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Measurements and Methods in CCS &EOR

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Outline

1. CCS overview

2. Integrating CO2-EOR and CO2 Storage

- CO2-EOR
- Improved methods

3.Application & Prospect

- Case
- Prospect

4. Summary &Suggestions

CCS Overview

What is CCS?

- Carbon Capture and Storage (or Sequestration) is a broad term for technologies involving three main steps:

  capturing the CO_2 from the combustion of fossil fuels at stationary sources

  transporting it to the storage site and,

  storing it underground in geological formations.

CCS Overview

- **Capture**
  - Power plants
  - NG treatment
  - Oil refineries
- **Transportation**
  - Pipelines
  - Ships
- **Sequestration**
  - Geological formations (underground)
  - Ocean

CCS Overview

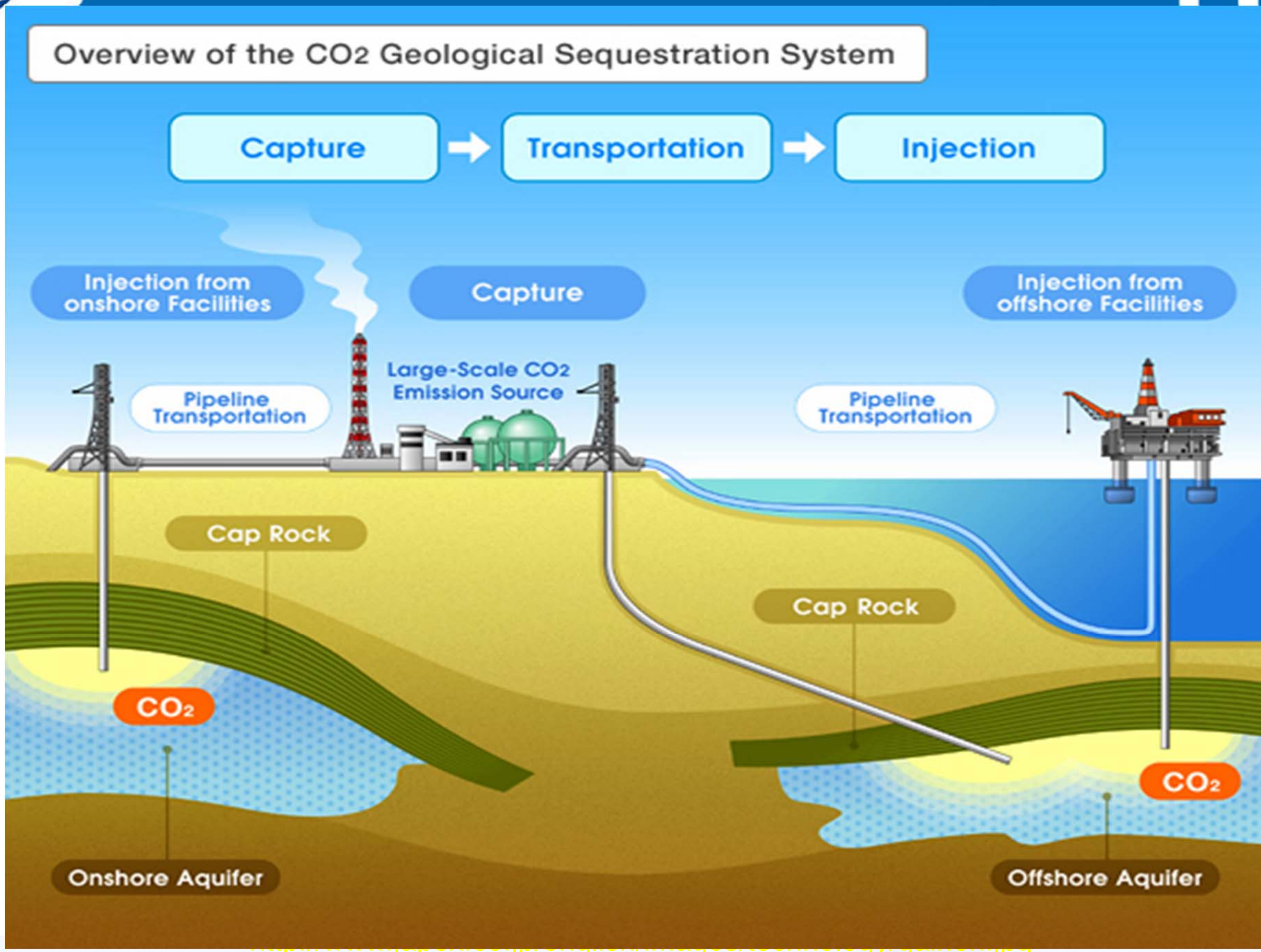
- **Systems**
  - Post-combustion
  - Pre-combustion
  - Oxy-fuel
  - Industrial processes (e.g. NG sweetening)

- **Separation technologies**
  - Solvents – aqueous amines and salts
  - Membranes – polymeric
  - Solid sorbents – Lime, zeolite, activated carbon
  - Cryogenic processes – Liquefaction/distillation

Carbon Sequestration

Comparison of CO_2 geological storage methods

Storage Methods	Advantages	Disadvantage
EOR in Oil fields	Mature technology, Extra economic return, Safe	Complex process; Gas injection volume and position limit; Safety of abandoned wells in oil field; Leak in fracture in the oil field.
EGR in Gas fields	Extra economic return； Large storage capacity. Safe.	Complex process; Lack of experience; Gas mixing and separation costs; Safety of the original wells.
EGR in Coal bed gas fields	Enhanced CH4 recovery, Near to CO2 resource (Power Plant).	Complex process; Low CO2 injection ability; Gas mixing and separation costs; Lack of experience
Storage in deep aquifer	Simple operating process； Large storage capacity.	No economic return; Long term security not confirmed; Lack of experience

