Colorado CO_2 Resource Study

November 2018

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Disclaimer

Colorado CO_2 Resource Study: Phase I report

1 Introduction

Naturally occurring sources of carbon dioxide (CO_2) in Colorado such as McElmo Dome and Sheep Mountain serve as sources for enhanced oil recovery (EOR) in the Permian Basin of Texas. As these natural sources become depleted, there is the opportunity for coal-fired power plants with CO_2 capture technology to serve as the source for CO_2 for EOR, while decreasing emissions. This could allow the continued supply of electricity from the plants and create jobs supporting the local economy.

This is phase I of a two-phase study that will evaluate the potential capacity of CO_2 to be captured, as well as the costs associated with replacing the natural sources with anthropogenic sources of CO_2 in Colorado. Phase I of the study was focused on providing a broad assessment of CO_2 resources in the state and opportunities for captured CO_2 from coal plants to support nearby enhanced oil recovery operations. Specifically, the scope included the following areas:

- Current CO_2 resources and transportation infrastructure in Colorado: pipeline capacity, expected lifespan of CO_2 sources, current and projected supply and marginal costs of natural CO_2 and the total supply and projected demand for CO_2,
- Current electricity market and costs in CO, and
- Identifying CCS opportunities for plants located close to CO_2 pipelines.

2 Phase I takeaways

2.1 The cost of generating electricity from coal power plants (among the top-twenty power plants in CO) is 35-59% lower than the current power purchase agreement prices for wind and solar energy in Colorado

Coal represents more than half (53%) of the power generation in Colorado and provides base-load generation (Figure 1). The average capacity factor for coal-fired units among the top-twenty Colorado power plants was close to 70%, whereas natural gas and wind units (among the top twenty) averaged only 39% and 37% respectively (CO does not have nuclear power generation). For comparison, the U.S. average capacity factors for coal, natural gas and wind generators in 2017 were 54%, 51% and 35% respectively, indicating that the coal-fired generation in Colorado is dispatched at a significantly higher rate compared to national average.

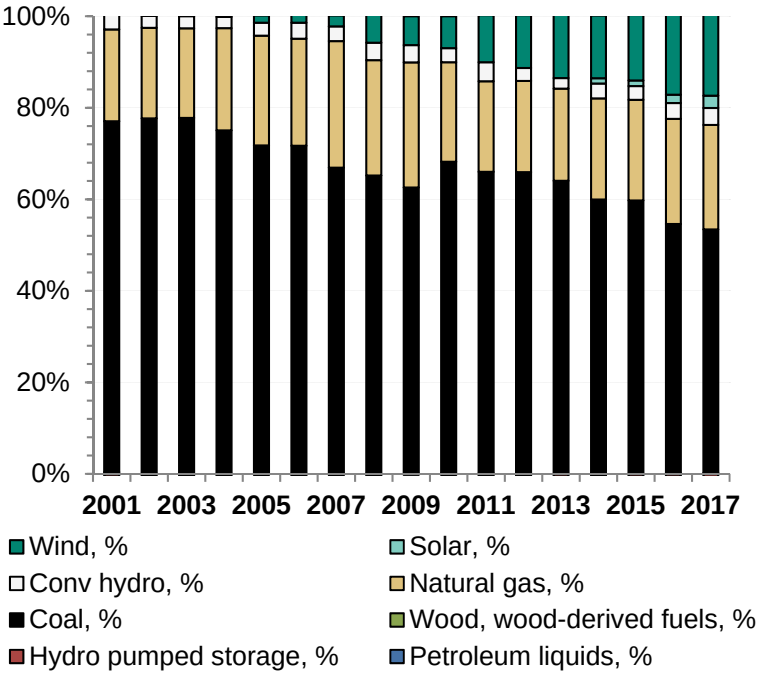

Figure 1: Percentage of electricity generation by energy source in Colorado, source EIA

