Carbon Management at Shenhua
RD&D initiatives and CCUS demonstrations

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Who is Shenhua?

- **State-owned enterprise**
  - Founded 1995 ... Fortune 200 last 7 years
  - Vertically integrated energy company ...
    - ... mining, power, chemicals, transport
    - ... #1 in coal in China (10+% share)
    - Top 5 in power (12+% share, 83 GW total)

- **Clean energy roadmap ... “1245” strategy**
  - Ultra low emissions (ULE) technologies
  - Water and reuse treatment
  - Green mining
  - Renewables (6+ GW wind)
Shenhua assets map

Source: Shenhua annual report, 2016
Who is NICE?

**Background**
- National Institute of Clean and low-carbon Energy
- Founded in 2009 as a corporate R&D lab for Shenhua group
- Mission: to become a world class R&D institute supporting Shenhua’s transition to clean and low carbon energy supplier
- 490+ researchers
- Sites: Beijing, China; Mountain View, CA; Schwäbisch Hall, Germany

**Mission driven R&D ... platforms**

Advanced Technologies
- emissions mitigation
- engineering innovation
- strategic growth
CO$_2$ management landscape in China
Policy context

COP15 Copenhagen (2009)
- 40-45% reduction in emissions vs 2005 by 2020

COP21 Paris commitments (2015)
- Peak emissions by 2030
- 60-65% reduction in emissions vs 2005 by 2030
- Increase non-fossil share to 20% by 2030

12th Five year plan (2011-2015)
Energy intensity (per unit GDP): -16% vs 2010
  Actual = 18.2%
Carbon intensity (per unit GDP): -17% vs 2010
  Actual = 20%
Share of non-fossil energy: 11.4%
  Actual = 12%
“Gradually establish a carbon trade market”

13th Five year plan (2016-2020)
Energy intensity: -15% vs 2015
Carbon intensity: -18% vs 2015
Share of non-fossil energy: 15%
National trading market: July 2017
Emissions trading markets – Phase 1

1. Shenzhen
   July 18, 2013
   30 MM tCO₂/yr
   635 companies

2. Shanghai
   Nov 26, 2013
   150 MM tCO₂/yr
   200 companies

3. Beijing
   Nov 28, 2013
   70 MM tCO₂/yr
   490 companies

4. Guangdong
   Dec 19, 2013
   350 MM tCO₂/yr
   202 companies

5. Tianjin
   Dec 26, 2013
   150 MM tCO₂/yr
   114 companies

6. Hubei
   Apr 4, 2014
   120 MM tCO₂/yr
   138 companies

7. Chongqing
   Jun 19, 2014
   100 MM tCO₂/yr
   242 companies

970 MM tCO₂/yr

• Phase 2: National market (2017-2020)
• Phase 3: National market with reductions (2020-2030)
• Phase 4: International linkages (2030+)

X. Zhao et al. Ren Sust Energy Rev. 59, 1229 (2016)
Emissions trading markets – Historical activity

Shenzhen (~ 30 RMB, 2017)

By end of October 2014,$^\text{1}$
- Cumulative trading volume: 13.8 MM ton
  6M t in Hubei; 2M t in Beijing
  >1 M t in Shanghai, Guangdong, Tianjin
- Total turnover value = 500 MM RMB

However, lessons remain to be learned about:
- Allocations ... legacy vs market
- Market operations ... liquidity, information

X. Zhao et al. Ren Sust Energy Rev. 59, 1229 (2016)

Beijing (~ 50 RMB, 2017)

Shanghai (~ 40 RMB, 2017)

http://www.tanpaifang.com/tanhangqing/
Shenhua CO₂ management strategy
Shenhua CO₂ sources

- Coal mine sources
- Low concentration (power)
- High concentration (chemicals)
Shenhua CO$_2$ strategy – Key elements

1. Standards, controls and trading
   - Assessment, monitoring, and controls
   - Participate in carbon trading markets

2. Efficiency projects on established plant/capex
   - Close excess capacity
   - Upgrade systems

3. Renewables
   - Currently 6+ GW wind

4. Advanced R&D and international cooperation
Carbon management within Shenhua Group

Shenhua Group

- **Power**
  - Capture demo 1 (solvent, 2018)
  - Capture demo 2 (solvent, 2020)

- **Chemicals**
  - Ordos storage project monitoring (Injection complete; site transferred to NICE)
  - CO₂ capture and sales (ongoing)

- **Mining**
  - CMM (ongoing)

- **Trading**
  - Carbon Markets (2017)

