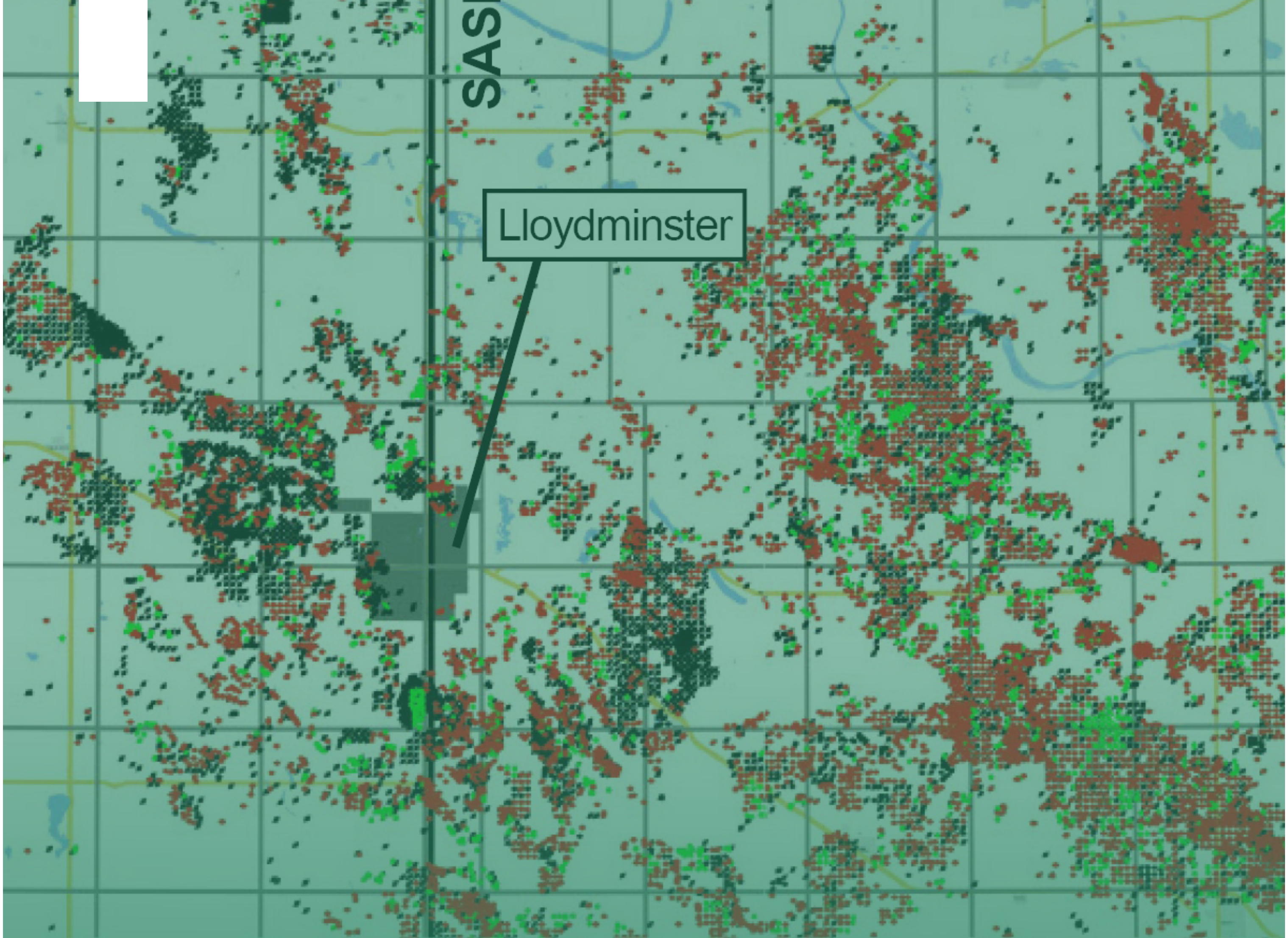

CCS Potential in the Heavy Oil Regions of Saskatchewan and Alberta

ptrc
Petroleum Technology
Research Centre

FOREWORD

The Petroleum Technology Research Centre is investigating the possibility of companies using captured CO_2 from sources within the heavy oil district of Alberta and Saskatchewan, along with external sources such as the Alberta Carbon Trunk Line, to enhance the sustainable development of heavy oil resources in the region. Where utilization in the oil reservoir is not possible and where operators are looking to reduce or eliminate the greenhouse gas emissions intensity of their operations, this study will also suggest alternative formations and scenarios that allow for the secure long-term storage of CO_2. A review of the geology of the region, past and existing research into solvent injection technologies for heavy oil, and previous PTRC research on the measurement and monitoring of CO_2 in oil fields and deep saline sandstone formations will also be discussed. Finally, recommendations and next steps for realizing the potential for CO_2 storage in the Lloydminster area will be made.

INTRODUCTION TO CHALLENGES IN THE HEAVY OIL ZONE

Figure 1. The heavy oil region straddles the border between Saskatchewan/Alberta, including the Lloydminster and Cold Lake areas. The oil sands are also portrayed here, in northern Alberta. (Lines et. al., 2005)

The heavy oil regions in the Lloydminster area (see Figure 1) in both Saskatchewan and Alberta contain an estimated 55 billion barrels of original oil in place (OOIP).