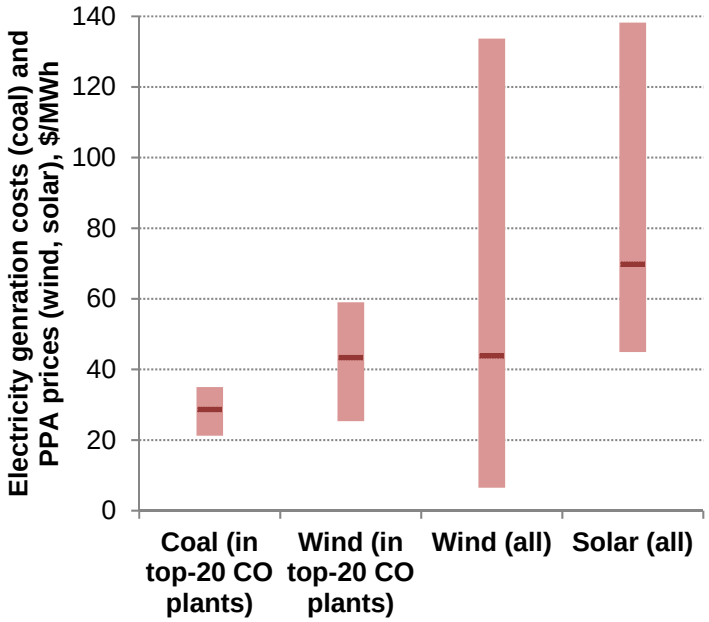

Figure 2: Current costs of generating electricity various coal plants (among the top-twenty power plants in Colorado) compared with the cost of replacement power, i.e., PPAs from wind and solar generators. The average value is shown in red. Source: FERC [2] [3]

Colorado state renewable energy standard (RES) [1] and the Federal renewable energy tax credits for solar and wind currently drive the deployment of renewable energy in Colorado. Currently, investor-owned utilities (Xcel Energy or Public Service Company of Colorado, and Black Hills Energy) are required to generate 20% of their retail electricity sales from renewable sources of electricity.

Cooperative electric associations in Colorado are required to generate 6 to 20% of their retail sales from renewable sources (depending on the market size), and the corresponding standard for municipal utilities is 6%. Coal power plants in CO can generate power for as low as $21/MWh [2]. The cost of replacement renewable energy in the form of power purchase agreements (PPAs) for solar photovoltaic (PV) and wind electric generation in Colorado averaged $43/MWh and $70/MWh in 2017 respectively [2]. Currently, the average cost of generating electricity from coal power plants among the top-twenty generators in Colorado is 35% lower than the price of PPAs for electricity from wind turbine power plants and almost 60% lower than the price of PPAs for solar PV

electricity (see Figure 2). Xcel Energy projects future solar and wind generation PPAs (including storage) could be lower than $20/MWh [3].

To make up for fluctuations in renewable energy generation, Xcel would need backup natural gas power plants or energy storage.

The average cost of electricity for residential consumers in Colorado was $121/MWh in 2017 [4]. The industrial price of electricity was $74.5/MWh. Xcel Energy and Y-W Electric Association were the largest utilities (number of consumers) in the residential and industrial markets respectively.

