Status and Cooperation Prospect for Coal/NG Chemical and CCUS Technology between China and US

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1. Energy policies and directions
2. Role of coal/NG in energy development
3. Status quo of clean coal, coal chemical and CCUS in China
4. Directions of clean coal and coal chemical technologies
5. Cooperation prospects for coal chemical and “CCUS” between US and China
Energy Policies and Directions in China
Strategic Target of Energy Development for the 12th Five-Year Plan

- Strengthen energy conservation and improve energy efficiency. By 2020, carbon dioxide emissions per unit GDP decrease 40% – 45% than that in 2005, as binding target, and establish corresponding domestic statistic, monitoring, evaluation system.

- Strive to develop new energy and renewable energy source, endeavor to increase the share of non-fossil energy consumption in primary energy consumption to around 15% by 2020.
Main Technical Direction for Energy

- Clean coal technology
- Renewable energy source technology
- Advanced nuclear technology
- Smart grid technology
- Energy saving and storage technology
- Hydrogen energy and fuel cell technology
Role of coal/NG in energy development
The world’s coal production has been in a continuous increasing trend in the past half a century with world economy development, though its share in primary energy dropped first and then increases, which is 30% in 2013.

China’s share in the world’s coal production has increased dramatically recently, which reached 47% in 2013.
Coal provides important back for China’s rapid growth in economy development.

Consumption structure of coal in China in 2012

- Production: 36.45
- Consumption: 35.26
- Conversion: 26.56 (75%)
- Terminal Consumption: 8.61 (25%)
- Loss: 1.13 (3%)
- Export: 0.09
- Import: 2.88

- Electricity: 17.85 (51%)
- Heat: 2.03 (5%)
- Coking: 5.41
- Chemical: 6.68 (19%)
- Methanol+Ammonia: 1.15
- Modern coal chemical: 0.12
- Industrial: 5.86 (17%)
- Others: 1.60 (5%)

Data source: China Energy Statistical Yearbooks 2013 (10^4 t)

- Coal provides tough back for the dev. of China’s industry and economy in middle and western part of China.
- Currently, power industry takes 90% of total coal consumption, and 80% in Germany.
Coal is an important supporting factor for China’s energy security

- Import dependency of oil and NG has been increasing rapidly recently, and China is now facing severe situations in energy security.
- Coal can not only be converted to clean power, but also can be transformed to clean gaseous and liquid fuel, and chemical products as well, partly taking the place of oil and NG, so coal is an important supporting factor for China’s energy security.

Source: Energy Statistics Annual Report for 2013
The dominant role of coal as China’s major energy will not change in a rather long period

- Coal is the most abundant fossil energy in China with verified reserves (96%).
- In 2012, coal takes 81.7% and 70.6% in China’s primary energy prod. and cons.
- China’s coal consumption will still increase in a rather long period, with its peaking at ~4.5 billion tonnes.
- It is predicted that coal consumption will still take >55% in China’s primary energy consumption in 2030.

Verified reserves of China’s fossil energy

Coal, 96.14%
Natural gas, 2.08%
Oil, 1.78%

Coal consumption and share in China’s total primary energy consumption before 2030

Coal Consumption

Ratio (%)

Billion tons

2011
2015
2020
2030
Coal is the most abundant and most fundamental energy resource in the world.

In all fossil energy, coal has a much bigger R/P ratio and longer economically exploitable period than oil and NG.

Coal is easier and cheaper to acquire than oil and NG.

Coal’s important role in China’s today, is very likely to appear in US or other countries or regions of the world in future.
Coal will still taking an important role in the history of world energy development

Evolution of world’s energy consumption structure

Prediction of energy cons. increasing during 2010-2030

Coal, oil and NG consumption will increased dramatically in the future; nuclear and renewable energy will replace part of power generation, but carbon-based chemical products will still rely on fossil energy.

It is predicted that with current technology development trend, producing carbon-based chemicals to partly replace the currently used liquid fuel, especially the aviation fuel will become an important trend in the world.
Coal utilization is an important path for US to achieve “energy independency”

Recently, thanks to the “shale gas revolution” and “energy independence”, import dependence of oil and NG has decreased at different rates in US, but oil import dependency is still as high as 45% currently.

