CO_2 geologic utilization and storage in China and Xinjiang

中国和新疆的CO_2地质利用与封存

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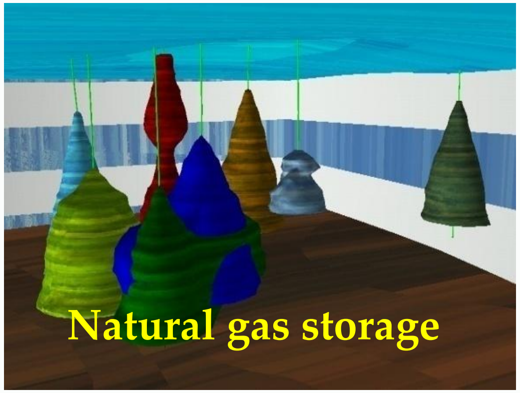

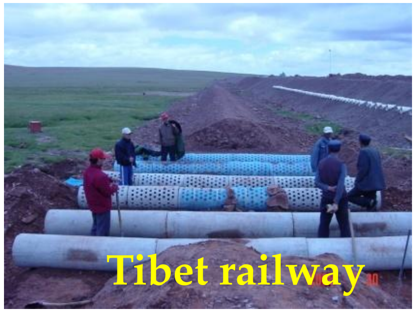

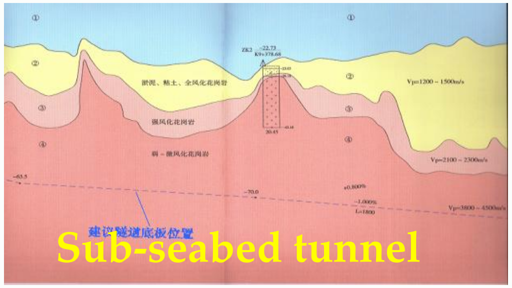

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CO_2 Geological Storage Group

- 13 researchers + 20 technicians + 22 students
- Scope: CGUS-associated THMC process, safety assessment and monitoring

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Overview 内容

- CCUS Technologies
- CGUS Capacity
- Technology maturity
- Sink-Source Matching
- Technical-Economic model for CO_2-EOR
- Conclusions

- CO_2利用与封存技术概念
- CO_2地质利用与封存容量
- 技术成熟度
- 源汇匹配
- CO_2-EOR技术经济模型
- 建议

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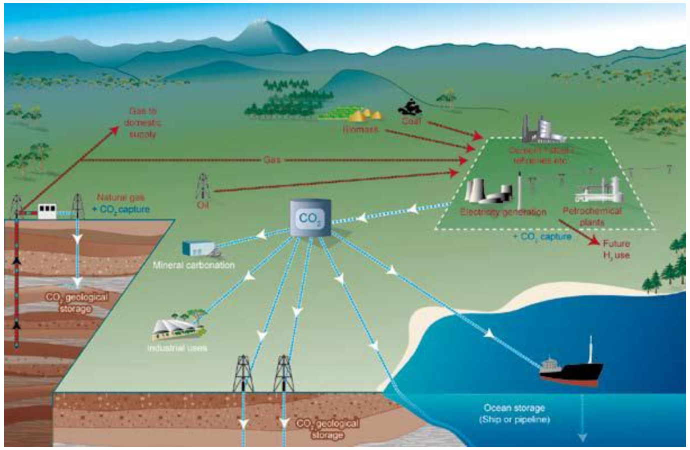
CCUS and CGUS

CCUS

- **CO_2 Capture 捕集**
- **CO_2 Transport 输送**
- **CO_2 Utilization 利用**
  - **Chemical Utilization 化工利用**
  - **Geological Utilization 地质利用**
  - **Biological Utilization 生物利用**
- **CO_2 Storage 封存**

CGUS 地质利用与封存



CO_2的直接参与、与传统技术相比能够实现净减排

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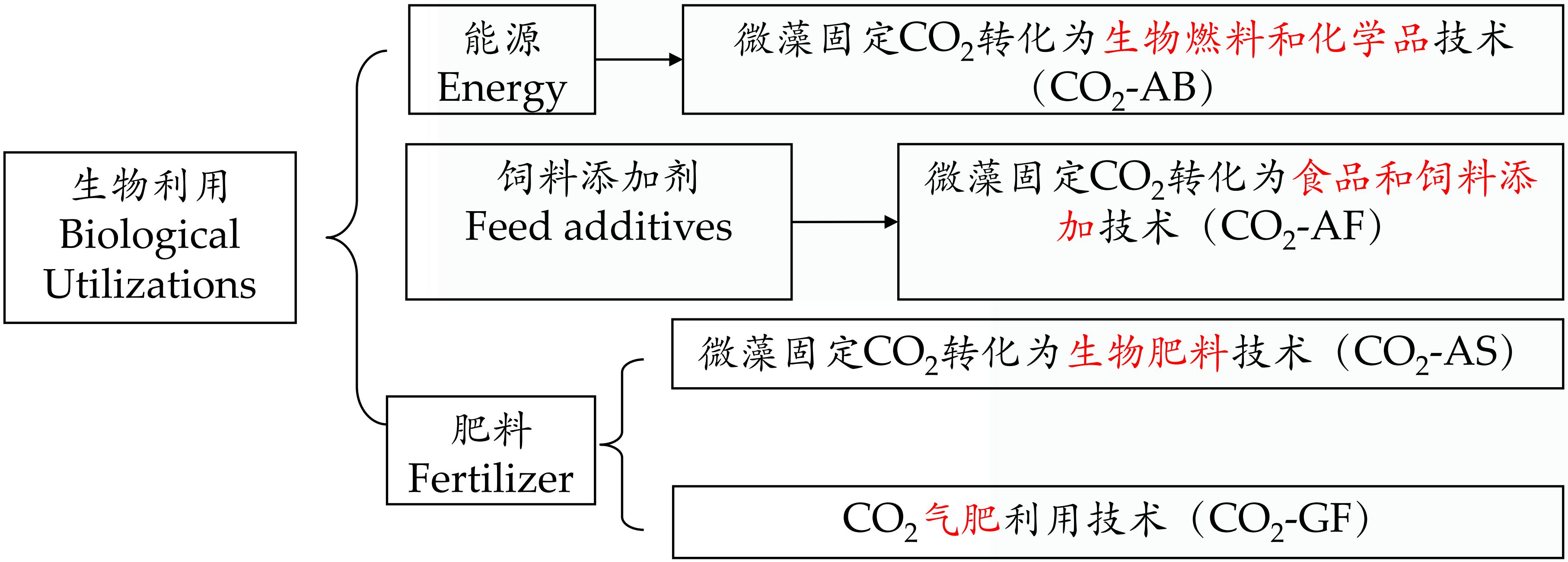
化工利用 Chemical Utilizations

化工利用 Chemical Utilizations	材料 Materials	CO_2合成可降解聚合物材料（CO_2-CTP）
		CO_2间接非光气合成异氰酸酯/聚氨酯（CO_2-CTU）
		CO_2间接制备聚碳酸酯/聚酯材料（CO_2-CTPC）
		CO_2间接制备乙烯基聚酯（CO_2-CTPET）
		CO_2-间接制备聚丁二酸乙二醇酯（CO_2-CTPES）
	能源 Energy	CO_2与甲烷重整制备合成气（CO_2-CDR）
		CO_2经一氧化碳制备液体燃料（CO_2-CTL）
	有机化学品 organic chemicals	CO_2直接加氢合成甲醇（CO_2-CTM）
		CO_2合成碳酸二甲酯（CO_2-CTD）
		CO_2合成甲酸（CO_2-CTF）
	无机化学品 inorganic chemicals	钢渣直接矿化利用CO_2（CO_2-SCU）
		钢渣间接矿化利用CO_2（CO_2-ISCU）
		磷石膏矿化利用CO_2（CO_2-PCU）
		钾长石加工联合CO_2矿化（CO_2-PCM）

生物利用 Biological Utilizations



CO_2 Biological Utilization Technologies

Source：ACCA21，2014）

地质利用与封存
Geological Utilization and Storage （CGUS）

Field 应用领域	Technologies 技术
Energy Production 能源生产	Enhanced Oil Recovery, CO_2-EOR，强化采油
	Enhanced Coalbed Methane, CO_2-ECBM，驱煤层气
	Enhanced Gas Recovery, CO_2-EGR，强化采气
	Enhanced Shale Gas Recovery, CO_2-ESGR，强化页岩气
	Enhanced Geothermal Systems, CO_2-EGS，增强地热系统
Mineral Resources 资源开发	Enhanced uranium leaching，CO_2-EUL，溶浸采铀
	Enhanced water recovery，CO_2-EWR，封存驱水
Geological Storage 地质封存	Depleted Hydrocarbon Fields，枯竭油气田

