China's CO2 EOR/CCUS Projects.

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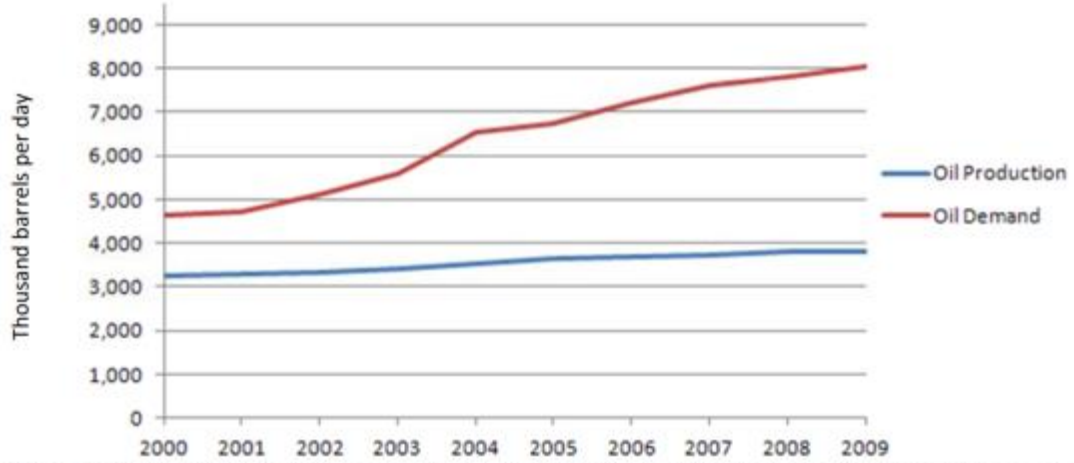
Clean Air Task Force (CATF): Building a US-China CCUS Technology Bridge.

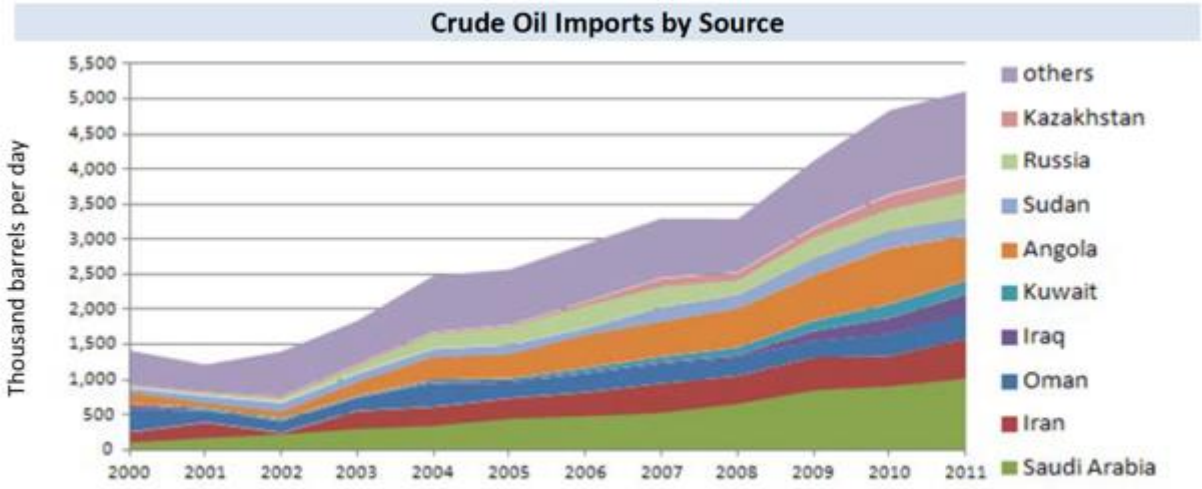
Serving as a U.S. technical resource and partnership builder in China in order to facilitate development of CCUS in China through development of CO2 EOR and carbon storage in combination with carbon capture technology.

China's Oil production increasingly lags consumption. Why China is interested in EOR.



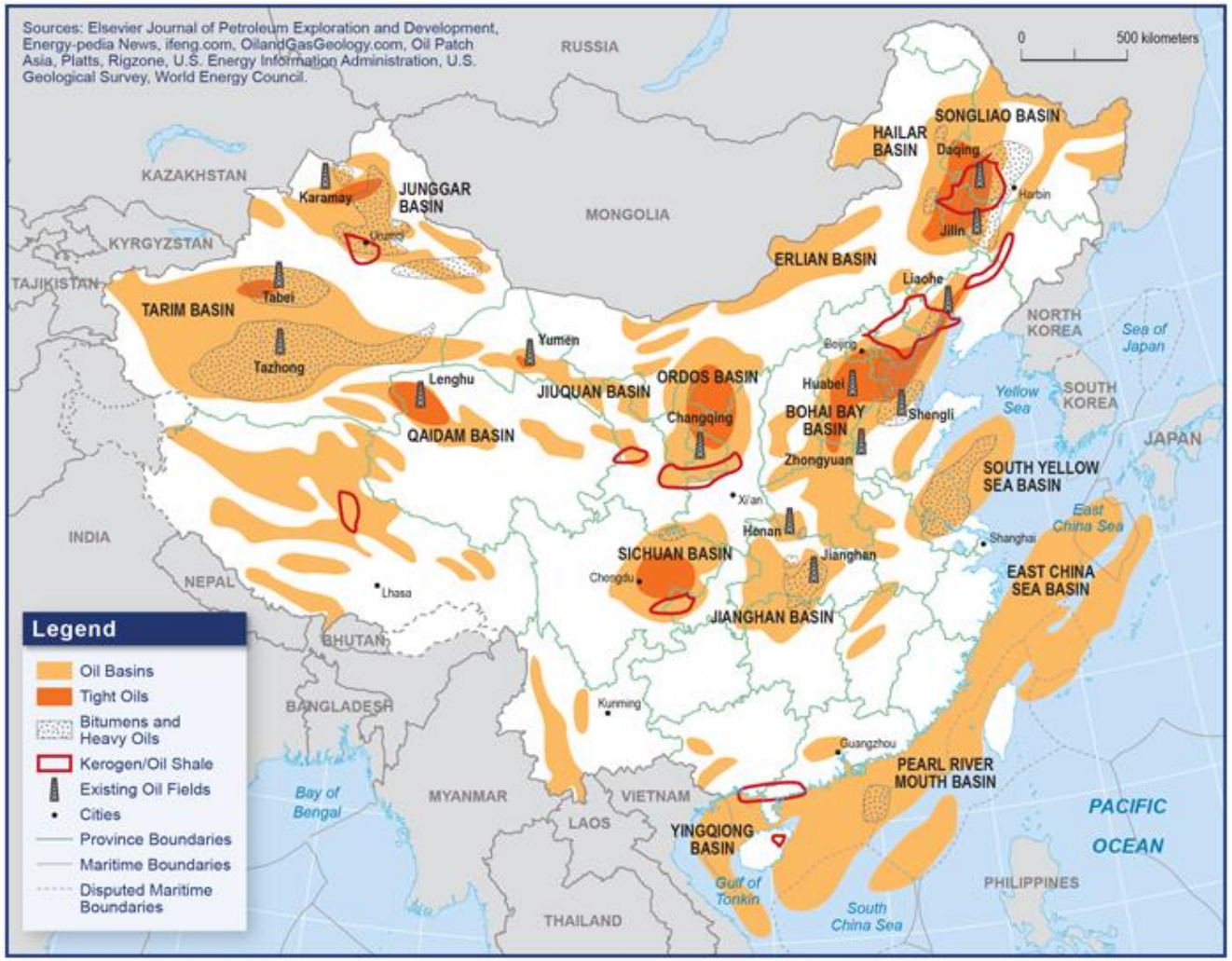
Source: Calculated by the IEA based on China Energy Statistical Yearbook 2010, National Bureau of