Taking use of the abundant coal resources to produce oil substitutes, and reduce the oil import dependency, is the real pathway for US to achieve energy independency.
CO₂ emission reduction is an important factor that promotes the transforming development of coal industry in China and US in the future.

In the past 40 years, US coal consumption has not changed much, with a little decrease in recent years; while China’s total coal consumption has been growing very rapidly.

Curves for CO₂ emission change and coal consumption change for the two countries are basically same, indicating CO₂ emissions has close relationship with coal consumption. China and US are facing huge pressure for CO₂ emissions reduction.

Facing the huge pressure for CO₂ reduction currently, China and US must working hard to develop clean and low carbon coal-conversion technologies.
Main points

- Coal is the most abundant fossil energy resource in the world.
- The important role of coal in the energy system in China, US and the world should not and cannot be neglected.
- Converting coal into special fuel and using coal as raw materials for carbon-based products is an important developing direction for future utilization.
- Coal conversion has already been or will be developed dramatically in China, US or other appropriate countries.
Status quo of coal/NG chemical and CCUS technologies in China
## Comparison of coal chemical industry (by end of 2013)

<table>
<thead>
<tr>
<th></th>
<th>Percentages of coal converted</th>
<th>Coal to liquid</th>
<th>Coal to gas</th>
<th>Coal to chemicals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Direct</td>
<td>Indirect</td>
<td>MTG</td>
</tr>
<tr>
<td>China</td>
<td>20%</td>
<td>1 set 1.08 Mt</td>
<td>3 sets 0.50 Mt</td>
<td>3 sets 0.40 Mt</td>
</tr>
<tr>
<td>US</td>
<td>Low</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>South Africa</td>
<td>High</td>
<td></td>
<td>3 sets 7.60 Mt</td>
<td></td>
</tr>
<tr>
<td>Others</td>
<td>____</td>
<td></td>
<td></td>
<td>1 set 0.1 Mt</td>
</tr>
</tbody>
</table>

- China is the first to achieve large scale industrialization in **direct coal liquefaction** and **coal to olefins**.
- China has reached **advanced level in the world** in key technologies, catalysts, equipments, systematic technologies, and engineering technologies for coal to liquids, and coal to chemicals.
- US and some other countries have been doing industrial experiments or demonstrations in all areas in coal conversion, achieving the goal of technology reserve, and are now still doing continuous development for technology industrialization.
Direct coal to liquid technologies
A 1.08mt/a industrial demonstration plant was installed in 2008, the first modern large scale direct coal to liquid plant.

This plant has achieved a continuous operation of nearly 300 days last year.

Products scheme for the dem. Plant

<table>
<thead>
<tr>
<th>Prod.</th>
<th>kt/a</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPG</td>
<td>100</td>
</tr>
<tr>
<td>naphtha</td>
<td>250</td>
</tr>
<tr>
<td>diesel</td>
<td>720</td>
</tr>
<tr>
<td>chemicals</td>
<td>10</td>
</tr>
<tr>
<td>Sum</td>
<td>1080</td>
</tr>
</tbody>
</table>
Direct Coal Liquefaction Technology
Indirect coal to liquid technologies
Indirect coal to liquid technologies

From 2010, China has installed and put into operation of 3 sets of 160-180 kt/a indirect coal to liquid industrial demonstration plants, applying Fe based catalyst, and slurry bed process.

A 1Mt/a Mid-T, Slurry bed demon plant is expected to be put into operation in 2015.

A 4Mt/a commercialized plant is now under, and is expected to be put into operation in 2016.

3 sets of 1Mt/a High-T, Slurry bed demon plants are now under construction.

A 140kt/a Co-based, Slurry bed industrial demon plant is now under construction.

A 100kt/a Co-based, static-bed industrial demon plant is expected to be put into operation by end of this year.
Various of process and catalysts have been developed, including:

- iron-based catalyst used for: high-, medium- and low-temperature slurry bed
- Cobalt-based catalyst used for: medium-temperature slurry bed and fixed beds
Coal to NG technologies
Coal to NG technologies

The 4 billion Nm$^3$/a coal to NG plant in Inner Mongolia is the 1$^{st}$ coal to NG plant, which was put into construction in 2009, and 1$^{st}$ phase project (1.3bNm$^3$/a) was completed and put into operation in 2012.

