Economics and Lifecycle Emissions of CO$_2$-EOR

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Three key points

1. Design and operational choices can be made that influence the amount of CO₂ stored in CO₂-EOR

2. Oil and CO₂ prices determine the “optimal” amount of CO₂ to use in CO₂-EOR

3. CO₂-EOR can deliver emissions reductions – even after accounting for combustion emissions – under the right conditions
Injected CO$_2$ drives oil production, is produced alongside the oil and recycled.
CO$_2$-EOR drives increased oil production from the Weyburn Unit

Around 30,000 bbl/day total production, over 20,000 bbl/day due to CO$_2$-EOR

Figure: Cenovus Energy/Malcolm Wilson, PTRC
There are many variables and design decisions in a CO₂-EOR project

**The Reservoir**
- Volume & distribution of oil in place
- Minimum miscibility pressure (MMP)
- Fluid properties
- Petrophysical properties
- Geomechanical properties
- Reservoir structure
- Past reservoir treatments

**Economic Variables**
- Capital costs of material & equipment
- Cost of labor & energy
- Cost of water treatment and disposal
- Cost and availability of CO₂
- Financing structure
- Expected Oil & NGL prices
- Royalties and severance taxes

**Regulatory Requirements**
- Occupational safety
- Air and surface water discharges
- GHG reporting
- Groundwater protection
- Wildlife protection

**Wells & Surface Infrastructure**
- Injection pattern
- Well spacing and infill drilling
- Injector & producer completion design
- Field development plan
- Artificial lift design
- Satellite & central battery capacity
- Natural gas liquids separation
- Recompression capacity and fuel choice
- Surveillance plan

**Operational Plan**
- Reservoir operating pressure
- “WAG” ratio and cycle size
- Injection-withdrawal ratios (VRR)
- Pattern balancing

**Performance**
- Recovery rates and efficiency
- CO₂ utilization & retention (storage)
- Return on investment
Technical Choices Can Impact the Rate of CO$_2$-Storage and Final Volumes

<table>
<thead>
<tr>
<th>Wells &amp; Infrastructure Design</th>
<th>Operating Plan Design</th>
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<tbody>
<tr>
<td>• “Gravity stable” floods$^2$</td>
<td>• Injecting proportionately more CO$_2$ (i.e., in HCPV terms)$^2$</td>
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<tr>
<td>• Targeting “residual oil zones” (ROZs)$^2$</td>
<td>• Optimizing WAG ratio and cycle size$^{1,3,6}$</td>
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<tr>
<td>• Well spacing, types, and placement$^2$</td>
<td>• Simultaneous Water-and-Gas (SWAG)$^5$</td>
</tr>
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<td>• Pattern development schedule$^6$</td>
<td>• Gas-after-water$^1$</td>
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<td>• Straight CO$_2$ injection$^{1,2}$</td>
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<td></td>
<td>• Adjustment of injected gas composition over time$^{1,4}$</td>
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<td></td>
<td>• Well control schemes and (e.g. GOR, BHP)$^{1,4}$</td>
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What factors influence the decision to implement these approaches?

1. Kovscek & Cakici, 2005
2. ARI & Melzer Consulting, 2010
3. Leach, Mason & van ’t Veld, 2011
4. Su et al., 2012
6. Ettehadtavakkol, Lake & Bryant, 2014
Three key points

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Storing CO₂ through EOR – EOR+

Objectives:

- Estimate the global technical potential and distribution
- Explore economics of storage cases
- Consider the emissions reduction potential
- Policy options to overcome barriers to EOR+
- Analysis by the IEA, Rystad Energy and StrategicFit

*International Energy Agency Insights*
*Paper released early in November 2015*
IEA report considers three EOR+ operational models

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Incremental recovery % OOIP</th>
<th>Net Utilisation tCO$_2$/bbl (mscf/bbl)</th>
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</thead>
<tbody>
<tr>
<td>Conventional EOR+</td>
<td>6.5</td>
<td>0.3 (5.7)</td>
</tr>
<tr>
<td>Advanced EOR+</td>
<td>13</td>
<td>0.6 (11.4)</td>
</tr>
<tr>
<td>Maximum Storage EOR+</td>
<td>13</td>
<td>0.9 (17.1)</td>
</tr>
</tbody>
</table>

- All projects undertake four storage-focused activities, i.e., the “+” in EOR+
- CO$_2$ is assumed to be captured from anthropogenic sources for the purpose of avoiding emissions
Shifting from conventional EOR to EOR+

1. **Site characterisation** to collect information on overlying cap-rock and geological formations, as well as abandoned wellbores, and **assessment of the risk of CO₂ leakage of from the reservoir**.

