CO_2 Geological Utilization Technologies
CO_2地质利用技术及前景评估

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May, 2014

PRESENTATION OUTLINE 概要

1. Background of CCS and CCUS

背景

2. CO_2 Geological Utilization R&D Activities

CO_2地质利用技术的研发

3. Prospect Evaluation on CO_2 Geological Utilization

CO_2地质利用远景评价

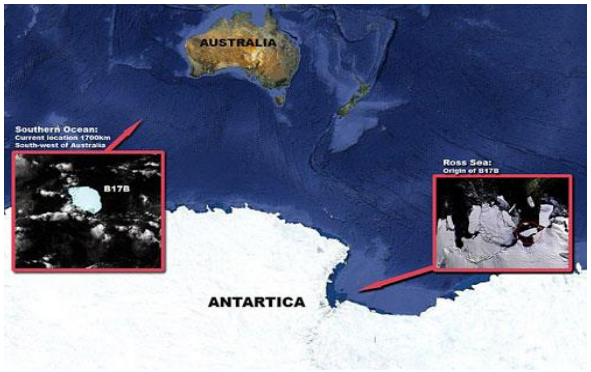
4. Integrated CO_2 Geological Utilization System

CO_2地质利用集成系统

1. Background

背景

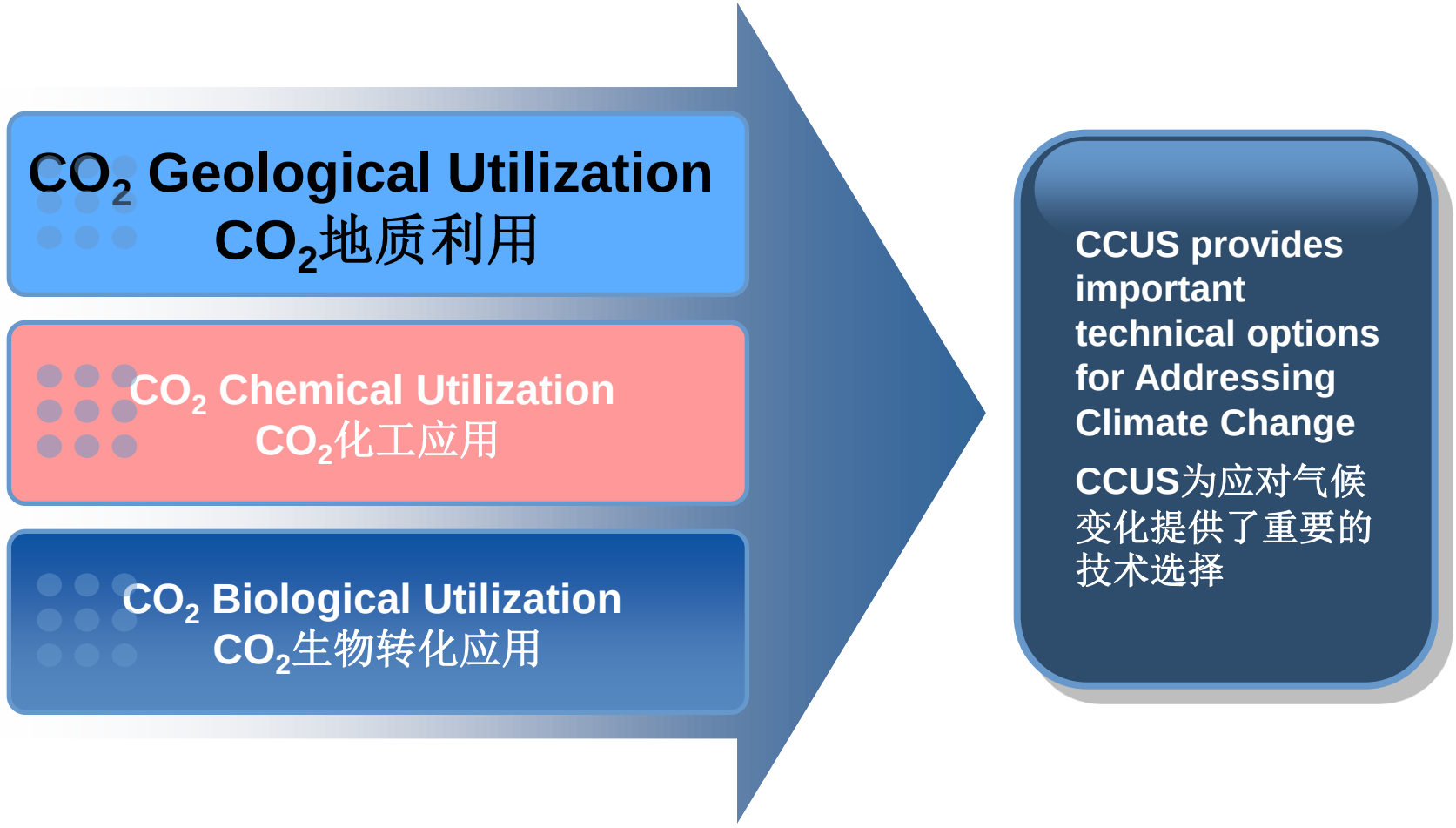
Climate Change Compromises the Whole World



CCUS

- CO2 Capture, Utilization/Use and Storage
- Purpose:
  - GENERATING REVENUE by USE can partially offset the cost of CO2 capture
  - AS a transitional measure to assist the accelerated uptake of CCS

CCUS provides important technical options for Addressing Climate Change



Role of CO_2 Geological Utilization Technology

Environmental benefits

-CO_2 reduction
CO_2减排

-Address climate change
应对气候变化

Time scale

-Long-term
长期性

-Security
安全性

Economic benefits

-Cost-effective
经济有效

-Additional output value
额外产出效益

Spatial scales

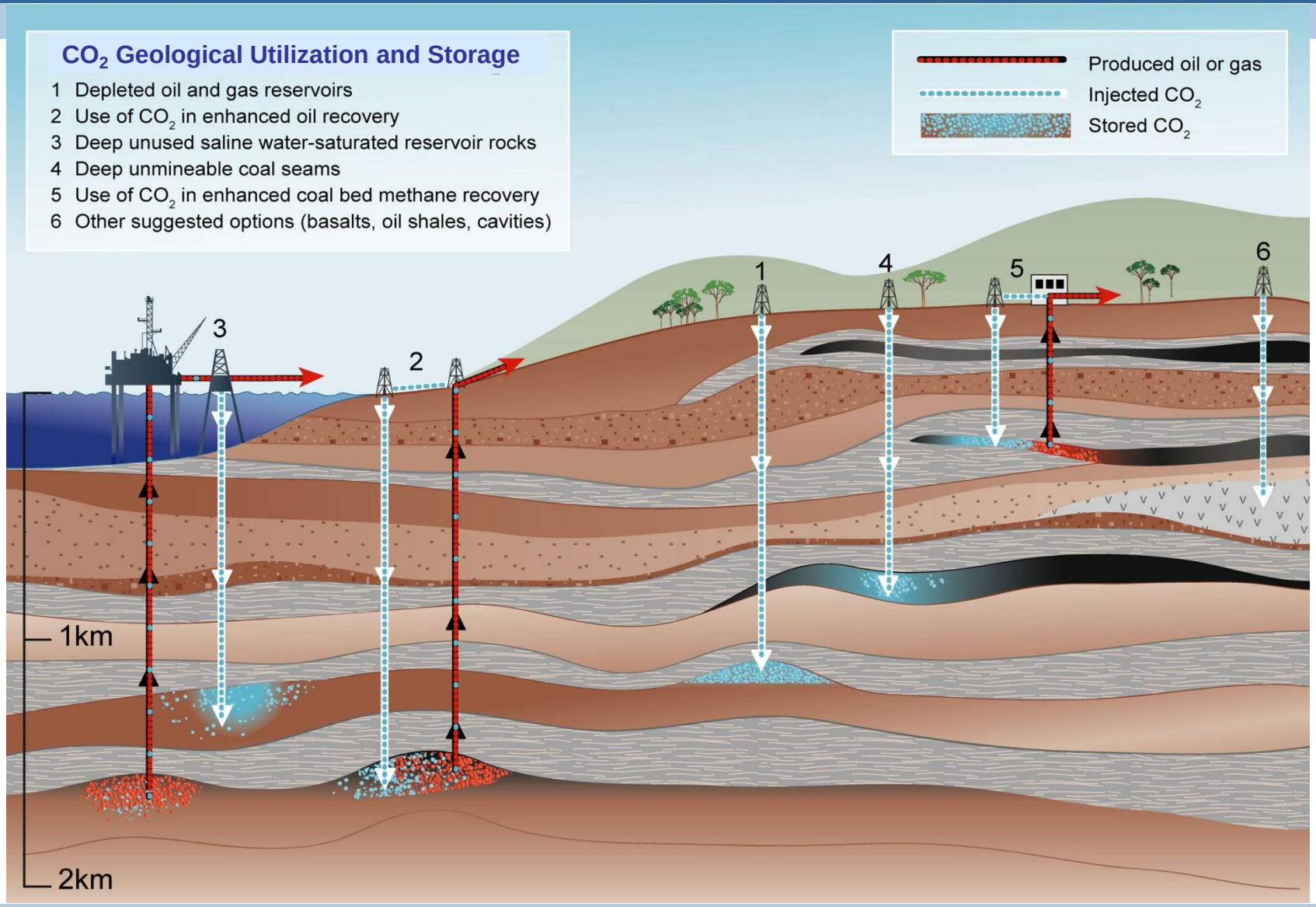
-Underground space
地下空间充足

-High reduction potential
减排潜力大

2. CO_2 Geological Utilization R&D Activities

CO_2地质利用技术的研发

CO_2 Geological Utilization and Storage



CO_2 Geological Utilization Technologies
CO_2地质利用技术

CO_2驱油 Enhanced oil recovery (CO_2-EOR)

CO_2提高煤层气采收率 Enhanced coal bed methane recovery (ECBM)

CO_2驱气 Enhanced gas recovery (EGR)

CO_2封存协助液矿体联合开采 Assisting joint exploration of liquid mineral

CO_2工质地热系统 Enhanced geothermal system

CO_2提高页岩气（天然气）采收率 Enhanced shale gas recovery

CO_2封存于玄武岩 Basalt storage

CO_2用于尾矿废渣的地质环境修复 Bauxite residue treatment

制造岩腔 Manufacturing rock cavity

CO_2地质碳汇作用 Geological carbon sink

1.CO_2-EOR
CO_2驱油基本原理

Injecting compressed CO_2 into depleted oil fields

Mixing CO_2 with residual oil, decreasing the viscosity of crude oil

Decreased the viscosity of oil, enhancing the oil recovery

向废弃油田中注入压缩的CO_2

CO_2与油田中残油混合降低其粘度

原油粘度降低更易被开采出来

Oil displacement by CO_2 injection relies on the behavior between CO_2 and crude. This interaction depends on the oil's weight, and the reservoir characteristics.

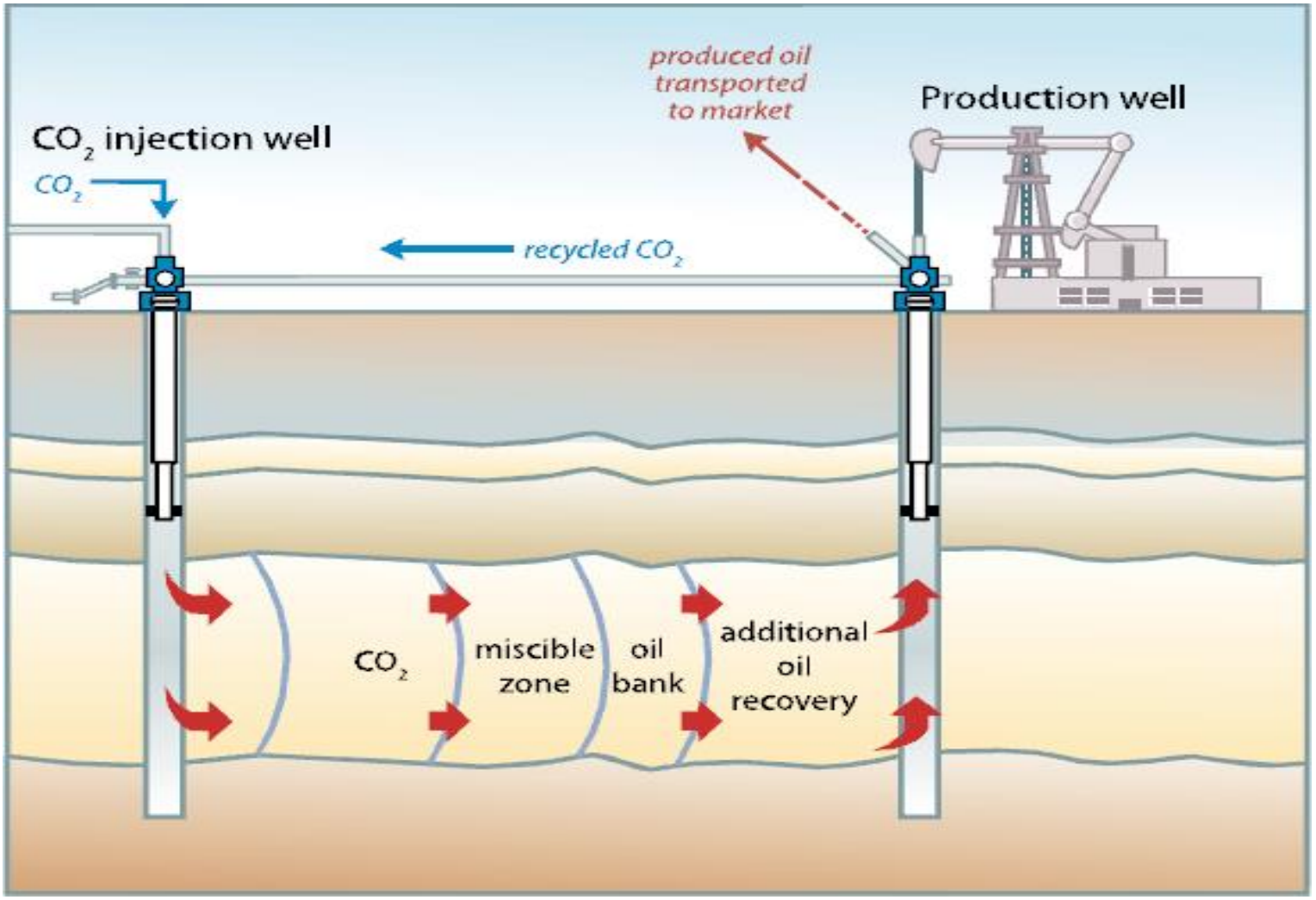
Miscible CO_2 flooding
CO_2混相驱油原理

In high pressure applications with lighter oils, CO_2 is miscible with the oil (in all proportions forms a single phase liquid), with resultant swelling of the oil, and reduction in viscosity, and possibly also with a reduction in the surface tension with the reservoir rock. All these effects serve to improve the flow of oil to the production wells.

The CO_2 miscible flooding can be used for low permeability reservoirs which is not fit for water flooding, sandstone reservoirs depleted with water flooding or deep lighter oil reservoirs arrives at the limitation of exploration.

CO_2混相驱适合开采的油藏主要有水驱效果差的低渗透油藏、水驱枯竭的砂岩油藏、接近开采经济极限的深层（高压）轻质油藏等。

Schematic diagram of CO_2-EOR
CO_2混相驱油原理示意图



Immiscible CO_2 flooding
CO_2非混相驱油原理

In the case of low pressure reservoirs or heavy oils, CO_2 (potentially along with alternating water injection) will form an immiscible fluid, or will only partially mix with the oil. Some oil swelling may occur, and oil viscosity can still be significantly reduced. However, in immiscible CO_2 flooding the main function of the CO_2 is to raise and maintain reservoir pressure.