The primary production in these regions has been predominantly Cold Heavy Oil Production with Sand (CHOPS). CHOPS is a method where down-hole screw pumps are used to produce a slurry of sand and oil, and while the technology has increased production in the region, it has only been able to produce about 8 to 10% of the OOIP. Even a small increase in incremental oil recovery could mean billions of barrels of additional reserves for Saskatchewan and Alberta. According to an Oil Reserve Summary Report from the Saskatchewan Ministry of Energy and Resources (SMER 2016) close to 32 billion barrels of heavy oil are in place in the Saskatchewan heavy oil zone. Maximizing recovery from these heavy oil resources plays an important role in energy security and sustainability for Canada, but additional recovery has also raised concerns related to greenhouse gas emissions and the energy intensity of recovery.

CHOPS wells generally produce for 6 to 8 years before they lose energy and production stops as reservoir pressure declines. To remedy this, where well spacing and other technical limitations allow, new wells are drilled. There are roughly 10,000 CHOPS wells in the heavy oil regions between Saskatchewan and Alberta (Alberta Innovates 2018), more than half of which are suspended. Figure 2 shows the critical scale of the issue, with the majority of wells in the heavy oil zone either suspended or abandoned. If these wells remain suspended for a number of years, they will have to be abandoned at significant cost, and new wells drilled, further adding to the environmental and economic impact of maintaining production.

Developing technologies that can be used in the existing fields in Saskatchewan and Alberta would considerably reduce the need for new wells and infrastructure, in effect saving tens of billions of dollars.[1] Enabling infrastructure reuse, deferral of decommissioning and abandonment costs, coupled with efficiency improvements of new technologies, will translate into considerable energy savings and significant reductions in GHG emissions, water and land usage, and other environmental benefits for Canada. CO_2 utilization for post-CHOPS operations is an important area of research that has shown promising results both in terms of improvements in production techniques and considerable reductions in emissions.

Currently, in the PTRC's Heavy Oil Research Network (HORNET) program, work is ongoing to develop new technologies to re-energize CHOPS reservoirs and enable sustainable production from existing wells and infrastructure. Since lessening environmental impacts of production are an important aspect of heavy oil production, sustainable production will depend on technologies that not only improve recoveries, but also improve production energy efficiencies and minimize emissions and surface impacts.

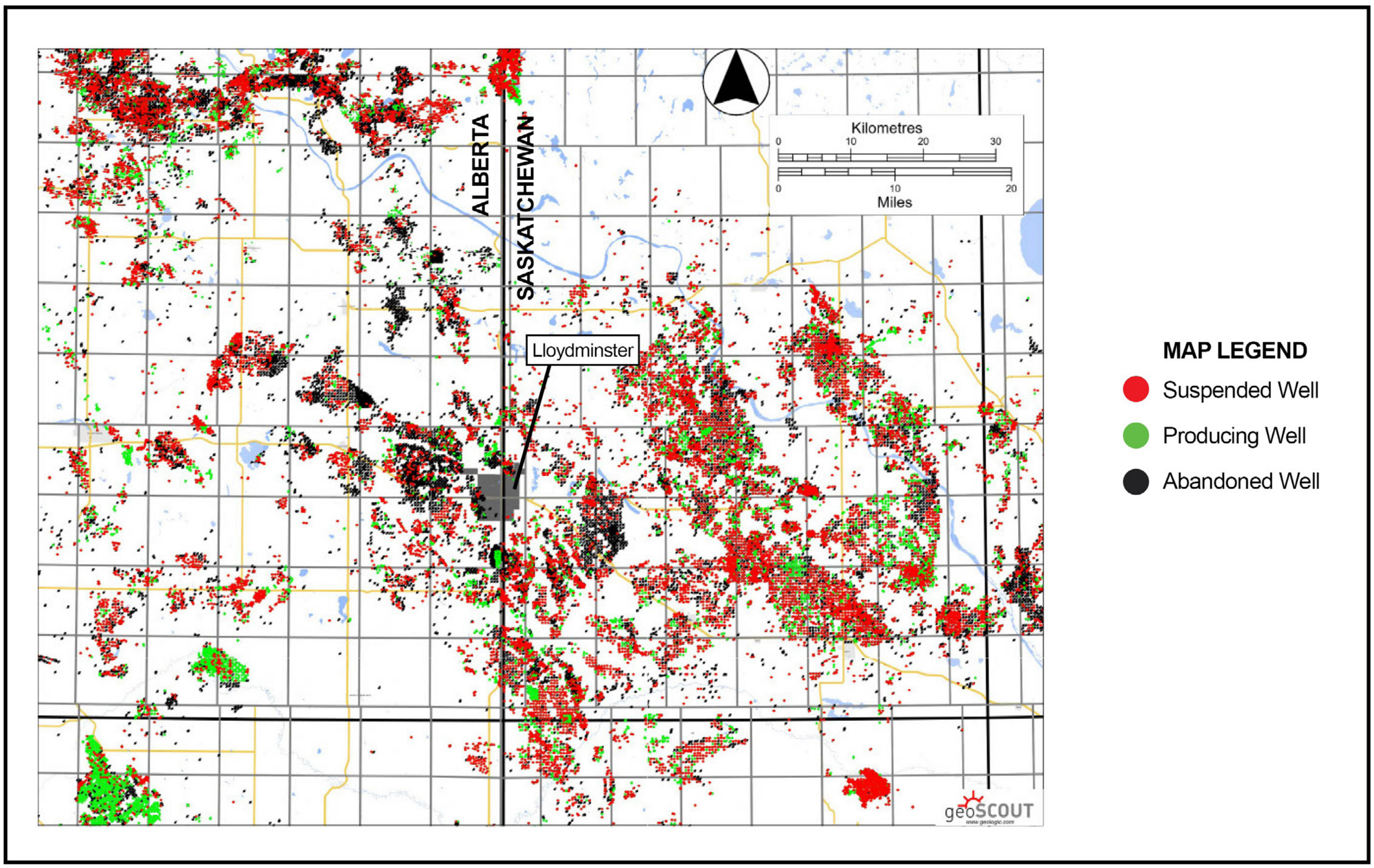

Figure 2. Suspended, abandoned and producing wells in the heavy oil zone of Saskatchewan and Alberta (Data in image provided by geoLOGIC systems ltd. Copyright 2020)

[1] One PSAC study (as reported in Young 2017) estimates the cost of vertical and horizontal wells in Alberta, dependent on geologies and regions, as variable from $500K to $4.0M (including completions). The cost of replacing 10,000 wells would vary between $5 billion and $40 billion dollars.

