CO_2-EOR Potential in the MGA Region

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CLINTON FOUNDATION | CLINTON CLIMATE INITIATIVE

IN COLLABORATION WITH

MGA Midwestern Governors Association | Great Plains Institute

EXECUTIVE SUMMARY

The Midwestern Governors Association (MGA) region has significant technical and economic potential to arrest the decline, and eventually grow the production of crude oil from its mature oil fields. The analysis of region's petroleum resources suggests that carbon dioxide enhanced oil recovery (CO_2-EOR) may be an attractive commercial opportunity.

CO_2-EOR is a thirty year old technology used widely in the Permian Basin of Texas and other geographies to extract significant volumes of incremental oil from mature fields that would have otherwise been left in the ground. Screens used in this assessment to identify EOR candidate fields suggest that an estimated 2 billion barrels of oil could be produced utilizing anthropogenic carbon dioxide for EOR. All four principal MGA oil regions in Michigan, Illinois/Indiana, Kansas, and Ohio were considered.

To produce this oil as much as 1 billion metric tons of anthropogenic CO_2 would be needed over a period of ten to twenty years. The CO_2 emissions from stationary sources in the region are at about 700 million metric tons per annum, significantly more than would be required for regional EOR, with power plants contributing about 80% of the volume. The cost of capturing CO_2 at power plants is still quite high, and may be prohibitive for enhanced oil recovery in the near term if oilfield operators were expected to pay for the full cost of capture from these facilities. However, the region is quite fortunate to have about 35 million metric tons per annum of CO_2 from ethanol fermentation, which can be captured at relatively low cost. ADM is currently capturing approximately 1MMT of CO_2 over three years from their Decatur plant and injecting it into the Mt. Simon saline aquifer in the first of two DOE/ISGS studies, demonstrating the cost and feasibility of CO_2 capture, injection, and geological storage. States such as Iowa and Nebraska, with large volumes of ethanol based CO_2, can play an important role in supplying the commodity to oilfield operators in neighboring MGA oil states.

Analysis of the potential economics of a CO_2 "flood" in a representative field in each of four principal oil regions suggests that CO_2-EOR in the MGA could be economically viable at the reference case assumptions. The reference case uses US EIA oil price projections (about 1% per annum real price increase), CO_2 cost at a current "market" price of about $32 per metric ton (in the future indexed to oil prices), and best available estimates of production curves and associated investment costs. In addition to the reference case, sensitivities around critical parameters were tested.

Generally, for the reference case, project economics lead to an after-tax IRR of 20% or higher with significant variation across states as described below. The economics of CO_2-EOR are highly dependent on the operator's projections of oil production response to CO_2 injection, and the capital investment required in wells and surface equipment to upgrade or replace lease assets already in the field. In most cases a CO_2 price of $80 per metric ton renders projects uneconomic. However a portion of the MGA's emissions sources, such as ethanol and natural gas processing, can supply CO_2 at or below current "market" prices, improving the potential commercial viability of EOR. Furthermore, a broader agenda for the growth and support of CO_2-EOR activity in the region, with possible investment incentives for operators and emitters, could have a catalyzing effect for the industry.

If CO_2-EOR were developed on a wide scale, MGA states could add at least 6000 direct new jobs and 3 times as many indirect jobs. Additional benefits would flow through royalties on state mineral interests where they exist, severance taxes on production, and corporate and personal income taxes.

CO_2-EOR can provide an important balance between the benefits of economic growth from an extractive industry and environmental benefits to society as a whole. As a "new" source of oil, it supports national energy security goals and can improve regional and local economies. As a market for carbon dioxide, it can establish a price signal for carbon, and catalyze, or perhaps even finance, infrastructure for carbon capture and sequestration. In producing more fossil fuels CO_2-EOR may actually play an important role in the reduction of greenhouse gasses from the atmosphere.

BACKGROUND

Most oil fields that are classified as economically "depleted" still have significant oil resources remaining in the ground. Traditionally, a field will go through a primary (conventional) and a secondary (water flood) stage of oil recovery before achieving "depletion" when production rates decline to a level no longer considered economic. Primary and secondary production combined typically produce only 30-40% of a reservoir's original oil in place (OOIP), often leaving over 60%, and at times as much as 90% of the original oil in the ground. A tertiary stage of recovery, also known as enhanced oil recovery can extract some of this remaining oil and extend field life. Specific geologies and oil characteristics determine the type of enhanced recovery technique an operator might use. CO_2-EOR is a technique particularly appropriate for many MGA region fields, and can yield an additional 10-15% or more of OOIP. Under the right geological conditions carbon dioxide becomes miscible with oil, making it easier to drive out of the reservoir rock. Even when miscibility cannot be achieved, carbon dioxide swells the oil and reduces its viscosity, thereby improving recovery. Some of the carbon dioxide is produced with the oil, and is then recycled and reinjected into the reservoir.

