Stacked storage and 45Q impact in the CO_2-EOR Sustainability

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1. What's the problem?

- Fossil energy is blamed for Climate change
- Growing global pressure to get rid of fossil energy
- Non-emitting alternatives are not yet scalable or affordable
- Fossil energy business as usual cannot continue
- CCUS/CO_2-EOR technologies are gaining a big momentum
- U.S. Government approved a carbon tax credit incentive (45Q)

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

Specifically in CO_2-EOR operation, integrating environmental and social-economic dimensions?

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2. Theoretical framework (1/3)…

Environmental dimension

Social dimension (externalities)

1. Dynamic Life Cycle Analysis (*d*-LCA):

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

2. Social cost & benefits:

Estimate NPV of the monetized damages associated with incremental carbon emissions in a given year, including (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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3. Theoretical framework ...(2/3)...

Economic Dimension

3. Marginalist Production Theory:

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

Productivity:

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

$\boldsymbol{MeProd} = (q/x_1^v)$ and $\boldsymbol{MgProd} = (\partial q/\partial x_1^v)$,

Economic optimum:

Max. Benefit $= Tot.Income_{max} - Tot.Cost_{min}$: *when* : $MgB_{max} = 0$; *when* : $Mg.Income = Mg.Cost$;

$Tot.Income = P * f(x_1^v)$; **and**, $\boldsymbol{Tot.Cost} = (r_1 * x_1^v) + FC$

so,

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

$f''(x_1^v) < 0$, *as 2nd condition, since relates to a maximum* ***(Mg.Prod's decreasing phase)***

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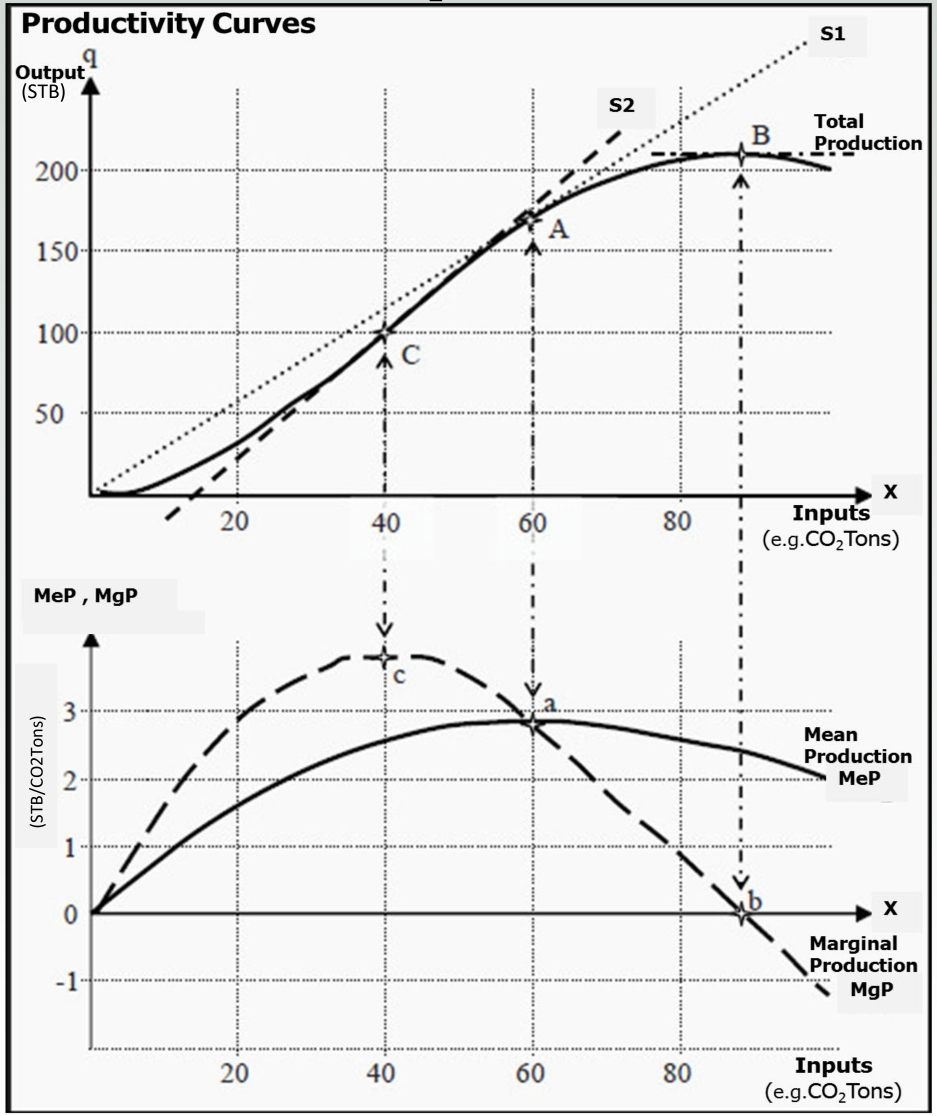
3. Theoretical framework …(3/3)…

