The impact of 45Q and stacked storage in the CO_2-EOR Sustainability

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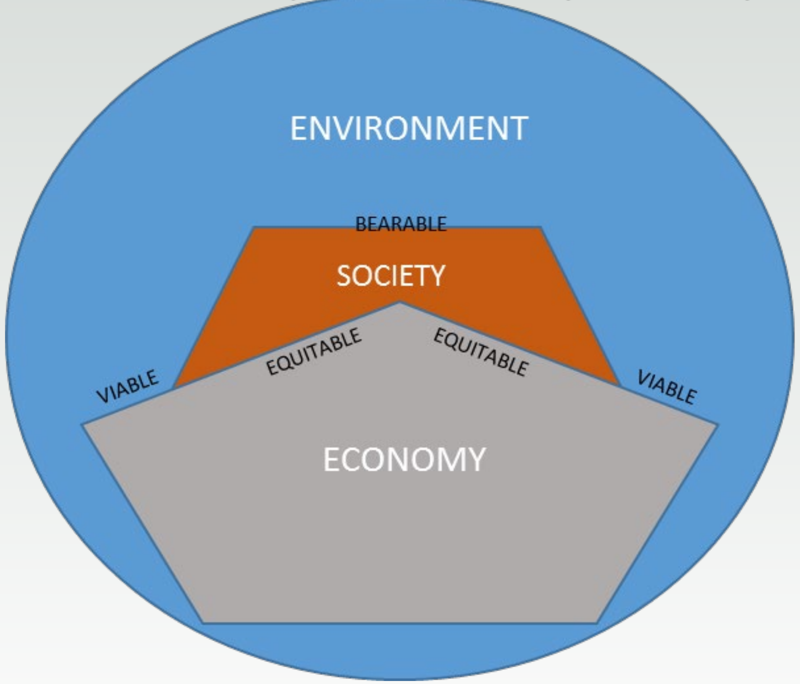
What's the problem?

Sustainability:

1.

Sustainability 3-Nested Dependency



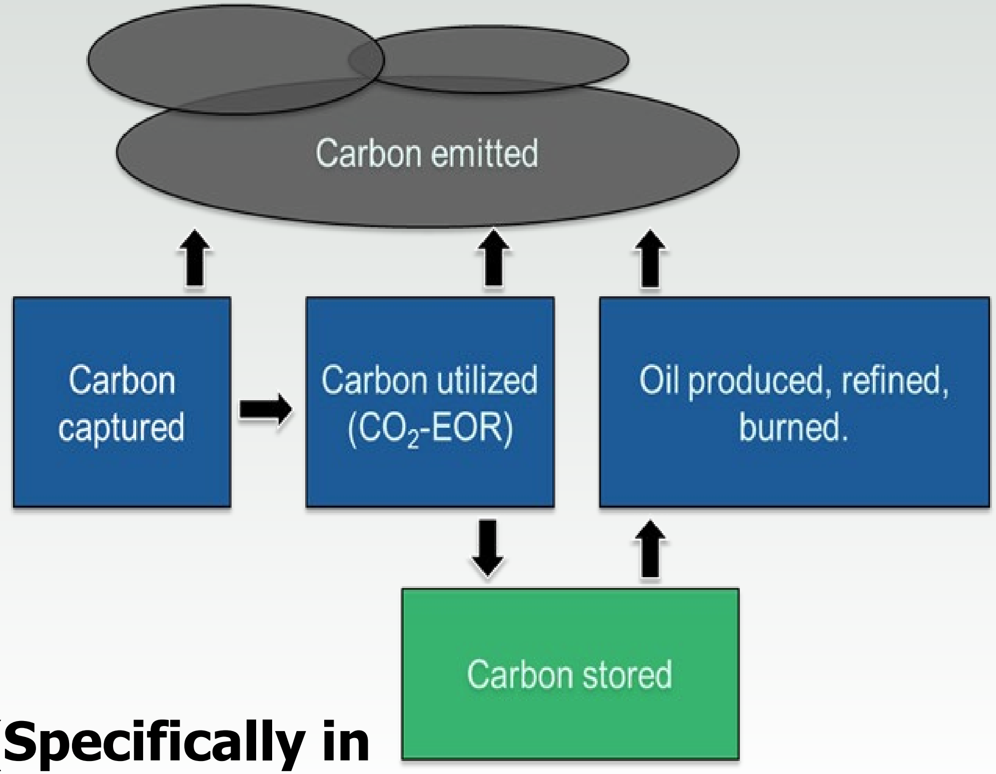
2.

"A conscious and responsible use of the resources, without exhausting them or exceeding their capacity for renewal, and without compromising access to them by future generations". (UN, 1987)

3.

In this case the limiting natural resource is the atmosphere

How can we make a Sustainable approach for CCUS decision-making?



(Specifically in CO_2-EOR operation, integrating the 3 nested dependency concept)

