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Carbon Capture to Serve Enhanced Oil Recovery: Overpromise and Underperformance

Shute Creek, the World's Largest CCUS Facility, Consistently Fails to Meet Its Targets

Executive Summary

ExxonMobil's Shute Creek Treating Facility is a classic example of a carbon capture project that had to overcome both technical and economic challenges.

Commissioned in 1986 by ExxonMobil and situated near the LaBarge field in southwest Wyoming, U.S., the facility was among the first to employ carbon capture technology to produce natural gas from a field with extremely high CO_2 content.

Raw gas extracted from reservoirs has a CO_2 content. The CO_2 must be removed and is typically vented to the atmosphere to produce a marketable 'natural' gas to be distributed through pipelines or liquefied in LNG plants for export. Producing usable natural gas is not possible without first separating the CO_2.

Some gas fields have extremely high CO_2 content. Extracted gas from ExxonMobil's LaBarge field is one of them, containing 65% CO_2 and only 21% methane.

Treating very high-CO_2 and low-methane raw gases is both technically challenging and expensive relative to producing low-CO_2 content gas. ExxonMobil was spending hundreds of millions of dollars at Shute Creek to remove a high amount of CO_2 for a small proportion of marketable methane.

Selling the separated CO_2 to oil companies was a great incentive for the economics of the project to stack up. Oil companies could inject the CO_2 into depleted oil wells, increasing the pressure to enable higher oil production, what's known as enhanced oil recovery (EOR).

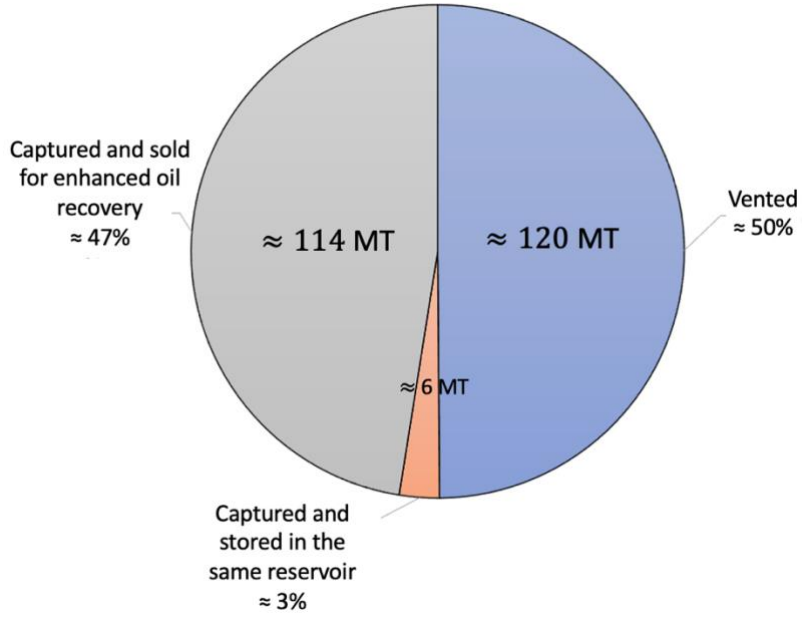
The Shute Creek project was conceived when there were high oil prices during the early 1980s. ExxonMobil could have assumed ongoing inflated demand for CO_2 from oil producers for EOR. The tacit assumption of long-term high oil prices was proved in error in the years following project commissioning.

The Facility became a "Sell or Vent" project. It could either sell the CO_2 to third parties or vent the CO_2 when prices were low and enhanced oil recovery was uneconomic. The excess CO_2 that could not be sold for EOR has been vented over the years.

Still operating today, the Shute Creek CCUS plant, the world's largest and third oldest, belongs to an era where there was little public discussion around climate change and the necessity of greenhouse gas emissions reduction.

Over its lifetime, IEEFA estimates that Shute Creek has captured up to around 120 million tonnes (MT) of CO_2, about 34% less than its capturing capacity targets. The project has rarely met its maximum capacity during its 35-year lifetime.

Shute Creek CCUS Lifetime CO_2 Capture Performance



Source: IEEFA Estimates, ExxonMobil Energy and Carbon Summary Reports 2019, 2020, 2021. Energy Procedia.[1]

According to the ExxonMobil, 120 MT accounts for approximately 40% of all anthropogenic CO_2 that has ever been captured.

That one project accounts for about 40% of all anthropogenic CO_2 captured during the 50 years of the technology's existence points to the fact that CCS has not been successfully scaled up, despite its longevity.

Moreover, about 114 MT or 95% of Shute Creek's captured CO_2 has been used for EOR.

According to the Global CCS Institute, about 73% of CO_2 captured every year is used for EOR to push more oil out of depleted fields, to be refined and burnt, producing emissions.

[1] In order to assure that the data presentation is accurate, IEEFA sent its findings to ExxonMobil, requesting a review. The company had not provided IEEFA with a response before this report was published.

CO_2-EOR is practically about the conveyance of CO_2 to produce more oil, rather than curbing huge amounts of CO_2 emissions. It is not a climate solution.

The Carbon Capture, Utilization, and Storage (CCUS) at Shute Creek has enabled the development of a gas field with extremely high CO_2 levels. Without selling CO_2 and other by-products, the gas at Shute Creek might have stayed in the ground as uneconomic.

The project has been unable to capture the volumes of CO_2 it was designed for, not for technical reasons but for economic reasons.

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For CCUS projects to be economic, it requires a high oil price, and in several cases, government subsidies.

The Shute Creek project has practically delivered gas with about half of its CO_2 emissions vented and just half captured.

The unsustainable "Sell or Vent" business model of CCUS projects like ExxonMobil's Shute Creek which serves the oil industry to produce more oil is not an emission reduction tool.

Investors, energy planners and governments should be wary of subsidising CCUS as a climate solution.

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For Shute Creek, Carbon Removal Was a Must, Not a Climate-friendly Preference

Despite the recent buzz, carbon capture technology has been around for decades, not necessarily as a climate-friendly solution to curb carbon dioxide (CO_2) emissions and avert climate consequences, but instead as an inevitable step in natural gas processing to produce a marketable gas. The economic viability of projects has been enhanced by selling the captured CO_2 [2] (especially for gas fields with low methane and high CO_2 content).