(IEA 2012).



Source: China Oil, Gas and Petrochemicals

China's Petroleum Basins



China Oil Production

- 3.9 MM bbls/ Day in Aug 2016
- Decline 6% in 2016.

(U.S.= 8.9 MM bbls/day 2016.)

China's CO_2 EOR - Big Picture

- Most projects initiated in the 2000s. Numerous CO_2 pilot projects date to the 1980s; Daqing lab tests as far back as 1960s, Liaohe field flue gas (10-15% CO_2?) injection in 1998.
- Commercial EOR projects rely mostly on trucked liquid CO_2, or pipelined gas phase CO_2, subsequently liquified.
- No supercritical CO_2 pipelines; several planned. A few operational & short gas phase pipelines (e.g Shengli, Jilin).
- Experimental CO_2 recycle facilities; none commercial scale.
- Most likely commercial projects will be internal to companies, matching industrial CO_2 with nearby fields.
- EOR Build out has been slowed by:
  - Technical challenges.
  - Lack of abundant natural CO_2 sources; must rely on capture.
  - Drop in Global oil prices (China indexed to Brent Sea Crude).
  - Limited CO_2 engineering know how.

Key CCUS/ EOR Projects* Highlighted in this Presentation.

I. Northeast China -Songliao Basin– CNPC Daqing and Jilin.

II. North-Central China Ordos Basin -Shaanxi Yanchang Yulin-Jingbian/Wuxi.

III. East China- Bohai Basin-Sinopec Shengli.

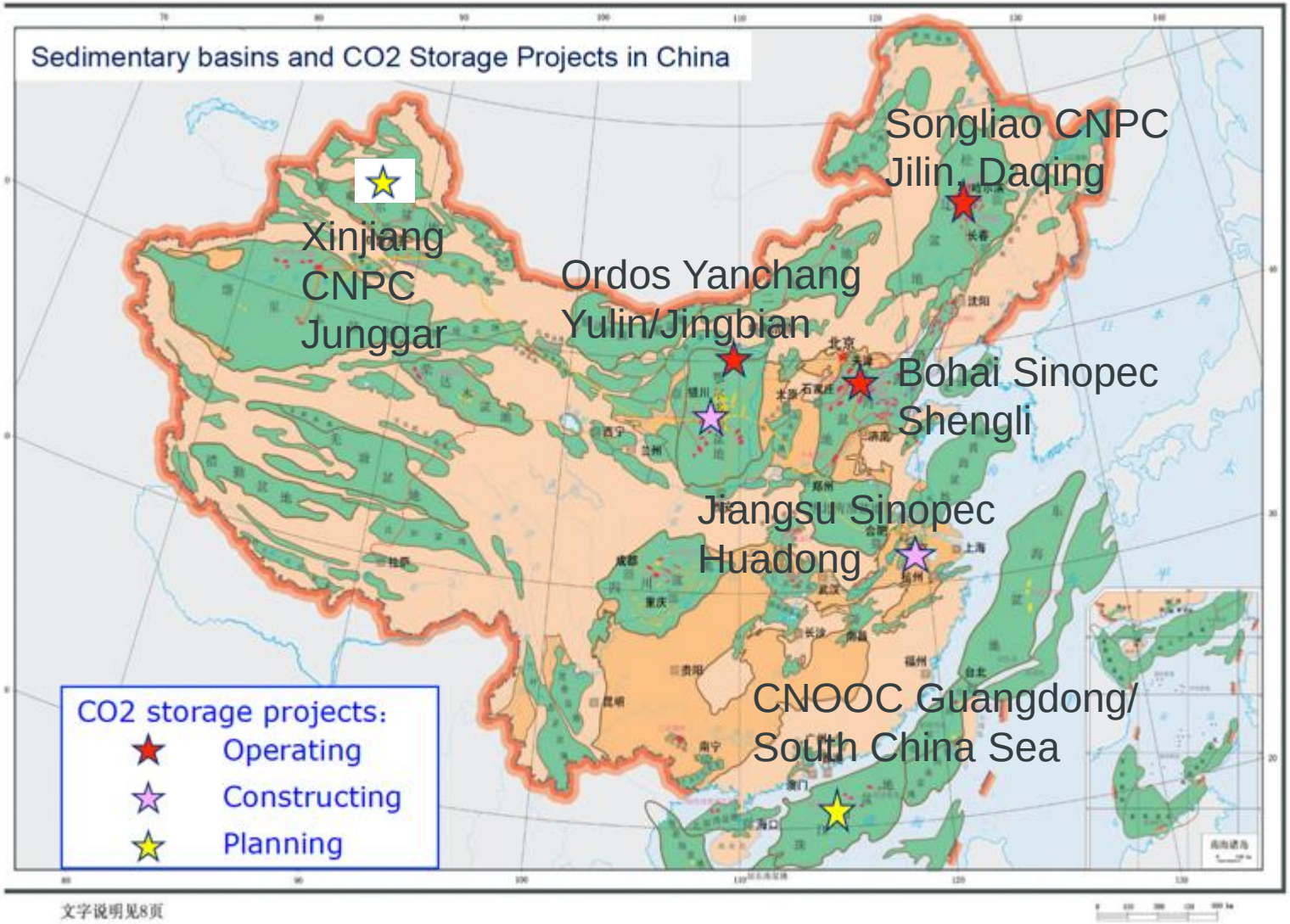
IV. South Yellow Sea Basin- Jiangsu-Sinopec Huadong Field.

V. W. China Junggar Basin Xinjiang. CNPC Zhundong, Karamay Fields.

VI. South China Sea/Guangdong: CNOOC.

*Not comprehensive. E.g. other projects: Zhongyuan, Liaohe, Changqing, Dagang.