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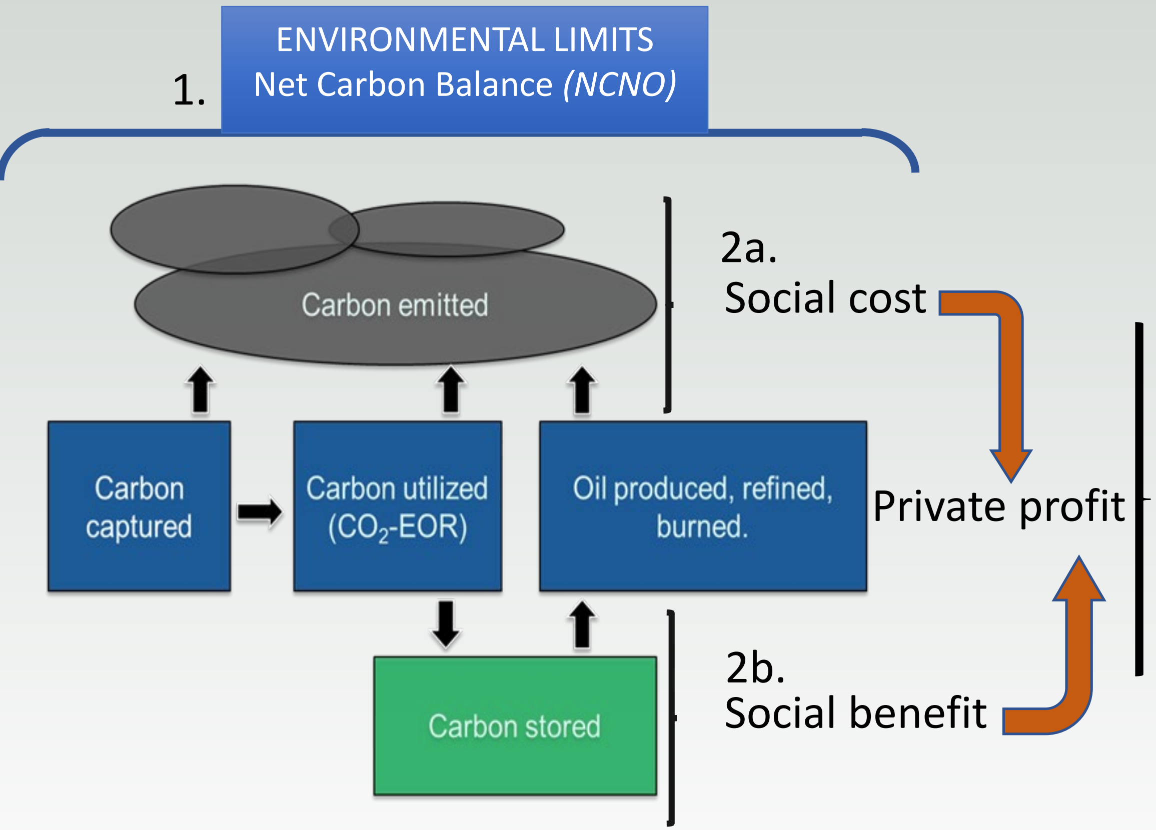
Methodology



3.

Margilnalist approach

Eo, when MgI=MgC

1. Dynamic LCA for CO_2-EOR for NCNO Classification

- Defined system boundary
- Dynamic reservoir model
- Four CO_2 *IS* (CGI, WAG, WCI and WAG+WCI)
- Four *GS* process (fract-refgrtn, membrane , Ryan–Holmes and w/o *GS*
- Operational results and Neutral Carbon Balance *(NCB)*

2. Integrating Externalities to economic analysis

Assessing social and environmental cost and benefits not normally accounted in private decision-making

3. Sustainability condition

- Determine economic optimum *(Eo), necessary condition*
- Compare *Eo* vs *NCB where Eo<=NCB,*
- *sufficient condition for SUSTAINABILITY*

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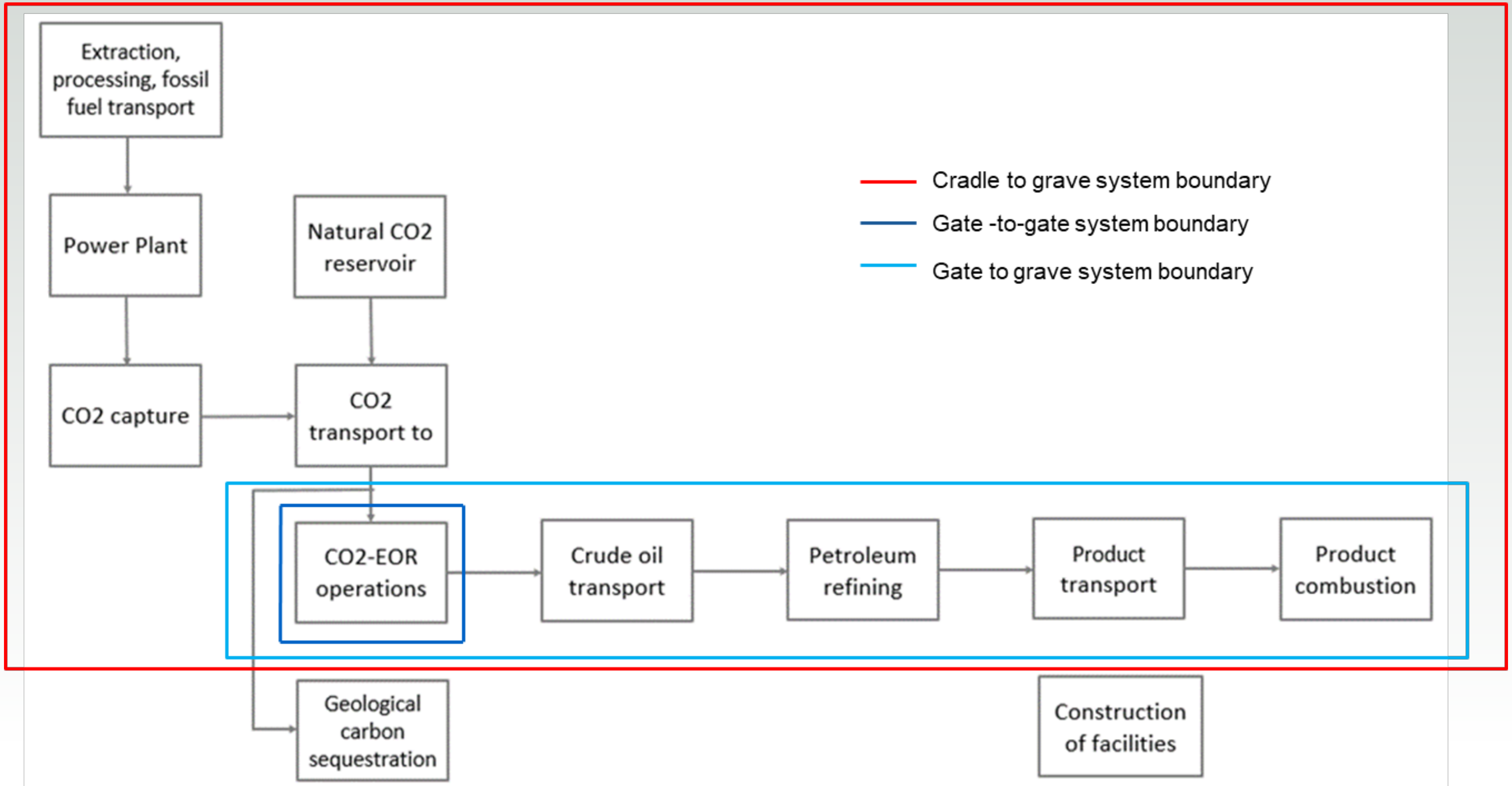
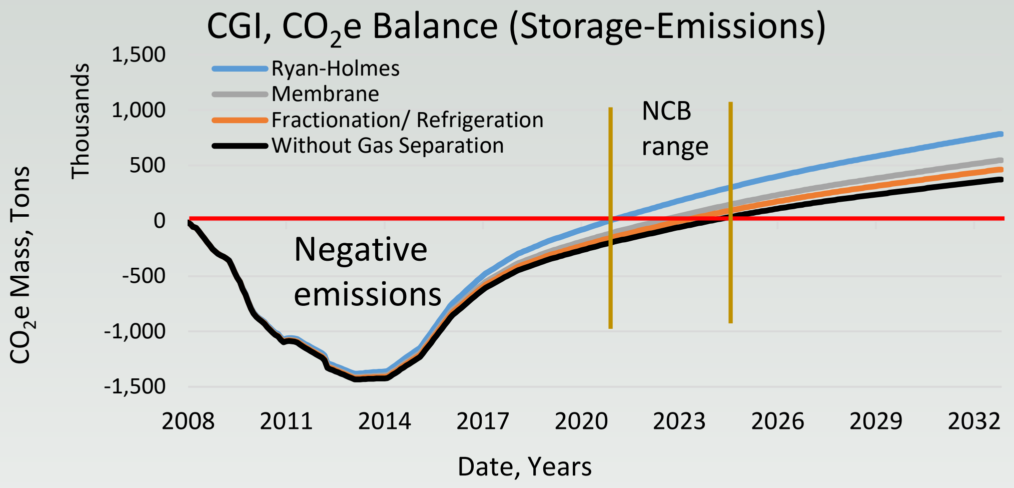
Environmental Performance: *d*-LCA

