ERA GRAND CHALLENGE ROUND 2
MANGROVE WATER TECHNOLOGIES LTD.
F0160017
DEMONSTRATION OF MANGROVE'S TECHNOLOGY FOR THE ALBERTA OIL SANDS

Saad Dara

MANGROVE WATER TECHNOLOGIES LTD. 216, 3800 Wesbrook Mall, Vancouver, BC, V6S2L9

Preamble

1. Project Information

ERA Project ID: F0160017

Title of project: Mangrove Water Technologies Pilot Demonstration

Name and contact information of Principal Investigator: Saad Dara

Name of ERA Project Advisor: Christophe Owttrim

Completion date of the project: April 30th, 2019

Total ERA funds received: $2,549,999

Amount of hold back: $450,001

Submission date: September 6th, 2019

2. Table of Contents

Contents

3. Executive Summary

Mangrove Water Technologies is commercializing a technology that fundamentally disrupts the traditional value chain of brine disposal, and chemical supply and logistics. Instead of waste brines being trucked away for disposal and chemicals being trucked to site, Mangrove's technology converts a customer's waste brines on-site and on-demand to chemicals and desalinated water for on-site utilization. Mangrove has customer commitments within Alberta to demonstrate and commercialize the technology with commercial deployment expected in 2020. During Round 2 of the ERA Grand Challenge, Mangrove made significant progress as summarized below:

1. **Met all project criteria successfully**
   - Achieved cell current densities in excess of the project targets.
   - Product concentrations of 24 wt% and 16 wt% were achieved exceeding the project target of 10 wt% and 7 wt% for sodium hydroxide and hydrochloric acid, respectively.
   - Durability testing of the technology for over 2,000 hours of continuous operation was demonstrated at the bench-scale.
   - The electrochemical cell was successfully scaled-up from a 5 cm^2 cell to a 5,000 cm^2 cell.
   - The 5,000 cm^2 cells were tested and identical performance in comparison to the bench-scale cells was achieved.
2. **Project advanced the technology to a TRL-7 by demonstrating a commercial scale system**
   - The stack of electrochemical cells was incorporated into an electrochemical skid with a control system for operation in different modes.
   - A pre-treatment skid consisting of suspended solids removal, oil and grease removal, dissolved oil removal and hardness removal was constructed and integrated to the electrochemical skid.
   - The system was operated with synthetic brines and carbon dioxide based on compositions from a prospective customer site in Alberta.

4. Project Description

Introduction and background

A significant industry challenge in the Canadian oil sands is the costly logistics for managing water flow to and from well sites. As an example, oil sands mining has a significant and critical problem where oil sands mining excavation leads to the mine becoming flooded from basal aquifer or ground water. As such, dewatering is critical for operations (as shown in Figure 1) and if not managed properly can prevent oil production. Often, the groundwater is too saline for it to be discharged into natural bodies of water and needs to be disposed or treated. However, economically or environmentally viable options for treatment or disposal are currently limited.

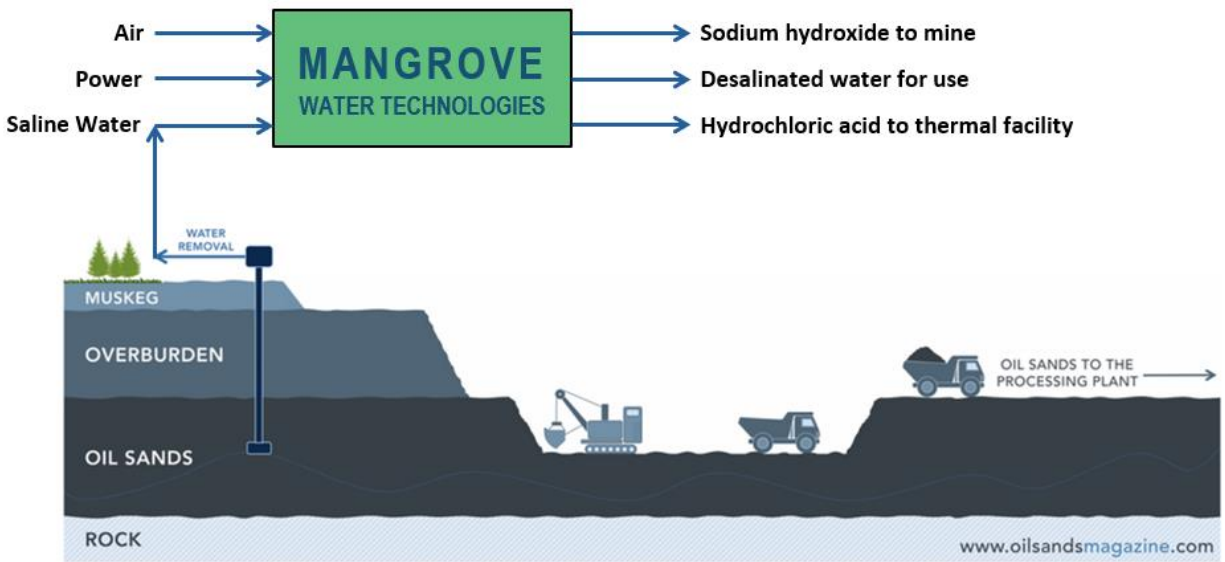


Figure 1: Mangrove's technology solves a critical problem for oil sands mining sites by converting their saline water to desalinated water and chemicals.

