Economics and Lifecycle Emissions of CO_2-EOR

ARB CCS Technical Discussion Series
Sacramento, CA

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23 August 2016

LLNL-PRES-701098
This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

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Three key points

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

Injected CO_2 drives oil production, is produced alongside the oil and recycled

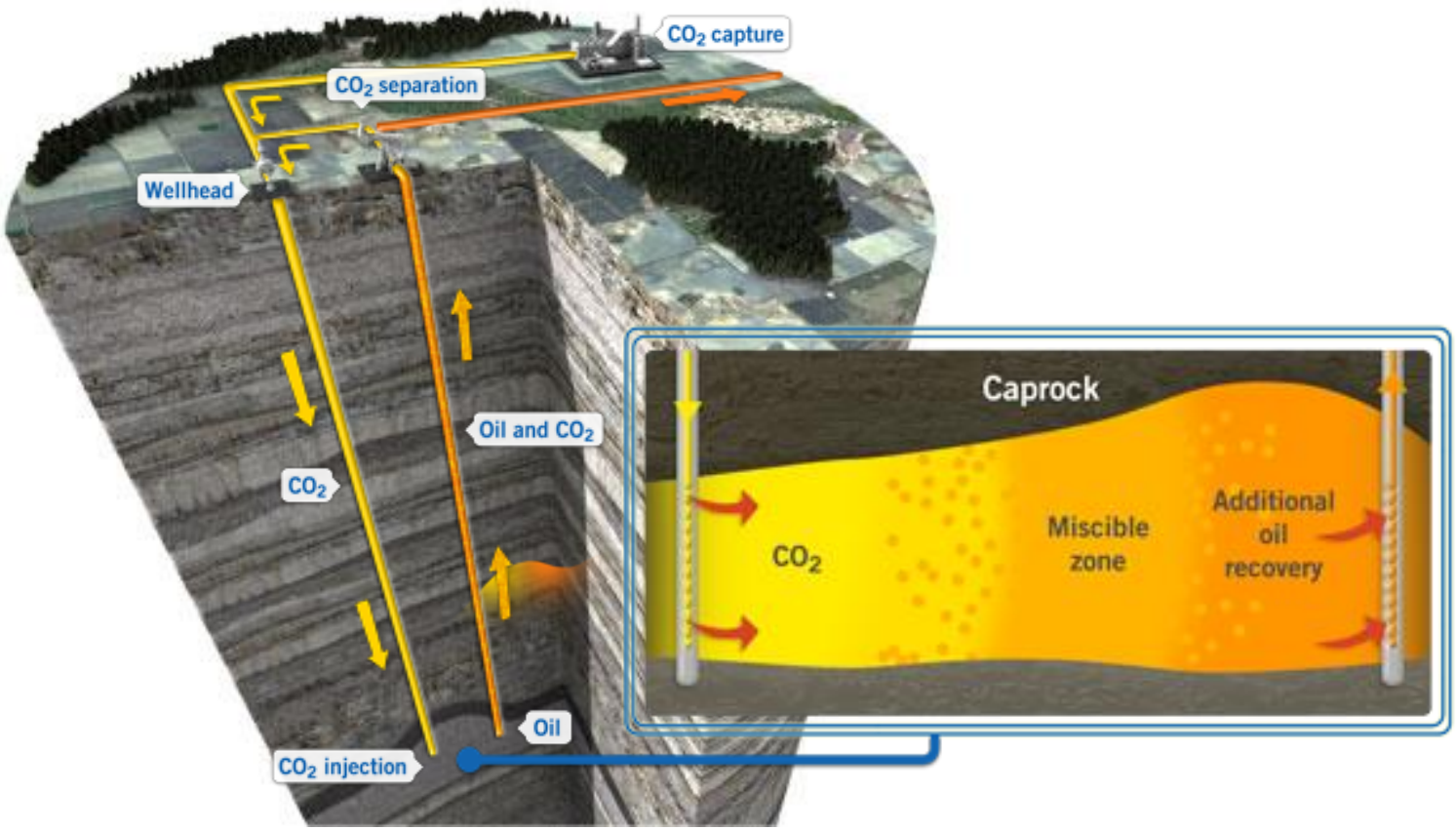

Image: Global CCS Institute

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

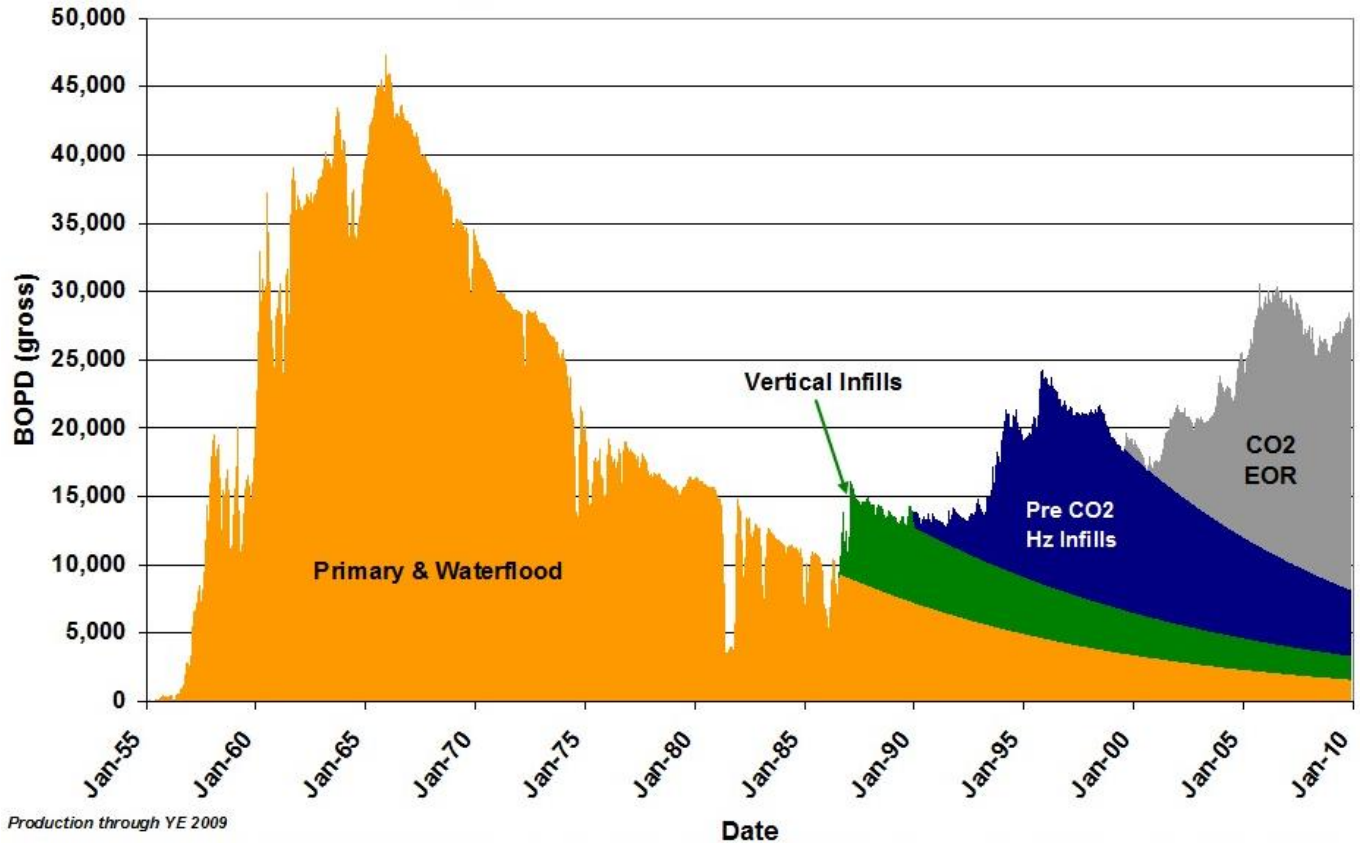

Figure: Cenovus Energy/Malcolm Wilson, PTRC

There are many variables and design decisions in a CO_2-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 CO_2
- 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
- CO_2 utilization & retention (storage)
- Return on investment

Technical Choices Can Impact the Rate of CO_2-Storage and Final Volumes

Wells & Infrastructure Design	Operating Plan Design
• "Gravity stable" floods[2] • Targeting "residual oil zones" (ROZs)[2] • Well spacing, types, and placement[2] • Pattern development schedule[6]	• Injecting proportionately more CO_2 (i.e., in HCPV terms)[2] • Optimizing WAG ratio and cycle size[1,3,6] • Simultaneous Water-and-Gas (SWAG)[5] • Gas-after-water[1]
