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Overview, status, and future of the Fort Nelson CCS project

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Abstract

The Plains CO_2 Reduction Partnership, led by the Energy & Environmental Research Center, and Spectra Energy Transmission (SET) are investigating the feasibility of a carbon capture and storage project to mitigate carbon dioxide (CO_2) emissions produced by SET's Fort Nelson Gas Plant in British Columbia, Canada. The project applies an integrated philosophy combining geologic characterization, modeling, risk assessment, and monitoring into an iterative process, producing superior-quality results during the project feasibility and development periods. Results to date suggest that the geology and hydrogeology of the project area are amenable to large-scale, long-term geologic storage of CO_2.

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Keywords: Deep saline storage; geologic storage of CO_2; carbonates; site characterization; modeling; risk assessment; monitoring

1. Introduction

The Plains CO_2 Reduction (PCOR) Partnership, led by the Energy & Environmental Research Center (EERC), and Spectra Energy Transmission (SET) are investigating the feasibility of a carbon capture and storage (CCS) project to mitigate carbon dioxide (CO_2) emissions produced by SET's Fort Nelson Gas Plant (FNGP) as a waste stream from natural gas processing. The FNGP is located near the town of Fort Nelson in northeastern British Columbia, Canada. The gas stream produced by the FNGP will include up to 5% hydrogen sulfide (H_2S) and a small amount of methane and, as such, is referred to as a "sour" CO_2 stream. The sour CO_2 gas stream would be injected into a deep saline carbonate formation.

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The Fort Nelson demonstration project provides a unique opportunity to develop a set of cost-effective, risk-based monitoring, verification, and accounting (MVA) protocols for large-scale (>1 million tonnes a year) storage of sour CO_2 in a deep saline formation. The likely injection target will be a carbonate formation in the Devonian Presqu'ile reef complex, with the 500-m-thick shales of the overlying Muskwa and Fort Simpson Formations serving as seals. The effectiveness of the MVA activities will be at least partially dependent on developing a thorough geologic characterization, modeling, and risk assessment effort. The results of the Fort Nelson activities will provide insight regarding 1) the behavior of dense-phase sour CO_2 in a deep brine-saturated carbonate reservoir environment; 2) the impact of dense-phase sour CO_2 on the integrity of sink and seal rocks; 3) the effects of large-scale sour CO_2 injection and storage on wellbore integrity; 4) the effectiveness of selected MVA techniques; and 5) the use of an approach that combines iterative geologic characterization, modeling, risk assessment, simulation, and MVA planning to safely and cost-effectively inject and store large volumes of sour CO_2.

The role of the PCOR Partnership is to provide the project with reservoir modeling and simulation, risk assessment of subsurface technical risks, and an MVA plan to address these risks. The PCOR Partnership applies a philosophy of integration that combines geologic characterization, modeling, risk assessment, and MVA strategies into an iterative process to produce superior-quality results during the project feasibility and development periods.

2. Background

SET is proactively exploring the addition of CCS technology to the FNGP. SET is working with the EERC through the PCOR Partnership (one of seven Regional Carbon Sequestration Partnerships established by the U.S. Department of Energy) to conduct activities in the areas of site characterization, modeling and simulation, risk assessment, and MVA. The goal of CCS at the FNGP is to capture the stream of sour CO_2 that is separated by the current gas-processing operations and store it long term in a deep saline formation. Presently, this sour CO_2 is processed in an existing sulfur plant to recover elemental sulphur, and the residual CO_2 and H_2S are passed through an incinerator and vented to the atmosphere. The Fort Nelson CCS project has several advantages that will facilitate a successful project:

- SET has a long history of safe and effective acid gas injection, with on the order of 200,000 tonnes of CO_2 injected annually across eight of its gas-processing plants in western Canada.
- Unlike most prospective CCS projects in North America, the Fort Nelson CCS project does not have the high costs associated with outfitting a plant with CO_2 capture technology since the sour CO_2 is already separated and captured as part of sour gas processing; however, the cost of compression, cooling, dehydration, transportation (pipeline), and sequestration remain.
- The prospective injection site is located in a remote area where population density is low and local public support is expected to be strong because of the history of sour gas processing, the economic benefits the plant brings to the local community, and SET's long-standing reputation as a safe and environmentally responsible operator.
- The storage reservoir is far below any usable water and is topped by a very laterally continuous 500-m (1500-ft)-thick cap rock that preliminary data indicate will successfully contain the injected sour CO_2.
- The British Columbia provincial government considers CCS to be a major component of its greenhouse gas reduction strategy and supports further development of the local natural gas resources.
- The federal governments of Canada and the United States, as well as the provincial government of British Columbia, have supported the Fort Nelson CCS project through cash and in-kind contributions.

3. Project Philosophy and Approach

The philosophy of the Fort Nelson project team is to integrate characterization, modeling, assessment, and monitoring strategies into an iterative process to produce superior-quality results (Figure 1). Elements of any of these activities are crucial for understanding or developing the other activities. For example, as new knowledge is gained from site characterization, it reduces a given amount of uncertainty in geologic assumptions. This reduced uncertainty can then propagate through modeling, risk assessment, and monitoring efforts. Data generated by injection operations and MVA activities over the duration of the Fort Nelson CCS project will facilitate refinement of SET's understanding of the geologic setting and risks. This, in turn, will allow for adjustment of the reservoir model and, if necessary, the MVA plan as a means of further minimizing or mitigating risks. Over time, the operational and MVA data will support the iterative refinement of the reservoir model in such a manner that it becomes a reliable predictor of CCS performance at the Fort Nelson site. This aspect of the project will be critical when addressing issues associated with long-term liability and ultimately necessary to hand oversight of the plume back to the provincial government.

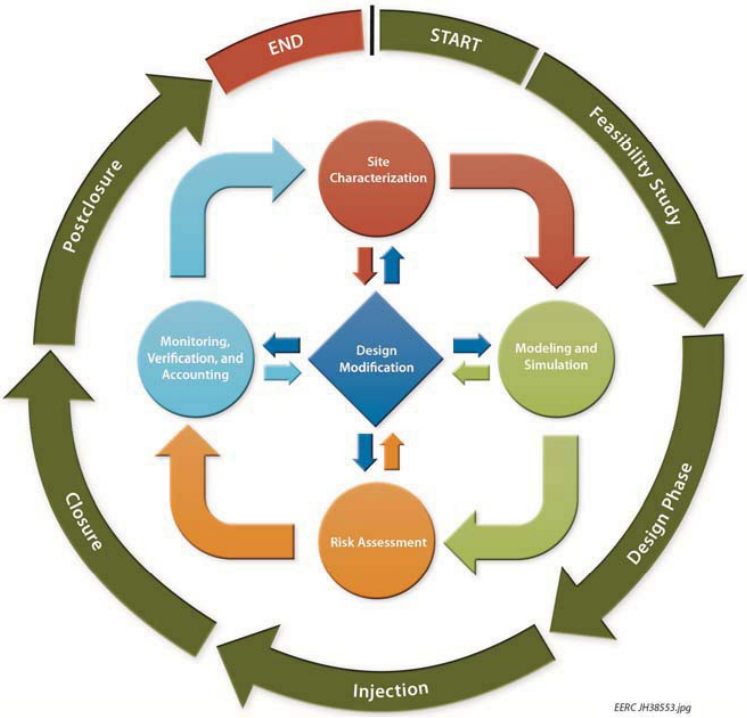

Fig. 1. Project elements of the Fort Nelson CCS project. Each of these elements feeds into another, iteratively improving results and efficiency of evaluation

4. Site Characterization

Site characterization efforts for the Fort Nelson CCS project have focused primarily on two different environmental settings, the deep subsurface environment that will serve as the sinks and seals for the stored CO_2 and the shallow-to-near-subsurface environment that could be adversely affected by potential leakage. Site characterization activities have been conducted to develop predictive models that address three critical issues to determine the ultimate effectiveness of the Fort Nelson test site: 1) the capacity of the target formation; 2) the mobility and fate of the CO_2 at near-, intermediate-, and long-term time frames; and 3) the potential for leakage of the injected CO_2 into overlying formations and/or the near-surface environment.

