Opportunities for early Carbon Capture, Utilisation and Storage development in China

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Presentation outline

- China CCUS policy, strategy and development status
- International developments in CCUS
- High-purity CO_2 sources and potential EOR locations in China
- Capture routes,
  - Separation technologies/processes
  - CO_2 purity specifications, compression and after treatment
  - CO_2 transportation options
  - Associated Cost
- Potential cost-effective full-chain CCUS projects in Shaanxi
- Barriers to CCUS development in Shaanxi
- Conclusions

China CCUS strategy and policies

- In the near term only R&D programs to support research centers and enterprises on CCS research exist.
- National Medium- and Long-Term Program for Science and Technology Development (2006-2020), State Council, 2006
  - **To develop efficient, clean and near-zero emission fossil energy utilization technologies - highlighted as an important frontier technology**
- China's National Climate Change Programme (2007-2010), State Council, 3rd June, 2007
  - **CCUS technology was included as one of the key GHG mitigation technologies that should be developed**
- China's Scientific and Technological Actions on Climate Change
  - **CCUS technology was identified as one of the key tasks in the development of GHG control technologies in China**
- China CCUS Roadmap (2011) prepared but not formally adopted
  - **Prioritizes industrial high-purity CO_2 sources and EOR for first full scale demonstration project**

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Proposed China CCUS roadmap

Launch full chain demo (2015)

Full chain scale: >300 k onne/a
Full chain energy penalty: <25%
Cost: 350 RMB/t

Capture scale: 300-1000 k tonne/a Capture energy penalty: <20%
Cost: 210 RMB/t

Transportation pipeline: >80km
Cost: 90 RMB/t
Capacity: 300 k tonne/a

Utilization capacity: 1m tonne/a
Oil production from EOR: 300k tonne/a

Storage: 300 k/a
Cost: 50 RMB/t

1Mt/a full chain demo (2020)

Full chain scale: 1m tonne/a
Full chain energy penalty: <20%
Cost: 300 RMB/t

Capture scale: 1m tonne/a
Capture energy penalty: <15%
Cost: 180 RMB/t

Transportation pipeline: 200 km
Cost: 80 RMB/t
Capacity: 1m tonne/a

Utilization capacity: 2m tonne/a
Oil production from EOR: 600k tonne/a

Storage: 1m/a
Cost: 40 RMB/t

Expand capacity (2030)

Full chain scale: >1m tonne/a
Full chain energy penalty: <17%
Cost: 240 RMB/t

Capture scale: >1m tonne/a
Capture energy penalty: <12%
Cost: 140 RMB/t

Transportation pipeline >=1000 km
Cost: 70 RMB/t

Utilization capacity: >2m tonne/a
Oil production from EOR: 1m tonne/a

Storage: >1m/a
Cost: 30 RMB/t

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Technically feasible and economically affordable climate change mitigation option

2015 | 2020 | 2030

Source: ACCA21, 2011

Status and plans for CCUS demos in China

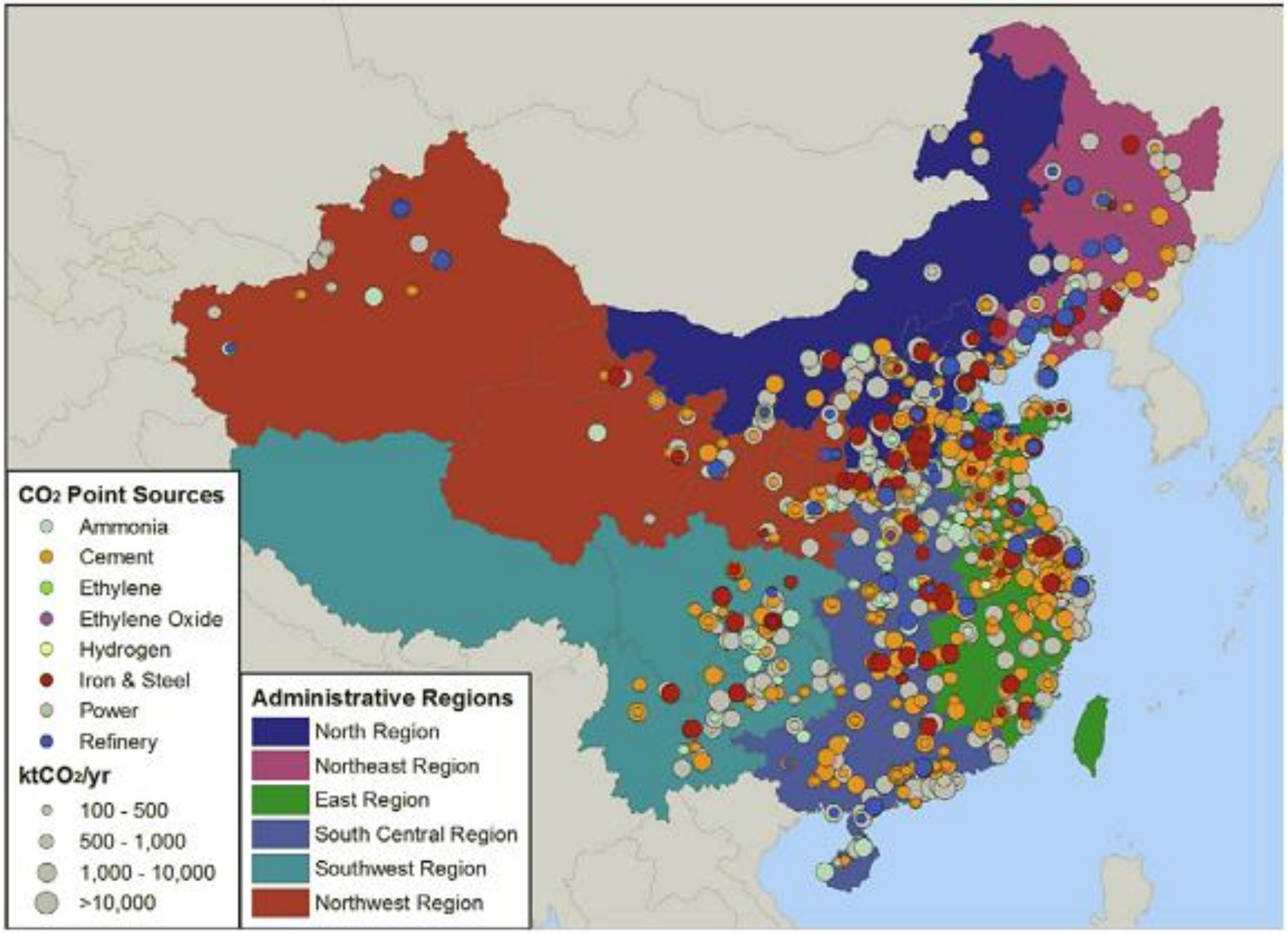
- **19 CCUS pilot/demonstration projects:**
  - 13 projects in operation
  - 6 projects planned
  - 2 projects phase II expansions
- **CO_2 utilization:**
  - 7 projects EOR (40-1000 ktCO_2/a)
  - 3 projects food/industrial use (3-120 ktCO_2/a)
- **Capture technology used in existing pilot/demo projects:**
  - Pre-combustion
  - Post combustion
  - Oxy-fuel
- **No high-purity CO_2 source industries are currently included in existing or planned CCUS demonstration projects in China**