PTRC's Research into CCS and Enhanced Oil Recovery

HORNET has conducted research into enhanced heavy oil recovery that has utilized gases/solvents such as CO_2 and methane to improve efficiencies in post-CHOPS production, including non-thermal recovery processes such as cyclic solvent injection to reduce GHG emissions during production.

Successful and widespread CO_2 utilization and storage in the heavy oil region, however, requires in-depth understanding of the geology, petrophysics, geomechanics and hydrodynamics of reservoirs and fields to maximize efficiencies and environmental benefits. Since 2005, in close collaboration with its industry members, PTRC has managed and supported programs such as Sustainable Technologies for Energy Production Systems (STEPS), Joint Implementation of Vapor Extraction (JIVE), the Weyburn-Midale CO_2 EOR Monitoring and Storage Project, and the Aquistore CO_2 Storage Project. These projects, in addition to developing a better understanding of the mechanisms and processes that lead to more efficient energy production with minimized environmental impacts, have also established the groundwork for investigating the storage and utilization of CO_2 in western Canada's heavy oil areas. PTRC is playing a leading role in the development of sustainable energy production methods in Canada.

Weyburn-Midale **CO_2 EOR and Storage**

PTRC's CCS endeavors began in 1999 with the initiation of the Weyburn Project. At that time, PanCanadian Petroleum, the owners of the Weyburn oilfield, were planning a large-scale rollout of a CO_2 EOR flood, with the CO_2 sourced from Beulah North Dakota's Great Plains Synfuels plant. As part of this rollout, PTRC designed and managed a research and funding consortium to study every aspect of the Weyburn field and the CO_2 EOR operations to investigate the efficacy of utilizing and storing carbon dioxide as a greenhouse gas mitigation strategy. All aspects of reservoir/CO_2/fluid interactions were characterized, modelled, and assigned risk factors. For the next 15 years, and two phases of funding, the Weyburn project produced valuable results for the advancement of CCS in Canada and the world. In the process, Canadian expertise in CCS was developed by professors at Canadian universities, many of whom still stand today as leading experts in the world on CCS.

Aquistore **Project**

The success of the Weyburn Project led the PTRC to build another large CCS project, Aquistore. Initiated in 2010, Aquistore was developed similarly to the Weyburn project, but was intended to study permanent CO_2 storage in a deep sandstone and saline reservoir, not associated with oil production. Timed perfectly with the completion of SaskPower's Boundary Dam Carbon Capture Unit in Estevan, Saskatchewan, the two wells that make up the Aquistore field lab began accepting CO_2 in April of 2015. As in the Weyburn-Midale project, advancement in the science of CCS was evident – from new monitoring technologies, to new seismic imagining techniques. Aquistore has been employing cutting-edge CCS monitoring technology for 5 years, and continues to lead the scientific community in the study of real-world CCS operations.

Joint Implementation of **Vapour Extraction Project**

The Joint implementation Vapour Extraction (JIVE) project took place from 2005-2010. PTRC worked with CNRL, Husky and Nexen on this $40 million initiative to develop, demonstrate and evaluate solvent injection processes (using gases like methane, propane and CO_2) for recovering heavy oil. JIVE was funded on the premise that the use of solvents in heavy oil recovery could reduce the amount of CO_2 emissions during extraction because it would reduce or even eliminate the need for energy intensive thermal operations like SAGD. The JIVE project resulted in valuable findings for solvent injection in the heavy oil region, including identifying critical factors for solvent recycling, and fundamental insights into reservoir drive mechanisms.

Heavy Oil **CO_2 EOR**

Research in the PTRC's HORNET program has been aimed at developing sustainable recovery methods that will maximize production from Saskatchewan's heavy oil deposits while reducing greenhouse gas emissions. Key to this endeavor is the use of cyclic solvent injection (CSI) whereby gases of varying compositions are injected into the reservoir, allowed to "soak" for a period of time, and then produced back from the same well. This causes favorable changes, such as reduced oil viscosity, improved wettability, and lowered interfacial tension that allow for improved recovery in an economically viable way.

Key to this process is the presence of CO_2 in the injected gas stream. As demonstrated in Figure 3, CO_2 has a higher solubility in heavy oil than other gases such as methane or propane. It lowers the viscosity of the oil more than methane alone (Gu and Ma, 2016).

