

# Carbon Management at Shenhua RD&D initiatives and CCUS demonstrations

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## □ 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)

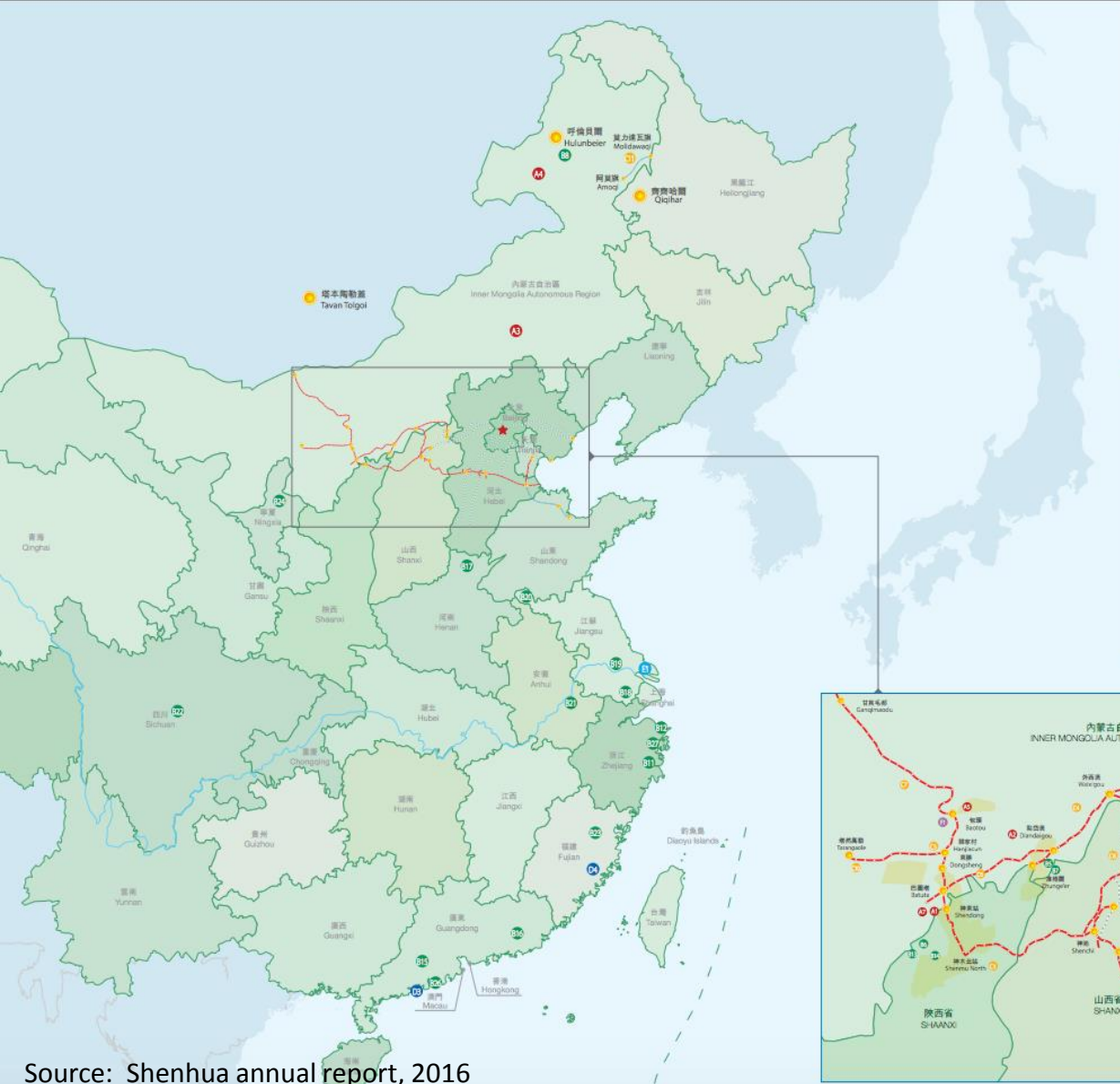


## □ Clean energy roadmap ... “1245” strategy

- Ultra low emissions (ULE) technologies
- Water and reuse treatment
- Green mining
- Renewables (6+ GW wind)



# Shenhua assets map



### 煤礦 COAL MINE

- A1. 神東煤礦 Shendong Mines
- A2. 達精礦業 Dajing Mines
- A3. 勝利礦業 Shengli Mines
- A4. 寶日希勒礦業 Baoshile Mines
- A5. 包頭礦業 Baotou Mines
- A6. 澳大利亞沃特瑪克探礦項目 (探礦階段中) Watermark Coal Project in Australia (stake under review)
- A7. 新疆台格蘇勒探礦區 (前期工作階段) Xinjiang Tagasol Exploration Area (preliminary work in progress)

### 電廠 POWER

- B1. 瀋陽電力 Shenyang Power
- B2. 三河電力 Sanhe Power
- B3. 定州電力 Dingzhou Power
- B4. 錦州電力 Jinzhou Power
- B5. 神東電力 Shendong Power
- B6. 神東電力 Shendong Power
- B7. 瀋陽電力 Shenyang Power
- B8. 廣安電力 Guang'an Power
- B9. 北京熱電 (已暫停) Beijing Thermal (stake down)
- B10. 綏中電力 Suizhong Power
- B11. 濟寧電力 Jining Power
- B12. 舟山電力 Zhoushan Power
- B13. 錦屏峽電廠 Jinping Energy
- B14. 神水電力 Shensui Power
- B15. 台山電力 Taishan Power
- B16. 惠州熱電 Huizhou Thermal
- B17. 五津電力 Wujin Power
- B18. 大拿電力 Canada Power
- B19. 陳家老電力 Chenjiaolao Power
- B20. 徐州電力 Xuzhou Power
- B21. 神皖電力 Shewan Energy
- B22. 神華四川能源 Shenhua Sichuan Energy
- B23. 神華福建能源 Shenhua Fujian Energy
- B24. 寧東電力 Ningdong Power
- B25. 西昌煤炭 Xichang M&M
- B26. 珠海風能 Zhuhai Wind
- B27. 永興電力 Yongxing Power
- B28. 北京燃氣 Beijing Gas Power

### 鐵路 RAILWAY

- C1. 神朔鐵路 Shenshuo Railway
- C2. 朔黃鐵路 Shuohuang Railway
- C3. 黃萬鐵路 Huangwan Railway
- C4. 大北鐵路 Dabai Railway
- C5. 包神鐵路 Baoshen Railway
- C6. 巴公鐵路 Baogong Railway
- C7. 甘泉鐵路 Ganquan Railway
- C8. 浩吉鐵路 Haoji Railway
- C9. 黃大鐵路 (在建) Huangda Railway (under construction)
- C10. 塔爾灣鐵路 Talan Railway
- C11. 阿瓦爾鐵路 (在建) Awa Railway (under construction)

### 港口 PORT

- D1. 黃驊港 Huanghua Port
- D2. 天津煤碼頭 Tianjin Coal Dock
- D3. 珠海煤碼頭 Zhuhai Coal Dock
- D4. 龍黃煤碼頭 (儲備中) Longhuang Coal Project (under preparation)

### 煤化工 COAL CHEMICAL

- F1. 煤礦煤化工 Baotou Coal Chemical

### 航運 SHIPPING

- E1. 神華中海貨運 Shenhua Zhonghai Shipping Company

註：於2016年3月24日之快照圖，僅供示意。  
Note: This map is as at 24 March 2016 is for illustrative purpose only.