In the United States, CO_2-EOR is a 30 year old technology that currently accounts for more than 280 thousand barrels of oil per day (mb/d) of production nationwide, predominantly in Texas, Louisiana, Mississippi, Oklahoma, and Wyoming. Historically, CO_2 has been supplied from natural CO_2 deposits, similar to natural gas, found in Colorado and New Mexico (supplying Texas and Oklahoma) and Mississippi (supplying the Gulf Coast). However, natural CO_2 is not very common, and there are no known reserves in the MGA region. In Wyoming CO_2 is supplied from a large natural gas plant that removes the CO_2 as an impurity from the gas. In the traditional CO_2 markets, demand from operators has begun to outstrip supply of natural CO_2, and increasingly industry players are turning to anthropogenic supplies of CO_2. Denbury Resources, a vertically integrated CO_2-EOR operator, signed MOUs with developers of proposed carbon capture power plant projects in the MGA region to purchase and transport their CO_2 down to the Gulf Coast to use for EOR if enough projects are built to justify a pipeline of that length.

Oil production from successful CO_2-EOR floods brings the same significant benefits to national energy security and to regional economies as oil production by other means. However, CO_2-EOR also provides potential environmental benefits by establishing a price signal for carbon, and catalyzing, or perhaps even financing, infrastructure for carbon capture and sequestration. Even in the production of additional fossil fuels, CO_2-EOR may be an important step towards the reduction of greenhouse gasses from the atmosphere.

As the technical skill set required to implement a CO_2 flood has spread beyond the Permian Basin and Mississippi operators, and as the industry increasingly turns to anthropogenic sources of CO_2, other oil regions have begun to explore the feasibility and potential of CO_2-EOR. This report provides a high level assessment of the commercial viability of CO_2-EOR in the Midwestern Governors Association political region, and is intended to assist MGA stakeholders in outlining a path forward. It was developed by the Clinton Climate Initiative in collaboration with the Great Plains Institute, pursuant to recommendations of the Midwestern Governors Association's (MGA) CCS Task Force and in advancement of Governor Pat Quinn's 2011 MGA Chair's Agenda.

REGIONAL OVERVIEW

The MGA has four principal oil and gas regions that are often shared with other non MGA states:

- Michigan Basin – Michigan
- Illinois Basin – Illinois, Indiana, (Kentucky)
- Appalachian Basin – Ohio (Pennsylvania, West Virginia, Kentucky, New York)
- Mid Continent – Kansas (Oklahoma)

The MGA region has rich oil history. To date Illinois, Indiana, Ohio, Kansas, and Michigan together have produced almost 13 billion barrels of crude oil. However, MGA fields are very mature and crude production has been in a long decline. Although Kansas has reversed this trend over the past decade, MGA states are producing at rates much lower than both historical and previous-30 year peaks, and many fields are producing less 5 barrels a day per well. Collectively, the five MGA oil states produced oil at a rate of 175 mb/d in 2010, compared to Texas' rate of 1,100 mb/d in the same year. Despite this, screens used in this assessment suggest that more than 2 billion barrels of oil could be produced from CO_2-EOR in the MGA utilizing a regional supply of anthropogenic CO_2.

The MGA region produces more than 700 MMT of CO_2 annually from stationary sources. This presents a potential supply of anthropogenic CO_2 for EOR uses throughout the region. Coal-fired power plants account for most of the CO_2 emitted, although industrial emissions are significant, including those that emit high purity streams of CO_2 from non-combustion processes, such as ethanol fermentation, gas processing, and ammonia production. Annually, the MGA region produces more than 35 MMT of CO_2 from ethanol fermentation alone. The cost of capturing CO_2 is largely dependent on the purity of the CO_2 stream produced in the flue gas, so high purity sources may present a viable economic option for CO_2 capture for EOR. Conversely, due to the low CO_2 purity of the flue gas from coal fired power plants, the cost of capture at these facilities is significantly more expensive at the moment, although this could change as technology improves.

