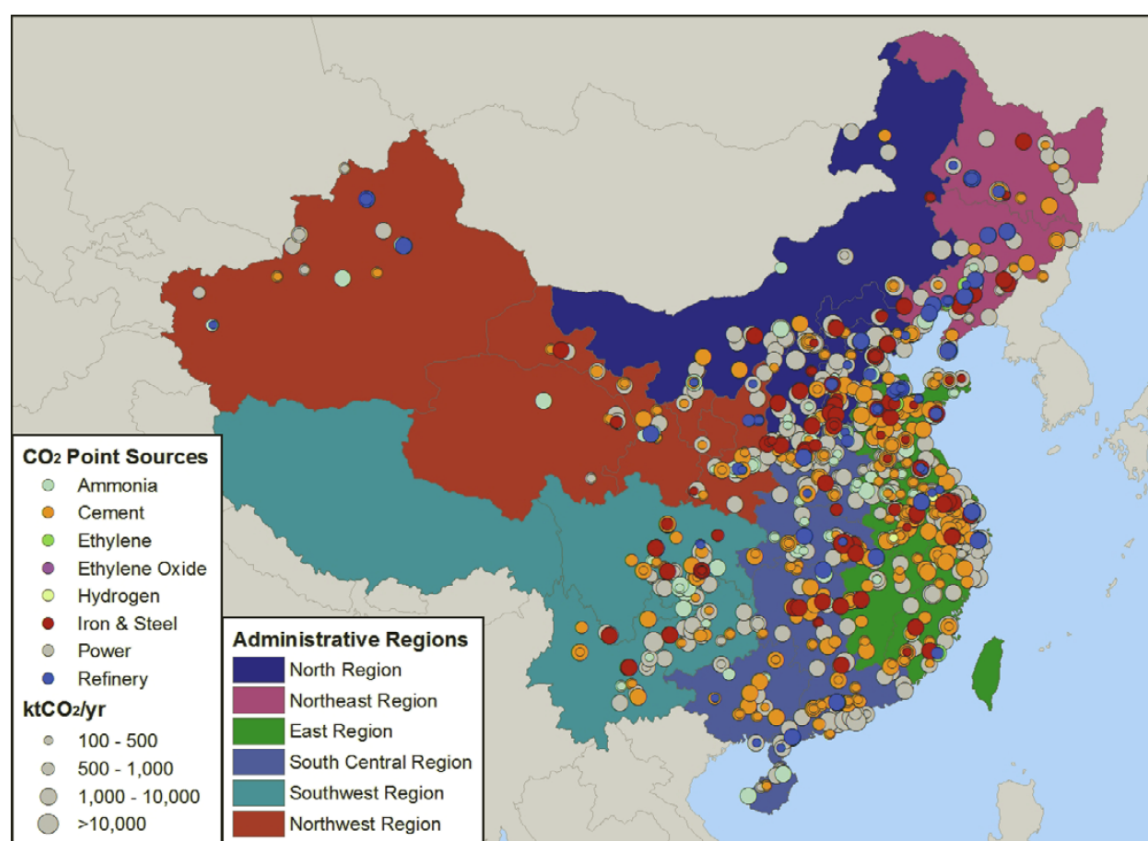
China has made significant progress in piloting and demonstrating CCUS technology over the past years. There are currently 13 CCUS pilot/demonstration projects in operation in China and another 6 projects are planned. Two of these planned projects are phase 2 extensions of existing projects. Out of the total of 19 projects in operation and planned, 7 projects use CO₂ for EOR (40-1000 ktCO₂/a) while 3 projects use CO₂ for food/industrial (3-120 ktCO₂/a) purposes. The large ranges of utilization volumes are an indication of the state of development of the CCUS industry, which started with very small utilization volumes and is now aiming for more significant volumes. It should be noted, however, that none of the currently implemented or planned projects capture CO₂ from concentrated high-purity CO₂ industrial sources.

5. High-purity CO₂ sources and EOR potential in China

A recent study by PNNL estimated that there are 994 large (0.1+ MtCO₂/yr) non-power industrial plants, emitting a combined 1081 MtCO₂/yr³. About one-half of this is from cement production with the remainder made up of iron and steel, petroleum refineries, ammonia, ethylene, ethylene oxide, and hydrogen. Figure 2 shows the location of these large point CO₂ sources, including from the power sector (73% of total annual emissions).

The same study by PNNL reviewed sixteen major onshore and 3 offshore depleted oil basins for their EOR potential and estimated their total CO₂ storage capacity at 4800 MtCO₂—of which 4600 MtCO₂ is found onshore. This would ultimately allow additional recovery of up to about 7 billion barrels of oil.