Source: Shenhua annual report, 2016

## □ Background

- National Institute of Clean and low-carbon Energy
- Founded in 2009 ... 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

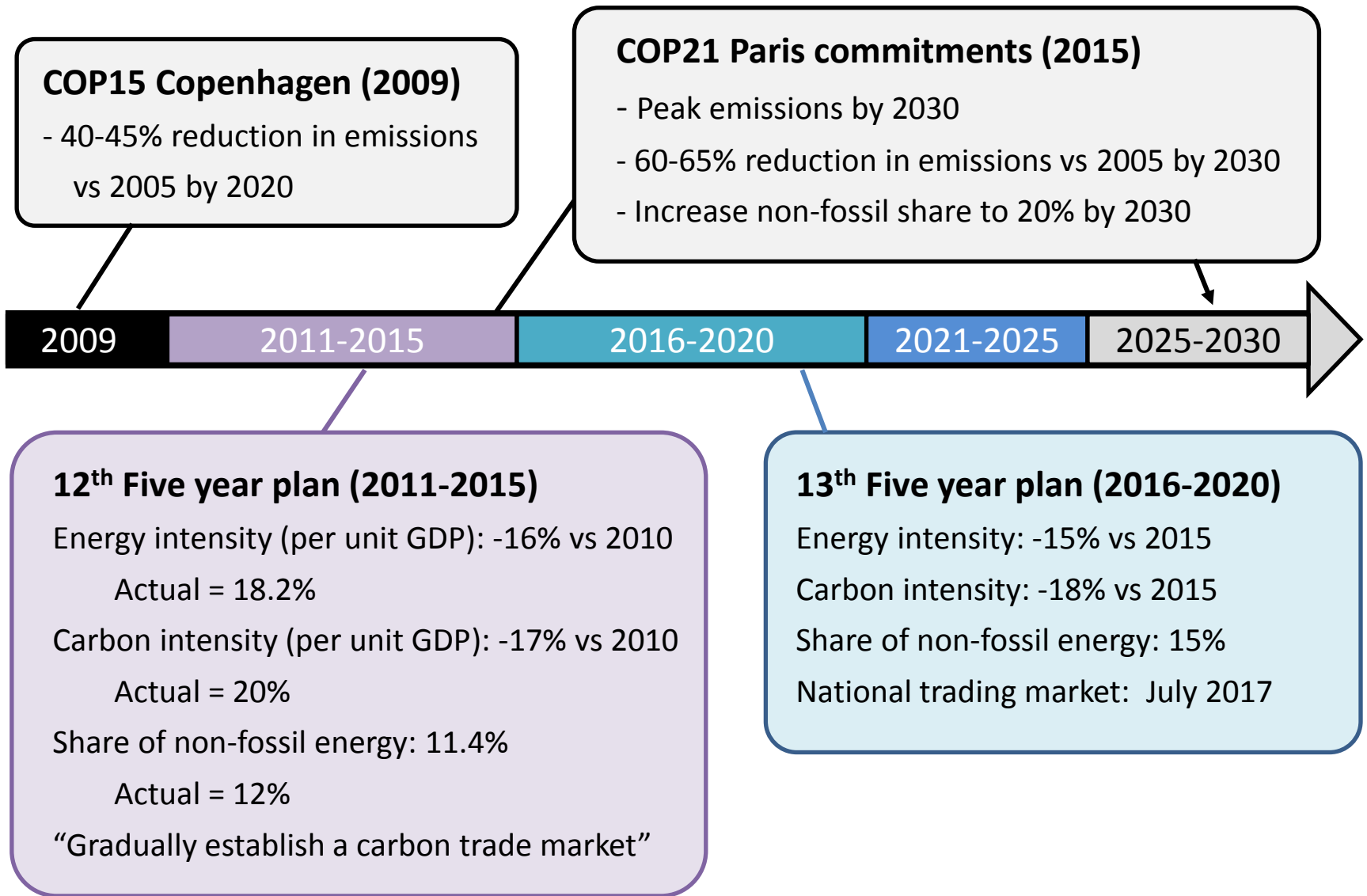


### Advanced Technologies

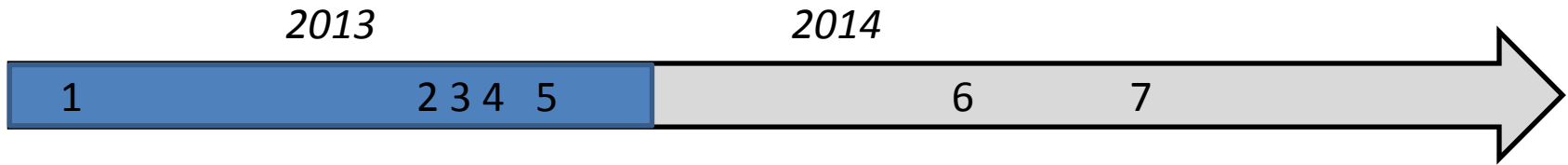
- emissions mitigation
- engineering innovation
- strategic growth

The background features several overlapping, wavy, semi-transparent green lines that create a sense of movement and depth. These lines are in various shades of green, from light to a slightly darker teal, and they curve across the frame.