The 4 billion Nm$^3$/a coal to NG plant is now under construction in Fuxin, Liaoning.

The 2 billion Nm$^3$/a coal to NG plant is to be completed and put into debugging soon.

A 1.3 billion Nm$^3$/a coal to NG plant has entered the phase of trial operation in Xinjiang.

A 4.0 billion Nm$^3$/a coal to NG plant is now under construction in Xinjiang.

Multiple projects have been ratified by the government.
China has made a breakthrough in R&D of catalyst and process and set up pilot plants by use of new technology.
Coal to olefins technologies
Baotou coal to olefins project is the world’s first large scale coal to olefins plant, applying the domestic methanol to olefins technologies (DMTO) with China’s own proprietary rights.
Installed and put into trial production in 2010.
Put into commercial operation in 2011.

- Has been operating for >300d accumulatedly.
- 2.6Mt raw coal can be treated and gasified.
- 1.6Mt methanol as intermediate products.
- 0.51Mt/a poly-olefins can be produced.
China has developed various of process and new catalyst for coal to olefin.

- 3 10,000 t/a pilot plants have been set up.
- China has set up a coal to aromatic plant.
Major industrial demonstrations of coal chemical plants in China
CCUS
Compared with coal-based generation and other coal utilization plants, part of the CO$_2$ from coal chemical plants are emitted in high concentration, and capturing this part of CO$_2$ only takes 1/3 cost compared with capturing CO$_2$ from other sources with mid or low CO$_2$ concentration sources, so coal chemical plants are superior for CCUS compared with other sources.

The high-concentration CO$_2$ mainly comes from the purification unit in coal chemical plants. Per unit CO$_2$ emissions are a little different for different crafts.

Total CO$_2$ emissions and percentage of high-concentration CO$_2$ are closely-related with the specific technical configuration in each plant, so these 2 numbers vary significantly for different plants.

### Analysis and comparison of CO$_2$ emissions for typical coal chemical plants

<table>
<thead>
<tr>
<th>Unit</th>
<th>Total CO$_2$ emissions</th>
<th>High concentration CO$_2$ emissions</th>
<th>Percentage of high concentration emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct liquefaction</td>
<td>tCO$_2$/t-oil</td>
<td>&gt;5.00</td>
<td>&gt;3.00</td>
</tr>
<tr>
<td>Indirect liquefaction</td>
<td>tCO$_2$/t-oil</td>
<td>&gt;6.00</td>
<td>&gt;5.00</td>
</tr>
<tr>
<td>Coal to NG</td>
<td>tCO$_2$/kNm$^3$</td>
<td>&gt;4.00</td>
<td>&gt;2.00</td>
</tr>
<tr>
<td>Coal to olefins</td>
<td>tCO$_2$/t-olefin</td>
<td>&gt;10.00</td>
<td>&gt;6.00</td>
</tr>
</tbody>
</table>
CCUS industrial demonstrations are in operation in China

- China is now implementing the largest number of CCUS industrial demonstrations around the world
- China has marched to the forefront in the world to develop and promote CCUS
- China’s effort in CCUS development will do great contribution to the world in climate change mitigation
# Integrated CCUS demonstration projects in China