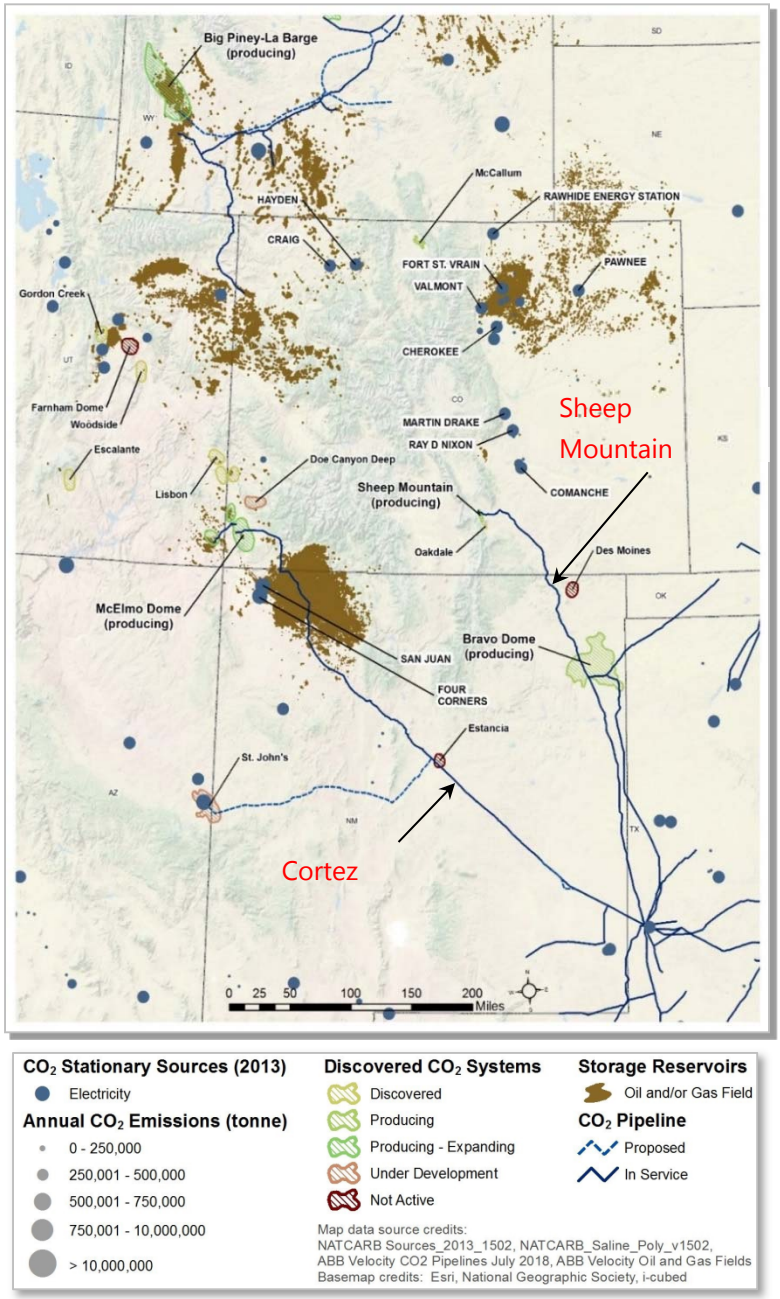

Figure 3: Natural sources of CO_2, coal-fired power plants, oil and gas fields and CO_2 pipelines in the Colorado/New Mexico/Arizona/Utah/Wyoming region.
Source: DOE/NETL

2.2 Colorado is a major supplier of natural CO_2 for EOR in the Permian Basin

The current market for Colorado CO_2 is in the Permian Basin Oil fields in west Texas and southeastern New Mexico. CO_2-EOR was first initiated in these oilfields in the 1980s. Colorado has two major sources of natural CO_2, McElmo Dome and Doe Canyon in Montezuma and Dolores counties, and the Sheep Mountain field in Huerfano County. These natural CO_2 sources, together with the Bravo Dome and West Bravo Dome fields in New Mexico supply a major portion of the CO_2 for EOR in Permian Basin oilfields (Figure 3, Figure 4).