# **CO<sub>2</sub> management landscape in China**



# Emissions trading markets – Phase 1



**1. Shenzhen**  
 July 18, 2013  
**30 MM tCO<sub>2</sub>/yr**  
 635 companies

**4. Guangdong**  
 Dec 19, 2013  
**350 MM tCO<sub>2</sub>/yr**  
 202 companies

**6. Hubei**  
 Apr 4, 2014  
**120 MM tCO<sub>2</sub>/yr**  
 138 companies

**970 MM tCO<sub>2</sub>/yr**

**2. Shanghai**  
 Nov 26, 2013  
**150 MM tCO<sub>2</sub>/yr**  
 200 companies

**5. Tianjin**  
 Dec 26, 2013  
**150 MM tCO<sub>2</sub>/yr**  
 114 companies

**7. Chongqing**  
 Jun 19, 2014  
**100 MM tCO<sub>2</sub>/yr**  
 242 companies

*Power  
 O&G  
 Steel  
 Cement  
 Chemical*

**3. Beijing**  
 Nov 28, 2013  
**70 MM tCO<sub>2</sub>/yr**  
 490 companies

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

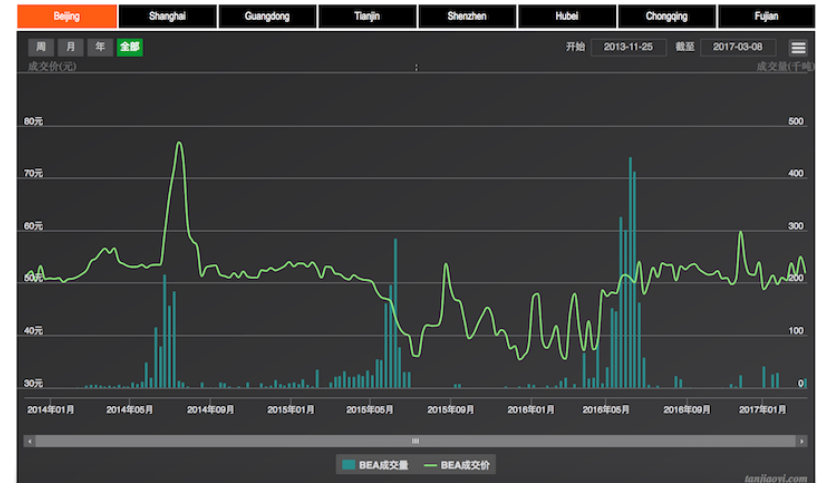
X. Zhao et al. Ren Sust Energy Rev. 59, 1229 (2016)



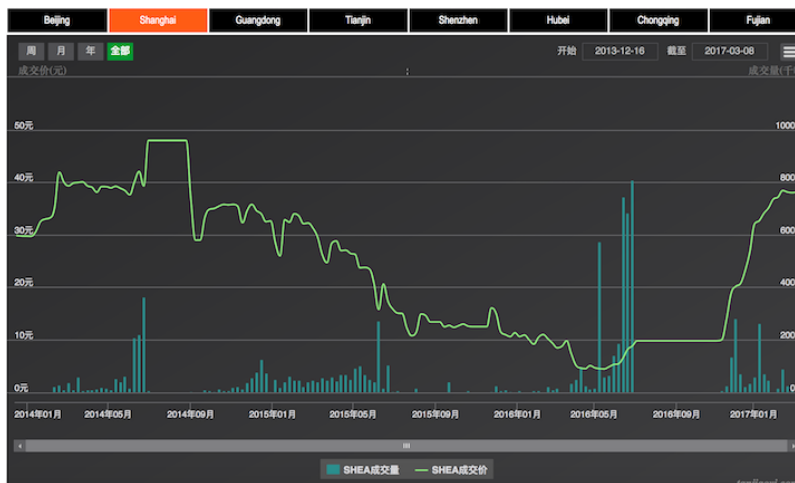
## Shenzhen (~ 30 RMB, 2017)



## Beijing (~ 50 RMB, 2017)



## Shanghai (~ 40 RMB, 2017)



By end of October 2014,

- 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

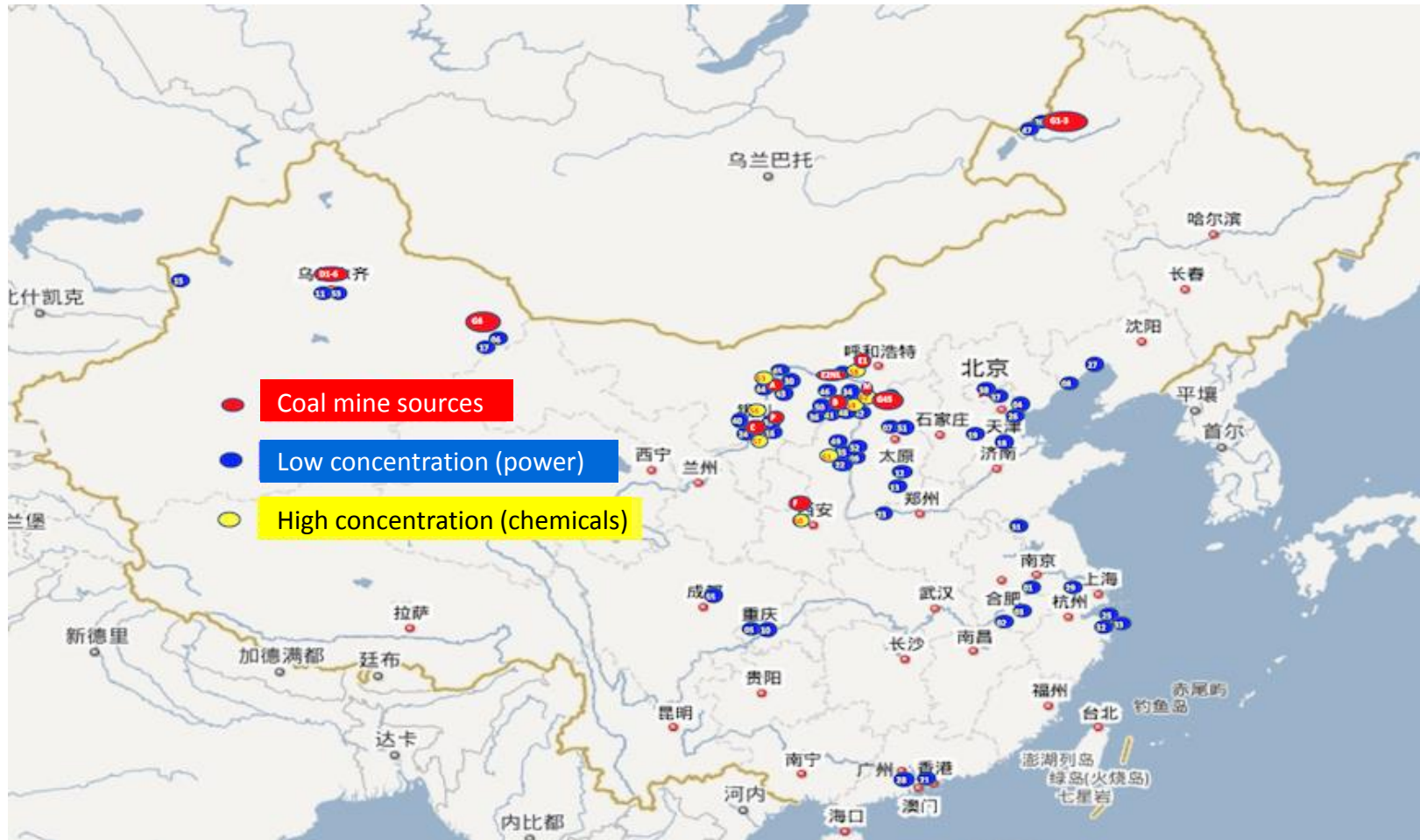
X. Zhao et al. Ren Sust Energy Rev. 59, 1229 (2016)