• Straight CO_2 injection[1,2] • Adjustment of injected gas composition over time[1,4] • Well control schemes and (e.g. GOR, BHP)[1,4]	

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
5. Kamali & Cinar, 2013
6. Ettehadtavakkol, Lake & Bryant, 2014

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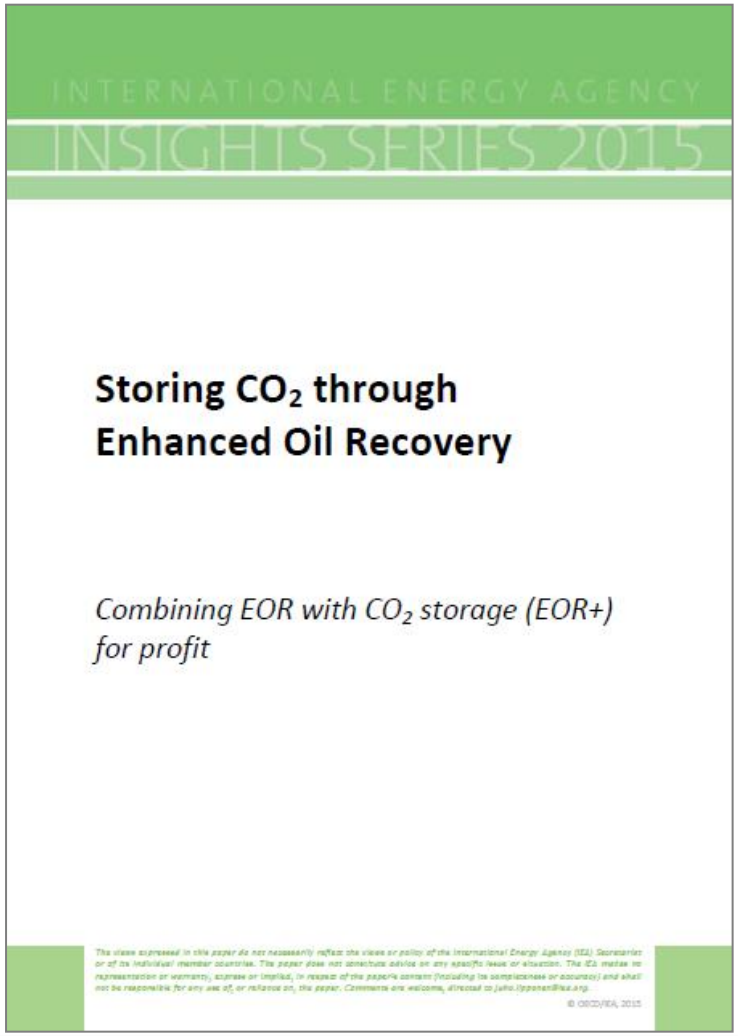
Storing CO_2 through EOR – EOR+

International Energy Agency Insights Paper released early in November 2015

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 SERIES 2015

Storing CO_2 through Enhanced Oil Recovery

Combining EOR with CO_2 storage (EOR+) for profit

IEA report considers three EOR+ operational models

Scenario	Incremental recovery % OOIP	Net Utilisation tCO_2/bbl (mscf/bbl)
Conventional EOR+	6.5	0.3 (5.7)
Advanced EOR+	13	0.6 (11.4)
Maximum Storage EOR+	13	0.9 (17.1)

- 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** CO_2 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 CO_2, in particular to ensure they withstand the corrosive effects of CO_2-water mixtures.