High-purity CO_2 sources and EOR potential in China

- A recent study by PNNL estimated that there are 994 large (0.1+ $MtCO_2$/yr) non-power industrial plants, emitting a combined 1081 $MtCO_2$/yr.
  - About one-half of his is from cement production with the remainder made up of iron and steel, petroleum refineries, ammonia, ethylene, ethylene oxide, and hydrogen.

- The same study by PNNL reviewed sixteen major onshore and 3 offshore depleted oil basins for their EOR potential and estimated their total CO_2 storage capacity at 4800 $MtCO_2$—of which 4600 $MtCO_2$ is found onshore. This would ultimately allow additional recovery of up to about 7 billion barrels of oil.

Large power and non-power industrial point CO_2 sources in China



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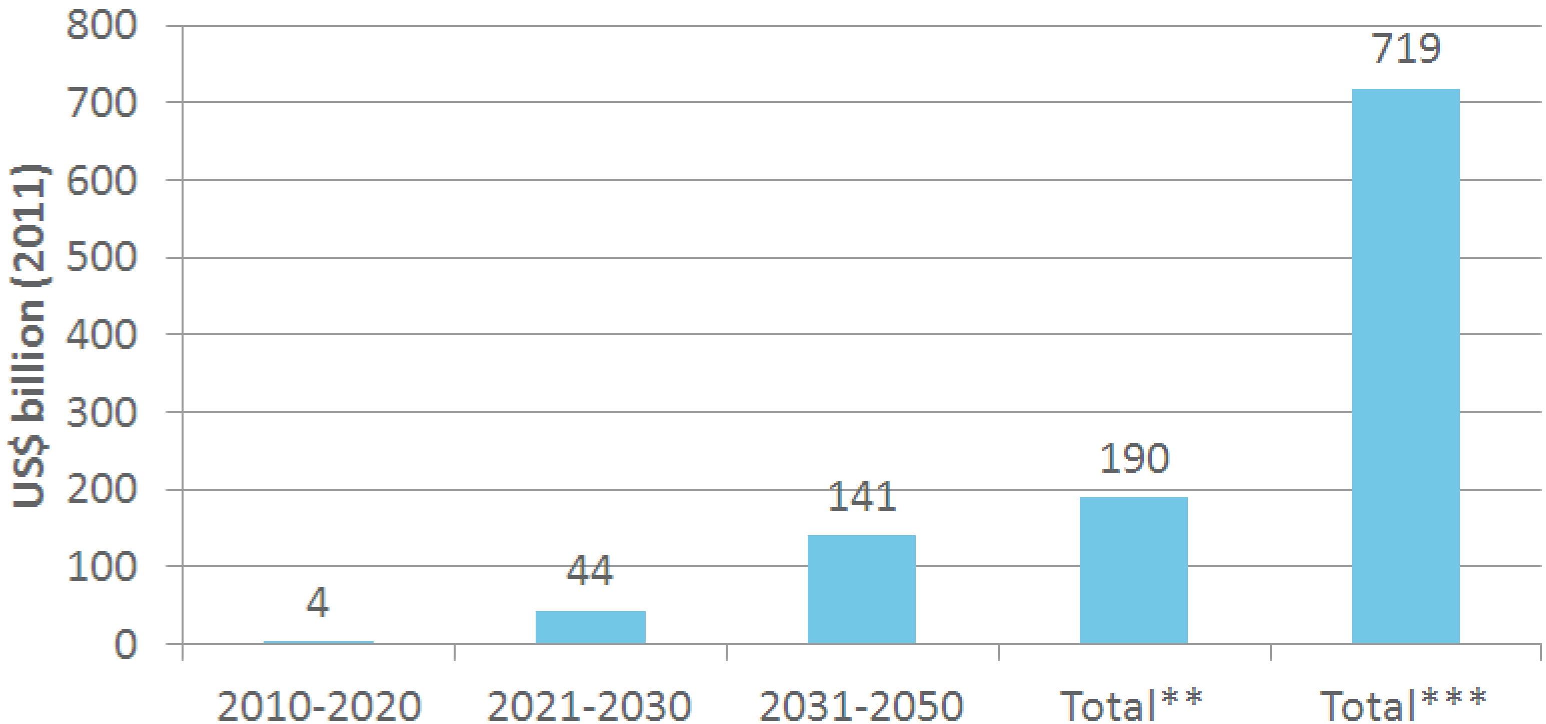
International CCUS developments

