

Opportunities and Challenges for the use of Improved and Enhanced Conventional Petroleum Recovery in GHG mitigation strategies

Kirk G. Osadetz¹, Donald C. Lawton^{1,2}, Amin Saeedfar¹, Michael Pastula³, Brain Borglum³, Matthew Woofter⁴
¹CMC Research Institutes Inc., ^{1,2}University of Calgary, ³FuelCell Energy Inc., ⁴Wexco Ventures Inc.

Summary

Climate and economic policies and goals make it necessary to progressively reduce industrial GHG emissions among other societal and industrial activities. Achievement of the COP-21 Paris goals requires the decadal halving of global CO₂ emissions until 2050, followed by the achievement of sustainable emissions of 5 MtC/PWh by 2100. Alberta's climate leadership plan includes significant emissions reductions in the electricity sector that are significantly offset by a growth of emissions from bitumen producers provided by the 100 Mt emissions cap and fuel-switching to natural gas. These policies and the resulting emissions indicate a pressing need to immediately implement large scale CCUS, the cost of which is mitigated by enhanced petroleum recovery, while developing future CO₂ transportation and storage infrastructure. A variation on previously proposed gas-to-wire technology could improve low pressure gas well recovery and performance, while also reducing gas well methane emissions and providing geographically distributed, variable base-load electrical power that is a potential alternative to sustainable, commonly intermittent, sources of electrical power.

Introduction

De Paolo (2015) discussed sustainable atmospheric GHG emissions considering natural processes and sinks for carbon. Anthropogenic carbon transfers from geological reservoirs, primarily into the atmosphere, are about 10 GtC/yr (36.64 GtCO₂e/yr), or >40 times the natural flux. The impacts of these transfers are usually portrayed as affecting ecological and climate systems (IPCC, 2014), which is true; however, they also impact human health (e.g. USEPA, 2017; West et al., 2006) and physiology (Satish et al., 2012). As a result, humanity faces an unprecedented challenge related to anthropogenic carbon transfers from geological reservoirs accompanying fossil fuel use and cement manufacturing into the atmosphere-ocean system.

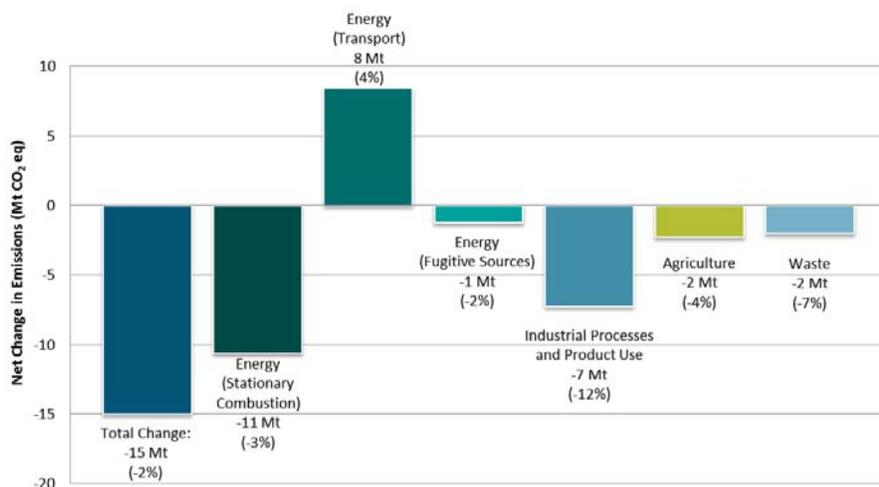


Figure 1: Overall and IPCC category reductions of Canadian GHG emissions between 2005 and 2014 ().

The Canadian response to emissions issues and commitments is based on national inventories of natural and anthropogenic GHG emissions reported to the Intergovernmental Panel on Climate Change (IPCC) that inform policies and actions which have reduced national emissions (2005-2014) by ~11 Mt CO₂e, a 2% decline. Reductions have occurred in most categories except transportation where increased vehicle numbers, weight and usage overwhelmed efficiencies. Canada hosts and supports several globally leading technology demonstration projects and strategies for GHG emissions management including Shell Quest, Aquistore, CMC Research Institutes' Field Research Station and planned activities related to the Alberta Carbon Trunk Line. Canada went to Paris maintaining its prior commitment to reduce emissions 30% below 2005 levels by 2030.

Canada's national emissions goals rely on Provincial initiatives like Alberta's Climate Leadership Plan that include:

- the reduction of Alberta petroleum industry methane emissions by 45% by 2025,
- a legislated 100 Mt CO₂ annual emissions limit on oil sands operations,
- the development of 5,000 MW of sustainable electricity generation capacity by 2030,
- and an end to coal-fired combustion for electrical power generation by 2030.

Still, it seems unlikely that existing Canadian initiatives will achieve COP-21 climate goals. A recent global emissions reduction roadmap (Rockström et al., 2017) outlines actions necessary to achieve COP-21 climate goals. It uses a "carbon-rule" that anthropogenic CO₂ emissions must be halved each decade and augmented by "immediately instigated" carbon removal and decreased land-use CO₂ emissions until 2050 to cap global warming to <2°C. This implies an unprecedented acceleration of GHG emissions reduction efforts from 2% during the previous decade to 50% during the next decade using existing technology. Ultimately, GHG emissions intensity needs to decrease to <5 MtC/PWh by 2100 to keep emissions below 1500 GtC/a (De Paolo, 2015).