A key component of the business model for commercial development of such gas fields, is capturing CO_2 and then selling it for enhanced oil recovery (EOR) to push more oil out of oil fields – which ultimately produces CO_2 emissions when oil is combusted.

The Shute Creek Treating Facility (SCTF) was initiated at a time when climate change was not a mainstream issue.

As stated by researchers in ExxonMobil Production Company and ExxonMobil Upstream Research Company in 2011[3]: "An important aspect of each of these projects [CCS projects in the natural gas processing industry] that in order to make the primary product, natural gas, marketable, the CO_2 must be removed, regardless of its ultimate disposition. This fact makes the capture component economically justified outside of any consideration related to CCS. CO_2 EOR [Enhanced Oil Recovery] projects using other forms of anthropogenic CO_2 (captured from combustion sources) will not normally enjoy this advantage."

The Shute Creek Treating Facility was initiated at a time when climate change was not a mainstream issue.

Extracted gas from all gas fields around the world has a CO_2 content that needs to be removed to produce a commercially usable pipeline/LNG gas. The reservoir CO_2 content varies from less than 3%[4] to up to 80%[5] in rare cases. The high-CO_2 gas,

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[2] E.J. Mackay. Heriot-Watt University UK. 3 - Modelling the injectivity, migration and trapping of CO_2 in carbon capture and storage (CCS). Geological Storage of Carbon Dioxide (CO_2). 2013.
[3] P.E. Michael E. Parker (a), Scott Northrop (b), Jaime A. Valencia (b), Robert E. Foglesong (a), William T. Duncan (a). ExxonMobil Production Company (a) and ExxonMobil Upstream Research Company (b). CO_2 management at ExxonMobil's LaBarge field, Wyoming, USA. Energy Procedia. April 2011.
[4] John Robert. Institute for Energy Economics and Financial Analysis. Should Santos' Proposed Barossa Gas 'Backfill' for the Darwin LNG Facility Proceed to Development? March 2021.
[5] W.F.J. Burgers (a), P.S. Northrop (b), H.S. Kheshgi(c), J.A. Valencia (d). ExxonMobil Exploration Company (a), ExxonMobil Development Company (b), ExxonMobil Research and Engineering Company (c), ExxonMobil Upstream Research Company (d). Worldwide development potential for sour gas. Energy Procedia. April 2011.

which in most cases also contains hydrogen sulphide, is called "sour" gas. Producing marketable gas from such high-CO_2 fields was technically challenging until the 1980s.[6]

The Madison gas reservoir in Wyoming, which includes the LaBarge field from which Shute Creek produces gas, is one of those high-CO_2 content reservoirs. Discovered in 1963, it remained undeveloped for more than 20 years due to technical challenges presented by the composition of the gas (65% CO_2, 21% methane, 7% nitrogen, 5% hydrogen sulphide and 0.6% helium).

Economic Feasibility: Next Hurdle After Technical Viability

Technology was not the only barrier to the plan. Even after marketable gas could be efficiently extracted from the Madison Reservoir in the early 1980s, making the economics work was the next hurdle.[7] Shute Creek was a classic example of a project that had to overcome both technical and economic challenges.

The largest and the third-oldest carbon capture project in the world, the Shute Creek natural gas processing facility was commissioned in 1986 by ExxonMobil near the LaBarge field. Gas from this field was the highest[8] and still is considered amongst the highest CO_2 and lowest thermal energy content gases commercially produced in the world. The inlet gas to the treating facility contains only 21% methane – considered as the marketable gas to be injected into the pipeline, and there is 65% CO_2 content.

Capturing CO_2 was essential at that point to make the project economically viable. IEEFA could not find where climate concerns figured in Shute Creek and several other Carbon Capture, Utilization, and Storage (CCUS) projects commissioned before the mid-1990s. In fact, the narrative around carbon capture projects before the global community started to take climate change risks more seriously (i.e., since the Kyoto protocol signed in 1997) was more about the economics than the environment.

Capturing CO_2 was essential, not because of climate change, but to make the project economically viable.

In 1983, three years before the construction of Shute Creek, authority to vent unmarketable non-hydrocarbon gases was granted by the four state and federal agencies with jurisdiction over that gas resource.[9] An operator could have initiated the project, producing gas and venting millions of tonnes of CO_2 and other toxic and non-hydrocarbon components when it was categorized as unmarketable. Such a

[6] Energy Procedia. CO_2 management at ExxonMobil's LaBarge field, Wyoming, USA. April 2011.
[7] Energy Procedia. Worldwide development potential for sour gas. April 2011.
[8] Energy Procedia. CO_2 management at ExxonMobil's LaBarge field, Wyoming, USA. April 2011.
[9] Energy Procedia. CO_2 management at ExxonMobil's LaBarge field, Wyoming, USA. April 2011.

regulatory decision implied that all of the marketable CO_2 should be captured and sold for EOR.

For Shute Creek's business model to improve, consideration of a revenue stream from selling the CO_2 that came with methane[10] out of the ground was necessary. The massive CO_2 of the field was the supply side, and the numerous oil companies in Colorado and Wyoming were supposed to provide the virtually unlimited demand side of the equation.

ExxonMobil, however, could not sell all the marketable CO_2 during the plant's first 20 years. It took just a couple of years after commissioning of the project to show the assumption that oil companies would be always thirsty for the CO_2 produced at Shute Creek was flawed and unrealistic.

Enhanced Oil Recovery With CO_2 (CO_2-EOR): What Is It and Who Benefits?

EOR, Injecting CO_2 to Emit CO_2

Enhanced Oil Recovery with CO_2 (CO_2-EOR) is the largest industrial use of CO_2. The basic idea is that the pressurized CO_2 is injected into existing oil and gas reservoirs to squeeze out more hydrocarbons. Today, EOR is the only industrial use of CO_2 to have reached considerable scale – about 73% of the CO_2 captured globally each year is used for EOR projects.[11]

EOR enhances the rate of oil production from fields that have passed maximum output rate. So, oil producers can make money by revitalizing oil fields with declining production rates.

On the other hand, EOR itself leads to CO_2 emissions both directly and indirectly. The direct impact is the emissions from the fuel used to compress and pump CO_2 deep into the ground. The indirect impact is the emissions from burning the oil that could not have been produced without EOR. Whether EOR-induced oil is combusted by a car in the street, or it fuels a jet plane, it still emits CO_2.