Viable options for treatment or disposal of brine are economically or environmentally prohibitive: Incumbent water management options through disposal or desalination are costs that would rather be avoided. Disposal of water by trucking is common, however it can be economically infeasible and carries a high degree of environmental and safety risk associated with spillage and accidents. Desalination by reverse osmosis or other incumbent desalination technologies is both economically and environmentally infeasible as incumbent desalination technologies only produce desalinated water and a concentrated waste-stream that still requires disposal.

Chemical logistics and security of supply is important: In addition to this, all oil and gas producers also consume significant amounts of hydrochloric acid and sodium hydroxide in their operations. The chemicals are purchased and trucked to site for use. Hydrochloric acid is used widely in the oil sands for water treatment or helping with downhole disposal of waste-water. Sodium hydroxide is also used widely for water treatment and scrubbing of ores to mobilize oil.

Mangrove converts oil and gas brines to chemicals for on-site utilization: Industry practice has been to treat saline water management and chemical supply logistics separately where both are a cost to the producer. Mangrove offers oil sands producers an elegant value creating alternative to this by combining desalination with on-site chemical production. Mangrove's waste-to-value innovation converts high salinity wastewater into value-added chemicals and desalinated water for on-site utilization. The modular design of the technology allows for simple scaling of the commercial module to meet the required capacity. The technology is particularly suitable for oil sands mine sites where it provides producers the ability to desalinate their basal aquifer water to any desired salinity level and generate hydrochloric acid and sodium hydroxide for use in their operations. This allows producers to reduce their freshwater usage and risk associated with an on-site waste stream while reducing overall costs of operation.

Technology description

Scientific basis: The core of the technology is a multi-compartment electrochemical reactor which operates on the fundamental scientific principles shown in Figure 2. The technology is differentiated from other technologies due to its ability to electrochemically produce chemicals and desalinate saline water. Air is fed to the cathode of the electrochemical reactor where the application of an external voltage across the electrodes produces hydroxide ions. At the anode, water oxidation is used to generate protons. A saline feed stream (e.g., seawater or waste-water) containing ionic species (e.g., Na^+, Cl^-) which are to be removed are provided to a separate compartment in between the anode and cathode. Under an externally applied voltage the anions and cations present in the saline water move towards the anode and cathode, respectively. A strategic pattern of anion and cation selective membranes is used to prevent back-transport of the ions leading to the concentration of a base (e.g., sodium hydroxide) and an acid (e.g., hydrochloric acid) while desalinating the feed saline stream. Implementation of proper control and automation allows for selective tuning of salinity to any desired salinity level. Overall, the system is fed with a mixture of air, and high salinity waste-water and produces desalinated water, a base and an acid. The sodium hydroxide can be used to convert carbon dioxide and other GHGs to carbonate or bicarbonate salts within the reactor or externally by the following reaction:

$NaOH + CO_2 \rightarrow NaHCO_3$ (1)

$NaHCO_3 + NaOH \rightarrow Na_2CO_3 + H_2O$ (2)

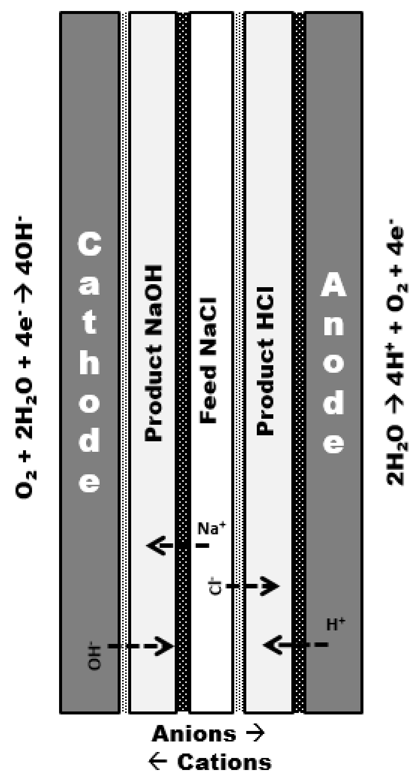


Figure 2: Mangrove's technology is based on strong fundamental science with known and proven commercial technological processes.

Project goals

The goals of the project were a pilot demonstration of Mangrove's waste-water desalination and carbon dioxide conversion technology with the following sub-objectives:

- Demonstration with customer waste-water compositions and/or samples in commercial scale reactor.

- Pilot scale demonstration of Mangrove's pilot reactor for the conversion of carbon dioxide and desalination of saline water.
- Validation of chemicals produced within the system for use in oil and gas operations.