Another main area of research in the HORNET program is the formation and movement of foamy oil inside reservoirs. Foamy oil forms when non-equilibrium gas exsolution in the reservoir causes the bubbles of gas to develop and mix with the oil, pushing it toward the production well. Understanding non-equilibrium conditions and dynamics of foamy heavy oil initiation is crucial to unlocking post-CHOPS enhanced oil recovery processes. With this in mind, researchers at the University of Calgary and the Canadian Light Source's Synchrotron in Saskatoon developed a

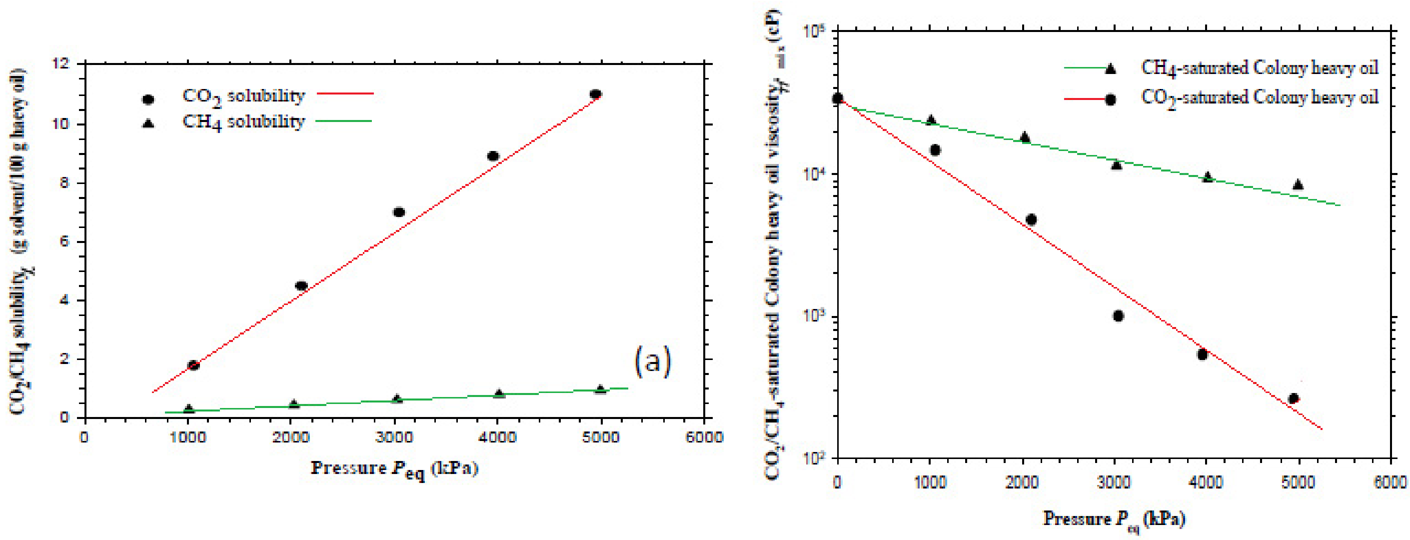

Figure 3. Solubility curves in heavy oil systems showing the relative solubility of CO_2 and methane along with relative viscosity reduction in a hypothetical cyclic solvent injection system. (Gu and Ma, 2016)

unique in-situ vessel, which allows them to capture real-time behavior of foamy oil in full three-dimensions (3D) while using real geological core samples. This was the first time that foamy oil flow and dynamics were examined using synchrotron-based computed tomography (CT). See Figure 4.

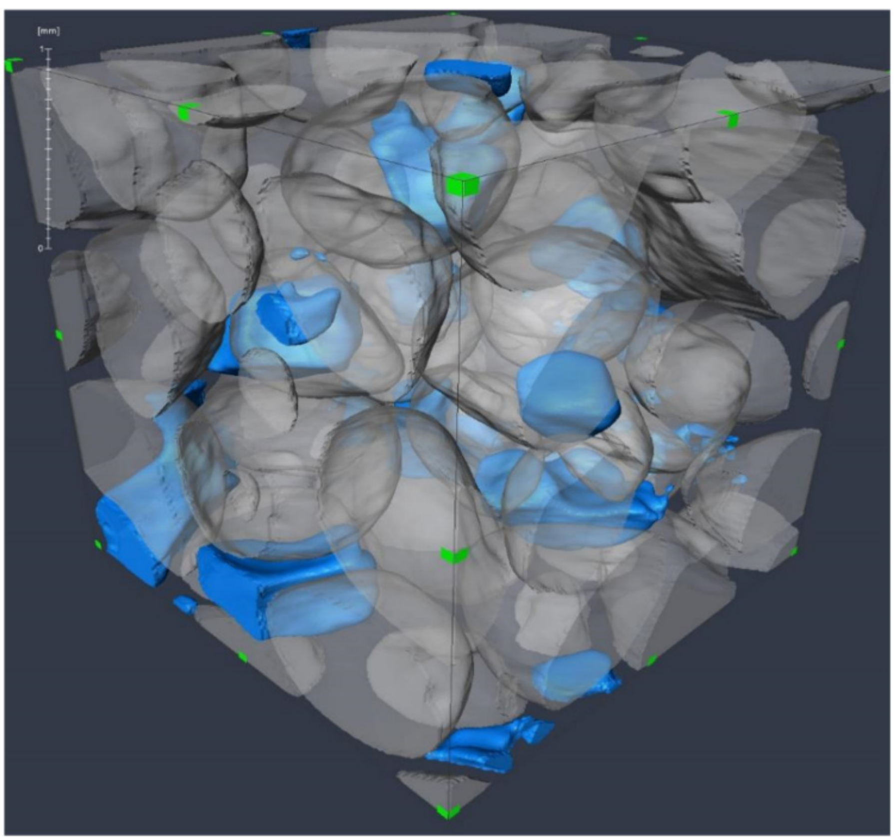

Figure 4. Evolution of free gas geometry, complete reconstruction of a representative cubic sub-volume taken from a scan during the experiment (gas bubbles highlighted in blue). (Gates et. al. 2018)

HORNET has also funded the study of wormholes (small diameter channels that develop inside a heavy oil reservoir during CHOPS). These wormholes facilitate the movement of heavy oil inside the reservoir and research has helped to understand the factors that govern their formation and growth, geometry and propagation, as well as their attributes and impacts on the efficiency of possible CO_2-based post-CHOPS technologies.