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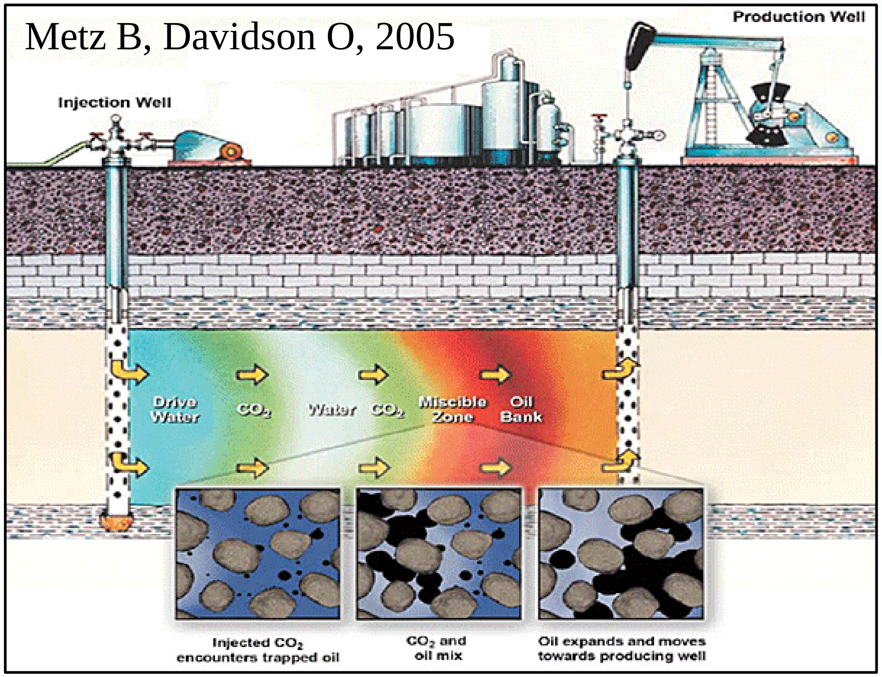
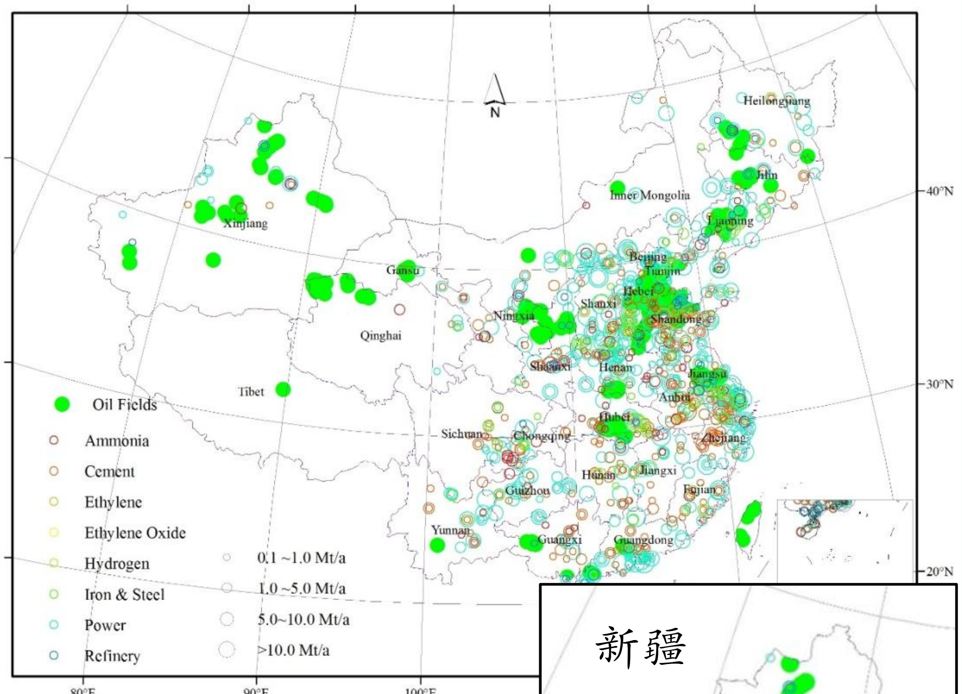
CGUS Capacity 地质利用的封存容量

CO_2-EOR and storage capacity 强化采油

(Ning Wei, Xiaochun Li, 2015)





China 全国

- Storage capacity：4.8 Gt（50% level）
- Additional oil: 1.44 Gt

Xinjiang新疆

- 2.73 Gt（50% level）
- 0.89 Gt

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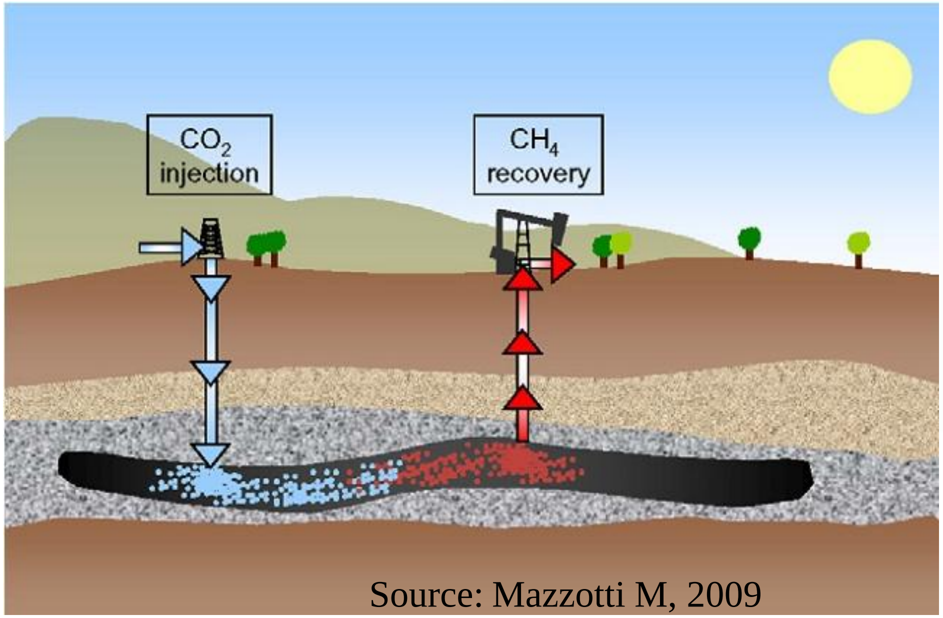
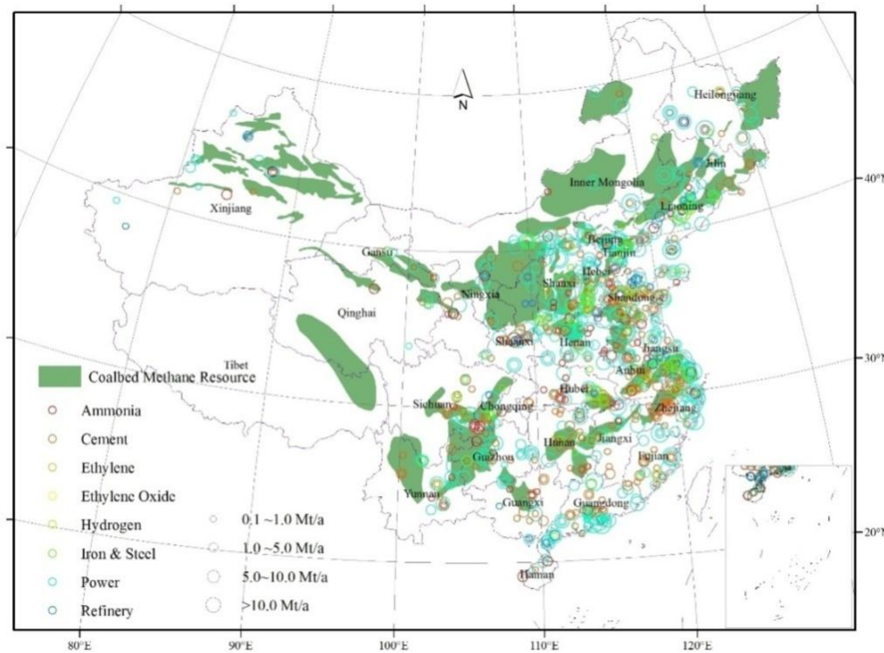
CGUS Capacity 地质利用的封存容量

CO_2-ECBM 驱煤层气 (Ning Wei, Xiaochun Li，2015)



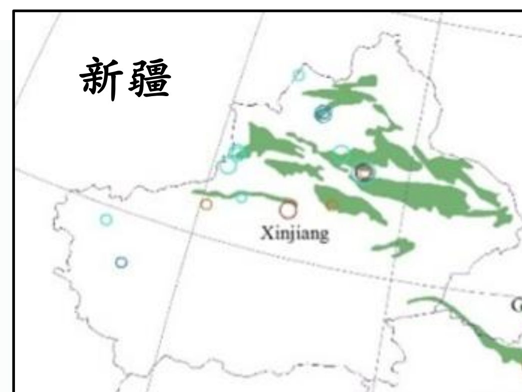
Source: Mazzotti M, 2009



China 全国

Storage capacity：11.4Gt (50%)

- Additional CBM：508 Gm^3 (50%)