Work scope overview

The work plan was divided into six milestones as follows:

1. **Parametric testing of 5 barrel/day system and gas diffusion electrodes:** The goal was to test the system, improve performance and provide necessary data for the commercial scale demonstration system.
2. **Front-end pre-treatment module engineering design and construction:** A pre-treatment module capable of treating a wide variety of waste-water was designed and constructed to reduce the presence of contaminants to within Mangrove's operating envelope.
3. **Pilot Testing:** Testing of the electrochemical cells in the pilot plant was performed in order to ensure that the cells were performing as expected.
4. **Conversion to mobile field pilot:** The demonstration plant was constructed and prepared for testing with the goal of being able to be transported to different sites as required.
5. **Validation of chemicals for use in O&G operations:** Samples of chemicals produced by the technology were analyzed to ensure the chemicals produced specifications required by the oil and gas sector.
6. **Integration and demonstration:** The demonstration plant was integrated and demonstrated at Mangrove's facilities with synthetic compositions of an Alberta customer's brines and flue gas compositions expected within the Alberta oil and gas sector.

5. Outcomes and Learnings

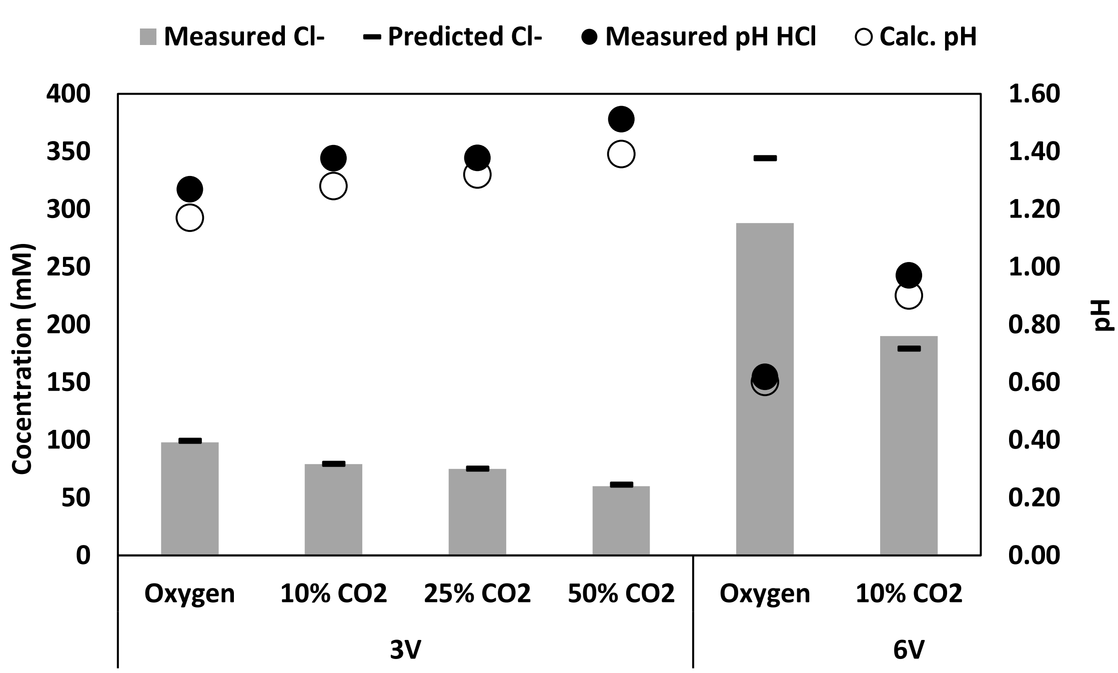
5.1 Parametric testing of 5 barrel/day system and GDEs

Bench-scale operations

Parametric testing of electrochemical cells was successfully completed: An internally developed bench-top electrochemical cell was tested with a synthetic sodium chloride solution and different compositions of carbon dioxide. The results of the testing are summarized in Figure 3 below which shows a comparison of expected concentrations with the measured concentrations of HCl and NaOH/Na_2CO_3 over the period of testing. Overall, the match between the expected and measured product concentrations is quite good. However, some mismatch in the cell concentrations is due to cell efficiency losses due to cross-neutralization of the acid and base streams.

Successful validation with brines to produce chemicals (HCl, NaOH) on-spec for operations: Mangrove successfully demonstrated the technology with samples of water from two Alberta oil and gas sites and demonstrated:

- Desalination to below 2,000 ppm - Mangrove achieved salinity levels as low as 680 ppm;
- Hydrochloric acid concentration of 7 wt% - Mangrove achieved hydrochloric acid concentrations of as high as 10.7 wt%;
- Sodium hydroxide concentration of 10 wt% - Mangrove achieved NaOH concentration as high as 11 wt%.



