The Role of CCUS in North America Energy System Decarbonization

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One of the key energy technologies that can significantly reduce carbon dioxide (CO_2) emissions across industrial processes and power generation is carbon capture, utilization, and storage (CCUS). We explore different scenarios of North America long-term energy system development with respect to CCUS technologies and, particularly, CO_2-enhanced oil recovery (EOR).

Keywords: Carbon Capture, Utilization, and Storage (CCUS), Carbon Dioxide (CO_2), Enhanced Oil Recovery (EOR)

EXECUTIVE SUMMARY

North America (U.S., Canada, and Mexico, jointly) is on track to achieve a significant (about 50%) carbon dioxide (CO_2) reduction by 2050 (relative to 2015) using CO_2 taxation. However, CO_2 taxation policy primarily affects the power generation sector. Achievement of the 2015 United Nations Climate Change Conference (COP21) commitments by North America requires immediate deployment of available clean energy technologies, including carbon capture, utilization, and storage (CCUS), and stronger decarbonization policies. Delay in decarbonization might imply the need for more radical intervention, e.g., a massive deployment of negative emissions technologies.

INTRODUCTION

With the ratification of the Paris Agreement, 195 nations committed to holding the increase in the global average temperature below 2 °C above pre-industrial levels. North America (U.S., Canada, and Mexico) formally joined the Paris Agreement in April 2016 [UN, 2019]. The U.S. indicated it would pull out of the agreement, though the exit won't be complete until 2020 [Tollefson, 2017; Diringer, 2017]. However, a new alliance of states, cities, and corporations has already vowed to help the U.S. meet the Paris reduction goals. Canada committed to a 30% reduction of 2005 greenhouse gas (GHG) emissions by 2030 and an 80% reduction by 2050 [CERI, 2017]. Notwithstanding Mexico's relatively low contribution to global GHG emissions, the country has undertaken important efforts to address the problem of climate change. Mexico set priority goals for controlling global warming: a reduction of GHG emissions by 22% by 2030 and a 50% reduction in the volume of emissions by 2050 [UNFCCC, 2019.

Carbon capture, utilization, and storage (CCUS) is one of the novel technologies by which carbon dioxide (CO_2) emissions are captured from sources such as fossil power generation or industrial processes, and either reused or stored. Globally, power and industry account for about 50% of all GHG emissions, and CCUS is among technologies that can prevent CO_2 from entering the atmosphere. While initial development of CCUS technology primarily focused on decarbonizing the power sector, the technology has evolved to include energy-intensive industries such as cement, steel, chemicals, and many other manufacturing sectors.

As of 2019, there are 43 large-scale integrated carbon capture and storage (CCS) or CCUS facilities all over the world (18 projects operating, 5 under construction, and 20 projects at development stage) [Global CCS Institute, 2019]. Those projects are located in several countries, but most are in the U.S. (12) and Canada (7); most captured carbon is used for enhanced oil recovery (EOR). EOR injects CO2 into oil fields to produce additional oil. CO2-EOR has been proved at a number of sites worldwide. In CO2-EOR projects, all of the injected CO2 either remains sequestered underground or is produced and re-injected. CO2-EOR can effectively lower the carbon intensity of oil production across the value chain.

CO2-EOR is a tertiary oil production process that is used after the primary and secondary oil production phases have been completed and it represents the process of CO2 injection into depleted or depleting oil and gas fields that causes the oil to run more freely to the producing well. During this process, the injected CO2 is produced with oil, separated and reinjected, and nearly all of the CO2 remains securely trapped within the deep geologic formation [NETL, 2010; Melzer, 2012].

CCUS technology development can accelerate deployment of viable options for reducing CO_2 emissions related to large point sources while increasing oil production. Despite its great importance, the deployment status of CCUS technology is still at the earliest stage. The investment cost of CCUS is very high; there is also a lack of effective government incentive policies. U.S. Congress approved a tax credit for CO_2 utilization and storage known as 45Q in February 2019. The new 45Q tax credit includes no cap on the storage, thereby providing more flexibility for projects that may take years to plan and develop. The new 45Q tax credit increases the subsidy values for the geological storage to \$US 50/tCO_2 and for CO_2-EOR utilization to \$US 35/tCO_2.

The objectives of this study are to evaluate the impact of the CO_2-EOR and 45Q tax credits on CCUS investment decision-making and on CO_2 emissions reduction in North America. The following sections describe the North America CO_2-EOR potential, MARKAL model and scenario definitions, modeling results, and discussion and conclusions.

NORTH AMERICA CO_2-EOR POTENTIAL

United States

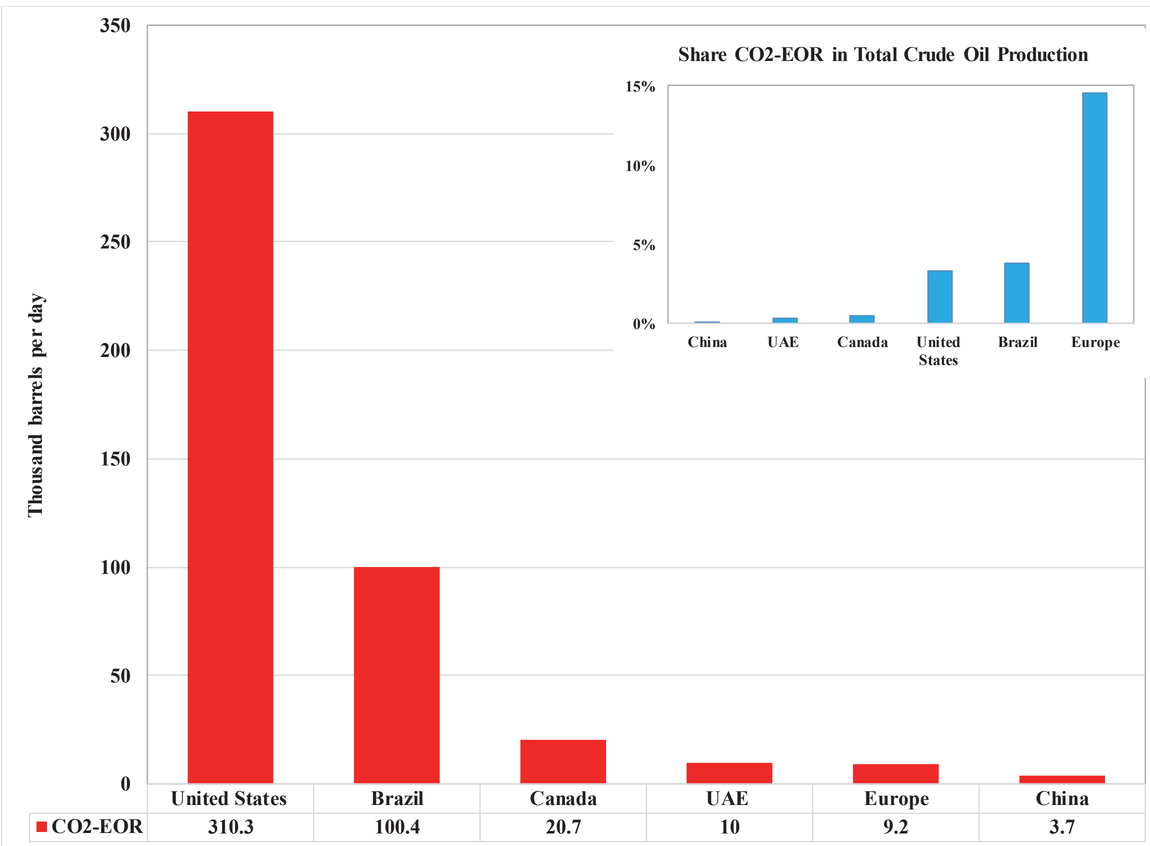
CO_2-EOR has been used in the U.S. for decades, beginning in the Permian Basin of West Texas and New Mexico (since the mid-1980s) and expanding to other regions [NETL, 2019]. There were more than 136 active commercial CO_2-EOR projects in the U.S. in 2014 and combined, they injected more than 68 million metric tons (Mt) CO_2 and produced more than 300 thousand barrels (bbl) of oil per day [Kuuskraa & Wallace, 2014]. It was estimated that 14 MtCO_2 from the industrial sector was stored through CO_2-EOR [Kuuskraa & Wallace, 2014].