Modelled core functional activities to examine different EOR practices

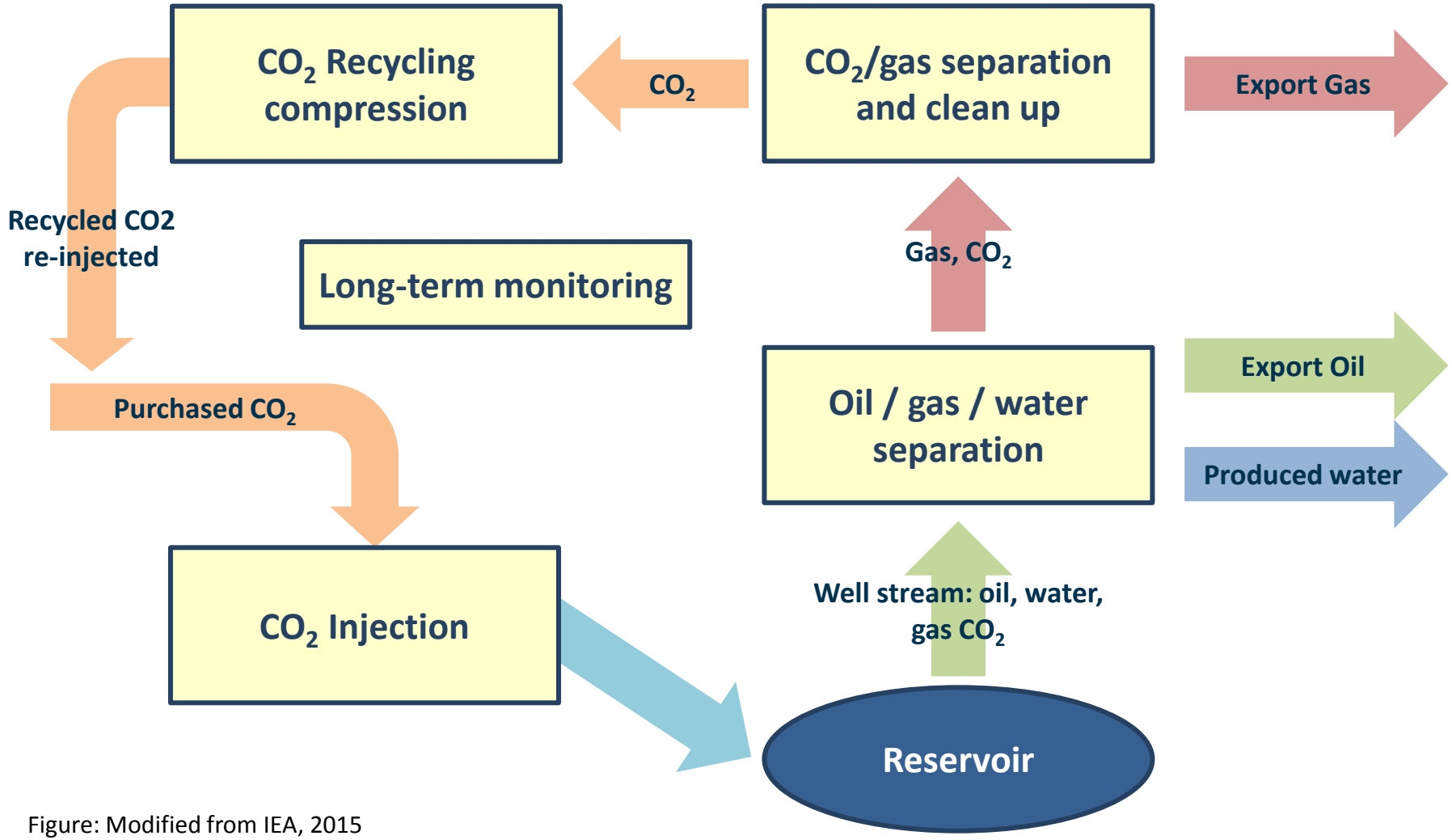
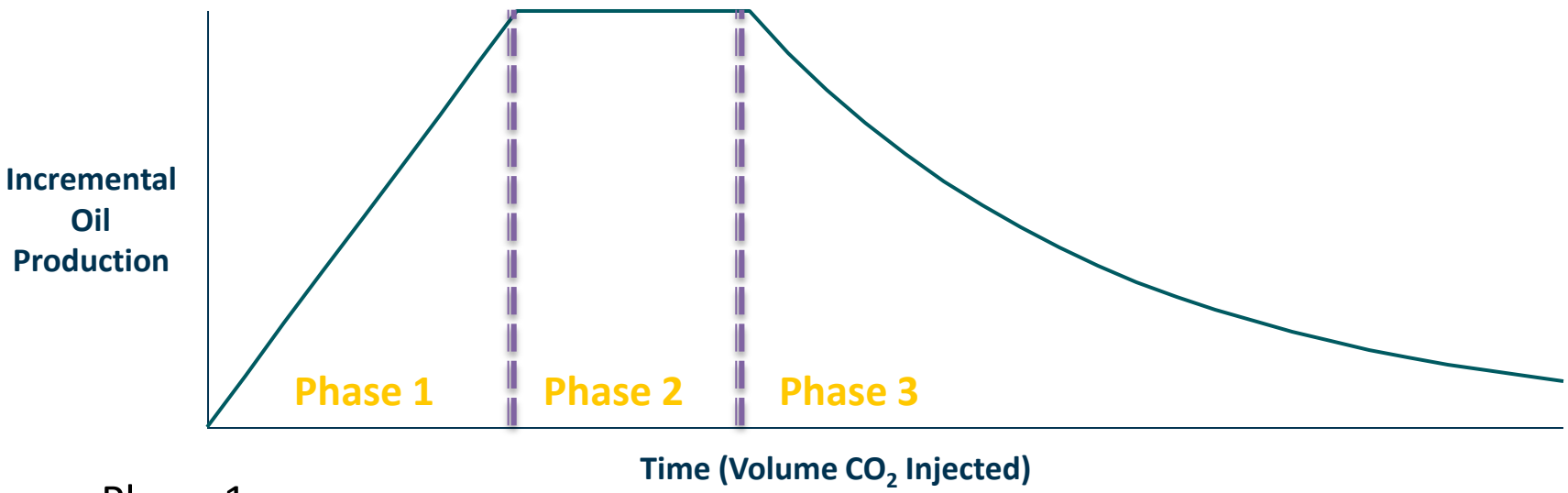


Figure: Modified from IEA, 2015

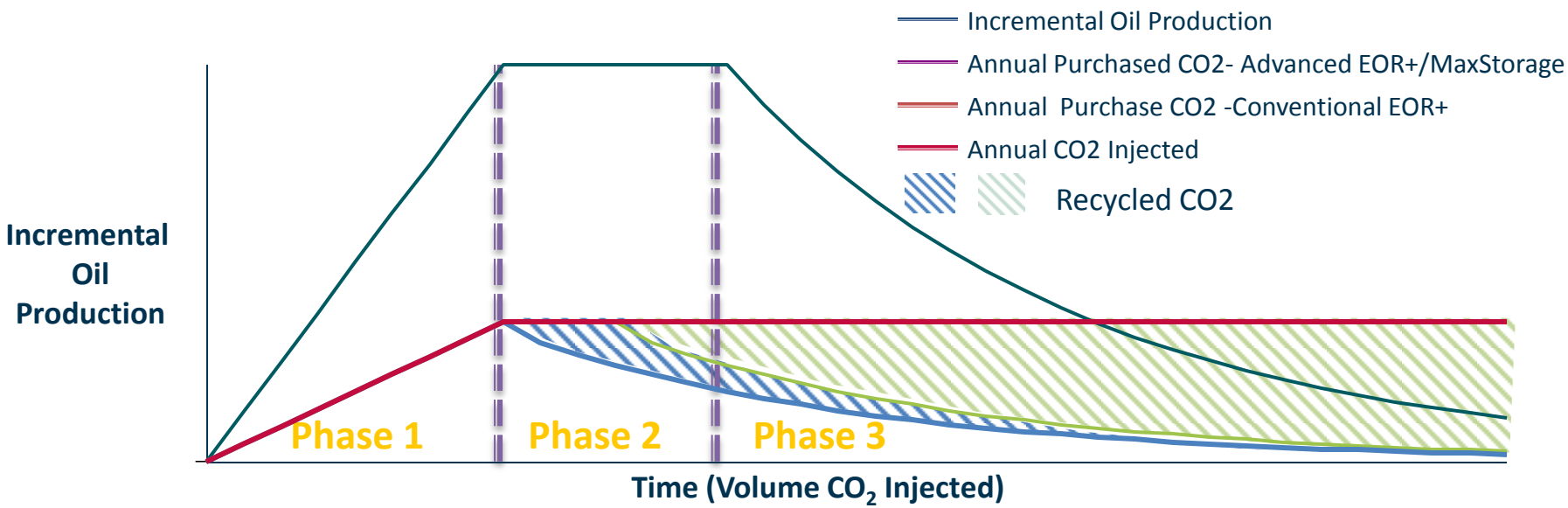
Stylized model of three phases of incremental oil production after CO_2 is first injected