CO$_2$-EOR Theoretical Model

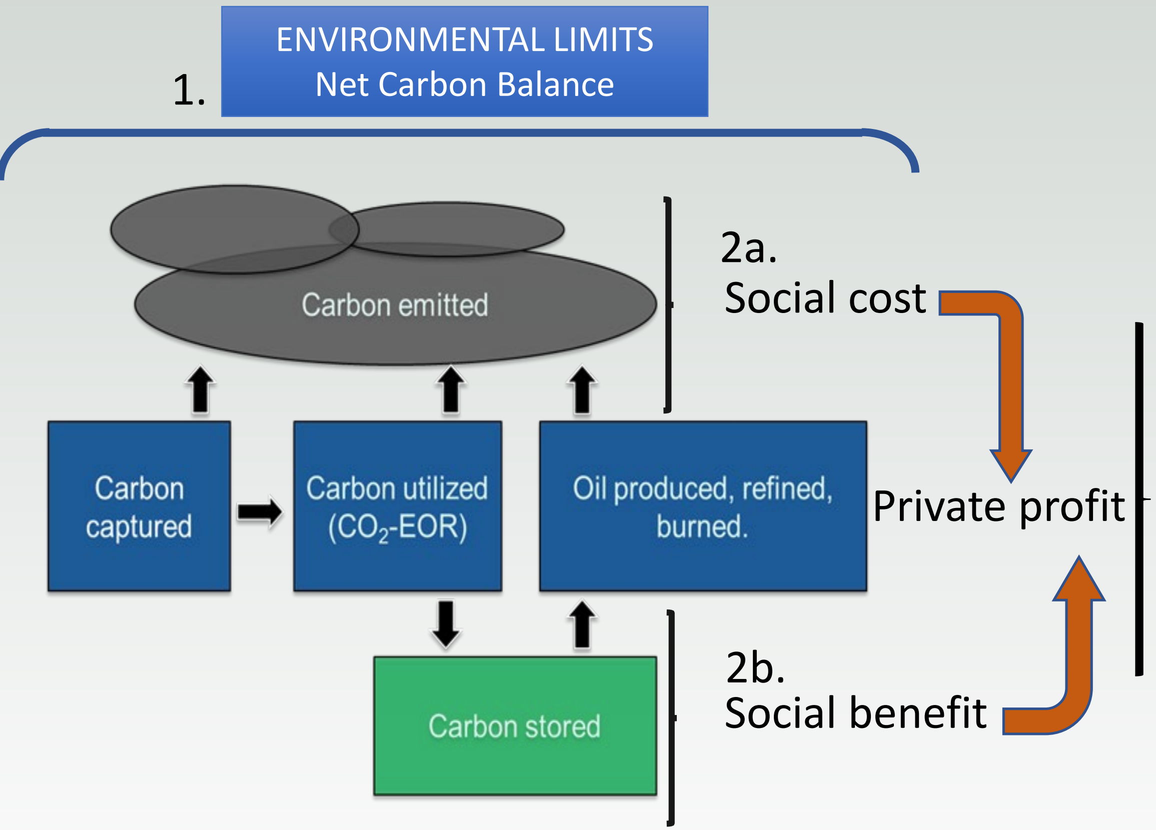


Modified from https://conspecte.com/Microeconomics/production-and-production-costs.html

Cont…

Economic Dimension

Methodology



3\. Marginalist approach

Eo, when MgInc=MgCost

1. CO_2-EOR dynamic LCA (*d*-LCA) for Neutral Carbon Balance

- 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

4\. Sustainability condition

- *Necessary condition:*
  Achieve economic optimum *(Eo).*
- *Sufficient condition:*
  Eo<=NCB

Scenarios and Sensitivity Analysis

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)
- **CO_2 price (escalated, \$/CO_2Ton):** 19-27, 23-46, *27-54 and 33-64* **(lasts two are related to a Low and Med Carbon Social Cost)**
- **45Q Tax incentive (\$/CO_2Ton):** 12 years, (EOR -17 to 38- and Saline Storage -28 to 54-)
- **O&M cost model** escalated from *ARI, 2006; King et all, 2011*

Functional Unit:

- **\$/STB**

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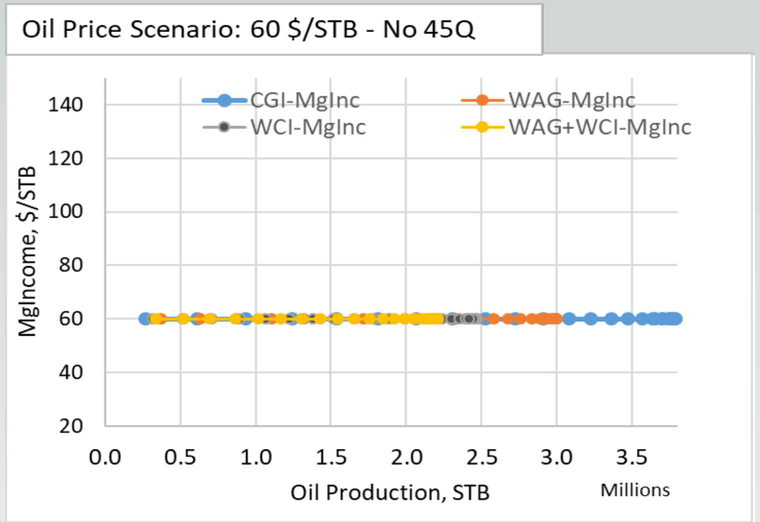
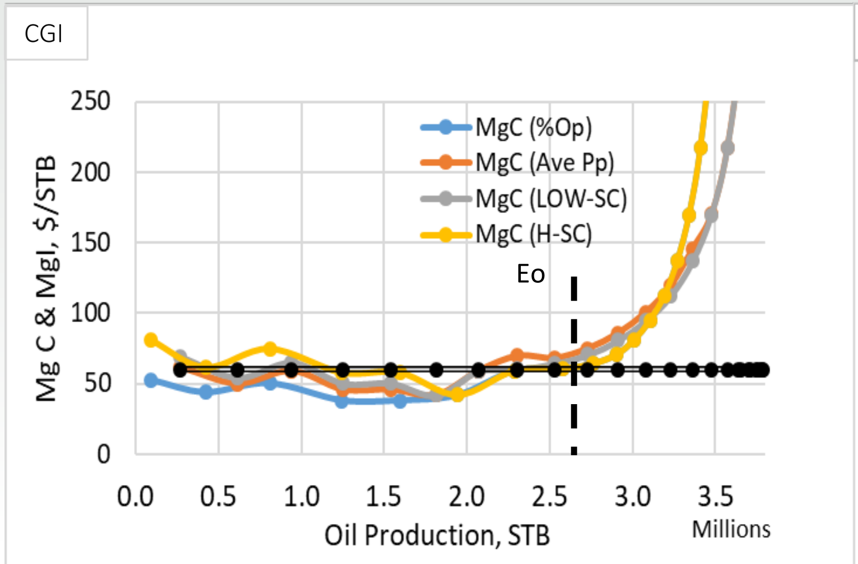
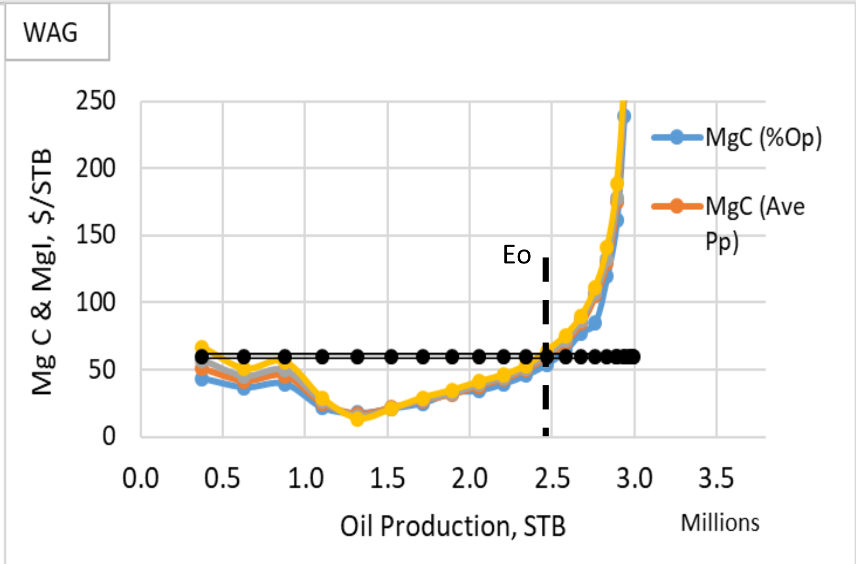
Economic Performance: EOR