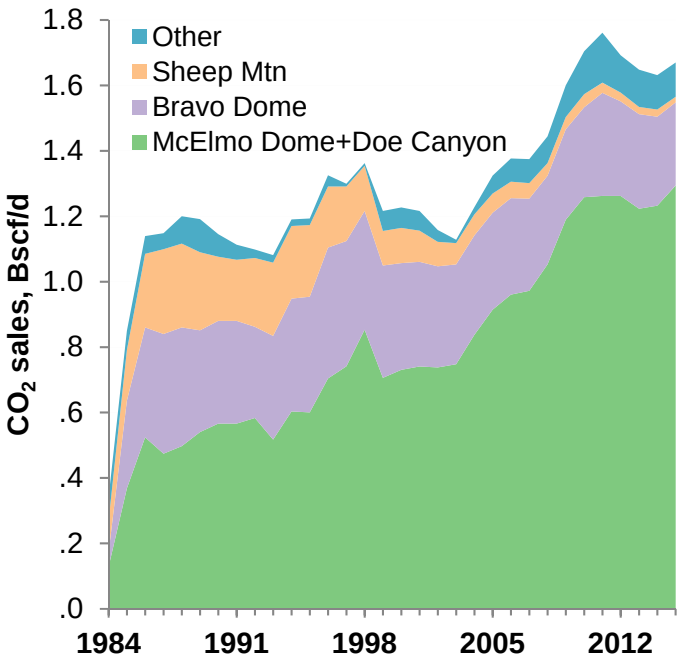

Figure 4: Quantity of CO_2 supplied for EOR in the Permian Basin by origin, source: Kinder Morgan

The Doe Canyon and McElmo Dome fields in southwest Colorado are operated by Kinder Morgan (KM) and have an estimated recoverable resource of 5400 Bscf, or 286 MMT CO_2. KM has added booster compression (to sustain production and extend well life), completed new seismic studies to understand the extent of the CO_2 resource, and has developed additional wells to offset declines in CO_2 production. Current CO_2 production is approximately 400 to 500 billion standard cubic feet (Bscf) of CO_2/d, or 27 million metric tonnes (MMT)/y.

Notwithstanding the new drilling program, recompletions, and additional investments in expanding/sustaining production, Kinder Morgan's CO_2 production is expected to peak at 1.6 Bscf/d by 2022, compared to current production of 1.3 Bscf/d in 2017. CO_2 from the McElmo Dome and Doe Canyon fields is transported by the 502-mile, 30-inch Cortez pipeline to the Denver City Hub in Texas (Figure 3). The Cortez pipeline has a capacity of 1.5 Bscf/d (548 Bscf/y).

2.3 Bravo and Sheep Mountain pipelines have spare capacity to carry anthropogenic CO_2

Occidental Petroleum (Oxy) is the major operator in the Sheep Mountain CO_2 field in southern Colorado, which has an estimated recoverable resource of 100 Bscf (5 MMT CO_2). CO_2 production from Sheep Mountain peaked at 35 Bscf/y in 1988 and has been declining subsequently (see Figure 4) [5]. Data from COGCC indicate that the current production is 7.7 Bscf/y (~0.4 MMT/y). The 24-inch, 508-mile Sheep Mountain pipeline (SMPL) also carries ~7.3 Bscf CO_2/y (separated from natural gas) from the La Veta gas processing plant, and likely also carries CO_2 from the West Bravo Dome Unit to the Denver City Hub. SMPL is a common-carrier pipeline rated at 215 Bscf/y and has an estimated spare capacity of 200 Bscf/y (~11 MMT/y) [6]. The Cortez pipeline is also common carrier, however the spare capacity of the Cortez pipeline is lower, at 73 Bscf/y (~4 MMT/y), and KM expects to produce more from their CO_2 fields in the near future.