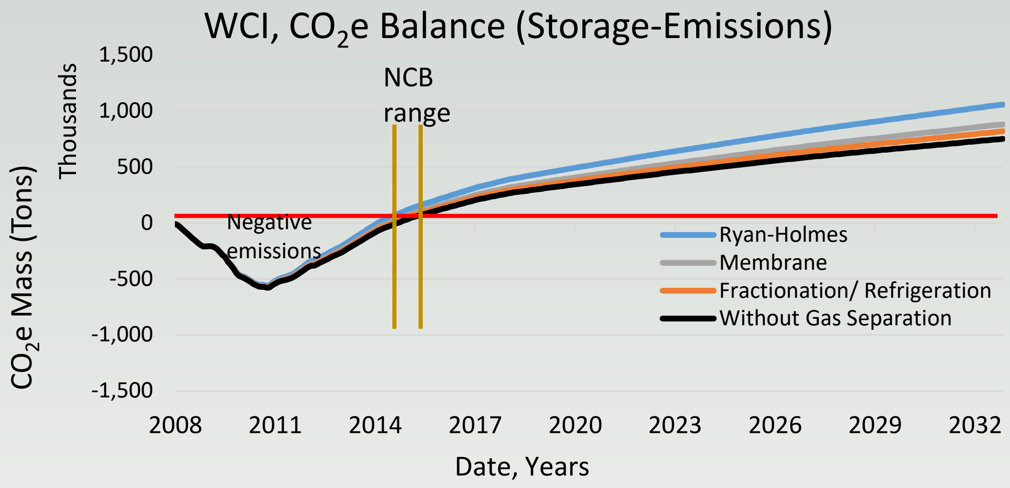
LCA System boundaries for NCNO classification

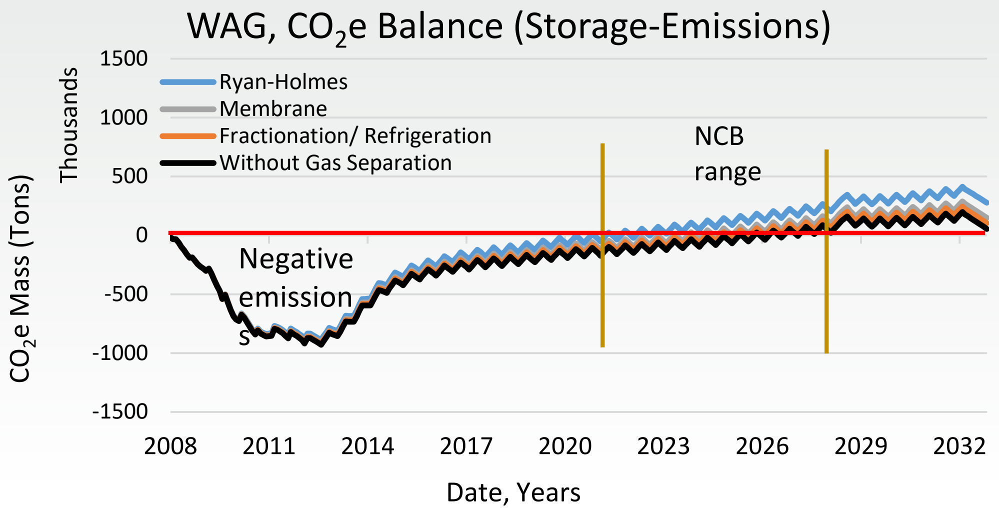


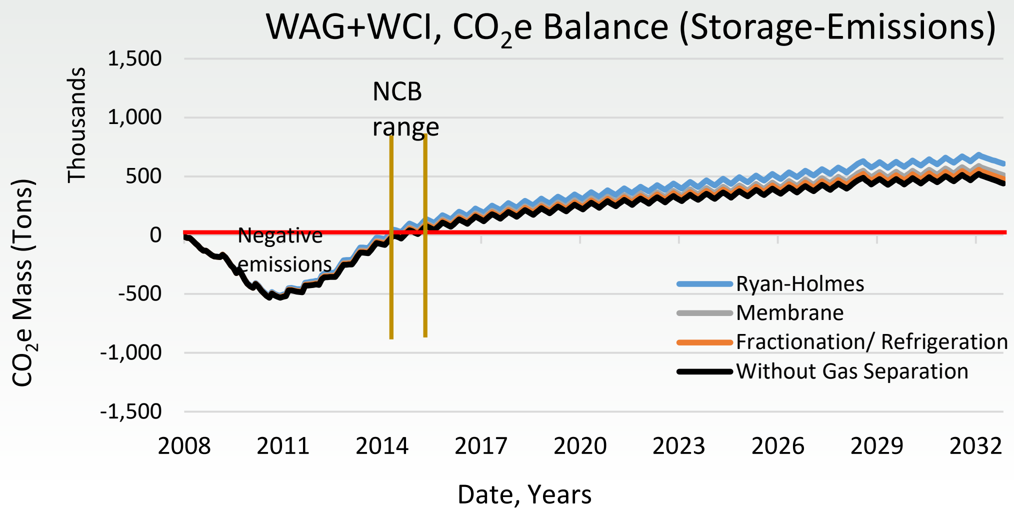
Environmental Performance:

Gate-to-grave (EOR)









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Environmental Performance:
Gate-to-grave (EOR)

Parameter at transition point	CGI	WCI	WAG	WAG+WCI
Cumulative oil production (million barrels)	**3.2 - 3.4**	1.4 - 1.5	2.6 - 2.8	1.37- 1.4
Percent of ultimate recovery (%)	81 - 87	48 - 57	**83 - 91**	46 - 62
Cumulative carbon storage/emissions (million tones)	**1.5 - 1.6**	0.7 - 0.72	1.3 – 1.32	0.65 - 0.69
Negative carbon footprint period (yrs.)	13 up to 16	6 up to 6.7	**14 up to 19**	6 up to 6.7
Negative carbon footprint period (% of project life)	58 up to 64	24 up to 27	**56 up to 74**	25 up to 27
Emission rate (tones CO2e/barrel)	**0.45 - 0.51**	0.47 - 0.51	0.47 - 0.51	**0.46 - 0.50**

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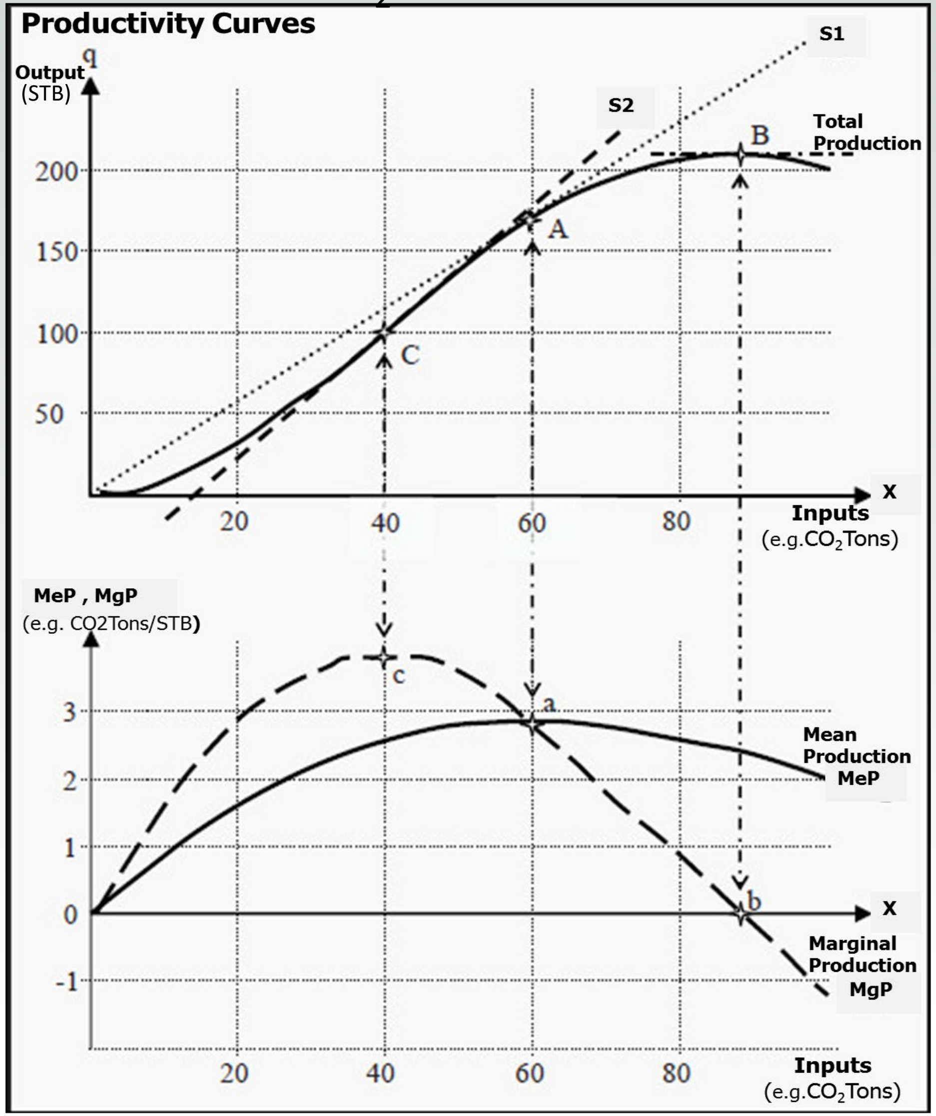
Theoretical framework

Economic Dimension

<u>Singificant relations for decision-making:</u>

- MgP: *TP* instant change per last input unit used
- MgP is maximum in inflexion point of *TP*, then decrease to 0 when *TP* is maximum *("C")*
- MeP: average productivity
- MeP**:** is maximum when *TP* slope (from the origin) is maximum and, intersect ***MgP*** in its decreasing phase *("A")*
- Optimum productivity: ***MgP*** decreasing phace from ***MeP*** *maximum to* ***MgP=0*** *("B")*
- Opposite behavior for cost curves, as the inverse of productivity

CO_2-EOR Theoretical Model



Modified from https://conspecte.com/Microeconomics/production-and-production-costs.html

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3. Theoretical framework

Economic Dimension

3. Marginalist Production Theory:

- differential calculations
- relationships between the objective functions
- the impact of the last input unit

Productivity:

$TP = q = f(x_1^v, x_2^k, x_3^k, x_4^k, \ldots x_n^k)$ *to simplify* $q = f(x_1^v)$,
then,

$$\boldsymbol{MeP} = (q/x_1^v) \text{ and } \boldsymbol{MgP} = (\partial q/\partial x_1^v),$$

Economic optimum:

$$\text{Max. Profit} = TR_{max} \text{-} TC_{min}: \textit{when}: MgB=0\,; \textit{when}: MgR=MgC;$$

$\boldsymbol{TR} = P * f(x_1^v)$; $\boldsymbol{and}, \boldsymbol{TC} = (r_1 * x_1^v) + FC$

so,

$$\boldsymbol{Bmax} = (\partial B/\partial x_1^v) = 0 \rightarrow (P*f'(x_1) - r_1) = 0 \rightarrow (P*f'(x_1)) = r_1, \textit{ as } 1^{st} \textit{ condition and,}$$

$$f''(x_1^v) < 0, \textit{ as } 2^{nd} \textit{ condition, since relates to a maximum (decreasing MgP phase)}$$

Assumptions:

1) Production curve is continuous and concave towards the origin
2) The values are always non-negative
3) Short Term –analysis
4) Efficiency is pre-defined and optimal
5) Inputs and outputs are flow (not stock) variables of a complete a whole cycle
6) Ceteris Paribus condition
7) ***Firm is price-receiver and always seeks to maximize its profit***.