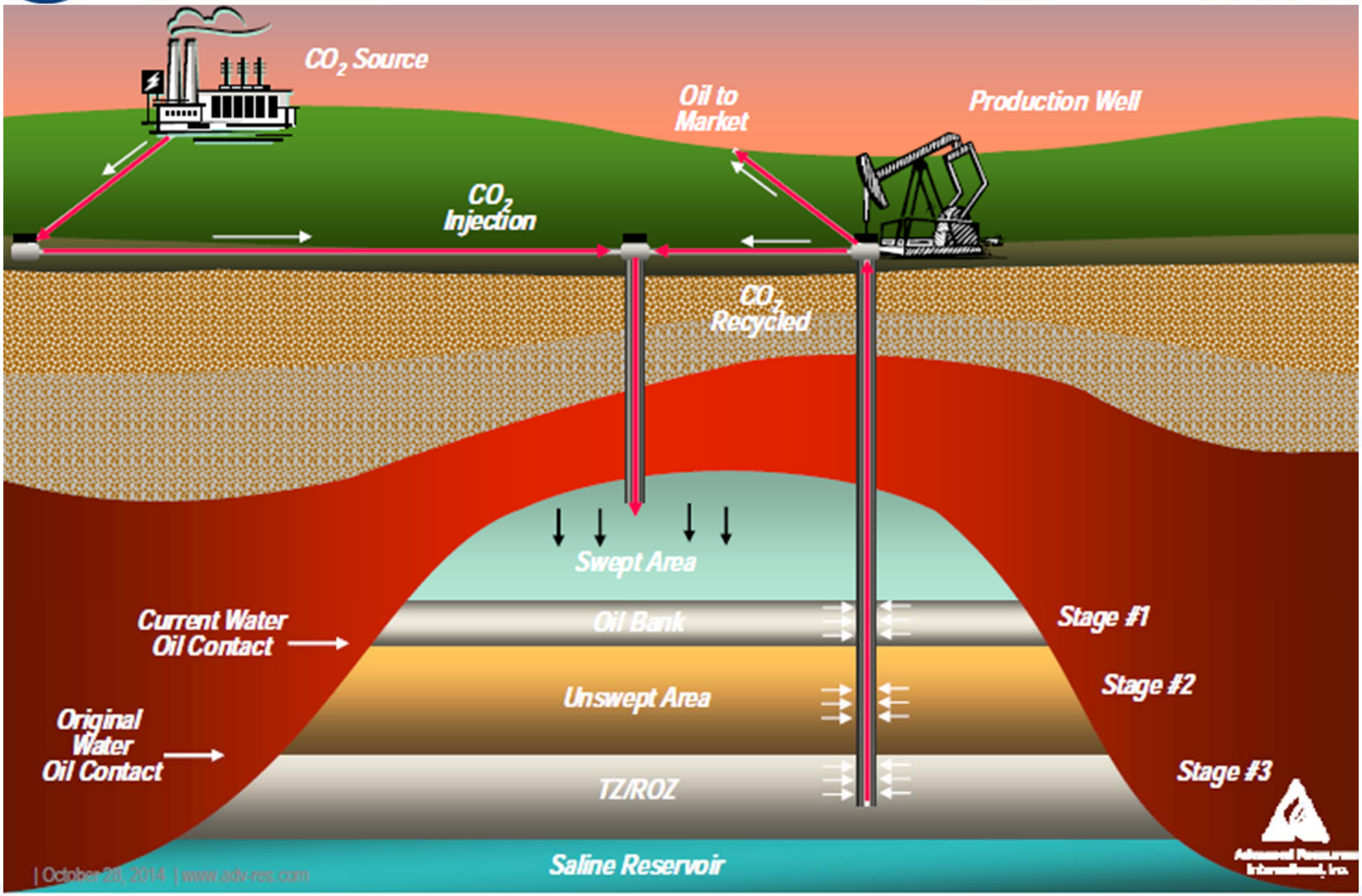


Overview of the CO2 Geological Sequestration System
Capture
Transportation
Injection
Injection from onshore Facilities
Capture
Injection from offshore Facilities
Large-Scale CO2 Emission Source
Pipeline Transportation
Pipeline Transportation
Cap Rock
Cap Rock
CO2
CO2
Onshore Aquifer
Offshore Aquifer

Carbon Sequestration

- Big Storage in oil reservoirs (depleted and EOR), natural formations, ocean storage
- Will it leak? Not likely – models suggest 99% containment
- Existing reservoir data can be used to estimate storage potential and address (water) concerns
- No groundwater contamination (salt?)