Global industrial markets for carbon, CO₂ (21.8 MtC/a, of which 13.6 MtC/a is used for EPR), carbon black (14 MtC/a) and graphite (1 MtC/a), are small relative to emission sources. Policy and climate objectives are achievable only if combustion employs storage in geological media augmented by zero-emission carbon or increased non-carbon energy sources. Fuel switching from coal to natural gas increases the efficiency and lowers net power generation emissions that, in the absence of direct air capture combined with either storage or fuel synthesis provides achievable interim goals.

Many plans, including Alberta's, assume that sustainable electrical power generation can provide about a third of the required GHG emissions reductions, and that CCUS and fuel switching will each provide 10-12% of emission reductions. Others infer that the achievement of sustainable energy goals is unlikely, since only about 1% of global energy demand comes from wind and solar sources currently, >40 years after oil price shocks stimulated renewable energy R&D and 20 years after climate issues motivated energy system de-carbonization (Kelly, 2017). He also notes that all sustainable energy improvements are incremental rather than innovative. Additionally, wind and solar power generation are intermittent electricity supplies that complicate grid management. It is unlikely that sustainable power will become more economically competitive considering recent petroleum price declines. As energy subsidies and market interventions appear limited to unlikely, especially in North America, it may be that fuel switching and CCUS will be required more than anticipated previously.

Method

Based on the magnitude and rate of required GHG emissions reductions, it is necessary to deploy existing and proven mitigation technologies directly rather than waiting for the development and commercialization of innovative technologies that are not yet commercial. Progress is required on all fronts. This article focuses on select actions that could result in either value propositions or reduced emission mitigation costs including:

1. (Fuel Switching) Fuel switching, especially away from coal, to natural gas.

2. (CCUS) Capture, with/without utilization/conversion, and storage in geological media.
3. (Gas to Wire) Natural and Flue Gas to electrical power technological combinations.

Fuel switching from coal to natural gas for electrical power generation provides an immediate halving of emissions intensity, however it imposes significant new capital costs on power generators. If we assume no electrical power demand growth in Alberta and that renewable and sustainable power provides 30% of the 2030 electricity supply, the natural gas demand for electrical power generation increases from $22.7 \times 10^6 \text{ m}^3/\text{d}$ in 2015 to at least $40.8 \times 10^6 \text{ m}^3/\text{d}$ by 2030 (AER, 2017a, b). Bitumen producers will increase production to the 100 Mt/a CO₂ emission cap probably by 2028 (PTAC, 2017). This implies natural gas demand growth from these two sectors that was $43.6 \times 10^6 \text{ m}^3/\text{d}$ in 2016 to about $62.3 \times 10^6 \text{ m}^3/\text{d}$ (AER, 2017a,b). The combustion of this demand growth alone results in 91.4 MtCO₂e/d emissions. As a result, about 55% of emissions reductions from renewable generation and fuel-switching strategies in the electricity sector are offset by emissions increases from bitumen producers by 2030. Thus, there is an inferred need to either implement capture and storage with the construction of new facilities, or at least to construct new facilities capture-ready. Note that daily carbon emissions from the anticipated growth of Alberta natural gas combustion (24.9 MtC/d) is just slightly larger than the current annual global demand for non-EPR industrial carbon utilization (23.2 MtC/a). As such, some combination of volumetrically significant fuel decarbonisation/post-combustion capture, transportation, utilization for EPR and eventual geological storage are inescapable consequences of Alberta's Climate Leadership Plan if we aspire to approach the "carbon-rule" implied by the COP-21 agreement climate goals.

Fortunately, CO₂ capture, utilization and storage in geological media provides an established and demonstrated mechanism for emissions reductions that benefits from both the experience at Weyburn (Hitchon, 2012) and from the long history of acid gas processing and subsurface disposal (Bachu and Watson, 2009). Initially EPR projects were evaluated as purely commercial ventures that were commonly successful technically (Gunter and Longworth, 2013). An initial round of EPR projects ended with the oil price collapse in the mid-1980's, as they were judged non-competitive investments compared to new oil opportunities in the early 2000's, and the surviving projects have either collapsed or come under intense cost pressure during the most recent oil price decline. As government policies and demand for CO₂ utilization or storage increases, EPR could have a new "lease on life" as a cost mitigation strategy for reducing GHG emissions. Tertiary recovery projects assist GHG management because:

1. Many CO₂ tertiary recovery projects provide revenues that mitigate the construction of CCUS infrastructure, specifically pipelines.
2. The petroleum pools subject to CO₂ floods provide some storage during EPR as well as providing safe future geological repositories for CO₂ storage after EPR ends, and
3. The total emission from incremental production of conventional oil has fewer emissions than those associated with bitumen projects and their upgrading.