Both Husky and CNRL, as funders of HORNET, have found research results very useful for their heavy oil operations. Applications of these findings have been very promising both in terms of improved recoveries, as well as CO_2 storage potential.

Steps for Increased CO_2 Storage and Utilization in the Lloydminster Area

Utilization of CO_2 in petroleum production has been practiced for many decades due to the favorable effects of CO_2 on oil and the reservoir. CO_2 improves recovery conditions in the reservoir, reducing oil viscosity and making it considerably easier for the oil to be produced. This is particularly important for heavy oil due to its higher viscosities and inability to easily flow. Currently, in many heavy oil operations, heat (in the form of hot water or steam) is used to enhance oil flow in the reservoir. Utilization of CO_2 to reenergize a reservoir can eliminate the need for using heat, and result in considerable reductions in the energy and emission intensity of production.

An important aspect of CO_2 utilization in petroleum production is its environmental benefits. In addition to energy efficiency gains, CO_2 EOR (like in the Weyburn-Midale Project) results in storage of a significant percentage of the injected CO2 through microporous trapping and capillary forces in the reservoir.

Building upon the wealth of knowledge and expertise that has been acquired at the PTRC through its aforementioned projects, research is now ongoing to develop the most effective CO_2 utilization techniques. A study is currently underway to determine CO_2 storage potential in the heavy oil regions in Saskatchewan and Alberta. PTRC's plan is to identify the formations in the heavy oil zone capable of CO_2 storage, along with the oilfields that have CO_2 EOR potential. PTRC will develop the measurement and monitoring requirements to assure safe and efficient utilization and storage.

Deep Saline Aquifers in the **Heavy Oil Disrict**

Deep saline aquifers in Saskatchewan have a significant potential for geological storage of CO_2. These formations are tectonically stable and contain saline/brine in porous/permeable rock that are confined by thick impermeable aquitards (caprocks). Deep saline aquifers in Saskatchewan occur in different formations and at variable depths in the southern half of the province. The Aquistore project just outside of Estevan, in the province's far southeast, is injecting CO_2 into the Deadwood Formation at a depth of 3.2 km. The Deadwood Formation is contiguous from western Manitoba, into the northern United States, and all the way to western Alberta. It is also located in the Lloydminster area, though at a much shallower depth than in the Estevan area (approximately 1200 metres).

The Basal Aquifer is the first stratigraphic unit resting immediately above the Precambrian basement and is conducive to hydraulic flow; however, the Basal Aquifer can include a number of formations spanning from the Middle Cambrian to the Lower Silurian. As such, the Basal Aquifer is comprised of four major stratigraphic units, or combinations thereof: 1) the Basal Cambrian Sandstone unit (Deadwood Formation), 2) a combination of the Basal Cambrian Sandstone unit and Black Island in the Winnipeg Formation, 3) the Black Island Member of the Winnipeg Formation, and 4) a combination of the Black Island Member and the Icebox Member of the Winnipeg Formation (i.e., the full Winnipeg Formation) and the overlying Ordo-Silurian carbonates. The architecture of the aquifer is, therefore, a result of a combination of geological factors that have acted to place several distinct stratigraphic units into hydraulic communication. These factors include erosional truncation, depositional limits and facies changes. (Bachu et. al. 2011)

Figure 5 indicates the CO_2 storage potential for just the first of these four parts of the Basil Aquifer – the Deadwood. As indicated above, the Deadwood's depth is much shallower in the Lloydminster area (1200 m), as compared to its depth at the PTRC's main CO_2 storage project at Aquistore (3200 m). But the formation holds promise in the Lloydminster area for long-term CO_2 storage.

Any specific CO_2 injection project into saline aquifers in the Lloydminster area cannot rely on characterizations of the Deadwood formation completed by the Aquistore project almost 400 miles away. CO_2 storage projects are reliant on site-specific characterization studies that include seismic imaging, core analyses, and geophysical modeling, to name a few methodologies. PTRC plans to work with operators in the Lloydminster region, interested in aquifer storage, to direct such characterization efforts in the next few years.