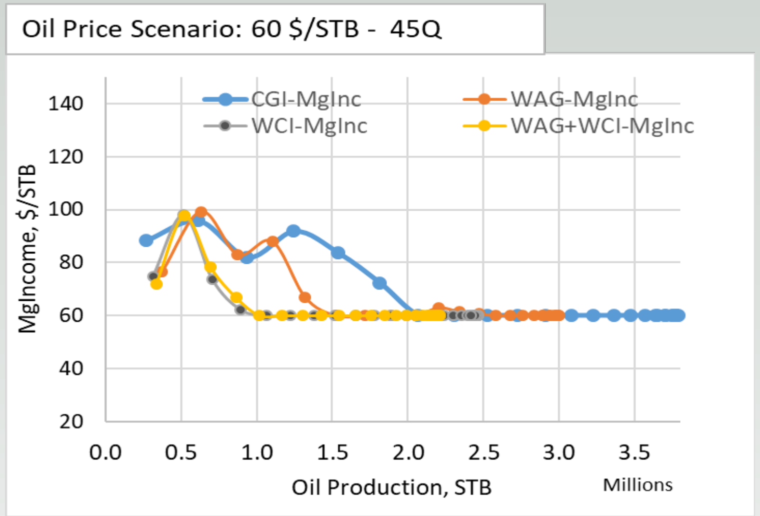


	CGI	WAG
Ave Cost	112,603,587	76,685,859
Ave Benefit	10,073,469	43,707,501
Benefit	**8%**	**36%**
Ave Standart Dev.	6,992,102	3,311,014
%	**69%**	**8%**

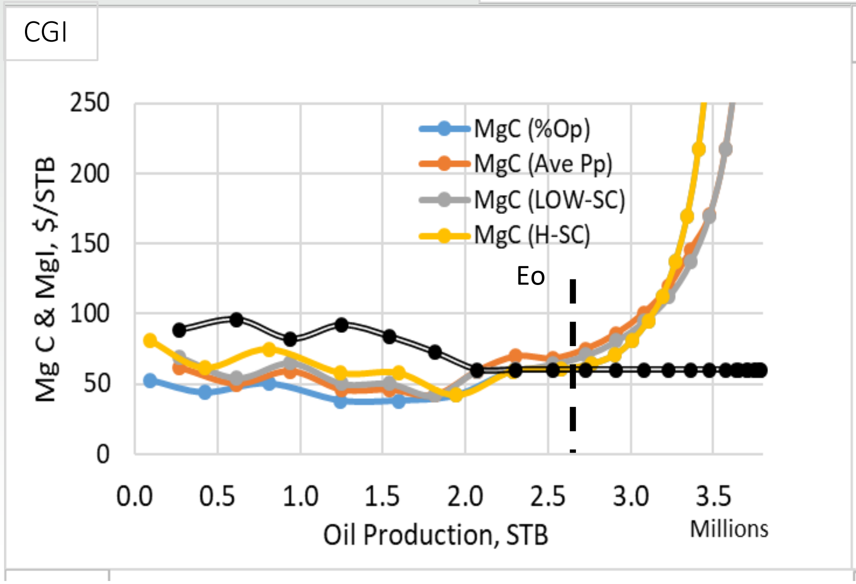


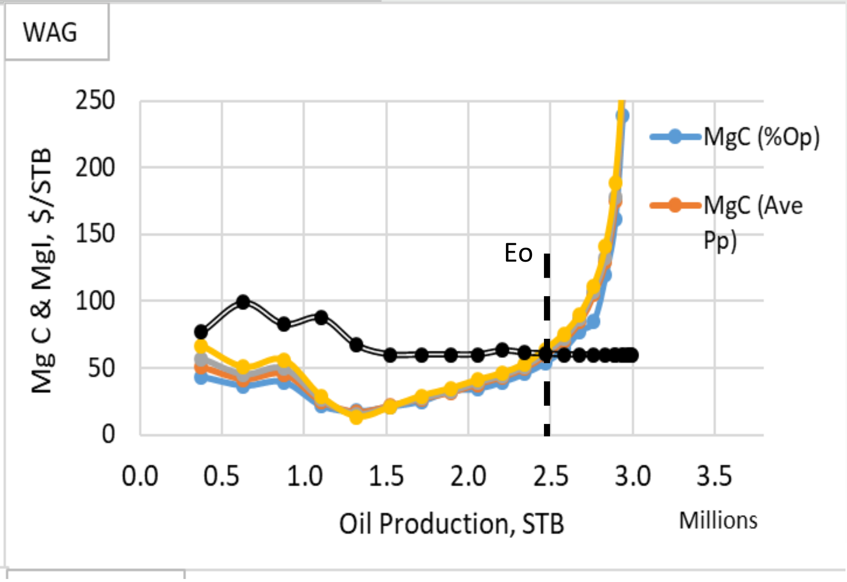


Economic Performance: EOR (45Q)



	CGI	WAG
Ave Cost	112,603,587	76,685,859
Ave Benefit	37,546,434	58,514,521
Benefit	**25%**	**43%**
Ave Standart Dev.	6,992,102	3,311,014
%	**19%**	**6%**