2. **Measurement of venting and fugitive emissions** from surface processing equipment.

3. **Monitoring and enhanced field surveillance** aimed at identifying and, if necessary, estimating leakage rates from the site and assessing whether the reservoir behaves as anticipated.

4. **Well abandonment processes** that increase confidence in long-term containment of injected CO₂, in particular to ensure they withstand the corrosive effects of CO₂-water mixtures.
Modelled core functional activities to examine different EOR practices

- **CO₂ Recycling compression**
- **CO₂/gas separation and clean up**
- **Oil / gas / water separation**
- **CO₂ Injection**
- **CO₂ Recycled CO₂ re-injected**
- **Purchased CO₂**
- **Long-term monitoring**
- **Gas, CO₂**
- **Export Gas**
- **Export Oil**
- **Produced water**
- **Reservoir**

Figure: Modified from IEA, 2015
Stylized model of three phases of incremental oil production after CO$_2$ is first injected

- **Phase 1**
  - CO$_2$ begins to be injected and incremental oil production is ramping up

- **Phase 2**
  - Plateau production before CO$_2$ breakthrough

- **Phase 3**
  - Exponential decline of the incremental oil production

Figure: Chris Jones, StrategicFit
The CO₂ required for EOR is initially purchased but gradually recycled volumes dominate

- **Phase 1**
  - New patterns are being brought online; CO₂ injection increases

- **Phase 2**
  - First breakthrough occurs, earlier for Conventional EOR+ than Advanced EOR+/Max Storage

- **Phase 3**
  - CO₂ is produced with the oil and is recycled at all wells

Figure: Chris Jones, StrategicFit
How CO\textsubscript{2} prices evolve will have a major impact either as a revenue stream or as a cost

- Considered CO\textsubscript{2} supply price from the \textit{perspective of an EOR operator}
- Used global averages of IEA 2°C Scenario (2DS), 4DS and 6DS CO\textsubscript{2} emission prices and a $40/t cost for capture to calculate the supply cost—i.e., what an EOR operator would have to pay (or receive) for CO\textsubscript{2}
- In the 4DS and 6DS the cost of capture is greater than any emission penalty, the CO\textsubscript{2} would be sold to an EOR operator, as is typical today—CO\textsubscript{2} a cost
- In the 2DS, the emissions price is greater than the cost of capture, so an EOR operator would be paid to verifiably store CO\textsubscript{2}—CO\textsubscript{2} is a revenue stream

Figure: IEA, 2015
The Advanced EOR+ strategy appears optimal for each of the future scenarios

- In a 2DS, Max Storage & Advanced EOR+ gain revenues by storing extra CO₂.
- In 4DS & 6DS Max Storage looks worse due to additional CO₂ purchasing costs.
- All scenarios have oil prices greater than $90/bbl, rising to $150/bbl in 6DS.

Figure: IEA, 2015
What drives the difference between different practices in a 2DS world?

- Increased oil revenues of Advanced EOR+ outweigh additional costs compared to Conventional EOR+
- Extra CO₂ revenues in Maximum Storage can’t overcome the cost increase as there is no further incremental oil

Figure: IEA, 2015
What would CO₂ and Oil prices have to be to make each strategy best?

- Advanced EOR+ is more attractive than Conventional EOR+ at not only lower (and negative) CO₂ supply prices, but also at higher oil prices (i.e., additional injection of CO₂ allows additional production).

- Very low supply prices are required to make Maximum Storage EOR+ attractive (i.e., more storage, but no additional oil production).