<table>
<thead>
<tr>
<th>No.</th>
<th>Project Name</th>
<th>Type</th>
<th>Site</th>
<th>Scale (tonnes CO₂/yr)</th>
<th>Year Begun</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Huaneng Gaobeidian CO₂ Capture Project</td>
<td>Post-combustion capture (PCC) from power plant flue gas</td>
<td>Beijing</td>
<td>3000</td>
<td>2008</td>
</tr>
<tr>
<td>2</td>
<td>Huaneng Shidongkou CO₂ Capture Project</td>
<td>PCC from power plant flue gas</td>
<td>Shanghai</td>
<td>100,000</td>
<td>2010</td>
</tr>
<tr>
<td>3</td>
<td>China Power Investment Co. Shuanghuai CO₂ Capture Project</td>
<td>PCC from power plant flue gas</td>
<td>Chongqing</td>
<td>10,000</td>
<td>2010</td>
</tr>
<tr>
<td>4</td>
<td>CO₂ Capture Project by Institute of Advanced Energy &amp; Power, CAS</td>
<td>Pre-combustion capture from IGCC fuel gas</td>
<td>Jiangsu</td>
<td>~10,000</td>
<td>2013</td>
</tr>
<tr>
<td>5</td>
<td>HUST CO₂ Capture Project</td>
<td>CO₂ capture from oxy-fuel combustion</td>
<td>Hubei</td>
<td>100,000</td>
<td>2013</td>
</tr>
<tr>
<td>6</td>
<td>Jilin Oilfield Project, PetroChina Co.</td>
<td>CO₂ EOR / storage</td>
<td>Jilin</td>
<td>300,000–1,000,000</td>
<td>1997</td>
</tr>
<tr>
<td>7</td>
<td>CUCBM Project, ChinaCoal Co.</td>
<td>CO₂ ECBM / storage</td>
<td>Shanxi</td>
<td>~1900</td>
<td>2005</td>
</tr>
<tr>
<td>8</td>
<td>ENN Project, ENN Co.</td>
<td>CO₂ utilized for microalgae cultivation and biodiesel production</td>
<td>Dalate</td>
<td>20,000</td>
<td>2010</td>
</tr>
<tr>
<td>9</td>
<td>Integrated CCUS Project by Shengli Oilfield Power Plant</td>
<td>PCC from power plant flue gas + CO₂-EOR with storage</td>
<td>Shandong</td>
<td>30,000</td>
<td>2010</td>
</tr>
<tr>
<td>10</td>
<td>Integrated CCUS Project by GreenGen, Huaneng</td>
<td>pre-combustion capture from coal-based fuel gas of IGCC plant + CO₂ EOR / storage</td>
<td>Tianjin</td>
<td>60,000–100,000</td>
<td>2012</td>
</tr>
<tr>
<td>11</td>
<td>Integrated CCUS Project by Shenhua Coal-to-Liquid Co., Ltd.</td>
<td>pre-combustion capture from coal-based fuel gas of chemical plant + saline aquifer storage</td>
<td>Ordos</td>
<td>100,000</td>
<td>2011</td>
</tr>
</tbody>
</table>
### China participates in CCUS international cooperation programs

<table>
<thead>
<tr>
<th>Project name</th>
<th>Sources of financial support</th>
<th>Execution time</th>
<th>Major participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>The China Australia Geological Storage of CO₂ (CAGS) Project</td>
<td>Ministry of Science and Technology (China) and Department of Resources, Energy and Tourism (Australia)</td>
<td>2009–2011</td>
<td>China side: The Administrative Centre for China's Agenda 21, China Geological Survey, Tsinghua University, etc. Australia side: GeoScience Australia;</td>
</tr>
<tr>
<td>Sino-Italian CCS technology cooperation project</td>
<td>Cooperation Action within CCS China-EU, COACH, Italian Ministry for the Environment, Land and Sea</td>
<td>2010–2012</td>
<td>China Side: The Administrative Centre for China's Agenda 21, Huaneng, Tsinghua University, Chinese Academy of Sciences, etc. Italian Side: Ministry for the Environment, Land and Sea, Enel, etc.</td>
</tr>
<tr>
<td>Cooperation Action within CCS China-EU, COACH</td>
<td>Ministry of Science and Technology of China and EU</td>
<td>2006–2009</td>
<td>China side: The Administrative Centre for China's Agenda 21, Huaneng, Tsinghua University, Zhejiang University, Chinese Academy of Sciences, etc. EU side: Imperial College, Air Products, Alstom, Shell, British Geology Survey, SINTEF, etc.</td>
</tr>
<tr>
<td>UK-China Near-Zero Emissions Coal project (NZEC)</td>
<td>Ministry of Science and Technology of China, Department of Environment, Food and Rural Affairs of UK</td>
<td>2007–2009 (Phase I)</td>
<td>China side: Administrative Centre for China's Agenda 21, Xi’an Thermal Power Research Institute, Tsinghua University, Zhejiang University, CAS, etc. UK side: Alstom, British Geological Survey, BP, Shell, Schlumberger, Doosan Babcock, Cambridge University, etc.</td>
</tr>
<tr>
<td>U.S.-China Clean Energy Research Center</td>
<td>Ministry of Science and Technology of China and U.S. Department of Energy</td>
<td>2010–2015</td>
<td>China side: Huazhong University of S&amp;T, S&amp;T and Industrialization Center of Ministry of Housing and Urban-Rural Development, Tsinghua University, etc. U.S. Side: West Virginia University, Lawrence Berkeley National Laboratory, etc.</td>
</tr>
</tbody>
</table>
Chinese government sponsors many CCUS related R&D programs

