CO2-EOR: Searching for an optimum

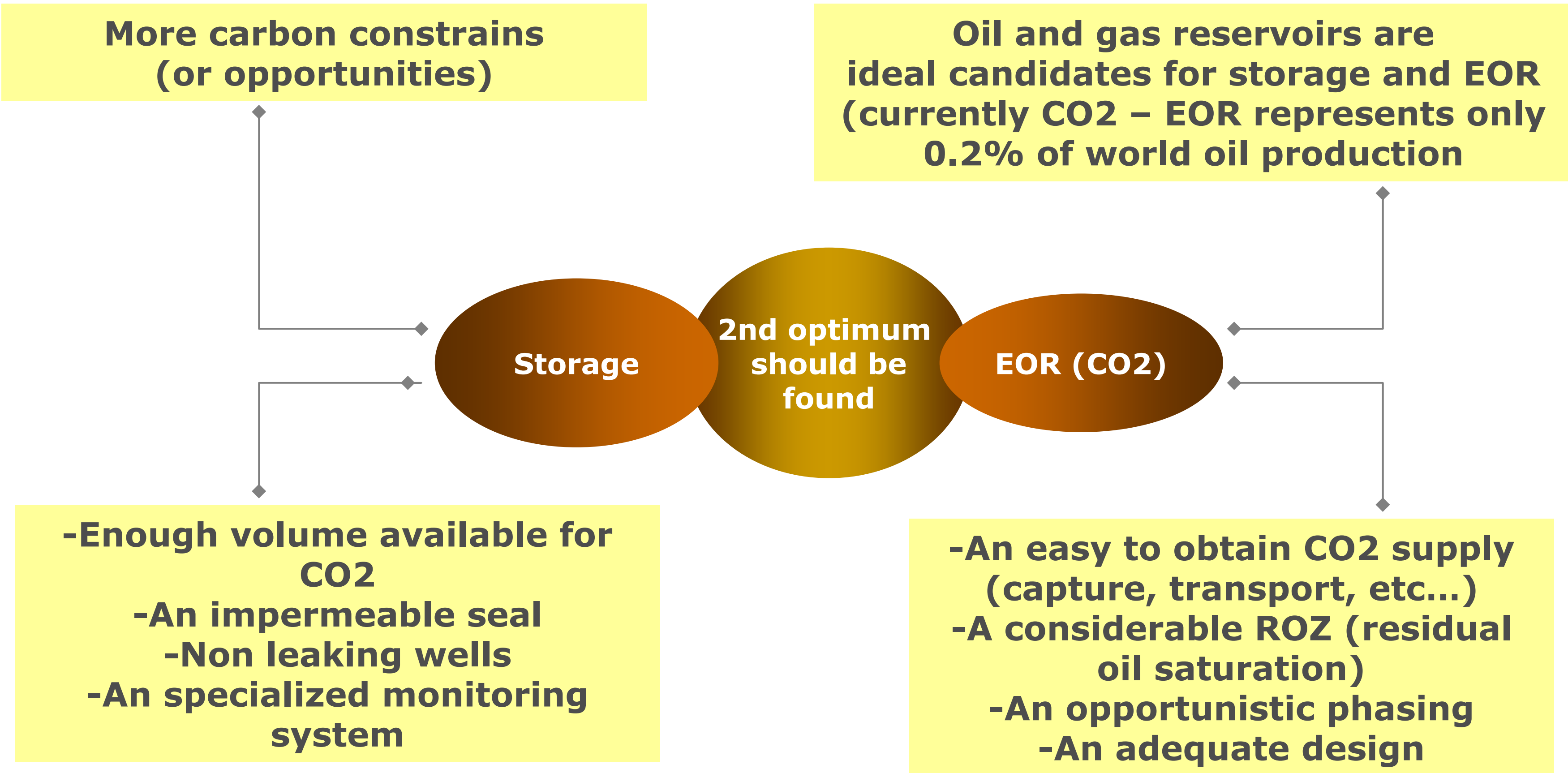
Bossie-Codreanu, IFP – March 2009

Outline

- Introduction
- CO2-EOR in the World
- Mechanisms
- Reservoir Issues
- Storage Issues
- Co-optimization (optimum search)
- Conclusion

Introduction

Introduction



CO2-EOR in the world - 1

- **Geography**

CO2-EOR in the world - 2

- **A few examples (geology criteria)**

		LATERAL HETEROGENEITY		
		LOW	MODERATE	HIGH
VERTICAL HETEROGENEITY	LOW	Wave-dominated delta Barrier core Barrier shore face Sand-rich strand plain (7) / [2]	Delta-front mouth bars Proximal delta front (accretionary) Tidal Deposits Mud-rich strand plain (2)	Meander belts* Fluvially dominated delta* Back Barrier* (2)
	MODERATE	Eolian Wave-modified delta (distal) (1) / [1]	Shelf barriers Alluvial Fans Fan Delta Lacustrine delta Distal delta front (3) / [1]	Braided stream Tide-dominated delta (3) / [2]
	HIGH	Basin-flooring turbidites [1]	Coarse-grained meander belt Braid delta	Back barrier** Fluvially dominated delta** Fine-grained meander belt** Submarine fans** (6)

* Single units **Stacked Systems

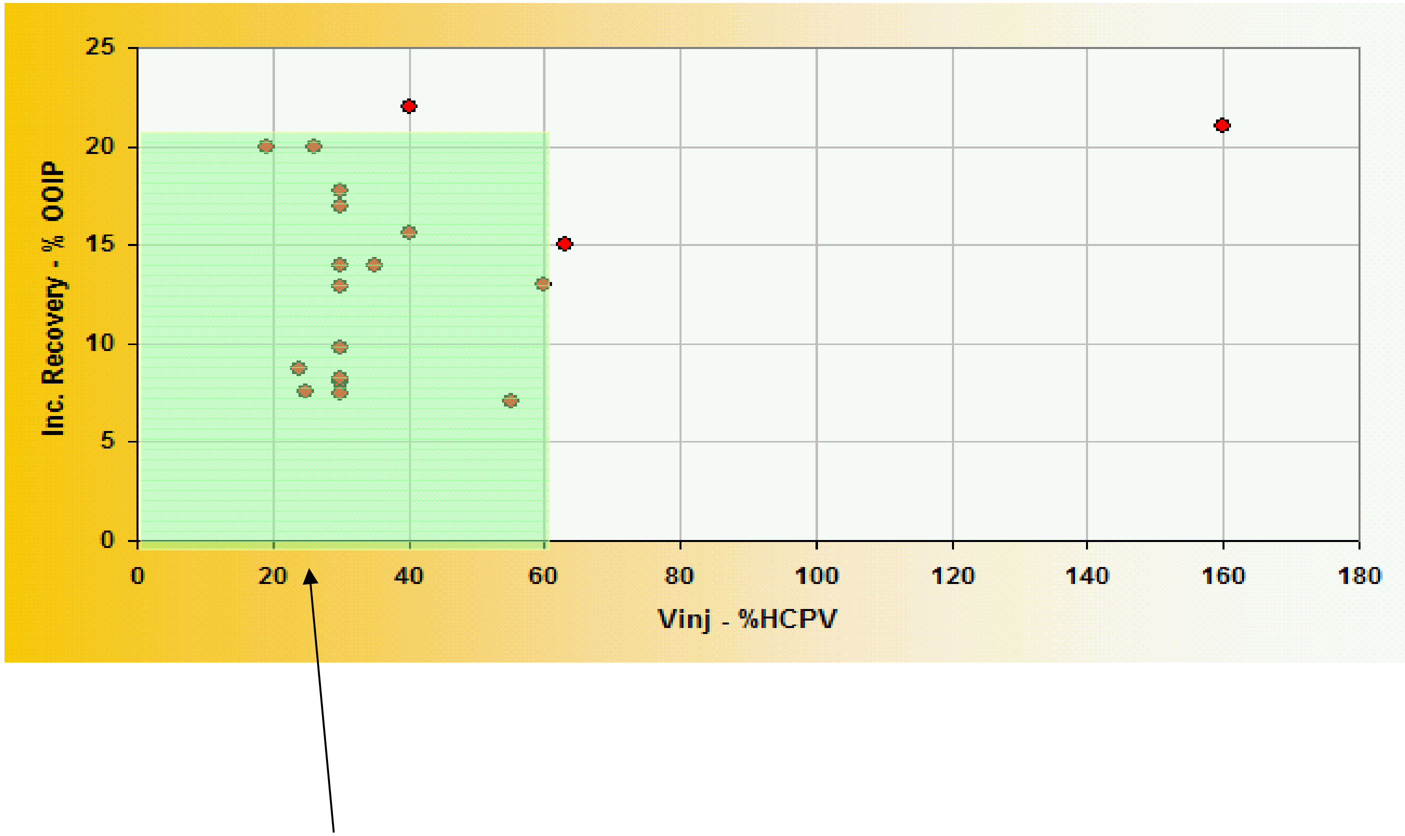
Tyler and Finley clastic heterogeneity matrix showing depositional systems of 24 successful (Blue) and 7 failed [Red] CO_2 injection projects