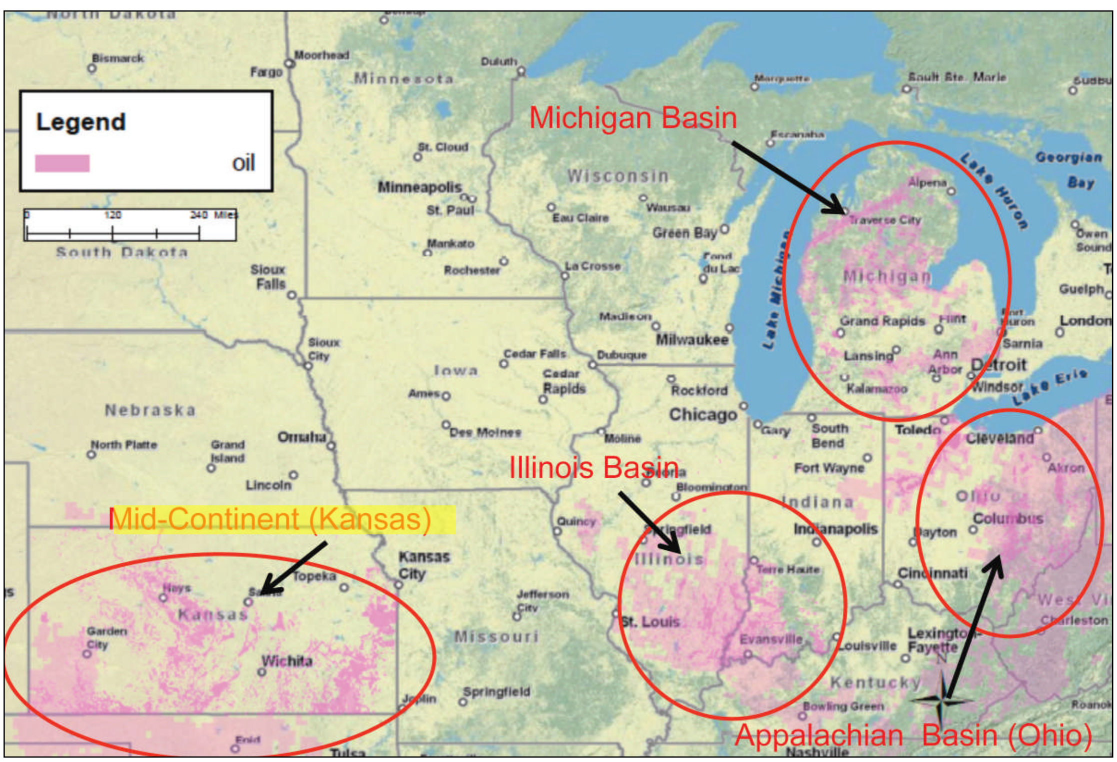

Figure 3: MGA oil and gas basins.

CO_2-EOR presents an opportunity for renewed growth in oil production throughout the MGA region. If developed on a wide scale, it may result in recovery of more than 2 billion barrels of incremental oil throughout the region. Furthermore, MGA states could add over 6,000 direct new jobs and up to 3 times as many indirect jobs. MGA states would also benefit from additional revenue flowing through state mineral interests, severance taxes, and corporate and personal income taxes. A net CO_2 demand of 670 – 1, 050 MMT CO_2 would be required to recover 2 billion barrels of incremental oil.

CO_2-EOR is only technically feasible under certain geological conditions. This assessment screened the majority of oil fields in the MGA region for technical CO_2-EOR potential using public domain information available through the state geological surveys. Carbon dioxide becomes miscible with