- 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 CO_2 required for EOR is initially purchased but gradually recycled volumes dominate



- Phase 1
  - New patterns are being brought online; CO_2 injection increases
- Phase 2
  - First breakthrough occurs, earlier for Conventional EOR+ than Advanced EOR+/Max Storage
- Phase 3
  - CO_2 is produced with the oil and is recycled at all wells

Figure: Chris Jones, StrategicFit

How CO_2 prices evolve will have a major impact either as a revenue stream or as a cost

- Considered CO_2 supply price from the *perspective of an EOR operator*
- Used global averages of IEA 2°C Scenario (2DS), 4DS and 6DS CO_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_2
- In the 4DS and 6DS the cost of capture is greater than any emission penalty, the CO_2 would be sold to an EOR operator, as is typical today- **CO_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_2 – **CO_2 is a revenue stream**

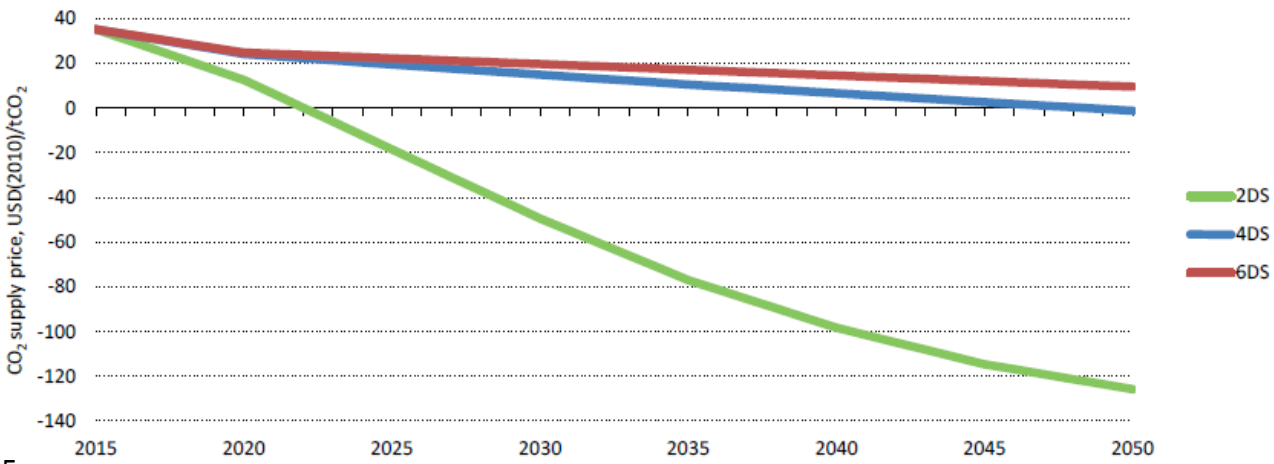
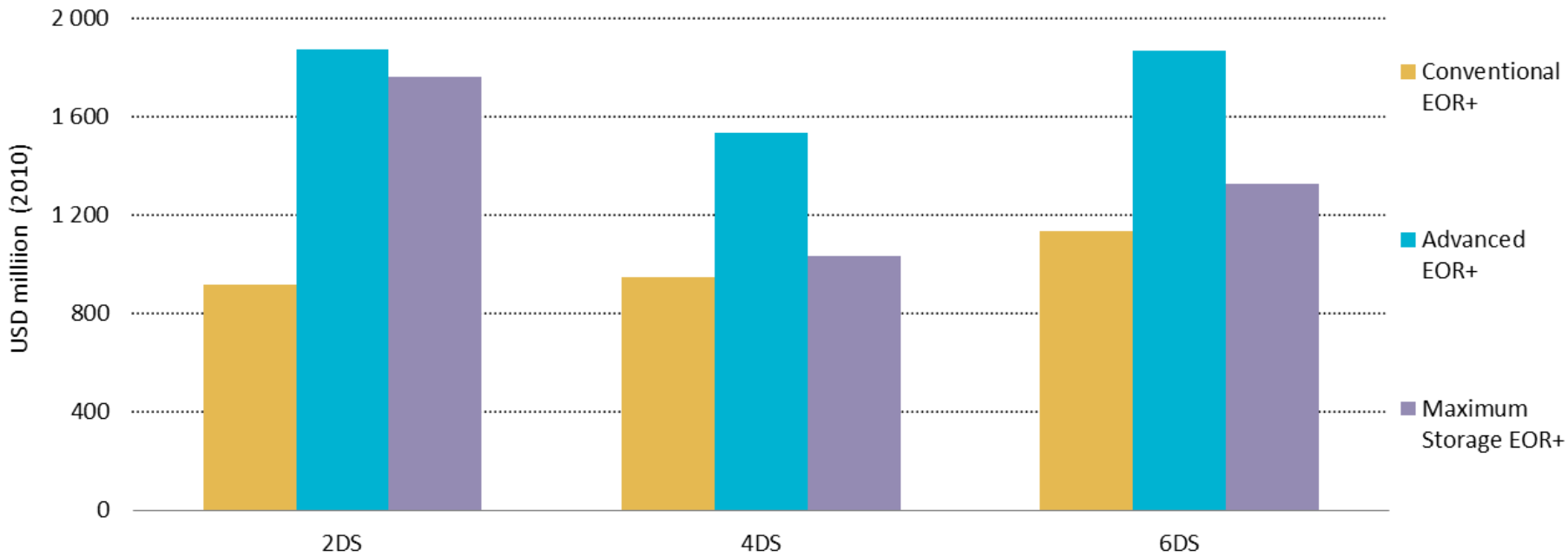