The ROZ will be different

The EOR strategies will be different

CO2-EOR in the world - 3

- **A few examples (performance)**



Inc.Recovery max = 20%
%HCPV = 60%

From SPE 18977

Mechanisms - 1

- **The CO2 - EOR - "Rubik Cube Dismantled"**

Mass Transfer
-CO2 >> Oil (condensation, swelling, $\mu_{o\ down}$,$\rho_{o\ up}$, IFT $_{down}$)
-Oil >> CO2 (vaporization, extraction, $\mu_{g\ up}$, IFT $_{down}$)
-CO2 >> Water ($\mu_{w\ down}$, transfer to blocked water)
-Methane (MMP $_{up}$)
-Multiple Contact Miscible (MCM)
-asphaltene drop

Areal sweep
-viscous fingering
-pattern confinement
-mobility control

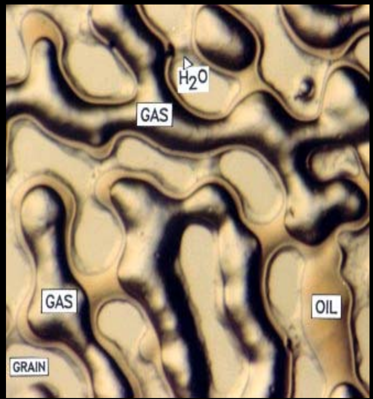
Vertical Conformance
-gravity override
-stratification
-dip stabilization

Trapping
-Kr hysteresis
-blocked pore space

Dispersion
-competition with MCM
-finger attenuation
-recovery from unswept pores

Mechanisms – 2

Pressure Increase



P = 69 bars

Solubility in oil

Oil swells

Immiscible

Non-Miscible

P = 103.44 bars

Mixing starts

Near miscible

IFT lowered

Favors RF

Near-Miscible

P = 172.4 bars

Full Miscibility

Extraction of light ends

Differentiation <u>light/heavy</u> ends

Full-Miscible

Condensation of heavy ends

If wettability favorable, condensation near walls

Discontinuous heavy end phase

Condensation

Continuous Heavy end

Film formation

Intermediate-heavy end differentiation

Wettability reversal

Non-Miscible

From MK technologies – adapted by DBC

Reservoir Issues - 1

- **Example 1 - The MMP**

Miscibility zone

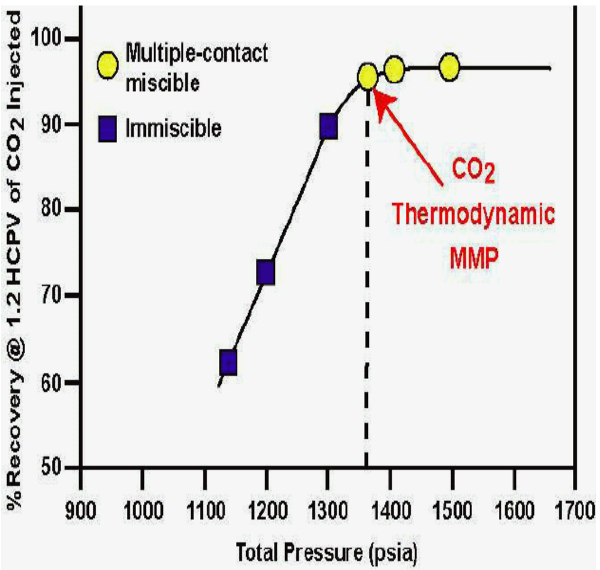
Supercritical CO_2	CO_2 volatizing light oil components	CO_2 condensing into oil	Original oil

Depends on the composition of oil

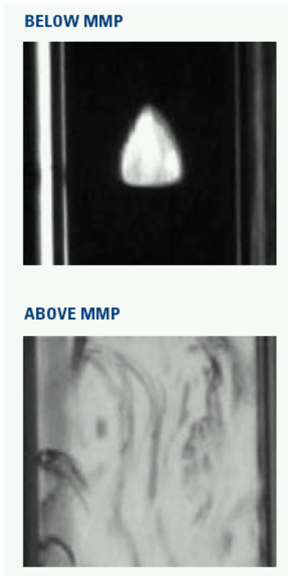
We can use correlations (ex. Cronquist)

$$MMP\ (psia) = 15.988\ T^{(0.744206 + (0.0011038 * MWC5+) + (0.0015279 * M\%C1))}$$

T = Temperature – F
MWC5+ = Molecular Weight of C5+ fraction
M%C1 = Mole Fraction C1 and N2 in the CO2 stream