Integrating CO2-EOR and CO2 Storage Could Increase Storage Potential



Benefits Of CO_2 -EOR

CO_2 Flood

Proven EOR process

Recover additional 15%– 25% IOIP

Extend production life by over 15 – 20 years

Reduce emissions of CO_2

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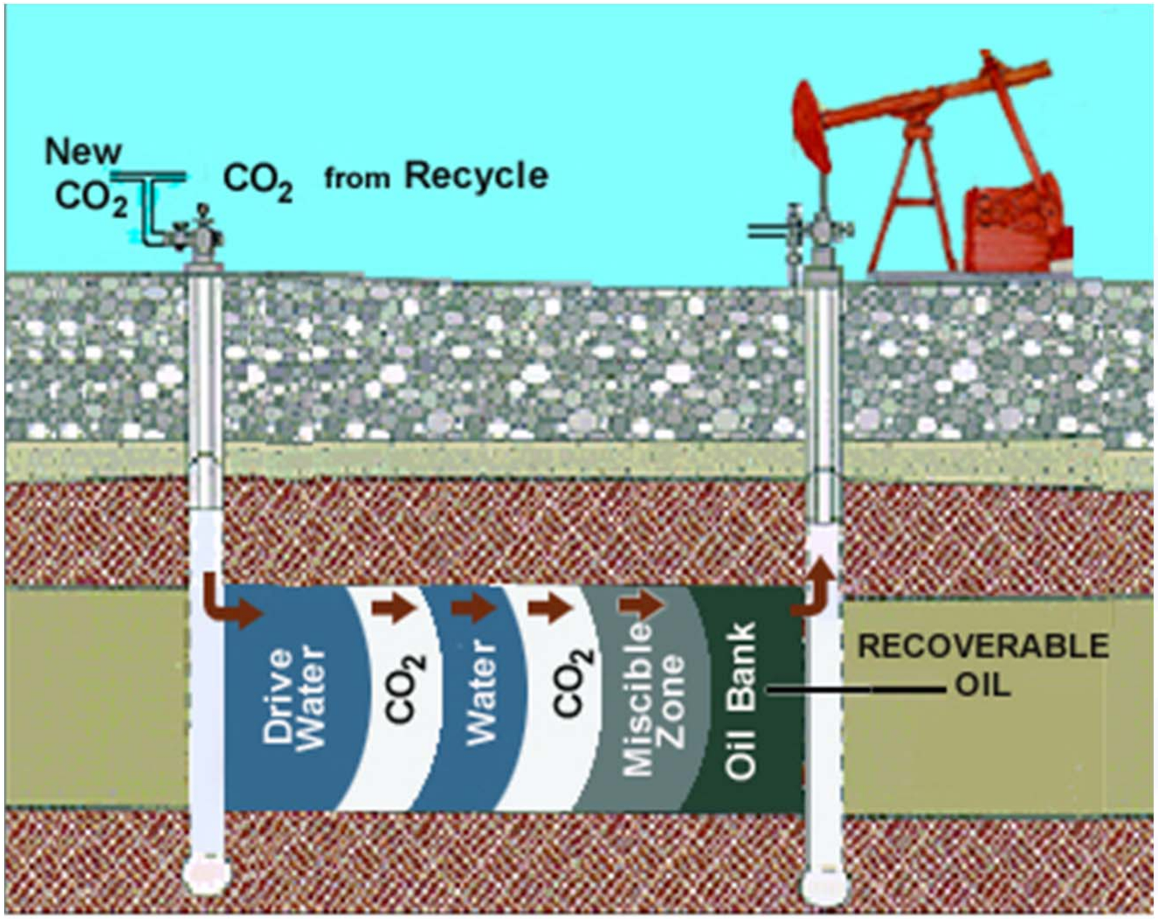
Schematic of CO2-EOR Injection



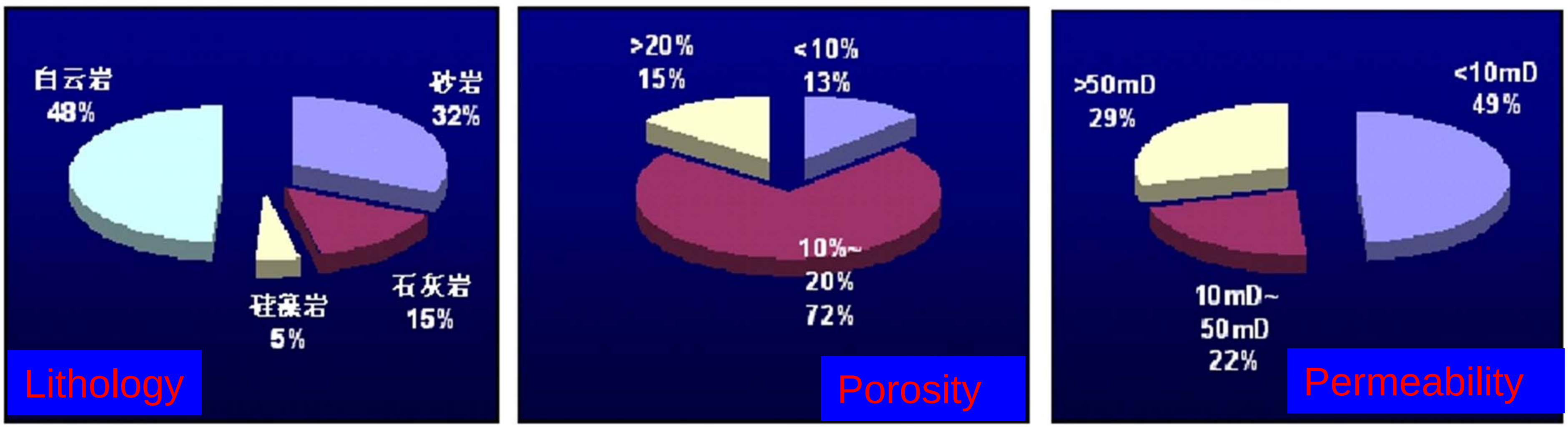
Graphic representation of CO_2 injection in reservoir for enhanced oil recovery (EOR)

Types of CO2-EOR

- Miscible CO_2 Flooding（MMP）
- Immiscible CO_2 Flooding
- Immiscible CO_2 Huff & Puff

Reservoir conditions for CO2-EOR

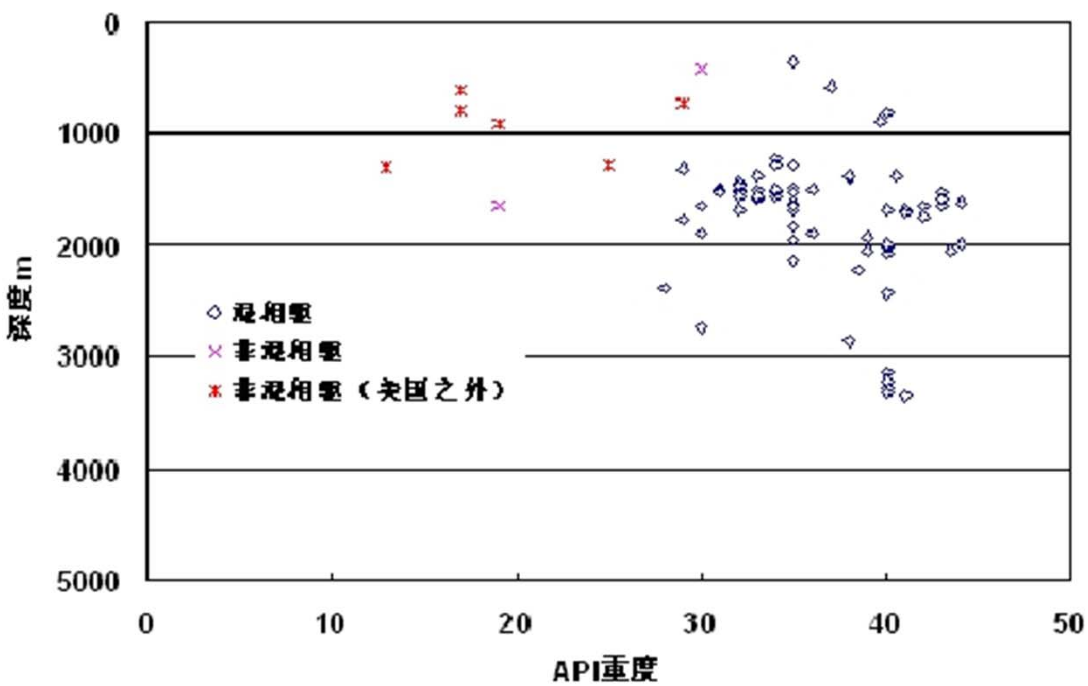
Reservoir conditions of CO_2-EOR Projects (USA)



CO_2-EOR prefer : sandstone, limestone, dolomite reservoirs with low perm. light oil , etc.