To date, the development of CO_2 flooding was favored in the Permian Basin; in addition, considerable growth in CO_2-EOR is occurring in the Gulf Coast, the Rockies, Oklahoma, and Michigan. The U.S. is a leading country in CO_2-EOR, and it is expected that new floods in Wyoming, Kansas, and California will increase the EOR production remarkably. Since the onset of CO_2-EOR, natural CO_2 sources were sufficient to provide the CO_2 needed for EOR. Today the situation has changed as depletion of the CO_2 sources and limitations of the CO_2 pipelines are now constricting CO_2-EOR growth.

A 2009 study by Advanced Resources International (ARI) assessed the role of CO_2-EOR technologies in the future U.S. oil recovery. ARI concluded that providing state production tax incentives, federal investment tax credits, and royalty relief, and establishing low-cost, reliable, CO_2 supplies could result in an additional 85 billion barrels (Bbbl) of technically recoverable oil from the 400 Bbbl of oil remaining in large reservoirs across 11 basins [NETL, 2010]. The new Clean Air Task Force (CATF) study on U.S. power sector modeling finds that 45Q federal tax credits for CCS can have a significant impact on CO_2 emissions reductions by 2030 [CAFT, 2019].

In CO_2-EOR development, the U.S. was followed by Canada and, to some degree, Europe (Turkey, Hungary), Brazil, the United Arab Emirates and China (see Figure 1). These countries also demonstrated that EOR from CO_2 floods is a proven technology, and that most of the mature oil fields facing the end of production can extend their lifetime and increase their values by implementing tertiary CO_2 floods.

FIGURE 1
2017 CO_2-EOR PRODUCTION BY COUNTRY AND SHARE OF CO_2-EOR IN TOTAL EOR PRODUCTION (RIGHT-HAND WINDOW)



SOURCE: [IEA, 2018]

Canada

The volume of original oil in place (OOIP) is a key variable in determining the CO_2-EOR potential of a reservoir and it is used to estimate how much oil remains as a target for the application of CO_2-EOR. In Canada, large field OOIP for CO_2-EOR is estimated at 37.6 Bbbl and large field technically recoverable resource (TRR) for CO_2-EOR is estimated at 5.7 Bbbl [IEA, 2009; Ahmed & Meehan, 2016].

The Boundary Dam project, which is the largest CO_2-EOR project in Canada, began in 2000 in the Weyburn and Midale fields in Saskatchewan [IEA, 2009; Brown et al., 2017]. This is the largest CO_2 storage project in the world and has been used to store around 13 Mt of CO_2 to date with CO_2 purchased from Dakota Gasification Company (a subsidiary of Basin Electric in North Dakota) [Brown et al., 2017]. The CO_2-EOR operations resulted in more than a three-fold incremental increase in oil production from 8,000 bbl a day in 2000 to approximately 26,000 bbl a day by 2014, reaching a peak of about 30,000 bbl a day in 2009. By 2016, the Weyburn Field had about 27 $MtCO_2$ in the ground, and the Midale Field had slightly over 9 Mt [Brown et al., 2017; Sacuta et al., 2017].

In addition to the projects mentioned above, several pilot projects are running and further CO_2-EOR projects are under development. The extent and maturity of development of CO_2-EOR in Canada is lower than in the U.S.

Mexico

Mexico's large field OOIP for CO_2-EOR is estimated at 92.6 Bbbl and large field TRR for CO_2-EOR is estimated at 14.1 Bbbl, most of which is concentrated in the Gulf of Mexico region [IEA, 2009]. Several factors contributed to difficulties in CO_2-EOR in Mexico, including investment constraints and reservoir service capabilities. In March 2014, Mexico launched its CCUS technology roadmap containing recommendations for actions to be taken at a national level up to 2024 focusing on geological storage in deep saline aquifers and EOR projects [Mexican Ministry of Energy, 2014]. This suggests that government investment in research and development (to bring down the cost of capture and infrastructure for sustainable supply of anthropogenic CO_2 to close the supply-demand gap) could expand CO_2-EOR storage opportunities.

CO_2 storage areas have been identified by the North American Carbon Storage Atlas [NETL, 2015], showing that most of the zones are located close to the Gulf of Mexico. The lack of current CO_2-EOR projects is largely because anthropogenic CO_2 sources are not available or economically feasible in Mexico. For instance, the amount of CO_2 available from industrial sources within a 100-kilometer (km) radius of the Villahermosa basin is estimated at about 1% of the CO_2 required for CO_2-EOR, while in the Tampico-Misantla basin is it still insufficient at 11% [Godec, 2011]. It was identified that non-anthropogenic CO_2 sources for CO_2-EOR projects could be existing industrial and power plants that emit CO_2 [Lacy et al., 2013] and also possible new gas-fired power plants in the Gulf of Mexico [González-Díaz et al., 2017].

MARKAL MODEL AND SCENARIOS DEFINITIONS

MARKet ALlocation (MARKAL) is an integrated-energy-systems modeling platform that can be used to analyze energy, economic, and environmental issues at the global, national, and municipal level over several decades. MARKAL is a bottom-up, dynamic, linear programming optimization model that finds cost-optimal decarbonization pathways within the context of the entire energy system. MARKAL represents energy imports and exports, domestic production of fuels, fuel processing, infrastructures, secondary energy carriers, end-use technologies, and energy service demands of the entire economy. MARKAL does not contain a built-in database, so the user is obliged to enter input parameters. In this study, the publicly available EPAUS9r2017 database for the U.S. energy system had been adopted and modified. EPAUS9r2017 (with the U.S. Census regions represented) was created by the Environmental Protection Agency (EPA) in 2017 to model changes in the U.S. energy sector through 2055. We extended EPAUS9r2017 and included Canadian and Mexican energy systems as two new regions.