<http://www.tanpaifang.com/tanhangqing/>



# Shenhua CO<sub>2</sub> management strategy

# Shenhua CO<sub>2</sub> sources



## **1. Standards, controls and trading**

- Assessment, monitoring, and controls
- Participate in carbon trading markets

## **2. Efficiency projects on established plant/capex**

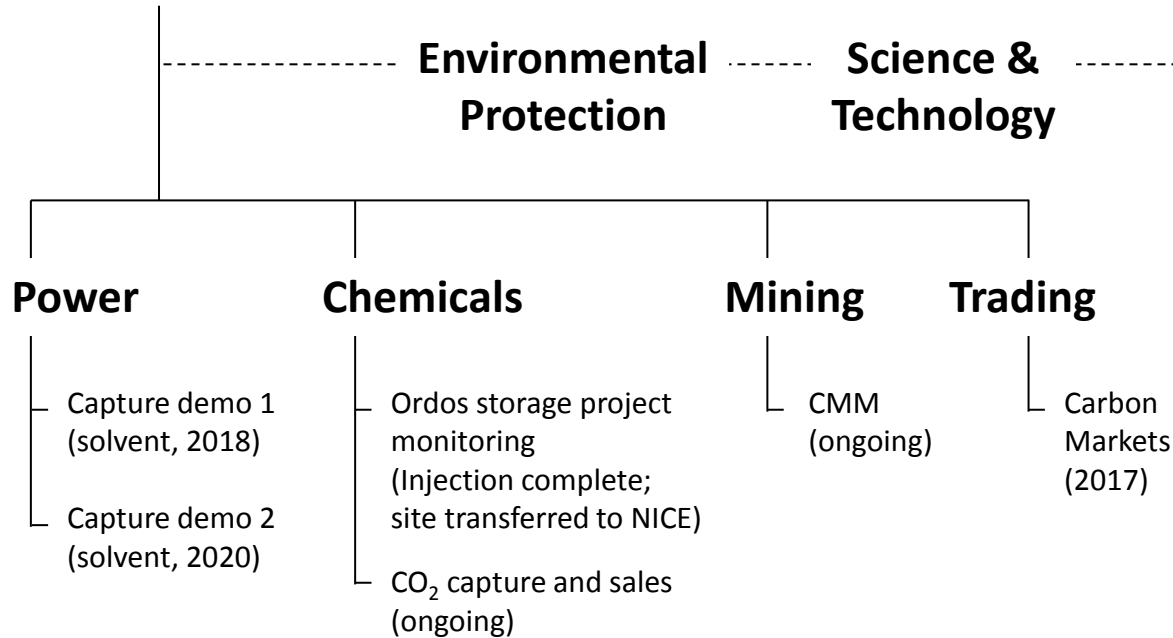
- Close excess capacity
- Upgrade systems

## **3. Renewables**

- Currently 6+ GW wind

## **4. Advanced R&D and international cooperation**

## Shenhua Group



Advanced RD&D to reach 2030 targets

Provide Shenhua with real technical options to affordably reduce CO<sub>2</sub> emissions by 65%

### Group-wide CO<sub>2</sub> reduction efforts (2016-2020)

- Closure of excess capacity (mines, low efficiency power generation, coking)
- Energy efficiency (boilers, machinery, mining)
- Renewables generation (wind, solar)

# Shenhua CO<sub>2</sub> footprint & reductions

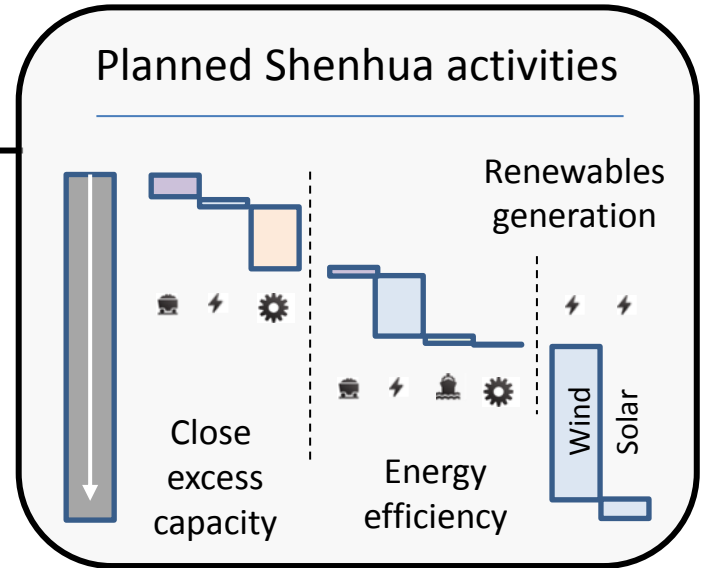
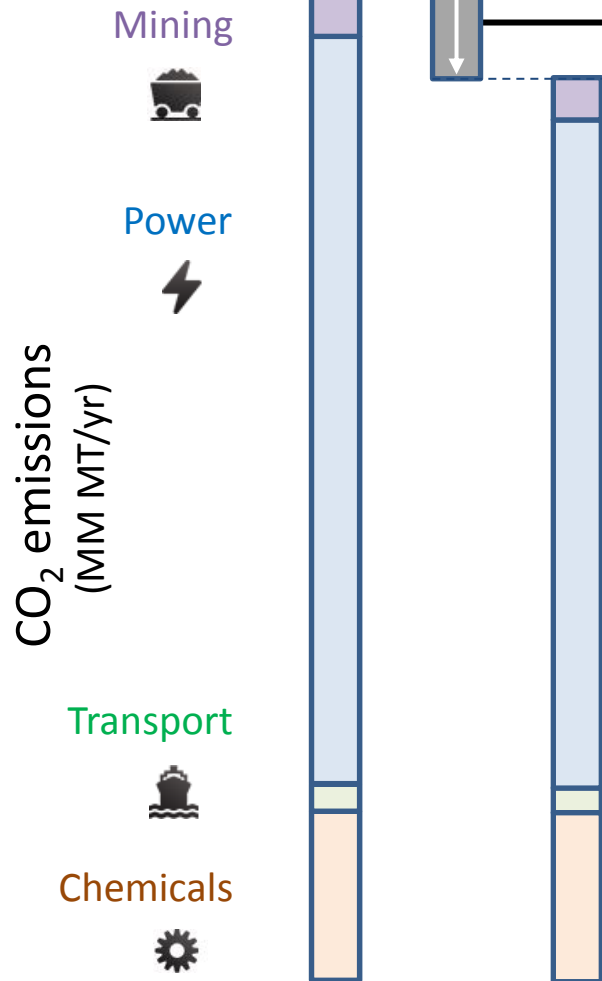
2020