CO_2-EOR basically *uses* CO_2 to produce more oil rather than curbing emissions.

In sum, CO_2-EOR basically *uses* CO_2 to produce more oil rather than curbing CO_2 emissions. The additional oil produced this way is either being burned or used for industrial processes, both of which produce CO_2 that is emitted into the atmosphere

[10] The plant was also designed to separate helium and sulphur for sale.
[11] Global CCS Institute. Global Status of CCS 2021. 2021. Page 63.

at the end of the day. Any claim that CO_2-EOR systems ultimately reduce CO_2 emissions by their nameplate capacity is overstated.[12]

About three-quarters of the CO_2 captured every year by multi-billion-dollar CCUS facilities, roughly 28 million tonnes (MT), is re-injected and sequestered in oil fields to push more oil out of the ground, where it is refined, burnt and at least partially returned to the atmosphere.

The CO_2-EOR Deal: Money for the Fossil Industry, Emissions for the Climate

In the CO_2-EOR value chain, CO_2 has a long journey from capturing to combustion. To determine winners and losers, the whole process needs a closer look.

On the capturing side, it provides a social license to extend the life of fossil fuel enterprises (from natural gas processing facilities to coal power plants). For example, a commitment signed at COP26 by 25 countries together with some public finance institutions[13] agreed to end international public support for the financing of "unabated" coal power plants by the end of 2022. However, a coal power plant can still be financed after 2022 if it is categorized as an "abated" project. "Abated" means a coal-fired power plant which is retrofitted with a carbon capture facility, or maybe even a coal power plant that is "CCUS-ready".

CCUS projects generally attract a huge amount of government subsidies and incentives for the companies that capture CO_2.

The Powering Past Coal Alliance (PPCA), a "coalition of national and subnational governments, businesses and organizations working to advance the transition from unabated coal power generation" provides another example of recent such movements awarding a social licence for fossil assets to continue to operate.[14]

To this end, CCUS projects generally attract a significant amount of government subsidies and incentives for the companies that capture CO_2. A notable example is the Tax Credit for Carbon Sequestration (Section 45Q) administered by the U.S. Department of Energy.[15] In addition, fossil fuel companies with CCUS facilities create an extra revenue stream by selling the CO_2 to oil companies for EOR.

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[12] Institute for Energy Economics and Financial Analysis (IEEFA). Boundary Dam 3 Coal Plant Achieves Goal of Capturing 4 Million Metric Tons of CO2 But Reaches the Goal Two Years Late. April 2021.
[13] United Nations Climate Change. End of Coal in Sight at COP26. 4 November 2021.
[14] Powering Past Coal Alliance (PPCA). Who we are.
[15] Global CCS Institute. The US Section 45Q Tax Credit for Carbon Oxide Sequestration: An Update. April 2020.

On the oil production side, companies can reverse the decline of mature oil fields and increase the overall oil percentage recovered from the field up to twofold using EOR[16], also known as tertiary recovery. It is an ideal process to increase the rate of oil production from a field that would not have produced much more oil due to the pressure drop.

The warming climate, however, does not benefit from the CO_2-EOR business.

CO_2-EOR "Sell or Vent" Business Model: Volatile as Oil Prices

Sensitivity of the Project to Oil Price Fluctuations

As a typical natural gas processing facility with access to a high-CO_2 gas content, Shute Creek's CCUS facility created a revenue stream for the project by selling the captured CO_2. That changed when oil prices dropped after the project started and the impact of those prices on oil extraction was felt.

Faced with low oil prices, oil companies could not make much profit and tended to reduce production and demand for CO_2 as compared to times when there was bullish market conditions. This basic economic principle, however, seems to have been ignored not only at the Shute Creek project but also in several newer CCUS projects aiming to make a profit from CO_2-EOR.

Beginning operations in late 2016, the 240-megawatt Petra Nova CCUS project at Unit 8 of NRG Energy's W.A. Parish Generating Station in Houston, Texas, is a classic example of the vulnerability of the CO_2-EOR business model to oil price fluctuations. Petra Nova CCUS was the only industrial-scale operational coal-fired power plant with a CCS facility in the U.S. However, the project was mothballed in mid-2020 because low oil prices during the COVID pandemic made using the captured CO_2 for EOR uneconomic.[17] The owners had not taken into account the inherent risk of low oil prices in such a business model.

This flawed approach can be recognized not only in the past and in currently operating CO_2-EOR projects, but also in business models of proposed projects. A case in point is the proposed Enchant Energy San Juan Generating Station CCUS project in New Mexico. The developers propose to extend the life of an old coal-fired power plant which is currently set to be closed in 2022. One of the main revenue streams justifying the project's assumption of profitability is selling the captured CO_2 for EOR. In IEEFA's view, the oil price volatility risk may have been underestimated and could potentially detrimentally affect the financial feasibility of this project.[18]

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[16] International Energy Agency (IEA). Whatever happened to enhanced oil recovery? November 2018.
[17] Institute for Energy Economics and Financial Analysis (IEEFA). Petra Nova Mothballing Post-Mortem: Closure of Texas Carbon Capture Plant Is a Warning Sign. August 2020.
[18] Institute for Energy Economics and Financial Analysis (IEEFA). Where's the beef? Enchant's San Juan Generating Station CCS Retrofit Remains Behind Schedule, Financially Unviable. May 2021.

It appears that this risk was underestimated in earlier CCUS projects such as Shute Creek as well. As stated in a paper written by ExxonMobil researchers in 2011:

"In fact, the full capacity of sales quality CO_2 from the SCTF has been under contract since the start of production, however actual takes of contracted CO_2 have been sensitive to oil prices… As a result of market sensitivities, annual CO_2 deliveries since start-up, through the early 2000s, averaged less than half of the contracted volumes."

Also in the same paper, the authors state that:

"The EOR market for CO_2 in the Rocky Mountain area developed more slowly than originally anticipated".[19]

In the late 1970s and early 1980s, before the Shute Creek Treating Facility was commissioned, the massive supply shortage in the oil market – due to Iran's revolution and its consequent war with Iraq – pushed oil prices up dramatically. However, through the mid-1980s, the oil price pulled back in the face of a demand slump, an incremental supply boost, and the ceasefire in the Iran-Iraq war.