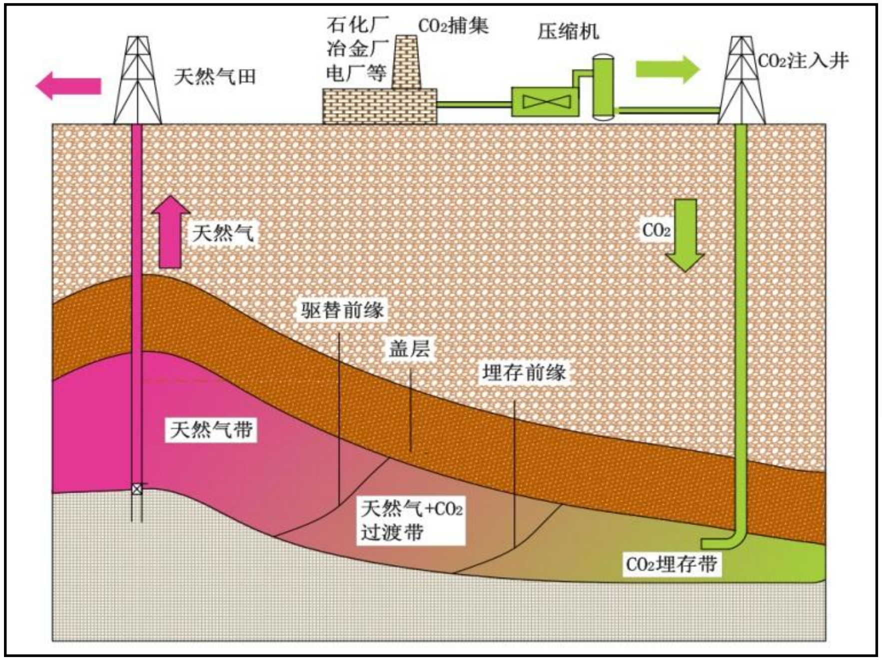
Xinjiang 新疆

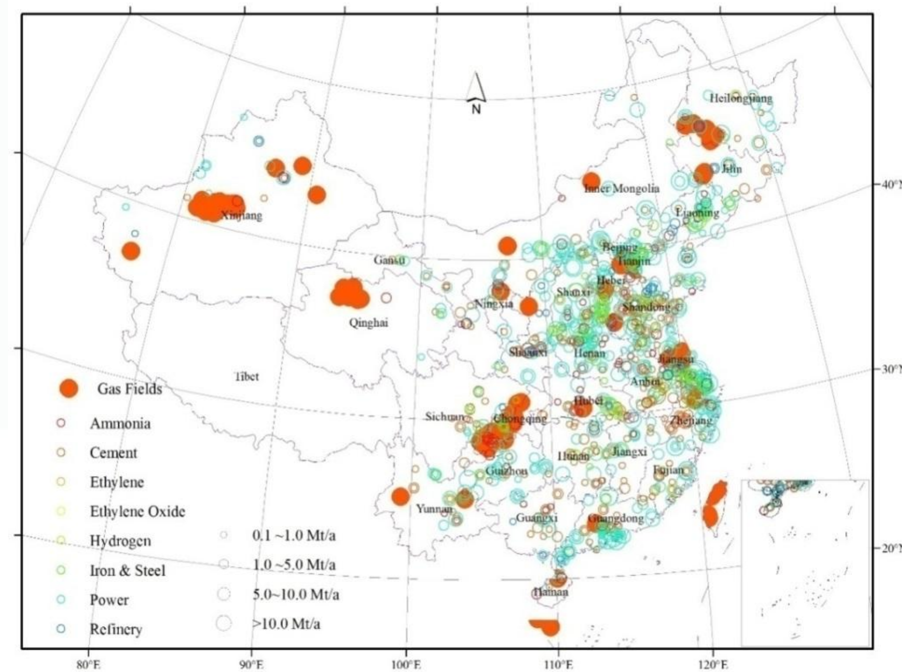
2.1 Gt (50%)

53 Gm^3 (50%)

CGUS Capacity 地质利用的封存容量

CO_2-EGR 强化采气 (Ning Wei, Xiaochun Li，2015)





China 全国
- Capacity: 4 Gt (50%)
- Additional NG: 64.7 Gm^3 gas (50%)

Xinjiang 新疆
0.67 Gt (50%)
2.8 Gm^3 (50%)

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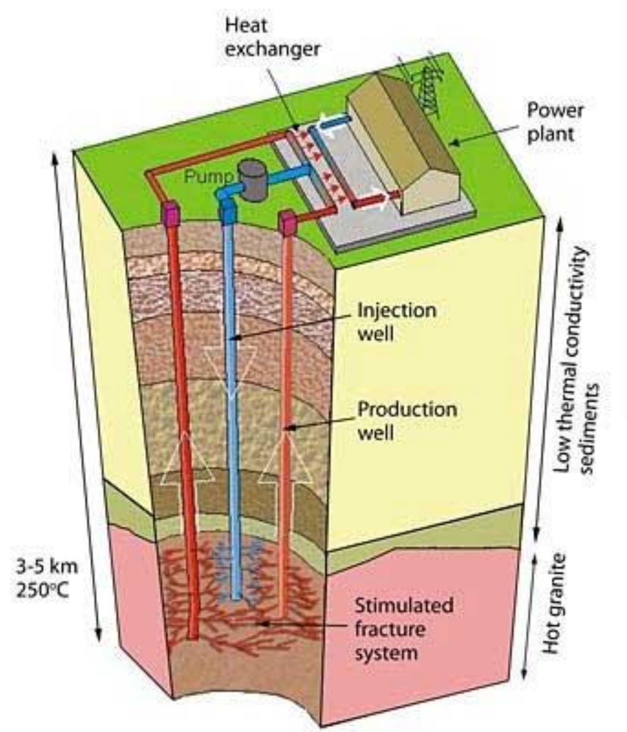
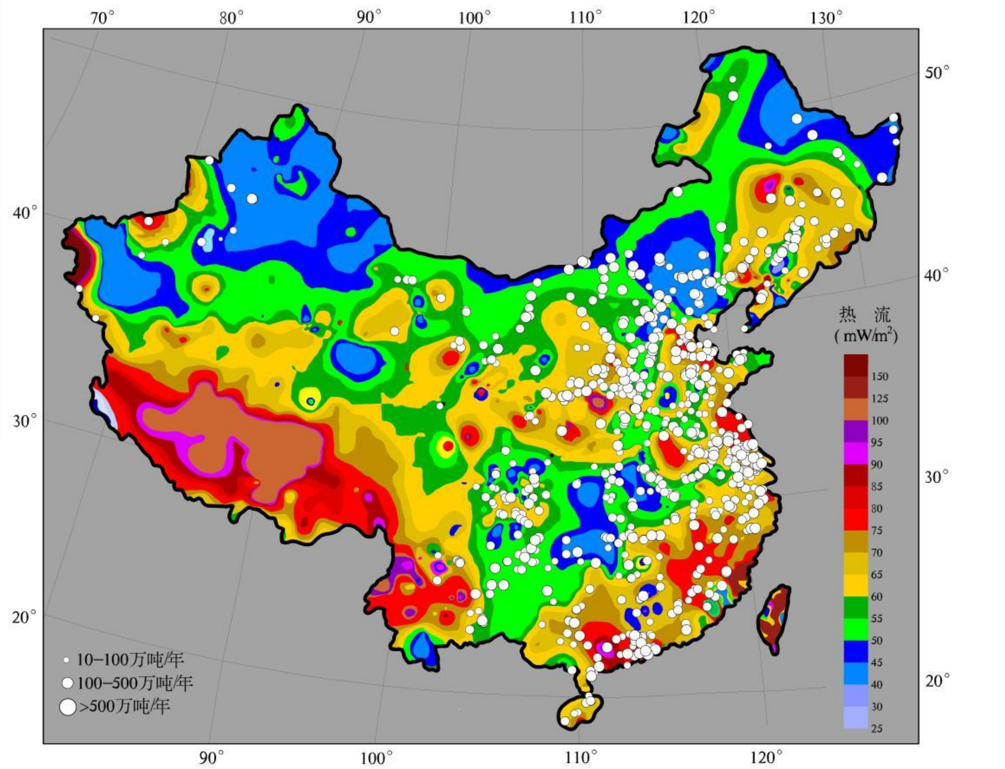
CGUS Capacity 地质利用的封存容量

CO_2-EGS 增强地热系统 (Ning Wei, Xiaochun Li，2015)



Source: http://geothermalworldwide.com/egs.html

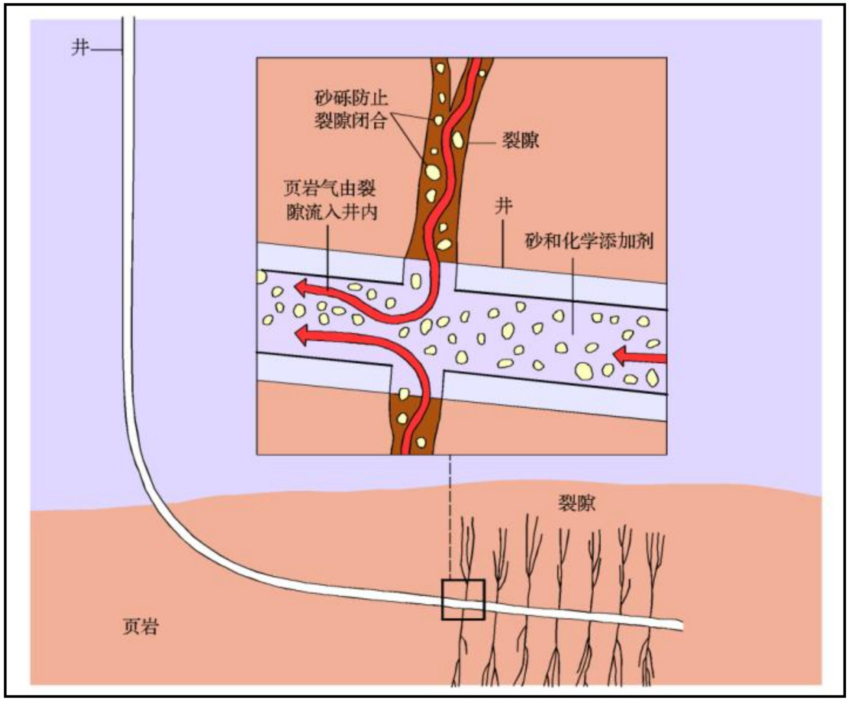


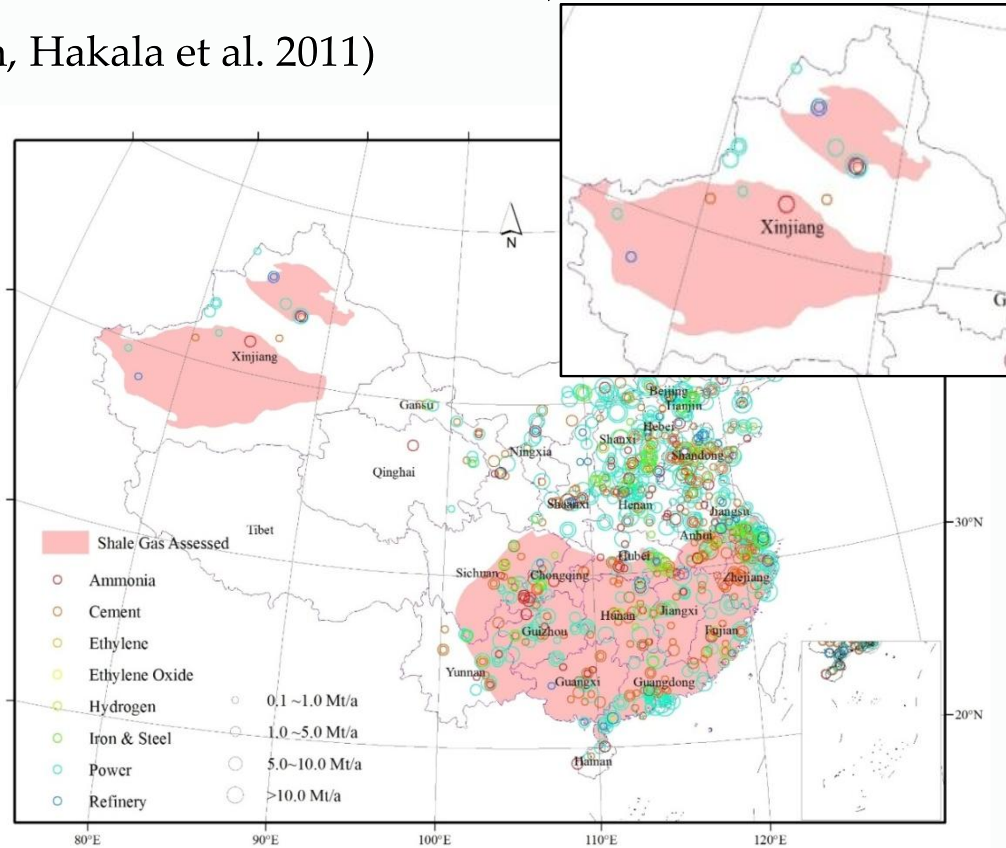
China:全国	Xinjiang
• Capacity: 2.9Gt (50%)；	• Not evaluated
• Production： 5.8e6 GJ (50%)	• Not evaluated