- The IEA/UNIDO have calculated that capture from high-purity industrial sources should account for 750 MtCO_2/yr globally by 2050.
- China is estimated to provide up to 120MtCO_2/yr.
- A total global investment of US$120 billion is expected to be needed for high-purity CCS, including transport and storage
- Financing options for CCS under the UNFCCC process are currently limited. CCS allowed in the CDM, but limited demand of carbon credits
- Business cases involving EOR, combined with bi/multilateral donor provisions are currently the primary channels for investment in CCUS

Investments needed for CCS in industry* in China 2010 – 2050



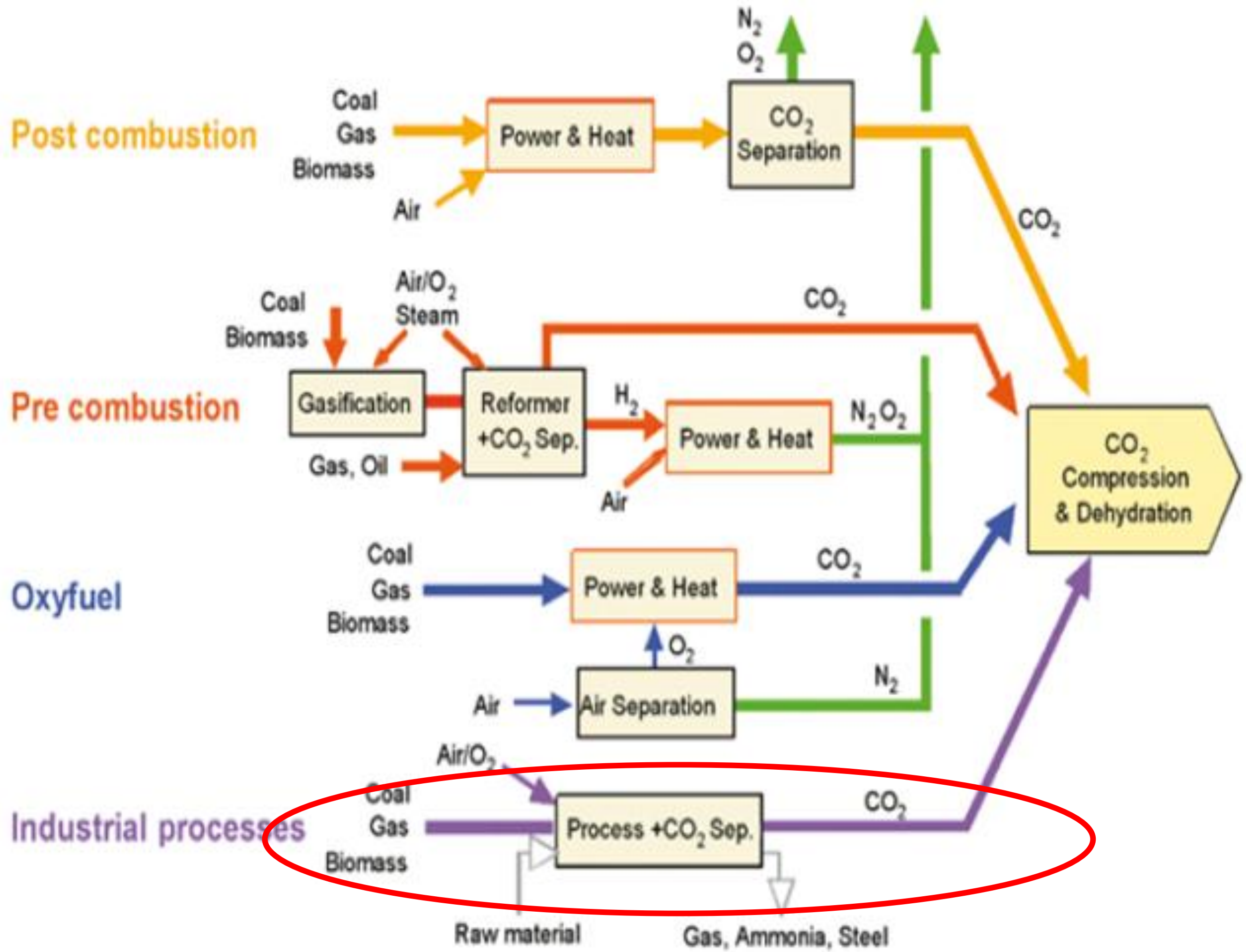
Source – IEA/UNIDO Technology Roadmap – CCS in Industrial Applications (2011)