Geochemical, mineralogical/petrophysical, geomechanical, and hydrogeological data have been collected and analyzed for the purpose of determining the applicability of safely and cost-effectively storing sour CO_2 in a deep-saline carbonate formation in the Devonian Elk Point Group. The top of the mid-Devonian strata occurs at a depth of over 1850-m below the surface. These strata include multiple sequences of tight vertical shales and porous and permeable dolostone rock, providing the robust sink–seal framework needed for sour CO_2 storage. Characterization data for the deep subsurface sink–seal framework were generated primarily from evaluation of well log and core analysis data from existing hydrocarbon exploration and production wells, acquisition and reprocessing of existing 2-D and 3-D seismic surveys, and the drilling and testing of a new exploratory well. The geophysical attributes that were obtained from the seismic surveying and other sources included seismic attribute and curvature analysis, lithofacies, information about natural fractures, porosity and permeability data, water saturations, water salinities, temperature gradient, surface elevation maps, small synthetic and antithetic faults, and sag features and breaches. These attributes were used to construct distributions of specific parameters throughout the Fort Nelson CCS project site area.

At the regional scale, the geology, stratigraphy, and lithology have been evaluated, delineated, and described for the entire sedimentary succession from the lower confining unit at the base of the Devonian-age Presqu'ile reef complex to the ground surface for the northwestern Alberta Basin. In addition, the structural elements of the reef complex have been investigated to identify any existing faults and/or fractures that would allow migration of any reservoir and/or injected fluids out of the storage reservoir. On this basis, a geologic model has been built, with particular attention given to the Devonian injection interval and overlying and underlying sealing formations.

With respect to the surface and near-surface environment, establishing baseline conditions is essential to effectively monitor for impacts potentially caused by leakage. The Fort Nelson area is largely dominated by rural boreal forest, which is a complex mosaic of fens, bogs, swamps and pools, and scrubby forest and is scarcely populated. The topography is generally flat, with slow-flowing rivers (i.e., the Muskwa, Prophet, and Sikanni Chief Rivers), lakes (most notably Clarke, Milo, and Klowee Lakes), and creeks being the only distinctive features. Regionally, the soil type is a poorly drained silty clay. Because of the remote nature of the Fort Nelson area and lack of permanent roads, surface land use activities are limited to hydrocarbon exploration and production as well as trapping, hunting, and fishing. The climate regime of the area is considered to be a muskeg or a taiga "subarctic" plain having an average mean summer temperature of 12°C (54°F), an average mean winter temperature of –15°C (5°F), and a mean annual precipitation range of 400 to 500 mm (16–20 in.). Shallow subsurface characterization has thus far focused primarily on the drilling and subsequent sampling of shallow groundwater wells in the vicinity of a deep exploratory well drilled by SET in 2009. The primary purpose of the groundwater-monitoring wells is to provide baseline data regarding the quality of shallow groundwater resources. These baseline data can then be used as points of comparison to later postinjection sampling events to determine what effects, if any, the storage of sour CO_2 may have on the shallow groundwater. The results from the samples collected in both May 2009 and January 2010 were used to determine baseline parameters for water quality in the area; additional future sampling will be beneficial for observation of seasonal variance, if such variance exists. Key findings of the characterization activities to date include the following:

- The Sulphur Point and Keg River Formations appear to have adequate storage- and injectivity-related properties to serve as primary sinks.
- The Fort Simpson and Muskwa Formations appear to have the tightness, competency, thickness, and lateral continuity necessary to be primary seals.
- The Slave Point Formation has been disqualified as a primary potential sink because of the proximity of commercial gas fields that occur within it.
- Evidence suggests the Slave Point, Sulphur Point, and Keg River Formations are in hydraulic communication (laterally and vertically) with each other.
- Surface, shallow subsurface, and deep subsurface characterization data are relatively limited because of the remote, inaccessible nature of the Fort Nelson area and because of the lack of hydrocarbons in the portion of the reef being considered for CO_2 storage.