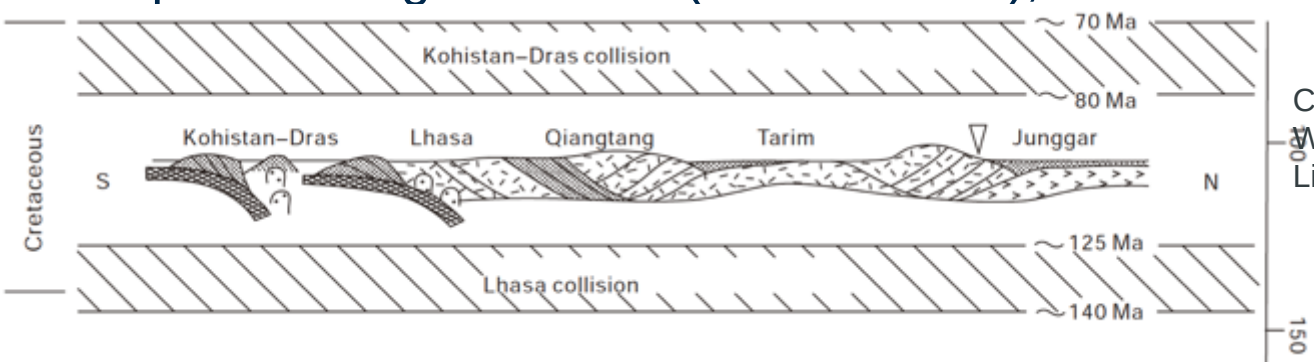
CO2 EOR/Storage Projects with Potential to be Full-Chain CCUS Projects



Modified after Di Zhou 2016

Reservoirs / Challenges

- Subsurface is considered a state secret…caveat emptor…!
- Largely continental Mesozoic-Cenozoic age clastics.
- -Commonly deep (exc. YPC Shaanxi) ,12% porosity, 1-10 mD k- tight.
- -Highly Fractured, under-pressured & hard to achieve MMP.
- -Low API gravity oil.
- -Water is scarce for flooding.
- -Poor condition of existing wells
- +Plenty of pure-source CO2 emissions; no supercritical pipelines.
- Limited engineering experience.
- Experimenting with fracs (water & CO2), horizontal wells.



Cretaceous Continental tectonics, Western China;
Li et al 2014

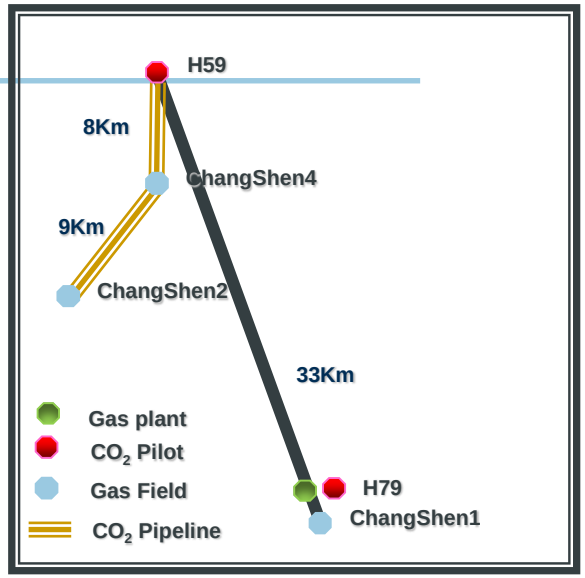
Representative Data- Selected CO2 Floods					
Company	Sinopec	Yanchang	CNPC	CNPC	Sinopec
Province	Shandong	Shaanxi	Jilin	Heilongjiang	Jiangsu
Field	Shengli	Jingbian Qiaojiawan	Jilin	Daqing	Huadong
Well	Gaoqing 89-1	2,9 &6	Hei-59	B-14	YYT-JL
Formation (member)		Chang-6	Qing-1		
Flooding Project start				1991	2010
Geology	tight sand	tight sand	tight sand	tight sand	tight sand?
Geology- descriptive		fractured Continental deltaic arkosic channel sand		River channel discontinuous continental	
Water flood				9249 injectors	
CO2 flood				immiscible	
Reservoir P		8 MPa			
Injection Depth (m)	3000	600-1900	2445	1730	2300
Injection period	2007	2012	2007	2009	2010-
Porosity	13%	8-14%	11%	12%	13%
Permeability --k	4.7 mD	1-10 mD	3 mD	1.1 mD	5-10 mD
Producer Wells	14	20	24		117
Injector Wells	5	5	6	10	43
Injectate	liquid CO2	liquid Co2	liquidified CO2	liquidified CO2?	WAG-Liquidified CO2?
CO2 source	natural & trucked	trucked CTX	NG separation		Natural HongQiao field
Injection P/ wellhead	6-19.5 MPa		22 MPa		
Injection rate		20 TPD	40 TPD		90,000 TPA
Production rate	5.2 TPD		3.3 TPD		
Total production to 2016		2550 T			
Incremental recovery rate		6-12%	10%		
Bottomhole P	23-27 MPa				
Bottomhole T (Deg C)	110	80	97	86	103
T CO2 injected (as of 2016)	128,000	720,000	341,000		

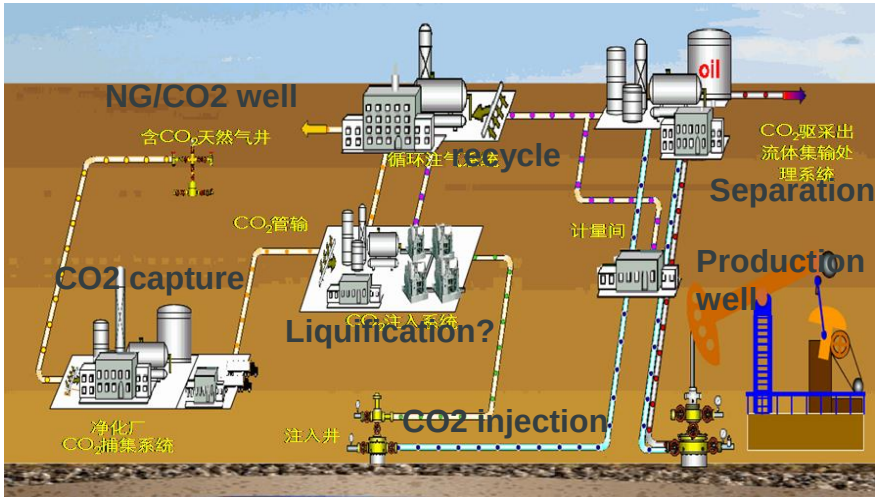
I. CNPC Jilin (Jilin) & Daqing (Heilongjiang) Oilfields, Songliao Basin