CO_2 immiscible flooding is suit for the reservoir with low pressure and permeability, reservoir with heavy oil, high inclination and vertical permeability, or the reservoirs with geochemical and geological conditions which is not fit for water flooding.

非混相驱适应的油藏类型主要包括压力衰竭的低渗透油藏、重油、高倾角、垂向渗透率高的油藏或地球化学、地质条件不适合水驱的油藏等。

CO_2-EOR效益 (Zama, Canada EOR)

	Total	Average	Time
CO_2 injection	2.30 million m^3	28316.86m^3/day	2006.12~2011
Oil production	25,000 barrels	100 barrels/day	2006.12~2009.8

- **提高石油采收率10%~15%，应用前景广阔。**
- **CO_2驱油技术相对成熟，其应用范围正不断扩大，通过规模化利用降低其成本。**

SIZE OF MARKET

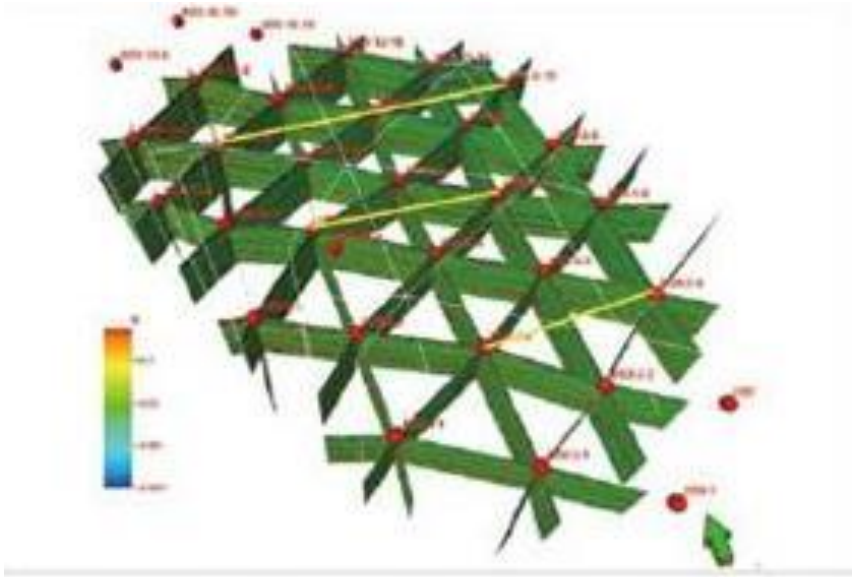
- In North America, the Department of Energy (DOE) estimated around 50 Mt CO2/yr is currently used.
- Currently, CO2-EOR is used to produce about 250,000 barrels per day of oil in the US that are incremental to base case production.

国内外主要CO_2-EOR项目列表

阶段	项目名称	开始运行时间	地点	捕集量/(Mt/a)
运行阶段	Val Verde 天然气厂	1972	美国	1.3
	Enid 化肥厂	1982	美国	0.7
	Shute Creek天然气处理设备	1986	美国	7
	Century Plant项目	2010	美国	5（另有3.5Mt正在建设中）
建设阶段	Lost Cabin煤气厂	2012	美国	1
	中石化胜利油田CO2捕集和EOR示范项目	2013-2014	中国	1
	边界大坝（Boundary Dam）CCS示范项目	2014	加拿大	1
	Agrium与ACTL合作的二氧化碳捕集项目	2014	加拿大	0.6
	Kemper Country IGCC项目	2014	美国	3.5
	中石油吉林油田CO2-EOR项目	2015	中国	1.2

PetroChina's CO_2-EOR Research and pilot Injection, Jilin Oilfield

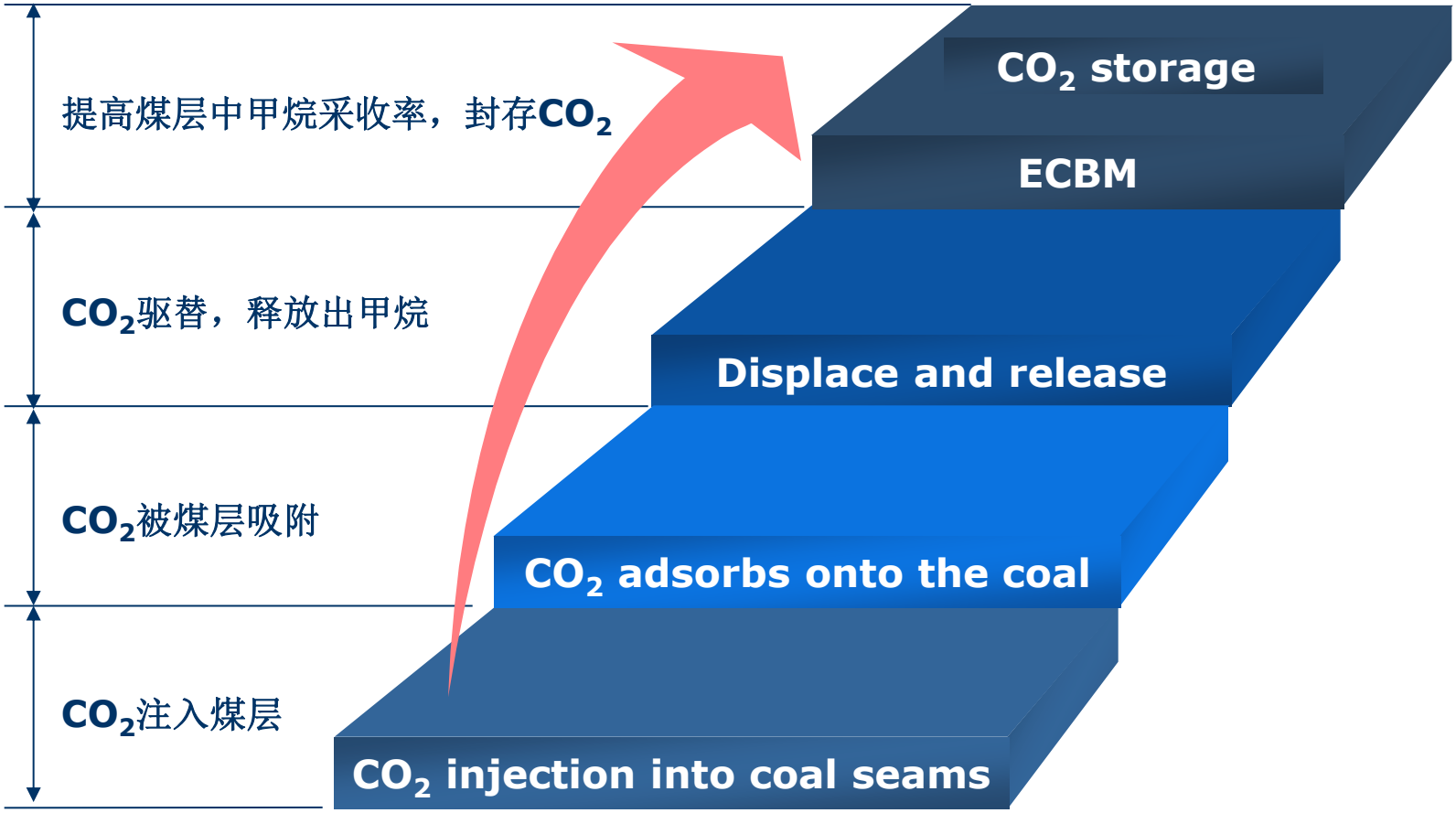
PetroChina EOR Project



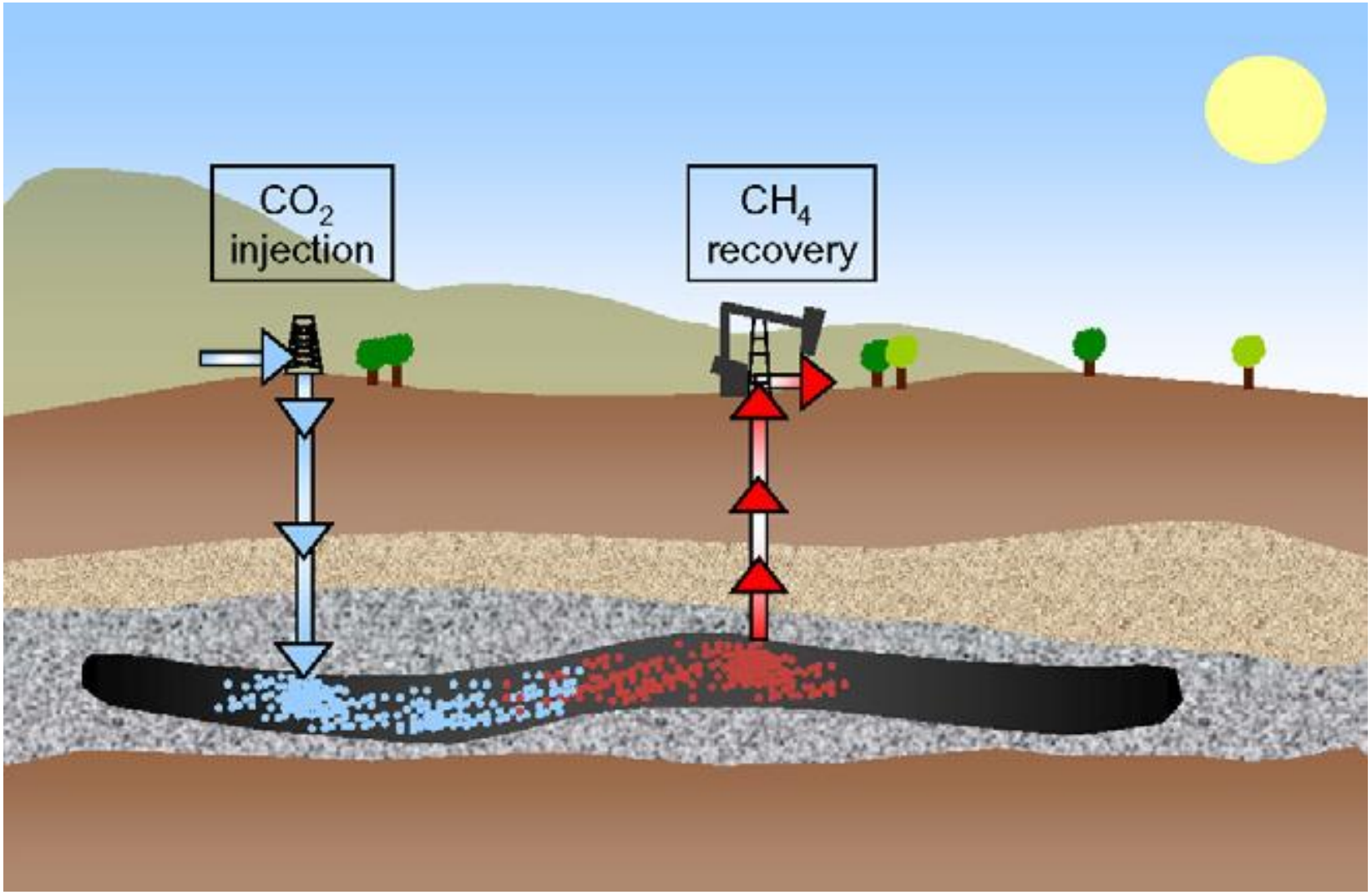
Jilin Oil Field CCS-EOR pilot test block well network design

Goal: 0.8-1.0 million tons storage of CO_2 annually (Phase II)
Site: Jilin Oil Field
Technologies: Separation of CO_2 from natural gas + EOR
Status: Phase I has been completed and phase II is in progress

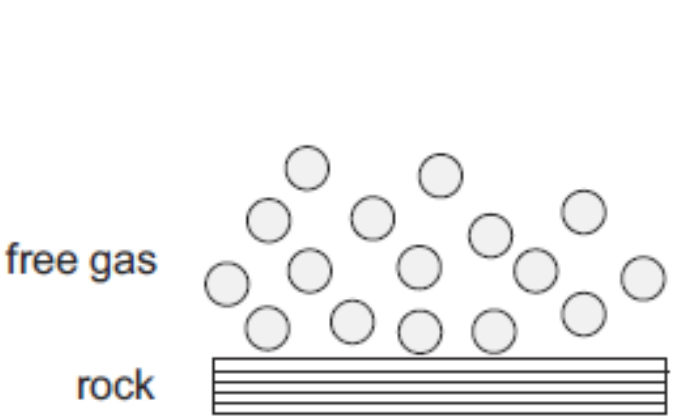
2. Enhanced Coal Bed Methane Recovery (ECBM)
CO_2提高煤层气采收率



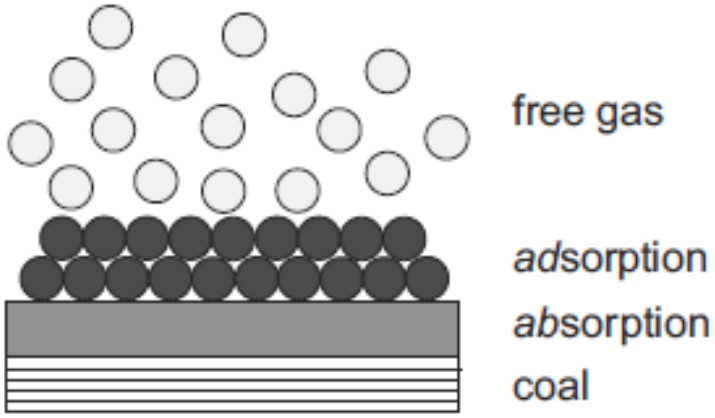
Schematic of an ECBM operation, where captured CO_2 from a power plant is injected into the coal seam and CH_4 is produced



Simplified schematic for the storage mechanism in a conventional gas reservoir (a) and in a coal seam (b).