Reservoir conditions for CO2-EOR

Relationship between reservoir depth and API in CO2-EOR projects



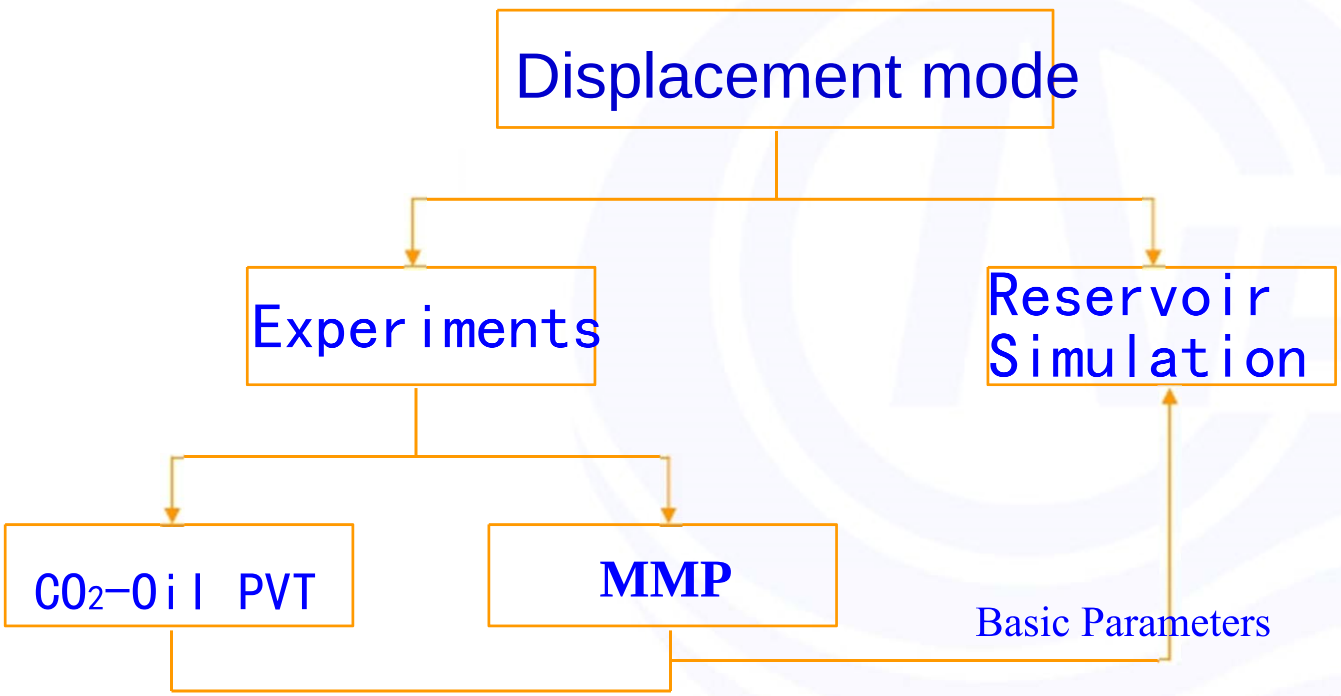
The depth of most CO_2 Projects were among 1000～3000, most CO_2 miscible Projects were used in reservoirs with oil API > 30, most immiscible projects used in shallow reservoirs (<2000m), and higher API (< 30).

Recovery Mechanisms Of CO_2 Flood

- Oil viscosity reduction
- Oil swelling
- Vaporization of oil (CO_2 extraction)
- Interfacial tension reduction
- Miscibility effects

What Should CO_2 EOR be Focus on?