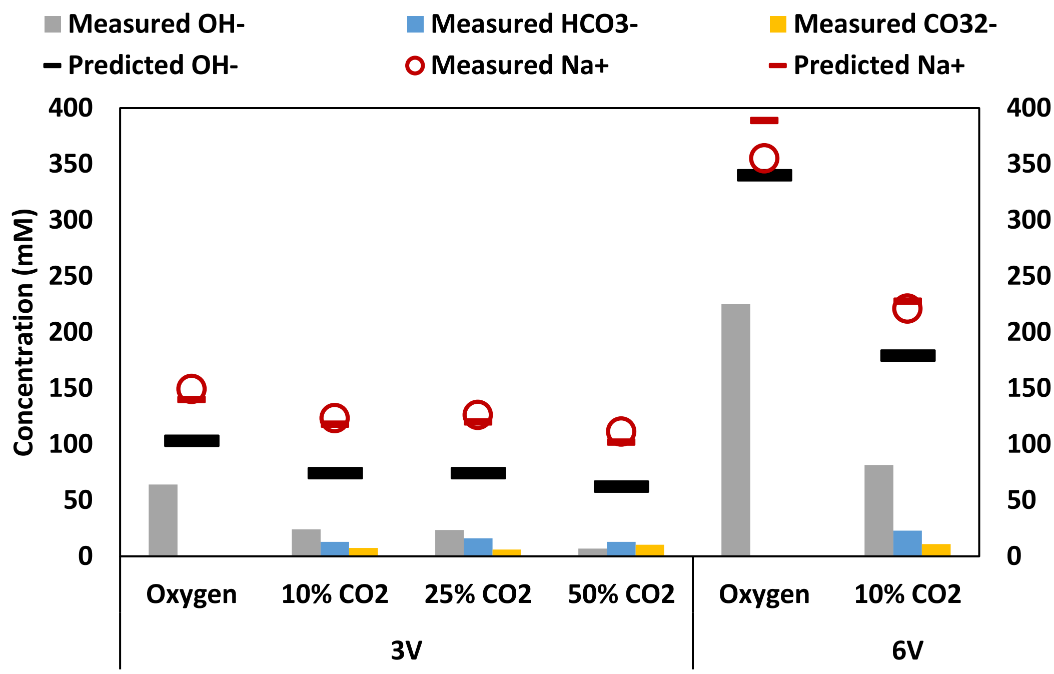


Figure 3: Top: Expected and measured pH and acid concentration in the acid compartment over 24 hours of testing. Bottom: Expected and measured sodium and anion concentration in the product compartment over 24 hours of testing.

Demonstrated over 2,000 hours of continuous operation: Over the course of the project, Mangrove further developed the technology and demonstrated durability of the electrochemical by operating a bench-scale cell continuously for a period of 80 days. To demonstrate the flexibility of the technology to different brines and acid and base concentrations the electrochemical cell was operated to different salinity levels, and sodium hydroxide and hydrochloric acid concentrations. The sodium hydroxide can be readily converted to sodium carbonate by using a carbon dioxide stream of any concentration and as such this was not investigated during these experiments.

5.2 Front-end pre-treatment design and build

Design specifications for the removal of dispersed and dissolved oils, hydrogen sulfide and calcium and magnesium were developed. Water samples and compositions from different sites were acquired to develop a database of water compositions. The water compositions include dissolved and dispersed oil content, hardness, heavy metals, crude oil content and total organic content. The water compositions include fracking, chemical enhanced oil recovery, steam assisted gravity drainage, oil sands mining, and conventional oil production sites. A treatment module that would be applicable to multiple sites and conditions was constructed.

Based on these water characteristics and requirements for the electrochemical cell a pre-treatment system was designed. The treatment train consists:

- Dispersed oil and suspended solids removal through a Mycelx system;
- Dissolved oil removal through granulated activated carbon;
- Hardness removal through the use of ion-exchange columns.

5.3 Pilot testing

A single cell 5,000 cm^2 cell was tested multiple times with different electrodes and compositions. The testing showed:

- A depletion in sodium chloride concentration to less than 0.4 wt% by the end of the testing meeting the success criteria for the project of 4,000 ppm desalination;
- Increase in hydrochloric acid concentration from up to 8.1 wt% surpassing the success criteria of 3% HCl for the project;
- Increase in sodium hydroxide concentration up to 9.2 wt% surpassing the success criteria of 4% NaOH for the project.

5.4 Conversion to mobile field-pilot

System description: Based on the testing above, a 4 m^3 per day capacity commercial scale demonstration system was designed, built, commissioned and operated as shown below in Figure 4 (3-D rendering and completed system). The system consists of a pre-treatment system for the removal of dissolved oils, organics, suspended solids, and hardness causing elements such as calcium and magnesium. The system also includes a demineralized water system to produce demineralized water for use in the plant for the build-up of chemicals and cleaning of the system. An electrical control cabinet is used to supply power for electrical equipment, such as pumps, heaters, etc., and to connect and control all instruments such as valves, pressure controls, gas and liquid flows, and all safety and hazard alarms and trips via an Allen Bradley PLC, and a connected HMI. An electrochemical skid with space for the different recirculation tanks allows for the system to be operated in several ways. A scrubber for the conversion of carbon dioxide to sodium carbonate or sodium bicarbonate is built into the electrochemical skid allowing for the system to be integrated to a variety of different carbon dioxide streams including atmospheric air for the conversion of carbon dioxide from the atmosphere.