Figure: IEA, 2015
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1. Design and operational choices can be made that influence the amount of CO$_2$ stored in CO$_2$-EOR

2. Oil and CO$_2$ prices determine the “optimal” amount of CO$_2$ to use in CO$_2$-EOR

3. CO$_2$-EOR can deliver emissions reductions – even after accounting for combustion emissions – under the right conditions
Estimating lifecycle emissions from CO$_2$-EOR is complex and results are often contentious

- Multiple studies have looked at the emissions impact of CO$_2$-EOR operations, e.g.:

  Aycaguer et al., 2001; Khoo & Tan, 2006; Suebsiri et al., 2006; Jaramillo et al., 2009; Falitnson & Guner, 2011; Wong et al., 2013; Cooney et al., 2015

- On first inspection, studies seem to reach different conclusions; however, they make very different choices of **boundaries, approaches and assumptions**

- They have been based on **limited data from real operations**

  CO$_2$-EOR is “no more a climate solution than drilling in ultra-deepwater, hydro-fracking, or drilling in the Arctic Ocean.” – Greenpeace
Important observations from past life-cycle assessment research into CO$_2$-EOR

1. Emissions depend on boundaries:
   a) Including combustion emissions from oil makes business-as-usual (BAU) CO$_2$-EOR a net emitter
   b) Changes to design and operation of BAU CO$_2$-EOR could decrease the CO$_2$ footprint

2. If energy-related emissions that would otherwise be produced from a functionally equivalent system are displaced, CO$_2$-EOR reduces emissions

3. Emissions reduction efficiency is a function of both energy displacement and CO$_2$ utilization
   a) Displacement of relatively more CO$_2$-intensive energy results in a relatively larger emissions reductions
The emissions, to what they can be allocated, and the way in which they are allocated depends heavily on the boundaries (Skone, 2013)
Regardless of boundaries, storing more CO$_2$ per barrel is beneficial for emissions.
Widespread CO$_2$-EOR would impact the price and demand for oil

1. How much production is displaced by CO$_2$-EOR?
2. How much additional production results from CO$_2$-EOR?
3. What is the resulting net impact on emissions?

Figure: IEA, 2015
Under the IEA 6DS scenario, about 20% of production would be additional

- More costly production is displaced: this is often, but not always, more carbon intensive (Gordon et al., 2015)
- Hence, we assume a “like-for-like” displacement

Figure: IEA, 2015
With displacement, even Conventional EOR+ can deliver a benefit

*Conventional crude of about 470 kgCO₂/bbl (Gordon et al., 2015); 80% displacement.
Three main barriers to reduce emissions via EOR+

1. Expanding the use of EOR – regardless of the “+”

2. Encouraging adoption of practices to “store” CO$_2$ consistent with the climate change mitigation objectives – the “+” in EOR+

3. Utilizing more CO$_2$ as part of the EOR extraction process

*Important to note that there are other legal barriers in the US to EOR*
Ensuring effective storage through CO$_2$-EOR

**Problem:** Little incentive to undertake the additional activities and reporting that make EOR+

**Solution:** Appropriate regulatory requirements for the “+” that activate whenever emissions are being avoided and:

1. Providing support to test, de-risk, and build experience with needed technologies
2. Resolve legal barriers that limit storage through CO$_2$-EOR (e.g., preference for oil production over CO$_2$-storage)
Using more CO$_2$ per barrel

**Problem:** Emissions reduction benefits are maximized when more CO$_2$ is used per barrel of oil recovered.

**Solution:** Let the market do the work:

1. Declining supply costs of CO$_2$ or increasing prices of oil – *ceteris paribus* – should lead to increased consumption of CO$_2$ by an EOR operator.
2. Pricing of CO$_2$ emissions or comparable regulatory interventions should expand the supply of CO$_2$ and drive down prices.
Three key points

1. Design and operational choices can be made that influence the amount of CO$_2$ stored in CO$_2$-EOR

2. Under some scenarios, it can be profitable to use and store relatively more CO$_2$

3. CO$_2$-EOR can deliver emissions reductions – even after accounting for combustion emissions – under the right conditions
Thank-you!

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References (1)


References (2)