Slim Tube



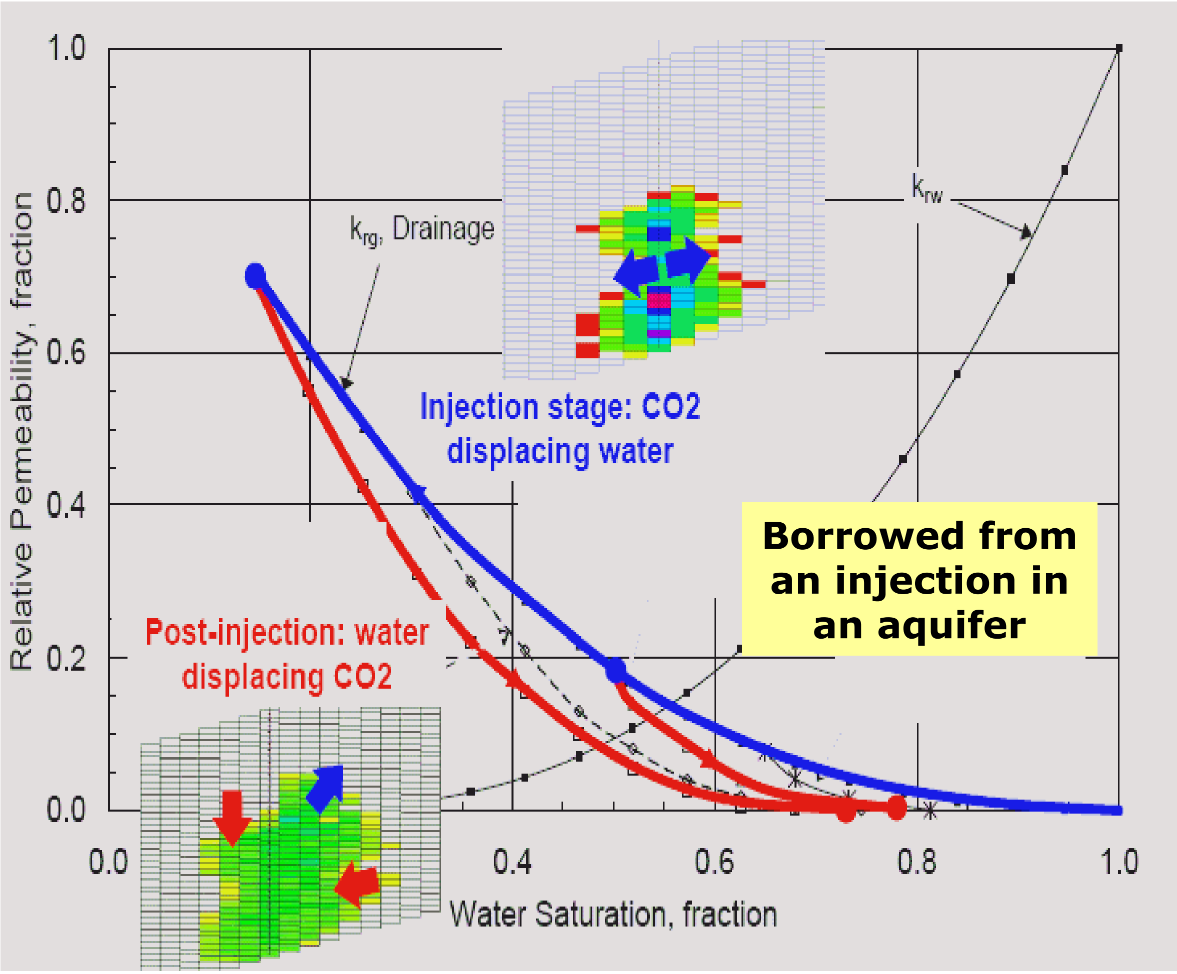
Raising Bubble

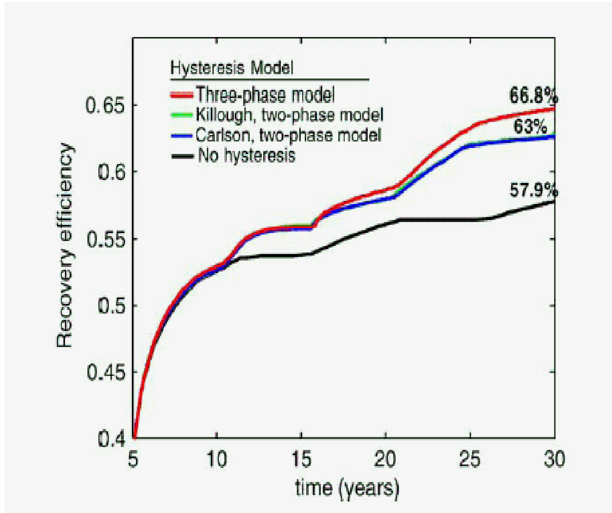
Miscibilility is not necessarily a goal in itself

-If WW a very low IFT is not a plus
- If OW the IFT close to zero competes with the viscous term