System commissioning: The system was transported from BC Research Inc. to Annacis Research Centre, Delta, BC as shown in Figure 5. The different skids of the system were connected, integrated and tested to ensure all electrical and instrumentation connections as well as all fluid and gas flows within the system were correctly connected and adjusted. The completed system underwent two levels of HAZOP/HAZID reviews and was connected to a transformer to allow for electricity to be supplied to the system. A transformer rectifier that is built on to the Electrolyser skid was energized with all safety standards being followed. The system was water batched with all connections and leaks being verified. Chemical commissioning was then performed to ensure all flows and loops were correct and that the system responds accordingly. This allowed us to then begin testing for the project.

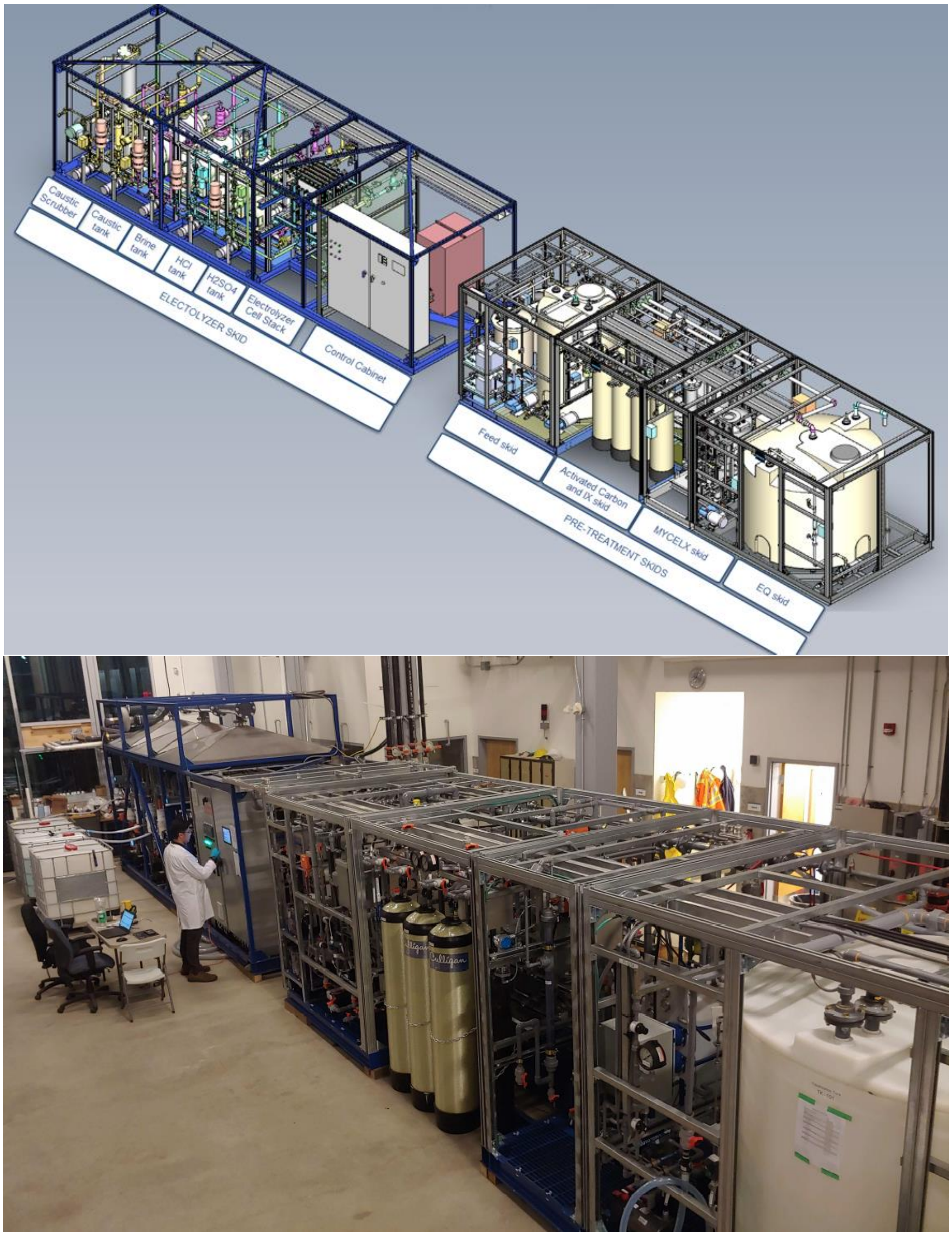


Figure 4: 3-D rendering and completed 4 m³ demonstration system.

Figure 5: Delivery of the pilot plant to Annacis Research Centre for integration and demonstration.