Figure 2 Large (>0.1 MtCO₂/yr) power and non-power industrial point CO₂ sources in China⁴.



6. High-purity CO₂ sources in Shaanxi

Shaanxi as one of the major coal bases in China has a highly developed coal-based chemical industry. To explore the potential for concentrated high-purity CO₂ capture

³ Dahowski, et al., Energy Procedia 1 (2009) 2849-2856.

⁴ Ibid.

in Shaanxi the project conducted a survey among non-power industries in Shaanxi. The survey collected information about the production characteristics and emission volumes of individual chemical plants in the ammonia, methanol, hydrogen, ethanol and dimethyl ether sectors in Shaanxi. In total, 22 sites with a combined CO₂ emission volume of approximately 62.5 Mt/year and CO₂ purity levels of 99% or higher were identified in these sectors. Of these projects 5 are currently in development either as new Greenfield developments or phase 2 expansion projects at existing production sites. Taking into account the technical feasibility of integrating carbon capture at these plants and minimizing the energy penalty and cost associated with such capture, a total of 9 plants with combined annual CO₂ emissions of about 27.5 Mt have been found suitable for source-sink matching in Shaanxi, see **Figure 3**.

7. EOR potential in Shaanxi

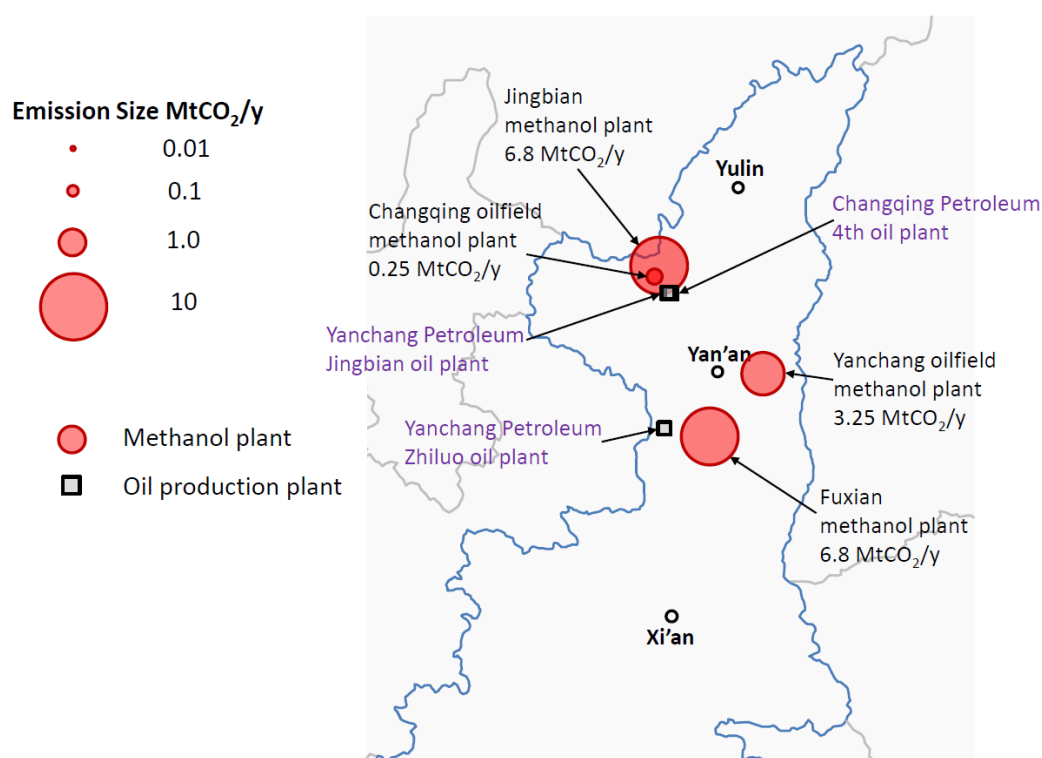
The main EOR sites in Shaanxi Province are the Yanchang Oilfield and Changqing Oilfield. Yanchang Oilfield is located around Yan'an. It is operated by the Shaanxi Yanchang Petroleum Group Co. and is owned by the Shaanxi Provincial Government. It is one of the oldest oil fields in China with production starting in 1905. In 2007 its production exceeded 10 million tonnes and in 2009 its production reached 11.2 million tonnes. Yancheng Oilfield currently applies water flooding for EOR and is actively researching options for using CO₂-EOR. The estimated indicative storage capacity of Yanchang Oilfield lies within a range of 45 to 88Mt CO₂.