5. Modeling

The modeling of the subsurface aids the understanding and prediction of the behavior of the injected sour CO_2 over the injection and postinjection periods. The modeling is also a highly valuable tool for assessing potential scenarios of leakage to the surface, to nearby productive natural gas pools, or into usable water resources. This type of assessment is an essential input to the risk assessment plan and the MVA plan. It lays the foundation for a project-specific, risk-based, goal-oriented MVA plan. The goal of the MVA plan is to effectively monitor the behavior of the sour CO_2 in the subsurface and help ensure that the risks are successfully mitigated.

Generation of an accurate geologic model is an iterative process that involves compiling a wide variety of data collected through site characterization activities into a complex computational package. The modeling process attempts to encapsulate the potential variation in physical and chemical parameters identified in the subsurface. Predictive simulations can then be carried out on this package to create a range of potential outcomes that may result from large-scale injection of sour CO_2. Results of these simulations can then be used, in part, to identify portions of the model that may be responsible for generating results with lower levels of confidence and thus requiring increased data input. As additional data become available (such as from new exploratory wells), the model can be updated and results improved or validated.

The Fort Nelson model is being created from existing well logs, cores, maps, testing, seismic data, reports and surveys, and other data provided by SET to recreate, as accurately as possible, the geologic regime of the region. Important data can be derived from well logs, core analyses, geophysical surveys, and petrographic analysis of cuttings and thin sections to determine mineralogy and lithology, all of which can be used to determine depositional environments. All of this supports the development of a model that accurately represents the true lithology and structure of the sink–seal system.

A stochastic approach was used to generate a range of potential outcomes in an attempt to encapsulate variability expected within the system. Individual geologic units were modeled first and then stacked into a regional model. Known faults, identified primarily through seismic data, can be applied to the model once the regional model is created. In addition, detailed local and regional pressure data and hydrogeological regime data and interpretation of those data were used to further understand reservoir connectivity.

Distributions of continuous local-scale properties, such as porosity and permeability, were populated based on the presence of the various lithologic facies identified earlier. Although rock types may be similar across an area, significant variation can exist primarily as a result of changes in the depositional environment. It is this variation that facies modeling attempts to encapsulate. Finally, after the various model elements are combined, regional-scale properties such as head pressure, salinity distribution, and hydrogeologic flow regimes were applied.

Once the static model construction was completed, dynamic simulations were carried out to predict the fate of injected sour CO_2 under various conditions. Included in these simulations is an analysis of geochemical interactions. A vigorous history-matching exercise was conducted using historical data from production and injection wells in the Fort Nelson area. This effort was essential to calibrate the model. The history-matching exercise has been used to demonstrate to stakeholders that the model reasonably represents the sink–seal system and can be used as the basis for predictive simulations. Future modeling efforts will further clarify how interactions between the injected gas, the reservoir fluids, and the rocks will influence mineral precipitation and its effects on permeability, injectivity, and ultimate storage. As these results are updated, the expected behavior and influence of injected sour CO_2 will be incorporated into the risk assessment evaluation, guide the collection of additional data, and aid in the design of the MVA plan.

6. Risk Assessment

There are several components to an effective risk management framework, including risk assessment, risk treatment, communication, and monitoring. Risk assessment consists of identifying the relevant site-specific risks; estimating the criticality, which is the overall risk to the project (using a combination of probability of occurrence and severity of potential consequences); and evaluating the need to treat the risk based on its rating. The assessment must include the acquisition and evaluation of data to confirm key site characteristics such as capacity, injectivity, and containment as described in previous sections of this document. Once assessed, the risks that have been evaluated as critical must be treated using one of four options: accepting, transferring, avoiding, or mitigating. Finally, the risks must be monitored to ensure that they are successfully controlled. A monitoring plan based on the results of the risk assessment helps ensure that the project is safe while also ensuring that funding is not spent on monitoring for risks that may not be relevant to the project. Additionally, communication with both internal and external stakeholders about risk is an essential part of gaining confidence and trust in the project.