Each of the 11 regions (9 of the U.S. Census regions, Canada, and Mexico) was modeled as an independent energy system with different regional costs, resource availability, existing capacity, and end-use demands. Regions are connected through a trade network that allows transmission of electricity and transport of gas and fuels. Electricity transmission is constrained to reflect existing regional connections between North American Electric Reliability Corporation (NERC) regions as closely as possible. Given the significant role of the U.S., Canada, and Mexico on the world energy system, our results represent an important contribution to the study of global energy trends.

We included CO_2-EOR technology in the database. The following assumptions and limitations are related to CO_2-EOR in MARKAL:

- Natural sources of CO_2 and industrial sources from gas processing plants, a host of nitrogen, hydrogen, fertilizer etc., were included into the model.
- There is no published work in the literature regarding potential of Canadian natural CO_2 sources to the knowledge of the authors, so natural sources of CO_2 in Canada were not included in the model.[1]
- CO_2-EOR projects are presented at the regional levels (not at the project or reservoir levels).
- The volume of CO_2 recycled for injection was not included. Instead "fresh" CO_2 usage rates were applied (fresh CO_2 and oil produced ratio). Fresh CO_2 usage rates can be calculated as CO_2 Purchased and Oil Produced ratio or CO_2 Injected minus CO_2 Recycled and Oil Produced ratio (see details on fresh vs. "injected" CO_2 in [Melzer, 2012]).
- The difference between the volume of CO_2 Injected and CO_2 Produced represents the volume of CO_2 permanently stored in the reservoir.
- We assumed CO_2-EOR recovery efficiency of 20% (from operational evidence from the Permian basin) suggests feasibility [Godec et al., 2011].

FIGURE 2
CO_2-EOR MODULE IN MARKAL MODEL AND RELATIONSHIP WITH TECHNOLOGY GROUPS

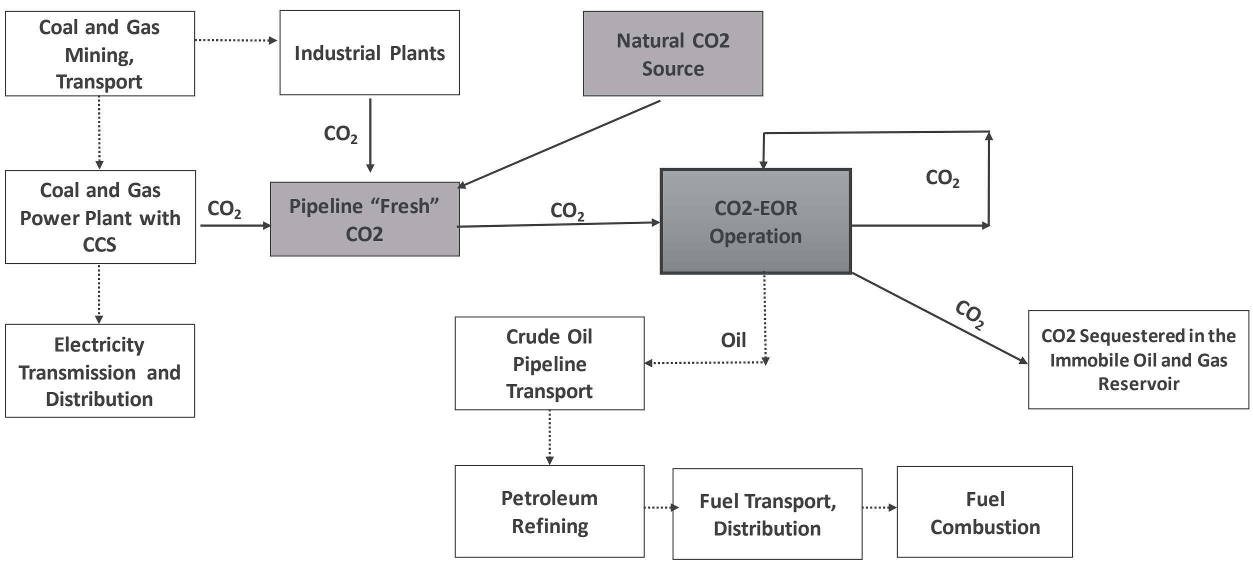


Figure 2 shows a simplified CO_2-EOR module that we developed for our study in MARKAL (marked by grey) and its relationship with other technologies groups in the model. During CO_2-EOR, a large percentage of the originally injected CO_2 gets trapped in the geologic formation and the trapping continues as long as the CO_2 is injected. As the result of this "incidental" sequestration, the CO_2 that is produced should be recycled (captured, compressed, and continuously added to newly purchased fresh CO_2) for EOR operations to continue. Because of the effective "closed loop," the experience of the industry to date is that 90–95% of the purchased CO_2 remains securely trapped within the deep geologic formation. As naturally occurring CO_2 can be permanently trapped safely in many geologic situations, CO_2 from EOR can be permanently trapped as well.

However, not every subsurface situation will provide the needed security and effective storage sites; geologic regimes with certain attributes are needed to assure the CO_2 will stay in the subsurface and not migrate toward the surface. We didn't address these safety issues in our study and assumed, per se, the selection of sites is best practices in the oil and gas industry and that CO_2 delivered to the EOR facility will be contained within the reservoir and in closed-loop recycle systems, and, thus kept out of the atmosphere.

We examined CO_2 emissions and energy system technologies deployments under the six scenarios (see Table 1 for scenario names and definitions).