Reservoir Issues - 2

- **Example 2 - The Kr (Hysteresis)**

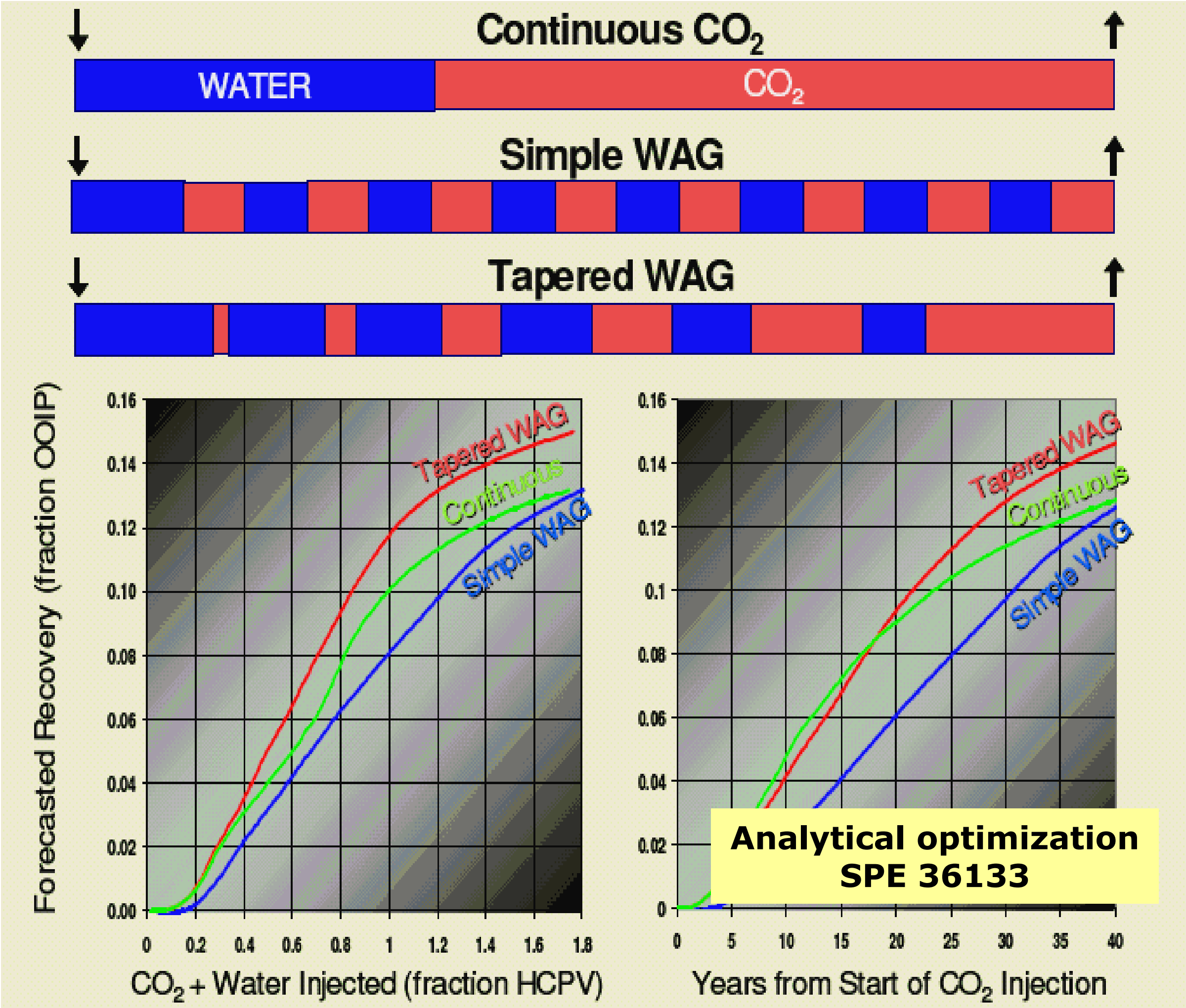




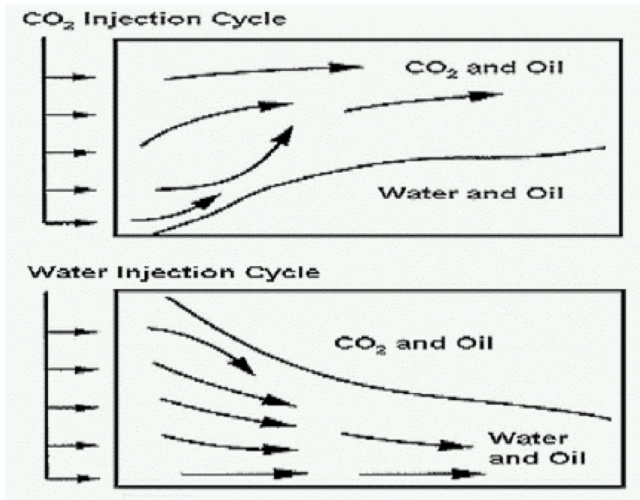
-Strong Laboratory validation (long core displacements)
-Need to carefully address the <u>upscaling issues</u>

Reservoir Issues - 3

- **Strategies – WAG examples**



Analytical optimization
SPE 36133



Issues

-Stratification – Kv/Kh
-WAG ratio optimum
-Size of slug optimum
-Trapping – Kr hysteresis
-Injectivity Loss

Storage Issues - 1

- **The main storage issues are:**
  - **Injection Issues**
  - **Capacity**
  - **Containment**
- **CO_2 Injection performance**
  - **Possible enhancement**
  - **Possible damage (deep skin) due to enhancement – production of fines**
  - **Loss in case of WAG – Kr effect**
  - **Vaporization of water near injectors due to dry CO_2 (vaporization can create halite deposition and therefore K impairment – *valid for great VP volumes)***
  - **Rule of thumb : Good WF injection = Good CO_2 injection**

Storage Issues - 2

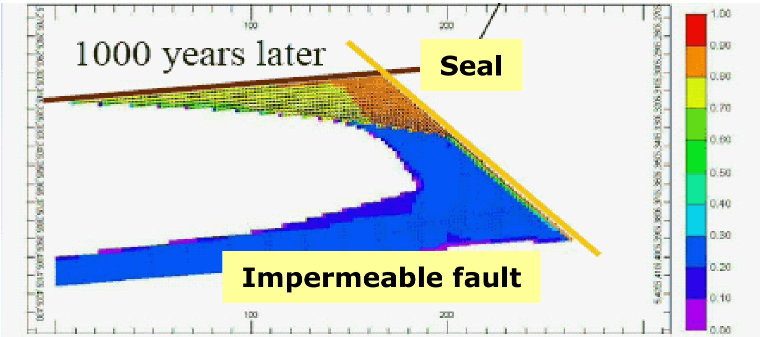
- Storage Capacity
  - f(EOR production and therefore ROZ)
    - Saturation situation prior to the storage
  - Pressure limited
    - Total compressibility

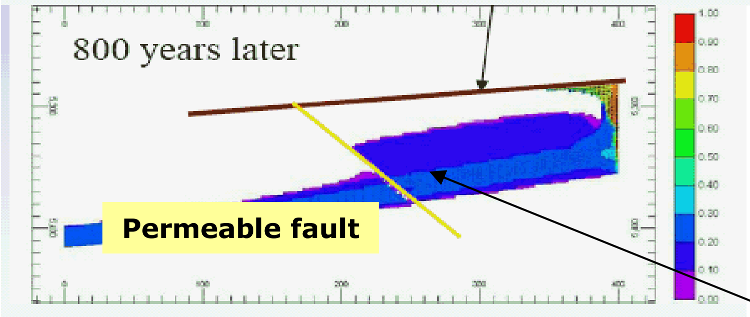
$$C_T = S_w C_w + S_{o\text{-}co2} C_{o\text{-}co2} + S_{o\text{-}free} C_{o\text{-}free} + S_{co2\text{-}free} C_{co2\text{-}free} + C_r$$

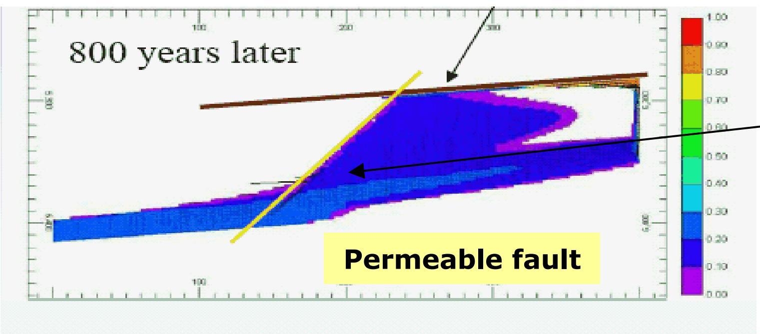
  - Governed by the % volume of oil contacted by the CO2
  - Trapping during the EOR (30% to 50%).
  - P_{th} and therefore the additional pressure allowance above $P_{res.initial}$