BAU

Target

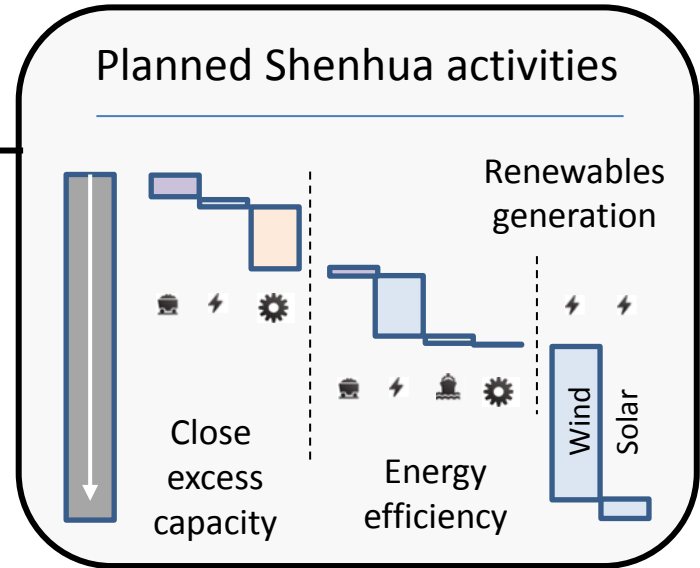
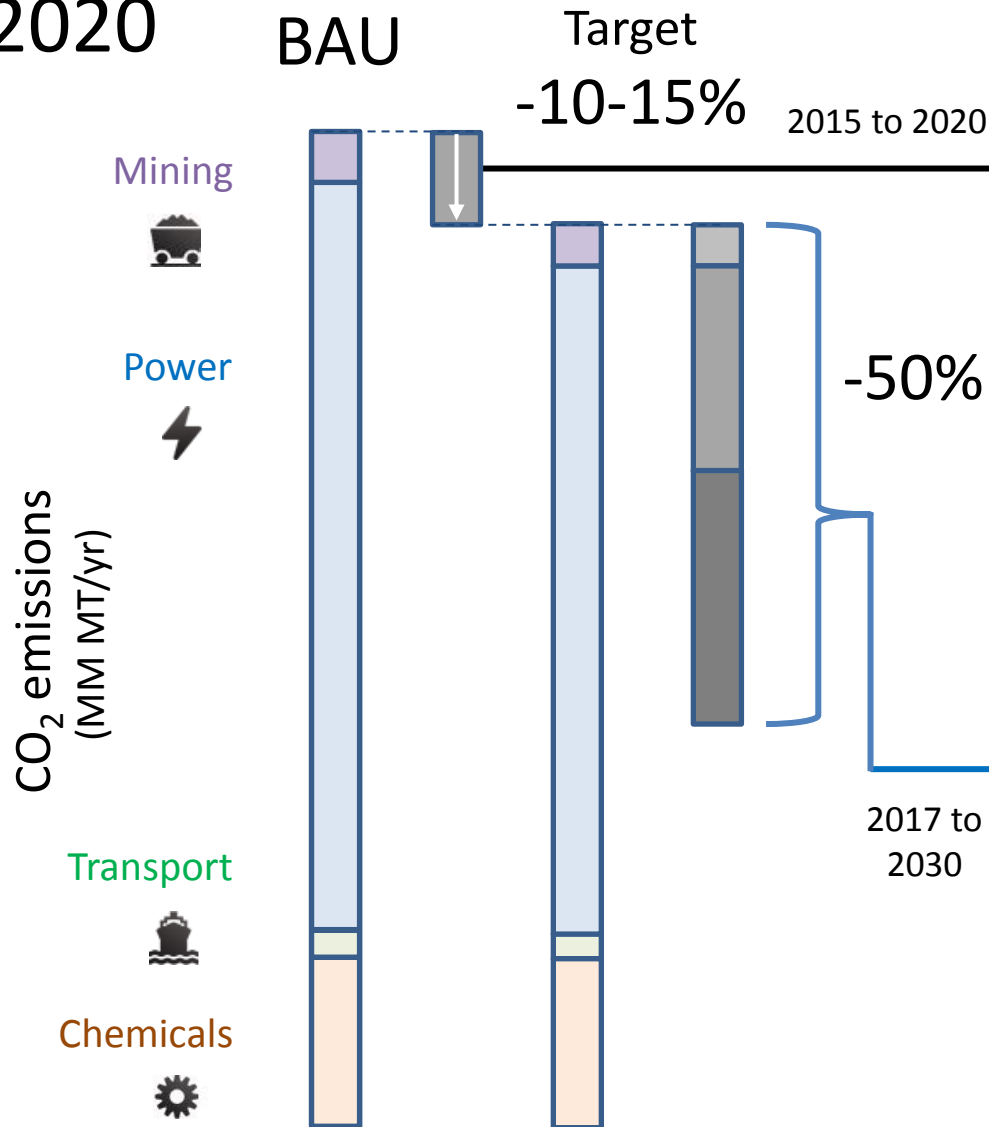
-10-15%

2015 to 2020



# Shenhua CO<sub>2</sub> footprint & reductions

2020



Advanced RD&D to reach 2030 targets

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

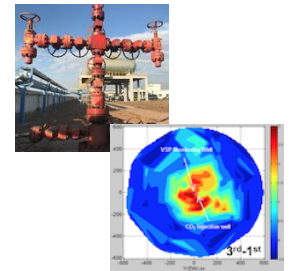
## Improve fleet-level efficiency.

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



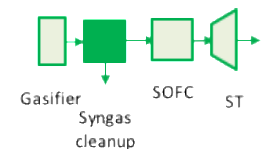
## Accelerate affordable industrial-scale CCUS.

- ◆ 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?



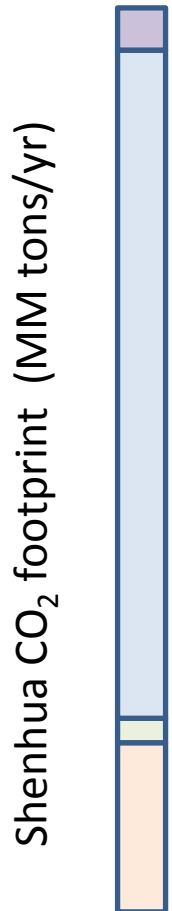
## Demonstrate concepts for zero-emissions power.

- ◆ “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. CO<sub>2</sub> capture
  - Power generation (existing)
  - Power generation (new builds)
  - Coal-to-chemicals (precombustion)
3. CO<sub>2</sub> disposition
  - Geological storage
  - Value-added utilization

# **NICE RD&D**

## **1. Enabling capabilities**

**Snapshot: Technoeconomic analysis**

China CO<sub>2</sub> capture costs  
~ \$34/ton

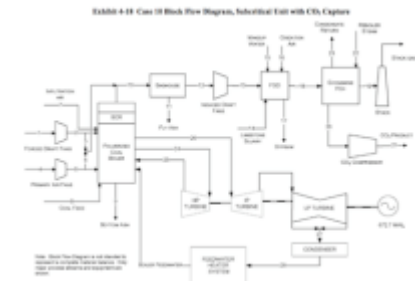
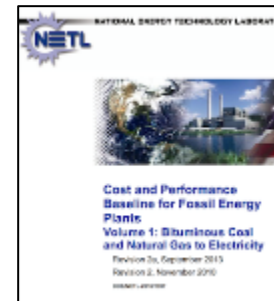
Reference	Year	RMB/ton	\$/ton
AE 87 3347	2010	162	25*
EP 4 1869	2011	203	31.2*
EP 4 1878	2011	206	31.7*
JCP 112 4123	2016	220	33.8*
E 58 117	2013	247**	39.44
JCP 139 612	2016	286*	44