Feasibility research of CO2-EOR Projects

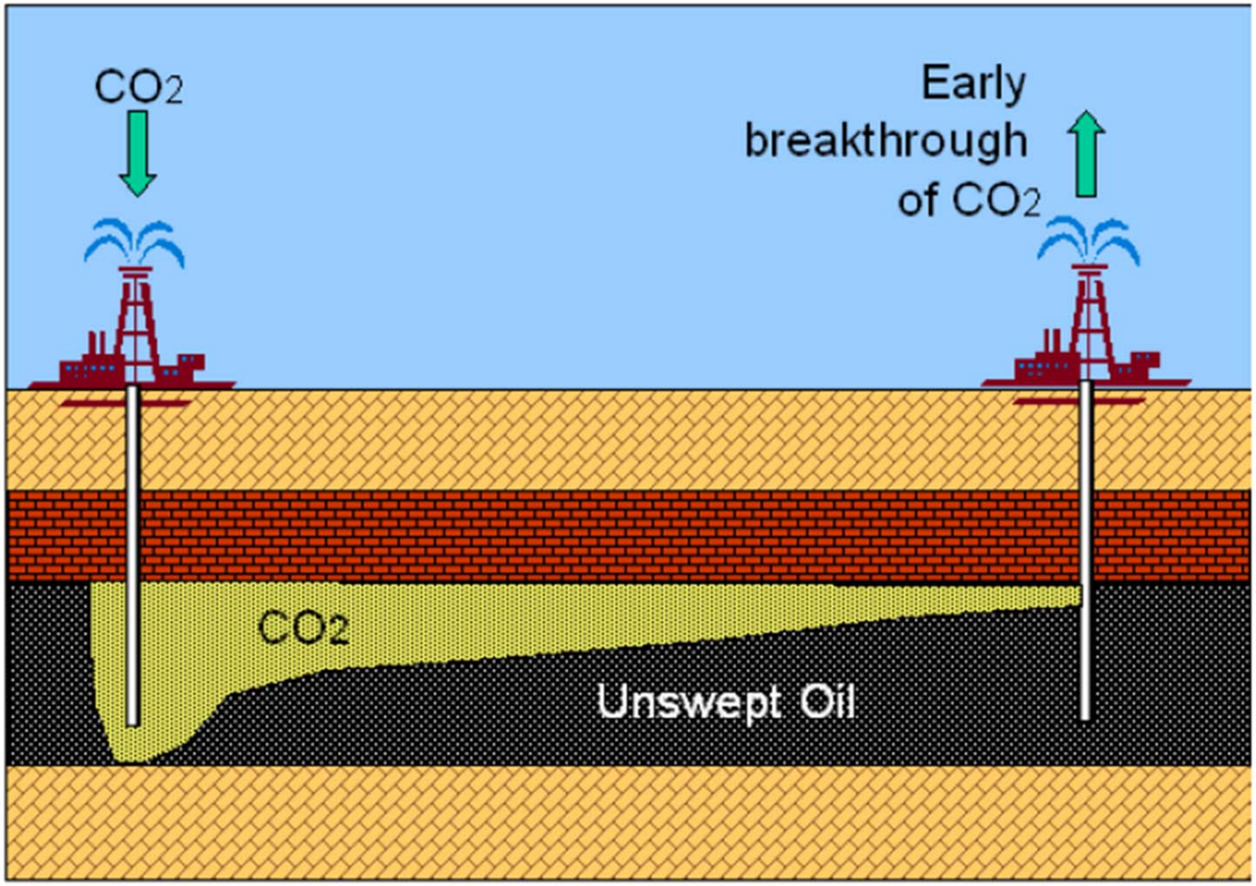


What Should CO_2 EOR be Focus on?

- Minimum miscibility pressure (MMP)
- Impurity in CO_2
- CO_2 injection strategy
- Wettability change and acidic effect
- Water blocking of oil
- Viscous instabilities, gravity segregation
- Heterogeneity