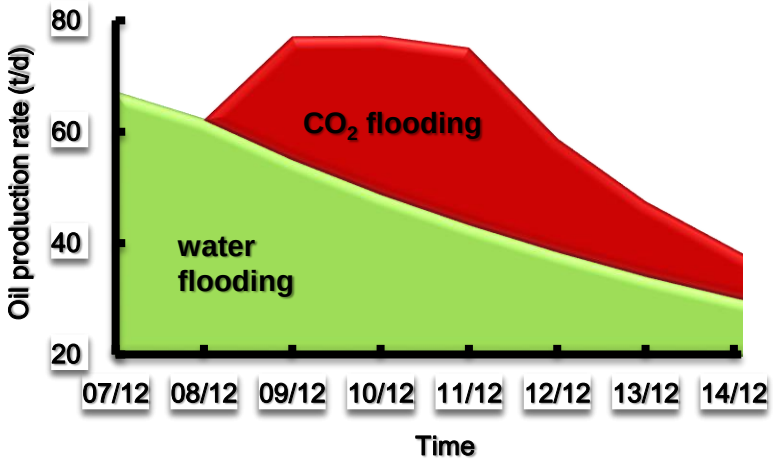
- Over 90% of CNPC fields are water flooded.
- Many/most of China's CO_2 floods have not achieved miscibility.
- Daqing: China's first CO_2 project,1980s, China's largest oil field. Plan (unexecuted) in 2009 to capture 1-3 Mt CO_2 at 2 600 MW coal plants in Harbin and pipeline 100km to Daqing.
- Jilin: CO_2 tests began in 2007-2009, in several phases. CO_2 source: natural gas separation. ~200,000 TPA
- Both: Tight fluvial channel sands.
- 12-13% porosity, single-digit k.
- CO_2 increased recovery 10%.

CNPC Jilin Project, Songyuan China

- Several short gas phase pipelines legs & liquification.
- CO2 source: Natural gas separation, Changshen gas field.
- 1 MT total as of 2016.
- Plan to expand to 800,000TPA_-1MT TPA (unexecuted) .





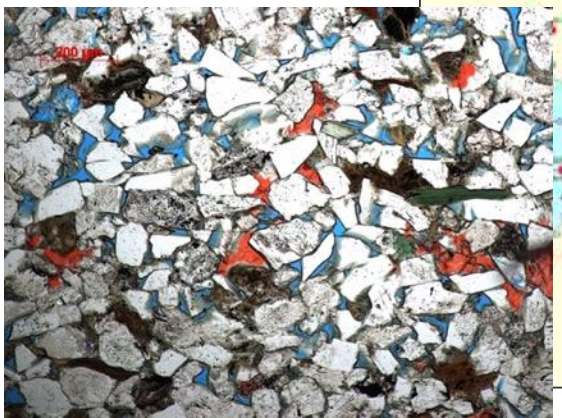


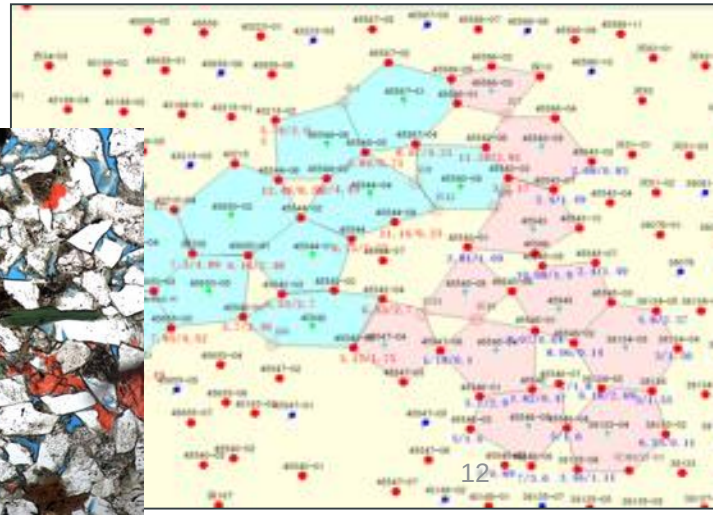
II. Shaanxi/ Ordos Yanchang (YPC)

- Yanchang Yulin CTX/ methanol plant; acetic acid process, 50,000 TPA CO2 capture.
- Liquid CO2 trucked 3x /day 80 km to Jingbian Oilfield.
- 360,000 TPA capture in planning.
- 80 km supercritical pipeline Yulin to Jingbian / Wuxi fields planned, not executed.
- US-China “Presidential Project”/ Presidents Obama-Xi in 2015.
- YPC Experimenting with CO2 fracs & horizontal drilling.

YPC Jingbian Qiaojiawan field

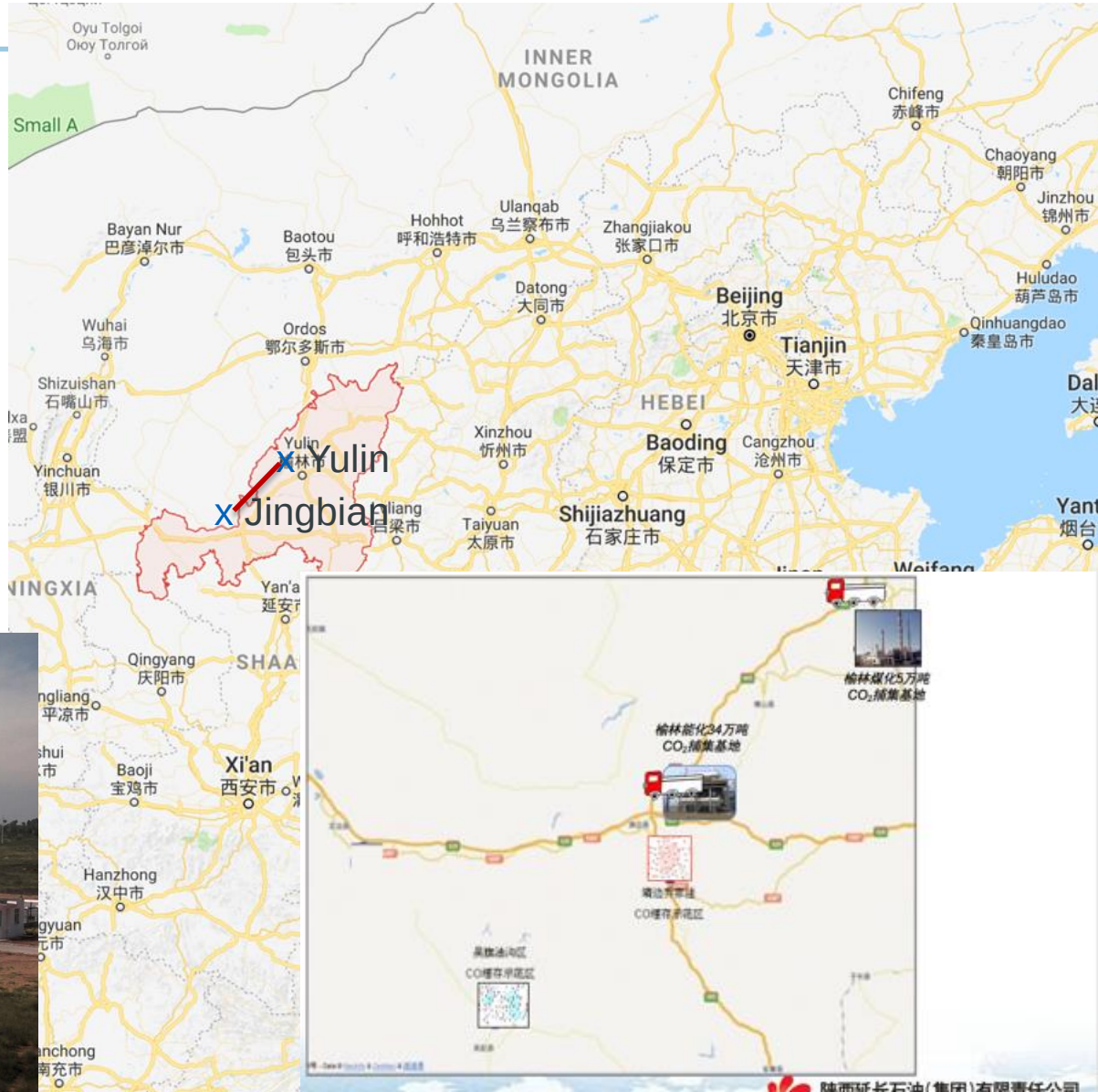
- Jingbian (2012) CO2 flood currently non profitable, immiscible, fractured tight sand.
- Jingbian injections: 20 TPD/well CO2
- Wuxi Field; injections started 2014; 35 injection wells planned, 100,000 TPA Tight, deep, low K, fractured channel deposit .
- Challenged reaching MMP; underpressured, shallow.