The Changqing Oilfield is located in the Shaanxi-Gansu-Ningxia basin and is owned by the China National Petroleum Corporation. It has proven geological oil reserves of about 336 million tones of oil. Like Yancheng Oilfield Changqing Oilfield currently applies water flooding for EOR and is actively researching options for using CO₂-EOR. A recent study on CO₂ EOR potential in the Changqing Oilfield estimated the EOR potential at approximately 98 Mt and the CO₂ storage potential at close to 240 Mt⁵.

The estimated indicative storage capacity of Changqing Oilfield lies within a range of 41 to 80Mt CO₂.

Figure 3. Shaanxi concentrated high-purity industrial CO₂ sources and EOR locations.

⁵ Liao Xinwei et al. (2012), Assessment of CO₂ EOR and its Geo-Storage Potential in Mature Oil Reservoirs, Changqing Oil Field, China, paper for the Carbon Management Technology Conference, Orlando, Florida, U.S. February 7-9, 2012.



8. CO₂ transportation options in Shaanxi

As a major coal-producing province, Shaanxi has a well-developed road and railway system suitable for transporting CO₂ from capture to EOR injection sites. The black lines in **Figure 3** indicate the railroads and the yellow lines indicate the highways. Road transportation has the benefit of being flexible, while using existing road infrastructure. However, it is also relatively costly. Transportation by rail is also flexible, also uses existing infrastructure and is comparatively more cost-effective than road transportation. Transportation by pipeline is the most cost-effective solution for transportation of larger volumes of CO₂ (>2MT/yr) for full-scale demonstration projects. For the early stages of CCUS development in Shaanxi transportation by railway or road is therefore considered most appropriate, while for larger demonstration projects pipelines would be recommended.

9. Integrated CCUS projects in Shaanxi

Based on the identified concentrated high-purity CO₂ sources suitable for CCUS development in Shaanxi and taking into consideration a range of criteria regarding technical feasibility, environmental aspects, transportation distance, cost and project complexity, four potential integrated cost-effective CCUS projects have been identified for Shaanxi (see

Table 1).

Table 1. Potential integrated cost-effective full-chain CCUS projects in Shaanxi.

CO ₂ source plant	Emissions (Mt/yr)	EOR Oilfield	Distance (km)	Transport	Cost (\$/t)				
					Compression, cleaning and drying	Transport	Injection ³	Total ⁴	Total including EOR benefit ⁵
Yanchang oil field methanol	3.2	Yanchang	160	Pipeline	15~20	1.6 ¹	6	22.6~27.6	- 50.4~5.6
Yanan Fuxian methanol	6.8	Yanchang	170	Pipeline	15~20	1.7	6	22.7~27.7	- 47.3~5.7
Changqing oil field methanol	0.25	Changqing	40	Highway	15~20	3.2 ²	6	24.2~29.2	- 45.8~7.2
Jingbian methanol	6.8	Changqing	40	Pipeline	15~20	0.4	6	21.4~26.4	- 48.6~4.4

1. Pipeline transportation cost estimated at 0.01\$/t/km.

2. Highway tanks transportation estimated at 0.08 \$/t/km.

3. Excluding EOR benefit : data from IPCC special report on carbon capture and storage.

4. Excluding EOR benefit.

5. Including the benefit from oil production. Based on IPCC report, the net EOR cost is around -16\$/t assuming the oil price is 20\$/t. In this report, the oil price is assumed to range from 20\$/t to 100\$/t.

The first two methanol plants in

Table 1 are both owned by Yanchang Petroleum. This has the benefit of mitigating some of the commercial risks that would arise in contracting external supplies of CO₂ for EOR. Furthermore, it allows Yanchang Petroleum to capture the full benefits of CO₂ capture and EOR. Similarly, the third and fourth methanol plant listed in **Table 1** are owned by the Changqing Oil company.

The economic feasibility of each project has been assessed using costs estimates derived from international literature. These estimates may or may not fully apply in China. However, they provide an indication of the range of likely cost per part of the CCUS chain, as well as the overall likelihood of achieving cost-effectiveness for the CCUS chain as a whole.

Table 1 clearly shows that the potential for cost-effective development of the proposed projects is significant. It should be emphasized that the cost of compression, cleaning and drying are likely to be in the lower parts of the ranges indicated in the table, as it concerns high-purity CO₂ emissions that are already captured in the respective source industries. For the third project the compression, cleaning and drying cost are likely to be somewhat higher due to the required liquefaction.