5.5 Validation of chemicals for use in O&G operations

The use of sodium carbonate and sodium hydroxide within the oil and gas sector is for the softening of water to remove hardness causing compounds such as calcium and magnesium. The sodium carbonate/hydroxide/bicarbonate causes elements such as calcium, magnesium, strontium, barium, iron, aluminum or manganese to precipitate out of solution in the form of a carbonate. The precipitate is then removed and disposed. In this manner, the carbon dioxide is mineralized and stored in the disposed waste. Sodium hydroxide is also used in oil sands mining operations for scrubbing of oil from oil sands and mobilizing the oil from within the pores. This also generates a waste that is then disposed. In both cases the quality of the sodium hydroxide and sodium carbonate is not of significant concern as there are no purity requirements. In addition, the production of a liquid sodium carbonate or sodium hydroxide stream is advantageous as it removes the need for dry caustic or soda ash handling systems. The alkaline chemicals and desalinated water produced were considered by Mangrove's customer to be of a sufficiently high quality for use in oil and gas operations.

Use of HCl for IX-resins

The hydrochloric acid produced has a more stringent requirement for use in oil and gas operations as it is used for the regeneration of ion-exchange resins. The presence of certain ions such as sulfate in the hydrochloric acid can be problematic as it may cause precipitation within the ion-exchange column. Organic content can also cause issues of fouling. One of the objectives of the testing was to determine the suitability of the hydrochloric acid produced by Mangrove's technology in ion-exchange regeneration processes. The product HCl produced by Mangrove's cell was compared against the recommendation from DOW for maximum impurity levels to be used as an ion exchange resin regenerant.

The chemicals were found to be suitable for use in the oil and gas sector as summarized below:

- Sodium carbonate: The sodium carbonate can be readily used for causing precipitation of hardness causing elements such as calcium and magnesium present in water. This is a common practice within the Alberta oil sands where the water needs to have hardness removed before steam generation.
- Sodium hydroxide: The sodium hydroxide can be used at oil sands mining for the scrubbing of oil from the ore. The sodium hydroxide can also be used for the regeneration of ion-exchange resins or the capture of carbon dioxide from flue-gas streams.
- Hydrochloric acid: The HCl can be used in the regeneration of ion-exchange resins that are widely used in the oil and gas sector. The HCl can also be used to remove scales that form on disposal wells or for the neutralization of blowdown waste from SAGD operations.

5.6 Integration and demonstration

3-Day Operation: The system was operated for a continuous period of 3-days as follows:

- Brine feed: The system was operated with a continuous brine feed of approximately 1 m^3 per day throughput.
- Hydrochloric acid: HCl was recirculated within the electrochemical cells with the aim of achieving the highest concentration possible within the 3-day test.
- Sodium hydroxide: The sodium hydroxide was recirculated through the electrochemical cells until the desired concentration was achieved. The sodium hydroxide was provided to the scrubber where it converted carbon dioxide to sodium carbonate/bicarbonate.

Cell performance: The two 5,000 cm^2 electrochemical cells performed as expected and demonstrated:

1. **Successful scale-up:** The two 5,000 cm^2 cells used in the system achieved performance matching that of the cells on the bench-scale and this showed that the technology can be easily scaled-up.
2. **Modular design:** The performance of the two 5,000 cm^2 cells was identical to each other showing that the system can be easily scaled by replicating a number of cells.

Production of sodium hydroxide: After the initial concentration of 5 wt% sodium hydroxide was achieved, the system maintained the concentration at the target 5 wt% by adding water. Over the period of testing, a total of 250 liters of 5 wt% NaOH was produced.

Conversion of carbon dioxide: The scrubber was only provided atmospheric air for the first half of operation while a 5 vol% carbon dioxide stream in air was provided during operation for the remainder of the testing period. This was done to demonstrate the flexibility of the system to convert carbon dioxide:

- **Conversion of carbon dioxide from atmospheric air:** During the first half of testing approximately 20% of the caustic was converted to a carbonate or bicarbonate form. These results show that the technology can convert atmospheric carbon dioxide to a mineralized form and does not require a concentrated carbon dioxide source to be brought to site.
- **Conversion of carbon dioxide from flue-gas streams:** A 5 wt% carbon dioxide stream was provided to the scrubber and converted to sodium carbonate and bicarbonate. A pure bicarbonate stream can be produced by stopping new hydroxide from the caustic tank being provided to the scrubber while a pure carbonate stream can be produced by stopping the carbon dioxide feed and converting the bicarbonate in solution to carbonate through the addition of sodium hydroxide.

Production of hydrochloric acid: Hydrochloric acid concentration of 6 wt% HCl was achieved with an a total of 100 liters of 6 wt% HCl produced.

Desalination of brine: 1665 liters of brine with an average flow rate of approximately 1.25 m³ per day was processed. As the goal of the testing was to demonstrate the production of chemicals, no specific target for desalination ability was set as this had already been demonstrated in previous testing. However, 1665 liters of the brine treated was reduced in concentration from 2.02% to 1.40%.