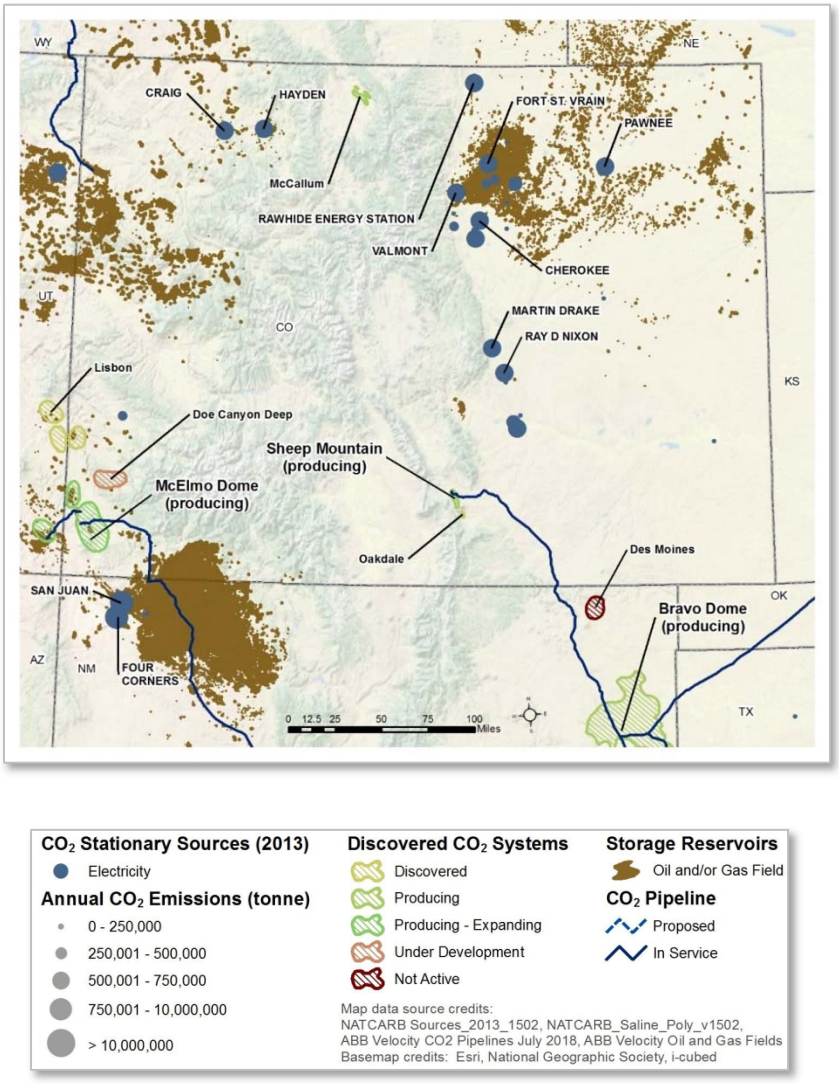

Figure 5: Power plants, CO_2 fields and oil and gas fields in Colorado Source: DOE/NETL

CO_2 from the West Bravo Dome Unit and the Bravo Dome CO_2 fields in New Mexico (Figure 3) is also supplied to Permian Basin oilfields. In addition to the SMPL, the 20-inch, 218-mile Bravo pipeline with a capacity of ~140 Bscf/y carries natural CO_2 from the Bravo Dome in New Mexico. Bravo Dome has an estimated recoverable resource of 2500 Bscf, or 133 MMT CO_2, and produced 104 Bscf in 2017, and therefore, the spare capacity in this pipeline is ~36 Bscf/y, or ~2 MMT/y. The approximate lifespan of this resource is 24 years.

The overall spare capacity in the CO_2 pipelines from Colorado to oilfields in the Permian Basin is 13 MMT/y (for SMPL and Bravo pipelines). Both SMPL and Bravo pipeline are common carrier and SMPL currently transports anthropogenic CO_2 from the La Veta gas processing plant along with natural CO_2 from Sheep Mountain. In comparison, annual CO_2 emission from all power plants in Colorado (see Figure 5) was 36 MMT [8], indicating that a significant fraction of the power plant CO_2 can be used for EOR in the Permian Basin if pipeline infrastructure and plant location are favorable.

2.4 Costs of CO_2 from natural sources: $12-$19/T CO_2 in 2017

The selling price of natural CO_2 for EOR is confidential and is based on contracts negotiated between the oilfield operator and the CO_2 supplier. Contracts may have a floor price and are usually indexed to crude oil price (e.g., price of CO_2 in $/Mcf = 2 to 3% x $/bbl). The price is based

on the combination of wellhead CO_2 price and the tariff to transport CO_2 from Colorado or New Mexico to the oilfields or the Denver City Hub. Accordingly, in 2007, KM's wellhead price for CO_2 from McElmo Dome was $0.52/Mcf and the pipeline tariff was $0.22/Mcf, for a supply cost of ~$14/T CO_2. Another source is the product valuation data reported to Colorado Oil and Gas Conservation Commission (COGCC). Using this data, KM's price for CO_2 was ~$1/Mcf in 2017 (~$19/T CO_2), and Oxy's price was ~$0.6/Mcf (~$12/T CO_2).