CGUS Capacity 地质利用的封存容量

CO_2-ESGR 增采页岩气 (Ning Wei, Xiaochun Li，2015)

Based on US-DOE methodology (Goodman, Hakala et al. 2011)





China: 全国
- Capacity： 69.3 Gt CO_2 (50%)
- Production： 11.7 Tm^3 gas (50%)

Xinjiang
16.6 Gt (50%)
2801 Gm^3 (50%)

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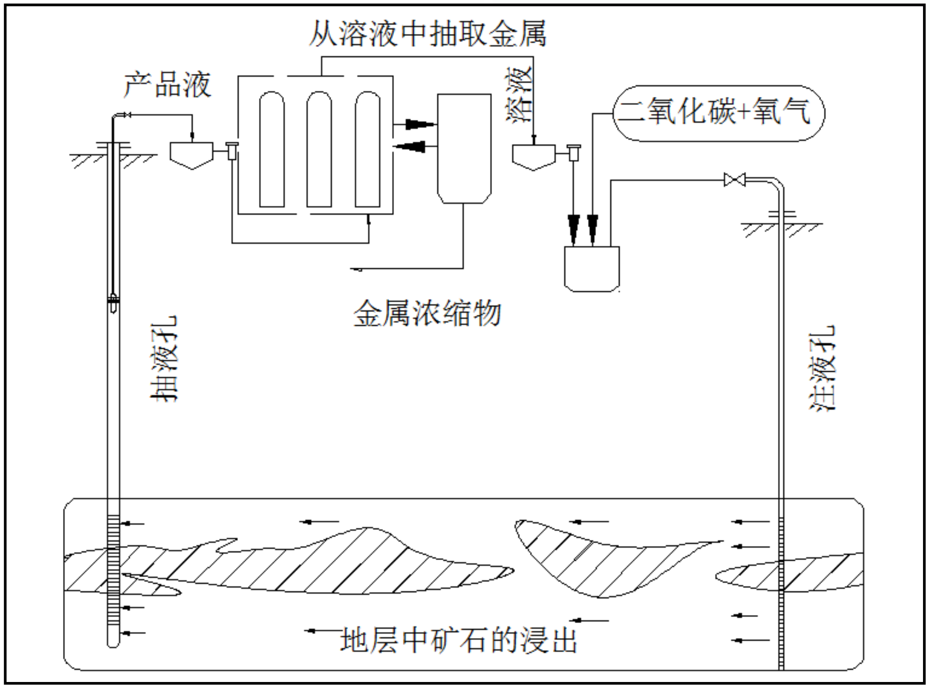
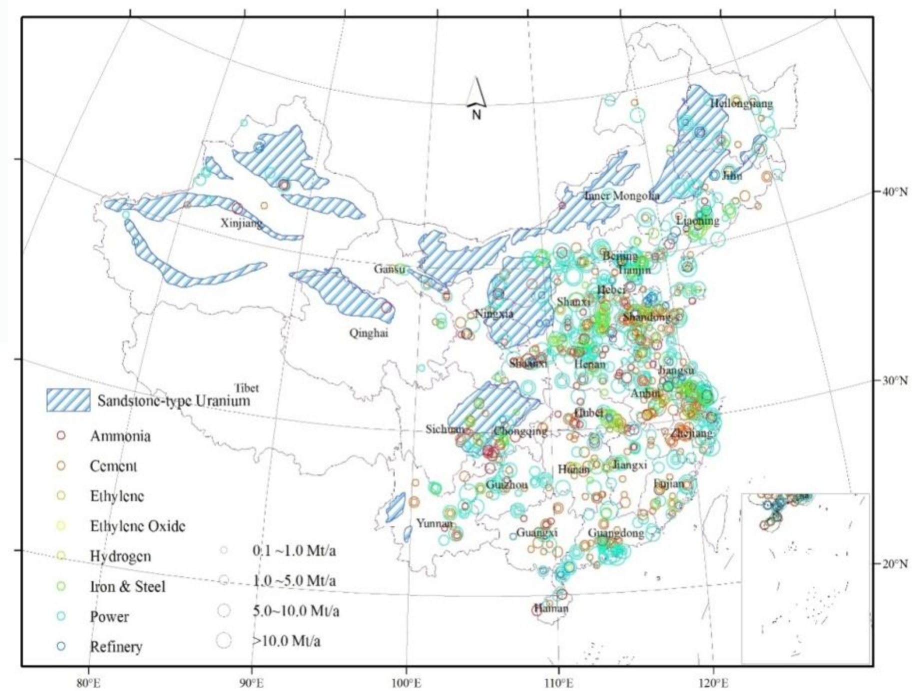
CGUS Capacity 地质利用的封存容量

CO_2-EUL 溶浸采铀 (Ning Wei, Xiaochun Li，2015)

Based on aquifer storage methodology





China: 全国

- Capacity: 157.7 Mt (50%)
- Production: 1.77 Mt of uranium (50%)

Xinjiang

- 48.41 Mt (50%)
- 321.6 Mt (50%)

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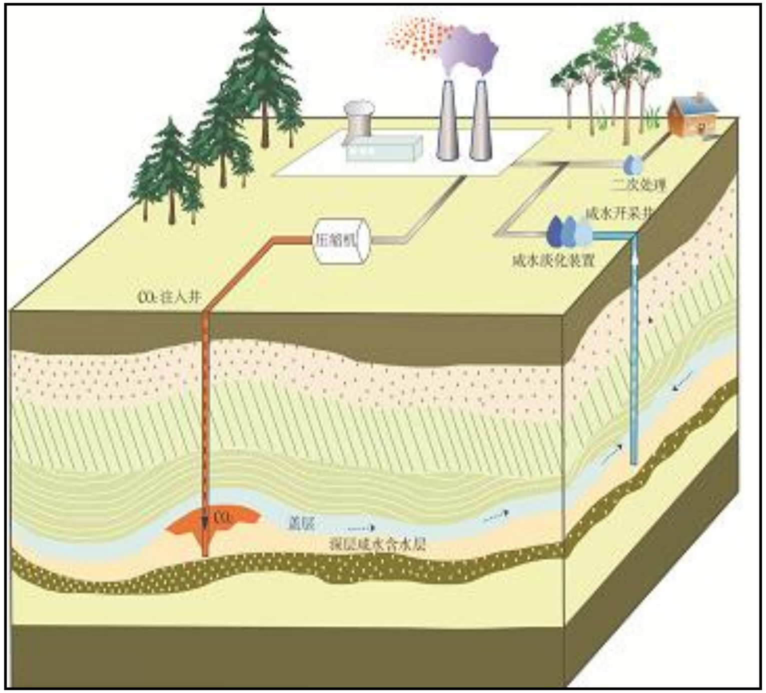
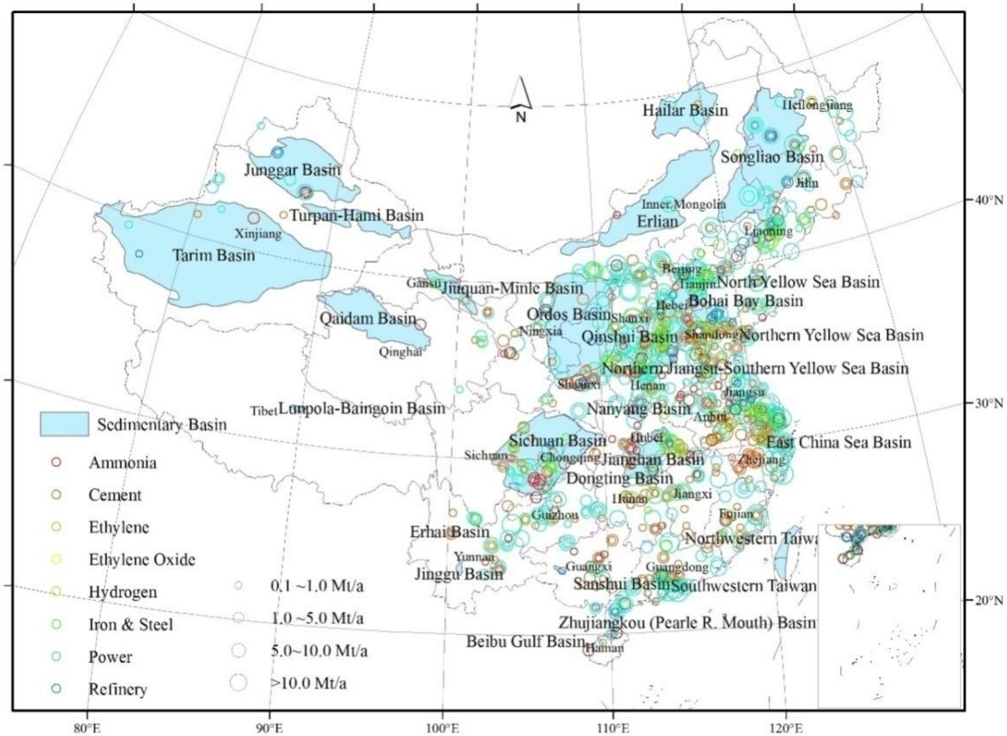
CGUS Capacity 地质利用的封存容量