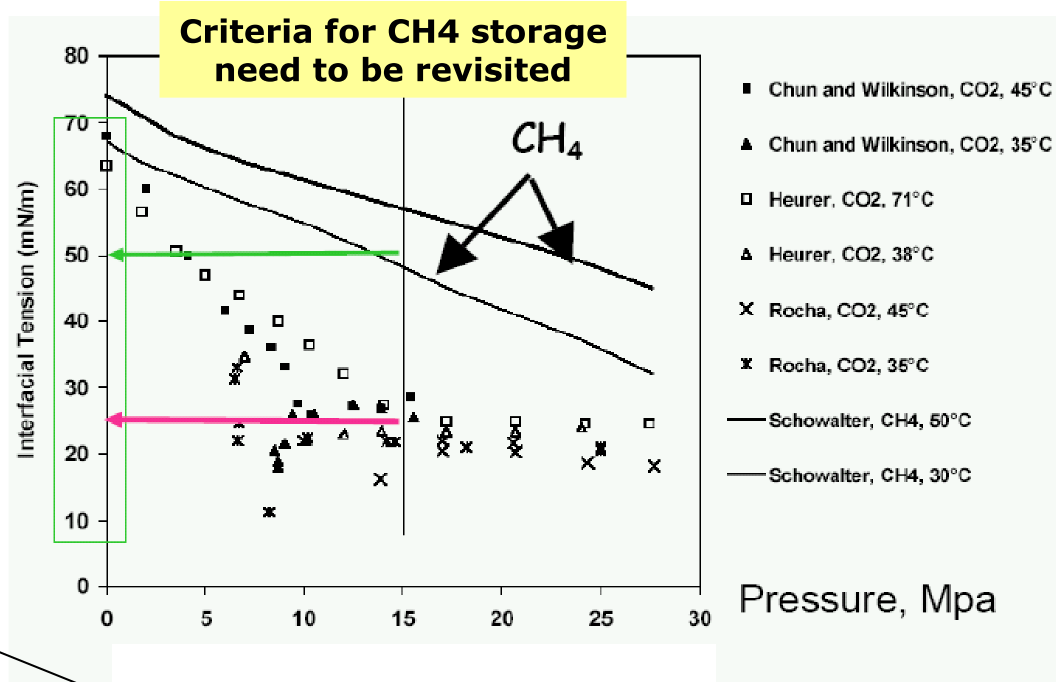
Storage Issues - 3

- **Containment (Pth and fractures)**





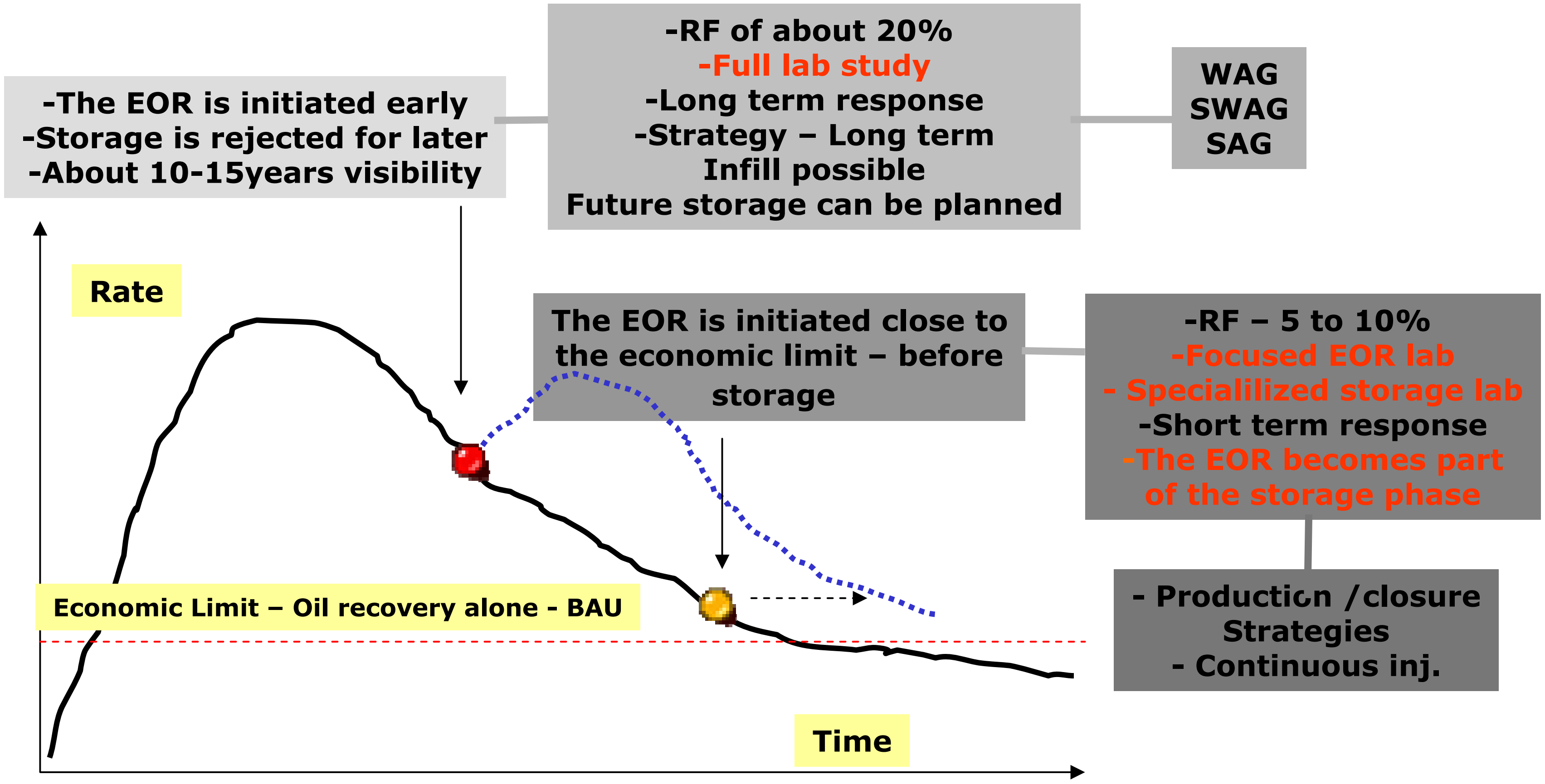




Issues
- **Fracture Orientation**
- **Pth (threshold pressure) for fractures**
- **T and IFT**

Co-Optimization - 1

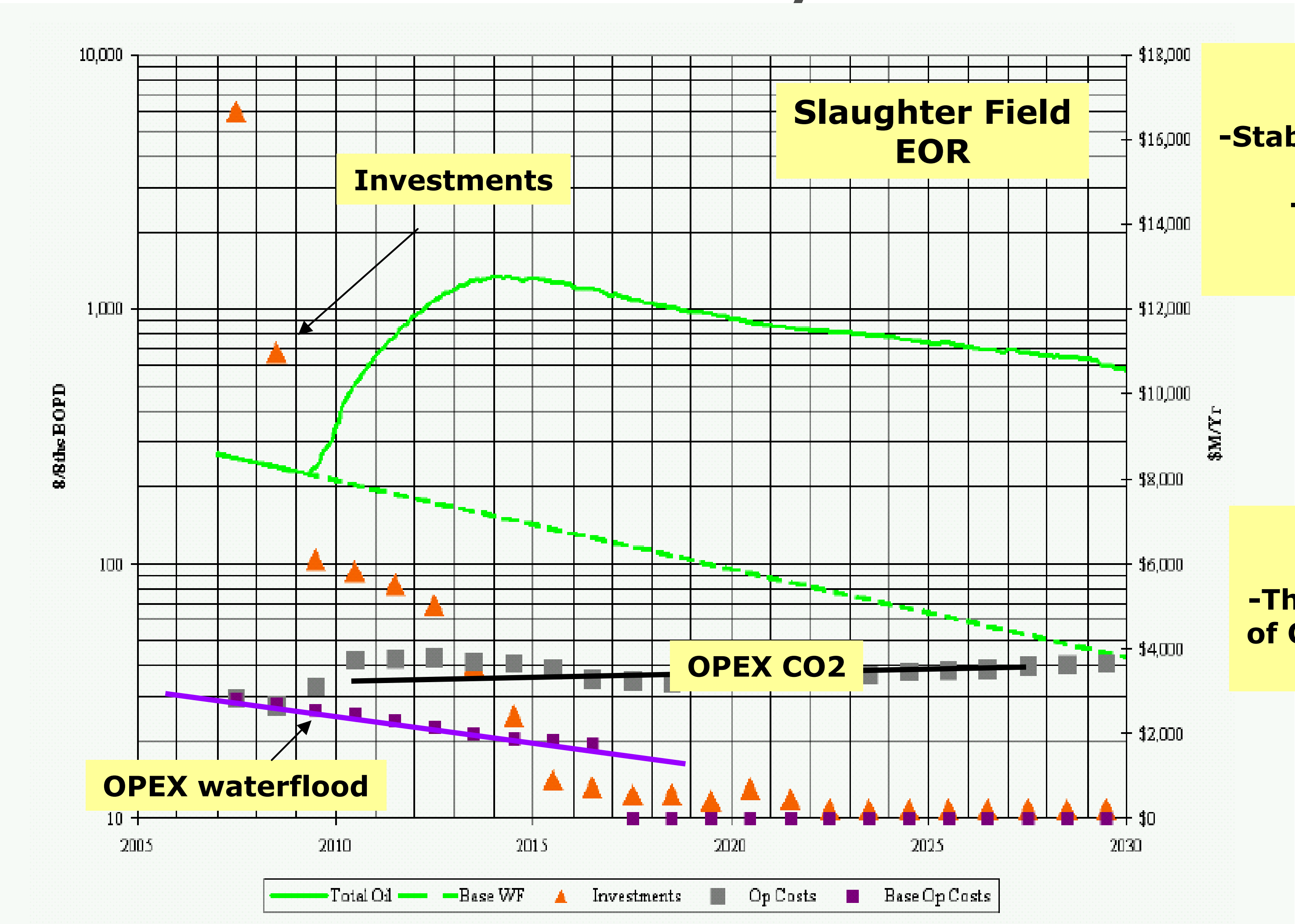
- **Two opportunity situations (phasing)**