2.5 Additional CO_2 supply could expand CO_2-EOR in the Permian Basin

Currently, 111 million barrels of crude per year (MMbbl/y) are produced in the U.S. using ~53 MMT CO_2. The Permian Basin represents a large fraction of this CO_2-EOR market. The potential future demand for CO_2 from oilfields in the southwest region of the U.S. is also very high. Another market for CO_2 in Colorado could be the oilfields in the north-eastern part of the state. Colorado coal power plants (e.g., Comanche, Nixon, Drake) are located close to existing oil and gas fields and CO_2 transportation infrastructure in southern Colorado, ideal for additional CO_2-EOR production.

One case study examined of the potential to source the market in the Permian with anthropogenic CO_2 is the Comanche power plant. The plants three units produce a combined summer capacity power generation of 1,410 MW_{net} and produce a total of 8.95 MMT/y of CO_2. Comanche has one of the lowest costs of generating electricity in the state, at $23/MWh, of which fuel costs are $15/MWh and provides low cost base-load power. Comanche also has several air pollution control technologies that would enable the installation of CO_2 capture technologies. For example, the plant's older two sub-critical units (Units 1,2, 670 MW capacity) have baghouses to control particulate matter, lime spray dryers for SO_2 control, low-NO_x burners with overfire air for NO_x control, and activated carbon injection for mercury control. The plant's newer supercritical unit (Unit 3, 750 MW) has a selective catalytic reduction (SCR) system for additional NO_x control along with other features. Another positive attribute is the plant's location with respect to CO_2 infrastructure – it is approximately 60 miles from the existing Sheep Mountain pipeline (SMPL). If 90% of the CO_2 is captured it would provide over 8 MMT/y to the Permian, well within the 11 MMT/y spare capacity in the SMPL. Transporting CO_2 from Comanche power plant to the oilfields in the Permian Basin would only need a feeder pipeline (over relatively favorable terrain) to transport CO_2 to the trunkline (SMPL). If CO_2 capture technology is installed at Comanche, and if the CO_2 is used for EOR in the Permian Basin, the average 45Q EOR tax credits from 2022 to 2037 would be $37/T. If we assume that the sales price of CO_2 to be $20/T (slightly above current natural CO_2 prices), the revenues from CO_2 sales and 45Q tax credits ($57/T CO_2) could almost offset the cost of capturing CO_2 (likely $40 to $60/T). The added benefit of this scenario is that the overall CO_2 emission into the atmosphere would be decreased, and that the state (TX or CO) would receive additional royalties from the production of the crude oil.

Utilizing appropriate capture technologies, industrial and power generation sources of CO_2 could fill the need in the Permian and with appropriate pipeline infrastructure investment could serve as a source for EOR in the oil fields in northeast Colorado bringing oil production revenue to the State.

This study finds that of all the Colorado coal plants the Comanche plant is in a unique position of being one of the lowest cost electricity producer in Colorado, being located close to the existing CO_2 infrastructure, and with the newly available 45Q Tax credits the economics of CO_2 capture at this plant would require a further more detailed examination. The next steps would be to analyze in more detail the Comanche plant and how CO_2 capture technology application at this plant could potentially help replace the currently declining natural sources of Colorado CO_2 used for EOR.

3 Acknowledgments

This report was prepared by LTI for the Office of Advanced Fossil Technology Systems, Office of Energy for the United States Department of Energy (DOE). This work was completed under DOE Contract Number GS-23F-0231R, order number DE-FE0022594; DE-BP0005230.

The authors also wish to acknowledge and express sincere gratitude to all those who assisted and supported the efforts and preparation of this report including:

Office of Program Performance and Benefits, National Energy Technology Laboratory, DOE
Leonardo Technologies, Inc.

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