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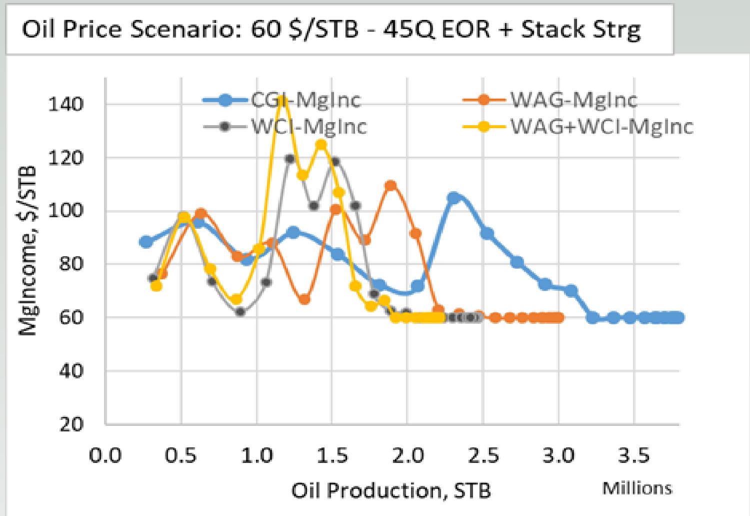
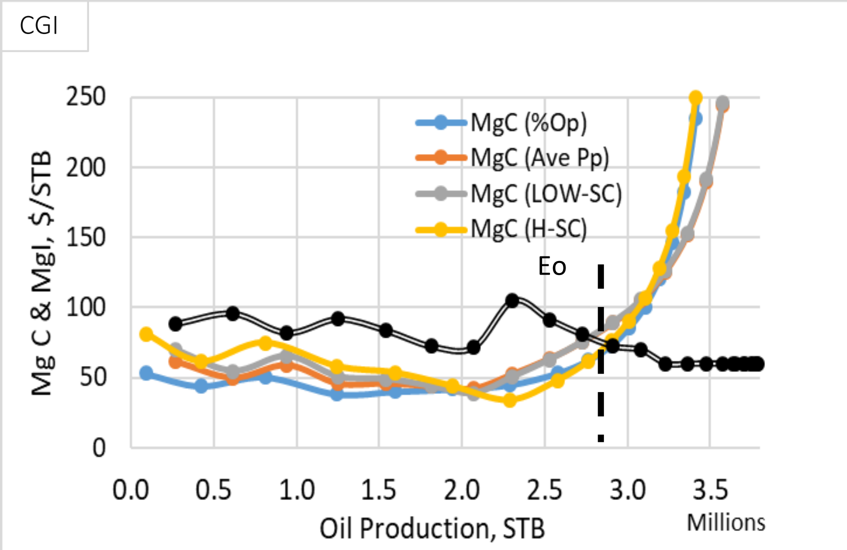
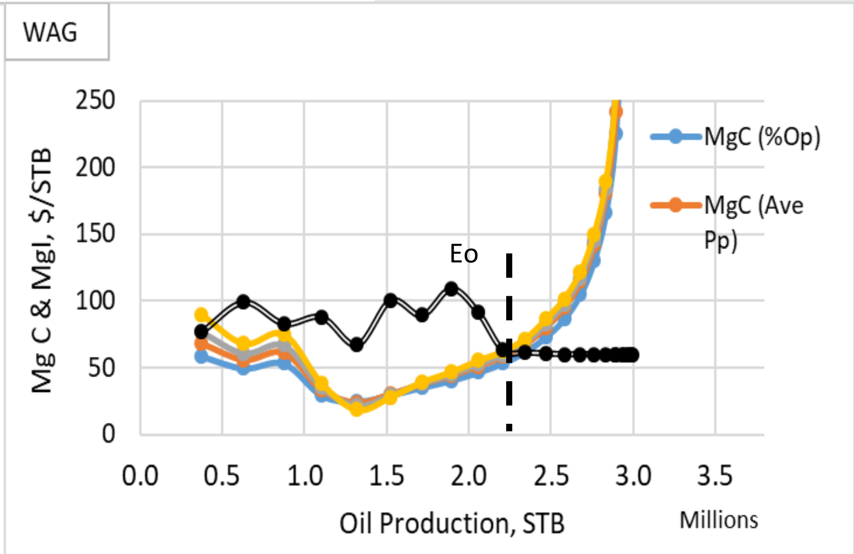
Economic Performance: EOR+ (45Q)

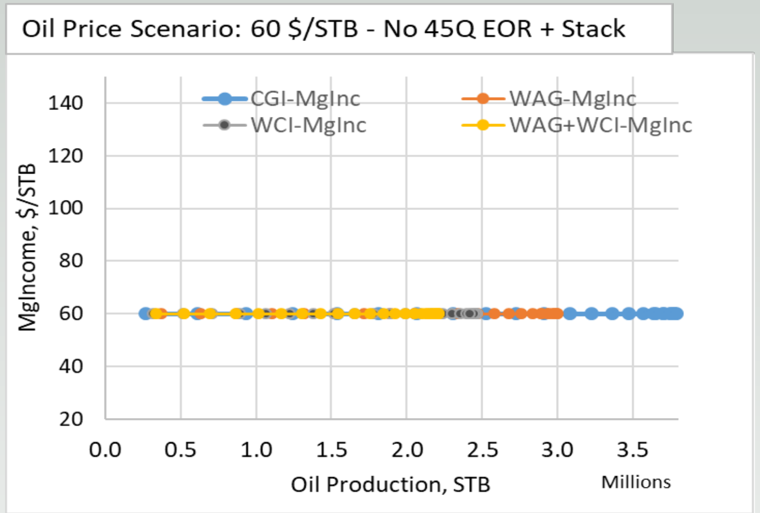


	CGI	WAG
Ave Cost	133,202,261	89,018,825
Ave Benefit	64,088,518	63,504,358
Benefit	**32%**	**42%**
Ave Standart Dev.	6,294,529	4,445,203
%	**10%**	**7%**