Planned Yulin – Jingbian 360,000 TPA CO2 Pipeline

<u>Side note</u> Shenhua did First China saline storage test- 100,000 TPA in Ordos. Image: Cornerstone Magazine. (Below.)



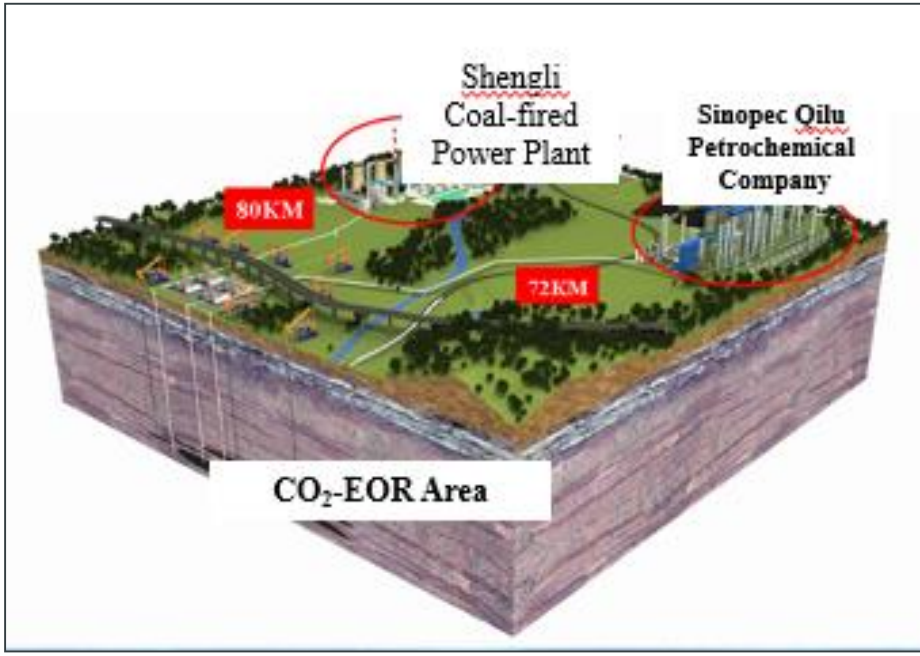
III. Sinopec Shengli Gaoqing 89

Zhenglizhuang Oil Field G89 Block

- Pipeline with gas-phase CO2 then liquified.
- Natural (99% purity) & trucked/ captured.
- 14 production wells, 5 injectors
- 5-Spot patterns
- 120 TPD gas phase pipeline-natural CO2
- Target for pipeline development

Shengli CCUS – Planned Pipelines

- **1 MT CO2 Pipeline from Shengli Coal-fired Power Plant**
- Construction investment：307 million RMB. (~$46M USD)
- Supercritical phase.
- 80 km.
- **500,000 TPA Pipeline from Sinopec Qilu Petrochemical Co mpany**
- Construction investment：252 million RMB. (~$38M USD)
- Gas phase.
- 72 KM.



Source: Sinopec

CCUS-Future CO2 Source: Sinopec Shengli Power Plant

- 50,000 TPA MEA capture pilot.
- Planned Expansion to 1Mt
- 80 km Supercritical Pipeline to Gaoqing Oilfield for EOR
- Unit 3 Capture Ready.

Dalian University of Technology Supercritical Pipeline Research Sites

- Sinopec Engineering in DongYing China is focused on pipeline design partner with Dalian University.
- Building China confidence and know-how on supercritical CO2 pipeline development

Dalian University and Sinopec Supercritical Pipeline Lab & Field Studies funded by EU

- 257 m test pipeline in Anbo, Liaoning Province.
- Build out of lab scale.
- Electrical heating wrap boosts pressurized liquid CO2 to supercritical.
- Accidental release tests in sand and above surface to test plume dispersion with sensors and video.
- Also tests crack propagation, decompression waves.

IV. Sinopec Jiangsu Huadong

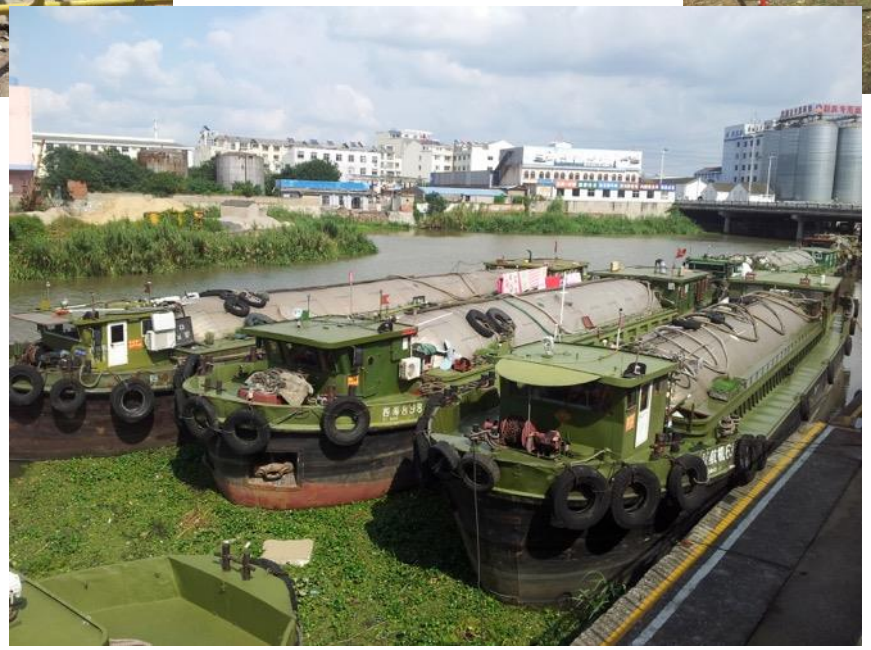
- Large (relatively unknown!) WAG project.
- 43 injectors, 118 producers.
- Natural CO2 source, Transport by barge. 90,000 TPA.
- Purified to 99.5% & liquified, like Gaoqing.
- Pre-FEED engineering completed in 2014 for 70 km. 10” supercritical pipeline, 700,000 TPA capacity.
- In 2015, tabled due to oil prices.