6. Greenhouse Gas and Non-GHG Impacts

Mangrove's technology would provide treatment of the saline water on-site, provide the chemicals on-site, and eliminate the need to dispose saline water in injection wells. Mangrove's technology would therefore indirectly eliminate GHG emissions associated with:

- **Saline water disposal:** Saline water produced on-site during or resulting from resource extraction no longer requires downhole disposal to a site on average 900 km away by trucking. A trucking emissions factor of 101 gCO_2/tonne/km is assumed. The distance assumed for trucking is based on an average distance within Alberta for oil and gas production sites near Fort McMurray to Grande Prairie or Calgary where disposal wells for saline water are more common.
- **Production of chemicals:** The Mangrove technology converts carbon dioxide into carbonate and/or bicarbonate salts. The system also produces hydrochloric acid. Both the carbonate/bicarbonate salt and hydrochloric acid are chemicals that can be utilized in oil and gas operations. The on-site generation of these chemicals will eliminate the need for these chemicals to be produced elsewhere. For this analysis, sodium carbonate and hydrochloric acid are the chemicals produced. Carbon dioxide emissions intensity of 0.441 $kgCO_2E$/kg sodium carbonate and 0.079 $kgCO_2E$/kg hydrochloric acid are used based on LCA values from the Ecoinvent database.
- **Avoided trucking of chemicals:** Chemicals are normally produced at centralized facilities and transported to distribution centers until they are transported to site for use. Hydrochloric acid is most often brought to oil and gas sites in the Fort McMurray area from Saskatoon, Calgary or Edmonton. However, the chemicals are almost always produced in other areas. Sodium carbonate is usually mined from Trona in Wyoming while hydrochloric acid is produced in plants in South-East USA. Based on this, an average trucking distance for chemicals of 1,500 km is assumed. A trucking emissions factor of 101 gCO_2/tonne/km is assumed.

Greenhouse gas emissions created by Mangrove's technology are:

- **Electrochemical reactor power consumption:** The technology relies on electric power. This is likely to be the largest component of GHG emissions associated with Mangrove's technology. The source of electricity is a combined heat and power system utilizing natural gas as the fuel source with a carbon emissions factor of 0.452 $kgCO_{2E}$/kWh.

In addition to reducing greenhouse gas emissions associated with water disposal and chemical supply, Mangrove's technology would also reduce freshwater consumption by providing desalinated water on-site. Greenhouse gas emissions created by implementation of Mangrove's technology are due to the electrical consumption of the system (dis-benefits). It is assumed that the electrical power for Mangrove's unit comes from electricity produced by natural gas.

Greenhouse gas and water usage reductions: A greenhouse gas analysis and the reduction in carbon emissions for a 1,000 m³ per day treatment system was performed. The analysis is performed for a 1,000 m³ per day system and then normalized on a per m³ basis for ease of calculation for the project and later for a commercial roll-out of the technology. The analysis showed that a 1,000 m³ per day capacity Mangrove system would:

- Reduce greenhouse gas emissions by 30,660 TCO_{2E}/year;
- Reduce water consumption by 313,856 m^3 of water per year.

Projected initial commercialization roll-out in Alberta: The roll-out of the technology is expected in Alberta by 2021. The expected roll-out of the Mangrove technology at these sites would be in multiple stages with clusters of 100 m^3 per day systems being rolled out over several years with an assumed 90% uptime for the systems. The greenhouse gas emissions resulting from the commercial deployment of Mangrove's technology after the project show that initial commercialization would result in annual GHG emissions reductions of 265 ktonnes CO_{2E} per year with a cumulative GHG reduction by 2030 exceeding 1 Mtonnes CO_{2E}.

Projected GHG impacts from commercial deployment: At a GHG emissions reduction rate of 0.084 $tCO2_E/m^3$ water treated and an estimated total saline water requirement at all oil sands mining sites of ~35,000 m^3 per day, Mangrove's technology could reduce GHG emissions by 1,073,000 tonnes annually. The treatment of this water would also:

- Convert 77.7 ktonnes of carbon dioxide every year;
- Reduce freshwater consumption by 10.9 million m^3 every year;
- Reduce 35,000 m^3 of saline water disposal.

Mangrove's technology can be applied to the entire oil sands mining market to eliminate saline water disposal, convert carbon dioxide from combined heat and power systems, and provide a local decentralized chemical production ability leading to greater than 1 Mtonne of GHG reductions. Each system deployed is expected to have an estimated lifetime of 20 years within the commercial setting.

Emissions reduction from project: The project was a pilot demonstration and the greenhouse gas emissions reductions from the project are immaterial. As such, a GHG verification and validation was not required.