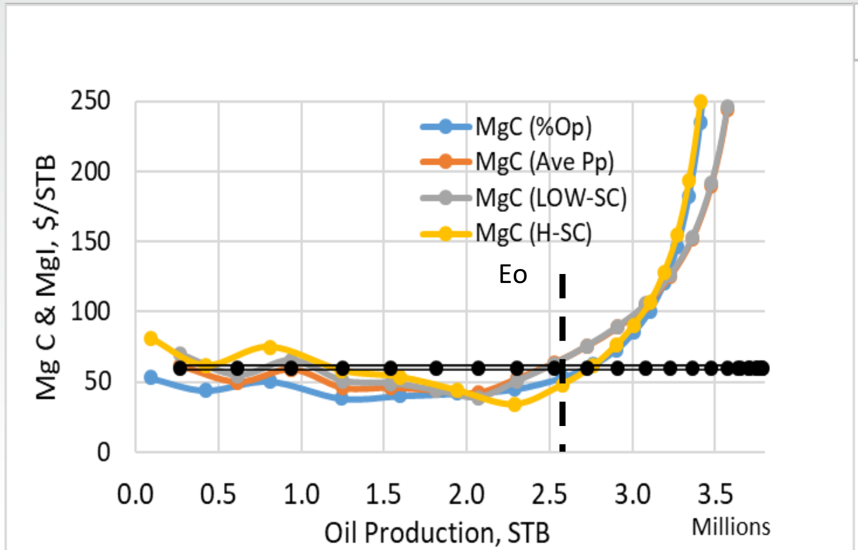


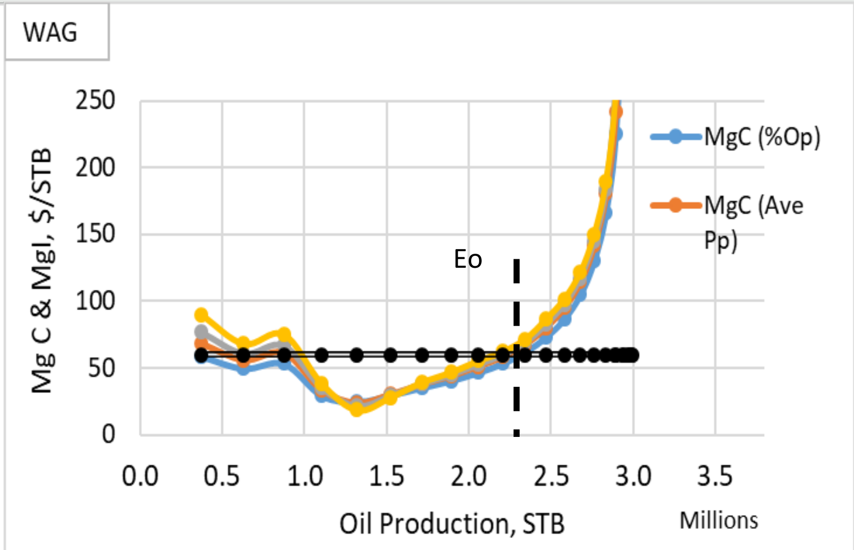


Economic Performance: EOR+

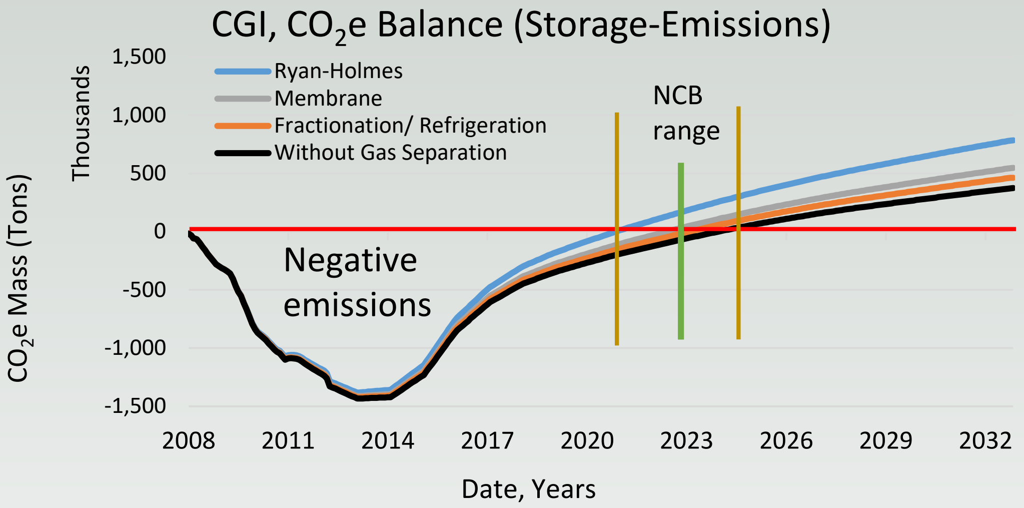


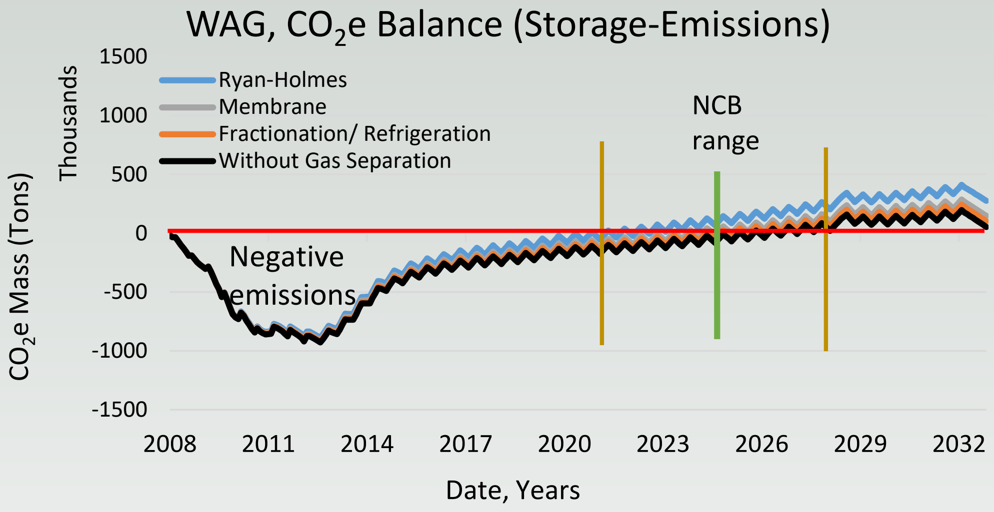
	CGI	WAG
Ave Cost	133,202,261	89,018,825
Ave Benefit	9,518,539	21,952,975
Benefit	**7%**	**20%**
Ave Standart Dev.	6,294,529	4,440,479
%	**66%**	**20%**

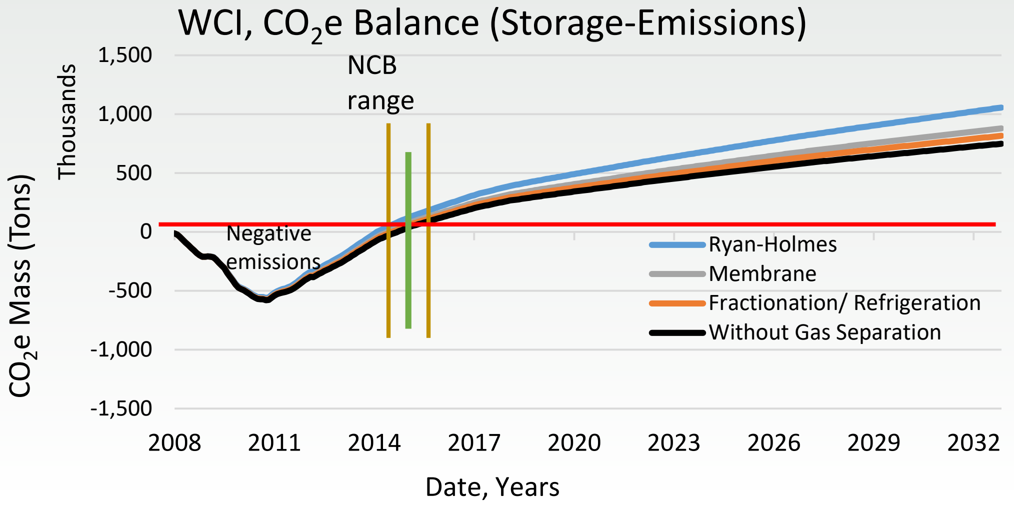


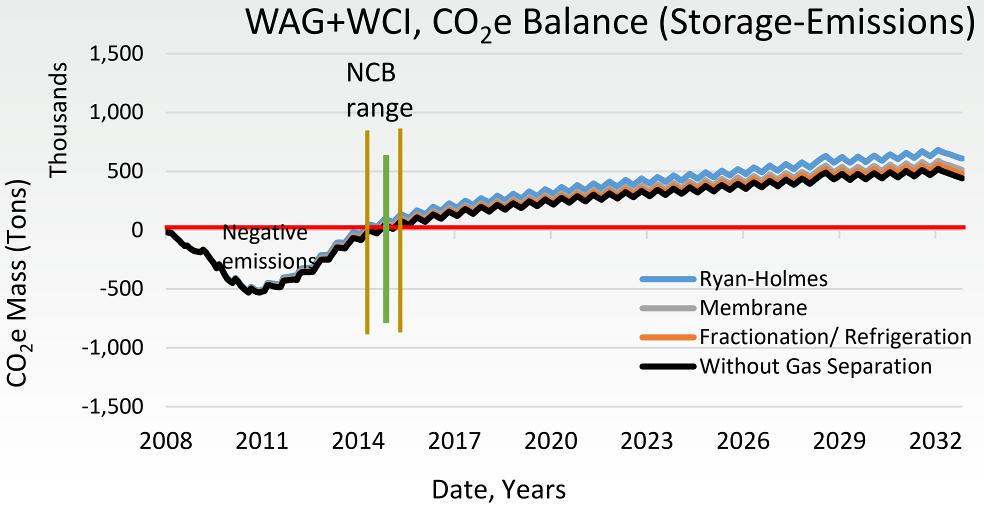


Environmental Performance:Gate-to-Grave (EOR)