* Including high-purity sector, biomass conversion, steel, cement production and refineries

Investment costs capture only * = investment costs including transport and storage

Total CO_2 captured in industry in China 2050 – 1 $GtCO_2$/yr, globally 4,5 $GtCO_2$/yr

Capture routes



Why use first high purity CO_2 sources?

- Capture of CO_2 from dilute gas streams is the most expensive component of the CCS chain:
  - Combustion plants (4-14% CO_2) – must be concentrated to make transport & storage economic
  - Low pressure & partial pressure – must use chemical solvents
  - High-levels of impurities (SO_2, particulates) – contaminate solvents
  - High energy demand for flue gas treatments (increases costs)

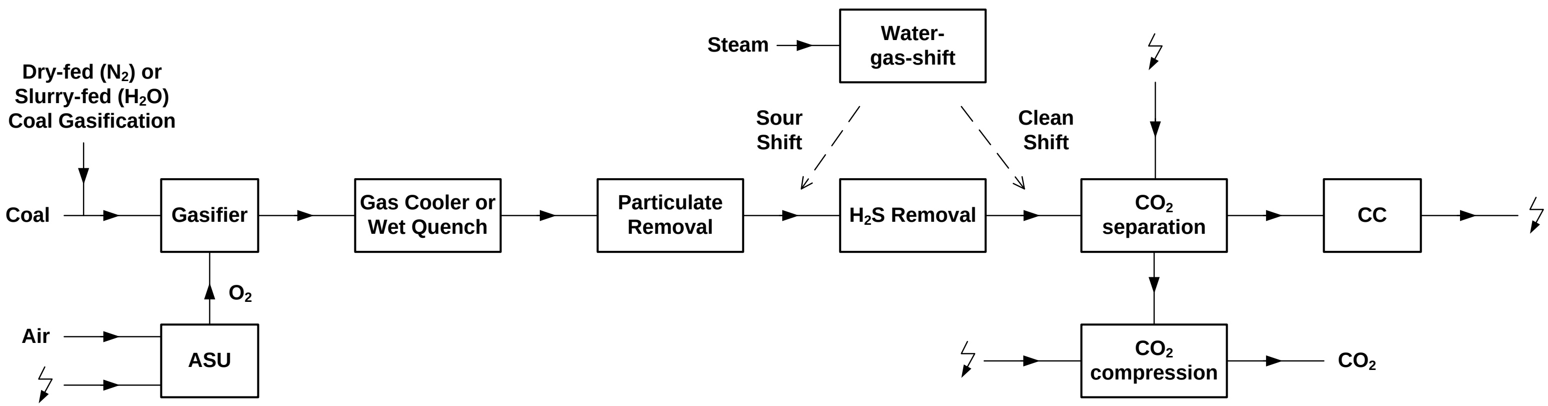
- High purity sources avoid many of these issues
  - CO_2 from the industrial process is required to purify the product, or because the CO_2 has an adverse effect on downstream steps in the industrial process
  - Since this CO_2 removal step is necessary in the industrial process, its costs are not attributed to CCUS.

Gas input streams composition resulting in high purity CO_2 sources

Source	CO_2 concentration % vol	Pressure of gas stream MPa[a]	CO_2 partial pressure MPa
Chemical reaction(s)			
• Ammonia production[b]	18	2.8	0.5
• Ethylene oxide	8	2.5	0.2
• Hydrogen production[b]	15 - 20	2.2 - 2.7	0.3 - 0.5
• Methanol production[b]	10	2.7	0.27
Other processes			
• Natural gas processing	2 - 65	0.9 - 8	0.05 - 4.4

[a] 0.1 MPa = 1 bar

[b] The concentration corresponds to high operating pressure for the steam methane reformer.