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Scenarios and Sensitive Analysis

Economic Dimension

Scenarios:

- **Injection strategies:** CGI, WAG, WCI and WAG+WCI
- **Operative set up:** EOR and EOR+ (plus stack storage)
- **Oil price ($/STB):** Low (50), Expected (60) & High (72)
- **45Q Tax incentive ($/$CO_2$Ton):** 12 years, EOR -17 to 38- and Saline Storage -28 to 54-)
- **CO_2 price (escalated, $/$CO_2$Ton):** 19-27, 23-46**, 27-54 and 33-64 (lasts two are related to a Low and Med Carbon Social Cost)**
- **O&M cost model** escalated from *ARI, 2006; King et all, 2011*
- **Sensitivity analysis:** based in 20% variation of Oil and CO_2 prices

Functional Unit:

- **$/STB**

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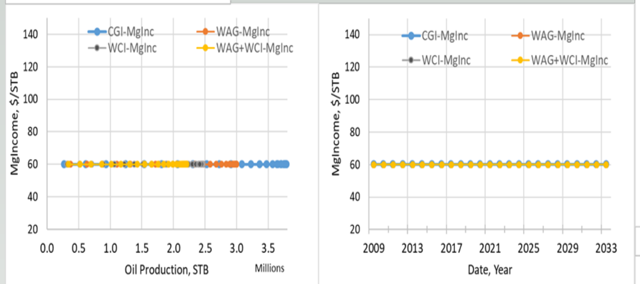
Economic performance

EOR

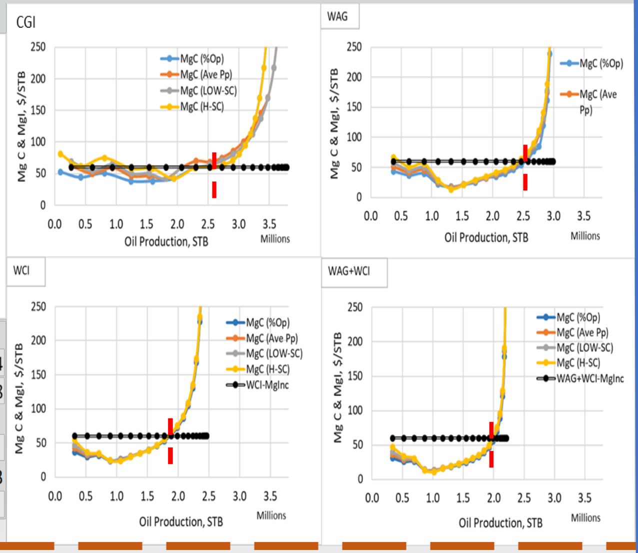
Oil Price Scenario: 60 $/STB - No 45Q

MgI



		CGI	WAG	WCI	WAG+WCI
	Ave Cost	112,603,587	76,685,859	59,023,812	44,520,754
	Ave Benefit	10,073,469	43,707,501	31,581,648	47,956,418
	Benefit	**8%**	**36%**	**35%**	**52%**
	Ave Standart Dev.	6,992,102	3,311,014	811,287	960,563
	%	**69%**	**8%**	**3%**	**2%**

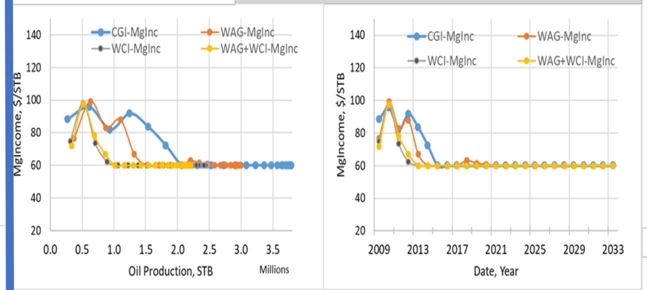
MgI vs MgC



EOR 45Q

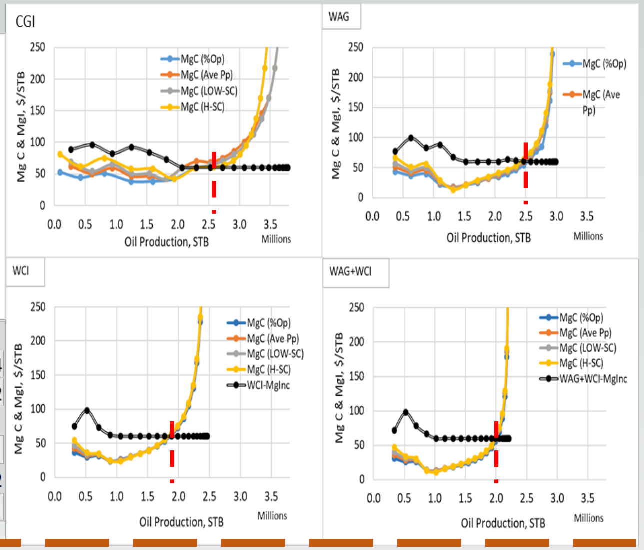
Oil Price Scenario: 60 $/STB - 45Q

MgI



		CGI	WAG	WCI	WAG+WCI
	Ave Cost	112,603,587	76,685,859	59,023,812	43,655,044
	Ave Benefit	37,546,434	58,514,521	35,709,155	53,364,652
	Benefit	**25%**	**43%**	**38%**	**55%**
	Ave Standart Dev.	6,992,102	3,311,014	811,287	798,422
	%	**19%**	**6%**	**2%**	**1%**