CO_2-EWR 封存采水 (Ning Wei, Xiaochun Li，2015)

$$G_{CO2} = A \cdot h_g \cdot \varphi_{tot} \cdot \rho_{CO2} \cdot E_{saline} \qquad EWR = OUIP \cdot R_U$$





China 全国

- Capacity: 2.4Tt CO2(50%)
- Production： 3.1Tt water(50%)

Xinjiang 新疆

- 1.1Tt (50%)
- 1.7Tt (50%)

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地质利用的封存容量 CGUS Capacity

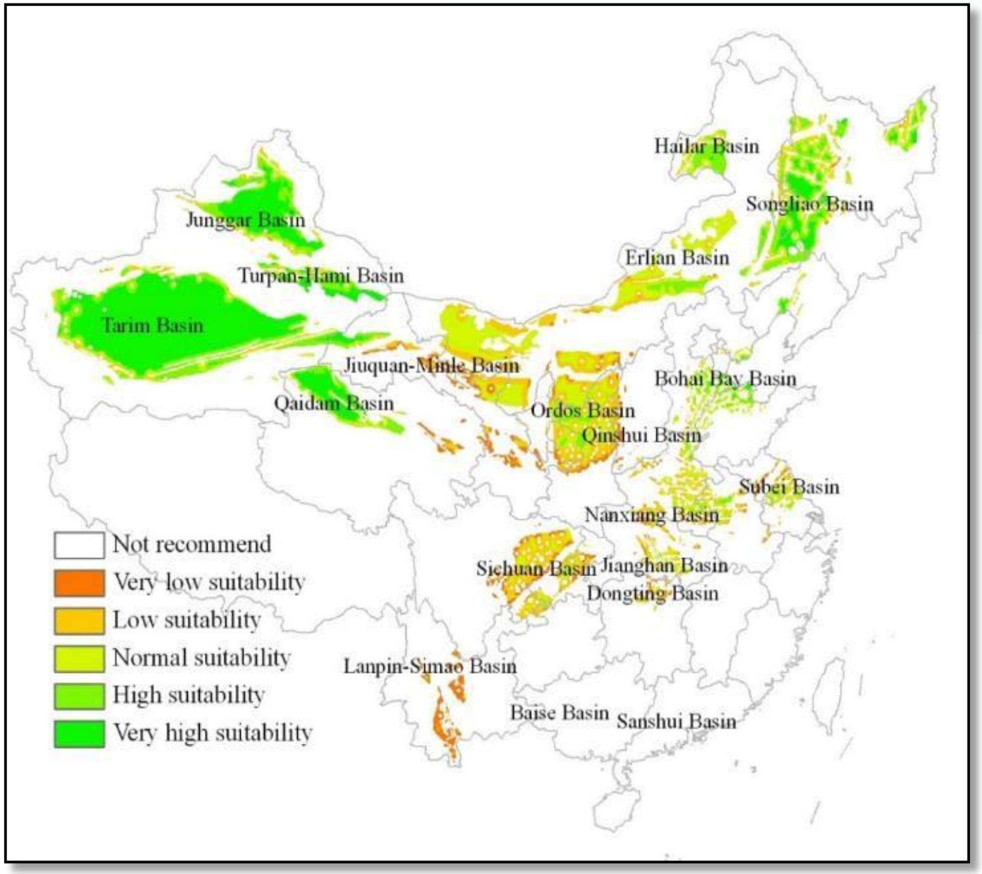
(Ning Wei, Xiaochun Li, 2015)

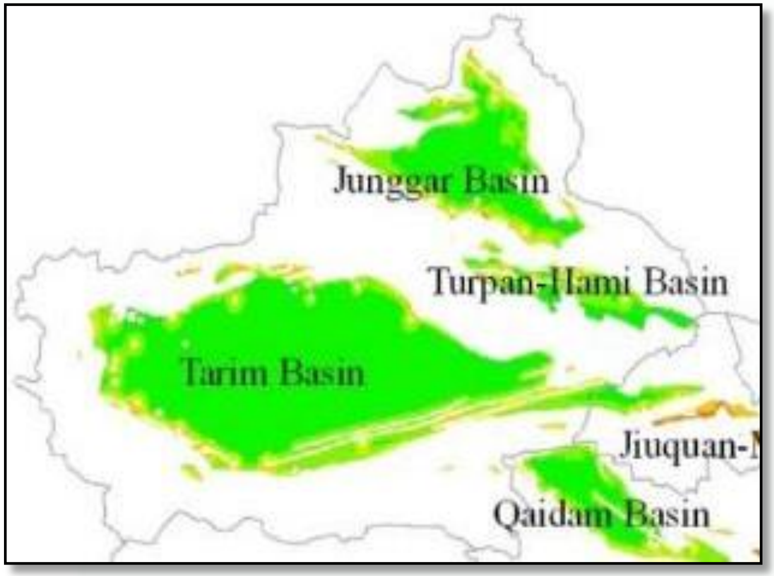
Tech.	P50 onshore storage capacity (Gt)			P50 products		
	China	XJ	XJ/CN	Units	China	XJ
EOR	4.8	2.73	0.57	Oil (Gt)	1.44	0.89
ECBM	11.4	2.1	0.18	CBM (Gm^3)	508	53
EGR	4.0	0.67	0.16	Nat. Gas (Gm^3)	64.7	2.8
ESGR	69.3	16.6	0.24	Shale Gas(Gm^3)	11683	2801
EGS	2.9	-	-	Geoth. (GJ)	5.8E+06	-
EUL	0.16	0.05	0.31	Uranium (kt)	780.0	321.6
EWR	2417	1072	0.44	Water (Gt)	3143	1715
Sum	2510	1097	0.44			

- For China, 2.5Tt capacity, aquifer storage/EWR accounts for 96%
- For XJ, 1.1Tt capacity, aquifer storage/EWR accounts for 96%
- XJ has diverse CGUS options except EGS

Aquifer storage/EWR suitability 适宜性

(Li et al., 2007)





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Ongoing CGUS Projects in China

Shenhua Ordos CCS Project
Industrial separation + aquifer
100kt/a

PetroChina Jilin Oilfield EOR Project
Industrial seperation + EOR
260kt/a

Sinopec Shengli Oilfield EOR Project
Post-combustion capture + EOR

Yanchang EOR Project
Industrial Separation + EOR
40kt/a

CUCBM CO_2-ECBM Pilot Tests
Post combustion capture +ECBM
1kt/a

Technical readiness levels

TRL-modified after US-DOE methodology

TRL	DOE-FE Definition	Different Stage
1	Basic principles observed and reported (原理揭示)	Conceptual study
2	Technology concept and/or application formulated (技术概念)	Conceptual study
3	Analytical and experimental critical function and/or characteristic proof of concept (功能刻画)	Conceptual study
4	Component and/or system validation in a laboratory environment (实验室验证)	Laboratory Scale
5	Laboratory-scale similar-system validation in a relevant environment (实验室验证)	Laboratory Scale
6	Engineering/pilot-scale, prototypical system demonstrated in a relevant environment (先导试验)	Pilot scale
7	System prototype demonstrated in a plant environment (中间试验)	Demo scale
8	Actual system completed and qualified through test and demo in a plant environment (工业试验)	Full-scale demonstration
9	Actual system operated over the full range of expected conditions (工业应用)	Full-scale demonstration
10	Actual system at commercial scale (商业推广)	Commercial process

TRLs and uncertainties

Technology	Storage capacity (Gt)	Products	Outputs	Values (TUS$)	TRLs
EOR	2-20	Oil (Gt)	1-1.44	0.3-0.43	7
ECBM	9.9-11.4	CBM (Gm^3)	508-13470	0.10-2.7	5
EGR	1-20	Natural Gas (Gm^3)	1-65	0-0.013	6
ESGR	1.8-69.3	Shale Gas (Gm^3)	?-11683	?-2.34	2
EGS	3-7862	Geothermal (GJ)	5.8E+06	?	3
EUL	0.16	Uranium (kt)	780.0	?	9
EWR	2417	Saline Water (Gt)	3143	1-?	6

- EUL, potential at depth? EOR and EWR LS demo;
- ECBM stagnant, pilot test for key technical breakthrough
- EGS、ESGR with high uncertainty, basic research

