Exploring major opportunities and critical enabling technologies for Carbon Capture and Storage (CCS) in China

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Outline

1. General Background
2. Major CCS opportunities
3. Critical CCS enabling technologies
4. In Chinese context!

Conclusions
Hard truth (1): self-reliance >90%, thirst for oil

Energy self-reliance: (Energy Production/TPES)

Source: China Energy Statistical Yearbook-2007
Hard truth (2): coal will continue to dominate the energy mix for decades to come

2005: 1742 Mtoe

2030: 3819 Mtoe

Hard truth (3): China now no. 1 in CO₂ emissions

<table>
<thead>
<tr>
<th></th>
<th>2005</th>
<th>2015</th>
<th>2030</th>
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</thead>
<tbody>
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<td>6.4</td>
<td>6.9</td>
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<td>8.6</td>
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<tr>
<td>India</td>
<td>1.1</td>
<td>1.8</td>
<td>3.3</td>
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China becomes the largest emitter in 2007

Key issues for Chinese energy strategy

• How to use coal in a carbon-constrained future?

• How to ensure oil supply?
CCS can reconcile potential conflict between coal use and climate change.

No silver bullet—portfolio needed to address climate change

- Developing CCS
- Developing low carbon energy
- Closing down low efficiency plants
- Promoting high efficiency technologies
- Energy Saving
- Controlling total energy consumption

'Stairways' to China’s low-carbon future
Carbon Capture and Storage (CCS)

- **Capture**
  - Post-combustion capture
  - Pre-combustion capture
  - Oxy-fuel combustion capture

- **Transportation**
  - Pipeline
  - Rail
  - Road

- **Storage**
  - EOR/ECBM
  - Deep aquifers
  - Depleted oil field
  - Deep ocean

- Key individual components are proven, but...
- No full scale integrated demonstration plant
- Lack of regulations for storage, longer-term liability and monitoring
- High efficiency penalty and cost
CCS in China: strategic arrangements

Key Guiding Documents

Key R&D Program

Key demo projects

International cooperation

3 “K” + 1
CCS in China: Guiding documents

  - State Council 2006
  - Formally establishes CCS as leading-edge technology

- **China’s National Climate Change Program (2007~2010)**
  - NDRC 2007
  - Sets the goal of the development and dissemination of CCS

- **China’s Special Science & Technology Action in Response to Climate Change (2007~2020)**
  - MOST 2007
  - Establishes the key task of RD&D on CCS
CCS in China: R&D programs

• National Basic Research Program of China (“973” Program)
  – Total: 36 million RMB

• National High-tech Research & Development Program of China (“863” Program)
  – Total: 30 million RMB
China’s first IGCC project: GreenGen

Under construction, partly funded by 863 program (11th Five-year Plan)

Three Stages of the GreenGen

- Stage I (2006-2009)
  - 2000 t/d Gasification
  - 250 MW IGCC polygeneration (Power-Heat-Syngas)
  - Build the GreenGen Laboratory

- Stage II (2010-2012)
  - R&D for Key technologies, Improve IGCC technology
  - Economic and technical compare between 3500 t/d and 2x2000 t/d gasifier
  - H2 production
  - CCS
  - Fuel cell power generation technology
  - Preliminary work of the GreenGen demonstration

- Stage III (2013-2015)
  - GreenGen demo-engineering
    - Build a 400MW GreenGen demo-Engineering, including H2 production, FC power generation, H2 turbine combined cycle generation and CCS
  - Operate the GreenGen plant
  - Prove the GreenGen economic viability
  - Prepare and extend for commercial system

Source: Shisen Xu (TPRI)
China forging ahead with carbon capture

The post-combustion capture pilot plant at Huaneng Beijing Power Plant is designed to capture 3000 tonnes per annum of CO₂

Pictures source: Qianlong
International cooperation
China’s CCS is still in its infancy

- Most activities are rather recent
- Involving a very limited actors
- Main drivers are almost exclusively in expert circles
- No elaborated policy exists so far to promote CCS
Outline

1. General Background
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Where are the CCS opportunities?

Total: 5100 Mt

2005:
- Power generation: 28%
- Transport: 7%
- Residential and services: 9%
- Other*: 7%
- Iron and steel: 6%
- Chemicals and petrochemicals: 4%
- Other**: 8%

2030:
- Residential and services: 31%
- Other*: 21%
- Power generation: 11%
- Transport: 6%
- Iron and steel: 8%
- Chemicals and petrochemicals: 6%
- Other**: 11%

CO₂ emissions by sector in China

Total: 11448 Mt (Reference Scenario)

weo2007
Coal power plants implies important opportunities

2008~2030: new installed capacity is 982 GW (coal: 657 GW)
Industry: iron and steel

**Crude steel production**

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<td>2007</td>
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**World steel CO₂ emissions in 2007**

- **China**: 51%
- **EU (25)**: 17%
- **USA**: 12%
- **Japan**: 8%
- **Russia**: 7%
- **Row**: 5%

**2005: 17% CO₂ emission**

**Industry 28%**

- 8%
- 6%
- 4%
- 10%
Industry: non-metallic minerals
—The second-largest industrial energy consumer in China

Industry 28%
Nonmetallic minerals
8% 6% 4%

2005: 19% CO₂ emission
Industry: Chemicals and petrochemicals

—the third-largest industrial energy consumer in China

Three main types of products

- Ammonia
- Methanol
- Petrochemicals

• The main sources of CO$_2$: steam boilers and CHP plants. CO$_2$ capture similar to that of other power plants.