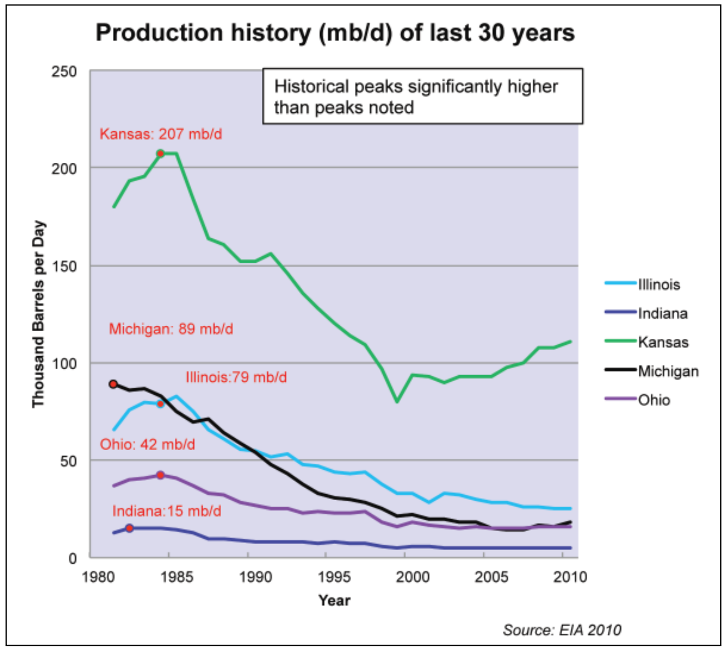

Figure 4: MGA 30 year production

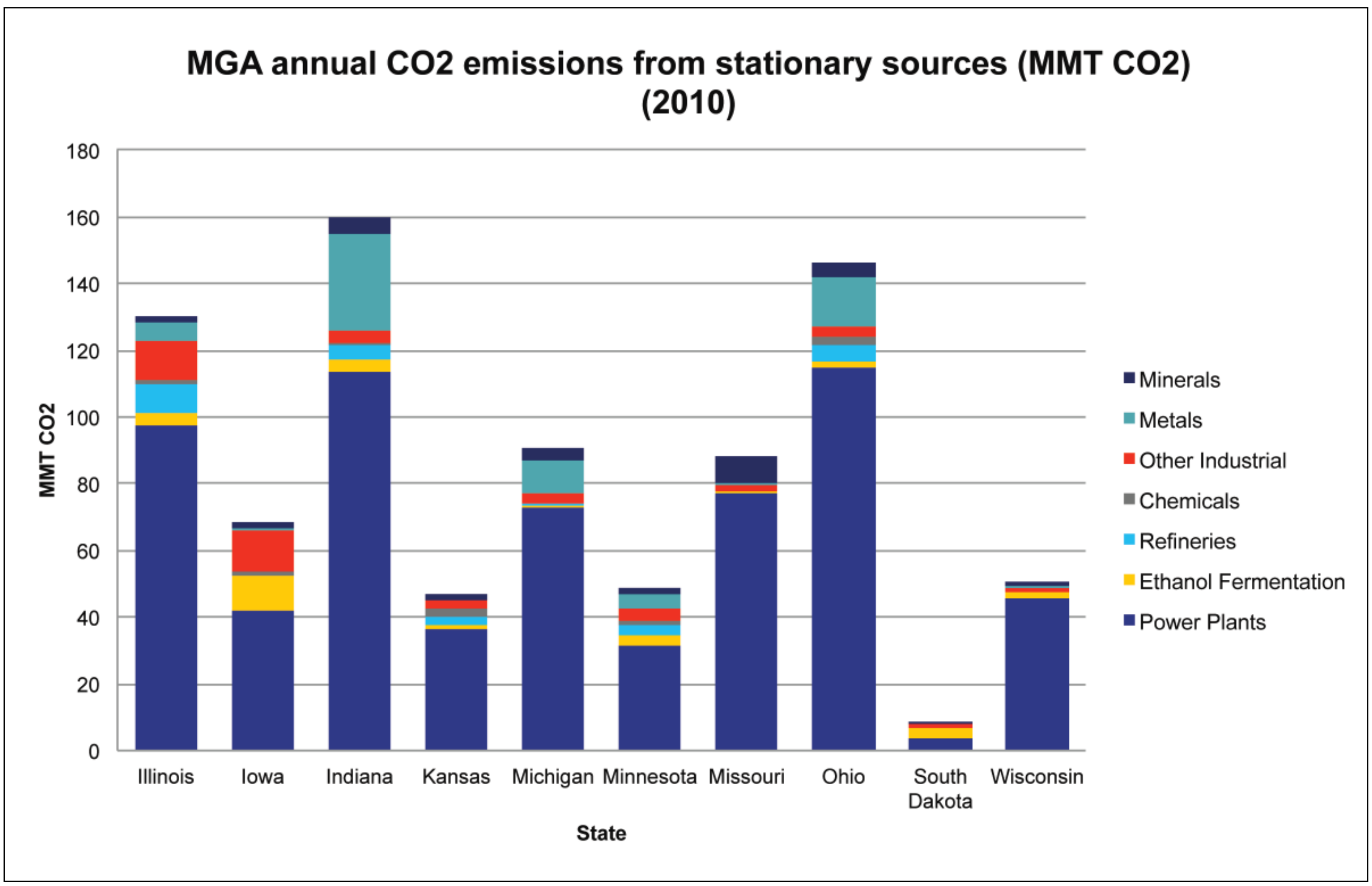

Figure 5: MGA region emits approximately 700 MMT CO2 annually

oil only under pressure. An operator assessing technical viability in a particular lease, would calculate the minimum pressure required to achieve miscibility, and then determine whether that pressure violated the naturally or legally allowed pressure in the target reservoir. Where possible, average minimum miscibility pressure (MMP) values were calculated for field-reservoir combinations and compared against assumed initial or fracture pressure values to screen for candidate fields. When sufficient data was not available, other parameters were used to approximate miscibility. In general, reservoirs with average depth below 2500 feet and oil gravities with API values between 30 and 50 were classified as miscible. For fields with multiple producing reservoirs, only the reservoirs that passed the screens would count for incremental oil recovery values.

Basin	EOR potential (Mil bbl)	Net CO_2 Demand (MMT)	Direct Jobs Created
Illinois/Indiana	500	160 – 250	1,550 – 3,100
Ohio	500	190 – 300	1,550 – 3,100
Michigan	250	80 – 130	800 – 1,800
Kansas	750	240 – 370	2,300 – 4,600
TOTALS	**2,000**	**670 – 1,050**	**6,200 – 12,400**

Michigan

Summary: CO_2-EOR could be commercially viable in Michigan.

- Analysis focused on fields in Niagaran Pinnacle Reef trend in the northern lower peninsula
- Representative field suggests strong operator economics
- Sourcing of “market price” CO_2 may be problematic
- State would benefit through additional revenue and jobs

Michigan has a long oil industry tradition, and to date has produced approximately 1.2 billion barrels of oil. This analysis focuses on the Niagaran-Silurian pinnacle reef trend in the northern lower peninsula, a long series of small, deep fields that were discovered in the 1960s and 1970s and reached peak production in the early 1980s. The trend stretches across most of the peninsula and overlaps the Antrim gas fields in the east. The trend’s relatively recent discovery