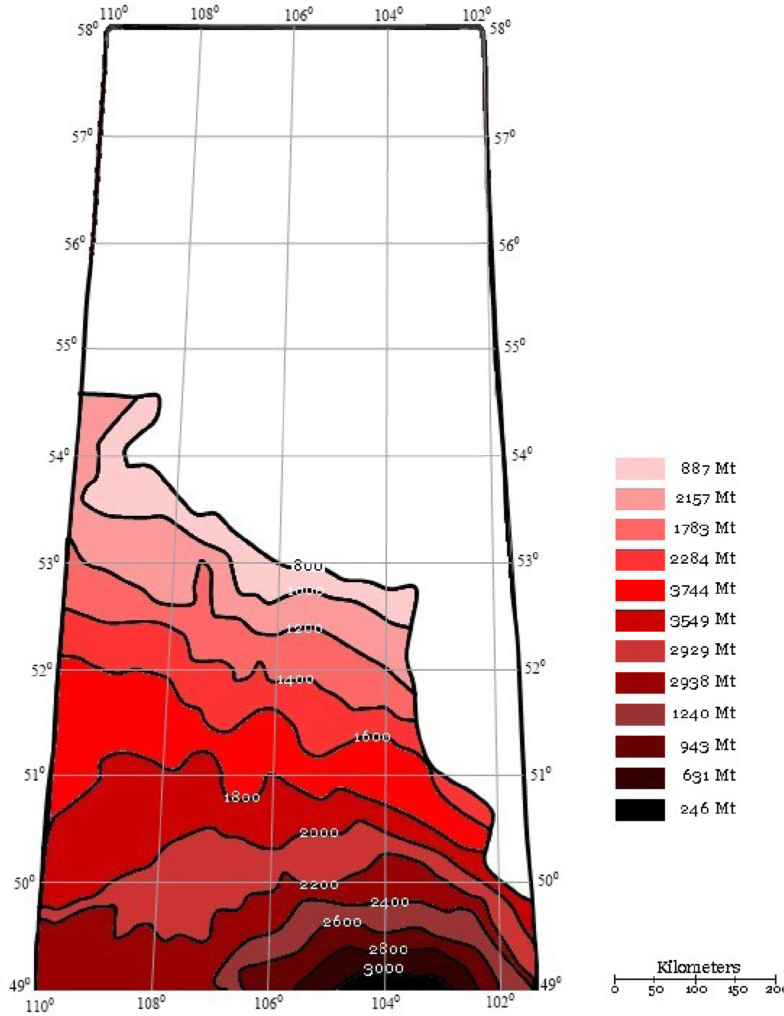

Figure 5. Depth contour map and CO_2 storage capacity estimation values for the Cambrian Basal (Deadwood) Aquifer. (Image from information contained in Nasehi and Liewkhaow. 2017)

CO_2 Utilization and Storage **in Lloydminster Oilfields**

Scenarios for CO_2 EOR in the Lloydminster area will depend upon the use of CO_2 that has been captured from anthropogenic sources (like the Husky Upgrader, for example, or power plants, SAGD facilities, cement manufacturers, chemical and fertilizer plants, steel makers, boilers and steam generators, etc.). CO_2 would not be vented as part of oil production, but would be recycled through separation and reinjection in a closed loop to eliminate CO_2 emissions to the atmosphere.

Husky Energy has already tested 5 separate, demonstration-scale cyclical CO_2 EOR projects using sources from its own ethanol plant in Lloydminster and from SAGD operations. The liquified CO_2 is transported from the ethanol plant to the various project areas, and to the Lashburn field from nearby SAGD operations. Thus far, CO_2 EOR for Husky has produced over four million barrels of incremental oil and the CO_2 is retained in the reservoirs through recycling and reinjection. (MacPherson 2017)

The heavy oil industry has estimated that about 1.5 million tonnes of CO_2 per year can be used for Post-CHOPS enhanced oil recovery in the heavy oil regions of Saskatchewan and Alberta by 2025. In addition to Post-CHOPS there are other CO_2 utilization potentials in Non-CHOPS reservoirs, including CO_2 enhanced waterflooding and other applications that can lead to this region's CO_2 EOR potential reaching as high as 5 to 10 million tonnes per year by 2030.[2] In addition to the Alberta Trunk Line that can potentially be extended to deliver CO_2 to the region, there are also other sources within the region with potential for capturing 3 to 4 million tonnes of CO_2 annually. Some of these sources are listed in Table 1, with their approximate locations illustrated in Figure 6.

Table 1. Main CO_2 Sources in Saskatchewan's Heavy Oil Zone

Facility Name	Activity/Company
Lloydminster Ethanol Plant	Ethanol Fuel Production/Husky
Lloydminster Upgrader	Heavy Oil and Bitumen Upgrading/Husky
Bolney Thermal	Heavy Oil Extraction/Husky
Pikes Peak Gas Battery	Heavy Oil Extraction/Husky
Pikes Peak South Thermal	Heavy Oil Extraction/Husky
Sandall Thermal	Heavy Oil Extraction/Husky
North Tangleflags	Heavy Oil Extraction/Husky
Paradise Hill Thermal	Heavy Oil Extraction/Husky
Senlac Thermal Oil Battery	Heavy Oil Extraction/Southern Pacific Resources
Meridian Cogeneration	NG Power Generation/Meridian Ltd
North Battleford	NG Power Generation/Northland Power
Yellow Head	NG Power Generation/SaskPower

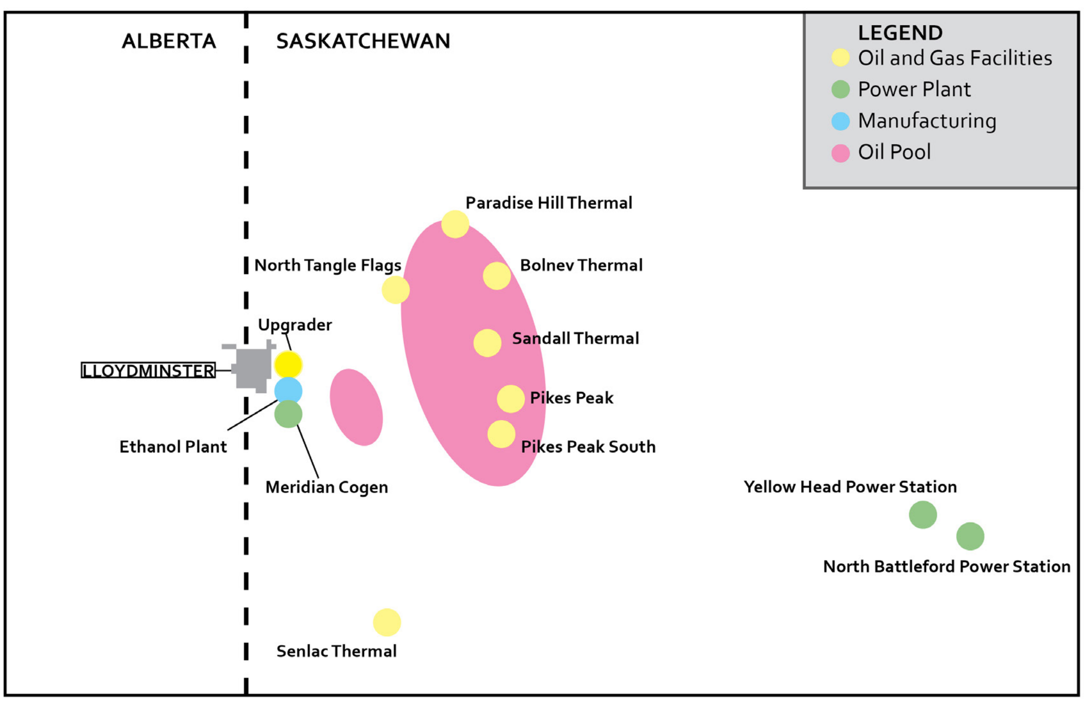

Figure 6. Approximate locations of the set point sources of CO_2 emissions in Saskatchewan's heavy oil zone