\* Assumes RMB:USD = 6.5

\*\* Assumes RMB:USD = 6.25

US CO<sub>2</sub> capture costs  
~ \$58/ton

Reference	Year	\$/ton
DOE Bituminous Baseline Report	2011	58.2



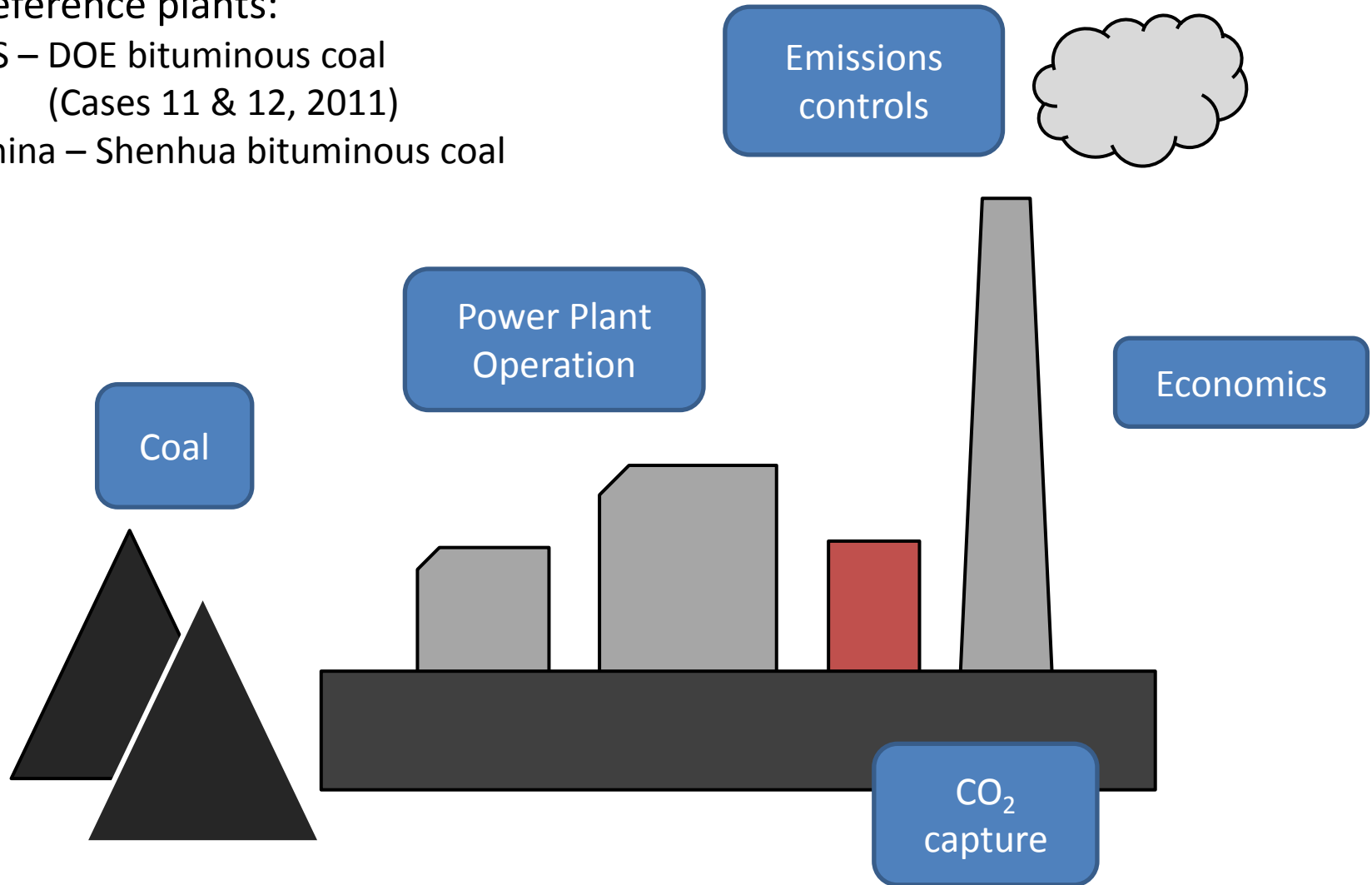
Why is there a difference?  
What are the key drivers?

# Baseline plant – Key assumptions

Reference plants:

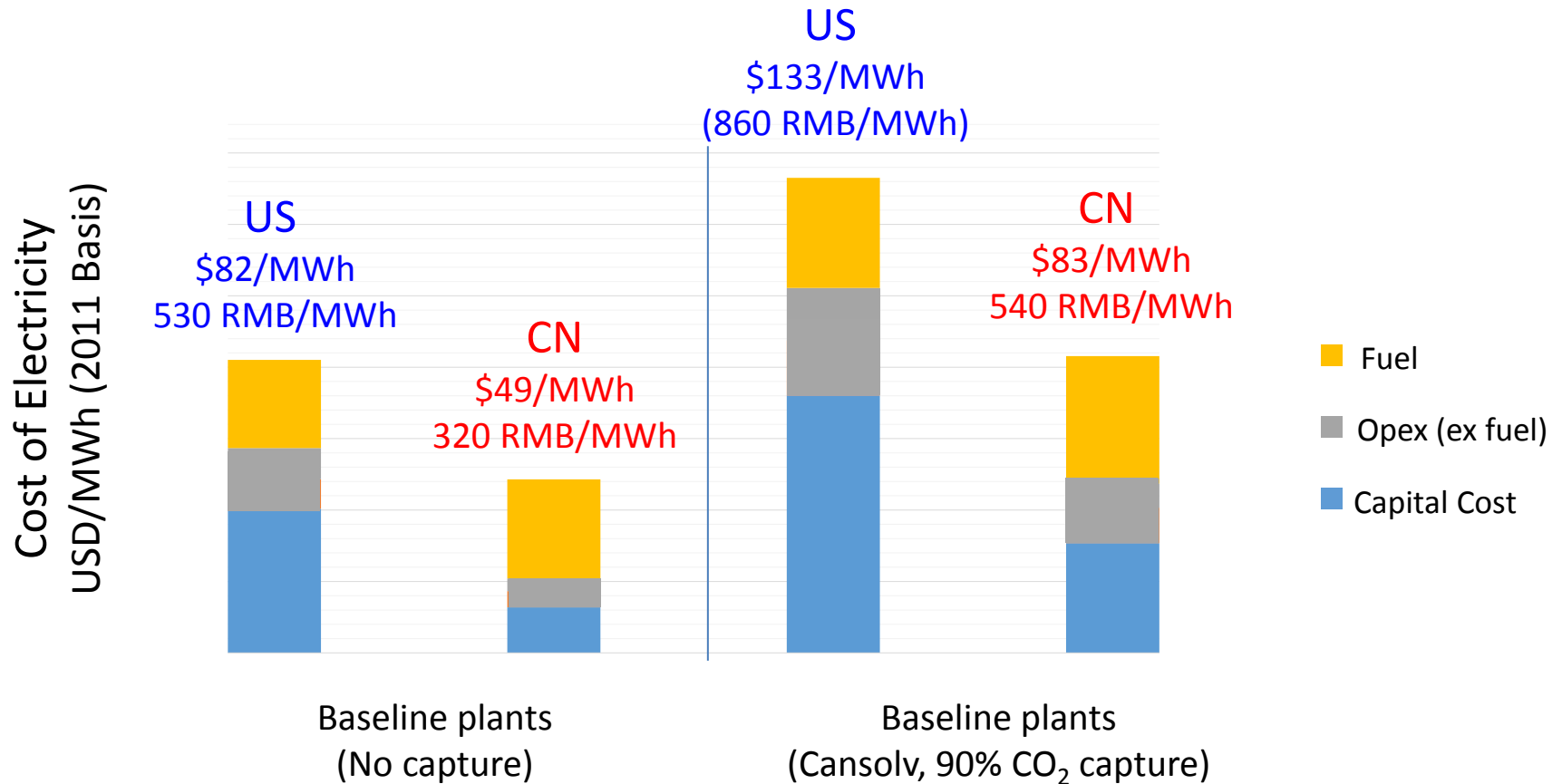
US – DOE bituminous coal  
(Cases 11 & 12, 2011)