ExxonMobil acknowledges that actual takes of contracted CO_2 have been sensitive to oil prices.

In the first 17 years of the Shute Creek plant, the nominal West Texas Intermediate (WTI) oil price per barrel averaged less than $31[20], meaning oil companies tended to invest less in EOR projects. Oil operators struggled to identify keystone projects or a critical mass of small projects to justify infrastructure expenditure to enable and maintain the CO_2 sale rates of the early years of Shute Creek.[21] Additionally, the lack of CO_2 transportation infrastructure at LaBarge, and the facility's remote location in relation to possible EOR opportunities at the time, hampered the early development of CO_2 resources there.

Climate Is Adversely Affected by CO_2-EOR Business Models' Instability

The Shute Creek plant's total CO_2 emissions from gas processing (excluding emissions from the operation of facilities) were calculated to be about 6 million tonnes per annum (MTPA) at the start of the project. The carbon capture facility was designed to capture, compress and distribute 4.3 MTPA, equivalent to 230 MCFD of sales quality CO_2 – around three quarters of the total emissions. The balance, about

[19] Energy Procedia. CO_2 management at ExxonMobil's LaBarge field, Wyoming, USA. April 2011.
[20] U.S. Energy Information Administration (EIA). PETROLEUM & OTHER LIQUIDS. Cushing, OK WTI Annual Spot Price FOB. November 2021.
[21] Energy Procedia. CO_2 management at ExxonMobil's LaBarge field, Wyoming, USA. April 2011.

1.6 MTPA which could not be marketed[22] would have inevitably been vented at the end of the process.[23] [24]

The facility was not planned to have a dedicated geological structure for CO_2 storage, so it became a "Sell or Vent" project. Were there a customer to buy the CO_2, it would be captured, compressed and transported. With fewer customers in the time of low oil prices, the excess captured CO_2 would be vented. For the first 17 years of the Shute Creek project, oil prices were not high enough to allow sales of the maximum amount of captured CO_2.

The "Sell or Vent" way of doing business illustrates that CCUS projects like Shute Creek are not about averting climate change and reducing emissions. In essence, the aim of such projects is to make a profit, both for the CO_2 supplier and the oil producer using CO_2 to extract more oil. These old CCUS projects have been rebranded recently, put forth by the fossil industry as climate-friendly solutions.

The "Sell or Vent" way of doing business illustrates that such projects are not about averting climate change and reducing emissions.

ExxonMobil's marketing program[25] reportedly ensured that the full capacity of sales-quality CO_2 had been under contract since the start of production.[26] However, annual realized CO_2 deliveries from Shute Creek, from start-up in 1986 to the mid-2000s, averaged less than half of the contracted volumes because of the CO_2 market's sensitivity to oil price volatilities.

Figure 1 illustrates the relationship between oil prices and annual CO_2 sales since the beginning of the Shute Creek project.

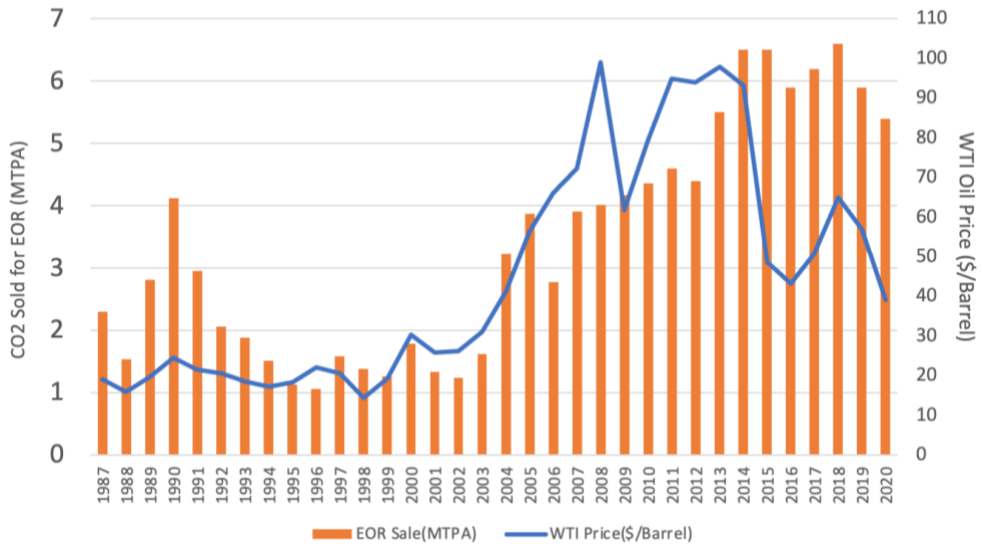
In the first 17 years of weak oil prices, from the beginning of the project to 2003, the plant could rarely capture and sell more than 2 MTPA. Since then, soaring oil prices enabled Shute Creek to sell more of its CO_2 for EOR. Sell volumes increased until 2014 concurrent with historically high oil prices. From 2014 - 2020, despite oil prices starting to fall, ExxonMobil could still manage to sell a high volume of CO_2 for

[22] Unmarketable CO_2 is defined as the proportion of the CO_2 that could not be captured during the gas processing and the CO_2 that is too impure to sell.
[23] Carbon Capture and Sequestration Technologies @ Massachusetts Institute of Technology (MIT). LaBarge Fact Sheet: Carbon Dioxide Capture and Storage Project. September 2016.
[24] Energy Procedia. CO_2 management at ExxonMobil's LaBarge field, Wyoming, USA. April 2011.
[25] As stated by ExxonMobil researchers in an academic paper published in 2011: "ExxonMobil has maintained an active CO_2 marketing program to maximize sales of existing capacity, seek new markets for additional CO_2 sale and reduce CO_2 venting. In fact, the full capacity of sales quality CO_2 from the SCTF has been under contract since the start of production". See Energy Procedia. CO_2 management at ExxonMobil's LaBarge field, Wyoming, USA. April 2011.
[26] Energy Procedia. CO_2 management at ExxonMobil's LaBarge field, Wyoming, USA. April 2011.