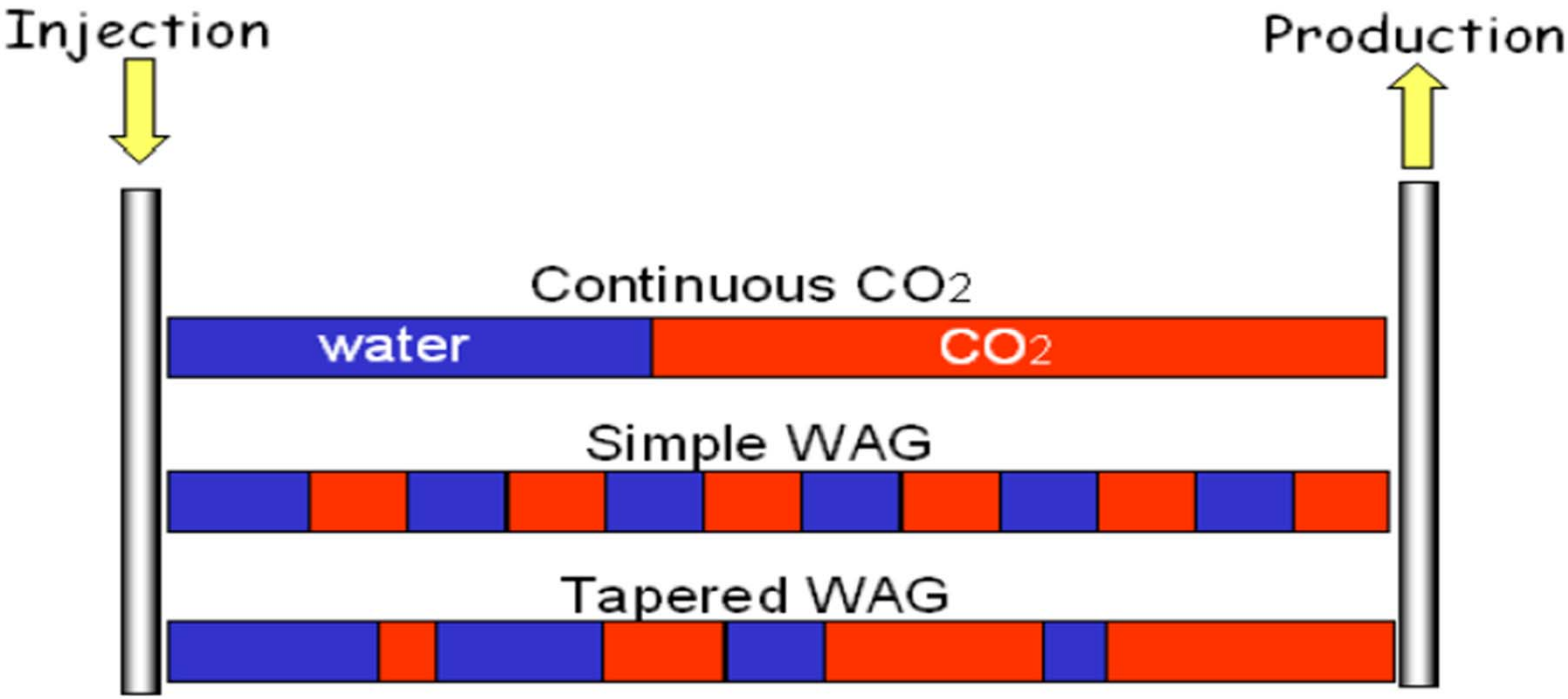
Improve the CO2-EOR injection pattern

CO_2 flooding front early breakthrough



Improve the CO2-EOR injection pattern

water & gas injection alternately



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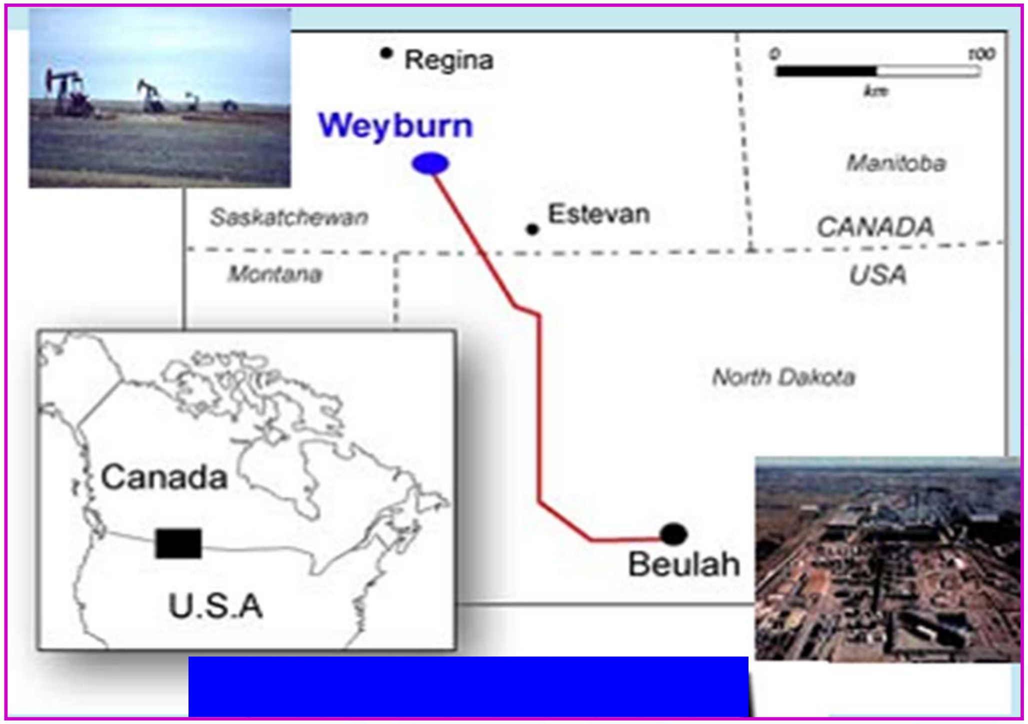
Application & Prospect

Survey of CO_2 EOR technologies application

- Most CO_2－EOR Projects are in North America；
- CO_2Projects in USA are mainly Miscible；
- Most projects（61，74% of total）are carried out after water flooding；
- Recovery increased by about8~15%。
- Field application analysis：

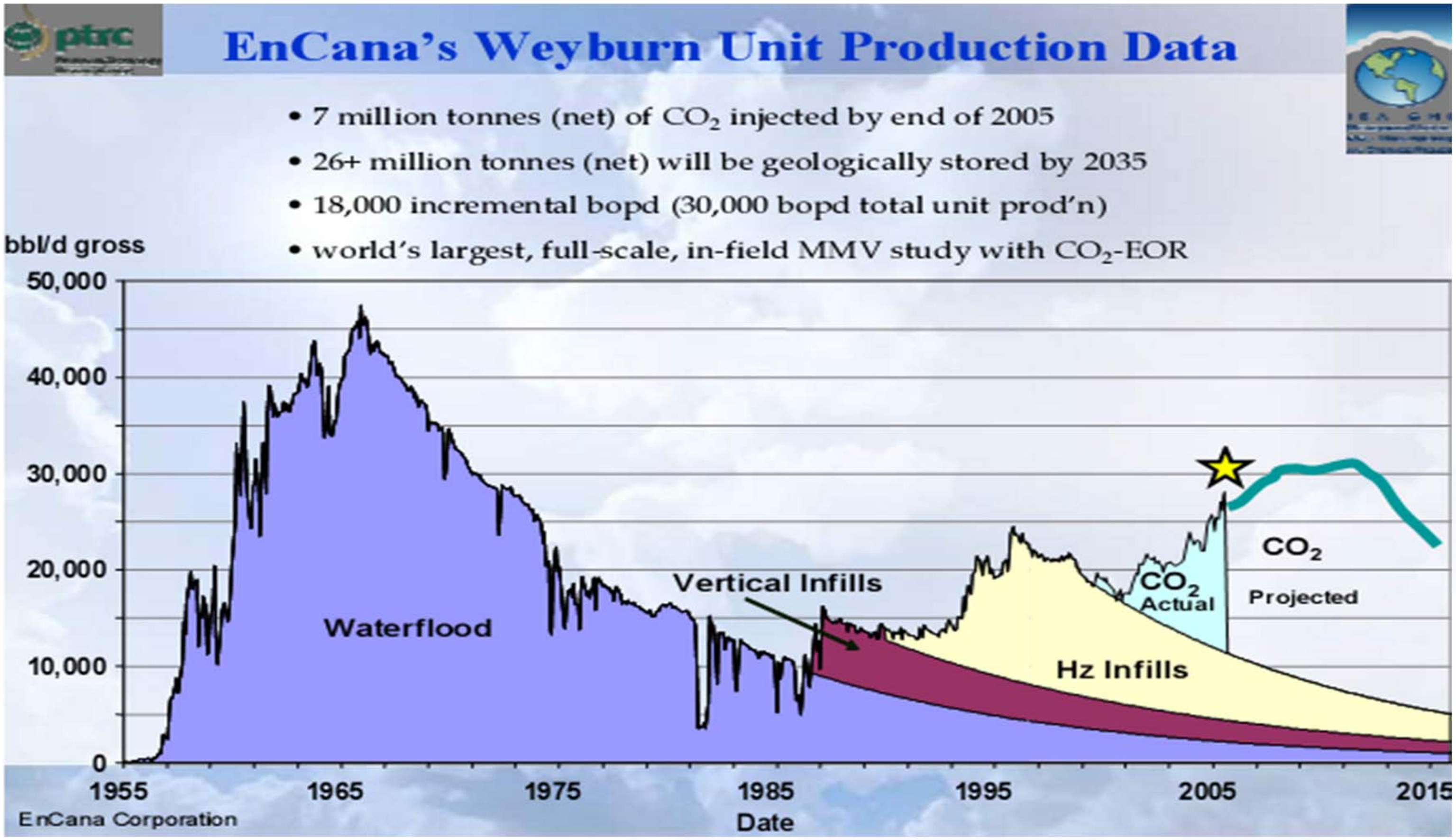
	Successful	Hopeful	Too early	Failed	Total
Number	56	16	5	5	82
Percent	68%	20%	6%	6%	100%