High purity CO_2 sources: examples

Industry	Technology producing high-purity CO_2
Power production	-
Gas and oil industry	Natural gas processing LNG production Coal-to-liquids Gas-to-liquids
Chemical industry	Hydrogen production Methanol production Ammonia/Urea production (Poly)Ethylene production
Biomass conversion	Biomass to Liquids Bioethanol production
Cement industry	-
Iron and steel industry	-
Refineries	- Hydrogen

CO_2 emission for coal based plants:

- 2 -3 ton CO_2 per ton NH_3
- 2,5 -3,5 ton CO_2 per ton of MeOH
- 3,8 -5,5 ton CO_2 per ton DME
- 2 -3 ton CO_2 Mm^3 CH_4

Separation technologies/processes

		BASF	DOW	EXXON	Fluor	Linde	Lurgi	Shell	Uhde/IFP	UOP
Monoethanolamine	MEA		O	O			O			
Diethanolamine	DEA						O			
Diisopropanolamine	ADIP							O		
Methyldiethanolamine	MDEA	O	O					O		
Potassium carbonate	Hotpot		O	O			O			
Methanol+MDEA/DEA	Amisol						O			
XXX+MDEA	Flexsorb			O						
Sulfolane+MDEA/DIPA	Sulfinol							O		
DME of PE glycol	Selexol									O
Methanol	Rectisol					O	O			
N-Methylpyrrolidone	Purisol						O			
PE glycol + dialkyl ether	Sepasolv	O								
Propylene carbonate	Fluor solvent				O					
Tetrahydrothiophenedioxide	Sulfolane							O		
Tributyl phosphate	Estasolvan								O	

Chemical

Mixed

Physical

Separation technologies/processes

		BASF	DOW	EXXON	Fluor	Linde	Lurgi	Shell	Uhde/IFP	UOP
Monoethanolamine	MEA		O	O			O			
Diethanolamine	DEA						O			
Diisopropanolamine	**ADIP**							**O**		
Methyldiethanolamine	**MDEA**	**O**	**O**					**O**		
Potassium carbonate	Hotpot		O	O			O			
Methanol+MDEA/DEA	Amisol						O			
XXX+MDEA	**Flexsorb**			**O**						
Sulfolane+MDEA/DIPA	**Sulfinol**							**O**		
DME of PE glycol	**Selexol**									**O**
Methanol	**Rectisol**					**O**	**O**			
N-Methylpyrrolidone	Purisol						O			
PE glycol + dialkyl ether	Sepasolv	O								
Propylene carbonate	Fluor solvent				O					
Tetrahydrothiophenedioxide	Sulfolane							O		
Tributyl phosphate	Estasolvan								O	

Chemical

Mixed

Physical

CO_2 purity specifications

- The specifications for CO_2 purity may be set by considerations on compression, transport and underground storage.
- How pure the CO_2 needs to be, depends on the impurity considered and CO_2 application.

Component	Limited by
Nitrogen	Compression costs
Hydrocarbons	compression costs, energy loss
Water	Corrosion
Oxygen	Corrosion, storage reservoir issues (EOR)
H_2S	Health and Safety
CO	Health and safety
Glycol	Operations
Temperature	Material integrity

CO_2 purity specifications

- Currently there are no national or internationally agreed standards for CO_2 purity.

- Specifications have been developed by EU research projects and European Benchmarking Task Force (EBTF), Franco, 2011)

	Recommended by EBTF	Aquifer	EOR
CO_2	> 90 vol	% > 90 vol	% > 90 vol %
H_2O	< 500 ppm (v)	< 500 ppm (v)	< 50 ppm (v)
H_2S	< 200 ppm (v)	<1.5 vol %	< 50 ppm (v)
NO_x	< 100 ppm (v)	NA	NA
SO_x	< 100 ppm (v)	NA	<50 ppm (v)
HCN	< 5 ppm (v)	NA	NA
COS	< 50 ppm (v)	NA	< 50 ppm (v)
RSH	< 50 ppm (v)	NA	> 90 vol %
N_2, Ar, H_2*	< 4 vol % *	< 4 vol % *	< 4 vol % *
CH4	< 2 vol %	< 4 vol % *	< 2 vol %
CO *	< 0.2 vol %	< 4 vol % *	< 4 vol % *
O2	<100 ppm vol	< 4 vol % *	<100 ppm vol

NA = Not available

Note: * - x + Σxi < 4 vol % = total content of all non-condensable gases

Impurities in delivered CO_2 (dry)

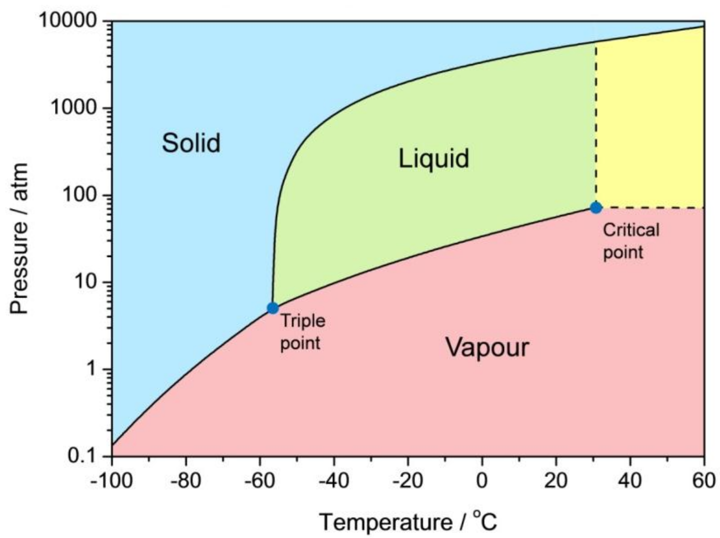
- Chemical solvents:
  - Because of the highly selective chemical reaction, the resulting CO_2 stream is very pure.