EOR projects in Alberta included both learning opportunities as well as many technical successes (Osadetz and Chen, 2007; Galas et al., 2011, 2012). Vertical miscible floods in the Pembina/Brazeau River Nisku reefs and the Rainbow Keg River reefs were outstanding often recovering >80% OOIP. Chemical floods were also successful, with both polymer and ASP floods increasing recovery. The total incremental oil recoverable for all 934 potential solvent flood targets pools is between 65 to $224 \times 10^6 \text{ m}^3$. For all EOR methods, the incremental oil potential is 100 to $300 \times 10^6 \text{ m}^3$, which is comparable to the remaining conventional reserve in the basin. Bachu (2016) recently re-evaluated tertiary recovery opportunities in Alberta and proposed the route of a major CO₂ transportation system to support EPR. Most of the candidate pools he identified were previously studied or piloted EPR targets. While some storage occurs during EPR operations, the additional benefits of using post-EPR depleted conventional pools is the presence of a geological trap that enhances containment and that provides assurance of safe storage in a continuous reservoir that hosted the petroleum accumulation.

Watenabee and others (2006) proposed "gas to wire" (GTW) for commercializing smaller Asian natural gas fields that would be otherwise stranded. GTW efficiently uses natural gas at or near the site of

production to make electrical power that can be transmitted to markets. The concept was developed on economic and energy security grounds when Japanese natural gas prices were USD\$7/MMBtu, which is slightly more than twice the current North American price. We propose a modification of GTW using fuel cell technology to generate electricity at low pressure well sites, where electrification is sufficiently nearby. The type of fuel cell employed depends on the rate of gas supply. Initial opportunities could be exploited using small portable, Solid Oxide Fuel Cell (SOFC) power plants of ~50 kW. SOFCs are easily linked to both fuel from gas wells and the power grid (Anon., 2000; Torabi, et al., 2016). SOFC power plants address several issues for the upstream petroleum industry:

1. They reduce both CH₄ and CO₂ emissions from upstream facilities and are an ultra-low GHG emissions source of electrical power.
2. They extend gas well lifetime, augment total sales gas volumes and delay well abandonment costs.
3. They have a significant waste heat resource that, used locally, might provide heat energy recovery more effectively than most WCSB geothermal opportunities.
4. Unlike wind and photo-voltaic power sources, SOFCs are variable base-load electrical power supply (24/7) either for use “inside the fence” or for sale into the provincial power grid.

About 123,000 producing natural gas wells are responsible for 34.4% of the annual Alberta upstream petroleum industry CH₄ emissions of 987.742 kt. This implies that each natural gas well, on average, is associated with 2.76 tCH₄/a. Distributed GTW power generation at individual wellheads using a 50 kW SOFC power plant could eliminate, on average, 42 t CH₄ /a emissions, while generating >400 MWh of power. This provides a superior climate remedy to fugitive CH₄ combustion. In the United States, FuelCell Energy and Exxon-Mobil announced fuel cell power generation using flue gas from a coal-fired power plant as a GHG mitigation strategy (Exxon-Mobil, 2016).

Compared to conventional coal-fired power plants, SOFCs are ultra-clean and can use a range of natural gas with the following emissions profile: NO_x <0.01 lb/MWh, SO_x <0.0001 lb/MWh, PM10 <0.00002 lb/MWh and CO₂ of 735 – 849 lb/MWh based on aging of the fuel cell over its functional lifetime. SOFC GTW power generation uses low fuel input pressure (~10-20 psi) that is below common Alberta gas well abandonment pressures (~30-50 psi). GTW eliminates compression, reduces gathering pipelines and increases gas well recovery while reducing CH₄ and CO₂ emissions. Improved gas well performance and increased sales gas volumes increases corporate revenues and provincial royalties and taxes. Unlike intermittent sustainable power sources, SOFC power plants are variable base-load power supply that is better assimilated into the grid supply. A SOFC power generator is able to maintain a high efficiency, >50% LHV NG, for the majority of its power output range, including ~75% of the turndown.

About 40% of the energy output of a SOFC is heat that could find application for heating primarily, but which, could be captured for additional power generation using an organic Rankin cycle engine. Fuel cell heat may be more effective and could have lower net emissions than most Alberta geothermal resources. When waste heat recovery is employed, SOFC performance improves about 20%. Calgary is home to FuelCell Energy’s SOFC research and development centre. This technology is currently at TRL-5, but with the incorporation of learnings from a recent DOE demonstration, this power plant could achieve TRL-7. The provincial economic and employment benefits of a “made in Alberta” ultra-low emission technology that improves low-pressure gas well environmental and economic performance could be considered as benefits of GTW distributed power generation.

Conclusions

Fuel switching from coal to natural gas achieves significant emissions intensity reductions in Alberta’s electricity sector that are significantly offset by new emissions from increased bitumen production. As a result, CO₂ capture, EPR utilization and storage in geological media are necessary consequences of Alberta Climate Leadership Plan. Achievement of COP-21 commitments requires immediate deployment of available technologies if we are to reduce emissions by half in the coming decade. Other strategies such

as distributed GTW variable base-load power generation using SOFCs at gas wells may also provide societal, corporate and environmental benefits in the near future.

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