10. Barriers to CCUS development

A number of barriers currently stand in the way of cost-effective development of integrated full-scale CCUS projects in Shaanxi and in China as proposed above.

At the national policy level there currently is no national CCUS development roadmap in place yet to guide CCUS demonstration policy development and implementation and to create the legal and regulatory frameworks necessary to safely and effectively manage CCUS projects. Furthermore, current policy frameworks for limiting industrial CO₂ emissions, such as China's carbon tax and potential plans for emissions trading, do not (yet) provide sufficient incentive for carbon capture in industry.

Institutionally, there is a need for coordination between NDRC, MOST, MEP and the Ministry of Land and Resources at all administrative levels affected by the CCUS project. NDRC needs to take the lead in coordinating other government departments to enable implementation of CCUS projects.

CO₂-EOR technology is at a relatively early stage of development in China and there remain significant uncertainties regarding the feasibility and potential benefits of CO₂-EOR in China. This means that the value of CO₂ for EOR is not clear and therefore the business cases for developing cost-effective integrated full-chain CCUS/EOR projects cannot be fully defined.

Financing a first-of-a-kind project such as a CCUS demonstration requires special sources of (public) funding, as normal commercial sources of funding are not likely to match the risk profile these early CCUS projects. Currently there is a lack of such specialized funding sources and mechanisms for CCUS project. Furthermore, the high initial investment cost associated with capture, transportation and injection infrastructure requires strong business case and long-term certainty regarding key economic conditions that define the business case, e.g. CO₂ price.

11. Conclusions

CCUS is a key climate change mitigation option globally and in China. Traditionally, research and development and demonstration has primarily focused on application of CCUS in the power sector at relatively high cost. Capture costs are lower at high-purity industrial sources with a global and China potential of 750 MtCO₂/yr and 120MtCO₂/yr respectively by 2050. This research has identified 4 potentially cost-effective full-chain CCUS projects based on existing high-purity CO₂ sources and EOR utilization potential in Shaanxi Province. A similar systematic screening of opportunities in other provinces of China is likely to yield further near-term cost-effective potential for CCUS development.

Key barriers impeding the development of these potentially cost-effective projects include the lack of a national CCUS roadmap, lack of a cap or price on CO₂ emissions, further required development of China's EOR capabilities, required coordination between government organisations and lack of national and international funding mechanisms.

12. Recommendations

Based on the findings of this project we submit the following recommendations for the development of cost-effective early CCUS opportunities in China:

1. Officially adopt a China CCUS roadmap provide the policy framework for developing detailed policies and regulations to enable larger and more CCUS demonstration projects. Prioritize concentrated high-purity CO₂ sources and EOR as target sectors for CCUS development in the medium term.
2. Support R&D activities on high-purity CO₂ capture, transportation and EOR as part of the National Future Science Development Plan. Such R&D activities will contribute to minimizing project risks and improving effectiveness throughout the CCUS chain. It is recommended that strong emphasis is put on EOR, as the further development of EOR technology and capabilities in China will help define the value of CO₂ for EOR as a primary driver for developing the CCUS chain. Existing R&D funding mechanisms under the 863 and 973 programmes of MOST may be used to support these activities.
3. Conduct detailed technical and economic feasibility assessments for the four identified full-chain CCUS projects in Shaanxi. Attracting investment in these projects will require the development of strong business cases with clearly identified technological, environmental, safety and economic risks to be allocated among the various stakeholders and the government. Detailed technical and economic feasibility studies are needed to ascertain these costs, benefits and risks.
4. Designate one high-purity CO₂/EOR project in Shaanxi as a national demonstration project to be implemented under the direct guidance and leadership of the NDRC, so that NDRC can coordinate the work of MOST, MEP and MLR from the national level down to the local level to ensure effective implementation of the project.
5. Develop CCUS demonstration funding mechanisms using government funds. Such funding mechanisms are required to address specific risks associated with large first-of-a-kind infrastructure projects such as full-chain CCUS projects and leverage finance from the parties in the CCUS chain. Possible financing mechanisms include low-interest loans, guarantees and direct government financing for public CCUS infrastructure such as pipelines.
6. Foster international collaboration on R&D, financing and development of demonstration projects. China already has extensive international collaboration in the field of CCUS. Such international collaboration can be leveraged to address specific knowledge barriers for developing CCUS

demonstration projects and may also provide funding for CCUS project feasibility assessments in China.

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