China – Shenhua bituminous coal



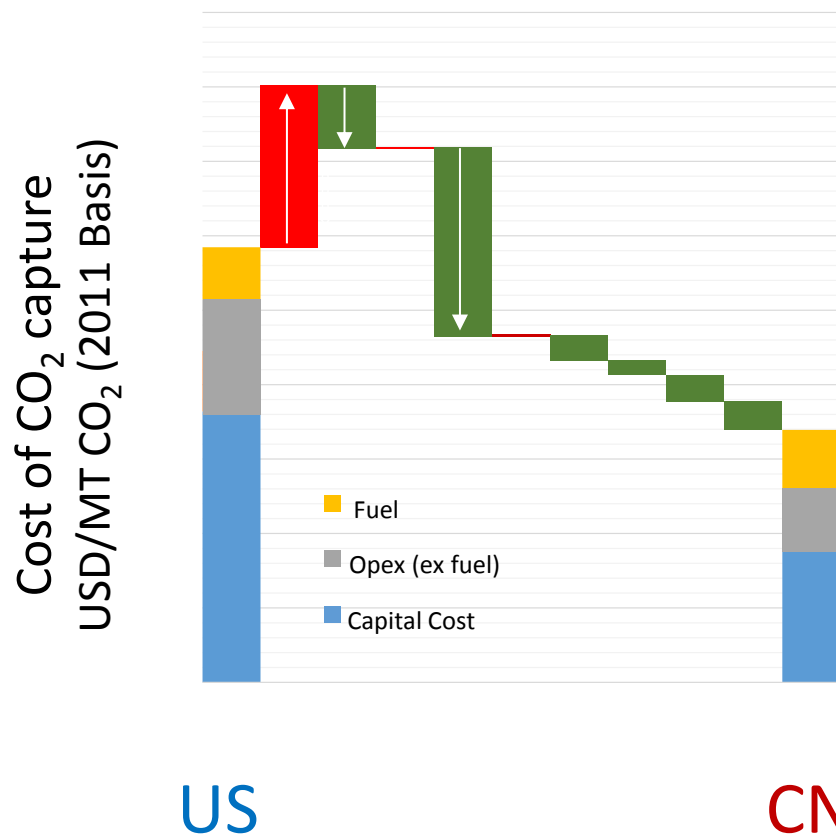
# Costs of electricity – US and China baselines

Preliminary results



## Preliminary results

### Drivers for CO<sub>2</sub> 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

## **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

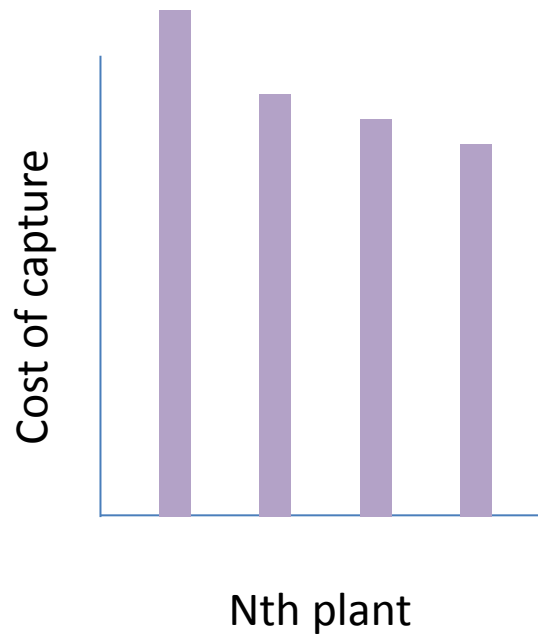
# **NICE RD&D**

## **2. CO<sub>2</sub> capture**

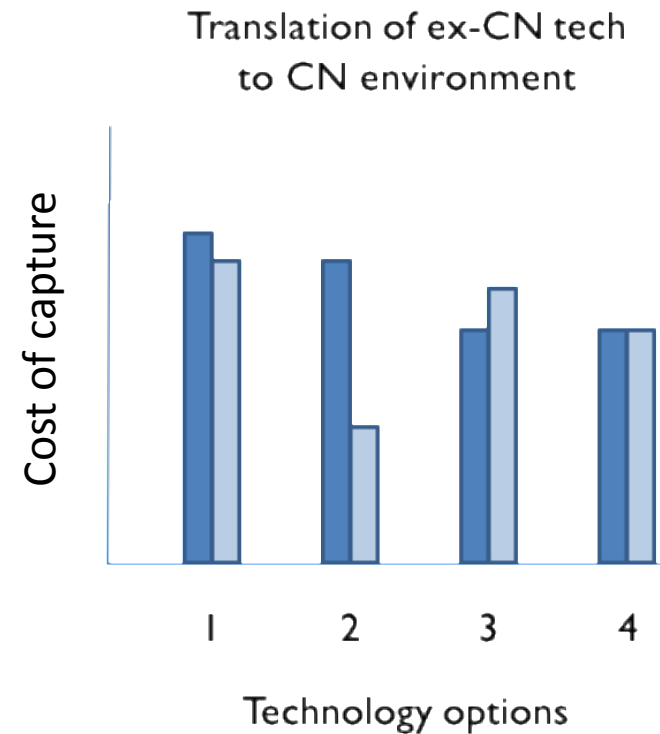
**Snapshot: Gen 2 capture tech for power generation**



Gen 1 technology  
(amine solvents)  
Cost maturation

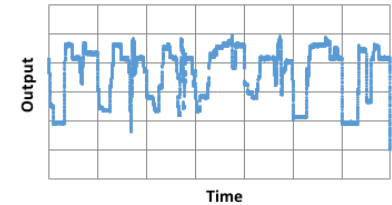


Gen 2 technology  
(alternate solvents, membranes, sorbents)  
Scale-up and validation