Sinopec Jiangsu Huadong Project

Images courtesy, Z. Fan, Sinopec Engineering

CO2 production well

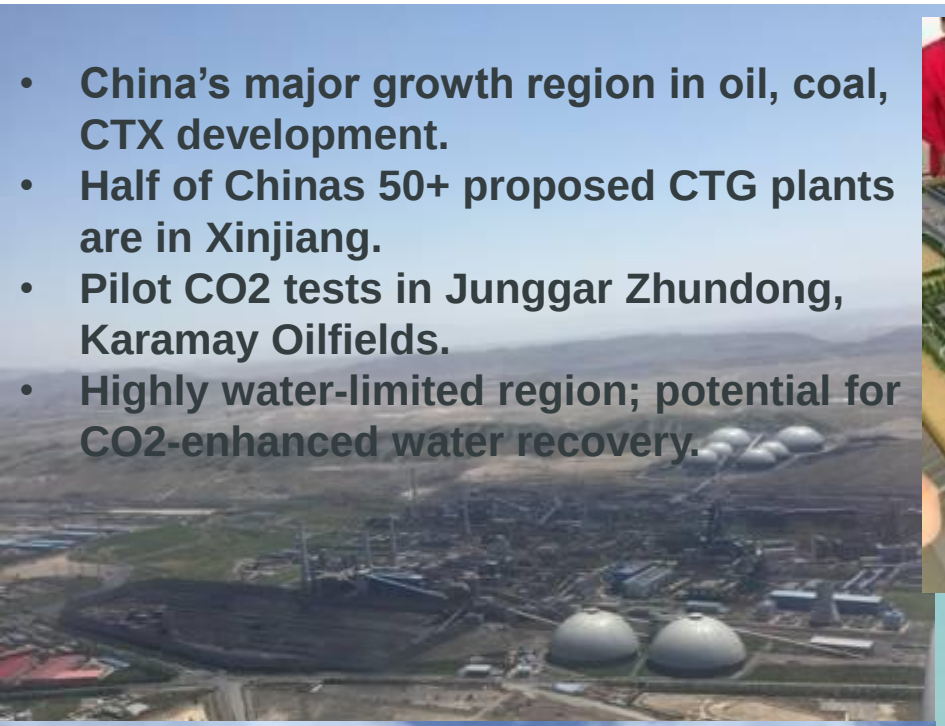
Injection Well

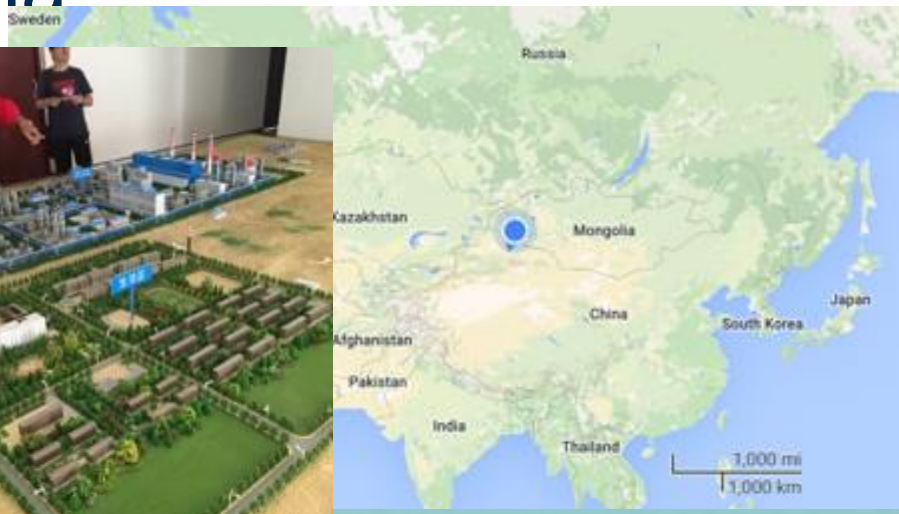


Barge transport of CO2

V. Xinjiang Autonomous Region, Gobi Desert, Western China

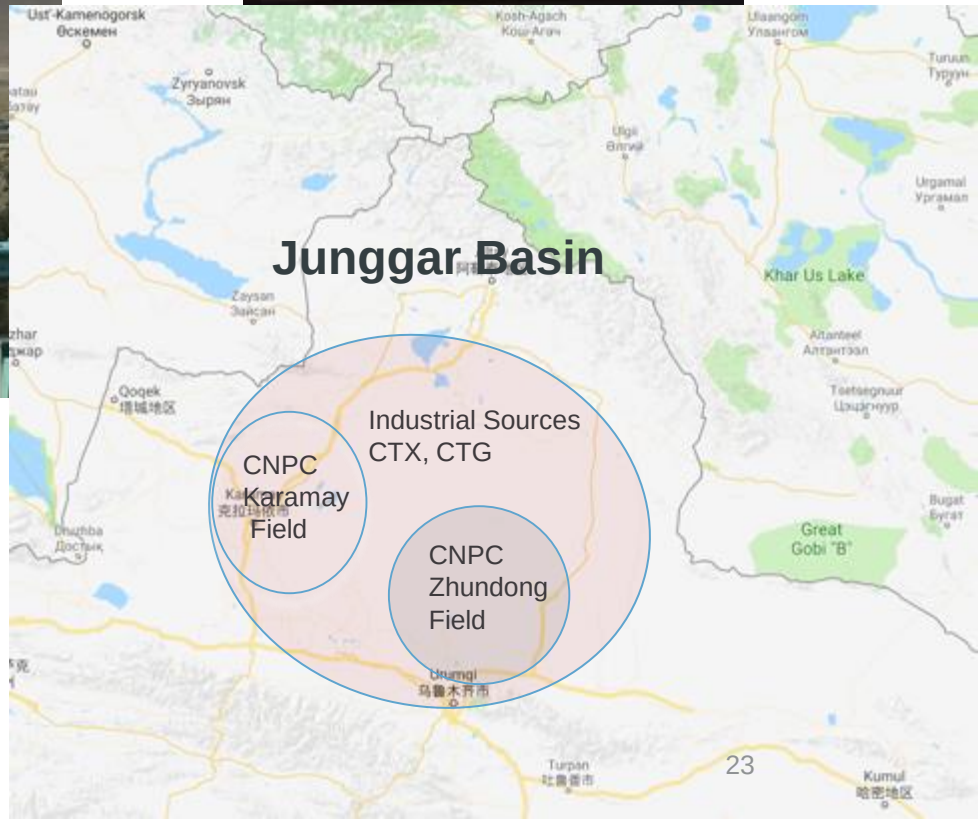
- China's major growth region in oil, coal, CTX development.
- Half of Chinas 50+ proposed CTG plants are in Xinjiang.
- Pilot CO2 tests in Junggar Zhundong, Karamay Oilfields.
- Highly water-limited region; potential for CO2-enhanced water recovery.