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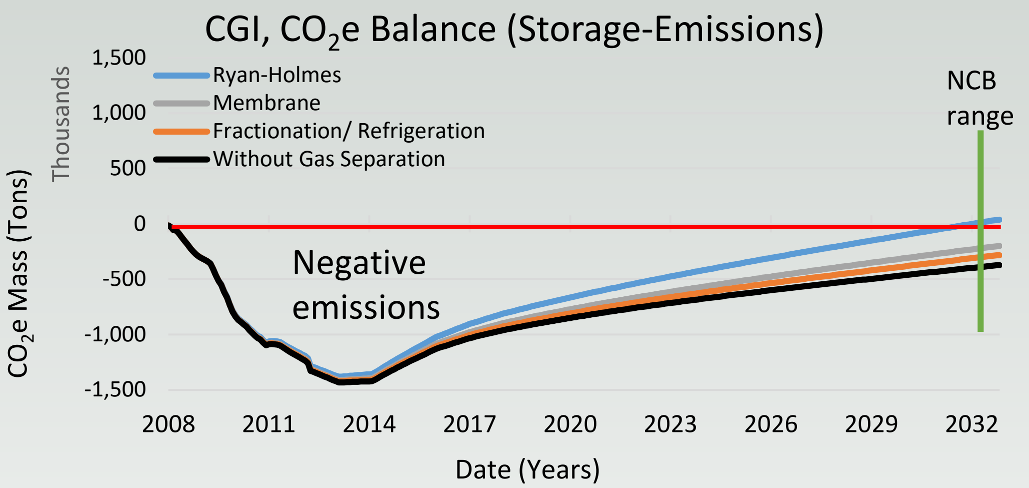
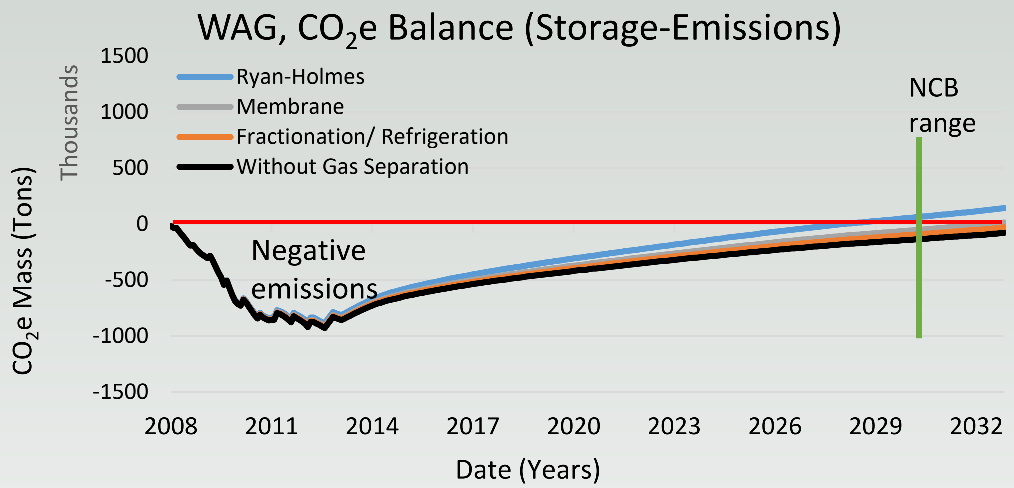
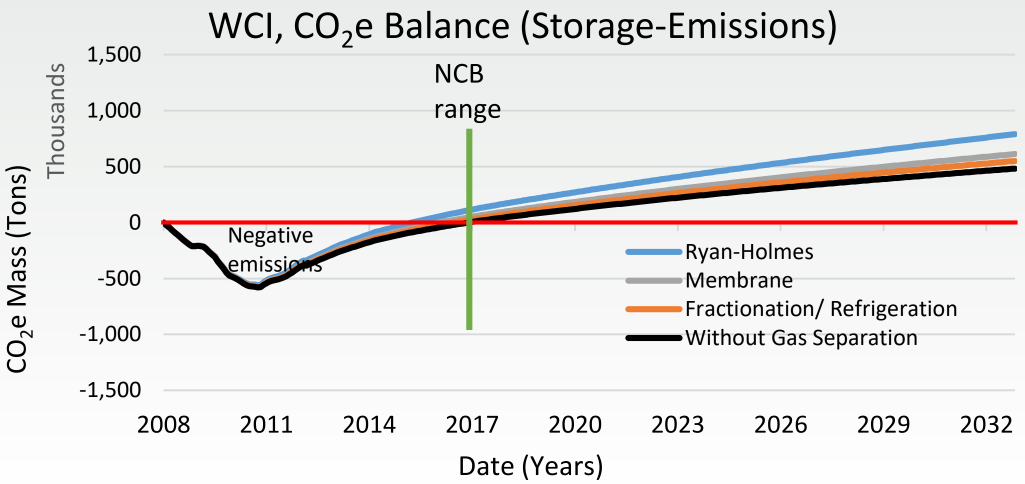
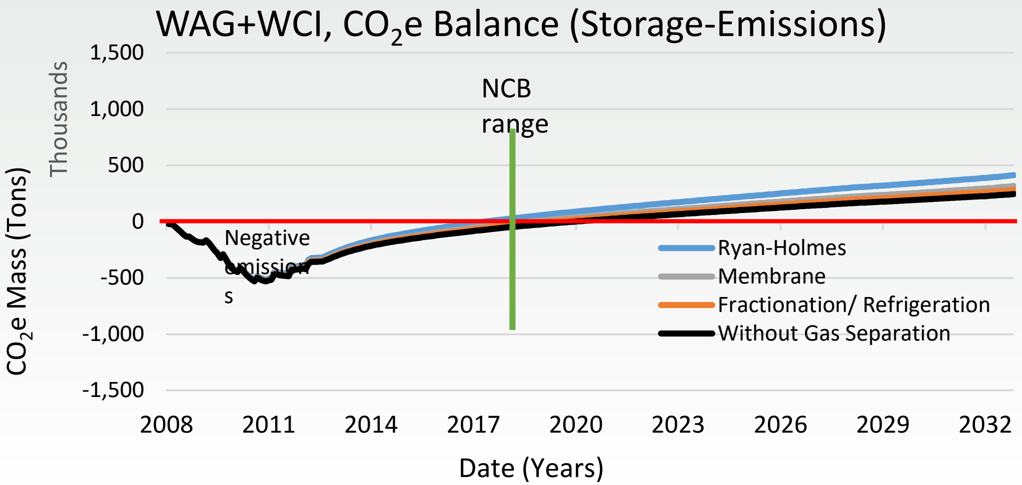
Environmental Performance:Gate-to-Grave (EOR+)