• Most carbon is stored in the synthetic organic products. This carbon is only available for capture when these products are combusted.
Ammonia & Methanol

Global Ammonia Production by Feedstock, 2005

- China: World’s largest producer
- 1t ammonia $\rightarrow$ ~3 t CO₂
- 1t methanol $\rightarrow$ 2 t CO₂
- China’s planning: coal to methanol
  - 2010: 16Mt
  - 2015: 38Mt
  - 2020: 66Mt

2007 production:
- Ammonia: 52 Mt
- Methanol: 11 Mt

Transport/Residential/Other*

- Small/scattered/mobile sources
- CO₂ Capture is complex and prohibitively costly
- Efficiency improvement and fuel switch are preferable options
Prime candidates for CCS in China

- Power
- Methanol
- Ammonia
- Cement
- Iron and steel
Outline

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4. Conclusions
Parallel & coordinated strategy needed

- Manufacturing process & energy conversion process
- CCS + CCS enabling technologies

ccs
Coal power generation: development trend

Coal → Pulverized coal → High temperature/pressure

Coal → System integration → Syngas

Coal → IGCC → Pre-combustion

Coal → SC/USC → Post-combustion

Coal → Oxy-fuel combustion

Large capacity
Yuhuan: a Chinese milestone

- Marking the beginning of widespread use of supercritical and ultra-supercritical technologies in Chinese power plants.
SC/USC in China

• By the end of 2008
  – 90 GW of SC and 11.2 GW USC units were in operation
  – Over 100 GW of SC/USC units were under construction.

SC/USC going to be the mainstay of the coal power generation
China’s capability on SC/USC: know how, doesn’t know why

- Key components depend on import
- MW USC units are jointly designed and manufactured

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Sources of MW USC technologies
IGCC in China: GreenGen

There are over 10 IGCC demonstration projects waiting for NDRC approval in China.
Polygeneration: an important way for promoting IGCC development in China
Coal polygeneration in China
——Yankuang 240,000 t/a methanol and 60MWe Co-Production Demo Plant

2001-2005, 863 Program
Coal polygeneration demonstration project (863 major project, 2006~2010)

- RMB 350 million from government
- RMB 35000 million from other sources

- Coal slurry gasifier (2000t/d)
- Dry feeding gasifier (2000t/d)
- Fuel flexible gasifier (600-1500t/d)
- Low emission GT retrofit
- System optimization & design
- Operation & control
- 3 IGCC demo plants
- 2 Power & CTL cogeneration plants
Gasification: leading technology in IGCC

Gasification Island

- Fuel
- Air
- O₂
- N₂

Gasifier

Shift
\[ \text{CO} + \text{H}_2\text{O} \rightarrow \text{CO}_2 + \text{H}_2 \]

CO₂ Adsorption

CO₂

CO₂ Adsorption

CO₂

Power Island

- H₂
- Gas Turbine
- Steam Turbine
- Power
Coal gasification technology in China

- **Gasifier:** ~54 Texco, ~37 Shell

Hubei Zhijiang, 2000t/d shell, 2006

Shanghai, 480t/d, Texco, 1996
ECUST: Opposed Multi-Burner Gasification Technology

13 projects, 33 gasifiers
TPRI: Two Stage Pulverized Coal Pressure Gasification Technology

36 t/d (10 MWth), 2004
Funded by MOST in 2005

700 kg/d 1996

2000 t/d, 2009
Iron making: development trend

- **Blast furnace iron-making**
  - Dominant technology
  - Severe pollution

- **Non-blast furnace iron-making**

- **Direct reduction**

- **Smelting reduction**
Production routes for steelmaking

Schematic illustration of the BF-BOF and DR-EAF routes
Smelting Reduction

- CO: 65-70%
- H₂: 20-25%
- CO₂: 2-4%

Corex process
Breakthrough CCS enabling technologies are needed to achieve large-scale CO$_2$ reduction.
Polygeneration based on Oxygen Blast Furnace