[2] This figure was presented by PTRC and its industry sponsors during a meeting with Government of Saskatchewan officials in October 2019.

What is most crucial for the advancement of both deep saline injection and CO_2 enhanced oil recovery in the area is the integration of both forms of storage. An example of the importance of this interconnectedness is demonstrated at Aquistore, where SaskPower's Boundary Dam Capture Facility has integrated the sale and transport of CO_2 to Whitecap Energy's Weyburn field with the slipstream storage available at Aquistore. When the oilfields are not able to take CO_2 from the capture plant, higher volumes can be injected and permanently sequestered at Aquistore. It is highly likely that heavy oilfield operators planning to use CO_2 for EOR will be interested in similar injection scenarios, with captured CO_2 from local operations needing to be sequestered if oilfields are unable to inject for operational reasons. Figure 7 is a schematic that offers just such scenarios, with closed-loop CO_2-EOR fields operating in conjunction with deep saline storage. These operational scenarios will need to be demonstrated and validated before injection begins.

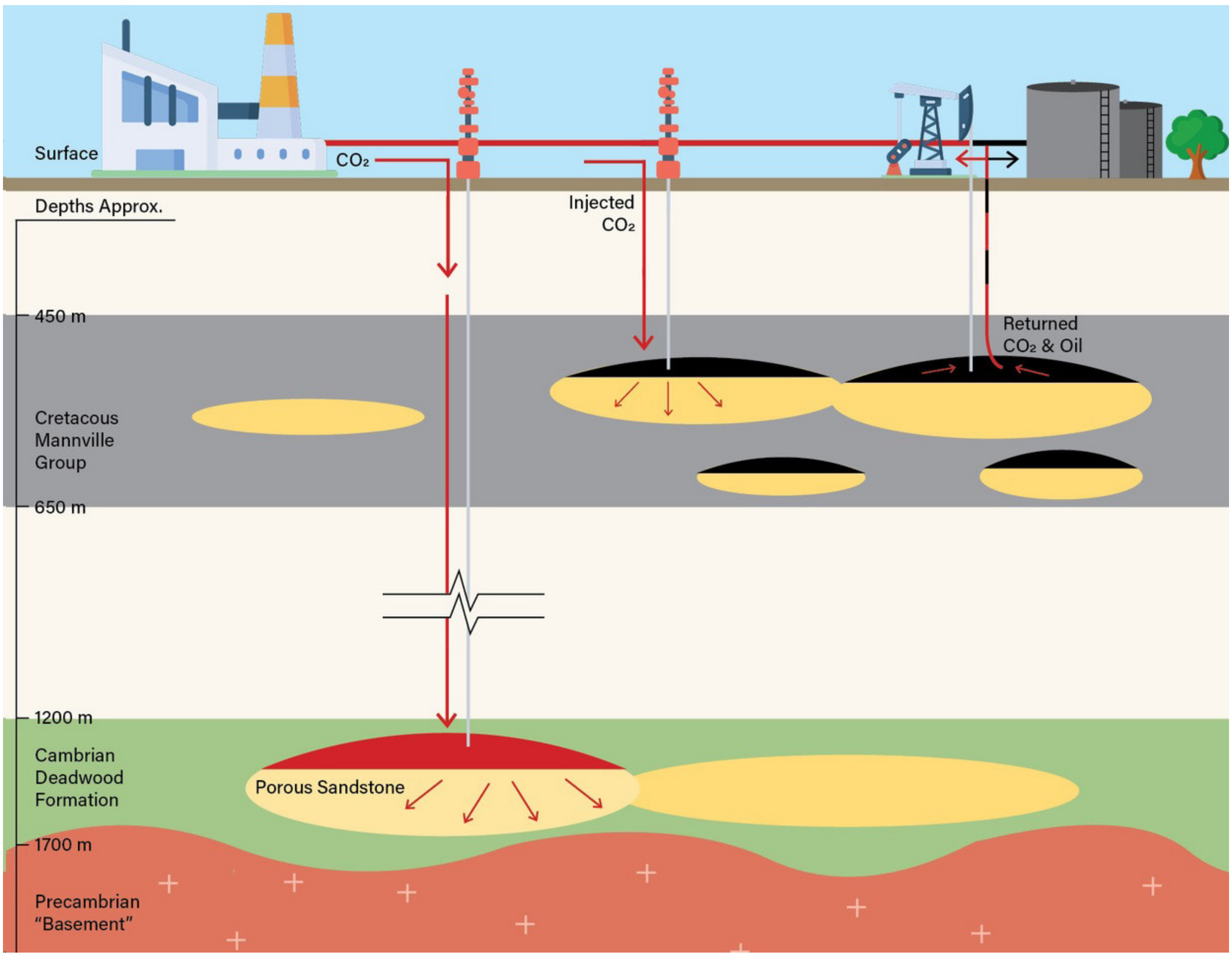

Figure 7. Schematic cross section showing the Mannville group oil and gas reservoirs, sitting well above the proposed CO_2 storage formation in the Cambrian Deadwood Formation. Red arrows indicate CO_2 flow and accumulation, black indicates oil production. (PTRC image)

Conclusions

Amid the global COVID-19 pandemic that has devastated the Canadian economy, safeguarding the energy supply and the thousands of jobs and skills which deliver it, are of major importance for our future. Energy security, more than ever before, plays a major role for a sustainable future economy in Canada.