Juxtaposed Coal Chemical Plants & Oilfields an Opportunity for CO2 EOR

CNPC Junggar Zhundong Oilfield



- CO2 injection tests only.
- Some of China's largest CTX CO2 sources above China's largest integrated coalfield
- Overlap with 2 major oil fields.

CNPC Karamay Oilfield, Xinjiang

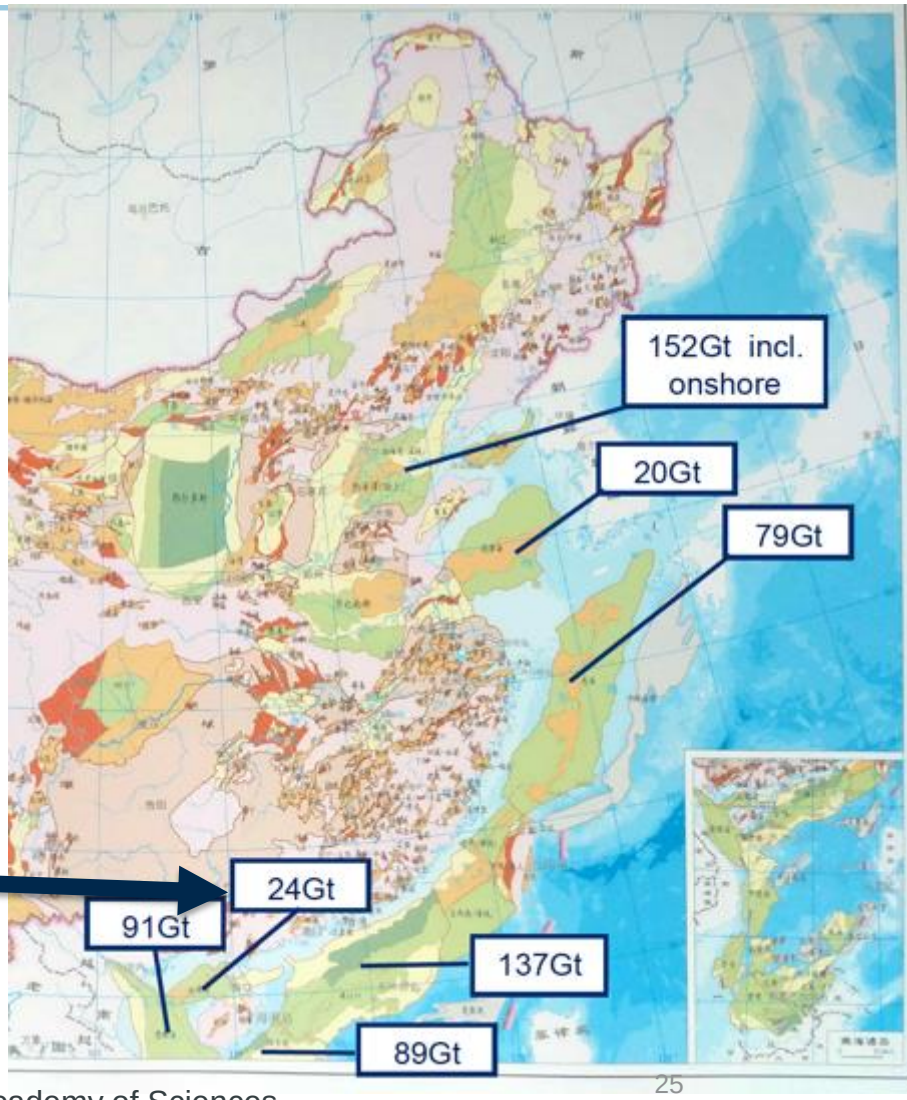
Photos: Courtesy Sue Hovorka

- 1955 Discovery; 12 B bbls OOIP. Karamay means “black oil” in Uighur
- Continental / Alluvial fan deposits
- Multiple CO2 EOR assessments by CNPC; pilot injections.
- Multiple high volume concentrated coal-based sources in region: CTX, cement plants, fertilizer plants, power

VI. South China Sea-Guangdong. China's Offshore

- 2012 CO2 storage assessment: 1655 GT offshore storage potential; 656 GT in10 near-shore basins
- Crystalline basement most of onshore so offshore storage is only option
- BP offshore development in 1980s.
- EOR scoping by CNOOC.

Guangdong Province:
China's Most industrialized Province

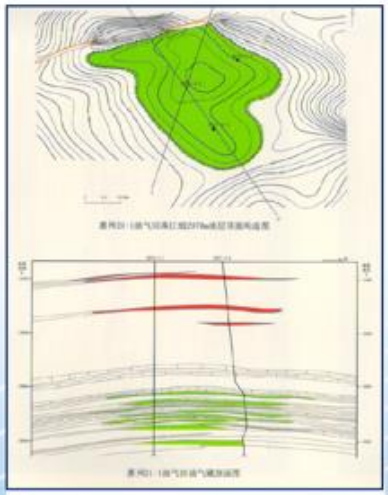


Source: Di Zhou South China Sea Institute of Oceanology, Chinese Academy of Sciences