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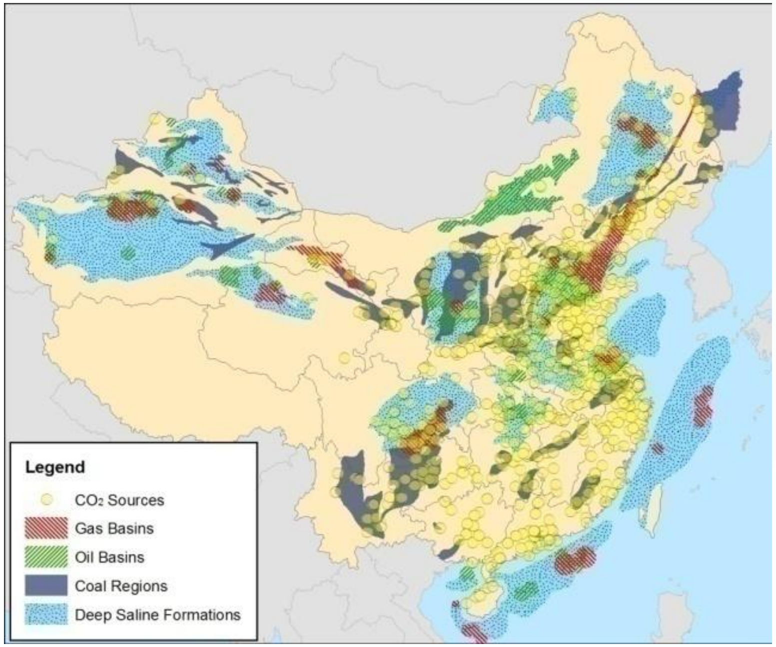
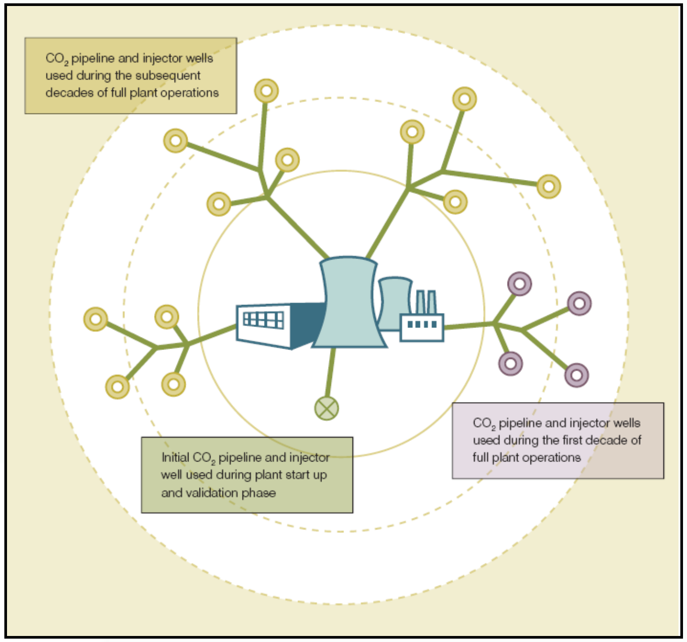
Sink-source matching and contribution

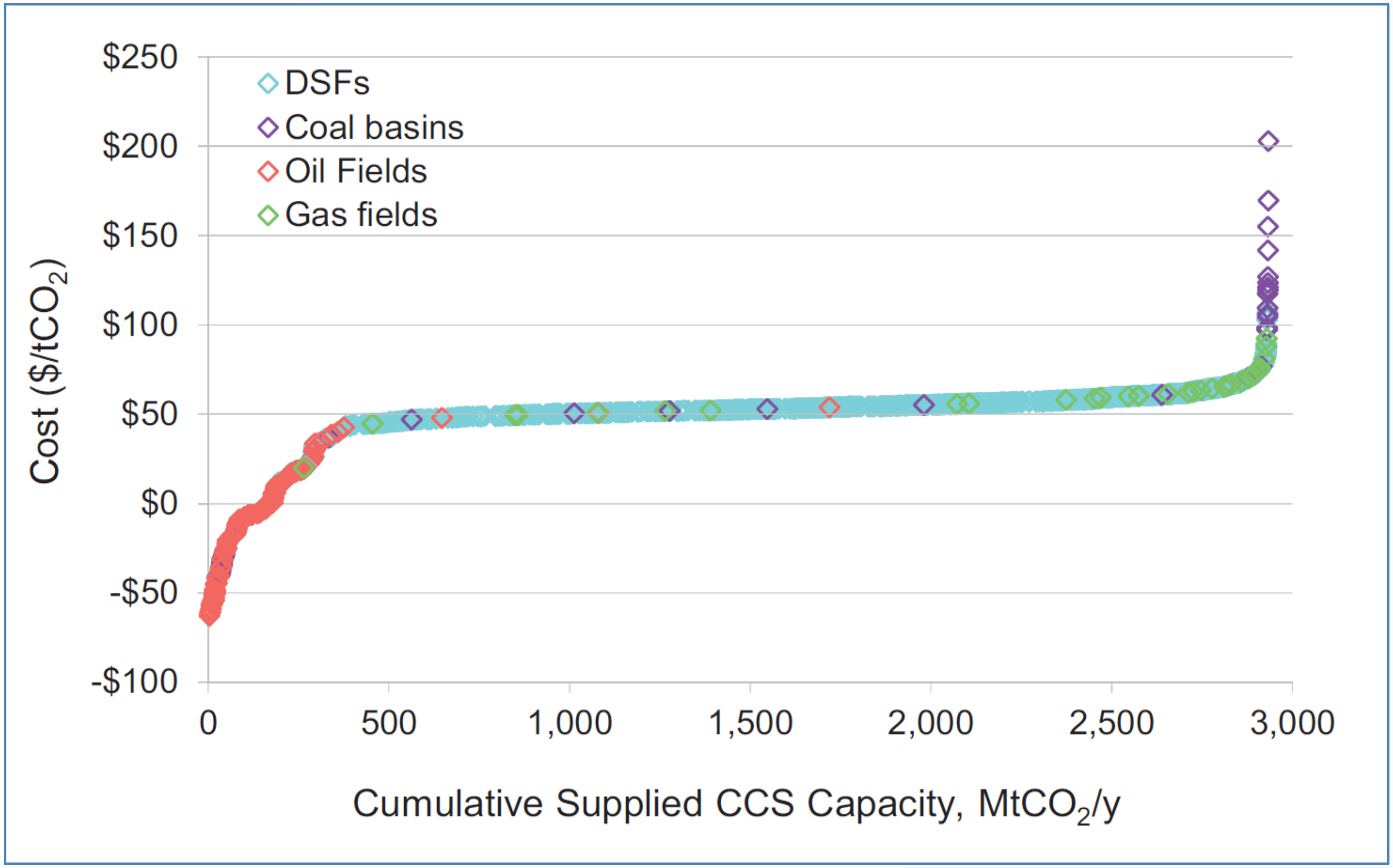
Joint work with PNNL





- Matching and cost estimations
- Cost: capture + compression + transport + storage - income

Sink-source matching and contribution



- Contribution: likely more than 1Gt/a, impossibly more than 3Gt/a
- Median cost: 50-60USD/t
- Low cost: lots of early opportunities for demonstrations

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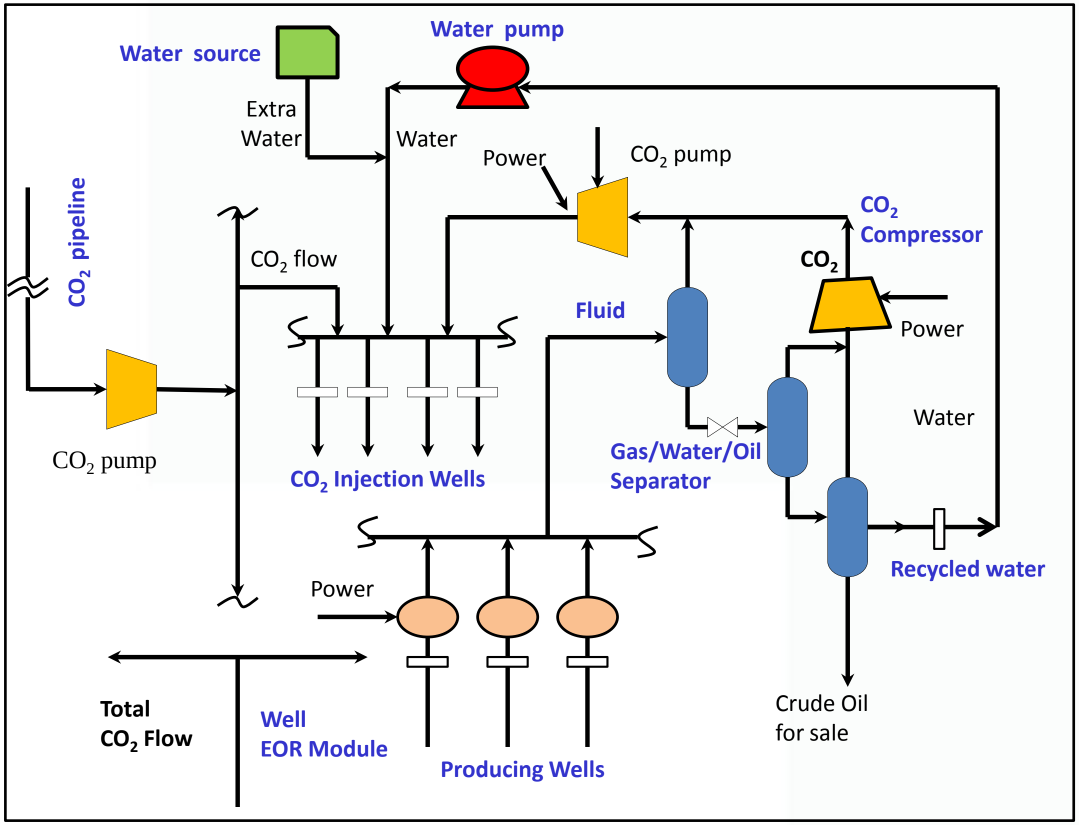
成本模型 Cost Evaluation of CO_2-EOR



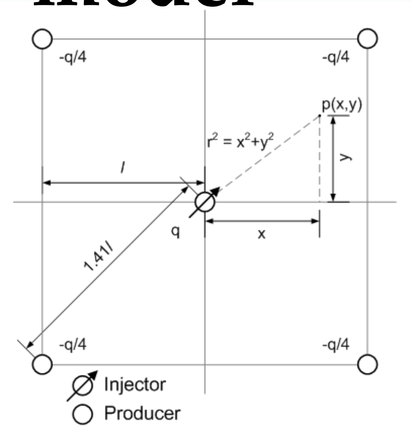
Schematic map of CO_2-EOR activities, modified from report by NETL (2011)