With this in mind, PTRC's work is aimed at reducing costs, risks and timescales of energy production while minimizing emissions and other environmental impacts. The PTRC is embarking on a program to study CCS in the heavy oil district of Saskatchewan. Carbon dioxide sources could be utilized from those listed in Table 1/Figure 6, or via pipeline from additional large Canadian set point sources nearby(Figure 8). Utilization of CO_2 in the heavy oil fields will ensure continuous production of this valuable energy resource in the region, and at much lower emissions intensity. An important additional aspect to our work is the storage of CO_2 when not being used to stimulate reservoirs, in deeper non oil-bearing formations such as the Cambrian Deadwood. The Deadwood could be seen as a permanent storage tank for CO_2 produced from all industrial operations in the region.

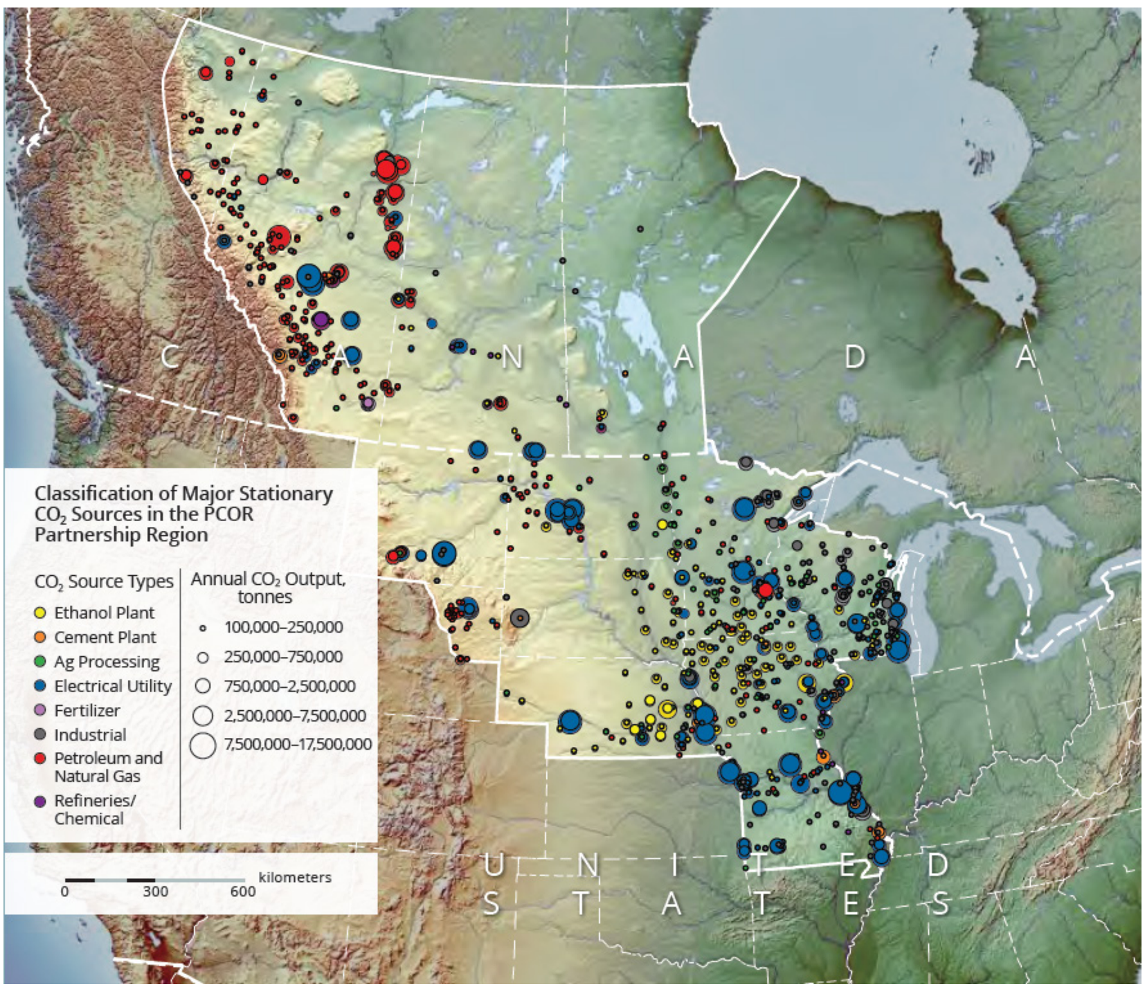

Figure 8. Large point sources of CO_2 throughout western Canada and the western United States. (EERC 2018)

The net results of this would be the continued development and strength of the oil industry in Canada, while at the same time reducing our GHG levels from many different sources and producing heavy oil with a low emissions intensity. The local economy in the Lloydminster region would benefit from not only the oil production, but the ongoing development and monitoring of the CO_2 storage areas. Saskatchewan, Alberta and Canada would also benefit from the capture and storage of millions of tonnes of CO_2, and the additional taxes and royalties created from securing heavy oil production for many years into the future.

Acknowledgments

The PTRC wishes to thank geoLOGIC systems ltd. for their contribution of data and software used in this study. All geoLOGIC systems ltd. data and software is copyright 2020.

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