EOR.[27] During this period, the amount of CO_2 sold continued to fluctuate with the rise and fall of oil prices, although with a lower magnitude of change compared to the previous periods.

From this 35-year perspective, the dependence of the CO_2-EOR business model on oil price volatility is clearly evident, despite the existence of some outliers.

Figure 1: Historical Trend of Oil Price – CO_2 Sold for EOR[28]



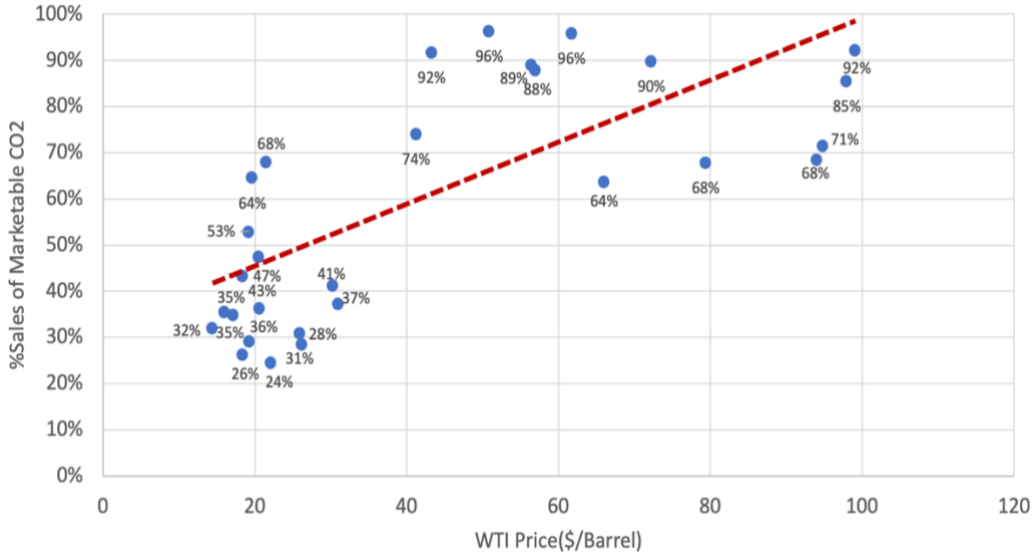
Source: ExxonMobil Energy and Carbon Summary Reports 2019, 2020, 2021. Energy Procedia, U.S. Energy Information Administration (EIA). Chevron' Gorgon Environmental Performance Report, 2021.

The correlation between oil price and the percentage of marketable CO_2 sales at Shute Creek is shown in Figure 2. The percentage of sales of marketable CO_2 is the proportion of the CO_2 sold for EOR relative to the maximum CO_2 that could be captured and sold by the facility. Therefore, at 100%, the Shute Creek plant would be selling the maximum CO_2 it can capture in that year.

Typically, the Shute Creek CCUS plant could sell large amounts of its nominal marketable CO_2 when oil prices were high. When oil prices were low, there was generally not enough demand for all of the CO_2 captured and consequently, a vast majority of the excess captured CO_2 was vented into the atmosphere.

[27] ExxonMobil. Energy and Carbon Summary. 2021, 2020, 2019.
[28] All of the numbers and estimates presented in this report are based on publicly available data in academic papers and/or official sources provided in the footnotes. However, normally there could be some estimates errors (+/- 5%) due to rounding numbers, unit conversions and simplifying assumptions.

Figure 2: Price - % Sales of Marketable CO_2 Correlation (1987-2020)



Source: IEEFA Estimates, ExxonMobil Energy and Carbon Summary Reports 2019, 2020, 2021. Energy Procedia, U.S. Energy Information Administration (EIA).

Shute Creek's Economics and Performance

Operational since 1986, the Shute Creek Treating Facility (SCTF) receives gas from the LaBarge field in the Rocky Mountains. Gas from 17 production wells collects in manifolds of the primary treatment facility at Black Canyon. After the initial treatment, the gas is exported 74km (46 miles) to SCTF for final treatment.[29]

With a current nominal CO_2 capturing capacity of 7 MTPA (post-expansion in 2010), Shute Creek CCUS is the largest such facility in the world.[30] It supplies CO_2 to several customers for EOR including Chevron's Rangely oilfield in Colorado, Fleur de Lis Energy's Salt Creek oilfield, Devon's Big Sand Draw oilfield, Denbury's Grieve oilfield in Wyoming, and its Bell Creek oilfield in Montana.[31]

Originally designed to capture around three-quarters of the plant's CO_2 emissions[32], in its 35-year lifetime, the SCTF and its CCUS plant have experienced the impact of regulatory decisions, technical changes, and varying CO_2 capture and sales volume.

In the following section, the plant's operation is discussed chronologically over four main time periods. For each period, a table is provided illustrating the Total CO_2 Content of the gas produced by the facility (excluding emissions from the plant operation); Capture Capacity Target, which was originally set as around 75% of the total CO_2 emissions of the facility; Actual Captured/Sold CO_2; Geologically

[29] Energy Procedia. CO_2 management at ExxonMobil's LaBarge field, Wyoming, USA. April 2011.
[30] Global CCS Institute. Global Status of CCS 2021. 2021.
[31] United States Department of Energy, Office of Fossil Energy. Wyoming Carbon Capture, Utilization, and Storage (CCUS) Study. August 2020.
[32] Energy Procedia. CO_2 management at ExxonMobil's LaBarge field, Wyoming, USA. April 2011.

Sequestered CO_2 in the same reservoir; and Vented CO_2, all in million tonnes (MT). A percentage distance from the capturing capacity target to the actual amount of CO_2 captured and sequestered is also provided. A negative percentage means the plant fell short of the maximum capacity target and a positive percentage means the plant overperformed in capturing CO_2.

Finally, a 35-year perspective is provided showing the capturing performance trend of the plant during its lifetime, compared to its capturing capacity target and the total CO_2 emission of the plant.

1987-2003: Period of Massive CO_2 Demand Overestimation

Table 1: Shute Creek CCUS Performance (1987-2003)

Period	Total CO_2 Content (MT)	Capture Capacity Target (MT)	Actual Captured/Sold (MT)	Sequestered (MT)	Vented (MT)	Distance From the Capture Capacity Target
1987-2003	≈101	≈76	≈32	0	≈66	≈ - 58%

Source: IEEFA Estimates, ExxonMobil Energy and Carbon Summary Reports 2019, 2020, 2021. Energy Procedia.