(a)
conventional gas
reservoir

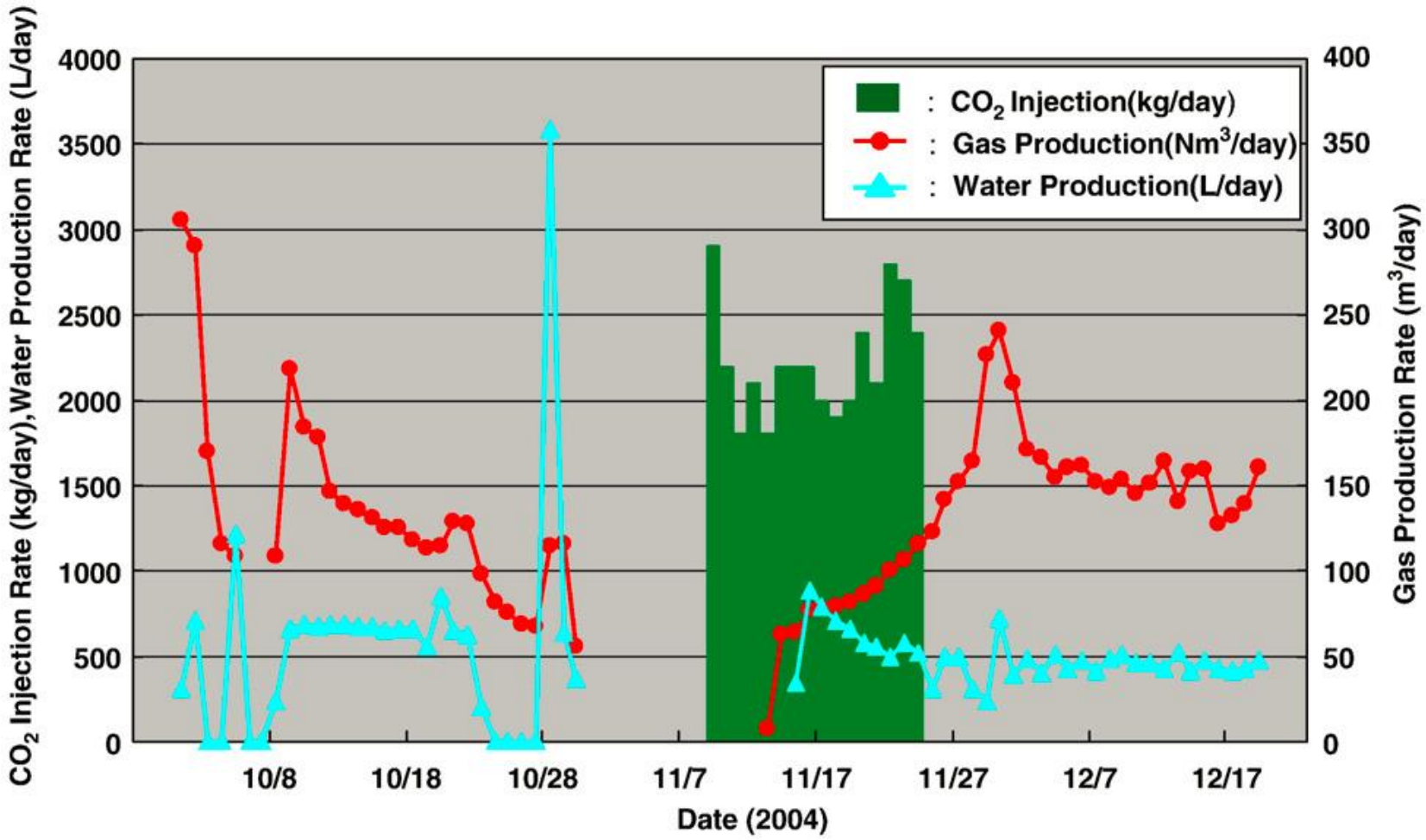


(b)
coal seam

The injected gas fills the available pore volume as a compressed fluid

The gas is additionally adsorbed and absorbed

CO_2-ECBM 效益



Production and injection rates of multi well pilot test in the Ishikari Coal Basin of Japan in 2004

国内外主要CO_2-ECBM技术主要现场试验项目情况

项目名称	国家	地点	项目开始时间	开始/停止注气时间	CO_2封存总量	煤层深度
Allison Unit	美国		1995	1995/2001	277 kt	950 m
SWP	美国			2008	35 kt	910 m
Fenn/Big Valley	加拿大		1997	1998	200t	
CSEMP	加拿大		2002	2008	10 kt	
RECOPOL	波兰	Kaniow	2003	2004/2005	760 t	1050-1090
	中/加		2001	2004/2004	192 t	478 m
Yubari Project	日本		2002	2004	0.884 kt	890 m
	中/澳	Liulin	2010	2010	2000 t	

China United Coalbed Methane Co. ECBM Pilot Project in Qinshui Basin--**Location**

China United Coalbed Methane Co. ECBM Pilot Project

CUCBM CO_2-ECBM Well Site

CUCBM CO_2-ECBM Well Site

Project Entity: China United Coalbed Methane Company (CUCBM)

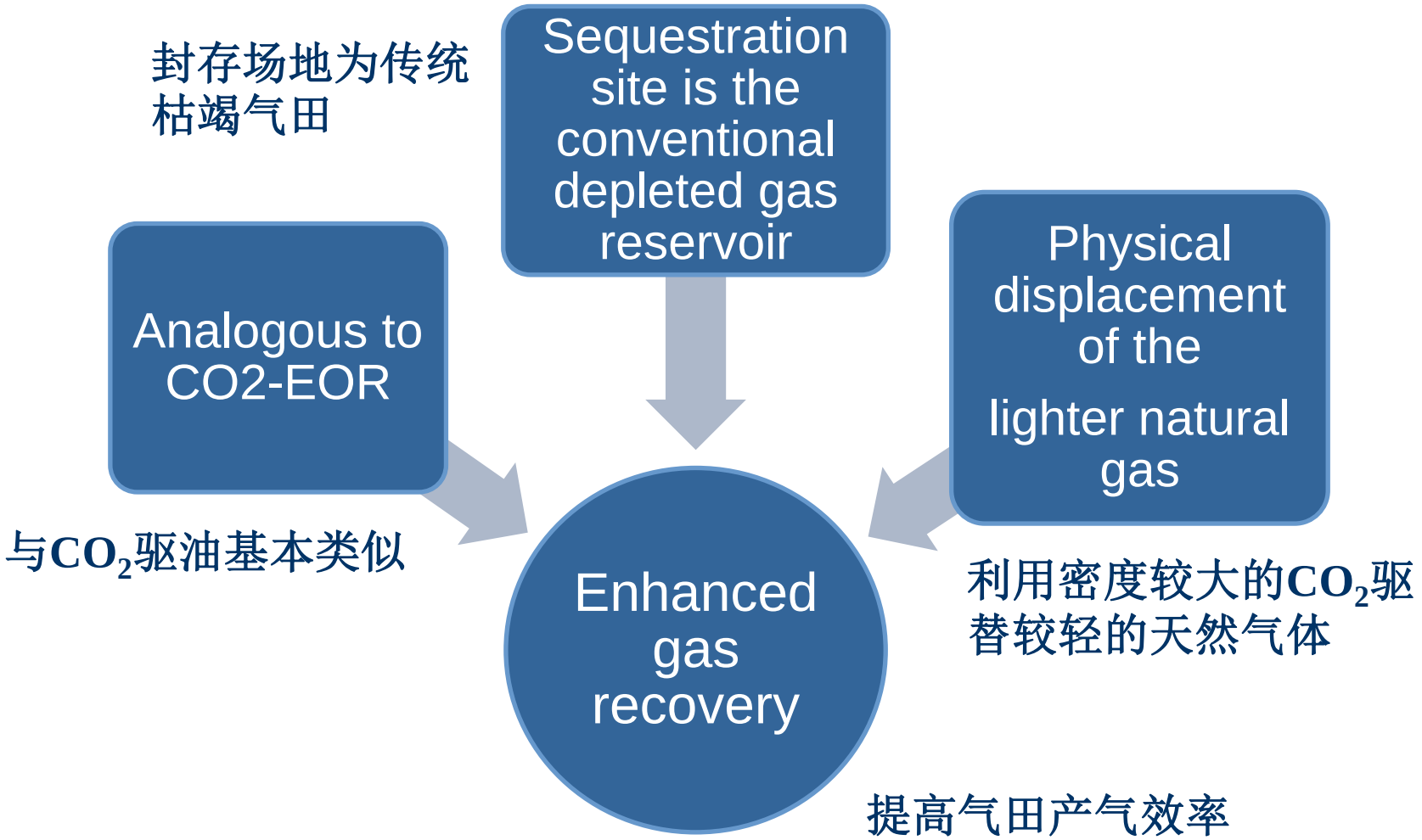
Goal: Studying and developing ECBM and CO_2 storage technology, testing safety and permanence of CO_2 sequestration.