Figure: IEA, 2015

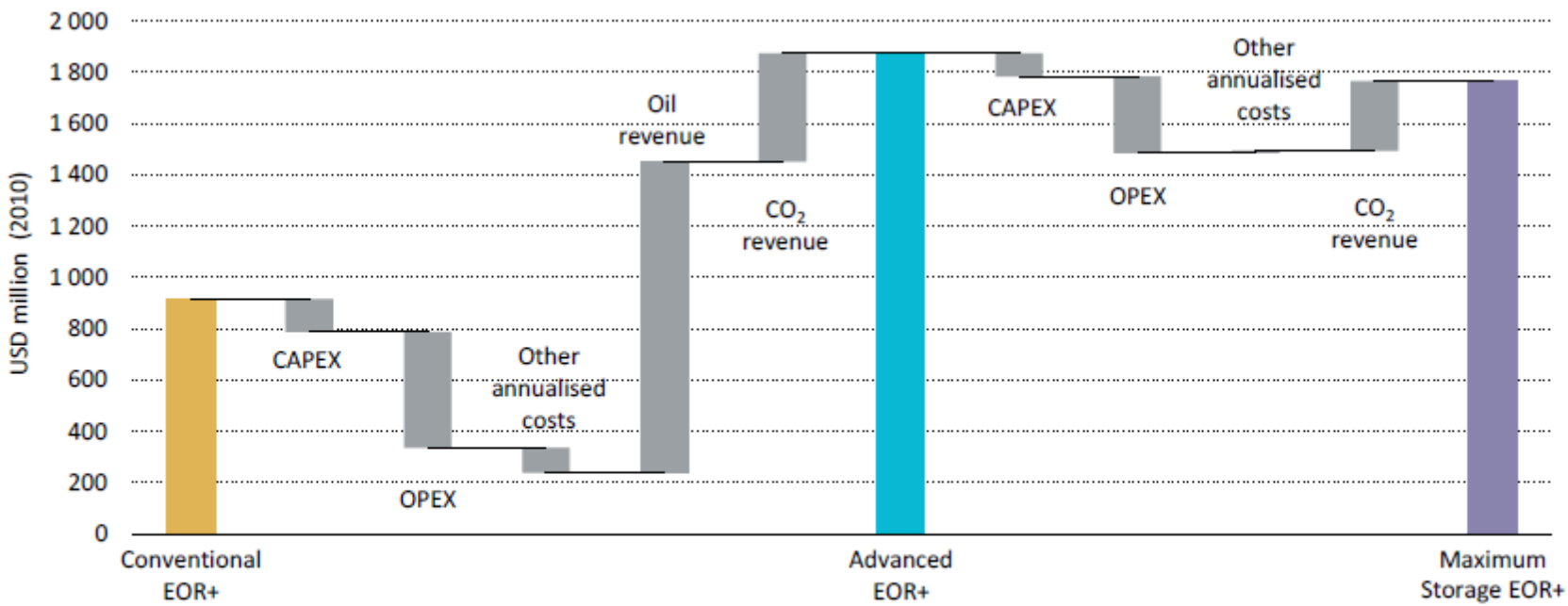
The Advanced EOR+ strategy appears optimal for each of the future scenarios



- In a 2DS, Max Storage & Advanced EOR+ gain revenues by storing extra CO_2
- In 4DS & 6DS Max Storage looks worse due to additional CO_2 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?



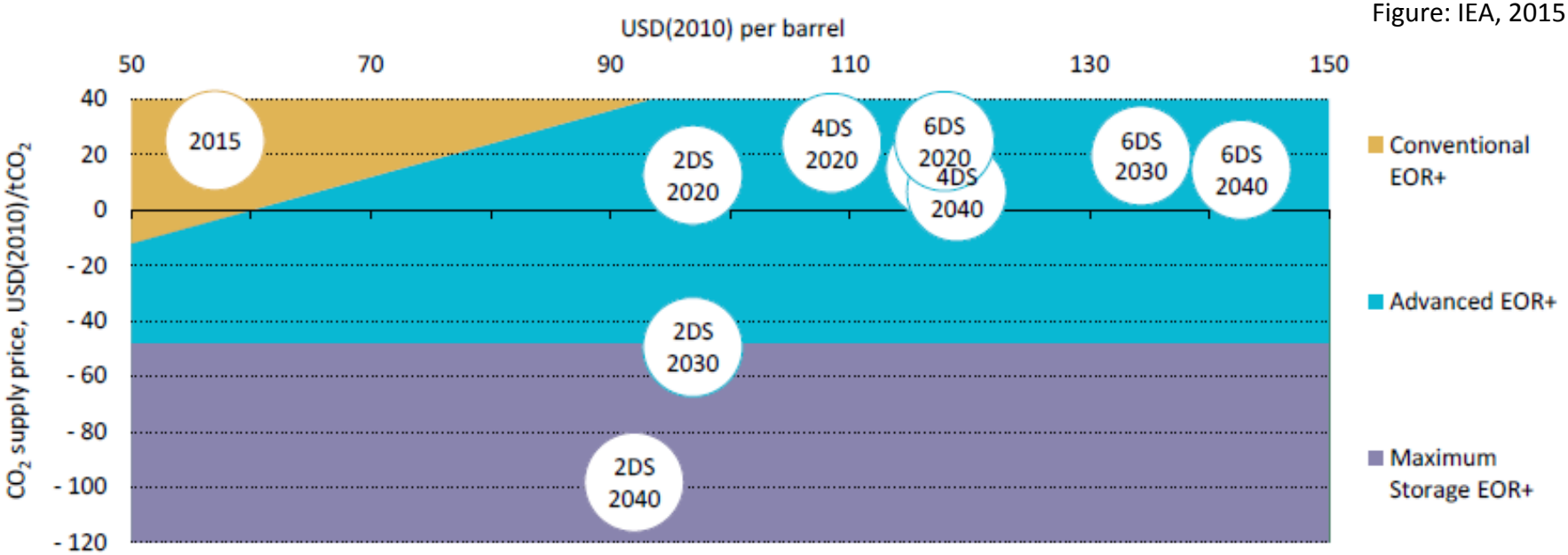
Notes: Other annualised costs include changes to produced water management and CO_2 storage monitoring costs. CAPEX = capital expenditures; OPEX = operational expenditures.

- Increased oil revenues of Advanced EOR+ outweigh additional costs compared to Conventional EOR+
- Extra CO_2 revenues in Maximum Storage can't overcome the cost increase as there is no further incremental oil

Figure: IEA, 2015

What would CO_2 and Oil prices have to be to make each strategy best?