Case1:



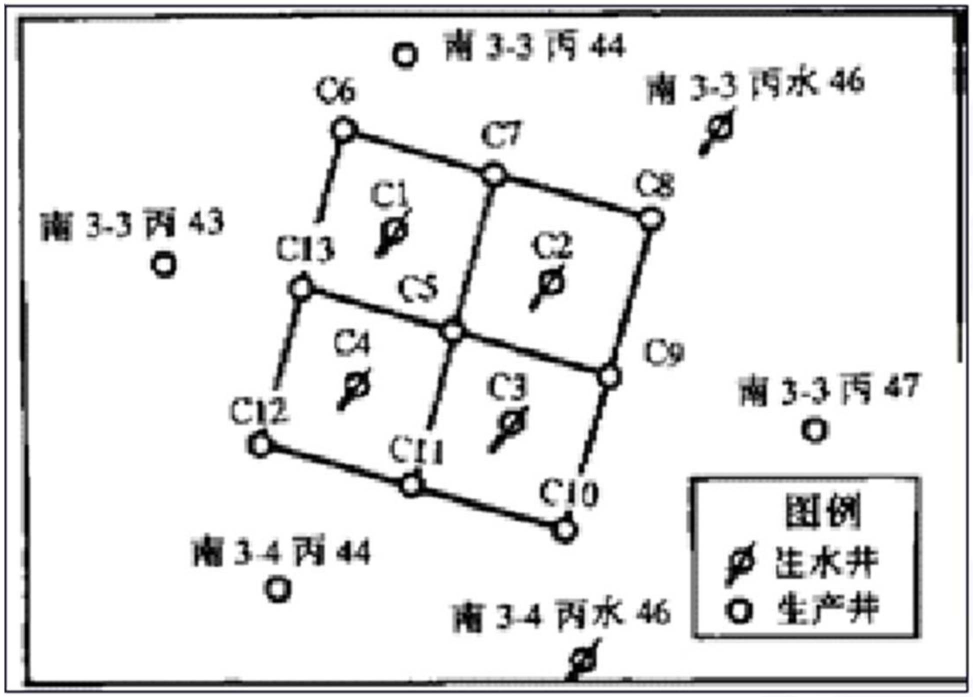
—CO2 from the United States by pipeline of 325 km to the oil field, over 5000 tons of CO2 daily (95% of CO2, the input pressure 18 Mpa)
—All produced CO2 i reinjection, accounting for 33% of the daily dosage

Case1:



After injection CO_2 25years， EOR13-19%

Case2:



CO2-EOR Pilot in Daqing Oilfield

Time: **From 1990 to1995, two pilots of immiscible CO2 in different layers.**

Developing Mode: Early-stage water floodi
Water alternative CO2 injection.
CO_2 injected volume 0.2PV.

CO_2 source : By-Product of Daqing oil refinery
purity 96%.

Performance:
Recovery increased by 6%,

Case3:

Research of CNOOC

Reservoir viscosity：0.681-0.817mPa·s

Ground Density：0.83～0.85g/cm3

GOR：20～50m3/m3

Reservoir T：108～110℃

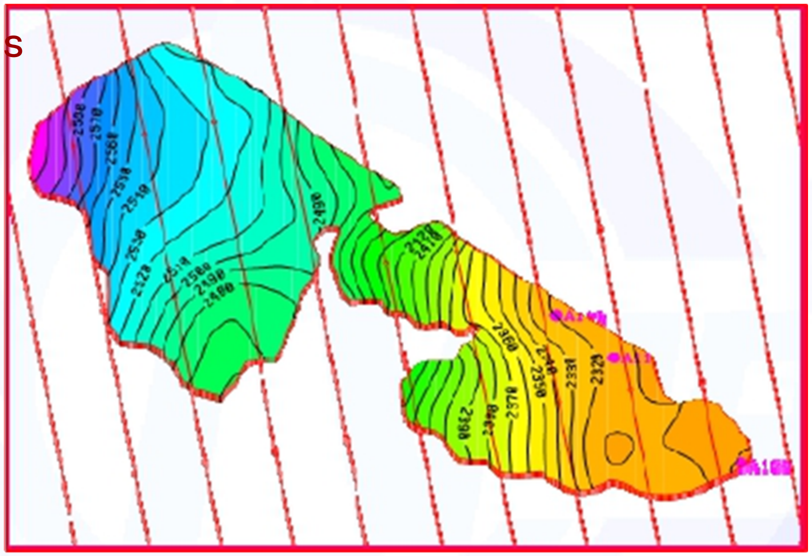
Reservoir pressure：21～23MPa

Saturation pressure <15.96MPa

Recovery 13.2％

CO_2 MMP：about 20-22MPa

Present reservoir pressure10.45MPa



A17b well **W**3Ⅲ Zone**C1** Sand： Area**0.8 Km**2， Reserves**44.9**×**10**^{4}**m**^{3}.

Research of CNOOC

Estimation of CO_2 before breakthrough :

$$M_{CO_2} = \rho_{CO_2res} \bullet RF_{BT} \bullet OOIP / S_h$$

Shaw, 2002

Reservoir Density of CO_2

Recovery before break through

OIIP

Oil Compression ratio

- The CO_2 storage is about **23.3 × 104t** in target field (**OOIP 44.89 ×10^4t**).
- According to above calculation result, the WZ12-1 field (with OOIP 2425 **×10^4t** and 7.4 Km^2) has CO2 storage capacity of 1258.7 **×10^4t.**

Announced Projects

- There are many CCS projects being announced worldwide. This database also contains dormant projects; those which have had no news on for multiple years but which have not been publicly cancelled.