Location: Shizhuang, Qinshui County, Shanxi Province

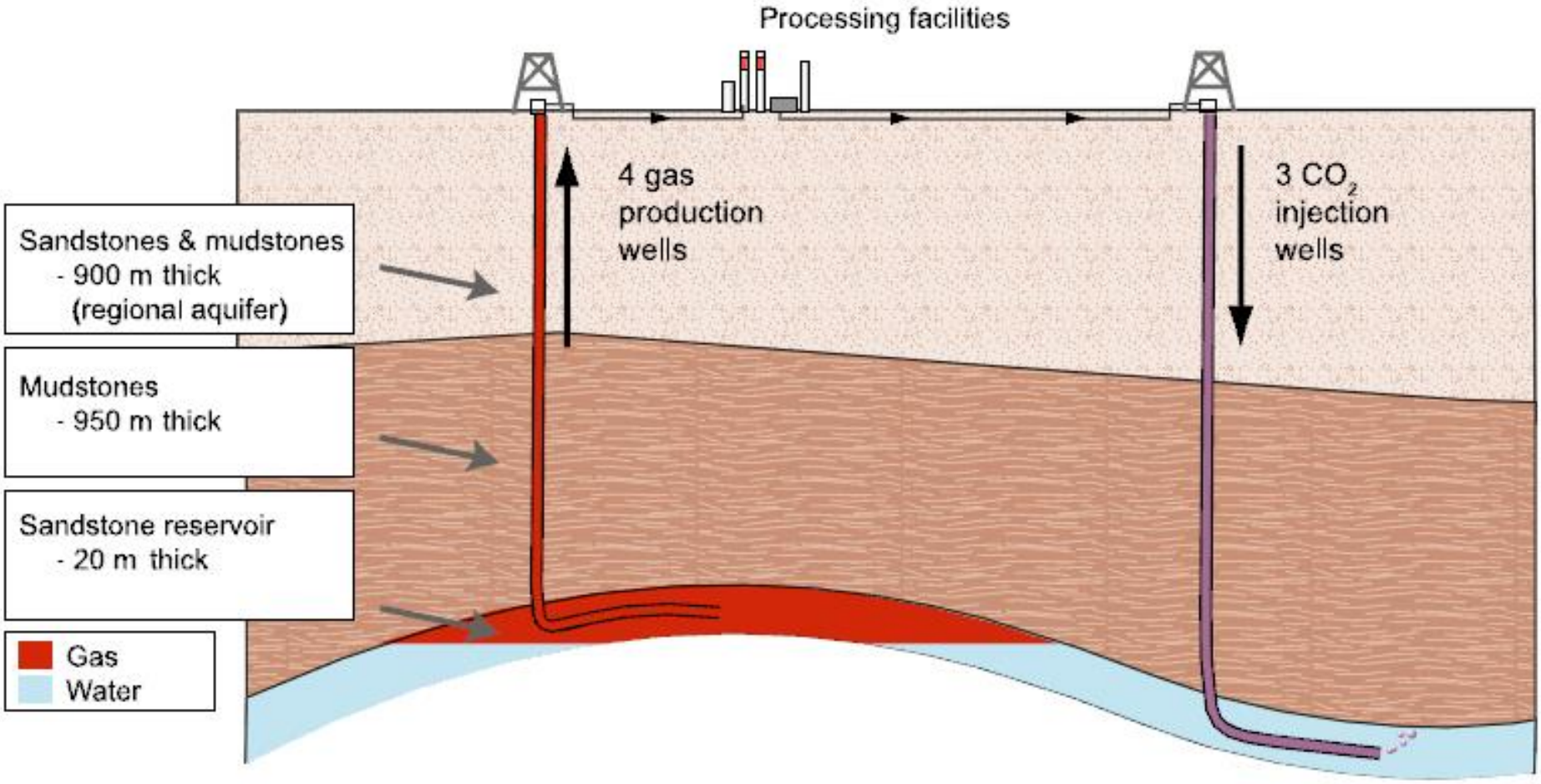
Technique: CO_2 Storage for ECBM

Current Status: Ongoing, injection test started since April 2010

3.Enhanced Gas Recovery (EGR)
CO_2驱气机理



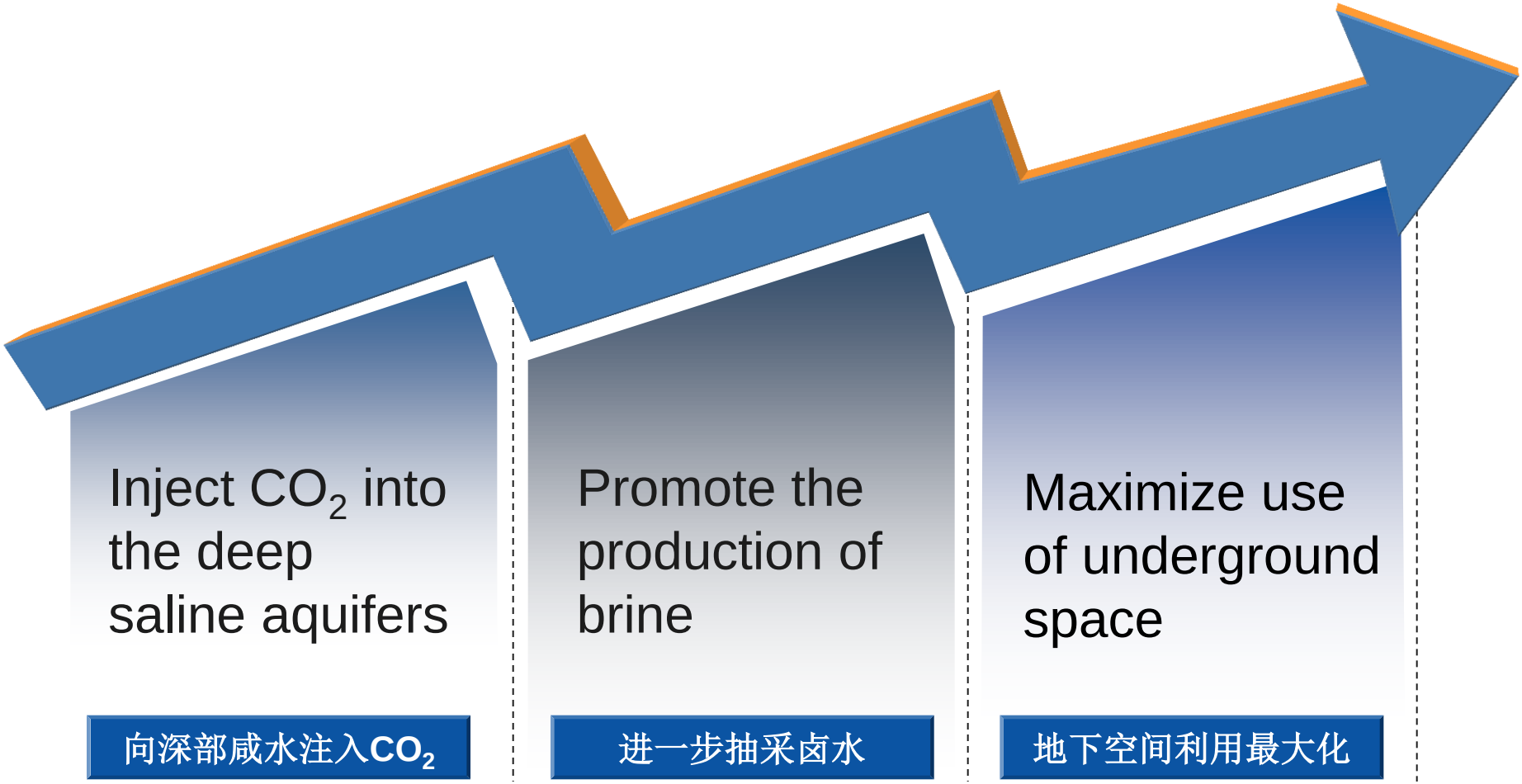
3.Enhanced Gas Recovery
CO_2提高天然气采收率



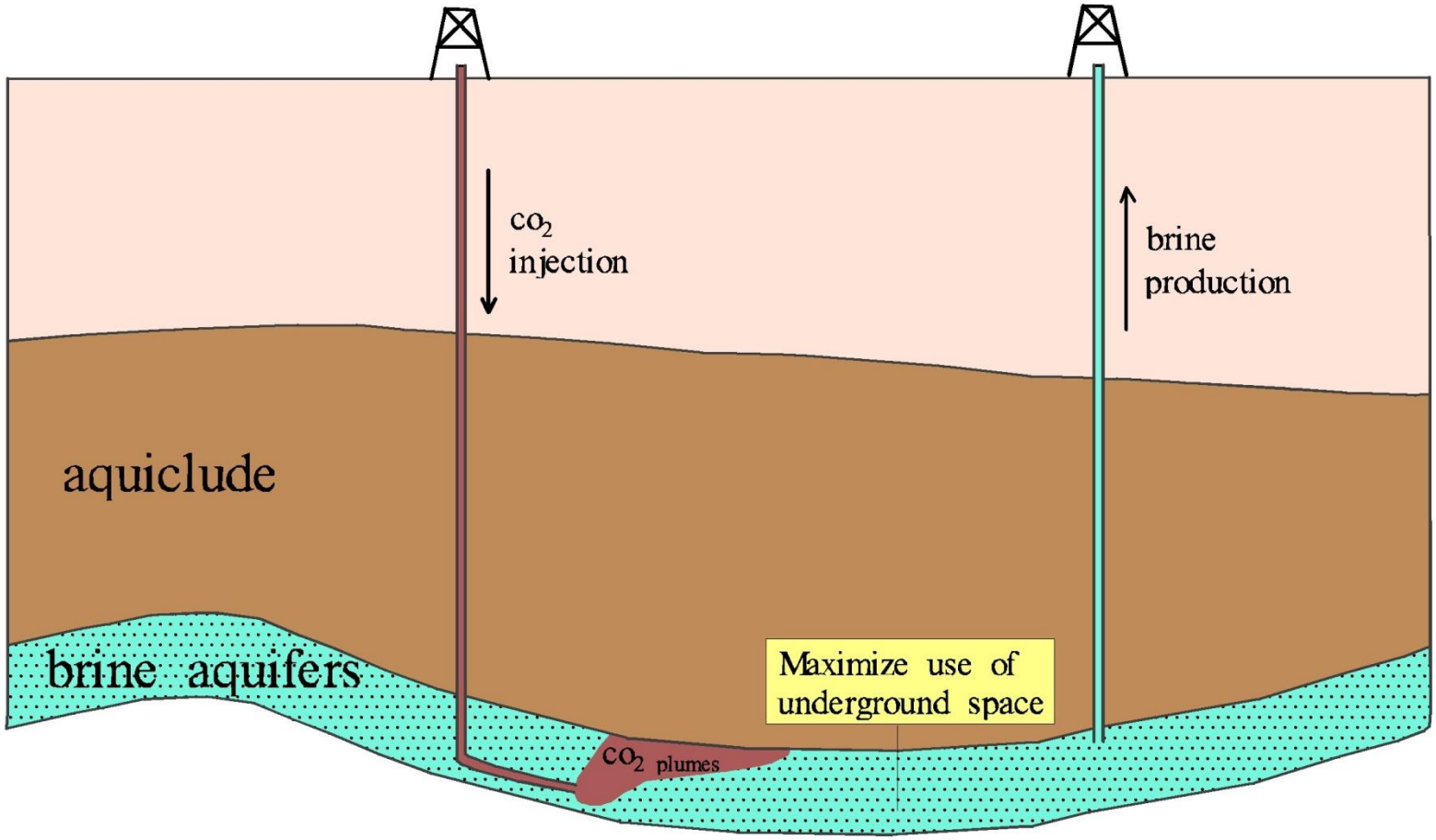
我国目前开展的CO_2-EGS研究项目情况

项目名称	技术类型	资金来源	研究类型	执行时间	主持与参与机构
二氧化碳增强地热系统的模拟预测研究	EGS	教育部博士点基金项目	基础研究	2011-2013	吉林大学
超临界二氧化碳在非常规油气藏中应用的基础研究	ESG	国家自然科学基金委重点项目	基础研究	2011~2014	中国石油大学
新型结合增强地热系统的大规模CO_2利用与封存技术研究	EGS	科技部国际合作项目	基础研究	2012 ~2014	清华大学、中国21世纪议程管理中心、中国科学院武汉岩土力学研究所、中国农业科学院
干热岩综合利用关键技术研究	EGS	科技部863项目	基础研究	2012-2015	吉林大学、清华大学、天津大学、广东能源所、中石油、中国科学院武汉岩土力学研究所等
基于页岩气藏CO2封存的CO2-CH4页岩体相互作用机理研究	ESG	国家自然科学基金项目	基础研究	2013~2015	重庆大学

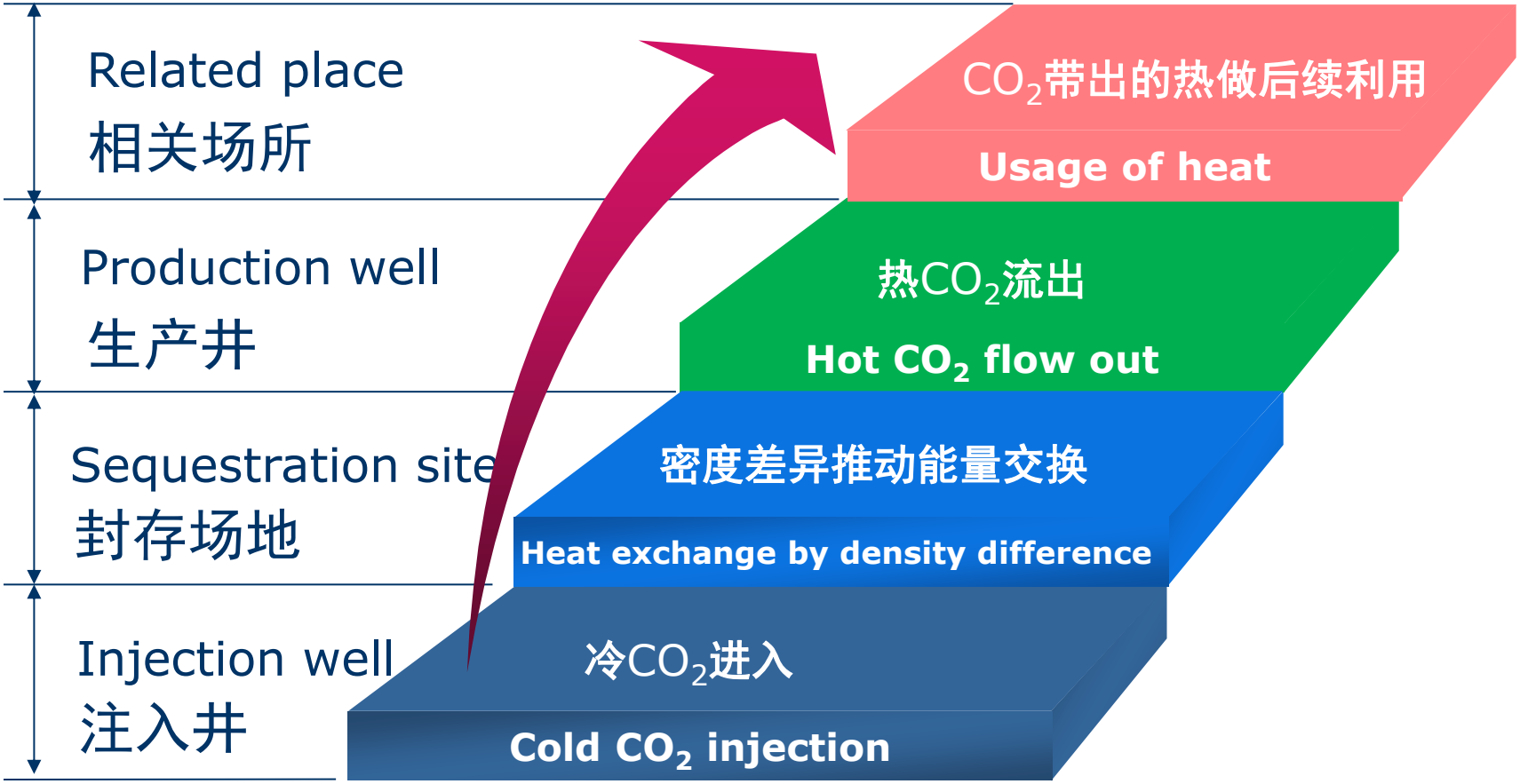
4. Assisting joint exploration of liquid mineral
CO_2封存协助液矿联合开采



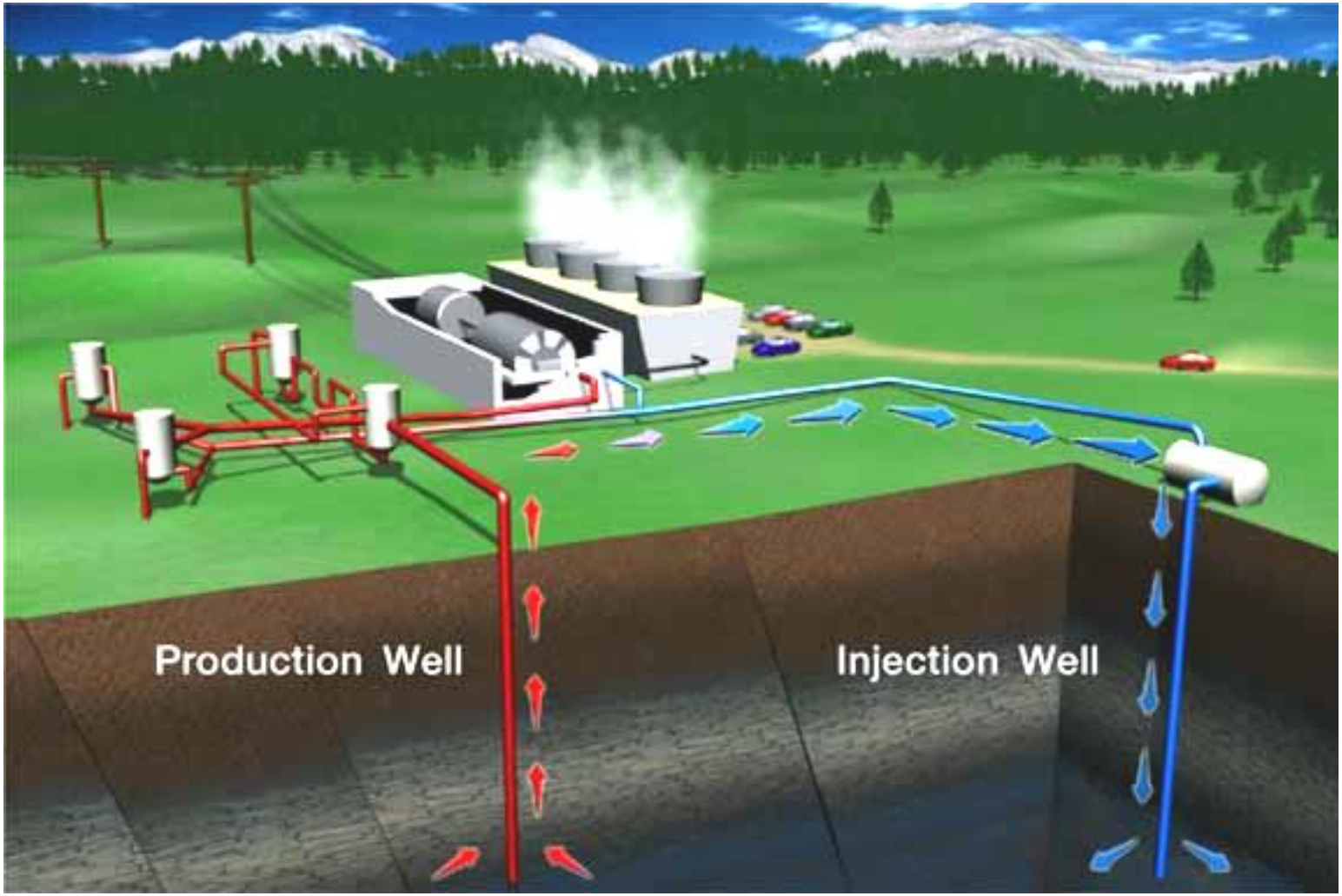
Schematic diagram of assisting joint exploration of liquid mineral CO_2封存协助液矿体联合开采原理示意图



5.Enhanced Geothermal System (EGS)
CO_2工质地热系统



Enhanced Geothermal System (EGS)
CO_2工质地热系统示意图



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新型结合增强地热系统的大规模CO_2利用与封存技术研究	EGS	科技部国际合作项目	基础研究	2012 ~2014	清华大学、中国21世纪议程管理中心、中国科学院武汉岩土力学研究所、中国农业科学院
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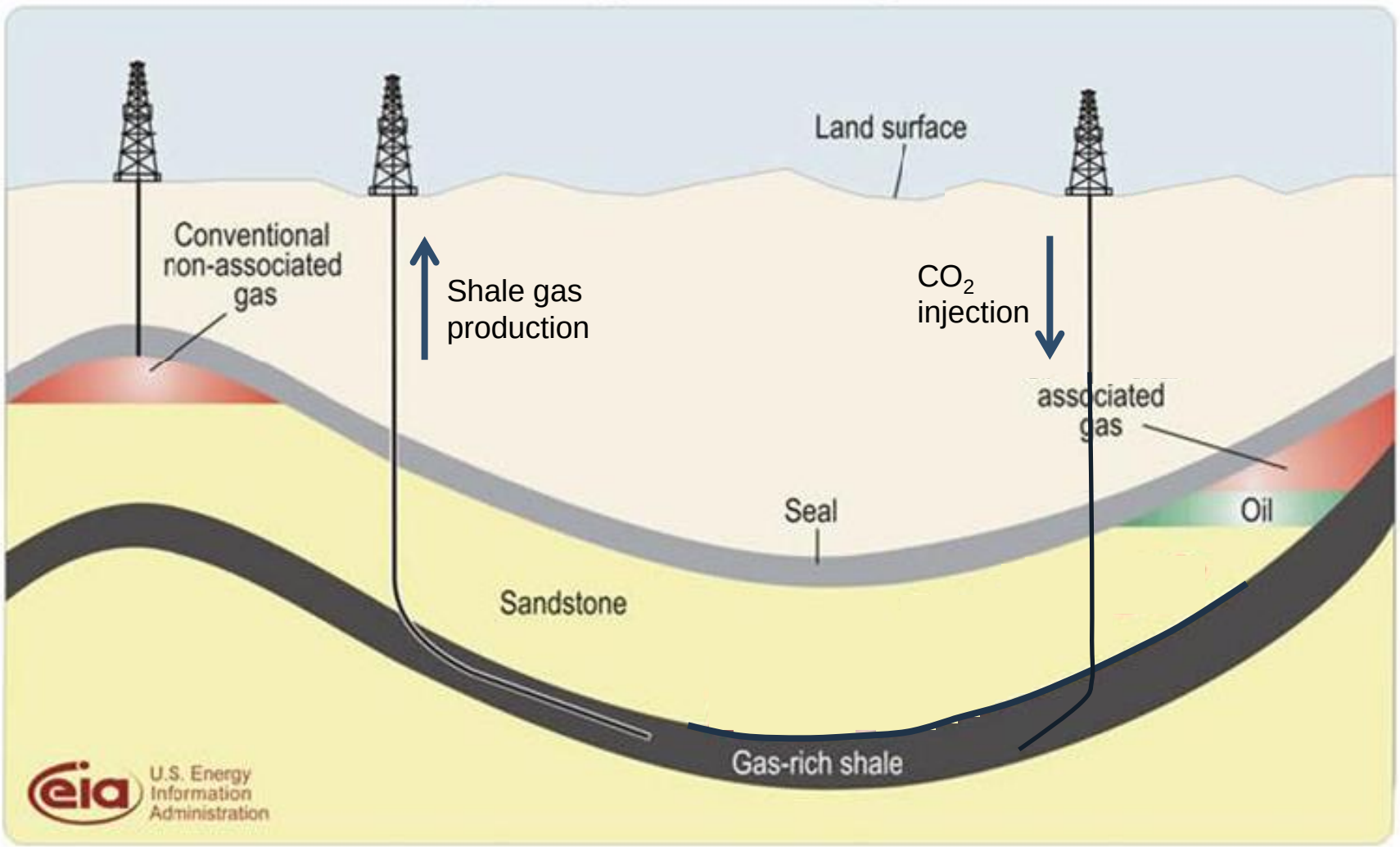
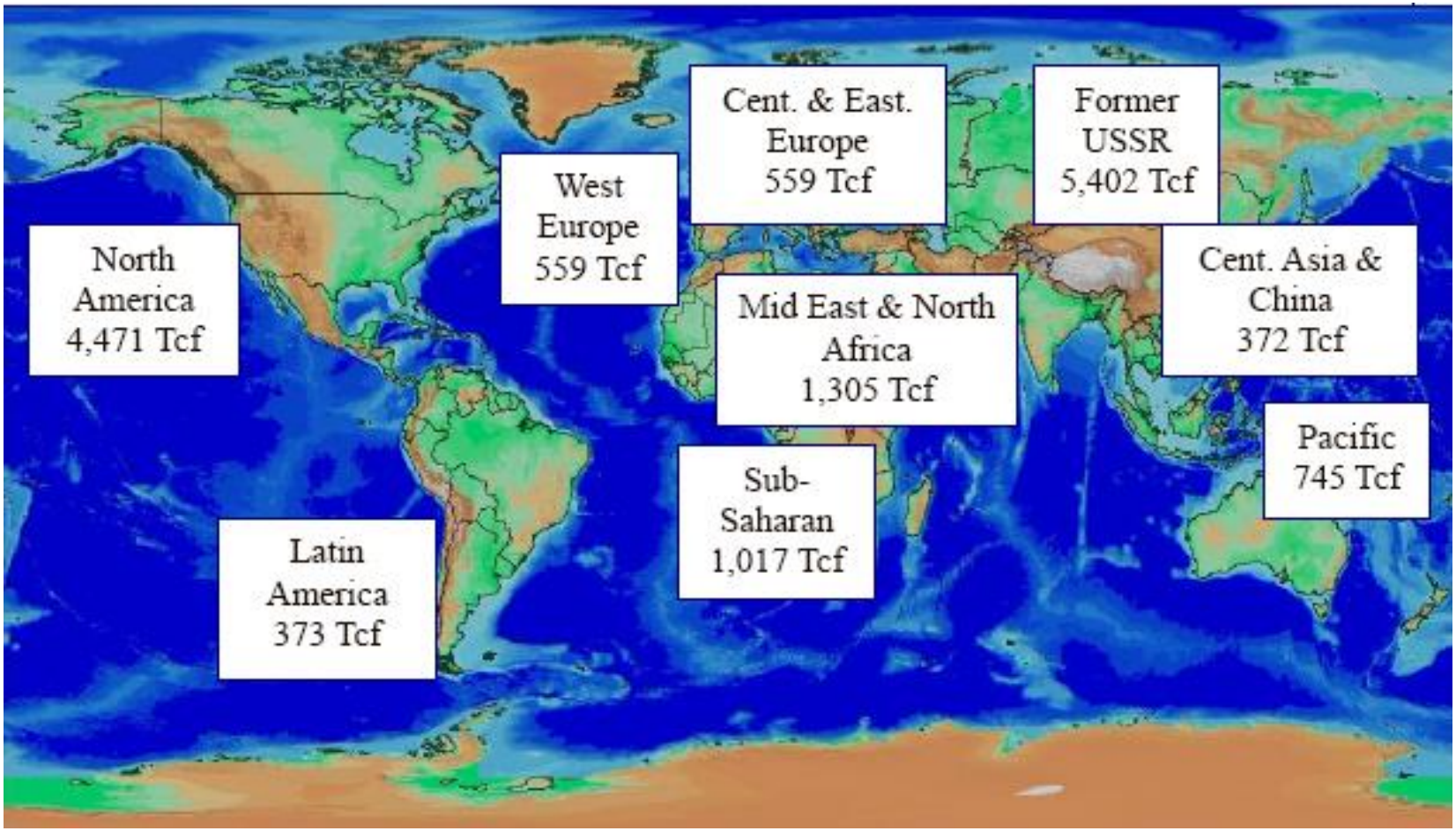
6. Enhanced shale gas recovery
CO_2提高页岩气（天然气）采收