TABLE 1
SCENARIO DEFINITIONS

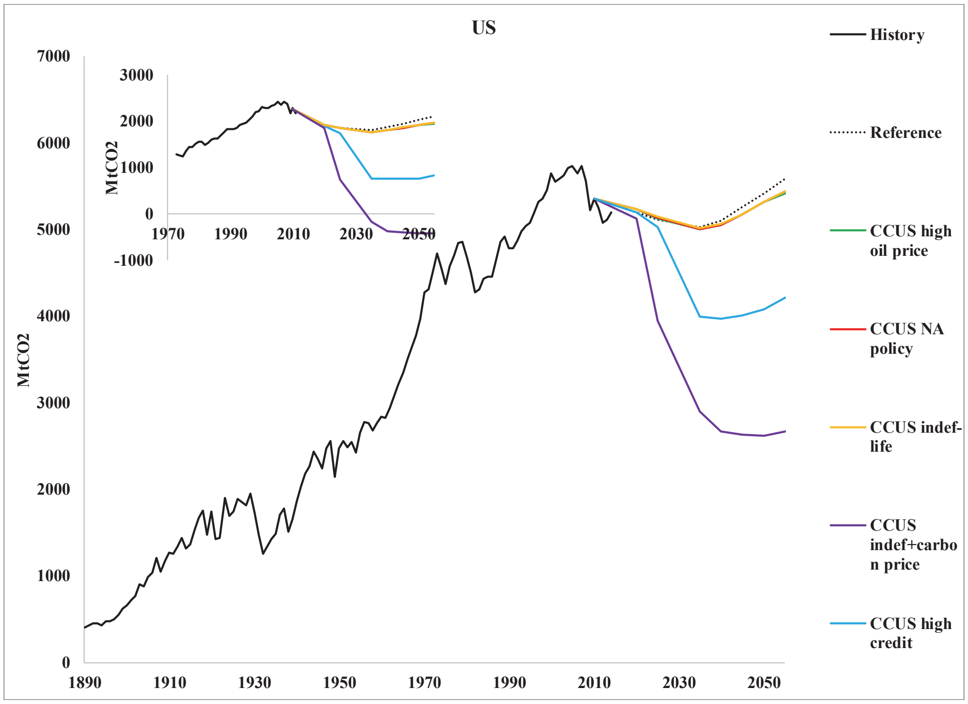
Scenario Name	Scenario Definition
Reference	Reference
CCUS indef life	Reference scenario with CO_2-EOR option in Canada and Mexico, and 45Q tax credits in 2020–2050 in the U.S. Tax credit of $US 30 per tonne of CO_2 for anthropogenic CO_2 going to EOR, and $US 50 per tonne if going to straight storage[2]
CCUS high credit	CCUS indef life with higher credits for 45Q. Tax credit of $US 50 per tonne of CO_2 for anthropogenic CO_2 going to EOR, and $US 75 per tonne if going to straight storage
CCUS high oil price	High oil prices and with CO_2-EOR in Canada and Mexico, and 45Q in the U.S. Oil prices are consistent with AEO 2017 low oil reserves scenario
CCUS indef life+carbon price	Carbon policy (scenario with environmental constraints): carbon taxes at $US 35/tonne starting 2020 and increasing at 5% per year until 2055. This scenario includes CO_2-EOR option in Canada and Mexico, and 45Q tax credit option in the U.S.
CCUS NA policy	CCUS indef life with 45Q in Canada and Mexico

MODELING RESULTS

System-Wide CO_2 Emissions

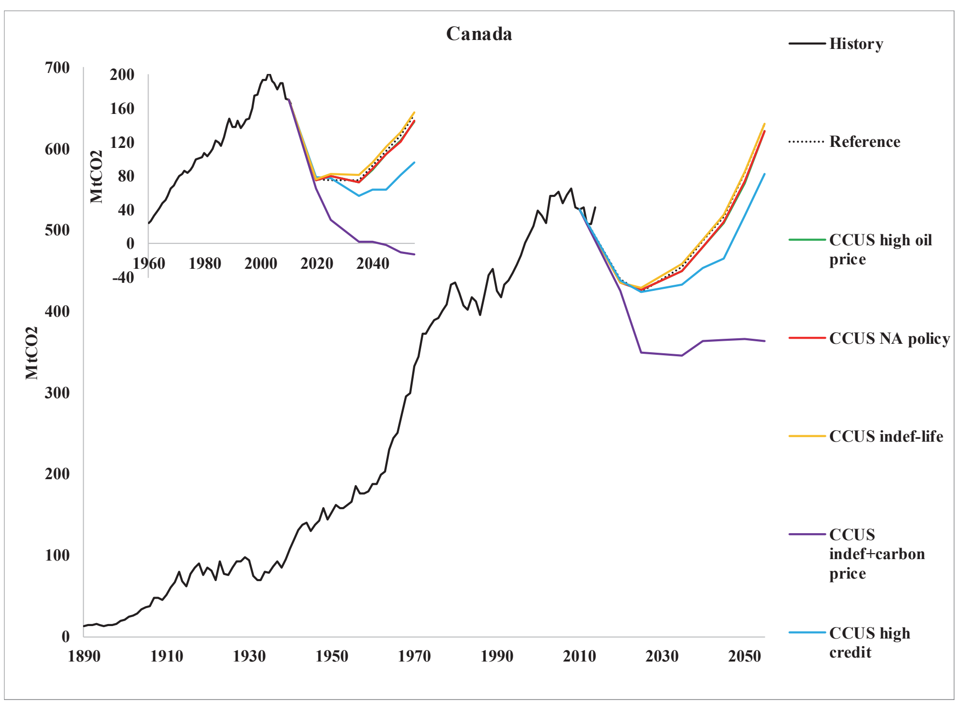
Figure 3 through Figure 5 show North America's system-wide, power sector CO_2 emissions (historical and scenario projections). In 2015–2030, energy system decarbonization can be observed in the U.S. and Canada in all scenarios as a result of the energy use exchange to lower carbon technologies such as natural gas or energy efficiency improvements (Figure 3 and Figure 4).

FIGURE 3
U.S. CO_2 EMISSIONS BY SCENARIO: ENERGY SYSTEM AND POWER SECTOR (LEFT WINDOW)



SOURCES: EIA (2019a); CDIAC (2019)

FIGURE 4
CANADA CO_2 EMISSIONS BY SCENARIO: ENERGY SYSTEM AND POWER SECTOR (LEFT WINDOW)



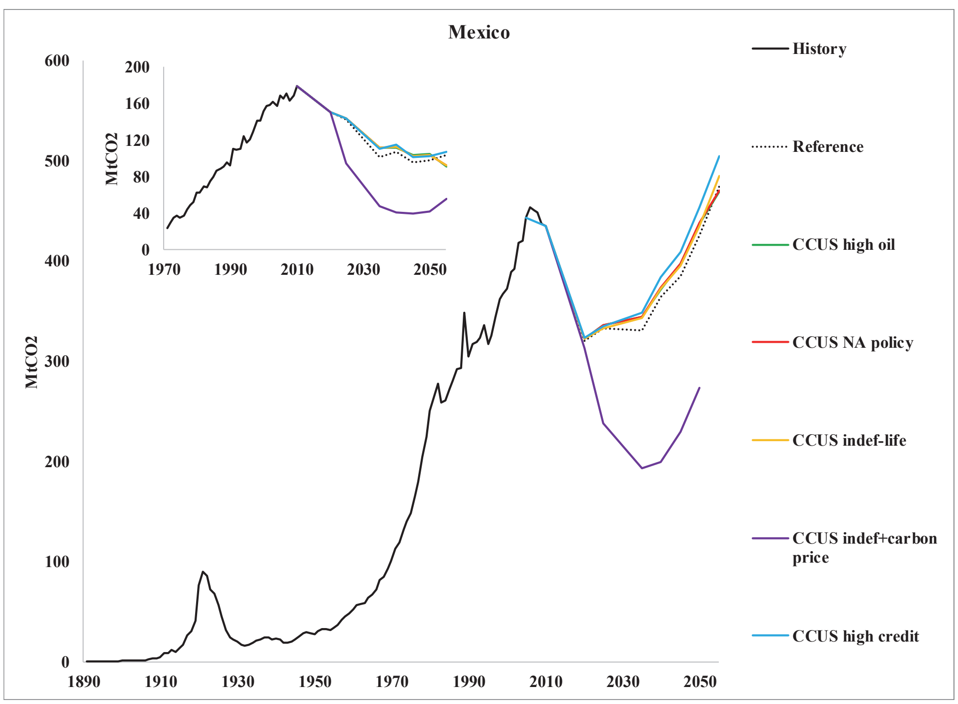
SOURCES: THE WORLD BANK (2019); CDIAC (2019)