- Air Separation Unit
  - Air
  - N₂, Ar
- Oxygen Blast Furnace
  - Coal
  - Ore
  - Limestone
  - O₂
  - Iron
- Converter
  - Steel
- Cogeneration units
  - Electricity
  - Methanol
  - Other
- Off Gas (CO, H₂)
- Shift Reactor
  - H₂
  - CCS route
- Separator
  - CO₂
  - Power Generation, Fuell Cell, and Other
  - Sequestration or Utilization
  - Steam
Polygeneration Based on Direct Reduction

Air Separation Unit

Air Separation Unit

Gasifier

Coal

Direct Reduction Unit

Direct Reduction Unit

Ore

Electric Arc Furnace

Electric Arc Furnace

DRI

Steel

Sequestration or Utilization

Power Generation, Fuel Cell, and Other

H₂

Separator

CCS route

Steam

Off Gas (CO, H₂)

Cogeneration units

Electricity

Methanol

Other
Polygeneration based on Smelting Reduction

Air Separation Unit
- Air
- N₂, Ar
- O₂

Smelting Reduction Unit
- Coal
- Ore
- Limestone
- Iron

Converter
- Steel

Separator
- CO₂
- H₂
- Steam

CO₂
- Power Generation, Fuel Cell, and Other

Shift Reactor
- CCS route

Cogeneration units
- Electricity
- Methanol
- Other

Off Gas (CO, H₂)
China’s Capability: Direct Reduction

DRI production: 2000-2006

13% of total amount
China’s capability: Polygeneration based on Smelting Reduction

Baosteel Started Up World’s Largest Corex Iron-making in 2007, the second Corex start-up is scheduled for mid-2010

Corex-C3000 (1.5 Mt/y) & Combined Cycle (160MW)
China’s capability: Polygeneration based on Blast Furnace

An Steel, 300MW

Word’s largest BFG Firing CCPP project

Tai Steel, Bao Steel, Wu Steel, Lai Steel; Han Steel……
CO$_2$ emission analysis in cement production

50% 

Quarry mining and transportation

CaCO$_3$ $\rightarrow$ CaO + CO$_2$

40%

5% 5%

Fuel combustion

Electricity

China: 0.89 t CO$_2$ / t cement
Oxy-fuel Combustion in Cement Kiln

Air Separation Unit

N₂

O₂

Flue gas recirculation

Cement Kiln

Flue Gas (CO₂-rich)

Clinker

Air

Fuel

Raw Material
• Ammonia industry is the largest consumer of gasification technology in China. Coal-based synthetic ammonia accounts for about 75% of total output
  – Consume 50 Mt coal per year
• coal-based methanol accounted for about 80% of total output.
  – Consume about 12 Mt coal
Summary of CCS enabling technologies

Power
- SC/USC
- Polygeneration (IGCC)
  - Polygeneration based on Oxygen Blast furnace
  - Polygeneration based on Smelting Reduction
  - Polygeneration based on Direct Reduction

Iron & Steel
- Coal gasification

Ammonia & Methanol
- Coal gasification

Cement
- Oxy-fuel combustion in cement kiln

Leading technology
How to use coal in a C-constrained future?

**GASIFICATION!**

Coal gasification is a more efficient, cleaner and more flexible way to use coal.
Towards a low-carbon future: China’s key technology pathway

- Coal gasification
- Polygeneration (power-chemicals & power-steel)
- Polygeneration (power-chemicals-steel)

Integration & Optimization

CCS
How to ensure oil supply?

CTL!

- **Coal production**
  - 2005: 2200Mt (320 Mt for coking-14.5%)
  - 2020: >3000Mt
- **80Mt methanol = 50 Mt gasoline**
  - Coal (to methanol) consumption : ~120 Mt
  - \( \frac{120}{3000} = 0.04 \)
Conclusions

• Tackling coal is critical for China’s low-carbon future; CCS is of great significance for sustainable use of coal; China’s CCS is still in its infancy.

• Power, steel, cement, ammonia, and methanol sectors are prime candidates for CCS employment.

• CCS enabling technologies should be identified and a parallel & coordinated strategy between CCS and its enabling technologies should be developed.

• Coal gasification and polygeneration should be given top priority to enable CCS development in China.
Thank you!

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Post-Combustion

Fuel → Boiler/Gas Turbine → Flue Gas → CO₂ Absorption → CO₂

Air → Boiler/Gas Turbine

Steam → Steam Turbine → Power

CO₂ concentration: 4%~15%

Other gases
Pre-Combustion

Air Separation Unit

Air

N₂

O₂

Fuel

Gasifier

Syngas (CO+H₂)

CO+H₂O→CO₂+H₂

Shift

CO₂ Adsorption

CO₂ concentration: 15%~40%

CO₂

H₂

Combined cycle

Power
Oxy-fuel Combustion

Air Separation Unit

Air separation

Boiler/Gas Turbine

Flue gas recirculation

CO₂ Adsorption

CO₂ concentration: 70%~85%

Other gases

Steam

Fuel

Power

N₂

O₂

Flue Gas (CO₂-rich)