Economic model – important

Co-Optimization - 2

- **Economical Elements/Needs**



Criteria

-Stable Oil Price for a long period
-Stable CO2 price
-Higher OPEX
-High CAPEX

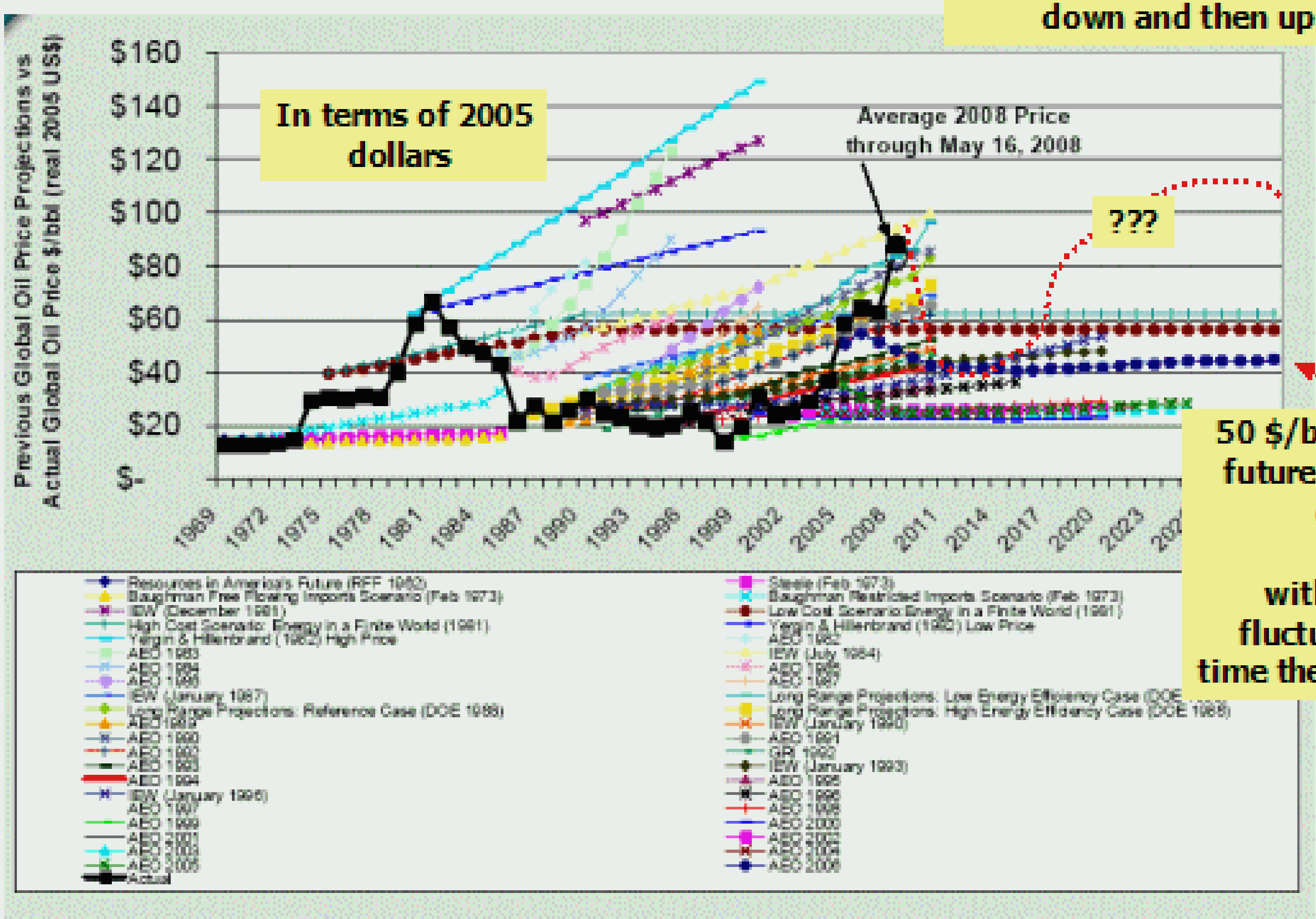
Needs

-The possible offsetting of OPEX though storage (ETS offset)