As part of the Shute Creek Treating Facility, the Shute Creek CCUS plant was commissioned in 1986. It was originally designed to capture about 4.3 MTPA of CO_2 from the 'sour' gas (highly concentrated CO_2 with a very low hydrocarbon content) extracted from the LaBarge field.

The original cost for the whole Shute Creek facility (including the CCUS plant) was US$170 million.[33] In addition to CO_2 and methane separation, the plant's parallel processing trains were also designed to separate sulphur and helium as by-products for sale.

ExxonMobil appears to have unrealistically assumed that all CO_2 to be stripped from the inlet gas would be sold to oil companies for EOR. However, due to weak oil prices in this period and despite ExxonMobil securing contracts for the maximum amount, less than 50% of the contracts proceeded successfully.

From 1987 to 2003, the CCUS plant captured *58% less* CO_2 than initially designed for.

[33] Carbon Capture and Sequestration Technologies @ Massachusetts Institute of Technology (MIT). LaBarge Fact Sheet: Carbon Dioxide Capture and Storage Project. September 2016.

As the project was a "Sell or Vent" system, the massive amount of CO_2 that failed to be marketed was vented during this period.[34] This alone added about 44 MT of 'extra' CO_2 into the atmosphere, which means the CCUS plant captured *58% less* than capturing capacity.

2004-2009: Forgetting About the Target, Being Questioned on CO_2 Management and Introduction of the 45Q Tax Credit Scheme

Table 2: Shute Creek CCUS Performance (2004-2009)

Period	Total CO_2 Content (MT)	Capture Capacity Target (MT)	Actual Captured/Sold (MT)	Sequestered (MT)	Vented (MT)	Distance From the Capture Capacity Target
2004-2009	≈53	≈39	≈22	≈2	≈27	≈ -39%

Source: IEEFA Estimates, ExxonMobil Energy and Carbon Summary Reports 2019, 2020, 2021. Energy Procedia.

This five-year period included treating capacity expansions (without capture rate improvement), getting the first emission reduction warning by regulators, introduction of the 45Q tax credit scheme by the regulator, and the addition of an Acid Gas Injection (AGI) facility.

In 2004 and 2005, in two stages, the facility's gas treating capacity increased by 50% to around 13.6 MTPA, which increased the facility's CO_2 emissions to around 9 MTPA. Despite the massive increase in emissions, ExxonMobil did not increase the capture rate; the capacity to capture CO_2 remained at 4.3 MTPA as it was in the pre-expansion period.

In the four years to 2008, the maximum capturing capacity (initially designed to be around 75% of the total CO_2 emissions) was still not increased.

In 2008, the Wyoming Oil and Gas Conservation Commission questioned ExxonMobil's effort in managing CO_2[35]. It emphasized that venting of marketable CO_2 is waste and thus would be a violation. It also raised a concern about whether or not ExxonMobil was failing to re-market gas that had been contracted for, but not actually taken up by customers. It instructed ExxonMobil to diligently pursue marketing the CO_2 and avoid venting any marketable gas.

In the same year, Congress enacted the Energy Extension and Improvement Act of 2008 to establish a tax credit for carbon capture. The 45Q tax credit scheme was

[34] Energy Procedia. CO_2 management at ExxonMobil's LaBarge field, Wyoming, USA. Page 5464. April 2011.
[35] Carbon Capture and Sequestration Technologies @ Massachusetts Institute of Technology (MIT). LaBarge Fact Sheet: Carbon Dioxide Capture and Storage Project. September 2016.

enacted to encourage companies to capture and store carbon dioxide.[36] ExxonMobil completed an expansion project at Shute Creek in 2010 that benefited from the 45Q tax credit, which presented another way for Exxon to profit from its CCUS technology.

Originally the plant was fitted with a Sulphur Recovery Unit (SRU) to convert hydrogen sulphide (H_2S) to elemental sulphur. Considering the long-term declining trend for the sulphur market, in 2005 the plant was retrofitted with an Acid Gas Injection (AGI) unit to dispose of toxic waste, comprising 60% H_2S and 40% CO_2. As a result, since 2005, about 0.4 MTPA CO_2 has been sequestered annually in the same reservoir the gas is extracted from.

In the six-year period from 2004 - 2009, despite the 50% increase in the plant's CO_2 emissions and no added capture facility in place, the distance to the capacity target improved compared to the previous period (though it was still deeply negative). This was due to the prevailing extremely bullish oil market, with prices soaring towards $90 per barrel. At such high prices, the plant could sell CO_2 at maximum capture capacity for a couple of years (nominal capturing capacity of 4.3 MTPA had been unchanged since the time of commissioning). This offset part of the excess CO_2 added to the plant's profile caused by the expansion in the gas treating facility.

In this period came the next wave of transport and pipeline infrastructure. With improved oil prices and identification of keystone EOR projects – Salt Creek Field needed about 2.4 MTPA of SCTF's CO_2 – the infrastructure for CO_2 transportation was significantly expanded. A 400-kilometre pipeline connecting Shute Creek and Salt Creek was completed in 2006.[37] The pipeline was then extended into the oil producing regions of central Wyoming.[38]

From 2004 - 2009 the amount of CO_2 emissions increased by around 50%. The company did not increase the capturing capacity.

In sum, from 2004 - 2009 the treating capacity and consequently the amount of CO_2 emissions increased by around 50%. The company did not increase the capturing capacity, but it managed to perform better than the previous period in terms of capturing and selling the volume of CO_2 thanks to very high oil prices.

[36] Global CCS Institute. The US Section 45Q Tax Credit for Carbon Oxide Sequestration: An Update. April 2020.
[37] ZeroCO2.NO. Shute Creek. 2016.
[38] Energy Procedia. CO_2 management at ExxonMobil's LaBarge field, Wyoming, USA. April 2011.

2010-2020: Capture Capacity Expansion and Performance Improvement

Table 3: Shute Creek CCUS Performance (2010-2020)

Period	Total CO_2 Content (MT)	Capture Capacity Target (MT)	Actual Captured/Sold (MT)	Sequestered (MT)	Vented (MT)	Distance From the Capture Capacity Target
2010-2020	≈97	≈73	≈62	≈4	≈28	≈ -10%

Source: IEEFA Estimates, ExxonMobil Energy and Carbon Summary Reports 2019, 2020, 2021. Energy Procedia.