Estimated Shale Gas Resource Potential - 2010



IGU 2003, VNIIGAS 2007, USGS 2008, BGR 2009

国内目前开展的CO_2驱页岩气研究项目

项目名称	项目来源	研究类型	执行时间	主持与参与机构
深井复杂地层安全优质快速钻井基础研究	973计划	基础研究	2010～2014	中国石油大学（北京）、中国石油集团钻井工程技术研究院、中国石化勘探开发研究院、中国科学院武汉岩土力学研究所等
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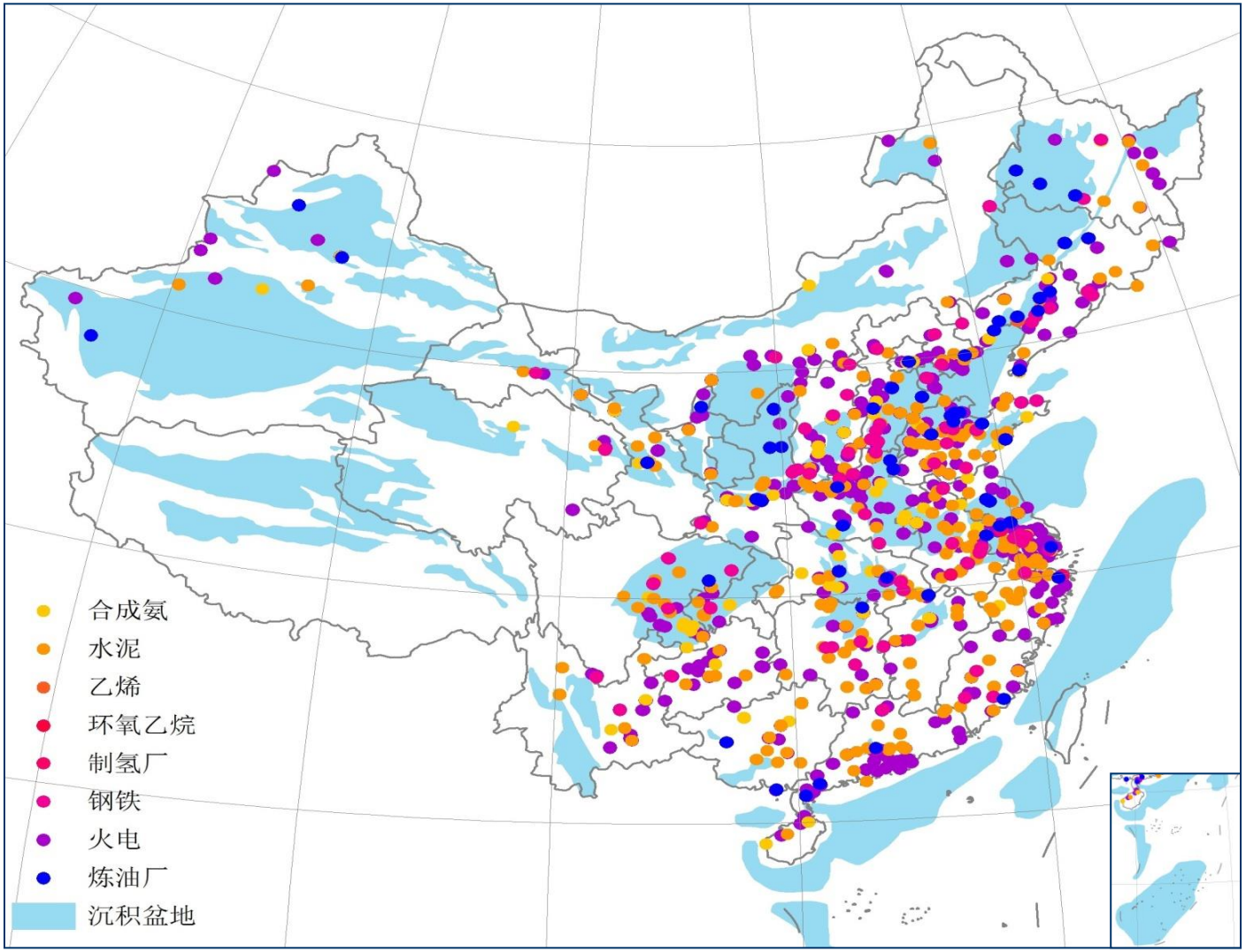
基于页岩气藏CO_2封存的CO_2-CH_4页岩体相互作用机理研究	国家自然科学基金项目	基础研究	2013～2015	重庆大学

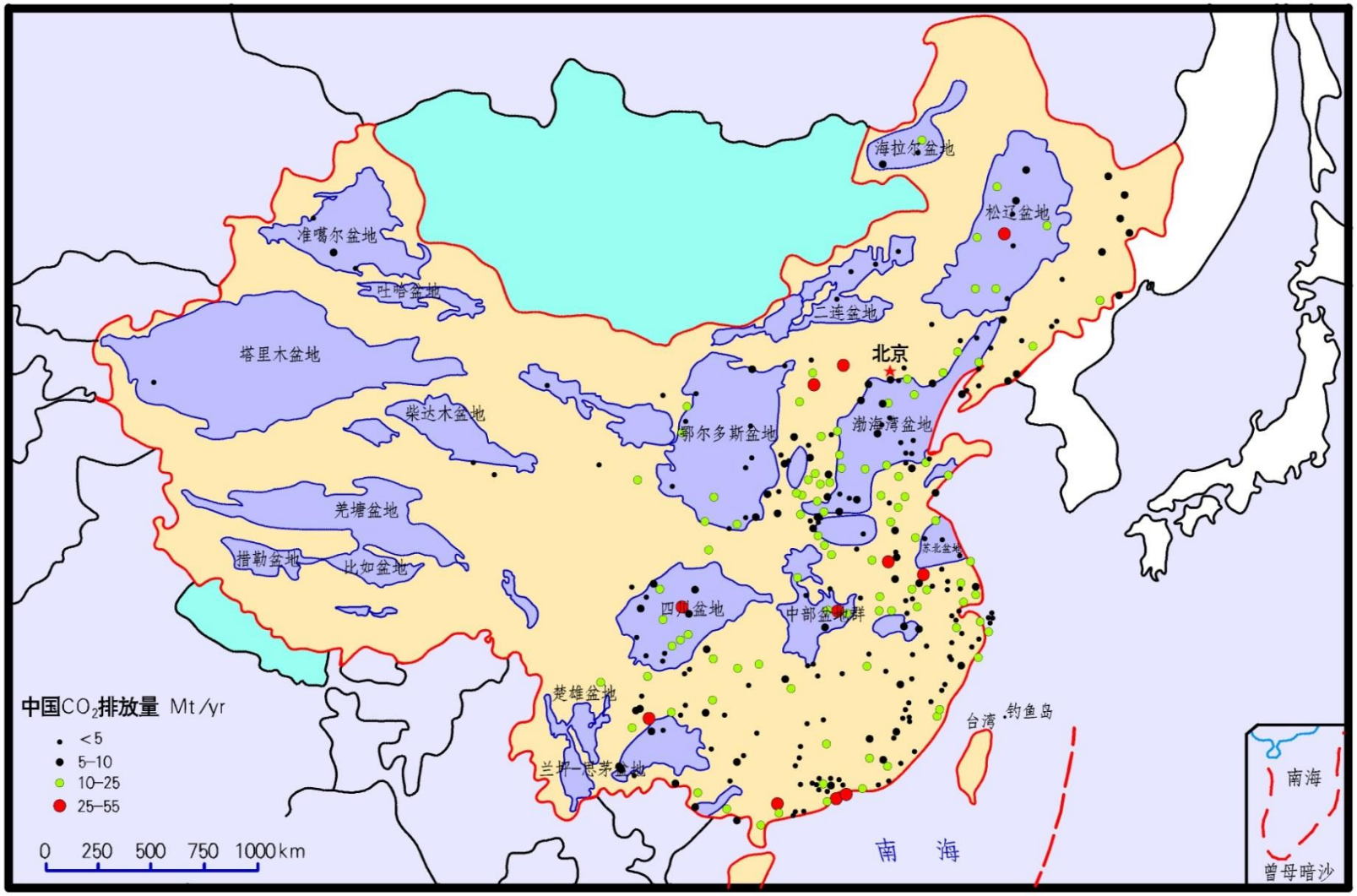
3. Prospect Evaluation on CO_2 Geological Utilization

CO_2地质利用远景评价

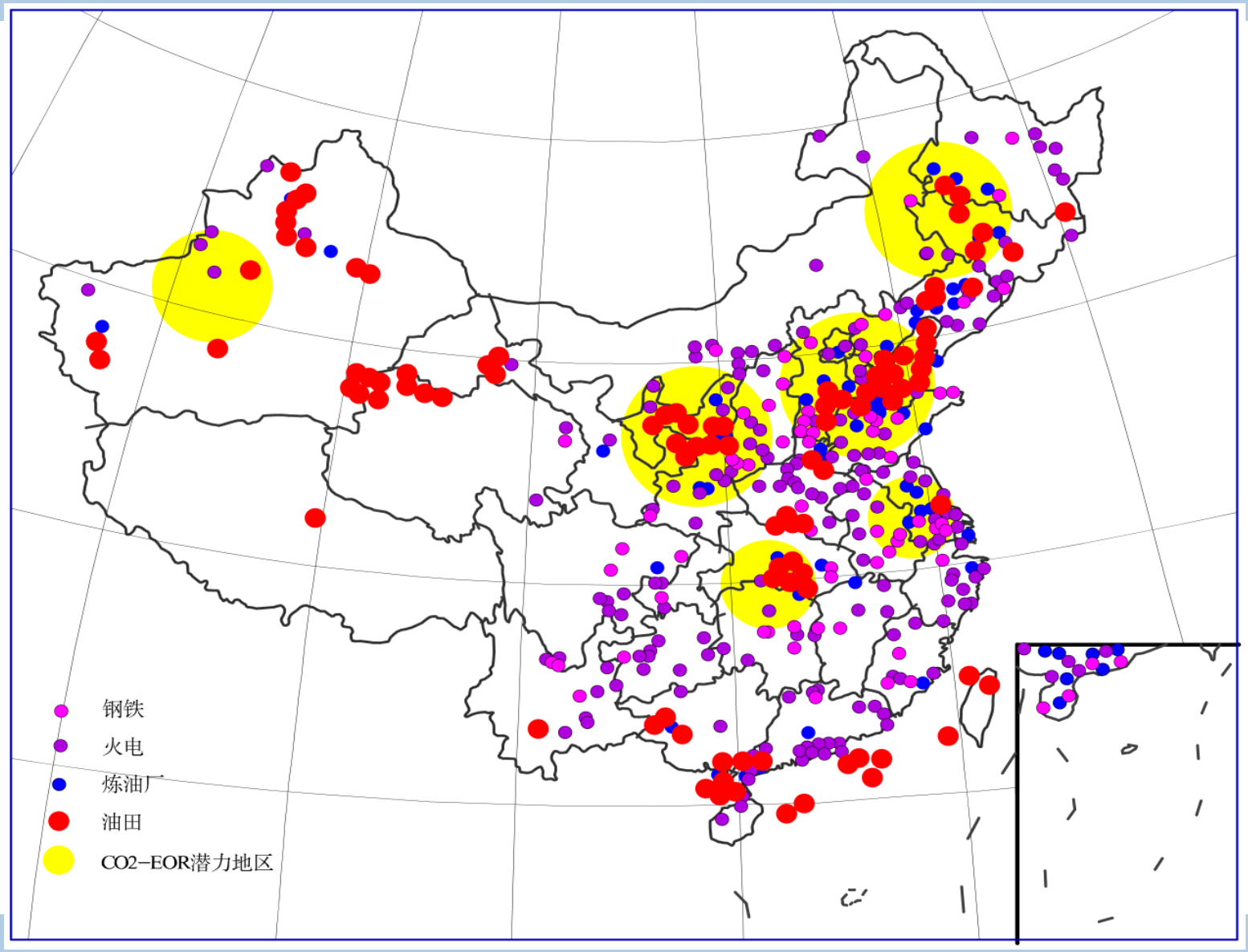
中国CO2碳源分布综合调查
China Carbon source distribution