Co-Optimization - 3

- **Price of Oil**

Price is cyclic – we are bound to go down and then up again

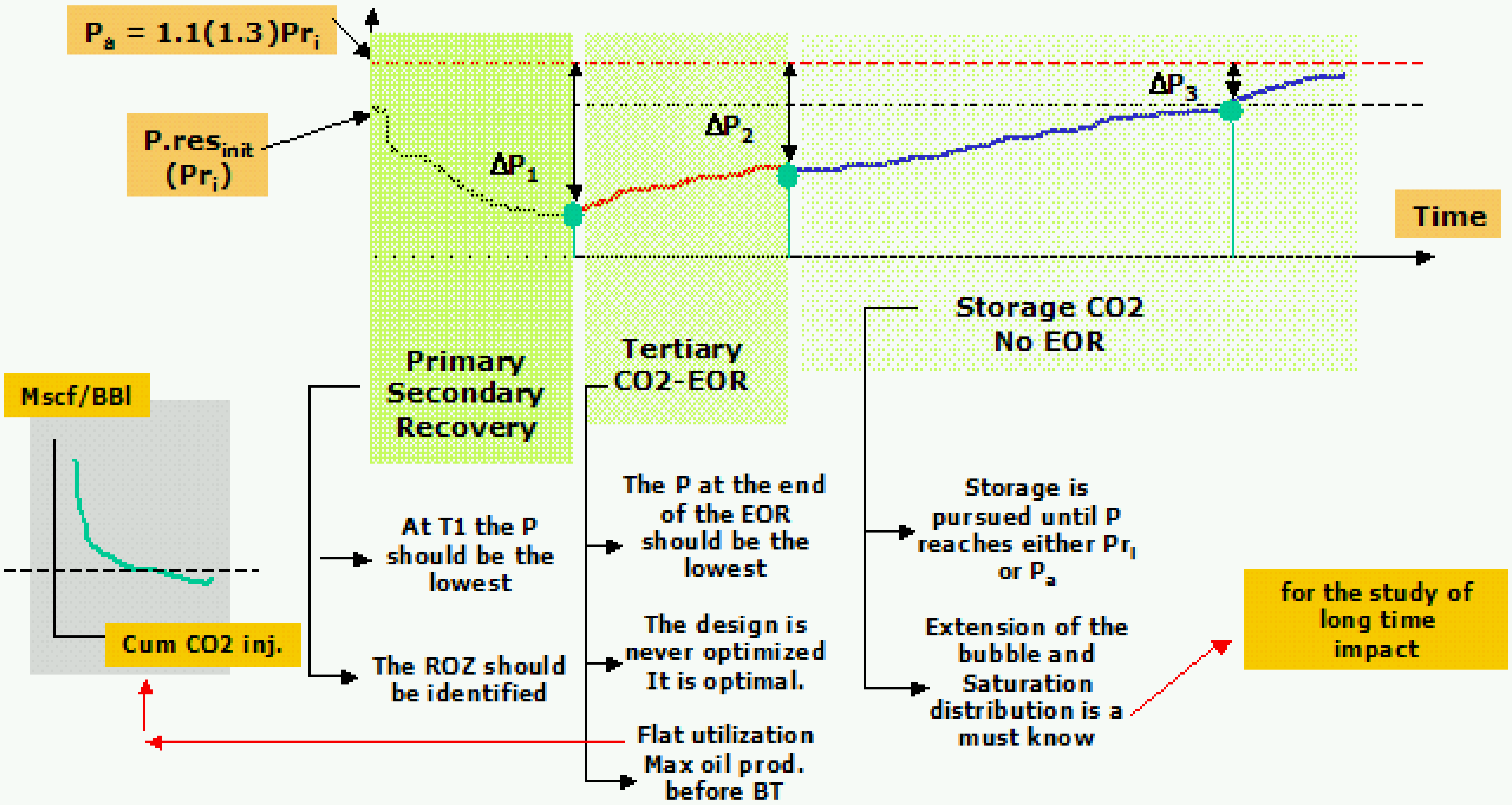


50 $/bbl average for future is likely to be correct

with 15 to 20$ fluctuations every time the world sneezes

Co-Optimization - 4

- The scheme



Co-Optimization - 7

- Different other methods
  - Stacked reservoirs storage design
    - Injection in aquifers below reservoirs
  - Injection point optimum
    - Bottom injection
  - Vertical/horizontal well scheme
    - Example - Weyburn
  - CO_2 thickening (BT retardation)
  - SAG
    - "Huff" applied to continuous injection
  - Any hybrid innovative method mobilizing the ROZ

Conclusions

- **CO2-EOR is a long-time investment**

- **CO2-EOR optimization needs**
  - **A CO2 utilization minimizing the volume of CO2 used**
  - **Tappered WAG (high WAG ratio)**
  - **Either homogeneous or carefully analyzed heterogeneous geological settings (ROZ opportunity)**
  - **Careful up-scaled lab (wettability, IFT study, Kr)**
  - **Near miscible conditions**
  - **Careful treatment of compositional and diffusion effects at the simulation stage**
  - **Goal setting – 20% RF**

- **The CO2-EOR (5 to 10 years) can lead to storage – to be planned eventually as part of the EOR**

Conclusions

- CO2-EOR + Storage optimum needs
  - Storage characterization
    - Cap-rock characterization
    - Well integrity
  - EOR-CO2 design (EOR part of the storage)
    - WAG is not necessarily an optimum. If WAG, short WAG ratio
    - Focused Lab – most important are Kr (3 phase)
    - An accurate assessment of the heterogeneity. Needs a good history match of the primary-secondary production
    - Assess the ROZ mobilization using the well scheme at hand
    - Assess injection capacity – if WAG especially
    - Use pure CO2 and if not (realistic case) don't use dry CO2
  - The Storage part is the most important. That means that oil production is not optimized – just an optimum – 5 to 10% RF
  - Stable oil price over 5 years favor the economy of the process

End

Before I came here I was confused about this subject.

Having listened to your lecture I am still confused.

But on a higher level.

Enrico Fermi

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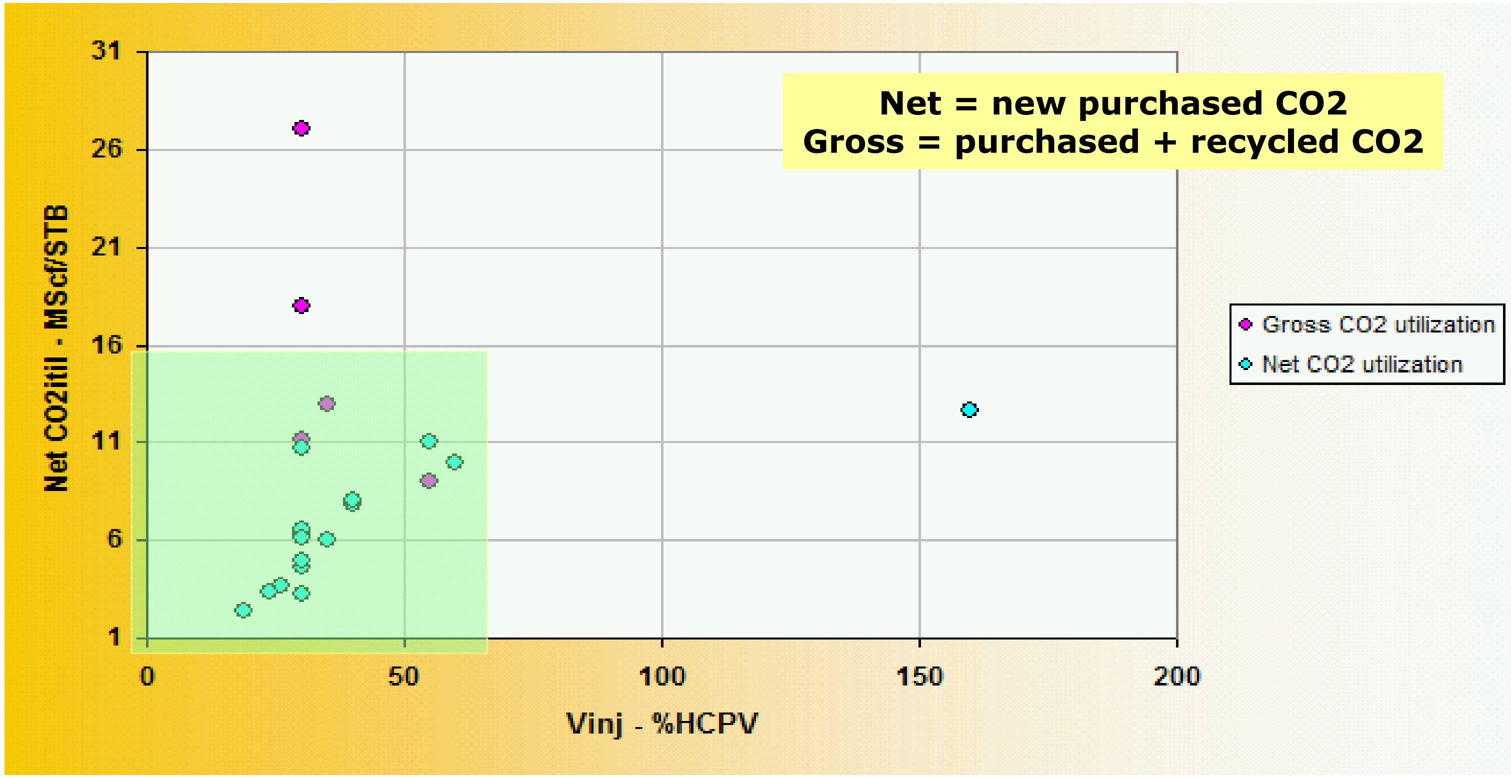
ifp
Innovation
Energie
Environnement