7. Overall Conclusions

The project was successfully completed with all objectives being demonstrated:

- **Parametric testing of 5 barrel/day system and gas diffusion electrodes at BCRI:** Significant progress was made with successful scale-up and design of Mangrove's technology which was demonstrated to the same performance as the bench-scale cells.
- **Front-end pre-treatment module engineering design and construction:** A pre-treatment module capable of treating a wide variety of waste-water was designed and constructed to reduce the presence of contaminants to within Mangrove's operating envelope.
- **Pilot Testing:** Testing of the electrochemical cells in the pilot plant was performed and demonstrated:
  - Matching cell performance between the bench-top and 5,000 cm^2 scales;
  - Hydrochloric acid concentrations of 8.1 wt% exceeding the project success criteria of 3 wt%.
  - Sodium hydroxide concentrations of 9.2 wt% exceeding project success criteria of 4 wt%.
  - Brine depletion to below 4,000 ppm exceeding the project success criteria of 5,000 ppm.
- **Conversion to mobile field pilot:** The demonstration plant was constructed and prepared for testing with the goal of being able to be transported to different sites as required.

- **Validation of chemicals for use in O&G operations:** Samples of chemicals produced by the technology were analyzed to ensure the chemicals produced specifications required by the oil and gas sector.
- **Integration and demonstration:** The demonstration plant was integrated and demonstrated at Mangrove's facilities with synthetic compositions of an Alberta customer's brines and flue gas compositions expected within the Alberta oil and gas sector. The testing completed included:
  - Demonstration of a commercial scale system: A 4 m^3 capacity demonstration system including pre-treatment was designed, constructed, integrated and demonstrated. The demonstration consisted of providing the system with a synthetic brine composition and carbon dioxide which was converted to sodium carbonate, hydrochloric acid and a desalinated water stream. The system also demonstrated conversion of carbon dioxide from air.
  - Demonstration of modular expansion of the technology: A stack of two-cells was demonstrated with identical performance achieved between each cell. This demonstrates the modular nature of the technology where scale-up is simply about replicating number of cells in a stack or number of stacks in a module.

8. Scientific Achievements

Scientific papers published:

"Conversion of saline waste-water and gaseous carbon dioxide to (bi)carbonate salts, hydrochloric acid and desalinated water for on-site industrial utilization." Saad Dara, Arman Bonakdarpour, Meghan Ho, Rubenthran Govindarajan and David P. Wilkinson. React. Chem. Eng., 2019, 4, 141.

Conferences attended:

- Banff Venture Forum - Start-up company presentations.

9. Next Steps:

The technology has been significantly de-risked through the demonstration of a commercial scale system. The risk of scale-up of the technology is relatively low as Mangrove has used off-the-shelf components with known supply chains.

Commercial module will be demonstrated with in Alberta under a SDTC funded project: Successful demonstration with oil and gas producers over the last two years has led to a commitment from an Alberta based oil and gas producer for a field demonstration of a commercial module. This first commercial module will be built and demonstrated under a recently funded Sustainable Development Technology Canada (SDTC) project and further advance the success of the ERA funded Round 2 project. The demonstration and deployment will serve as a reference site and accelerate commercialization with other Alberta oil and gas customers.

Project – Round 3 project will lead to full-scale deployment in Alberta's O&G sector: The ERA Round 3 project will build on the SDTC project but focus on the commercial deployment of a cluster of 100 m^3 modules with oil and gas customers in Alberta. The Mangrove technology would accept carbon dioxide from cogeneration power systems or another carbon dioxide source and saline water from oil and gas operations to provide sodium carbonate, hydrochloric acid and sodium hydroxide on-site and on-demand for use in operations. The overall goal of the project is to:

- Optimize performance and build operational field experience on the commercial modules;
- Validate economic assumptions of durability, uptime and process economics during operations;
- Set-up supply chain and manufacturing capability for cell components, and assembly of electrochemical cells.

The Round 3 project will complete engineering design work for the integration of the technology with a carbon dioxide source and multiple modules to meet the total customer requirement. The deployment of these commercial modules enable Mangrove to fully de-risk the technology by demonstrating reliability of operations, validating assumptions of durability and economics, and proving scalability of the business model. The majority of the project will be carried out in Alberta resulting in job creation directly through Mangrove's employees and indirectly through project partners and subcontractors that Mangrove will engage with. A successful operation of these systems will allow Mangrove to achieve the next inflection point in value and allow Mangrove to secure debt financing for future systems.

10. Communications plan

Mangrove's strategy has been to identify industry partners are work with them directly to advance commercialization of the technology. This allows Mangrove to work with end-users of the technology and own the customer relationship. As Mangrove moves forward, we will continue to work directly with customers of the technology and communicate the technology through the following:

- **Refereed and non-refereed Journals:** An article has featured our technology in APEGBC. Two articles have been published in high impact journals sharing results of the project.

- **Conference Presentations:** In addition, we will present our results in a number of conferences including COSIA Water Conference and the International Desalination Association (IDA).

- **Clean Resource Innovation Network:** Mangrove is a part of the CRIN network and will continue to communicate its success through the network to potential project partners.

- **Web presence:** We jointly plan with our partners to communicate our collaboration and project technology on their company websites (BCRI and NORAM) as well

- **Company website:** The website of the startup company (currently in formation) will communicate the project results and the state of the technology