Figure: IEA, 2015



- Advanced EOR+ is more attractive than Conventional EOR+ at not only lower (and negative) CO_2 supply prices, but also at higher oil prices (i.e., additional injection of CO_2 allows additional production)
- Very low supply prices are required to make Maximum Storage EOR+ attractive (i.e., more storage, but no additional oil production)

Three key points

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

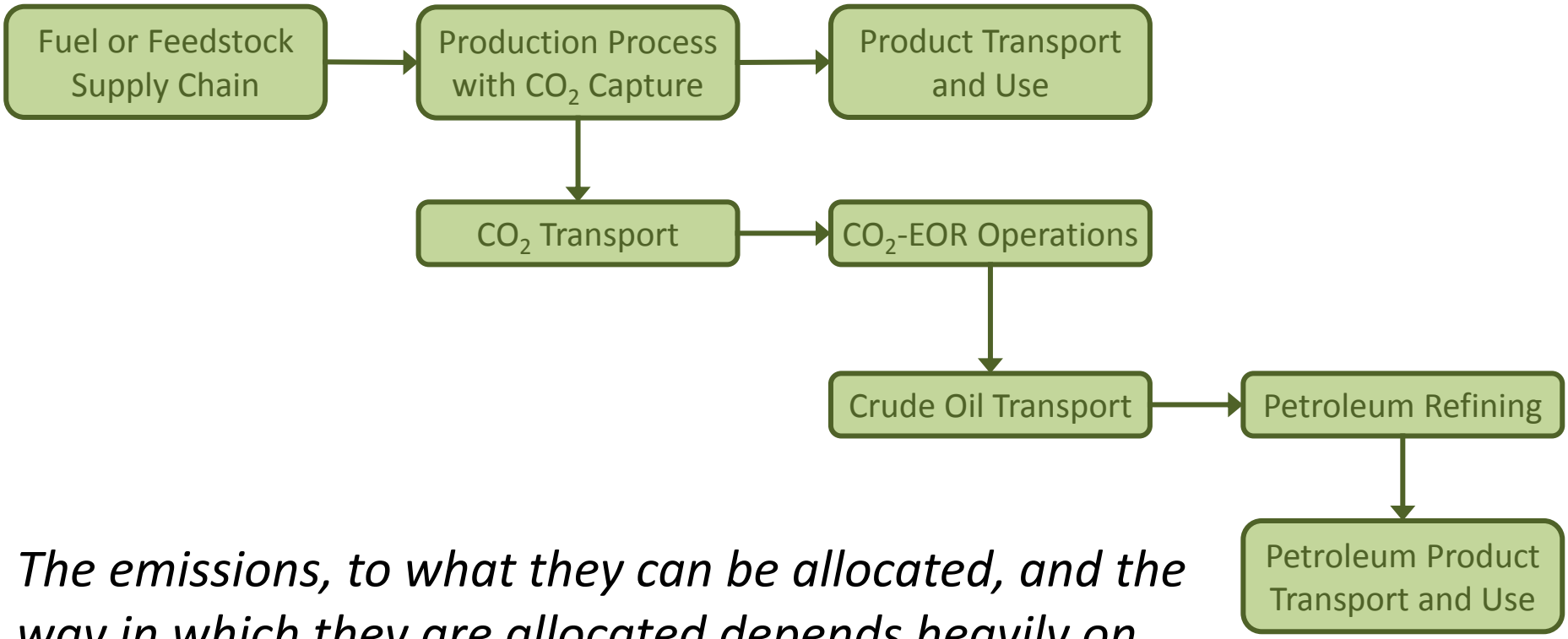
Important observations from past life-cycle assessment research into CO_2-EOR

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

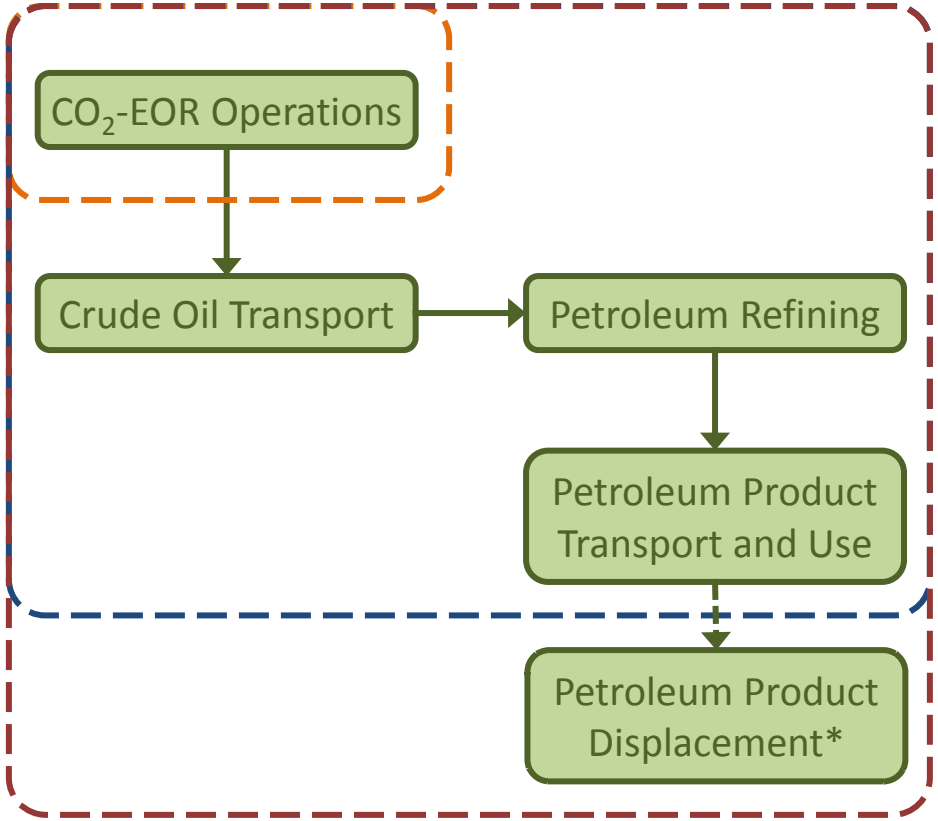
3. Emissions reduction efficiency is a function of both energy displacement and CO_2 utilization
   a) Displacement of relatively more CO_2-intensive energy results in a relatively larger emissions reductions