In 2010, ExxonMobil spent another US$86 million on the project and expanded the capture capacity to about 7 MTPA.

Thanks to the AGI unit sequestering 0.4 MTPA of CO_2 (that would have been vented before 2005), and historically high oil prices (about $100 a barrel) from 2010 - 2014, the CCUS plant operated better than in the previous period.

Although the facility's performance improved from 2010 - 2020, during part of the decade when low prices prevailed, the project fell short of its capture capacity by approximately 10%. Further research and disclosure are needed to provide a more robust description of the evolution of the project's operation.

In 2012 - 2013, ExxonMobil completed the demonstration of its Controlled Freeze Zone (CFZ) technology, a single-step cryogenic separation process that freezes out and then melts CO_2 while removing other components of the feed gas. According to ExxonMobil, this method was more efficient and cost-effective than other carbon separation methods such as amine-based methods and could reduce energy use and consequently the plant's operational emissions.[39]

2020 Onwards: Expensive Expansion to Come Online Until 2025

In May 2020, ExxonMobil was granted a permit to construct and operate the LaBarge Carbon Capture Project, which included additions to the Shute Creek gas plant, a CO_2 disposal (injection) well, and the construction of a 15km CO_2 pipeline.[40]

In October 2021, an ExxonMobil media release stated that the company planned to increase carbon capture at LaBarge, with the expansion project aiming for an extra 1 MTPA CO_2. This has remained in the design and permit phase with the oil company seeking bids for engineering, procurement and construction. A final investment

[39] ExxonMobil. ExxonMobil invests $1 billion per year in energy research, emerging technologies. September 2018.
[40] United States Department of Energy, Office of Fossil Energy. Wyoming Carbon Capture, Utilization, and Storage (CCUS) Study. August 2020.

decision (FID) is expected in 2022 and the project could be operational by 2025. The investment cost is estimated at about US$400 million.[41]

Lifetime Capturing Performance Trend (1987-2020): Overpromises and Underperformances[42]

Shute Creek CCUS plant is the largest and third-oldest operating CCUS plant in the world.[43] Although it has the capacity to capture more CO_2 than any other CCS facility in the world, in its 35 years of operation, it has failed to reach its original target of capturing about three-quarters of the CO_2 emissions of the gas treating facility.

It was commissioned in the 1980s, when climate change was not a widespread public concern. It was planned not only to prepare a marketable gas but also to improve the economics of producing gas from one of the lowest-hydrocarbon fields in the world. Selling CO_2 for EOR was regarded as one of the project's main revenue streams.

In its 35 years of operation, the Shute Creek CCUS plant has failed to reach its original targets.

Two decades later, amid increasing global attention on increasing emissions and climate change, and the emergence of more stringent environmental regulations in the U.S. and around the world, the Shute Creek CCUS project gradually started to be rebranded by the proponents as a climate savior.

The key assumption behind the CO_2-EOR business model – the existence of ongoing and inflated demand for CO_2 – was proven wrong during periods of low oil prices and the plant rarely came close to its maximum capture capacity, doing so mostly when oil prices were very high.

Going forward, even if it could come close to its target, selling CO_2 to produce more oil out of the ground (EOR) is 'passing the buck' in terms of managing the release of emissions – it is not a net-zero solution. CO_2-EOR projects practically convey a considerable proportion of CO_2 from a gas field into the oil to be combusted, where the CO_2 is released into the atmosphere again, what is called scope 3 emissions.

Figure 3 summarizes the performance of the Shute Creek CCUS plant over its 35-year lifetime. Despite its improved performance over recent years, the plant has

[41] ExxonMobil. ExxonMobil plans to increase carbon capture at LaBarge, Wyoming facility. October 2021.
[42] IEEFA derived the post-2009 data from its review of ExxonMobil's Energy and Carbon Summary Reports 2019, 2020, 2021 and other reports from companies partnered with ExxonMobil. In order to assure that the data presentation is accurate, IEEFA sent its findings to ExxonMobil, requesting a review. The company had not provided IEEFA with a response before this report was published.
[43] Global CCS Institute. Facilities Database.

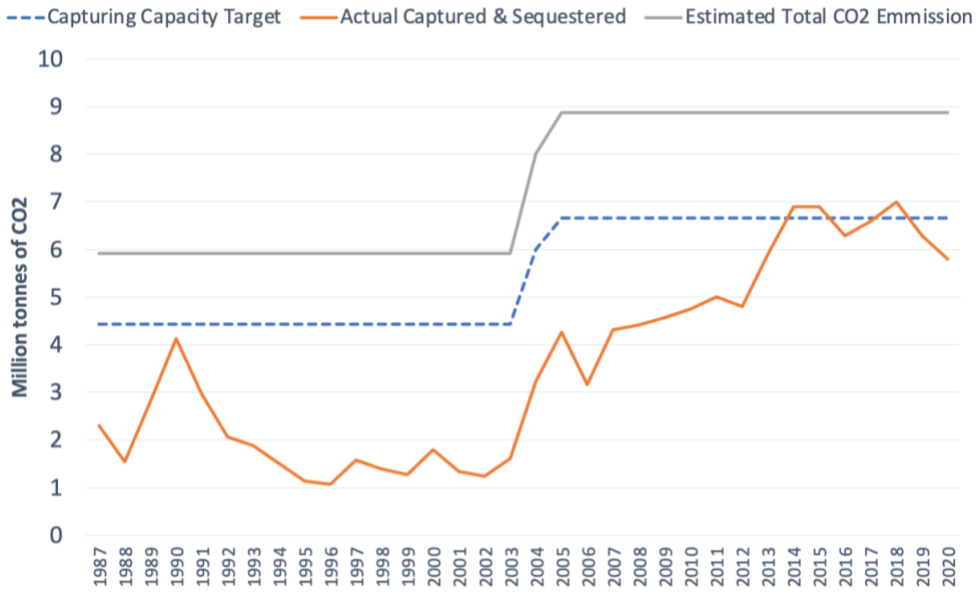
reached its capturing capacity target (around 75% of total CO_2 emissions) in only a few of those years since the day of commissioning. At all other times, the plant has fallen short of reaching that, mostly by a wide margin.