- The R&D programs are mainly carried out by joint-body of enterprises, universities and institutes through collaboration
- Covering a wide range of technology approaches for all sections of CCUS including CO2 capture, storage and utilization
- The sponsoring programs mostly last for 3~5 years, but there might be new programs that will continue to provide support according to the progress made by each program

Distribution by type of the major CCUS R&D programs sponsored by Chinese government

- Adopting the same technology and process as Gaobeidian Dem. at a much larger scale, with flue gas treating capability of 66,000Nm3/h, and capturing 100~120 ktCO2/year
- The largest post-combustion CO2 capturing project in power plant in the world till now
- CO2 is sold to chemical plants and food factories as raw material at a normal price constrained by a limited market
Projects - Oxyfuel Dem by Huazhong Univ. of S&T

- Establishing China’s 1st, the world’s 3rd 3MWth oxyfuel combustion CO2 capturing dem. in Wuhan in 2009, capturing 7000 tCO2/year
- Now a 35MWth oxyfuel combustion CO2 capturing dem. with capturing capability of 100,000 tCO2/year, which is the world’s largest, is under construction
- This dem. marks the forefront of development of oxyfuel combustion CO2 capture technology in the world
Jilin Oilfield has been working on CO₂ EOR since 1997, with targeting support from MOST and CNPC.

Now 150,000 tCO₂ is injected annually, and crude oil production rises by 80%, with most of the injected CO₂ effectively stored in the oilfield.

It is planned that annual CO₂ injection rate into the oilfield will be increased to 300,000-1,000,000 tCO₂.

It is the first demonstration of this kind in China. This dem. has great significance to understand the technical and economical performance of EOR.
GreenGen Co. established China’s first 265MW IGCC dem. plant in 2012. GreenGen plans to carry out a pre-combustion CO$_2$ capture dem. project on part of the flue gas applying the Selexol CO$_2$ capture technology in 2015. Annual capturing capability is 60-100 ktCO$_2$/year. If successful, a full-scale fuel gas CO$_2$ capturing retrofit will be performed. The captured CO$_2$ is planned to be used for EOR or stored in saline aquifer. The area around Dagang Oilfield is preliminarily selected.
Projects - whole process CCUS dem. by Shengli Oilfield

- Applying an proprietary MEA CO\(_2\) capture technology by Sinopec, Shengli Oilfield conducted a post-combustion CO\(_2\) capture retrofit on its self-generation power plant, and CO\(_2\) is used for EOR dem.
- The first whole process CCUS dem. project for conventional pulverized coal-fired power plants. 40,000t/a (100t/d) CO\(_2\) is captured.
- Up till May 2014, accumulated 177kt CO\(_2\) has been injected into the oil deposit, with 40kt oil yield increasing.
- Shengli plans to enlarge this whole process CCUS demonstration into 1MtCO\(_2\)/a in 2015.

![Diagram of CCUS process](image-url)
Projects - CCUS integrated dem. by Shenhua Co.