and exploitation suggest the infrastructure should be in far better condition than older fields elsewhere in Michigan, reducing capital cost requirements. Importantly, it contains the only commercial CO_2 floods in Michigan and the MGA region, demonstrating the technology’s feasibility and potential. CORE Energy produces oil from five fields using a carbon dioxide stream from a natural gas processing plant. In aggregate, this assessment suggests that the Niagaran trend has over 125MM bbls of incremental oil potential which would require 40-60MMT of CO_2 to produce.

One potential development strategy assumes that larger central production facilities (CPFs) that serve multiple fields or wells could serve as locations for initial CO_2 recycling plants, and the fields they serve would serve as anchor demand for a CO_2 pipeline. CPFs in the trend, and their associated fields, were ranked by gross sales and the largest were identified and mapped together with their fields. Incremental oil potential from these anchor fields is more than 50 million barrels.

Chester 18 field was chosen as a representative field for the economic analysis, as data for the field was available in the public domain. Our reference case assumptions lead to a pre-tax project IRR of 70% and after-tax of 49%. Local experience suggests that oil production may be better than the underlying Illinois based production curves used in the cash flow model, suggesting stronger economic potential. Worst case capital investment sensitivities still realize after-tax IRR values of over 20%. In summary, although Chester 18 is one of the larger fields in the trend, results suggest that there is commercial potential in the smaller fields.

Kansas

Summary: CO_2-EOR should have commercial potential in Kansas.

- Screens used in this study indicate 750 million barrels of technical CO_2-EOR potential
- Kansas has access to high volume of region's ethanol-based CO_2
- Modeling suggests positive economics, but requires further analysis
- State economy would benefit from additional 2,300 – 4,600 direct jobs if CO_2-EOR deployed widely