System-wide CO_2 emissions are projected to fall from 2015 through 2030 with 8% decline in the U.S. in the Reference, CCUS indef life, CCUS high oil price, and CCUS NA policy scenarios; 20% decline in the CCUS high credit scenario; and 36% decline in the CCUS indef life+carbon price scenario. In Canada, in 2015–2030, system-wide CO_2 emissions decline by 8% in the Reference, CCUS indef life, and CCUS high oil price scenarios; 11% in CCUS NA policy scenarios and CCUS high credit scenarios; and 28% in the scenario with environmental constraint. Thus, in the U.S. and Canada, system-wide short-term CO_2 emissions are projected to decline even without climate policies.

However, CO_2 emissions start to increase in 2030 in the Reference, CCUS indef life, CCUS high oil price, and CCUS NA policy scenarios; the U.S. system-wide CO_2 is about 3% lower and in Canada about 29% higher by 2050 than in 2015. The deepest CO_2 reduction—52% in the U.S. and 23% in Canada by 2050—can be observed only in the CCUS indef life+carbon price scenario. Still, without carbon policy, but under higher 45Q tax credits assumptions, in the U.S. CO_2 emissions decline more than 25% from 2015 to 2050.

Historical observation shows that total CO_2 emissions in Mexico start to decrease in 2012 at about 2% annual rates (Figure 5). Our modeling results display a system-wide CO_2 emissions decrease until 2020 and increase afterwards through 2050 in all scenarios, excluding the scenario with environmental constraints. By 2030, system-wide CO_2 emissions are 5–10% higher than in 2015 in the Reference, CCUS indef life, CCUS high oil price, and CCUS NA policy scenarios. By 2030, Mexico system-wide CO_2 emissions in the CCUS indef life+carbon price scenario are 38% lower than in 2015 and increase afterwards; by 2050, CO_2 is 12% lower than in 2015.

FIGURE 5
MEXICO CO_2 EMISSIONS BY SCENARIO: ENERGY SYSTEM AND POWER SECTOR (LEFT WINDOW)



SOURCES: THE WORLD BANK (2019); CDIAC (2019)

System-wide CO_2 emissions in North America (the U.S., Canada, Mexico) are projected to decrease in the short-term, by 2030, in all scenarios: 36% reduction below the 2015 in the CCUS indef life+carbon scenario, 18% reduction in the CCUS high credit scenario, and 7% reduction in all other scenarios. In the long-term, by 2050, decarbonization is observed in only two scenarios: 48% reduction below the 2015 in the CCUS indef life+carbon scenario and 19% reduction in the CCUS high credit scenario. In all other scenarios, power sector CO_2 is only 8–12% lower than 2015 levels by 2050.

Power Sector CO_2 Emissions

U.S. power generation CO_2 emissions fell more than 20% from 2007–2015, while system-wide CO_2 emissions have decreased by 12% over the same time period (see Figure 3). A major contributing factor to lower CO_2 emissions from the power sector is increased generation from natural gas that replaced generation from coal, largely due to lower gas prices resulting from increased shale gas availability. Similarly, CO_2 emissions from electricity generation are projected to be 19% below the 2015 level by 2030 in the Reference, CCUS indef life, CCUS high oil price, and CCUS NA policy scenarios; 49% below in the CCUS high credit scenario; and 84% below in the CO_2 taxation scenario.

Short-term CO_2 reduction in the power generation sector in Canada is greater than in the U.S.: 34–40% below the 2015 level by 2030 in the Reference, CCUS indef life, CCUS high oil price, and CCUS NA policy scenarios; 48% below in the CCUS high credit scenario; and 93% in the CO_2 taxation scenario (Figure 4).

After 2030, the U.S. power sector CO_2 emissions in the Reference, CCUS indef life, CCUS high oil price, and CCUS NA policy scenarios start to stabilize with an increase afterwards and are projected to be 8–12% below the 2015 level by 2050. In the CCUS high credit scenario, CO_2 emissions are 65% below the 2015 level by 2050. Power sector CO_2 emissions become net-negative in the CCUS indef life+carbon price scenario due to biomass integrated gasification combined cycle (IGCC) with CCS deployment with about 120% reduction by 2050.

In the long-term, by 2050, power sector decarbonization rates in Canada are lower than in the U.S.: CO_2 emissions in the Reference, CCUS indef life, CCUS high oil price, and CCUS NA policy scenarios are 8–17% higher the 2015 level by 2050. CO_2 emissions become net-negative in the CCUS indef life+carbon price scenario by 2050 with about 109% reduction by 2050 below the 2015 level by 2050. In the CCUS high credit scenario, power CO_2 emissions are 28% below the 2015 level.

Remarkably, power sector CO_2 emissions in Mexico are in decline with about 30% reduction below the 2015 level by 2050 in all scenarios excluding the scenario with CO_2 taxation. CO_2 taxes lead to 70% emissions reduction by 2050 in Mexico (Figure 5).

Electricity generation CO_2 emissions in North America are projected to decrease in the mid-term, by 2030, in all scenarios: 83% reduction below the 2015 in the CCUS indef life+carbon scenario, 47% reduction in the CCUS high credit scenario, and 19% reduction in all other scenarios. In the long-term, by 2050, deep power sector decarbonization is observed in only two scenarios: 116% reduction below 2015 levels in the CCUS indef life+carbon scenario and 61% reduction in the CCUS high credit scenario. In all other scenarios, power sector CO_2 is only 8–12% lower than in 2015 by 2050.

Power Sector Technological Changes

Modeling CO_2 emissions results indicate that most reductions occur primarily in power generation; therefore, analysis of technological change in electricity sector is valuable. The U.S., Canada, and Mexico power sector technologies mixes are presented in Figure 6 through Figure 9 for all six scenarios.