**Group-wide CO₂ reduction efforts (2016-2020)**
- Closure of excess capacity (mines, low efficiency power generation, coking)
- Energy efficiency (boilers, machinery, mining)
- Renewables generation (wind, solar)

**Advanced RD&D to reach 2030 targets**
Provide Shenhua with real technical options to affordably reduce CO₂ emissions by 65%
Shenhua CO₂ footprint & reductions

2020

BAU

Target -10-15% 2015 to 2020

Planned Shenhua activities

Renewables generation

Close excess capacity

Energy efficiency

Wind Solar

CO₂ emissions (MM MT/yr)

Mining

Power

Transport

Chemicals

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Shenhua CO₂ footprint & reductions

2020

BAU

Target
-10-15%

2015 to 2020

-50%

Planned Shenhua activities

Renewables generation

Close excess capacity

Energy efficiency

Advanced RD&D to reach 2030 targets

• Efficiency – plant & fleet
• Industrial scale CCUS
• Zero-emissions power

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NICE RD&D strategy for Carbon management

Improve fleet-level efficiency.
- Technology insertion ... boosting efficiency at individual sites.
- System optimization ... marginal savings from fleet evolution.

Accelerate affordable industrial-scale CCUS.
- Lower cost capture ... establish cost benefits and operability of Gen 2 tech under China-specific operating conditions.
- Storage and utilization ... how do we ramp up to 100+ MM tpa scale?

Demonstrate concepts for zero-emissions power.
- “Transformational” power cycles ... design, enablers, pilots.
- Renewables integration with fossil ... practical options in China.
The aspirational goal of the NICE CCUS RD&D effort is to provide Shenhua with the technical capacity to affordably implement CCUS at 100+MM tpa scale by 2030.

**RD&D focus areas**

1. **Enabling capabilities**
   - Technoeconomic assessment tools
   - Carbon market dynamics

2. **CO₂ capture**
   - Power generation (existing)
   - Power generation (new builds)
   - Coal-to-chemicals (precombustion)

3. **CO₂ disposition**
   - Geological storage
   - Value-added utilization
NICE RD&D

1. Enabling capabilities

Snapshot: Technoeconomic analysis
## Survey of reported CO₂ capture costs

**China CO₂ capture costs**  
~ $34/ton

<table>
<thead>
<tr>
<th>Reference</th>
<th>Year</th>
<th>RMB/ton</th>
<th>$/ton</th>
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<tr>
<td>AE 87 3347</td>
<td>2010</td>
<td>162</td>
<td>25*</td>
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<tr>
<td>EP 4 1869</td>
<td>2011</td>
<td>203</td>
<td>31.2*</td>
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<tr>
<td>EP 4 1878</td>
<td>2011</td>
<td>206</td>
<td>31.7*</td>
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<td>JCP 112 4123</td>
<td>2016</td>
<td>220</td>
<td>33.8*</td>
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<td>E 58 117</td>
<td>2013</td>
<td>247**</td>
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<tr>
<td>JCP 139 612</td>
<td>2016</td>
<td>286*</td>
<td>44</td>
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</tbody>
</table>

* Assumes RMB:USD = 6.5  
** Assumes RMB:USD = 6.25

**US CO₂ capture costs**  
~ $58/ton

<table>
<thead>
<tr>
<th>Reference</th>
<th>Year</th>
<th>$/ton</th>
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<tbody>
<tr>
<td>DOE Bituminous Baseline Report</td>
<td>2011</td>
<td>58.2</td>
</tr>
</tbody>
</table>

Why is there a difference?  
What are the key drivers?
Baseline plant – Key assumptions

Reference plants:
US – DOE bituminous coal
(Cases 11 & 12, 2011)
China – Shenhua bituminous coal
Costs of electricity – US and China baselines

Preliminary results

<table>
<thead>
<tr>
<th>Cost of Electricity USD/MWh (2011 Basis)</th>
<th>US</th>
<th>CN</th>
</tr>
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<tbody>
<tr>
<td><strong>Baseline plants (No capture)</strong></td>
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<tr>
<td>Capital Cost</td>
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<td>Opex (ex fuel)</td>
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<tr>
<td>Fuel</td>
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<tr>
<td><strong>Baseline plants (Cansolv, 90% CO₂ capture)</strong></td>
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</tr>
<tr>
<td>Capital Cost</td>
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<tr>
<td>Fuel</td>
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</table>

US
- $82/MWh
- 530 RMB/MWh
- $133/MWh (860 RMB/MWh)