On average, Shute Creek CCUS facility has fallen short of its target by around 34% over its lifetime, which translates to approximately 66 MT of CO_2 released into the atmosphere. Further, this figure excludes emissions from operating both the gas treating facility and CCUS plant, and also excludes fugitive emissions and potential leaks from pipelines and geological structures, EOR-based oil combustion, etc. Factoring in these emissions, the "net avoided CO_2" would be much lower.

The project has delivered gas with just half of CO_2 emissions captured and the other half vented.

The project has delivered gas with around half of CO_2 emissions captured and the other half vented.

Figure 3: Capturing Performance Trend of the Shute Creek CCUS Plant (1987-2020)



Source: *IEEFA Estimates, ExxonMobil Energy and Carbon Summary Reports 2019, 2020, 2021. Energy Procedia.*

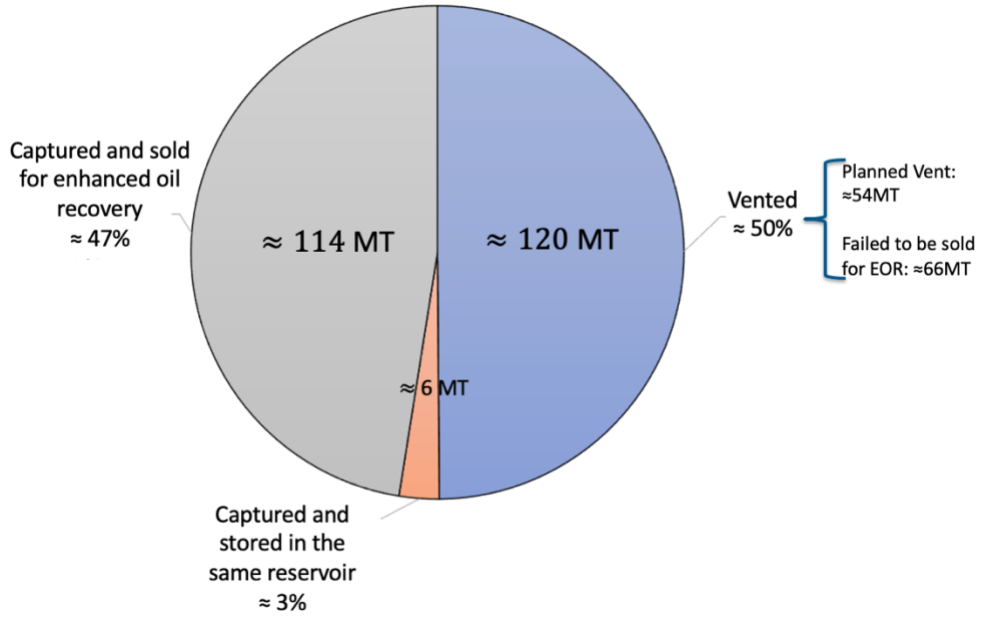
Figure 4 provides a lifetime performance snapshot of Shute Creek CCUS plant.

Until the end of 2020, IEEFA estimates that the treating facility on its own directly produced 240 MT of CO_2, of which around 47% (≈ 114 MT) has been captured and used to enhance the recovery rate of oil production (EOR).

Over its lifetime, around 3% of total CO_2 emissions have been sequestered in the same geological formation the feeding gas is extracted from. And the remaining 50% of CO_2 content of the produced gas from the Shute Creek gas treating facility, estimated to be around 120 MT, has been vented. These numbers suggest that the CCUS plant has only reduced the gas at the Shute Creek field from extremely high CO_2 (65% CO_2) to very high CO_2 (33% CO_2).

For perspective, that figure of 120 MT is greater than the entire national emissions of Norway, Sweden and Finland in 2018 cumulatively, according to the World Bank.[44] Indirect emissions through the industry value chain and the consequent emission from burning the recovered oil would dramatically add to this figure.

Figure 4: Shute Creek CCUS Lifetime CO_2 Capture Performance



Source: IEEFA Estimates, ExxonMobil Energy and Carbon Summary Reports 2019, 2020, 2021. Energy Procedia.

[44] The World Bank. CO_2 emissions(kt) – Norway, Sweden, Finland.

Conclusion

Shute Creek, one of the longest running CCUS projects in the world, has captured over its lifetime around 40% of all CO_2 captured in history – close to 120 MT. This is around 34% less than its pre-specified capturing target set at the beginning of the project. Further, about 114 MT or 95% of this captured CO_2 has been used for EOR to produce more oil, which at least partially negates the initial capture from a climate perspective.

A key feature of the project is that it started before climate change was a widely recognized issue. It was not developed as an environmental project - it was developed because the oil and gas fields at Shute Creek were particularly high in CO_2 content (at around 65%) and the CO_2 had to be removed to be able to produce and sell the gas. The CO_2 was expensive to remove, and the economics of the project were not likely to stack up unless the CO_2 was treated as a by-product, not a waste product.

Selling CO_2 to nearby oil producers for EOR became one of the promising revenue streams of the project, especially with high oil prices which seemed likely in the early 1980's before the project started.

During periods of low oil prices however, the vulnerability of the CO_2-EOR model against oil price volatilities was revealed and the project could not sell the maximum volume of CO_2 it could capture.

For most if its life to date, the facility has not been able to sell the maximum volume of CO_2 captured. As the project was designed to either sell the CO_2 to third parties or, when prices were low and hence EOR uneconomic, to vent the CO_2, the excess CO_2 that could not be sold for EOR has been vented.

It is estimated that the project has vented around 120 MT of CO_2 over its lifetime. Of this, more than half is the CO_2 that was captured but failed to be marketed. Such figures reveal the inefficiency of the CO_2-EOR business model in the context of this flagship CCUS project.

Governments, companies and investors should take note. CCUS projects could prove to be unsustainable both economically and environmentally.

About IEEFA

The Institute for Energy Economics and Financial Analysis (IEEFA) examines issues related to energy markets, trends and policies. The Institute's mission is to accelerate the transition to a diverse, sustainable and profitable energy economy. www.ieefa.org

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