技术经济模型方法学

Methodology of Technical-Economic model

Performance model 技术模型

Recovery efficiency
采收率计算



$$E_r = E_m \cdot E_a \cdot E_d \cdot E_v$$

$$E_d E_v = V_{i,PV}|_{bt} + \int_{V_{i,PV}|_{bt}}^{V_{i,PV}} [1 - \frac{K - \sqrt{K / V_{i,PV}}}{(K-1)}] dV_{i,PV} = \frac{2\sqrt{KV_{i,PV}} - V_{i,PV} - 1}{(K-1)}$$

$$V_{a.PV} = \frac{V_{i,PV}}{E_d E_v}$$

$$V_{d,PV} = \frac{V_{i,PV}}{E_A} = (\frac{E_v E_d}{E_A}) V_{a,PV}$$

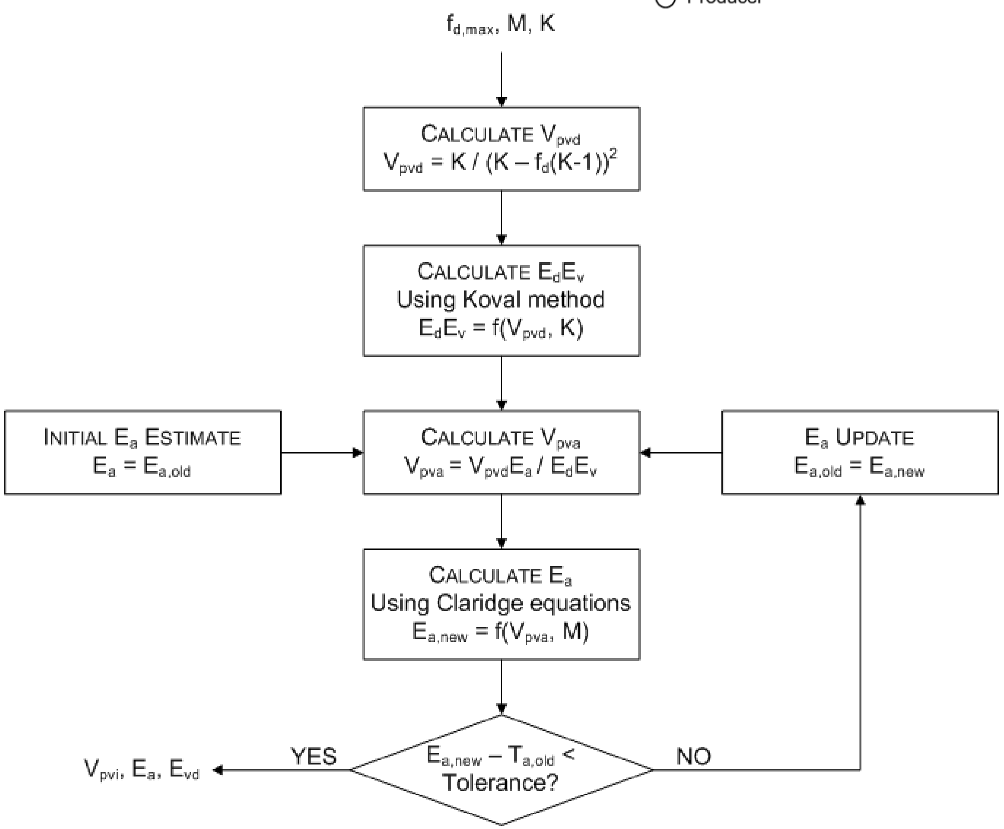
$$E_{a,bt} = \{^{V_{a,PV}, V_{a,PV} \le 1}_{1.0, V_{a,PV} > 1}$$

$$M_{bt} = \frac{1 - E_{a,bt}}{E_{a,bt} - 0.4}$$

$$E_a = \frac{E_{a,bt} + 0.4M'}{1 + M''}$$

$$M' = 25 \frac{M_{bt}^{5/6} + 0.3 + 2.3(V_{a,PV} - 1)}{V_{a,PV} + 1}$$

$$M'' = \frac{M - M_{bt}}{(M' - M_{ht})^{(0.85 - 0.55 E_{a,bt} + 0.25 V_{a,PV})}}$$



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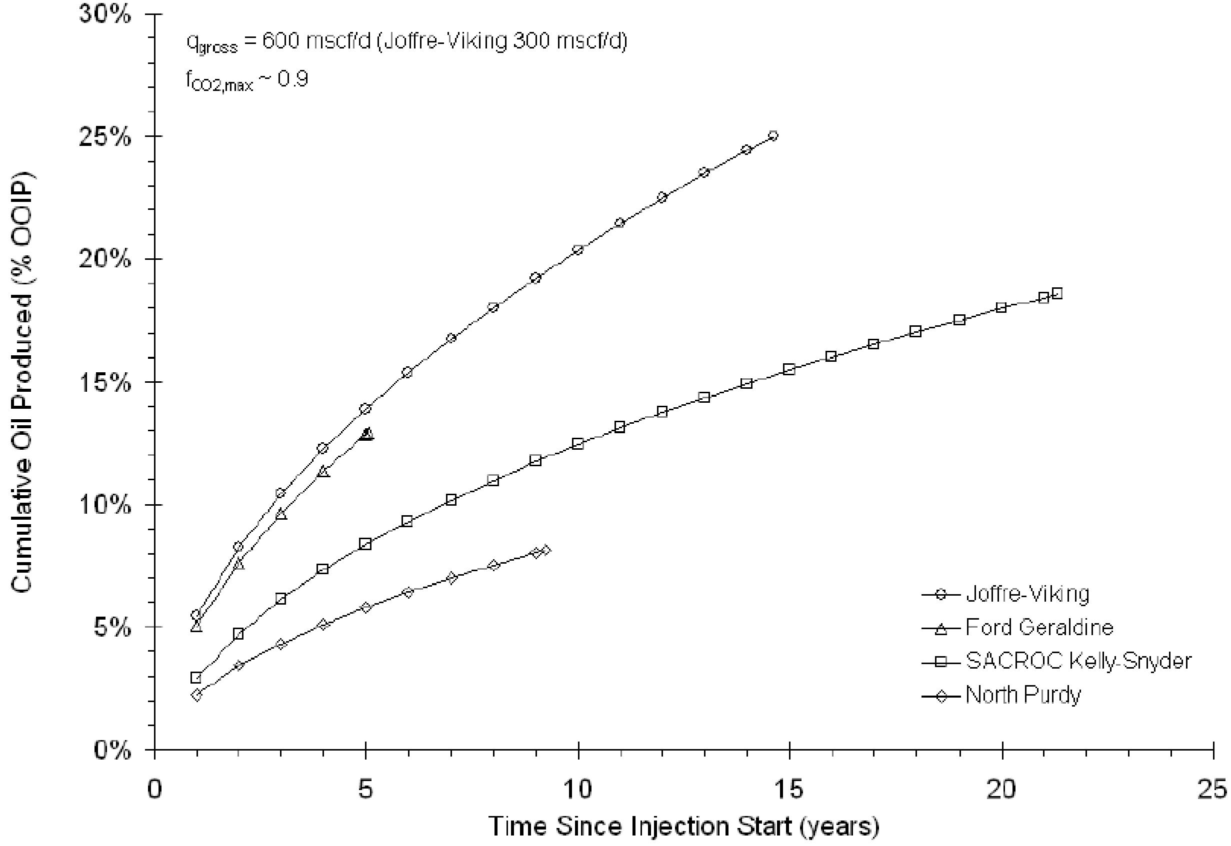
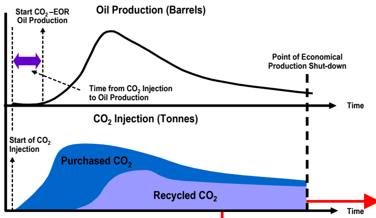
技术经济模型方法学
Methodology of Technical-Economic model

Performance model 技术模型



The production cure match production curve in field well.
生产曲线

成本模型 Cost Evaluation of CO_2-EOR



Assumed CGUS production curve
生产曲线

Incremental oil recovery and CO_2 storage capacity
增采率和封存量

Purchased, recycled CO_2 and product production by single phase
新CO_2购买、回收、生产

Oil production 产量

Recycled CO_2 cost
回收成本

Purchased CO_2 cost
购买成本

Oil field properties：
OOIP 原始石油储量
Pattern area 井场面积
Net thickness of 层厚
“payzone”
Permeability 渗透率
API gravity 重度
Viscosity粘性Porosity孔隙度
Residual oil saturation残余油饱和度
Well pattern井网
CO_2 loss ratio损失率
and so on.

Cost model of single phase (well drilling & completion, connection, and anti-erosion)
单项成本模型（钻井、完井、连接、防腐）

production recovery and CO_2 storage capacity
增采和封存

Assumed production curve of multi-phase CCUS project
生产曲线和多项评估

CAPEX资本成本

O&M cost 运行维护成本

Discount rates
Royalties& Tax rates
Incentives
折现率、税收、激励

Economic of single phase
单项经济性

The cost model mainly follow the economic model by McCoy 2008, but with different performance model. 技术模型不同

技术经济模型方法学
Methodology of Technical-Economic model

- Net Present Value (NPV) 净现值

Cash flow is the cash received less the cash spent over lifetime of CCS project. 现金流为收益减成本

$$NPV = \sum_{t=1}^{T} (C^t_{production} + Tax^t_C - Cost^t - Tax^t_{annual})/(1+r)^t$$

- The net cost or net income

$$Cost_{net} = \sum_{t=1}^{T} NPV / M_{CO2}$$

- Economic model 经济模型

1. CAPEX and OPEX
✓ 固定投入与运行维护费用
2. Revenue from production
✓ 产品收益
3. Tax policy
✓ 税收政策
4. Net present value or levelized value
✓ 净现值或平准化成本