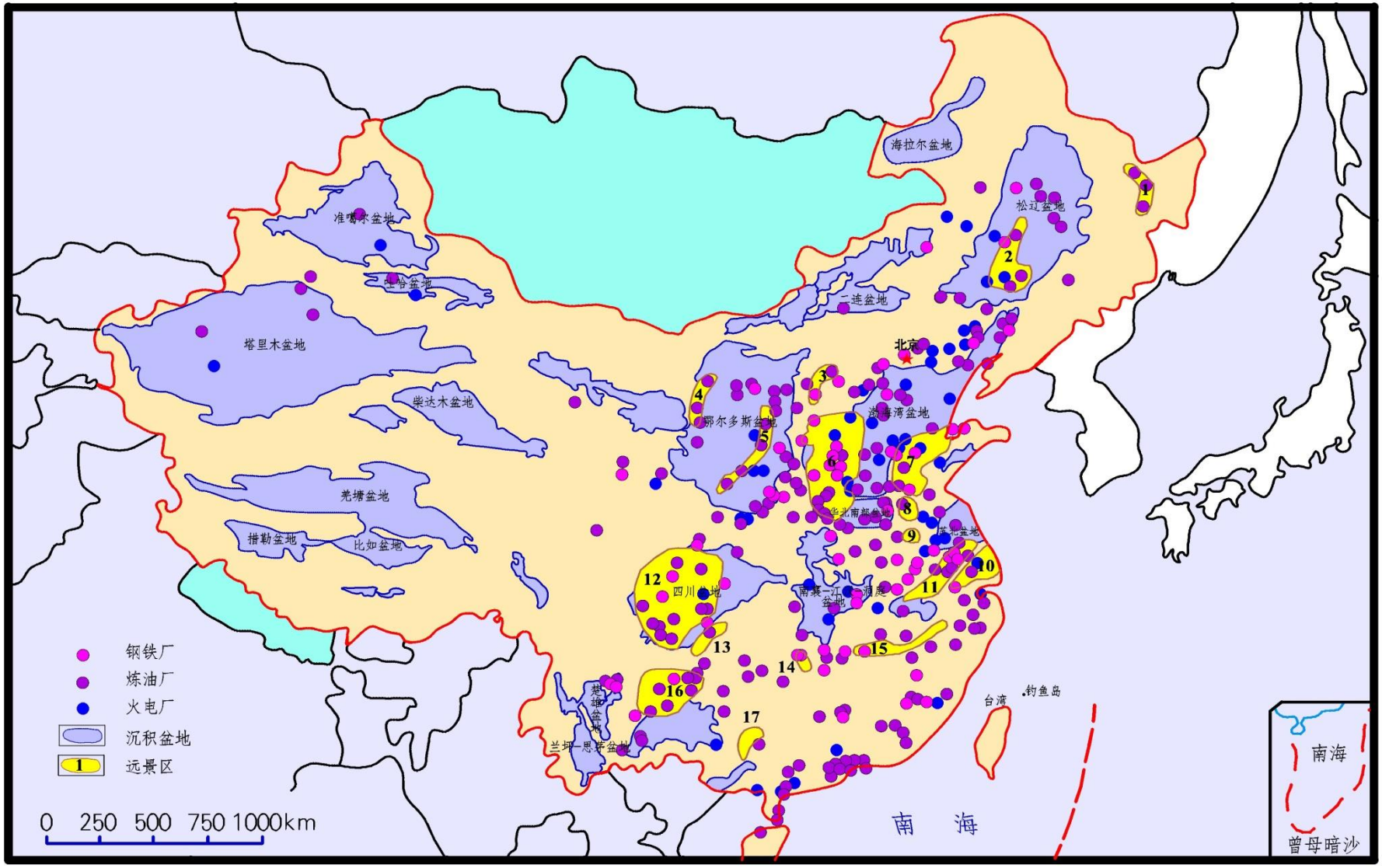
中国CO2排放量分布综合调查
China CO2 emission distribution



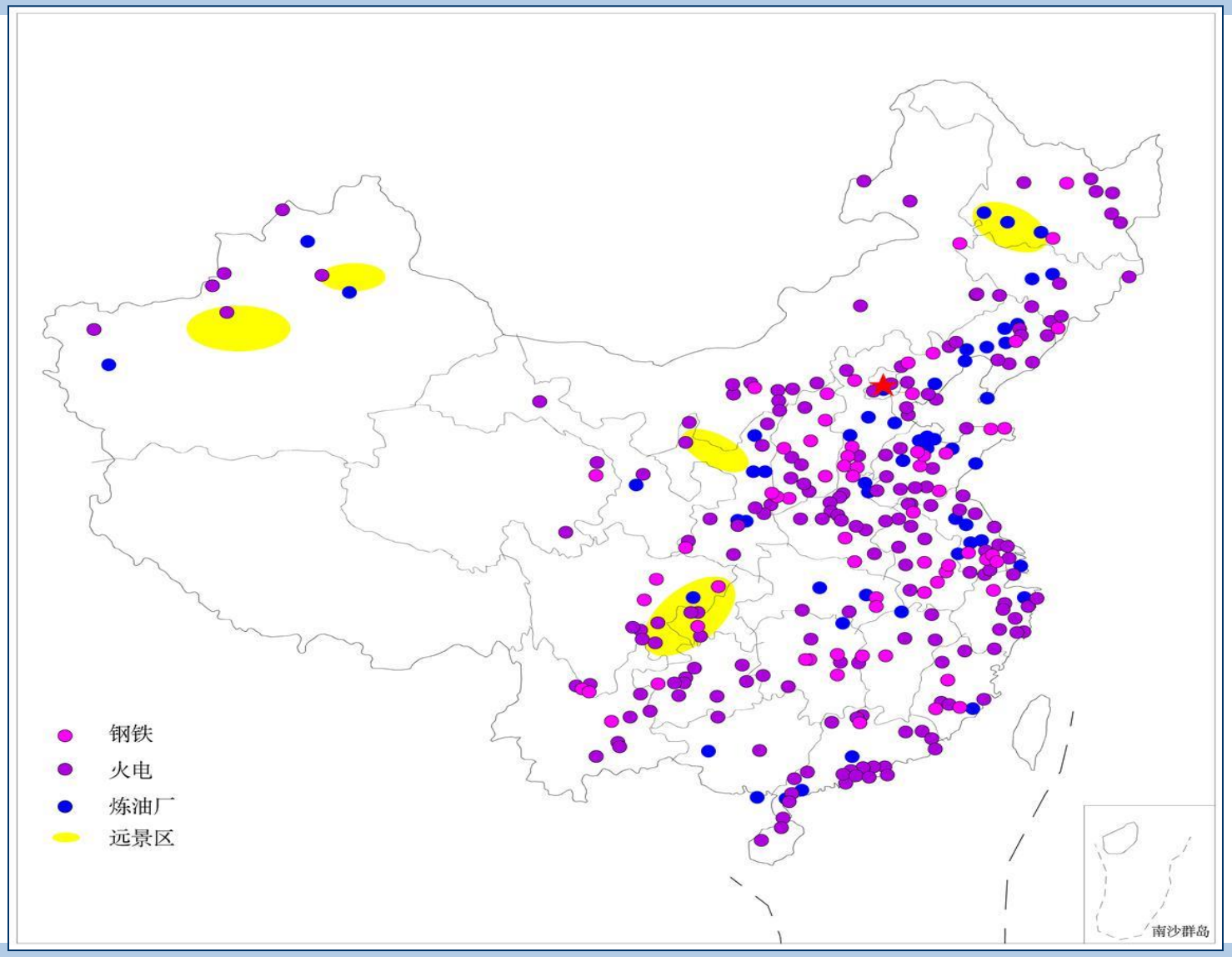
CO2-EOR远景评价
Prospect evaluation map of CO2-EGR



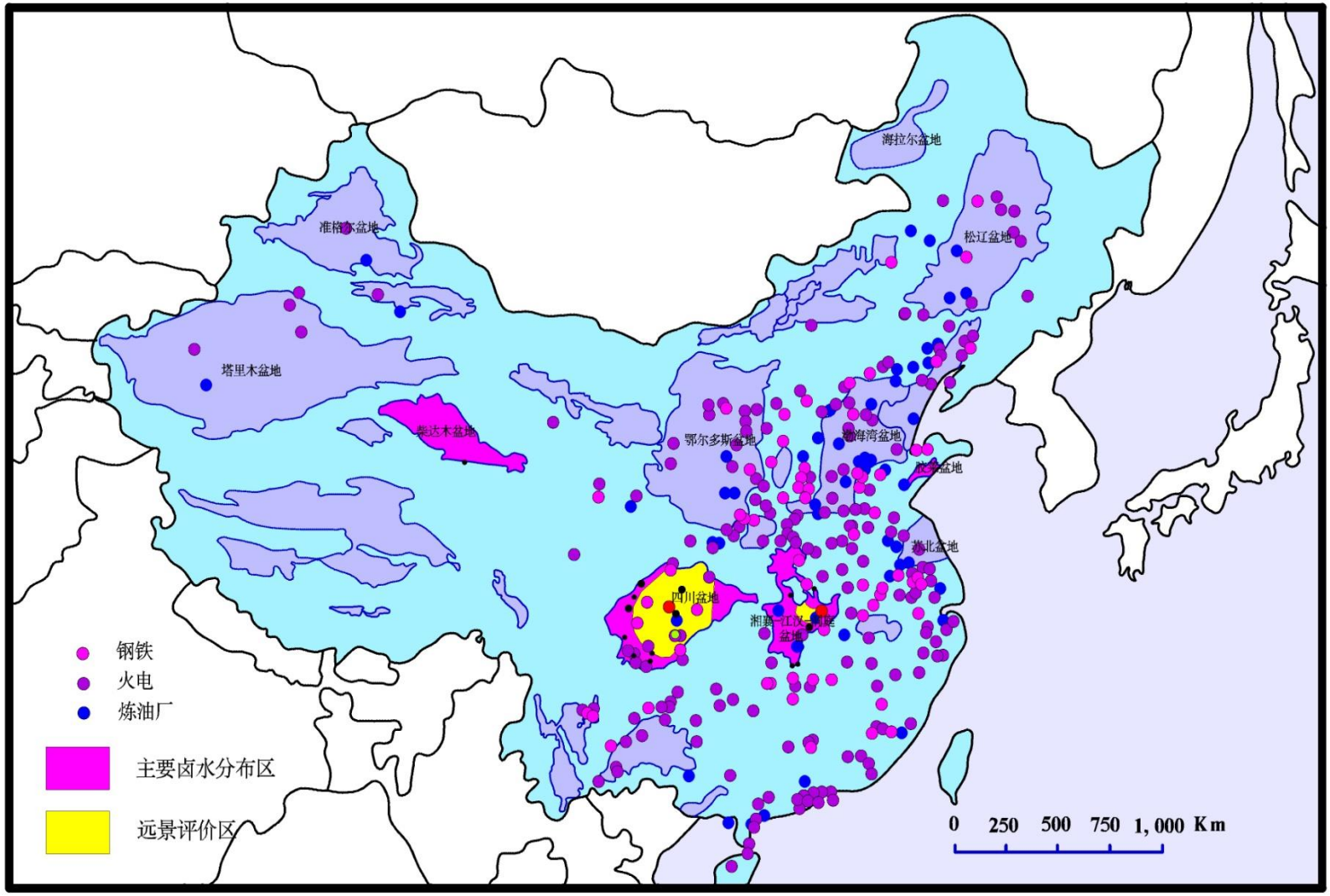
CO2-ECBM远景评价
Prospect evaluation map of CO2-ECBM



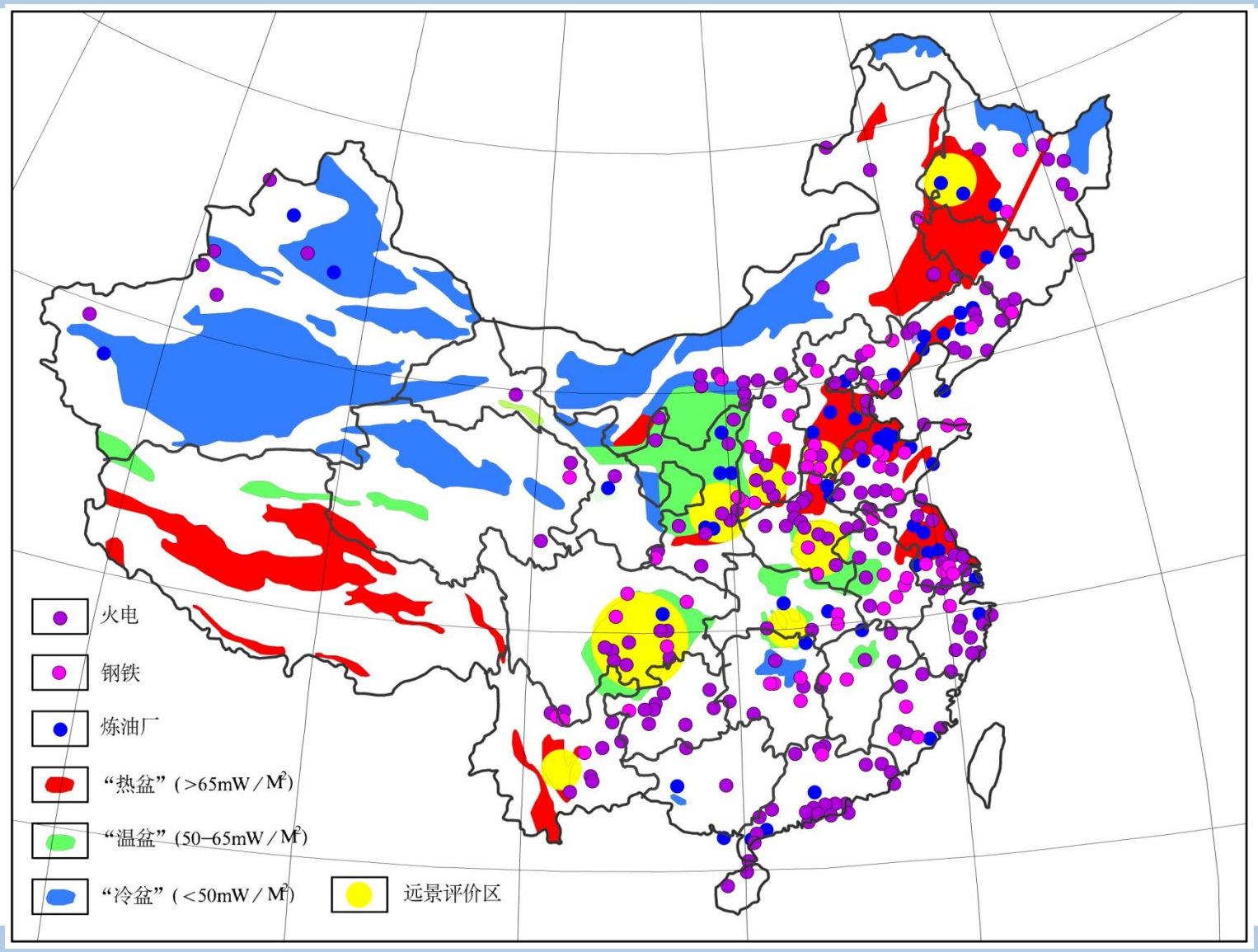
CO2-EGR远景评价
Prospect evaluation map of CO2-EGR