- Shenhua established the world’s first 1Mt/year direct coal-to-liquid (DCTL) facility in 2009
- In 2011, Shenhua established a CO\(_2\) pre-comb. capturing dem. facility for the high CO\(_2\) content waste gas, which can capture 10,000 tCO\(_2\) per year
- The captured CO\(_2\) is transported to a site 17km away, and then injected into and effectively stored in the saline aquifer 2244m deep, up to 200,000tCO\(_2\) has been stored up till June, 2014
- China’s first CO\(_2\) geology storage demon project, and also the first whole-process integrated CCUS dem. project, providing lots of important geological data and engineering experience for China
Main points

- Modern coal chemical has become an important development direction for China coal utilization technologies.
- China has made great breakthroughs in the field of modern coal chemical industry.
- >50% of the CO$_2$ emissions from modern coal chemical plants are of high concentration.
- Pollutants including S, N, and Hg, etc., can be removed and utilized as resources at rather low cost.
Progress in Clean Coal Conversion Technology in China
Key Directions of Clean Coal
From Government
Clean coal technology

Clean conversion

Coal-fired power generation

CCS

IGCC cogeneration

Pollution control

Gas turbine

Industrial fire coal and energy conservation
Key Directions

- Key basic research
- Key core technology development
- Major technology integration and project demonstration
Key Basic Research

- Basic research for quality improvement and conversion of coal
- Basic research for highly efficient clean fired-coal power generation
- Basic research for gas turbine technology
Key Core Technology Development

1. Coal quality improvement and integrated resource application
2. Power generation by highly efficient and clean coal
3. Coal-based clean fuel
4. Highly efficient fire coal and industrial energy conservation and emission reduction
5. CO$_2$ capture, storage and application technology before, in the middle and after combustion.
6. Pollutant control and resource application
Major Technical Integration and Industrial Demonstration

1. IGCC-coal-based polygeneration integrated demonstration, 400-500MW grade power plant, 1 million ton grade liquid fuel, 3000 t/d grade gasification furnace, 9F grade low heat value gas turbine, etc.

2. Demonstration for large scale efficient coal-based conversion and polygeneration, system efficient is increased over 5% and direct energy consumption for critical products is reduced more than 10%.

3. Industrial demonstration for complete set of technology of >600°C/1200MW grade ultra supercritical power generator.
Key Directions of Clean Coal
From Baoju
Main technical areas and directions for Baoju S&T Co.

**CO₂ management and utilization**

**Energy sector:**
- unit technology;
- integrated technology;
- strategic technology

**Integrated conversion of coal and oil**
- Novel coal gasification technology, coal to clean fuel gas
- Multiple raw material pyrolysis tech.
- Deep coke oven gas deep-processing; coal-based carbon-contained technology
- Mild T hydrogenation craft and corresponding catalysts; integrated production of oil and gas.

**Inferior oil processing**
- Residue oil, heavy oil
- High S, high viscosity oil
- High heavy, high asphalt oil
- Discarded oil, oil mud

- Judgement database and model of coal for coal gasification and liquefaction
- A gasification of integrated processing of coke oil, residue oil and inferior oil is now under construction.
Suggestion for Development of Coal/NG Chemical and CCUS in USA
To Establish the Assessment System for the Development Strategy of Coal/NG Conversion in USA
Baoju’s Coal Conversion Evaluation System

Baoju has developed a number of project evaluation systems

- Gasification
- Liquefaction
- Coal and oil Co-processing
- And so on

Items to be evaluated

- Technology
- Economy
- Environment
Evaluaiton system for decision making on development strategy for coal conversion industry

Judgement system for decision making on development strategy for coal conversion industry
Evaluation system for decision making on development strategy for coal conversion industry

- Government
- Companies
- R&D
- Market
- Decision making

Coal conversion processes:
- Coal combustion
- Coal liquefaction
- Coal gasification
- Coal coking

Output processes:
- Power
- Heat
- Gas
- Liquid
- Chemicals
- Poly-generation

Technologies:
- Tech. of China
- Tech. of US
- Other tech.

Input:
- Making choice

Judgement for decision making

Environment
It is suggested USA build a CCUS industrial demonstration unit based on coal chemical industry.
An innovative coal conversion system based on CO$_2$ capture

- coal
- oil
- gas
- biomass
- wastes

- Advanced hydrogenation in slurry bed
- Co-conversion of coal and oil
- NG to hydrogen
  - Optimized desulfurization and decarbonization
  - New integration method

High purity CO$_2$

Oil and chemical products with high value added
The high-efficiency, and clean conversion and utilization of coal, will be an essential road for the world to adjust its energy structure and ensure sustainable economic development.

We are willing to help promote cooperation between energy companies of the two countries, especially in the field of clean coal technology and CCUS technology.

Thank you!