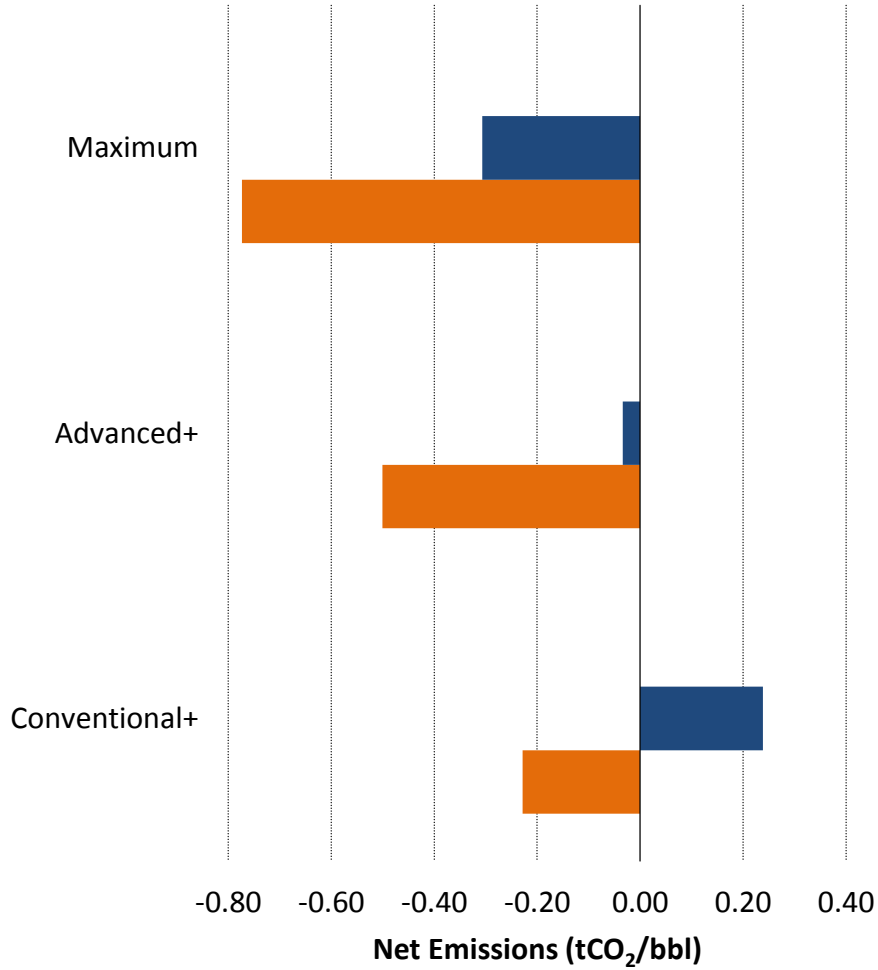
The boundaries used to assess emissions from CO_2-EOR matter



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?

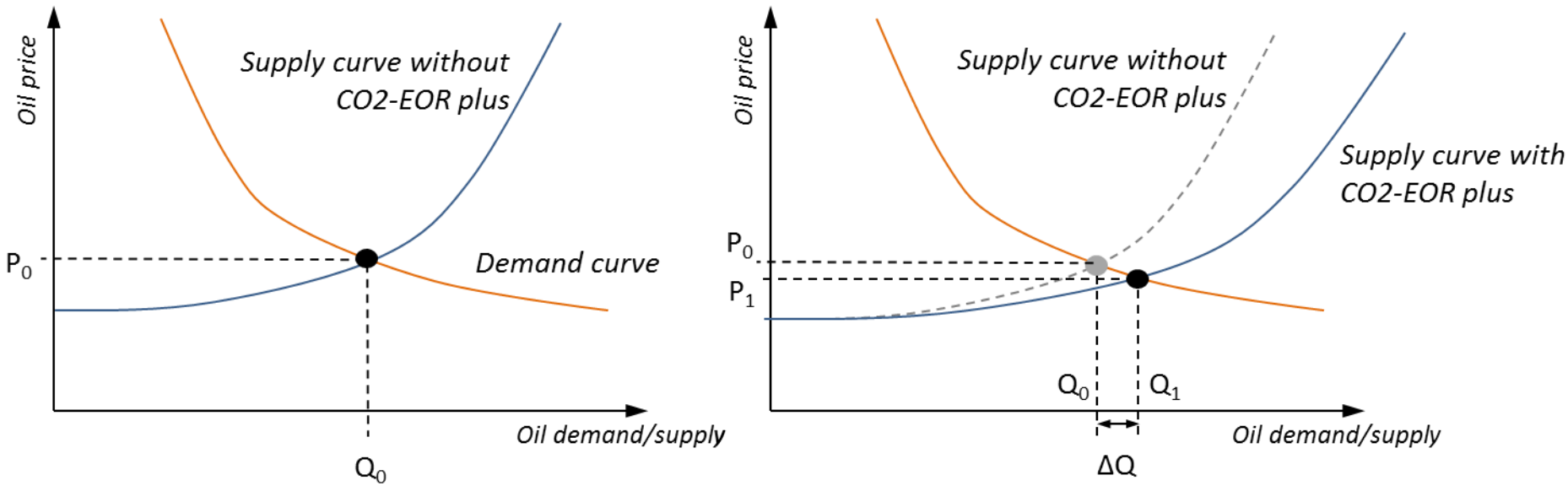
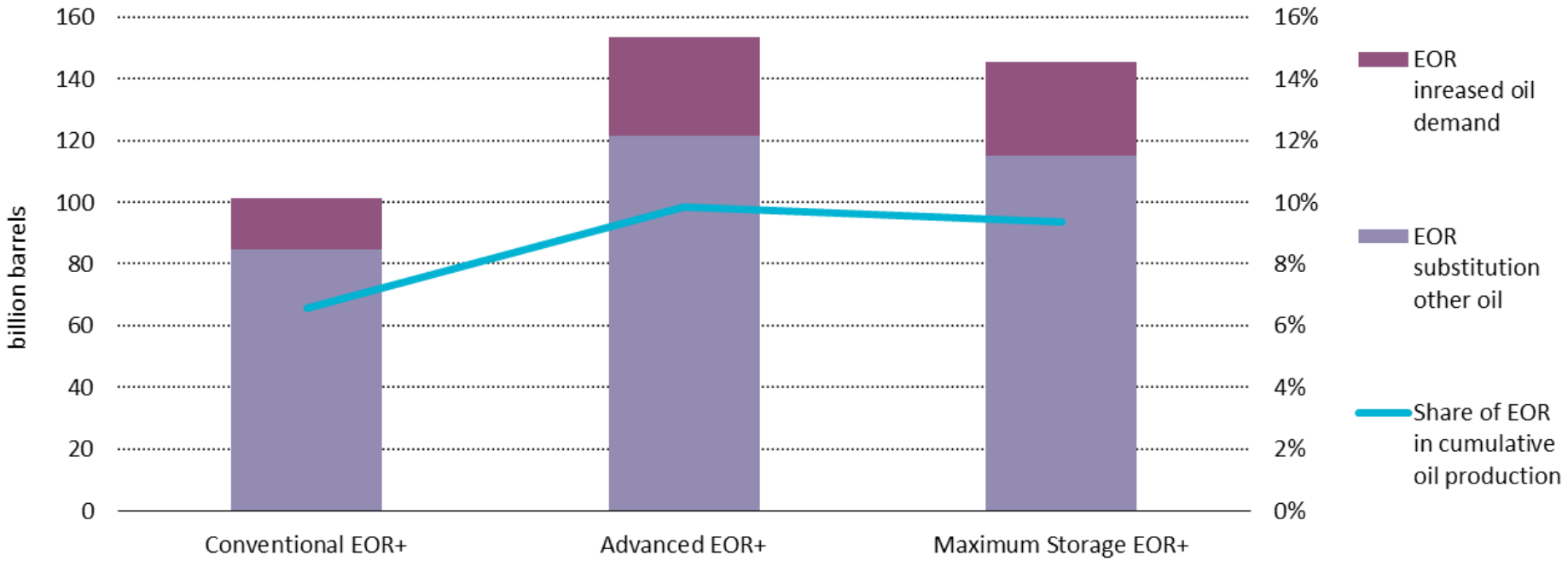