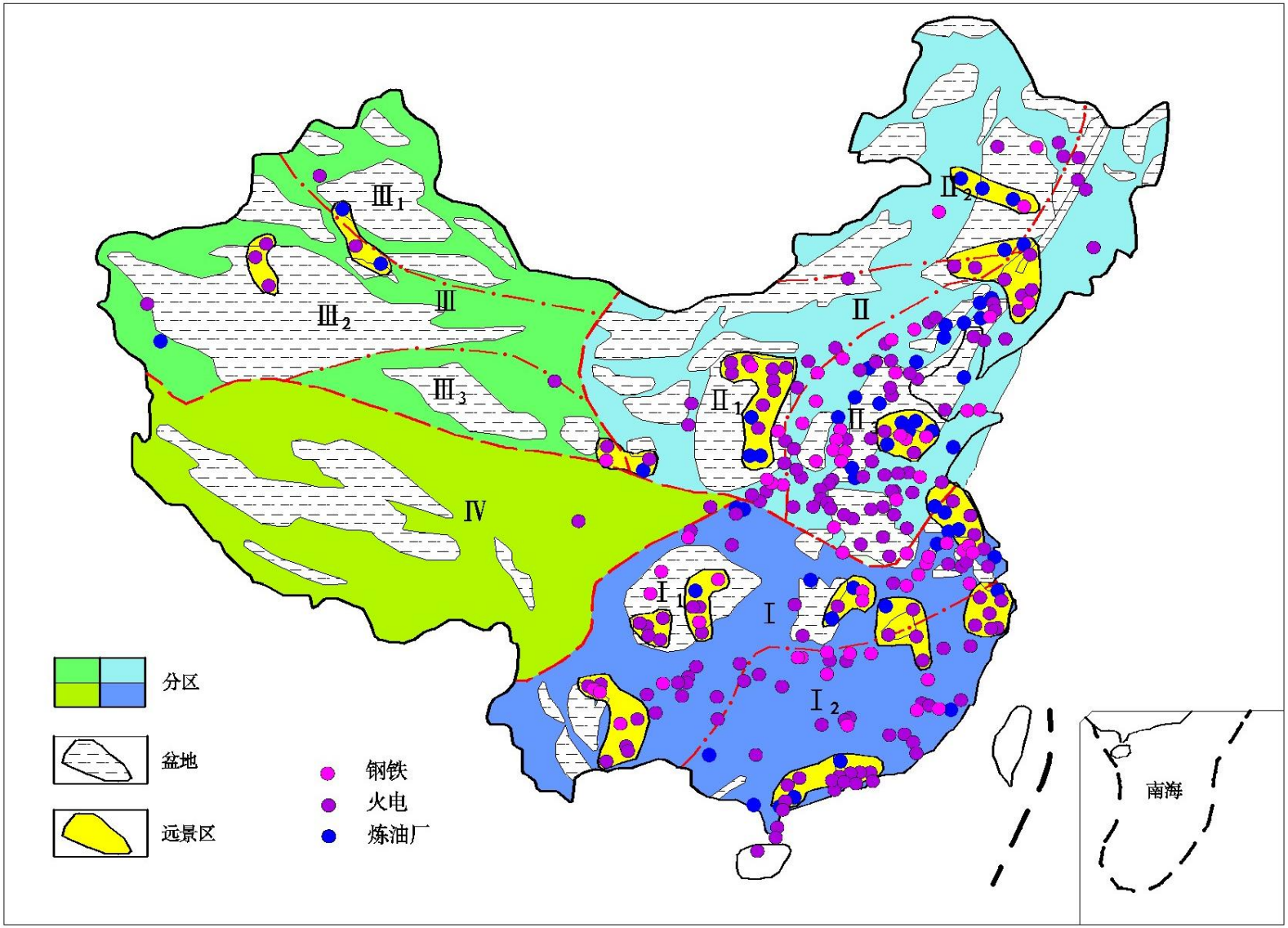
CO2驱卤远景评价
Prospect evaluation of Assisting joint exploitation of liquid mineral



CO2-EGS远景评价
Prospect evaluation of CO2-EGS



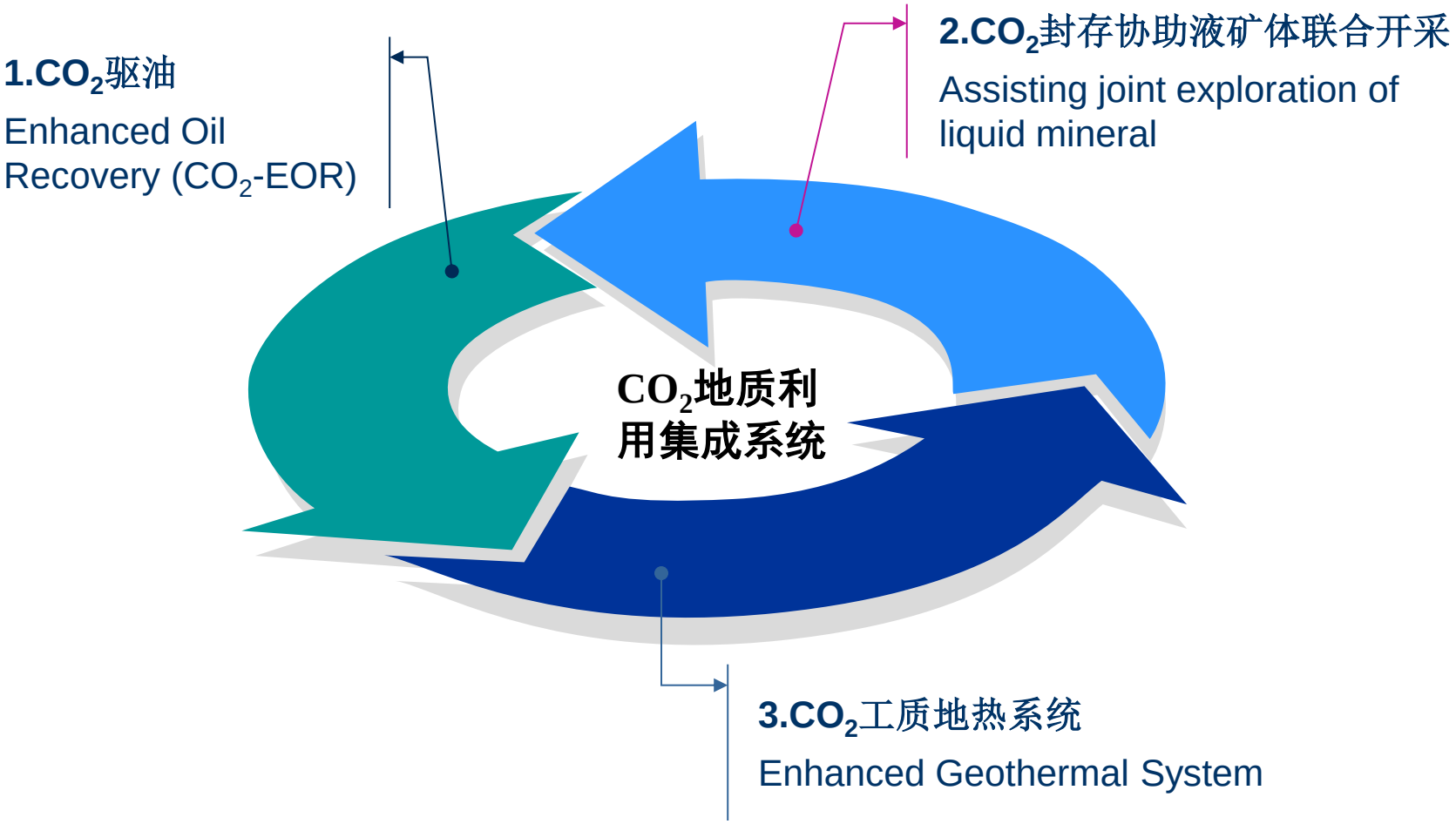
CO2-ESGR远景评价
Prospect evaluation of CO2-ESGR