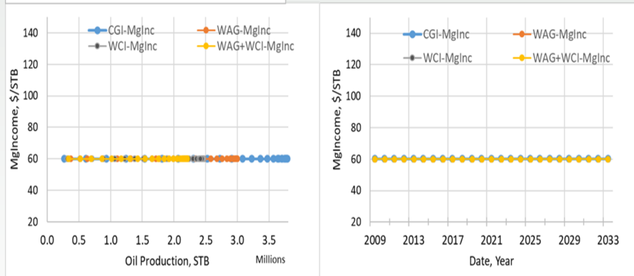
MgI vs MGc



EOR+

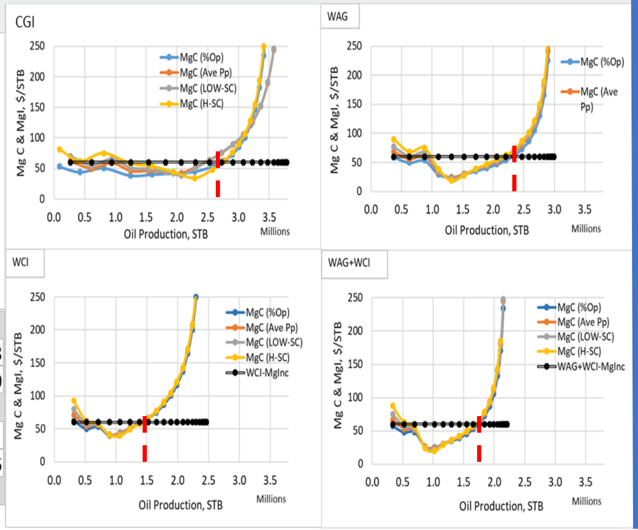
Oil Price Scenario: 60 $/STB - No 45Q EOR + Stack

MgI



		CGI	WAG	WCI	WAG+WCI
	Ave Cost	133,202,261	89,018,825	77,591,311	60,159,478
	Ave Benefit	9,518,539	21,952,975	1,914,509	20,737,250
	Benefit	**7%**	**20%**	**2%**	**26%**
	Ave Standart Dev.	6,294,529	4,440,479	1,092,111	1,566,976
	%	**66%**	**20%**	**57%**	**8%**

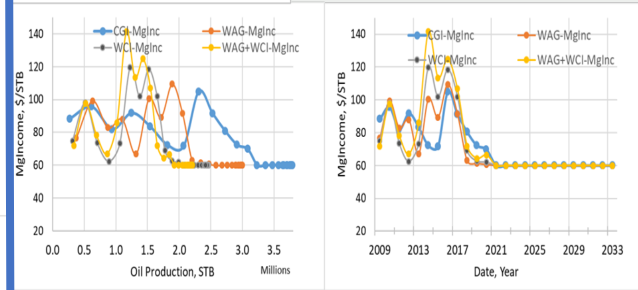
MgI vs MgC



EOR+ 45Q

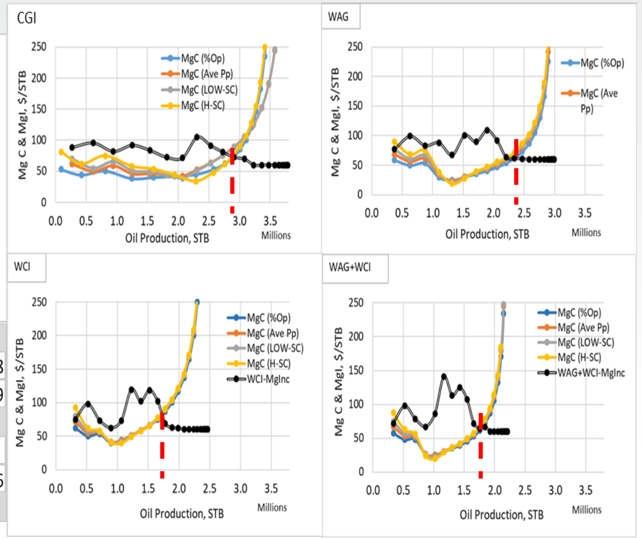
Oil Price Scenario: 60 $/STB - 45Q EOR + Stack Strg

MgI



		CGI	WAG	WCI	WAG+WCI
	Ave Cost	133,202,261	89,018,825	77,591,311	60,159,478
	Ave Benefit	64,088,518	63,504,358	38,546,517	63,800,699
	Benefit	**32%**	**42%**	**33%**	**51%**
	Ave Standart Dev.	6,294,529	4,445,203	1,092,111	1,566,976
	%	**10%**	**7%**	**3%**	**2%**

MgI vs MgC



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Red vertical dash line = economic optimum

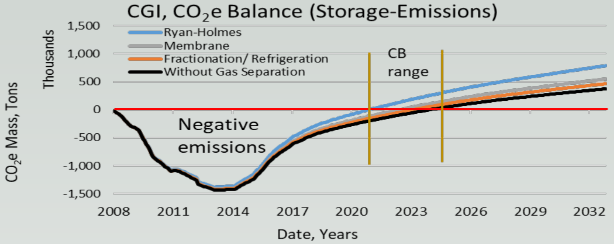
Staked Storage impact in EOR (45Q)