United States

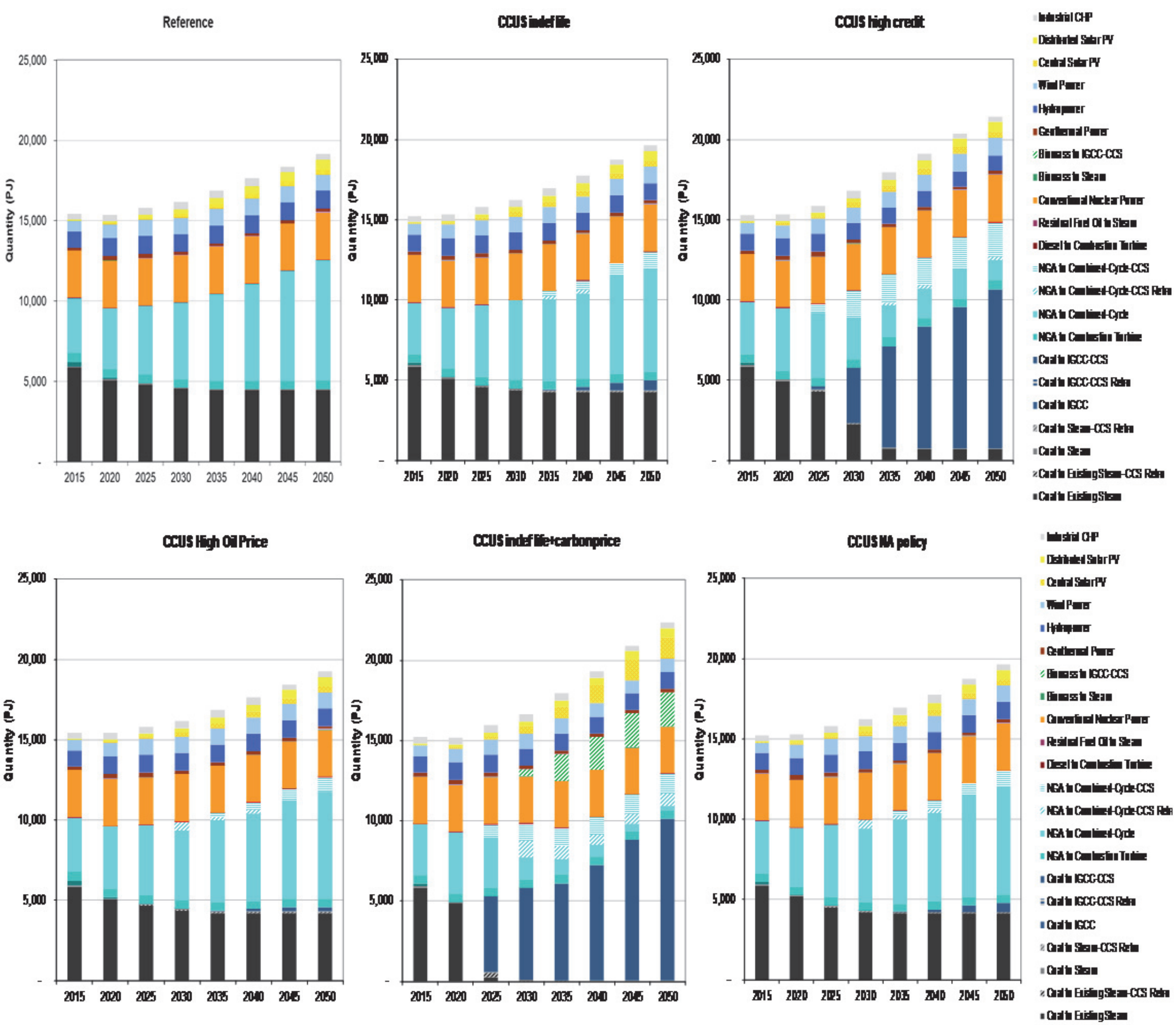
In the U.S., fossil fuels are the largest source of energy for electricity generation. Natural gas and coal were the largest source—about 33% each—of U.S. electricity generation in 2015. Nuclear energy provided about 19.6% of U.S. electricity generation in 2015. Renewable energy sources provide 17% of U.S. electricity in 2015: hydropower plants produced about 6%, wind about 5%, and solar energy about 1% [EIA, 2019b].

In the U.S., in the Reference, CCUS indef life, CCUS high oil price, and CCUS NA policy scenarios (Figure 6), most conventional coal plants remained active through 2050 though their share in total electricity generation is decreasing. By 2050, about 43% of the electricity generated is from natural gas, 24% from coal, and 17% from renewables. There is some CCS deployment in the scenarios with 45Q:

natural gas and coal plants retrofit by 2035 and new IGCC and natural gas combined cycle (NGCC) plants with CCS by 2045. Results show that high oil prices do not affect much of the U.S. power generation mix.

In the CCUS high credit scenario, new NGCC with CCS deployment starts by 2035 and new IGCC with CCS starts by 2050, with coal's share of power generation, primarily IGCC CCS, reaching 51%. By 2050, about 40% of the electricity is generated from natural gas (11% from NGCC CCS), 14% from nuclear, and 16% from renewables in the CCUS high oil price scenario. In the scenario with CO_2 taxation, IGCC CCS and NGCC CCS deployments start by 2025 and biomass IGCC with CCS starts by 2030. By 2050, about 65% of the electricity is produced by power plants with CCS, 18% from renewables, and 13% from nuclear. In addition, total electricity generation in the CCUS indef life+carbon price scenario is about 17% higher than in the Reference scenario by 2050.