4. Integrated CO_2 Geological Utilization System

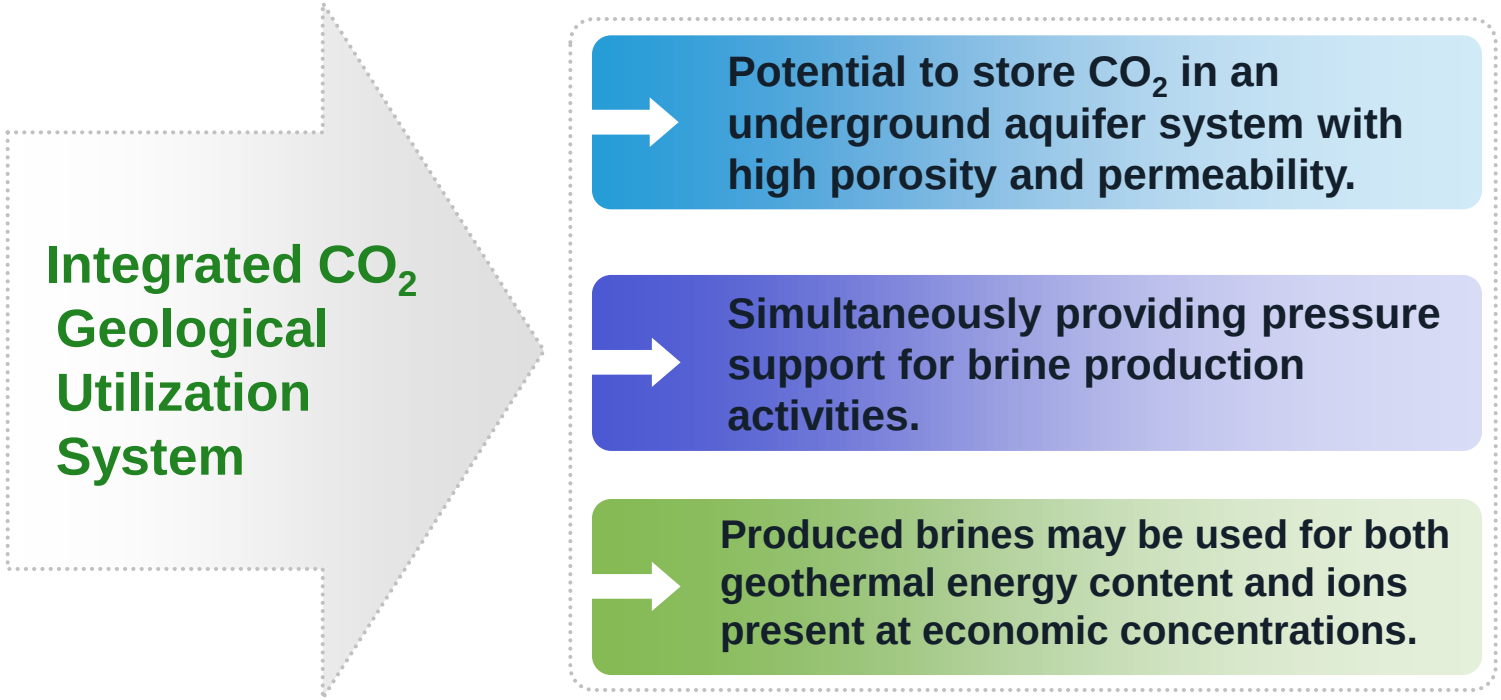
CO_2地质利用集成系统

Integrated CO_2 Geological Utilization System
CO_2地质利用集成系统

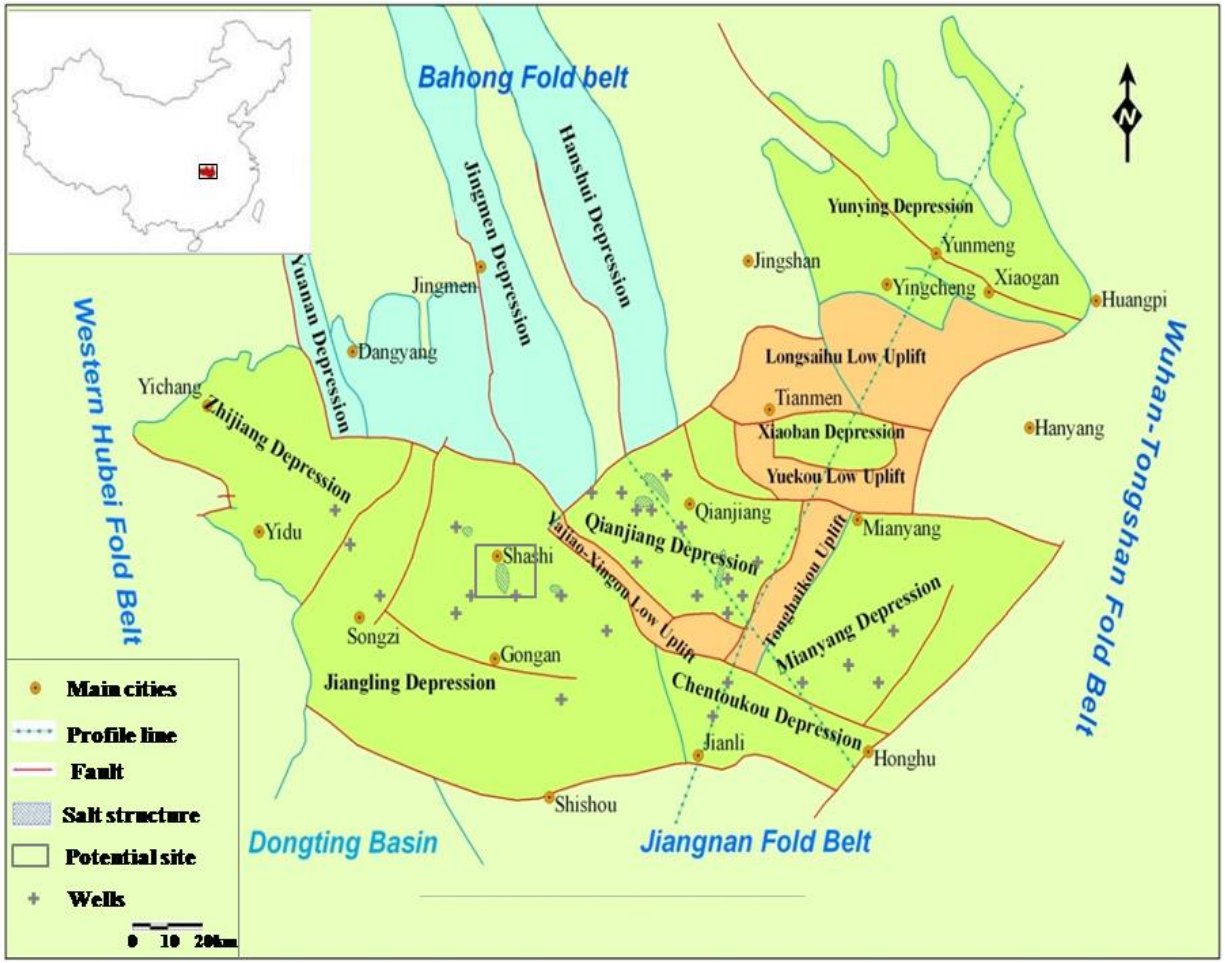


Integrated CO_2 Geological Utilization System

The advantages of this concept are as follows：



Example： Jianghan Basin

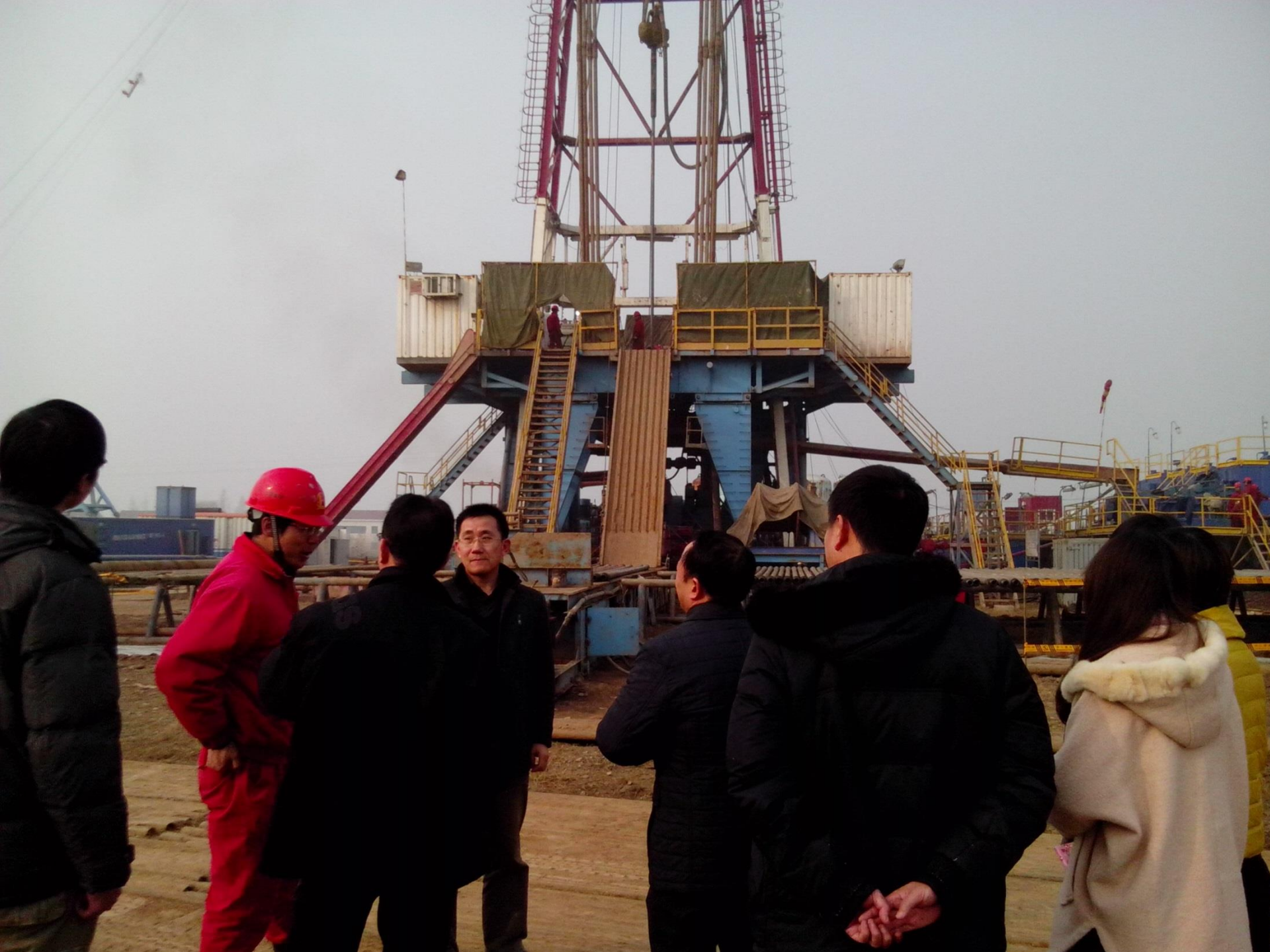


Location of the research area in Jianghan Basin

The Jianghan Basin is a representative salt-lake rift basin covering an area of 36350 km² with the salinity on the order of 150-340g/L. Jiangling Drepression is the brine-richest area.

The temperature of geothermal aquifers is about 100 °C. The K^+ content of this brine is up to 1.6%, which is more than 1.0% of industrial mining grade can be used to produce KCl.

江汉盆地属于我国典型的盐湖裂谷型盆地，面积36350km²。其地热温度约为100 °C，卤水中钾含量已超过工业开采水平。



Example : Jianghan Basin

The average concentration of salt in brine is about 280g/L

KCl in brine: 64%1.

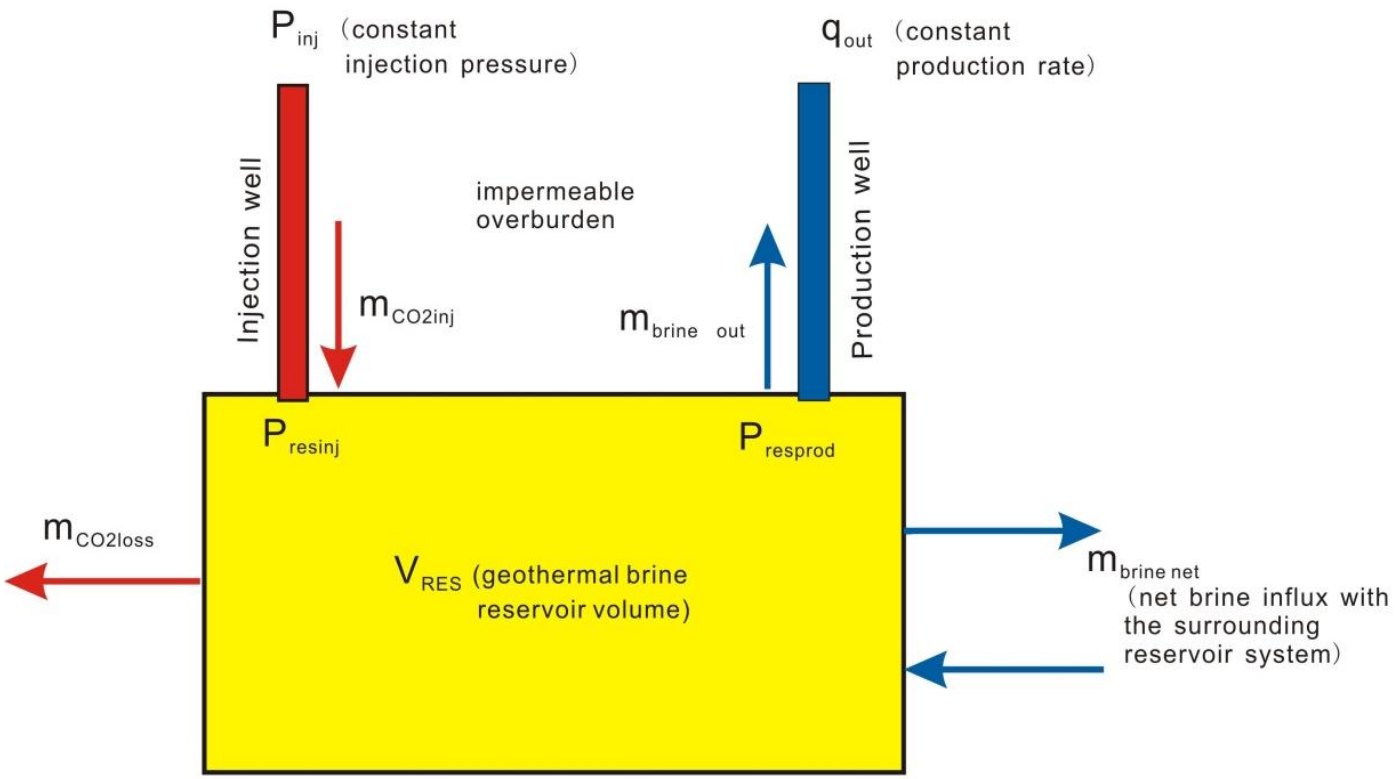
High concentration in Li, B,I, Br

The Value of brine will be more than 2000 billion RMB

14 oil fields in Jianghan Basin, never use CO2 flooding

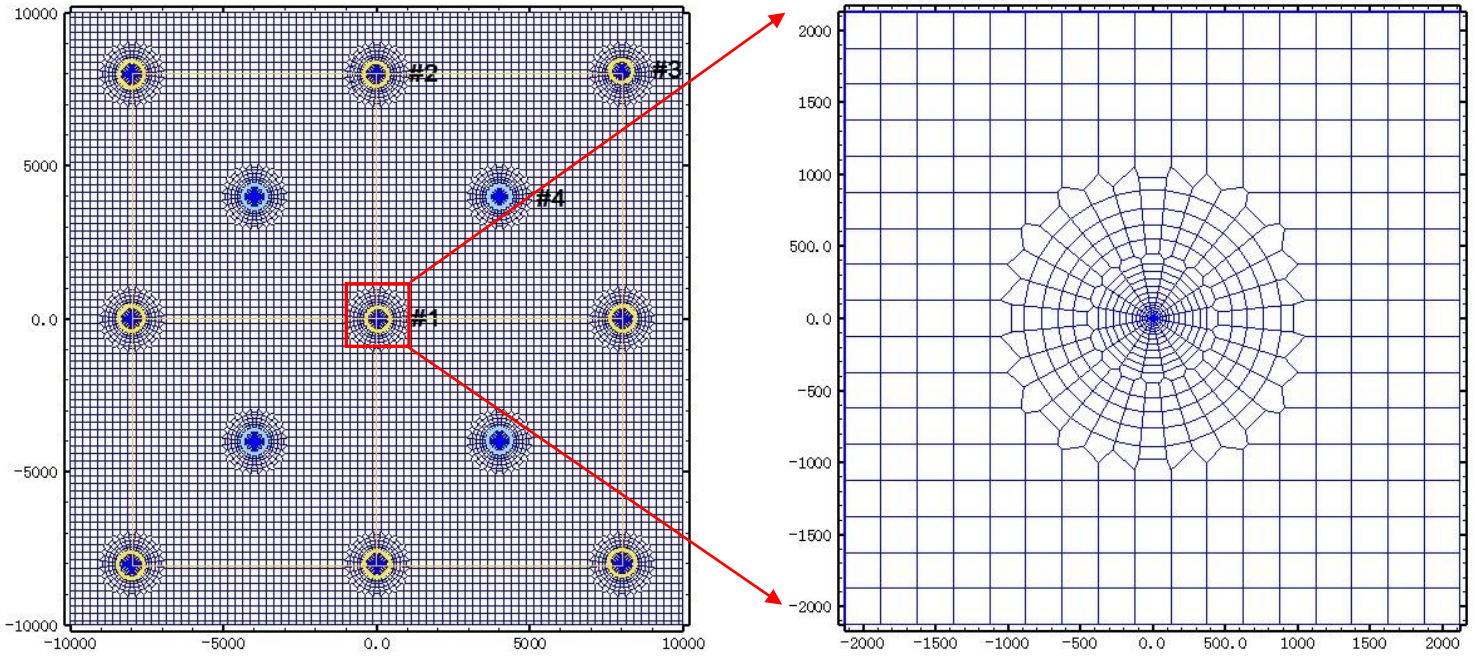
Geothermal gradient: 3.5 celsius degree per 100m

Conceptual Model



Well placement

As for the strategy of brine extraction and CO_2 injection, we arranged 13 vertical wells in a rectangular pattern with the same well spacing of 8 km in the study area.

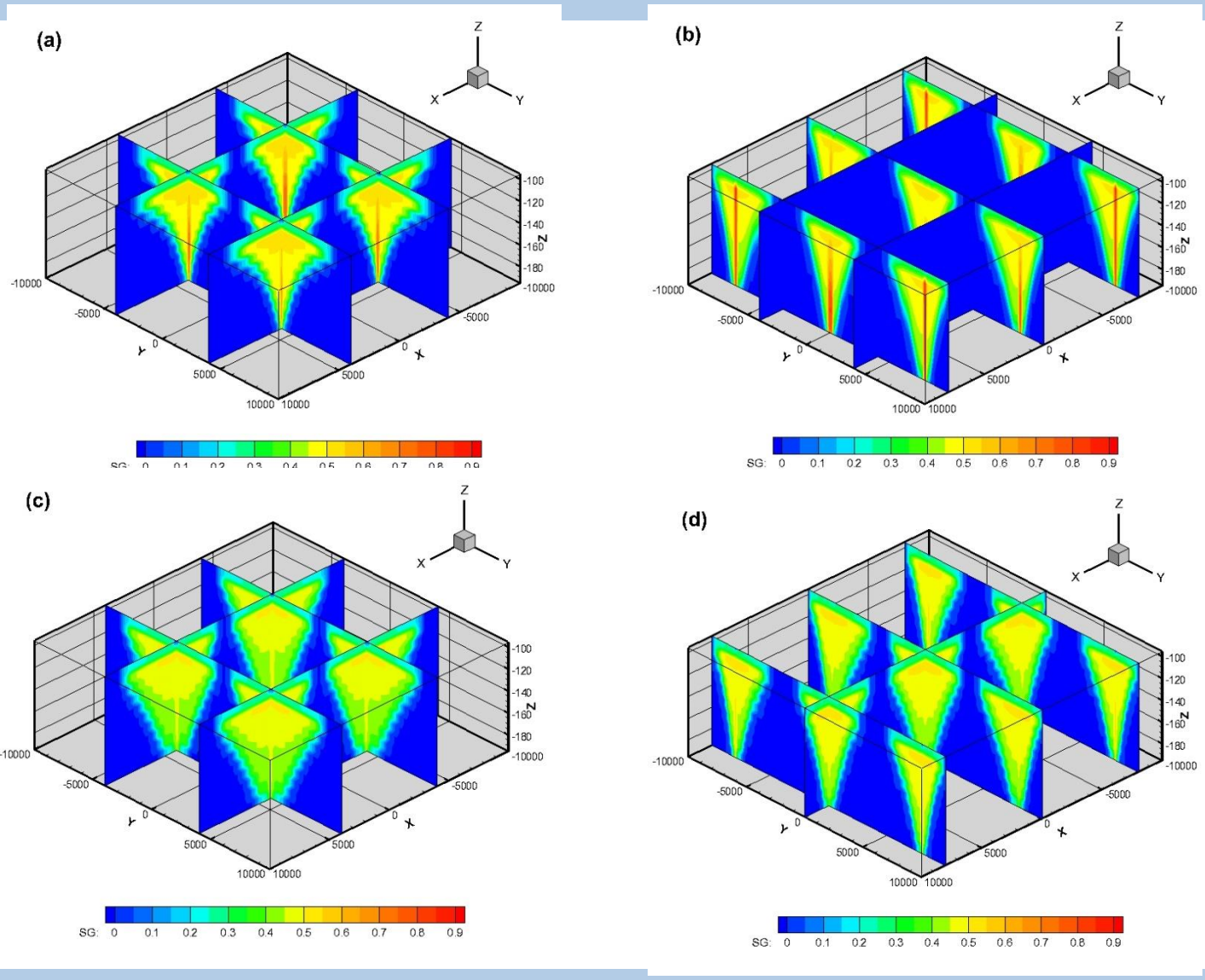


The 13 vertical wells are divided into two groups, and the yellow-circled wells are in one group while others are in another. Due to symmetry, we chose four wells marked as #1, #2, #3 and #4 to observe pressure response and flow change varying with time.

注采方案

Scheme 注采方案	9B4C_Q	4B9C_Q	9B4C_P	4B9C_P
Number of CO_2 wells CO_2注入井个数	4	9	4	9
Number of brine wells 卤水开采井个数	9	4	9	4
CO_2 Injection scheme CO_2注入方案	Constant injection rate 0.25Mt/yr per well		Constant inejction pressure of 40Mpa	
Brine Extraction scheme 卤水开采方案	constant extraction pressure of 1Bar 固定抽水压力为一个大气压			
Simulation Run Time 模拟时间(yr)	Simultaneous CO_2 injection and brine extraction for 100 years and monitoring for 100years			
Simulation Tool 模拟软件	TOUGH_ECO2N_MP			

Spatial distribution of CO_2 plume （CO_2羽分布）



Integrated CO_2 Geological Utilization System
CO_2地质利用集成系统

本系统通过抽采咸水层中卤水，降低了地层压力，留出了储存空间，运用CO_2与高盐卤水的联合注采技术，向地下深部咸水层注入CO_2过程中，进一步抽采咸水层中的卤水，改变单纯性注入模式，实现地下空间最大化利用，获取卤水和地热资源，实现热水型和CO_2工质型地热卤水的长期开发利用。

同时开展CO_2-EOR项目联动二氧化碳地质封存，提高石油产量，实现规模化与资源化，极大地降低CCS成本，并产生附加经济效益和环保效益，从而推动CCS—CCUS的真正实现。

Many kinds of integrated CO_2 Geological Utilization Systems need to be established …

Thank You !