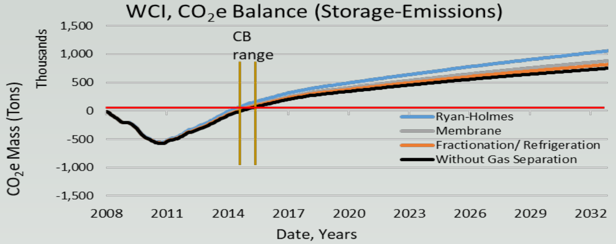
Environmental performance: *NCB*

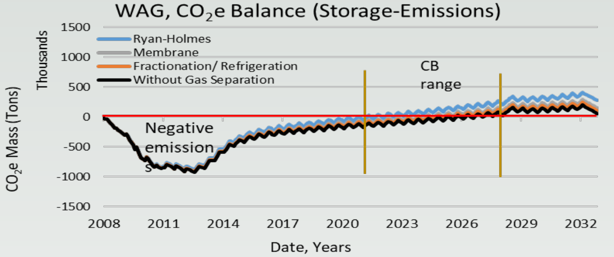
Sustainability (45Q): *Eo <= NCB*

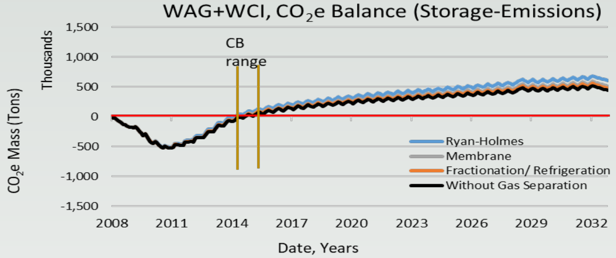
EOR

d-LCA

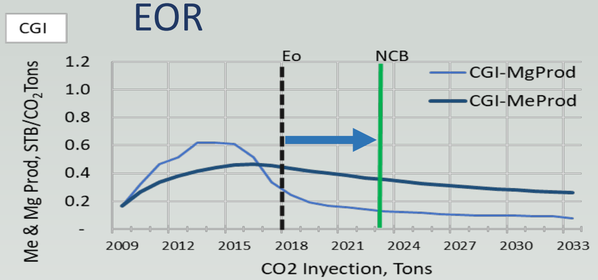


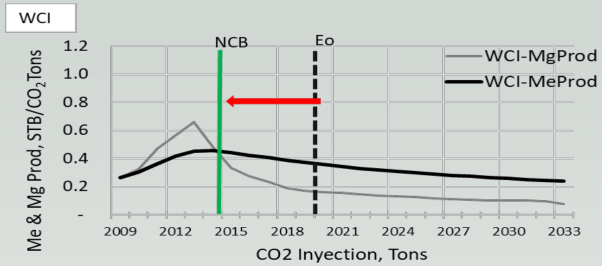


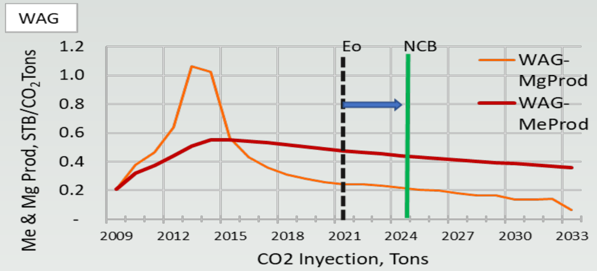


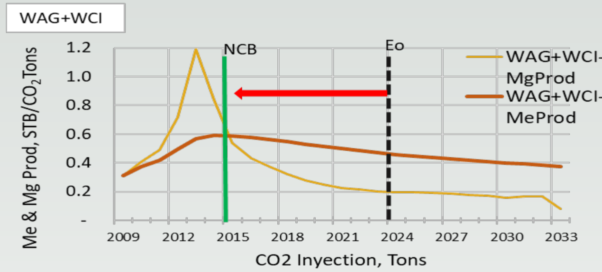


EOR



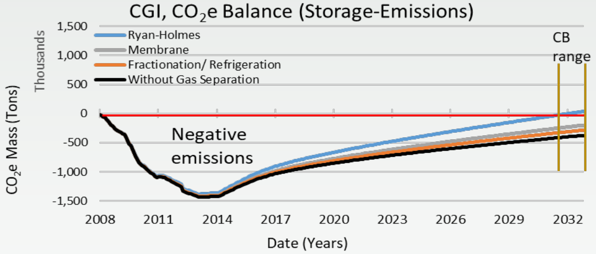


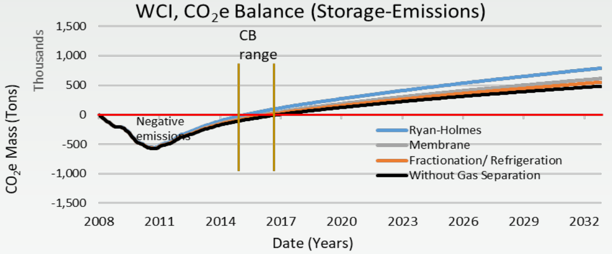


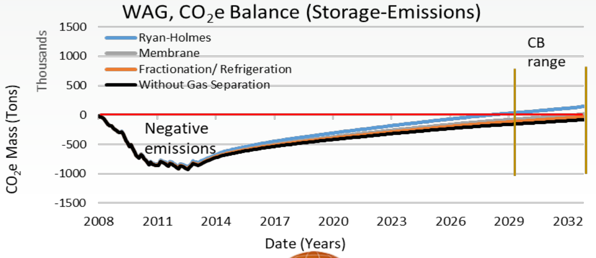


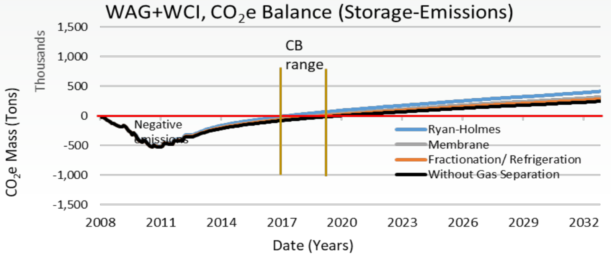
EOR +

d-LCA

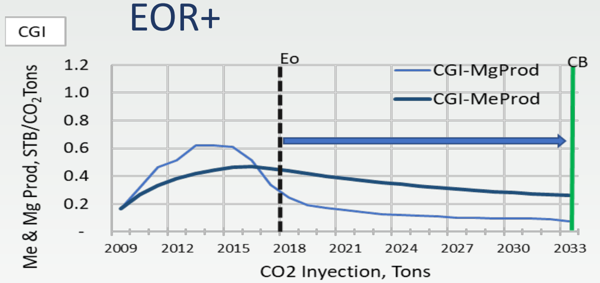


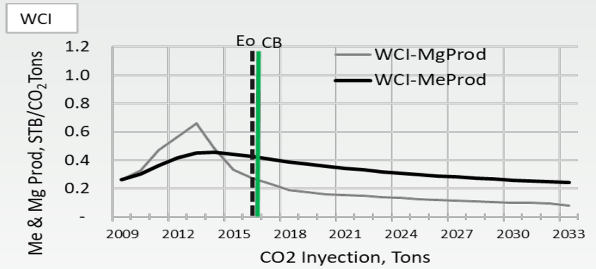


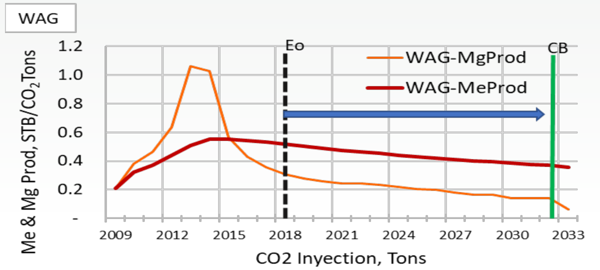


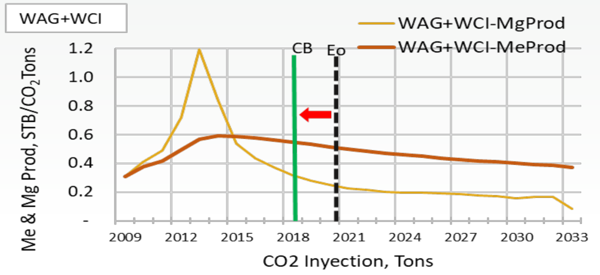


EOR+









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Conclusions

1. **CGI and WAG *ISs* deliver CO_2-EOR sustainable operations in all cases** that could be adopted as clear climate change mitigation options to accelerate CCUS commercial implementation.
2. **EOR+ make a mayor impact in the sustainable conditions for CCUS**
3. **EOR+ makes WCI a sustainable operation** fulfilling both necessary and sufficient conditions (Eo<=CB)
4. **Oil price drives larger impact in the *Eo* than 45Q and CO_2 cost**
5. **45Q don't make substantial impact in the *Eo*** but it has mayor impact in the operator's finances.
6. **Assessing CCUS economic performance through a marginalist theory approach is a novel, simple and yet comprehensive process of integrating environmental (*d*-LCA) and economic performance, which can serve as a tool for decision-making in the meso level, leading to the sustainability CCUS systems**.

Next steps

1. Revision and adjustment of the cost model and results
2. Integrate an accurate social benefits to the equation
3. Apply the methodology to other type of reservoir (sedimentary, and unconventional)