Additional material -1

- **A few examples (performance)**



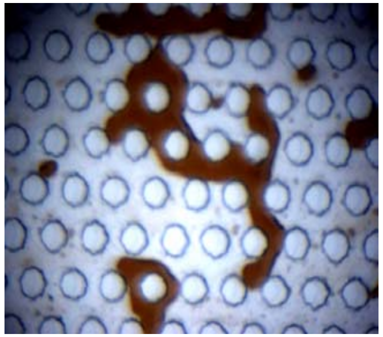
No substantial difference between Net and Gross

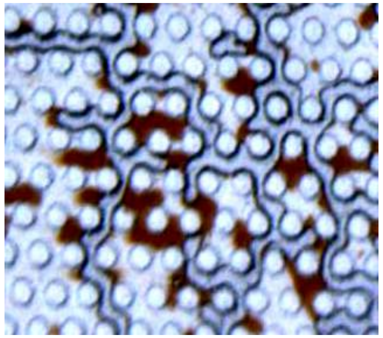
From SPE 18977

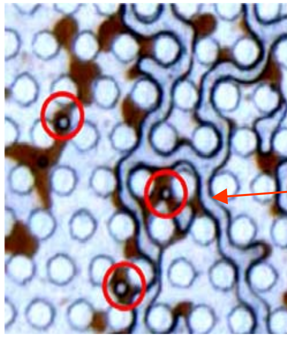
Additional material - 2

- **Wettability behavior**

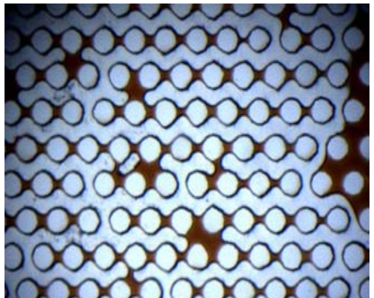
courtesy of M.Robin, IFP



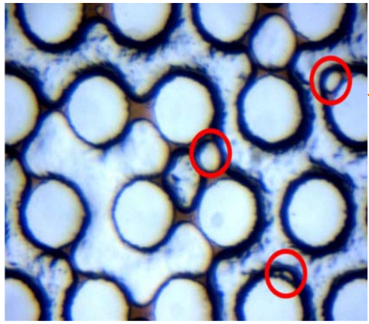




Water Wet – CO_2 at S_{or}
Oil is found between brine and gas
Continuous phase = brine film
<u>CO_2 trapped within oil</u>



Oil film

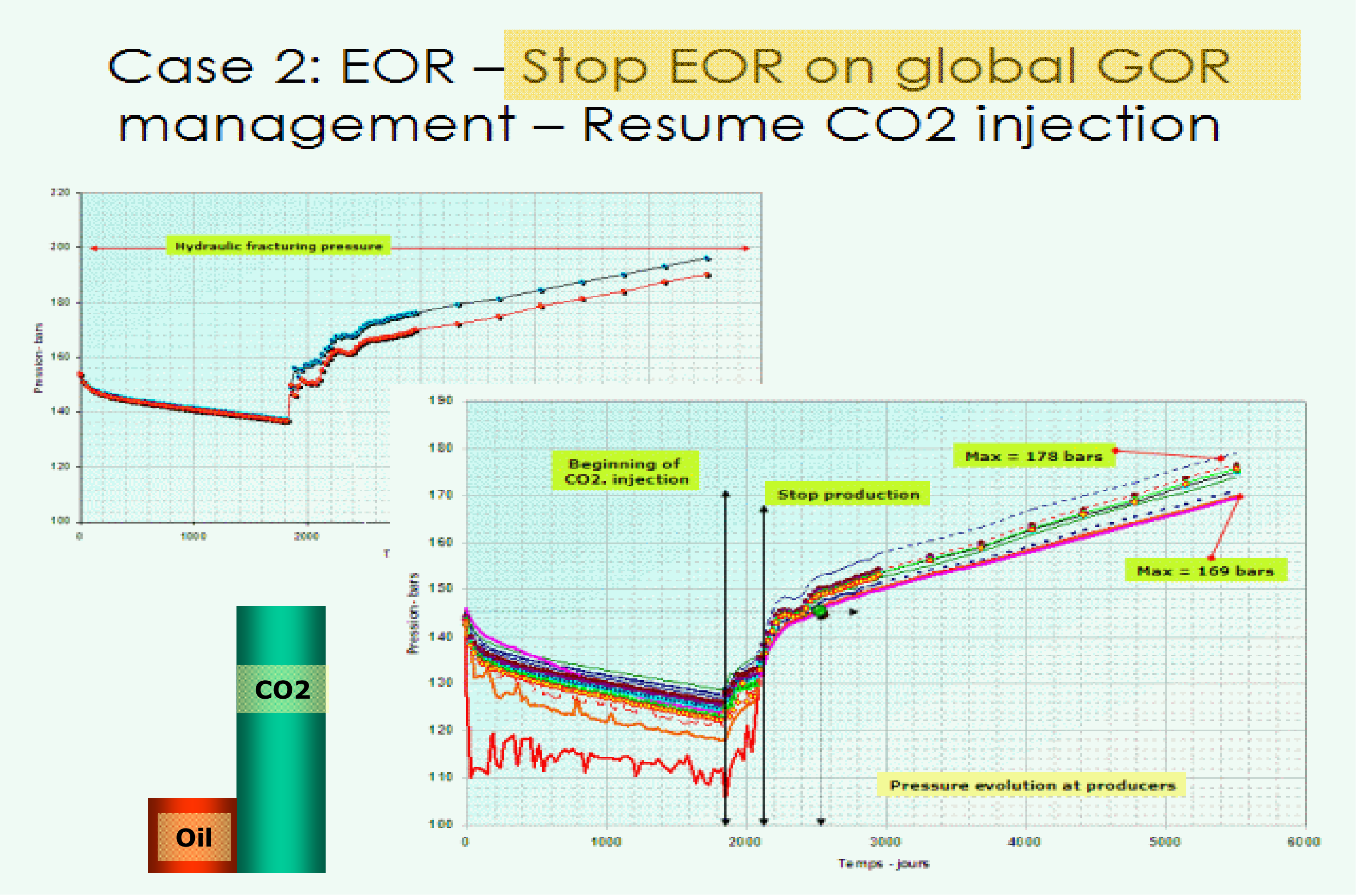


Oil Wet – CO_2 at S_{or} (residual oil saturation)
Brine is trapped within the oil phase
<u>No contact between CO_2 and brine</u>

Important for the understanding of the Kr (imbibition/drainage)
Important to understand how CO_2 will mobilize the residual oil

Additional material - 3

- **An Example - 1**



Additional Material - 4

- **An Example - 2**

Case 3: EOR – Stop EOR on well by well GOR management – Resume CO2 injection