技术经济模型方法学

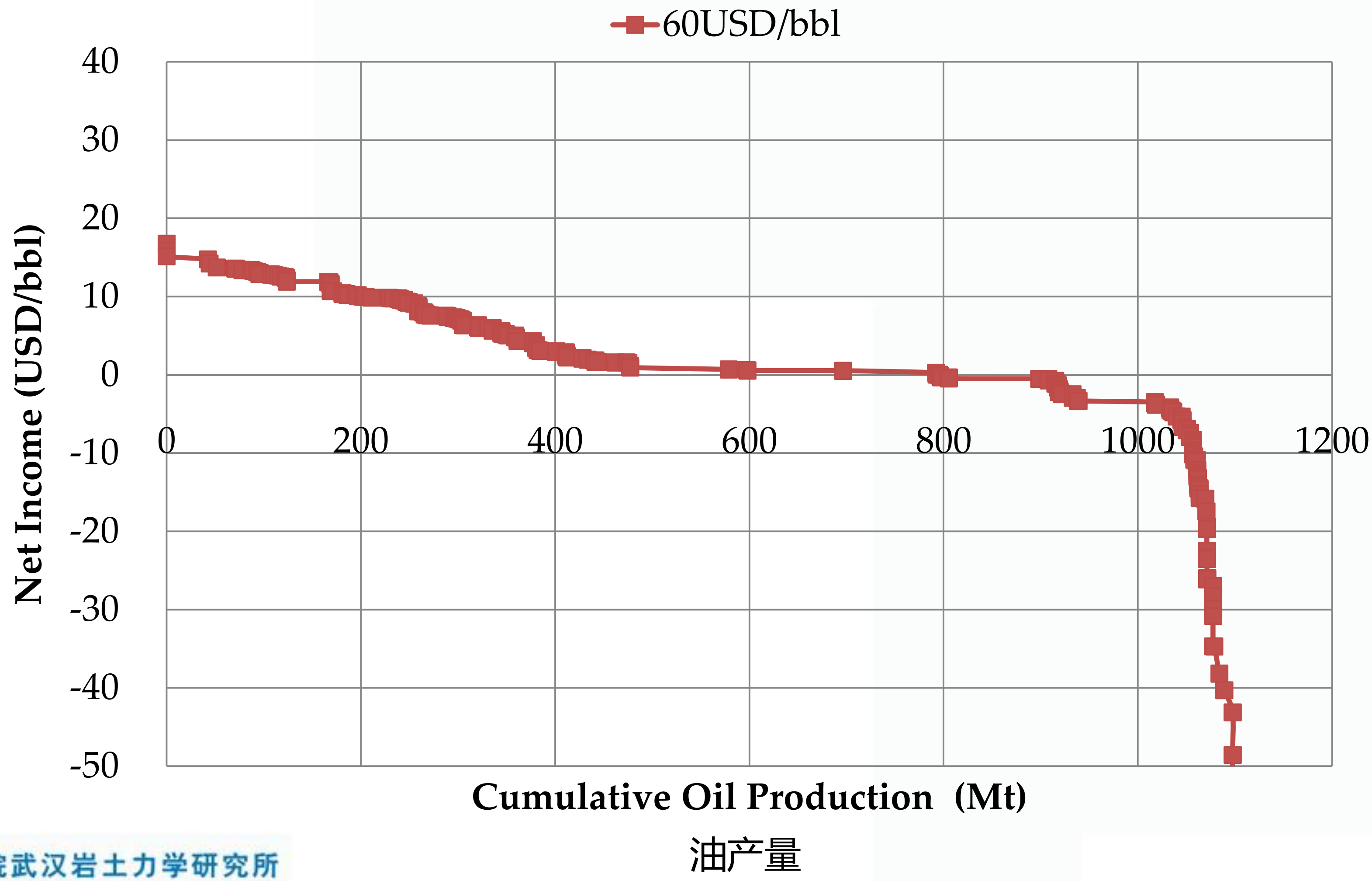
Methodology of Technical-Economic model

Tax model 税收模型

No.	Content	Oil industry	Context	U.S. case	Low case (CN)	High case (CN)	Description
(1)	Wellhead oil price		USD/bbl	100.0	100.0	100.0	Predicted by IEA report
(2)	Less: royalties	(3)+(4)+(5)	USD/bbl	17.5	21.7	21.7	
(3)	Mineral compensation tax				1.2	1.2	About 1.2% of oil price
(4)	Resource tax	(1) × 5–10%	USD/bbl		5.0	5.0	Changed to 5–10% in 2011 in China; 5% is used in cost analysis
(5)	Oil special revenue tax or windfall tax	[(1) – 55] × f – a USD/bbl	f, a		15.5	15.5	Current tax policy
			0%, 0.0		0.0		Wellhead oil price (1) less than 55 USD/bbl
			20%, 0.0		0.0		Oil price (1) ranges from 55 to 60 USD/bbl
			25%, 0.25		0.0		Oil price (1) ranges from 60 to 65 USD/bbl
			30%, 0.75		0.0		Oil price (1) ranges from 65 to 70 USD/bbl
			35%, 1.5		0.0		Oil price (1) ranges from 70 to 75 USD/bbl
			40%, 2.5		15.5	15.5	Oil price (1) greater than 75
(6)	Production tax or ad valorem tax			5.0	2.0	12.5	About 2–12.5% of total oil price in China
(7)	Total tax	(2)+(6)	USD/bbl	22.5	23.7	34.2	
(8)	CO_2 purchase costs		USD/tCO_2	17.5	17.5	17.5	
(9)	CO_2 recycling costs		USD/tCO_2	12.0	12.0	12.0	Calculated by NRDC group (Qian, 2012)
(10)	Other O&M costs		USD/bbl	8.0	8.0	8.0	Calculated by NRDC group (Qian, 2012)
(11)	Amortized CAPEX		USD/bbl	4.0	4.0	4.0	Calculated by NRDC group (Qian, 2012)
(12)	Total costs and tax	(7)+(8)+(9)+(10)	USD/bbl	64.0	65.2	75.7	
(13)	Net cash margin	(1) – (12)	USD/bbl	36.0	34.8	24.3	
(14)	Income taxes	((1) – (12)) × 25%	USD/bbl	12.6	8.7	6.1	35% of net cash margin in U.S. and 25% in China
(15)	Net income	(13) – (14)+(16)+(17)+(18)	USD/bbl	>26.9	26.1	18.2	
(16)	Additional incentives		USD/t CO_2	3.5	0.0	0.0	Additional tax credit for storage of anthropogenic CO_2 in U.S.
(17)	Severance tax reduction/extension		USD/bbl	Yes	No	No	There is no incentives for EOR in China
(18)	Other EOR tax and incentive			Yes	No	No	

成本模型 Cost Evaluation of CO_2-EOR

Cost curve of onshore CO_2-EOR in China
中国陆上油田EOR成本曲线



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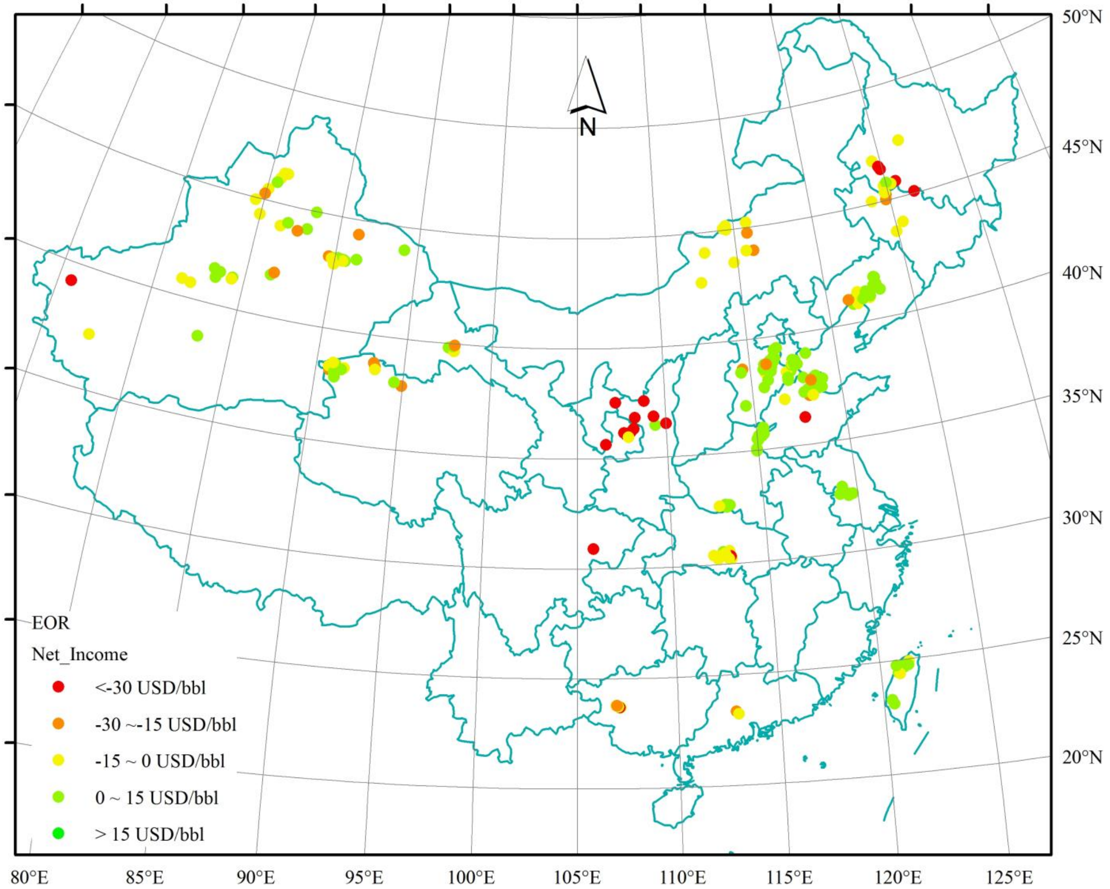
成本模型 Cost Evaluation of CO_2-EOR

Net income of onshore CO_2-EOR in China
中国陆上油田EOR净收入 评估结果



60 USD/bbl oil ； 50 USD/t CO_2

评估采用：油价 60USD/bbl 和CO_2价50USD/t

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Conclusions

- China has a great CGUS capacity, diverse options, and application prospect
- Large-scale demonstration of EOR and EWR technically feasible now, especially in Xinjiang
- Xinjiang also has a big ECBM, EGR and ESGR potential, more challenging due to insufficient research and/or timing

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Thank you !

for your patient!

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