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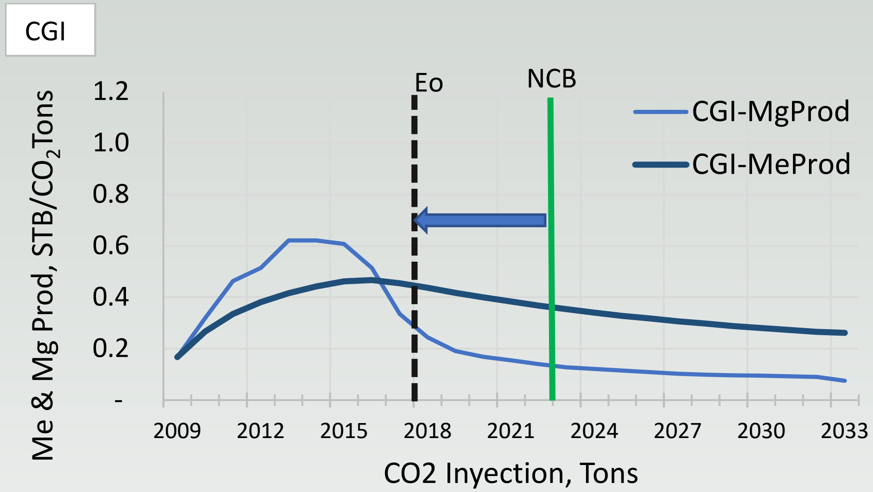
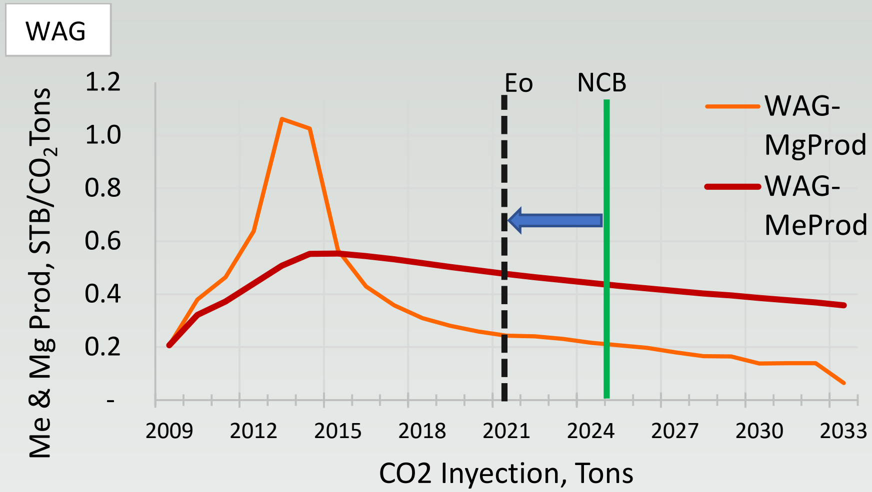
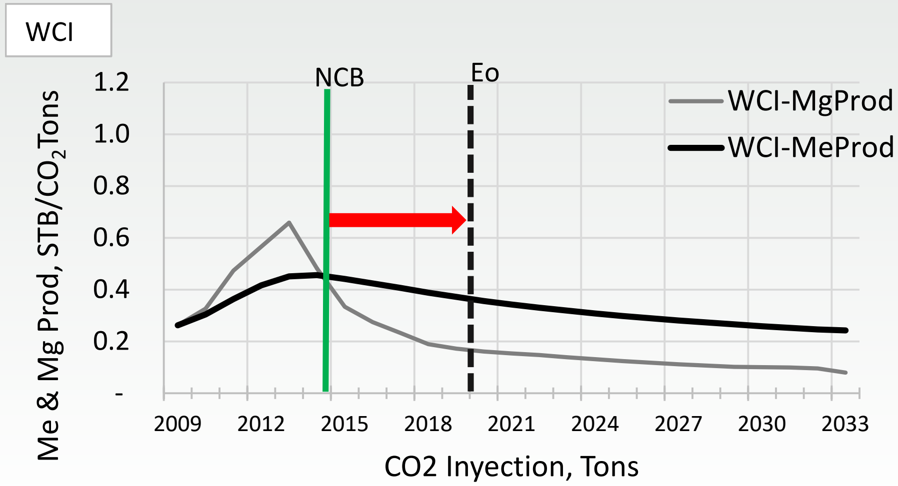
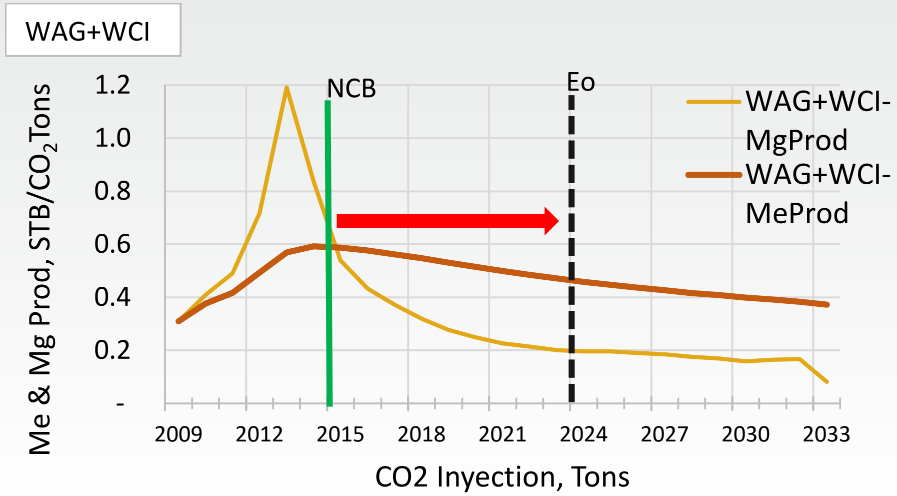
EOR 45Q Sustainability