The Fort Nelson CCS project has undergone two full iterations of the risk assessment process. While the results of the risk assessment activities are confidential, they have been used by the project team to identify areas requiring additional characterization and develop MVA plans for the deep subsurface and surface–shallow subsurface environments.

7. MVA Planning

The Fort Nelson CCS project is being evaluated and planned under the assumption that the regulatory authorities of British Columbia will require that a proper site-specific MVA plan be implemented at the project site. SET and the EERC are using a risk-based approach to define the MVA strategy. This means that the MVA plan will stem from the risk assessment of the storage project and be primarily focused on the early detection of the occurrence of the most critical risks and their mitigation. Once key measurable parameters are identified for each high-criticality risk, relevant MVA technologies can be proposed. The technical applicability of each MVA technology will be evaluated in terms of its maturity/applicability, cost–benefit ratio, and likelihood of success. The following is a short list of relevant MVA technologies that are being considered for monitoring the deep subsurface based on initial assessments:

- Multicomponent surface seismic
- Microseismic (well-based)
- Vertical seismic profiling
- Surface (wellhead) injection rate measurements (mandatory by regulation)
- Downhole fluid chemistry/geochemistry
- pH measurements
- Tracers
- Annulus pressure measurements
- Geophysical and well integrity logs
- Downhole and surface pressure/temperature measurements (mandatory by regulation)

Periodic surface wellhead injection rate measurements, surface pressure and temperature, and downhole pressure and temperature measurements are mandatory and required by British Columbia regulatory agencies as part of the license to operate an injection scheme.

8. Summary of Project Status

To date, a variety of regulatory permitting, public outreach, site characterization, modeling, risk assessment, and MVA planning activities have been conducted. Key activities include the following:

- Acquisition of existing well data, 2-D and 3-D seismic surveys, log analyses, and core testing results.
- Studies on various aspects of the hydrogeological, geochemical, petrological, and geomechanical characteristics of potential sink and seal formations.
- The drilling, coring, and testing of an exploratory well.
- Iterative development of static geologic models that include not only the potential CO_2 storage area but also neighboring natural gas fields.
- Dynamic modeling and simulations including base case and injection scenarios, history matching, and predictive simulations with sour CO_2 injection before and after history matching.
- Two iterations of a comprehensive risk assessment of the geologic risks associated with the project.
- Collection of baseline data for shallow groundwater characteristics in the project study area.
- Development of key permitting application documents.
- Development of outreach products for the general public, including posters and fact sheets.

Results to date suggest that the geology and hydrogeology in the vicinity of the FNGP are amenable to large-scale, long-term geologic storage of CO_2. However, to properly implement an effective, economical, and optimized commercial-scale CCS project at the Fort Nelson site, an iterative update process between site characterization, modeling and simulation, risk assessment, and MVA must be conducted so as to ensure regulatory compliance and project safety. Currently, first- and second-round risk assessment evaluations have been performed and are being used to identify additional characterization activities that are beneficial to the project. The results of the risk assessments also provide a basis for updated simulation work in order to help guide the selection of a site-specific injection strategy. Upon completion of the current and planned site characterization and modeling activities, specific injection scenarios can be evaluated in terms of criteria set forth by SET.

9. Path Forward

Once a final injection strategy has been defined, the risk assessment will be updated to include risk criticality rankings for the specific selected injection strategy based on simulation results, which will, in turn, be used to guide a specific MVA strategy. The updated MVA plan will include specific technologies, spatial locations of measurements, acquisition frequencies, and baseline data necessary to address critical project risk and regulatory requirements and identify potential deviations from expected conditions in a timely manner. Once the updated assessment has been completed, the injection program can begin. However, periodic updates will be necessary throughout the injection phase of the project in order to confirm system behavior and agreement between the physical injection, simulation results, anticipated risks, and successful deployment of MVA strategies. Although specific techniques and procedures may change as the project proceeds, the philosophy of iteratively integrated geologic characterization, modeling, and risk assessment will ensure that MVA strategies remain fit for purpose, cost-effective, efficient, and have the greatest potential for success throughout the lifetime of the project.

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