FIGURE 6
U.S. ELECTRICITY GENERATION MIX BY SCENARIO

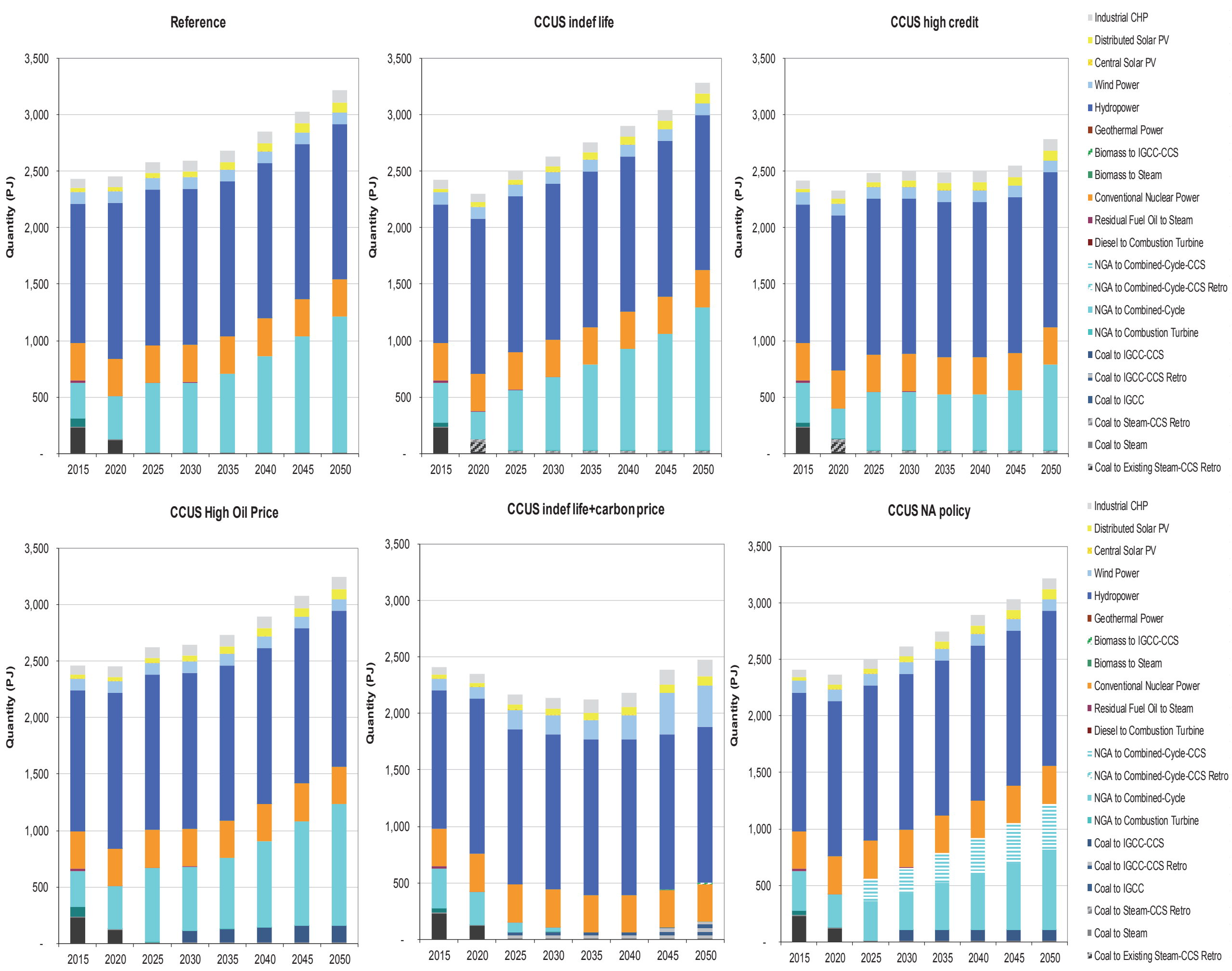


Canada

Electricity in Canada is generated from a less diversified mix of sources than in the U.S. The majority of supply comes from hydropower (more than 50%), while nuclear, coal and, to a lesser extent, natural gas provides the remaining production (Figure 7). In 2015, coal, nuclear power, and natural gas contributed about 14% each. Small volumes of electricity were produced from renewables and waste—about 5%. The Canadian electricity system is part of an integrated North American electricity grid. Canada is a net exporter of electricity to the U.S. and in 2015, net exports of electricity to the U.S. were about 60 Terawatt-hours (TWh) [NEB, 2019].

The projections of electricity mixes sources do not greatly vary in the Reference, CCUS indef life, and CCUS high oil price scenarios. Total hydropower production is about 43% of total power generation by 2050. Electricity generation from natural gas increases significantly and is about 40% by 2050. Electricity production from coal makes a negligible contribution after 2020 in all scenarios excluding CCUS high oil price and CCUS NA policy because higher oil prices and tax credits for CO_2-EOR stimulate IGCC CCS deployment after 2030. In two scenarios (CCUS high credit and CCUS indef life+carbon price), total electricity generation is 30% lower than in the Reference scenario by 2050 because deployment of more efficient end-use technologies and electricity imports from the U.S. are more economically attractive than increasing renewable or nuclear capacities.

FIGURE 7
CANADA ELECTRICITY GENERATION MIX BY SCENARIO

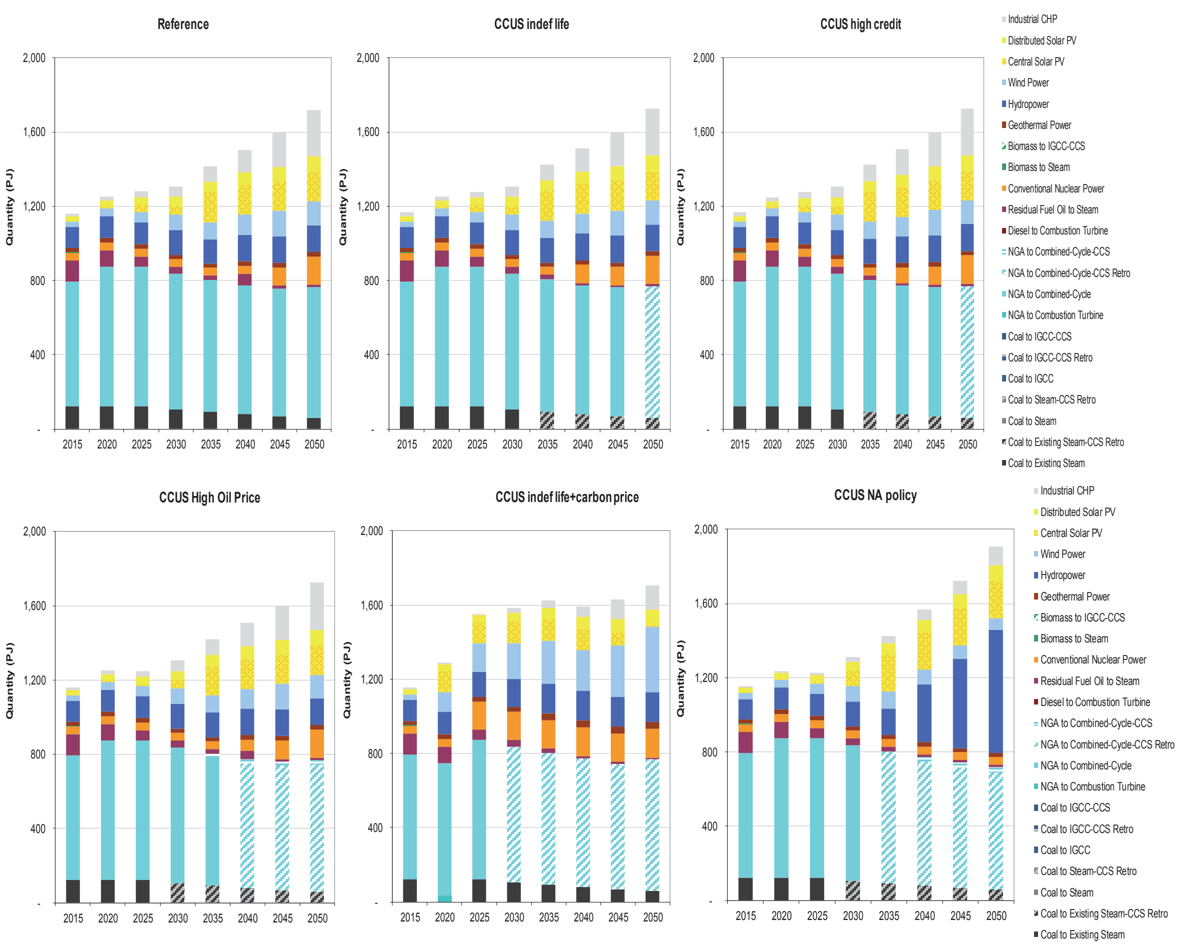


Mexico

Mexico generated an estimated 310 TWh of electricity in 2015, an increase of 21% from 2005. Fossil-fuel power plants provided 72% of Mexico's electricity capacity and 80% of electricity generation in 2015 [EIA, 2016]. In 2015, the share of electricity generation from nuclear was 3.8%, from hydro 10.4%, and from other renewables 3.5% (Figure 8). U.S.-Mexico electricity trade is small compared to the electricity trade between the U.S. and Canada. Natural gas used for electricity generation in Mexico has risen rapidly since 2005 and had reached 60% of total production by 2015, as price and availability have made it a more economic fuel source. Coal represents only 7% of total electricity generation. Mexico is a net importer of coal, supplying about 80% of its coal demand domestically.