Announced Projects

Project Name	Location	Leader	Size	Further information
CarbonNet	Australia	Victorian Government	Network	CarbonNet Website
South West Hub	Australia	Western Australian Dep. Mines and Petroleum	2.5 Mt/yr	CO_2 capture from various industrial sources, including fertilizer and power generation for onsshore EOR.
Lula	Brazil	Petrobras	0.7 Mt/Yr	Capture and Sequestration EOR in offshore Lula oil field
Shand	Canada	SaskPower & Hitachi	Unknown	SaskPower & Hitachi to build CCS test facility
Shanxi	China	Shanxi Energy Group	350 MW	New build Super critical Power plant with 2-3 Mt/yr
Qilu Petrochemical CCS	China	Sinopec	0.5 Mt/yr	The FEED study has been completed and is awaiting approval by Sinopec. Anticipated start date is 2016. CO_2 is to be used for EOR.
YiHe Coal plant	China	China Energy & Seamwell	1000 MW	$1.5 billion clean coal plant to be built in Inner Mongolia (June 2011)
Ledvice	Czech Republic	CEZ	660 MW	Retrofit post combustion plant. Financingproposed
Hodonin	Czech Republic	CEZ	660 MW	Considering 2 sites for pilot plants
Hassyan Clean Coal	Dubai	DEWA	1200 MW	Dubai Electricity and Water Authority (DEWA) has competition to select developer for 49% of its new clean coal power plant. Commissioned by 2020
Nord	France	Total	N/A	The French Environment and Energy Management Agency (ADEME) selects the project for E54M
Saline Joinche	Italy	SEI	2*660 MW	EU announced CCS project [PDF]
Eemshaven RWE	Netherlands	RWE	0.19 Mt/yr	RWE project webpage
Husnes	Norway	Sargas	2.6 Mt/yr	Project webpage
Turceni	Romania	Turceni	1.5 Mt/yr	GCCSI awards Romania project $2.55 ((October 2010) Project is on hold as more funding is secured for FEED and storage appraisal
Caledonia Clean Energy Project	UK	Summit Power	N/A	Summit Power, National Grid and Petrofac Team Up on DECC Carbon-Capture Programme in UK (March 2010)
CO2 solutions and EERC	USA	CO2 Solutions and EERC	N/A	CO2 Solutions Announces Testing Program with Energy & Environmental Research Center (EERC) (September 2014)
Medicine Bow	USA	Sinopec	2.5 Mt/yr	Medicine Bowl Project presentation (2011) Coal to liquids facility with CO_2 for EOR. Start 2018
Quintana	USA	Great Northern Power Development	2.1 Mt/yr	Quintana South Heart Project 2.1 MT/Yr, IGCC pre-combustion capture. New Build. Start in 2018

While CCS Needs the U to make CCUS Viable, CO2-EOR Also Needs the CO2 from CCUS

- While CCS needs the U to make CCUS, CO2-EOR also needs the CO2 from CCUS
- Growth in production from CO2-EOR is now limited by the availability of reliable, affordable CO2.
- If increased volumes of CO2 do not result from CCUS, then these benefits from CO2-EOR will not be realized.
- The Global CCS Institute reports 60 large-scale integrated projects (LSIPs) at various stages of the asset life cycle
- Of the projects in operation, under construction, or nearing final investment decisions, 74% (20 of 27) are using or intend to use captured CO2 for CO2-EOR.

Oil Recovery and CO2 Storage Potential in World's Oil Basins*

Region	Technical CO_2-EOR Oil Recovery (Billion Barrels)	Associated CO_2 Demand/Storage Capacity (Billion Metric Tons)
1. Asia Pacific	47	13
2. C. & S. America	93	27
3. Europe	41	12
4. FSU	232	66
5. M. East/N. Africa	595	170
6. NA/Other	38	11
7. NA/U.S.	177	51
8. S. Africa/Antarctica	74	21
TOTAL	1,297	370

* Includes potential from discovered and undiscovered fields, but not future growth of discovered fields.
Source: IEA GHG Programme/Advanced Resources International (2009)

“Next Generation” CO_2-EOR Technologies

1. Advanced reservoir characterization (to map residual oil and reservoir heterogeneity)
2. Combination horizontal/vertical wells plus “smart” well technology (to better contact bypassed oil)
3. CO_2 mobility and flow path control agents (to improve reservoir conformance)
4. Increased volumes of efficiently targeted CO_2 (to improve oil recovery efficiency)
5. Near-miscible CO_2-EOR technology (to expand CO_2-EOR to additional oil reservoirs)
6. Advanced reservoir surveillance and diagnostics technology (to “see and steer” the CO_2 flood)

Life Cycle Analyses of the Integration of “Next Generation” CO2 Storage with EOR

	"Next Generation"	"Second Generation" CO_2-EOR & Incremental Storage		
	CO_2-EOR	CO_2-EOR	Inc. Storage	Total
CO_2 Storage (million metric tons)	32	76	33	109
Storage Capacity Utilization	22%	53%	23%	76%
Oil Recovery (million barrels)	92	180	-	180
% Carbon Neutral*	74%	90%	-	129%

Potential Barriers to Lower Cost, Publicly Acceptable CO_2 Supplies for CO_2-EOR

- Limitations of today's CO2-EOR technology
- Increased operator knowledge, comfort with, and willingness to pursue CO2-EOR
  - Reducing the uncertainty of CO2-EOR economics
- Achieving both requires research on and demonstration of "next generation" CO2-EOR technologies
  - As well as possible financial incentives to promote CO2 supplies for CO2-EOR
- Willingness/ability of regulators to permit/ encourage CO2-EOR and associated CO2 storage

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Summary &Suggestions

1. CO_2-EOR Offers Large CO_2 Storage Capacity Potential. CO_2-EOR in oil fields can accommodate a major portion of the CO_2 captured from industrial facilities.
2. CO_2-EOR Needs CCUS. Large-scale implementation of CO_2-EOR is dependent on CO_2 supplies from industrial sources.
3. CCS Benefits from CO_2-EOR. The revenues (or cost reduction) from sale of CO_2 to EOR helps CCS economics, overcomes some barriers, while producing oil with a lower CO_2 emissions .
4. . Both CCS and CO_2-EOR Still Need Supportive Policies and Actions. Focused R&D investment, supportive policies.

Thanks!