Approach: Repurpose Platforms and Pipelines

Near depleted field

HZ21-1



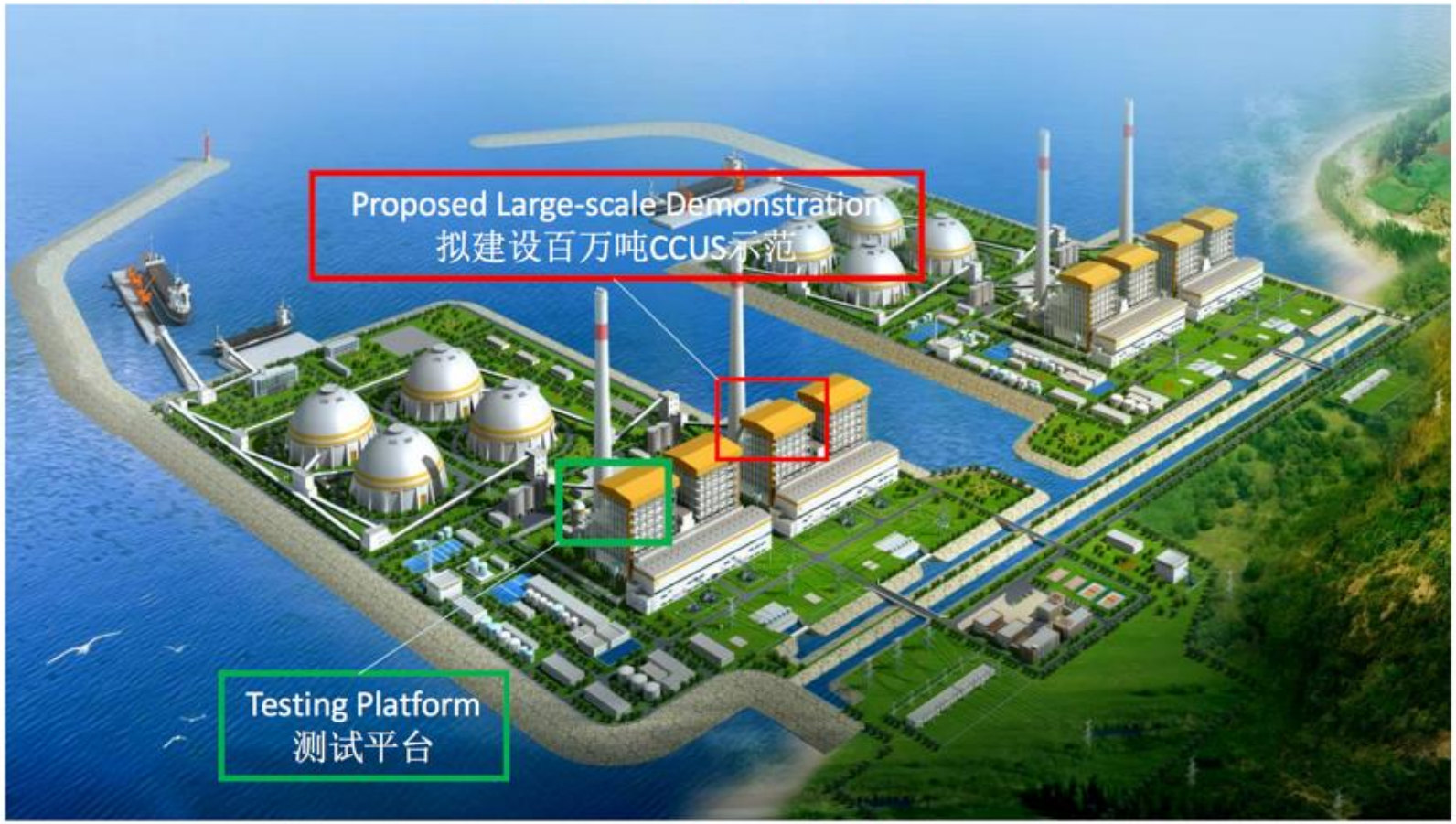
- Dome of 10.5 km^2
- OOIP ~16 Mt
- 8 oil reservoirs, 2820~3000m sub-seafloor
- Producing oil&gas since 1990; now oil production is small
- 4-leg platform with 15 well slots + gas processing platform
- A 233km 20”pipeline to coastal terminal

Source: Di Zhou South China Sea Institute of Oceanology, Chinese Academy of Sciences

Haifeng Plant designed as a capture R&D testing platform, like Mongstad.

CLEANAIR TASK FORCE

Aerial view of China Resources Haifeng Power Plant
华润海丰电厂鸟瞰图



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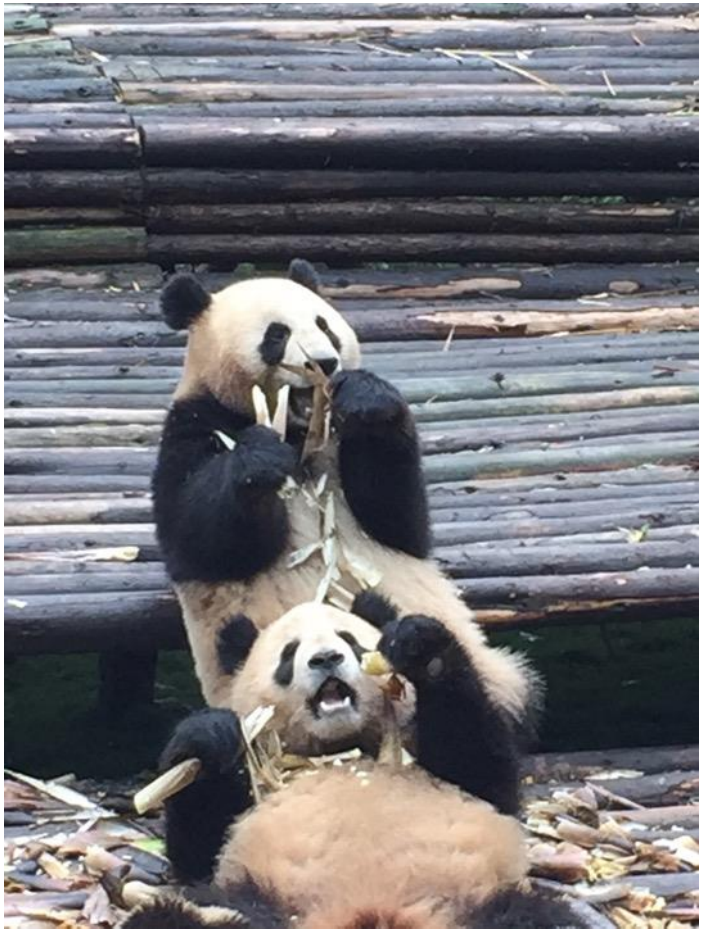

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China's support for CCUS/CO2 EOR RD&D

In 2006,China Ministry of Science and Technology(MOST) approved CNPC to undertake a National Fundamental Research Program—*Research on Utilizing Greenhouse Gas as a Resource for EOR and Storage*

In 2008, the Chinese government approved a Major national program—*CO_2 Capture and Storage for EOR*

Since 2011, Chinese National Fundamental Research Program (973 program) and Chinese National Major Science and Technology Projects have approved by government

CCUS is called out in Greenhouse Gas Control Action Plan 12th 5 year plan (2011-2015)

Clean and efficient utilization of coal listed # 8 of 100 key projects in 13th 5 year plan.

-source: CNPC RIPED