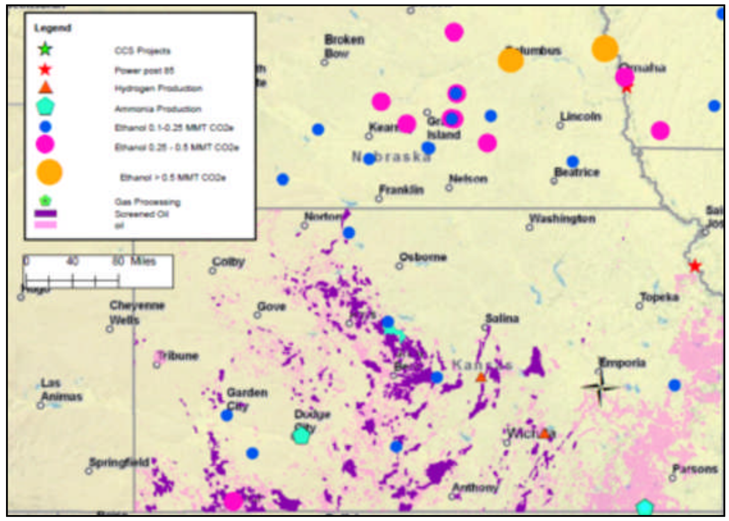

Figure 9: Kansas and Nebraska.

Kansas' oil history dates back to the 1860's though production did not accelerate until the discovery of the El Dorado field in 1915. The statewide production rate peaked in the 1950's and has since declined significantly, despite a recent turnaround. The state has cumulatively produced more than 6 billion barrels of oil. The three most prolific producing horizons, the Arbuckle, Lansing-Kansas City, and Mississippian formations, are responsible for approximately 70% of this amount. The 10 county Central Kansas Uplift area, which includes large portions of the Arbuckle and Lansing-Kansas City formations, is responsible for approximately 40% of the state's historical production, although "stripper" wells producing under 5 barrels/day are now typical and representative of the statewide decline.

The screens used in this study suggest 750 million barrels of technical CO_2- EOR potential. Kansas has the largest oil resources in the MGA region and shares geological formations with Oklahoma, where commercial CO_2 floods are proven and are serviced by existing and planned CO_2 pipeline infrastructure. If adopted on a wide scale CO_2-EOR would require 240 – 370 MMT of CO_2. However, the full EOR potential of the Arbuckle, Kansas' largest formation, is still uncertain due to geology that makes miscibility difficult to achieve. However near-miscible flooding techniques may be feasible and a DOE-sponsored University of Kansas Center for Research Tertiary Oil Recover Project (TORP) study to examine these techniques in the Arbuckle is currently underway.

Kansas has a moderate supply of in-state relatively low cost CO_2 from ethanol and fertilizer plants, and has previously used ethanol CO_2 for CO_2-EOR pilots in Russell and Liberal. The state is currently "exporting" ethanol based CO_2 from Liberal (and will be exporting ammonia based CO_2 from Coffeyville) via pipeline for EOR in Oklahoma. Chaparral Energy, an Oklahoma operator, is shipping the CO_2 to its fields via a growing Oklahoma CO_2 pipeline network. In Kansas, an independent operator, Petrosantander, may purchase all of the CO_2 from the Bonanza Energy ethanol plant in Garden City for EOR in the Stewart field nearby. Sunflower Energy has previously expressed interest in EOR for a proposed CO_2 capture component at its 800 MW coal fired power plant in Holcolmb, although the status of the project is uncertain, and the capture cost would be significantly higher than for ethanol. Kansas could have access to the significant volumes of ethanol-based CO_2 in Nebraska, which produces approximately 6MMT per annum.

Our financial modeling suggests positive economics, but with significant uncertainty and a need for further analysis. The Hall Gurney field was selected for analysis as there was field-reservoir data available in the public domain. The field was also the site of a Kansas Geological Survey (KGS) CO_2-EOR pilot in a lease near Russell, although results were mixed. The reference case economics suggest an after-tax project IRR of 22%; however significant questions remain around modeling assumptions including: OOIP, a more representative production profile than the Illinois simulations, and better definition of operator strategy. Changes in these variables can lead to significantly different outcomes.

Kansas has a state severance tax of 8%, but tertiary oil production is given a full exemption, so no incremental severance tax revenues were assumed. If developed on a wide scale, the state economy could benefit from an additional 2,300 – 4,600 of direct jobs.

This analysis suggests a large commercial potential for CO_2-EOR in Kansas but with significant uncertainty. More characterizations and pilot tests are required to validate the resource base and commercial production potential in the state. Three KGS studies are in progress in fields that overlay typical producing formations: Lansing-Kansas City, Mississippian, and Arbuckle. Characterizations and recovery models from these studies can be used as analogs for appropriate fields elsewhere in the state to develop scoping models of CO_2-EOR potential.

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