- Physical Solvents
  - CO_2 from physical solvents typically contains about 1- 2% H_2 and CO and traces of sulfur.

	SO_2	NO	H_2S	H_2	CO	CH_4	$N_2/Ar/O_2$	Total
COAL FIRED PLANTS								
Post-combustion capture	<0.01	<0.01	0	0	0	0	0.01	0.01
Pre-combustion capture (IGCC)	0	0	0.01-0.6	0.8-2.0	0.03-0.4	0.01	0.03-0.6	2.1-2.7
Oxy-fuel	0.5	0.01	0	0	0	0	3.7	4.2
GAS FIRED PLANTS								
Post-combustion capture	<0.01	<0.01	0	0	0	0	0.01	0.01
Pre-combustion capture	0	0	<0.01	1.0	0.04	2.0	1.3	4.4
Oxy-fuel	<0.01	<0.01	0	0	0	0	4.1	4.1

Compression and after treatment

	Temperature (°C)	Pressure (bars)	Comment
Pipeline	10 (NL)	80-200	Pressure drop in pipeline is compen-sated by high entrance pressure
Ship	-54 to -50	6 to 7	Liquid > 6 bar , <-55
Train	-10 to -20	25	Own estimate
Truck	-30	20	



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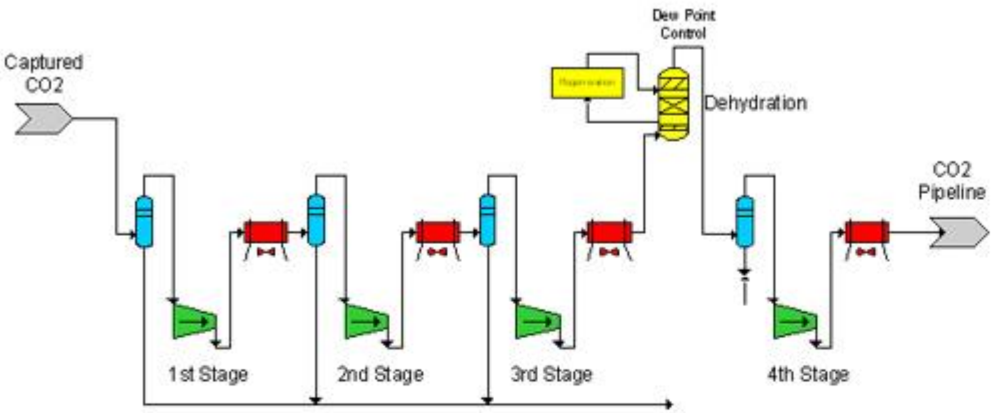