According to scenario projections, fossil fuels will play an important role in power generation, though their share is projected to decrease from 80% in 2015 to 40–53% by 2050 in Mexico. In all scenarios (Figure 8), most conventional coal plants remain active through 2050 and in the majority are retrofitted with CCS by 2030–2035. There is NGCC CCS deployment by 2050 in the CCUS indef life and CCUS high credit scenarios. In the CCUS high oil price scenario, NGCC CCS deployment starts by 2040 to support CO_2-EOR projects. Implementation of 45Q policy in Mexico resulted in NGCC CCS deployment and conventional coal plants retrofits by 2035.

FIGURE 8
MEXICO ELECTRICITY GENERATION MIX BY SCENARIO



In the CO_2 taxation scenario, deployment of NGCC CCS started earlier than in other scenarios, by 2030; there is no CCS retrofit in conventional coal plants. In the Reference scenario, by 2050, about 48% of the electricity is generated from natural gas, 4% from coal, and 37% from renewables (10% from hydro). In the CO_2 taxation scenario, about 36% of the electricity is generated from natural gas with CCS, 3% from coal, and 57% from renewables (37% from hydro) by 2050. Thus, natural gas plants (with and without CCS) and renewables play a more important role in future power generation in Mexico.

DISCUSSION AND CONCLUSIONS

Though uncertainties remain regarding technological change, economic growth, and political agendas that affect scenario projections, the following conclusions emerge from this study:

- Analysis reveals that there clearly is momentum toward decarbonization in the short-term future: less efficient coal power plants are disappearing from the generation portfolios and a main factor in the observed decarbonization is the switching of coal-based generation to natural gas. However, the emissions of a large natural gas-based fleet create issues later in the forecast period without climate policies.
- Reaching 2015 United Nations Climate Change Conference (COP21) 2030 goals is problematic for the U.S. and Canada; reaching 2050 goals is problematic for all of North America without climate policies that are stronger than CO_2 taxation. Delay in decarbonization might imply the need for more radical intervention, e.g., a massive deployment of negative emissions technologies.
- Analysis finds that successful CCUS development depends on regulatory frameworks, such as 45Q tax credits. However, project finance remains the most challenging piece without incentives to encourage CCUS deployment.

The main finding of this study is that it is technically feasible to achieve about 50% CO_2 emissions reduction below the 2015 levels by 2050 in North America through CO_2 taxation and deployment of existing or near-commercially available technologies. These emissions reductions are primarily achieved through high levels of electricity sector decarbonization in the U.S. and Mexico, electrification of end uses in the U.S., and energy efficiency improvements in Canada. The results show that CO_2 taxation policy accelerates the deployment of CCUS in the U.S. and Mexico, but to a lesser degree in Canada, where the share of renewables and, predominantly, hydro is significantly higher than in the U.S. and Mexico. Thus, the CO_2 taxation scenario shows that the North America economies' decarbonization over the next 35 years requires a large transformation of the energy system.

The results show that CO_2-EOR technologies deployment doesn't have an impact on energy-wide CO_2 emissions reductions, though some impact on power sector CO_2 can be observed. Modeling results demonstrate that power generation mixes are largely dependent on CO_2 constraints and, to some degree, on CO_2-EOR policies. Though CCUS deployment can be seen in all of North America, the highest level of deployment is in the U.S., and this is a result of 45Q tax credits policies.

CO_2-EOR is not a new phenomenon, and commercial, profitable CO_2-EOR projects have existed for more than 30 years in the U.S. CO_2-EOR has been deployed extensively in the Permian Basin of West Texas and a few other areas in the U.S. since the mid-1980s. An extensive CO_2 pipeline network has been established to deliver the CO_2 required by these projects, often over long distances, primarily from high-purity and low-cost natural sources of CO_2. However, 45Q tax credit policies make CO_2 from industrial and power plants sources more economically attractive.

Including similar tax credit policies into scenarios for Mexico and Canada show that Mexico is more responsive to CCUS deployment than Canada. The reason is that an optimal candidate for CO_2-EOR project is a mature, declining, water-flooded oil field; there is higher reserve base for CO_2-EOR projects in Mexico than in Canada. In addition, for the first decades of CO_2-EOR, the natural CO_2 source usually provides the CO_2 needed for EOR, but there are few small CO_2 fields in existence in Canada and the CO_2 deliverability from these fields would be inadequate for CO_2-EOR projects. Thus, in Mexico, with depleted oil fields and significant natural CO_2 sources, only pipeline limitations would likely constrict EOR growth.

The major barrier to CCUS deployment is that currently there is no value placed on sequestered CO_2 emissions; CO_2 that is injected for storage is considered waste, not a commodity. In addition, CCS power plants are not commercially competitive in today's power generation market due to high costs. Combining CCS with EOR could provide a critical financial incentive to facilitate development of CCS projects in the near term.

There are no specific technological barriers or challenges in transitioning and converting a pure CO_2-EOR operation into a CO_2 storage operation but there are a number of legal, regulatory, and economic differences that must be addressed if an EOR project is to serve as a CCS project.

ENDNOTES

1. There are a few small CO2 fields that exist in the southwest corner of Saskatchewan. The CO2 deliverability from these fields would be inadequate for CO2-EOR projects [Brown, et al., 2017].
2. Section 45Q is a part of the U.S. Congress Bipartisan Budget Act of 2018. Section 45Q provides a performance-based tax credit for carbon capture projects of $US 30 per metric ton of CO2 for anthropogenic CO2 going to EOR, and $US 50 per metric ton if going to straight storage. The credit is linked to the installation and use of carbon capture equipment on industrial sources, gas or coal power plants, or facilities that would directly remove CO2 from the atmosphere. The captured carbon can then be utilized in the development of products or EOR, or it can be disposed of as waste in deep saline geologic formations. There are several conditions to the credit, including that it applies to new plants that commence construction before 2024 and there is a 12-year time limit on the tax credits [CATF, 2019].

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