CN
- $83/MWh
- 540 RMB/MWh
- $49/MWh
- 320 RMB/MWh
Cost walk

Preliminary results

Drivers for CO₂ capture cost differences

Key drivers
1. Capacity factor
2. Plant size
3. Coal consumption
4. Capex
5. Coal price
6. Labor
7. Fixed opex
8. Variable opex
9. Other economic assumptions
Summary and Next steps ... Enablers

Baseline China plant has been defined
- Internal methodology to convert “US costs” into “China costs”
- Core design and economic assumptions
- Performance and costing ... sensitivity analysis in progress

Next steps and collaboration opportunities
- Validate internal results and publish a “China coal power base case”
- Track and understand impacts of carbon trading markets
- Engage global community on cost impacts of China-specific factors
NICE RD&D

2. CO$_2$ capture

Snapshot: Gen 2 capture tech for power generation
Paths to affordable capture

Gen 1 technology (amine solvents)
Cost maturation

Gen 2 technology (alternate solvents, membranes, sorbents)
Scale-up and validation

Cost of capture

Translation of ex-CN tech to CN environment

Technology options

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Operational differences – China vs US

1. Capacity factor/load following
   - Turndown can cause CO₂ concentration fluctuations
   - Effect of ramping on performance and economics

2. Capture rate
   - NG equivalence ... 60-65% capture
   - Fleet-level trade-offs for partial capture

3. Other
   - Emissions controls ... sensitivity to contaminants and dynamics
   - CO₂ product specs ... pressure, purity, off-take rates
Gen 2 technology – Screening criteria

Technical maturity
TRL 3 demo completed

Yes

Economic entitlement
<60% increase in COE?

Yes

No

Recalculate costs using CN baseline assumptions

Candidate short list

Addressable knowledge gap
China-specific testing; Innovation opportunity

Yes

No

Consider for future demos

Partnership potential
Willingness/Timing
Hardware availability

Yes

No

Field test

Revisit, if future situation changes

Yes

No

Revisit when more mature

Revisit when more mature

No

Revisit when more mature
Slipstream test facility

Jiangyou site (Sichuan province)

• 4 subcritical boiler units:
  • 2 x 300 + 2 x 330 MW
• Emissions controls: SCR, FGD

• Capture slipstream
  • 0.1 MW$_{e}$ (400 to 500 kg/hr)
  • Modeled after NCCC bench-scale testing platform

• Design and construction in progress ...
  Qualification testing starts 4Q2017

Thanks to NCCC for helping us get to this point quickly.
Summary and Next steps ... Capture

Slipstream evaluation of Gen 2 technologies in progress

Technology screening criteria:
- Economic potential (<60% increase in COE)
- Addressable knowledge gaps

Next steps and collaboration opportunities

Support maturation of Gen 1 and Gen 2 capture technologies
- Focus on operability and economic entitlement
- Open to new technology options

Develop technical and commercial roadmap for implementation within
Shenhua power generation and coal-to-chemicals business units
3. CO\(_2\) utilization and sequestration

Snapshot: Geological storage demo at Ordos
Shenhua Ordos demonstration project

- China’s first geological storage project
- Active from 2011-2014
- Low permeability saline aquifer
- Total CO₂ injected: 300,000 MT
- NICE role: Monitoring
CO₂ source

- **Coal to liquids (CTL) initiative**
  - Significant national initiative in 1990s-2000s
  - Reduces energy security risks around oil imports
  - Utilization of low S, low ash coal reserves

- **Ordos DCL project**
  - Direct coal liquefaction ... high T hydrogenation
  - Phase 1 Commercial operation 2011
    - 1 MM tpa liquids product (3.4 MM tpa coal)
  - CO₂ footprint
    - 3.6 MM tpa from coal to H₂
    - 0.7 MM tpa from power and steam
  - CO₂ for storage demonstration
    - DCL capture ... 80% purity
    - purification ... 95% purity
Ordos project ... Process map & current status

Long-term monitoring responsibility transferred to NICE

- Plume modeling
- Risk-based approaches
Summary and Next steps

Closing out Ordos project
- Continuing monitoring for long-term safety and CO$_2$ assurance
- Review lessons learned to inform future sequestration projects
- Transition focus to EOR partnerships and other utilization opportunities

Next steps and collaboration opportunities
- Engage international community to stay current on storage developments
- Ramp up efforts in utilization (EOR, others)
Conclusion

Globally, much progress is being made towards industrial CCS.

NICE is pursuing RD&D to assemble the technical capacity for Shenhua to do affordable CCS at 100+MM tpa scale by 2030.

We are open to learning from others, sharing our lessons learned, and partnering to develop technologies suited to the China landscape.