4. **Promote this methodology as a valid tool to assess the sustainability of other CCUS alternatives.**

Questions?

THANKS!

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Economic functions

Income function:

1. TR = Oil price * STB + Tax Incentive * Vol. CO_2 storage
2. MgI = Oil price + Tax Incentive ($/$CO_2$Ton) * CO2 Utilization rate (CO_2Ton/STB)
3. *MgI = $/STB (oil) + $/STB (45Q)*

Cost function:

1. TC = CAPEX + OPEX
2. MeVarC = OPEX/STB = (CO_2 purchase + CO_2rcycling + O&M)/STB

Where,

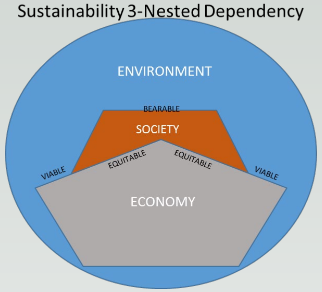
OPEX = b_0+b_1D, where: b_0= $38.447 and b_1= 8.72 $/ft, D is the depth of **EOR** (production and injection wells 10,000 ft (21) and **EOR+** [2 injection wells 10,500 ft *(ARI, 2006; King et all, 2011)]*

3. MgC = $/$CO_2$Ton * (1/MgP) + $/Ton * (1/Mg$CO_2$rec) + MgO&M

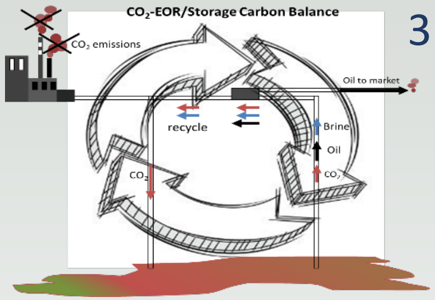
MaxB when = 0 or
MgR=MgC;

Presentation Outline

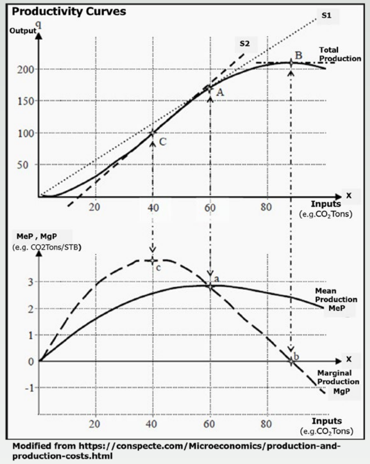
1. What's the problem?



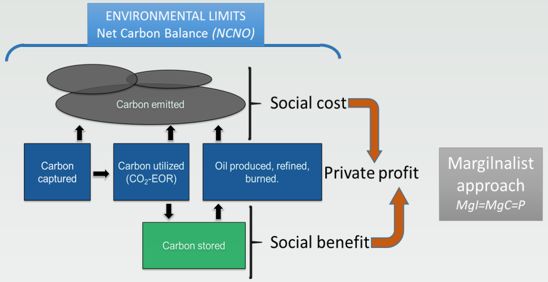
2. Objectives



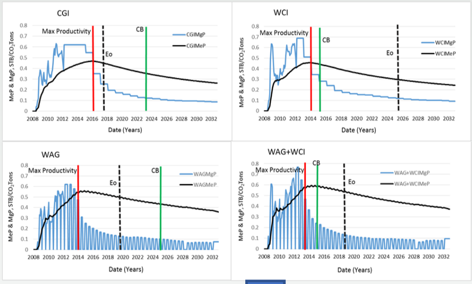
3. Theoretical framework



4. Methodology



5. Results



6. Conclusions and next

3. Theoretical framework (1/3)…

Environmental limits

1. CO_2-EOR Life Cycle Analysis (LCA):

Assess Carbon Balance throughout the CO_2-EOR whole system from raw material extraction, CO_2 capture, transport, EOR operations, product transport, refinery processing, distribution of end products, and combustion of final products.

Social dimension

2. Social cost & benefits:

Estimate NPV of the monetized damages associated with an incremental increase in carbon emissions in a given year., include (but is not limited to):

- changes in net agricultural productivity,
- human health,
- property damages from increased flood risk,
- value of ecosystem services due to climate change.

(U.S. Interagency Working Group on Social Cost of Carbon, 2015)

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