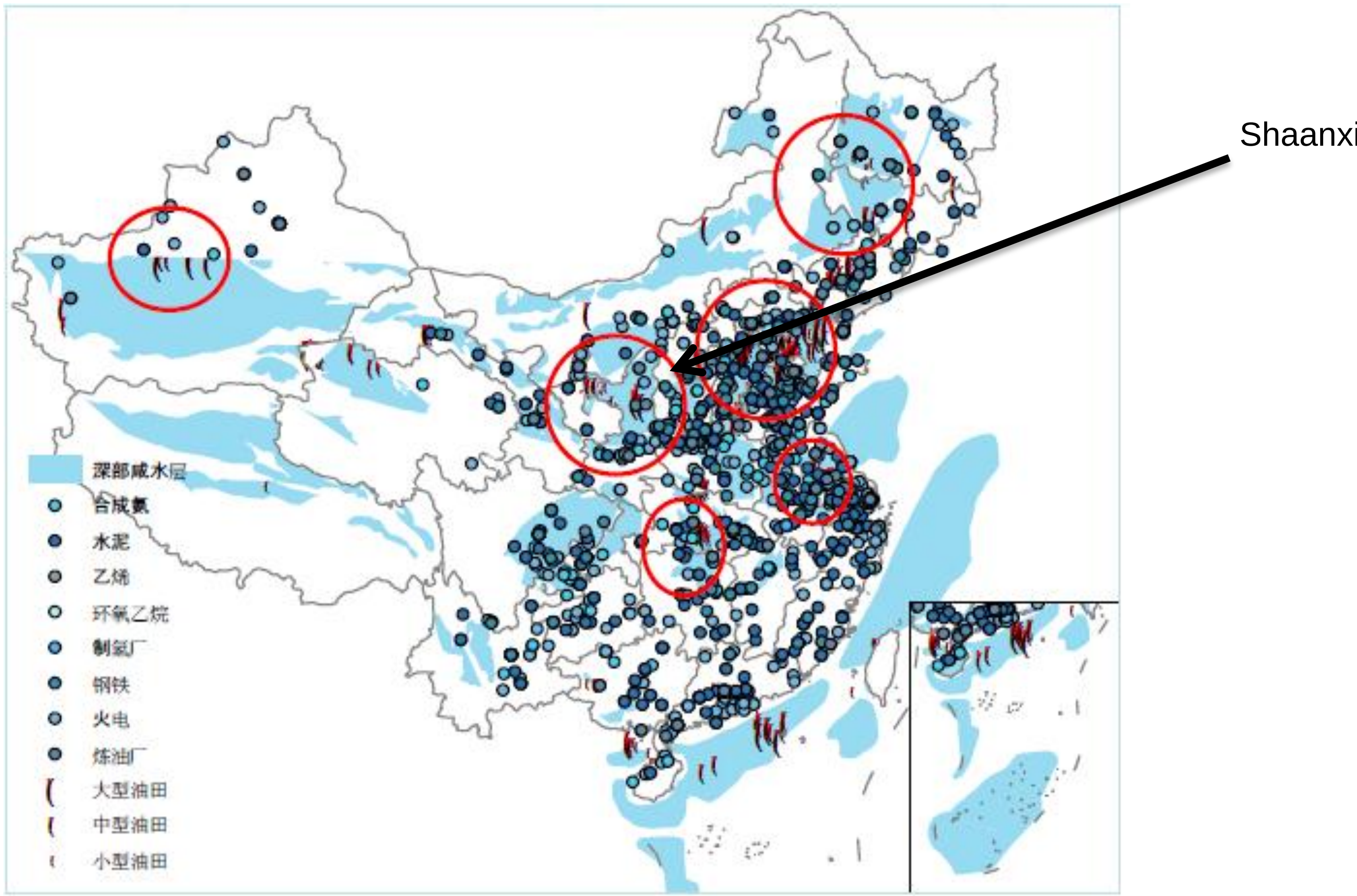
“Capture” cost

- Since the CO_2 removal step is necessary in the industrial process, its costs are not attributed to CCUS!

- Costs are associated only with:
  - Investment costs for:
    - Purification, dying and Compression or liquefaction 85 M$ for 4 Mton/year
  - *Energy costs for:*
    - *Liquefaction* *130 kWh/kg CO_2*
    - *Compression* *110 kWh/kg CO_2*