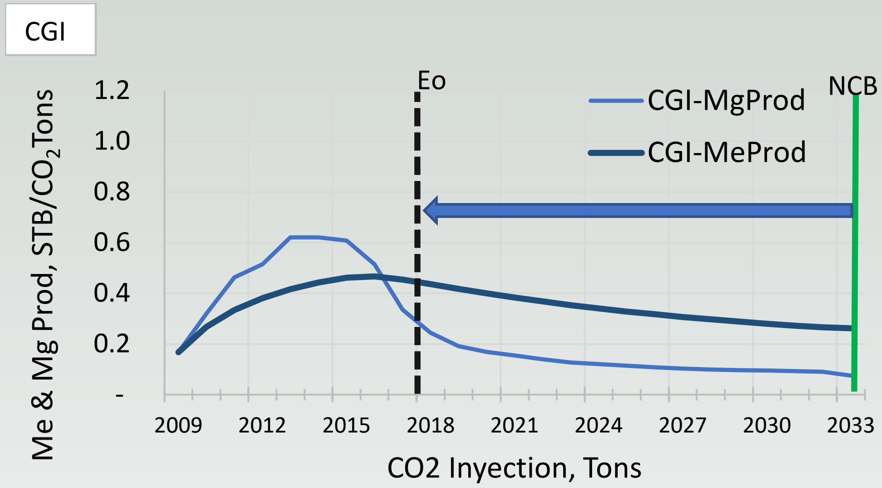


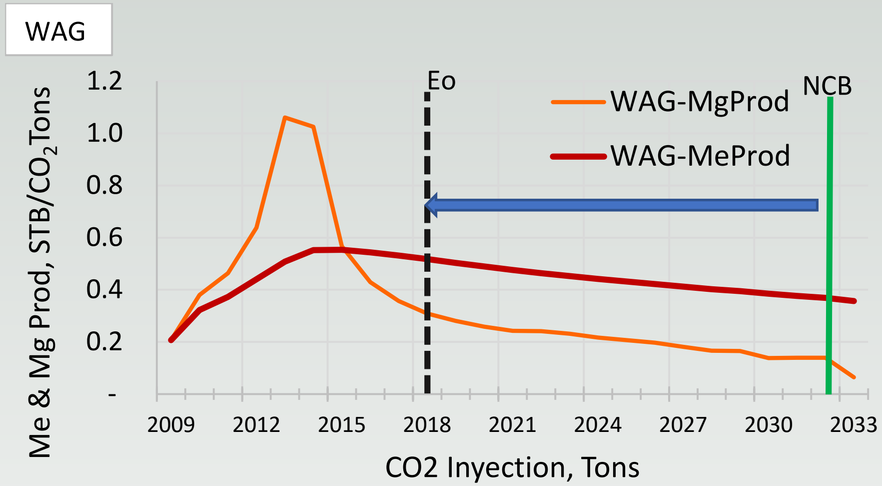


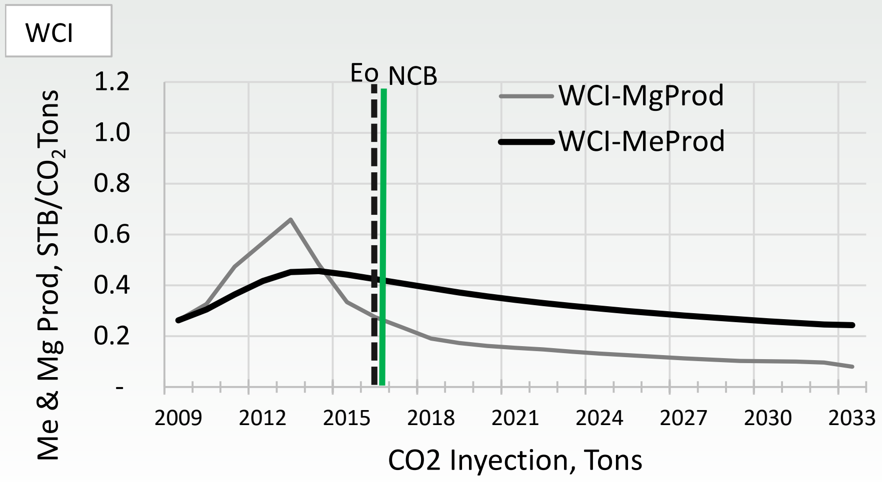


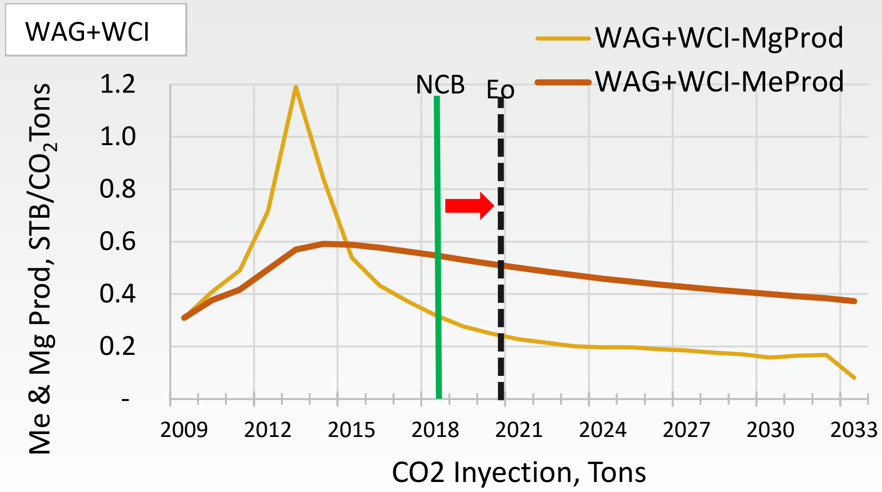


EOR+ 45Q Sustainability









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6. 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<=NCB)
4. **Oil price drives larger impact in the *Eo* than 45Q and CO2 cost**
5. **45Q don't make substantial impact in the *Eo*** but it has mayor impact in the operator's finances.
6. **Assessing CO2-EOR economic performance through a marginalist theory approach is a novel, simple and yet comprehensive process of integrating environmental and socio-economic assessment, which can serve as a tool for decision-making in the meso level, leading to the sustainability in CCUS systems**.

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Next steps

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

Questions?

THANKS!

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Economic functions

Income function:

1. TR = Oil price * STB + Tax Incentive * Vol. CO_2 storage
2. Mg_{INCOME} = Oil price + Tax Incentive (\$/CO2Ton) * CO_2 Utilization rate (CO_2Ton/STB)
3. *Mg_{INCOME} = \$/STB (oil) + \$/STB (45Q)*

Economic Optimum (*Eo*)

MaxB = 0 or MgR=MgC;

Cost function:

1. TC = CAPEX + OPEX
2. Me_{VarC} = 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 the **EOR** (production and injection wells 10,000 ft (21) and **EOR+** (injection wells 10,500 ft (2) *(ARI, 2006; King et all, 2011)*

3. MgC_{VAR} = \$/CO_2Ton * (1/Mg_{PROD}) + \$/Ton * (1/Mg_{CO2rec}) + $MgC_{O\&M}$

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