Figure: IEA, 2015

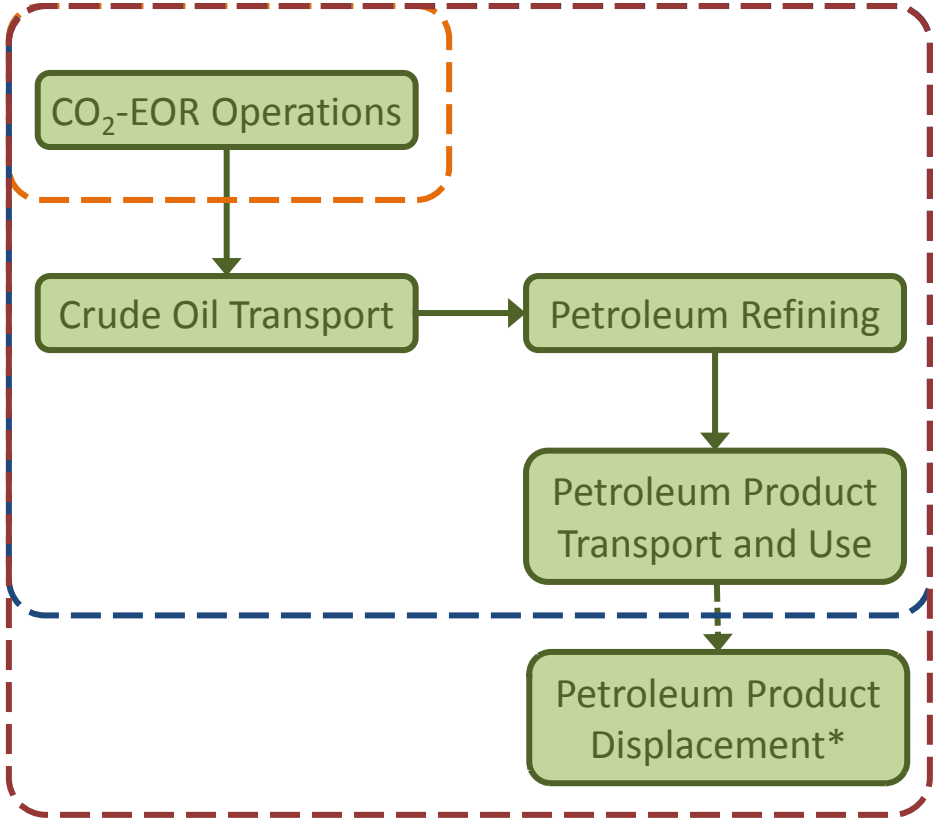
Under the IEA 6DS scenario, about 20% of production would be additional

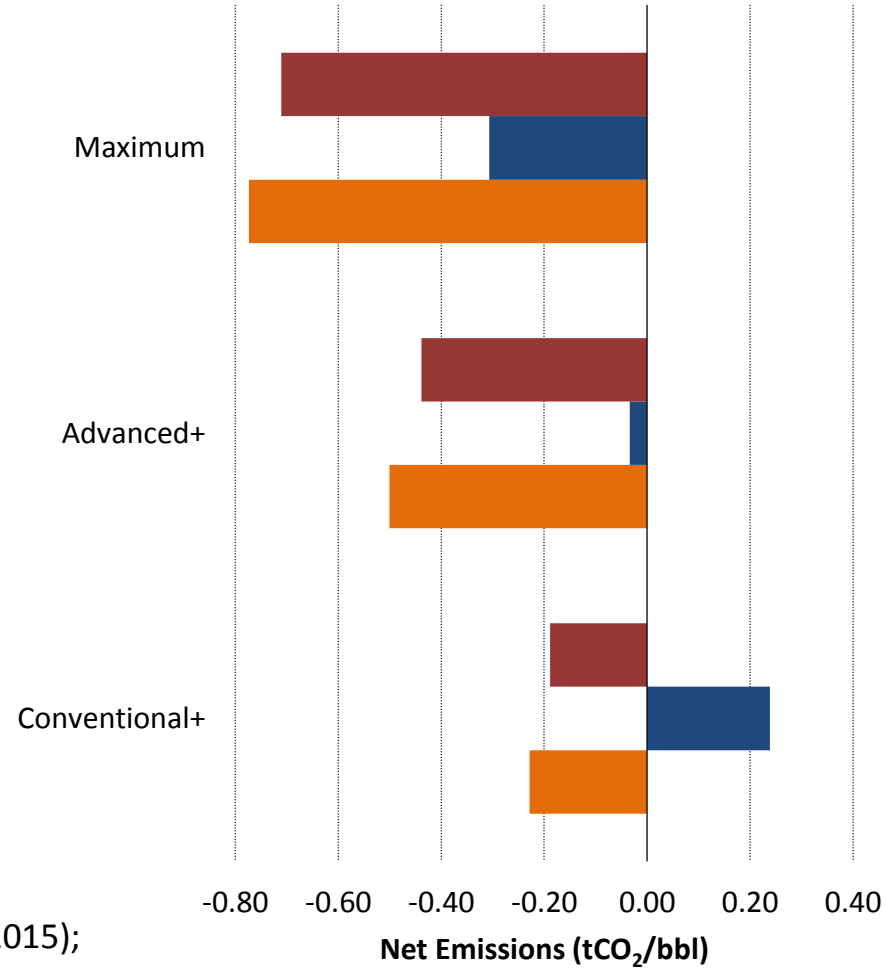


- More costly production is displaced: this is often, but not always, more carbon intensive (Gordon et al., 2015)
- Hence, we assume a “like-for-like” displacement

Figure: IEA, 2015

With displacement, even Conventional EOR+ can deliver a benefit





*Conventional crude of about 470 $kgCO_2$/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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