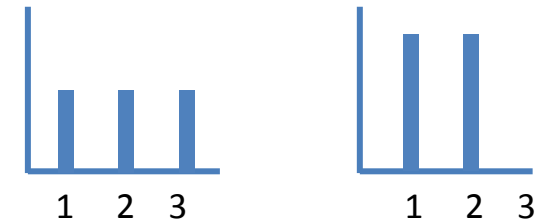
## 1. Capacity factor/load following

- Turndown can cause CO<sub>2</sub> concentration fluctuations
- Effect of ramping on performance and economics



## 2. Capture rate

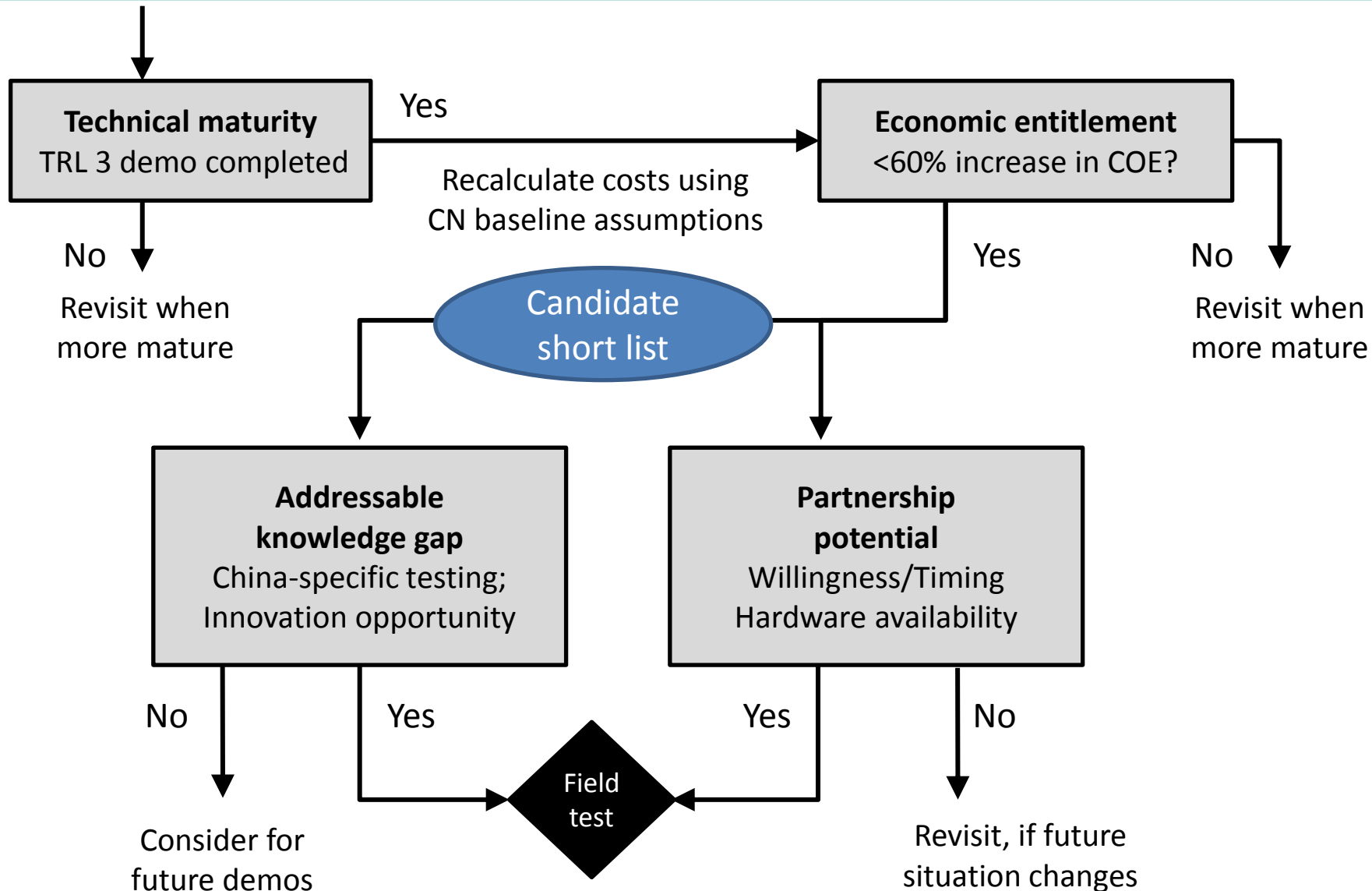
- NG equivalence ... 60-65% capture
- Fleet-level trade-offs for partial capture



## 3. Other

- Emissions controls ... sensitivity to contaminants and dynamics
- CO<sub>2</sub> product specs ... pressure, purity, off-take rates

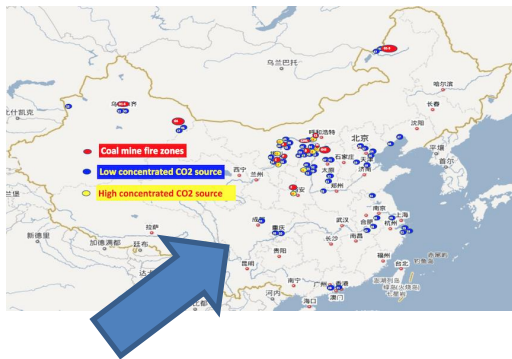
# Gen 2 technology – Screening criteria



## Jiangyou site (Sichuan province)



- 4 subcritical boiler units:
  - 2 x 300 + 2 x 330 MW
- Emissions controls: SCR, FGD
- Capture slipstream
  - 0.1 MW<sub>e</sub> (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.

## **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

## **NICE RD&D**

### **3. CO<sub>2</sub> utilization and sequestration**

**Snapshot: Geological storage  
demo at Ordos**



## □ 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



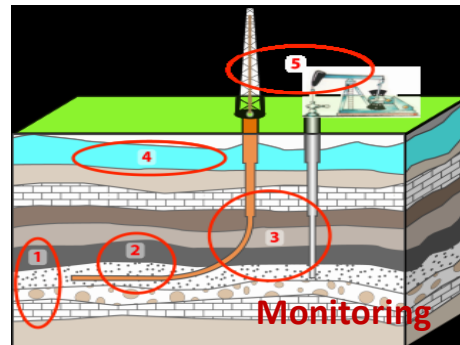
## □ Ordos DCL project

- Direct coal liquefaction ... high T hydrogenation
- Phase 1 Commercial operation 2011
  - ... 1 MM tpa liquids product (3.4 MM tpa coal)
- CO<sub>2</sub> footprint
  - ... 3.6 MM tpa from coal to H<sub>2</sub>
  - ... 0.7 MM tpa from power and steam
- CO<sub>2</sub> 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

## **Closing out Ordos project**

Continuing monitoring for long-term safety and CO<sub>2</sub> 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)

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.