- Total cost 12 – 15 $/ ton of CO_2

Large point CO_2 sources and EOR potential

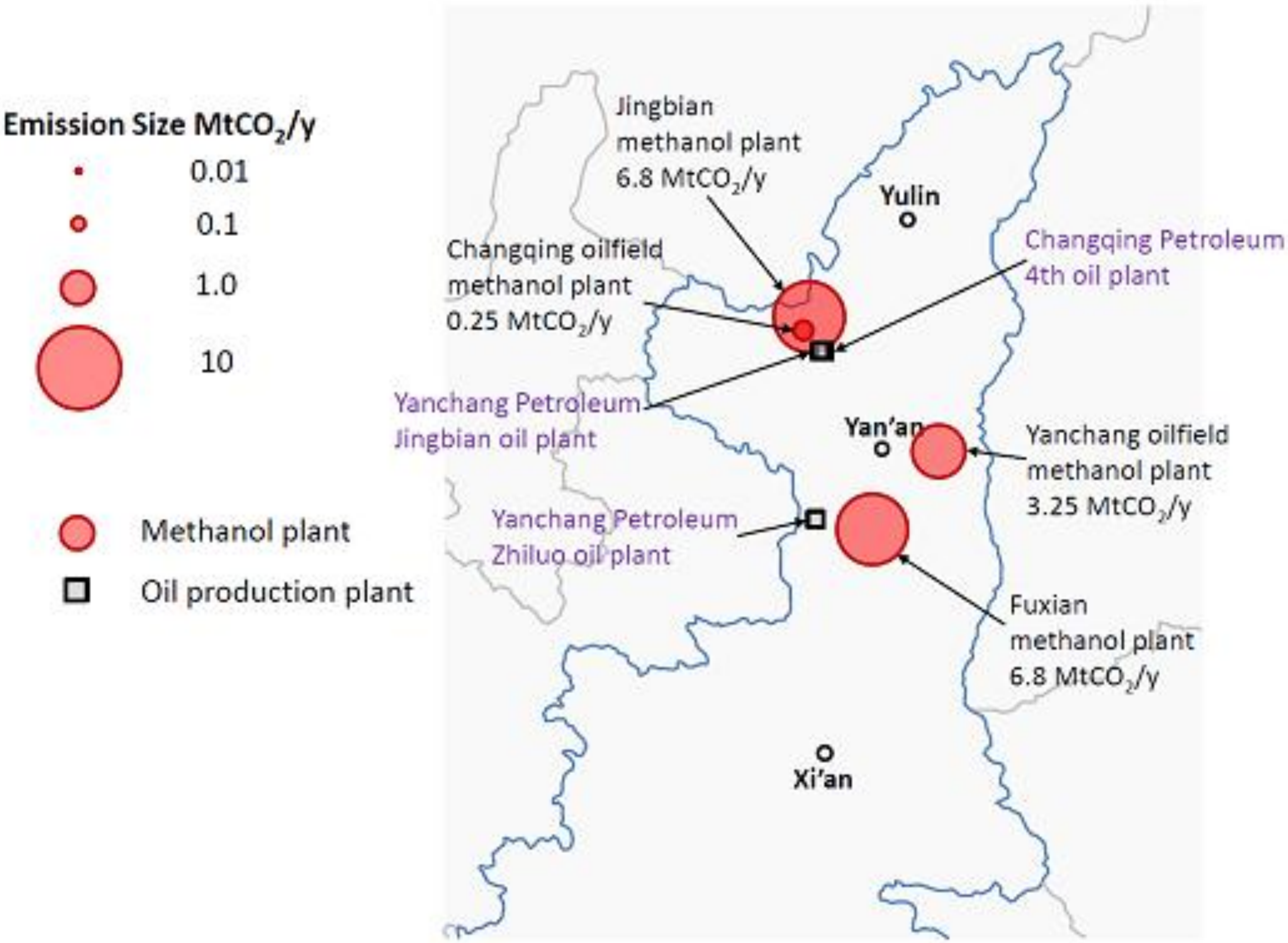


EOR potential in Shaanxi

- Yanchang oil field
  - 2010 production 12 million ton oil
  - Ownership: Shaanxi provincial government
  - Estimated indicative storage capacity: 45~88Mt CO_2
  - EOR plans: promote and apply water flood recovery, actively research and develop CO_2-EOR

- Changqing oil field
  - Part of Shaanxi-Gansu-Ningxia basin
  - Proven geological oil reserves of about 336 million tons, controlled reserves of about 394 million tons and prognostic reserves of about 533 million tons since 1999.
  - Ownership: PetroChina
  - Indicative storage capacity: 41~80Mt CO_2
  - EOR plans: currently promote and apply water flood recovery, actively research and develop CO_2-EOR

High-purity CO_2 sources in Shaanxi



CO_2 transportation options in Shaanxi

- Road – flexible, using existing road infrastructure
- Rail – flexible, using existing rail infrastructure
- Pipeline – more cost-effective, suitable for larger volumes (>2MT/yr), full-scale demonstration projects

- **Road and rail most suitable in early stages of CCUS development in Shaanxi**
- **Pipelines most suitable for larger scale CCUS projects in Shaanxi**

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Integrated CCUS projects in Shaanxi

Project	CO_2 sources	Emission volume	Transportation method	Storage type	Storage location
Case 1	Yanchang oil field methanol plant	3.2 Mt/yr	pipeline	EOR	Yanchang oil field
Case 2	Yanan Fuxian methanol plant	6.8 Mt/yr	pipeline	EOR	Yanchang oil field
Case 3	Changqing oil field methanol plant	0.25 Mt/yr	Highway/railway tanks	EOR	Changqing oil field
Case 4	Jingbian methanol plant	6.8 Mt/yr	pipeline	EOR	Changqing oil field

Cost-Benefit Analysis Shaanxi CCUS projects

	CO2 capture cost	Transportation cost	Injection cost[5]	Total CCS cost[6]	Total CCS cost after considering the oil benefit[7]
Case 1	15~20	1.6[1]	6	22.6~27.6	-50.4~5.6
Case 2	15~20	1.7[2]	6	22.7~27.7	-47.3~5.7
Case 3	15~20	3.2[3]	6	24.2~29.2	-45.8~7.2
Case 4	15~20	0.4[4]	6	21.4~26.4	-48.6~4.4
Capture from power sector	~22	~11	~4.6	~37	

Barriers to CCUS development in Shaanxi

1. **Policy and regulatory**:
   - Lack of clear national CCUS development roadmap
   - No legal framework for regulating industrial CO_2 emissions
   - No regulatory framework for managing CCUS safety aspects
2. **Technical:**
   - CO_2 EOR technology not mature in China
     - Value of CO_2 for EOR not clear
     - Business case for CCUS cannot be made concrete
   - No CO_2 monitoring system in place
3. **Finance:**
   - First-of-a-kind project requires special sources of funding
   - high initial investment requires strong business case and long-term certainty regarding key economic conditions
   - lack of funding mechanisms and sources

Conclusions

- CCUS is a key climate change mitigation option globally and in China
- Globally CCUS demonstration has focused on the power sector, at relatively high cost
- Capture cost are lower at high-purity industrial sources with a global and China potential of 750 MtCO_2/yr and 120Mt CO_2 /yr by 2050.
- Preliminary cost-effective potential for developing 4 integrated full-chain CCUS projects based on high-purity CO_2 sources and utilization for EOR exists in Shaanxi Province.
- Key barriers impeding the development of this cost-effective potential include the lack of a national CCUS roadmap, further required development of China's EOR capabilities, required coordination between government organisations, lack of a cap or price on CO_2 emissions and lack of funding mechanisms.

Demo project development recommendations

- Conduct detailed technical and economic feasibility assessments for the identified 4 Shaanxi projects
- Select 1 national high-purity CO_2/EOR demonstration project in Shaanxi
- Develop detailed business models for the operation of the national demonstration project
- NDRC and MOST to coordinate key authorities for full chain projects

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Cost-Benefit Analysis assumptions

1. Pipeline transportation, 150km
2. Pipeline transportation, 300km
3. Highway tanks transportation, 100km.
4. Pipeline transportation, 300km.
5. Excluding EOR benefit : data from IPCC special report on carbon capture and storage.
6. Excluding EOR benefit.
7. 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.
8. CO2 is captured from traditional coal-fired power plant.
9. Pipeline transportation, 300km.

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