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Recommendations for Injection and Storage Monitoring

WABAMUN AREA CO_2 SEQUESTRATION PROJECT (WASP)

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INTRODUCTION

Studies completed under WASP Phase I have characterized the Nisku Formation over an area of slightly greater than 5,000 km^2. Various reports describe the development of a geologic static model (Eisinger and Jensen), regional geochemistry (Shevalier, et al.), regional geophysics (Alshuhail et al.), geomechanical modelling and analysis (Goodarzi and Settari), reservoir simulation (Ghaderi and Leonenko), well design and integrity (Nygaard) and water disposal well analysis, including those wells that experienced lost circulation (Lavoie). Log data and cores from wells in the area are sparse and reservoir models are poorly constrained in terms of porosity and permeability trends. Some 3D seismic surveys in the area provided additional trends of interpreted physical properties of the Nisku reservoir and overlying formations.

Programs for site monitoring during and after injection of CO_2 have two principle objectives:

(a) identifying and tracking the injected CO_2 plume in the storage reservoir, if possible; and
(b) early detection of CO_2 breaches through the caprock of the storage reservoir and upward migration of CO_2 into overlying stratigraphic units, shallow groundwater, soil or into the atmosphere.

Of paramount importance to carbon capture and storage (CCS) is the ability to track CO_2 plume movement on a best effort basis to assess whether the CO_2 flow is consistent with model predictions, and to optimise safeguards for early leak detection. These goals are vital for public acceptance of CCS, particularly during early projects as the technology becomes implemented at commercial scale. Comprehensive yet affordable monitoring protocols thus need to be established. A wide range of technologies have been developed for monitoring CO_2 injection and storage, including surface and subsurface measurements, but continued research and development is required for next generation technologies that will enable effective monitoring programs to be implemented.

Within the WASP project area, the Nisku Formation is between 1,600 and 2,000 m below ground surface. The Nisku aquifer pressure is approximately 16 MPa, therefore the injected CO_2 will remain in a supercritical phase in the reservoir.

1. WASP II CO_2 INJECTION PROGRAM

The recommended monitoring program for WASP II CO_2 injection would be staged in accord with the overall program implementation. This technical component of this program may consist of:

Stage I Site selection for a test well, based on models developed from WASP Phase I, or a continuation of the approach used in Phase I over a larger region.

Stage II Local geological, geophysical, hydrogeological and geomechanical characterization of the selected site using existing data (possibly additional to WASP Phase I database).

Stage III Drilling of a well to test Nisku reservoir connectivity and CO_2 injectivity with site specific characterization based on a comprehensive core analysis program (including caprock), full geochemical evaluation of the reservoir fluids and a detailed suite of geophysical logs from the well, followed by an update of the static geological model.

Stage IV Further characterization of the reservoir via a period of pressure transient testing using brine production or injection as the pressure disturbance mechanism. The pressure disturbance could take the form of either an extended drawdown (production of brine) followed by a buildup period (shut-in) or, ideally, simply conducting a long period of drawdown while monitoring the flowing bottom hole pressure (via surface recording sensors located below an electrical submersible pump [ESP]). This would serve as a reservoir limits test. Either way, the objective would be two fold; i) to assess the bulk average reservoir permeability-thickness over an extended distance away from the well and ii) assess the distance at which reservoir boundaries are experienced. Brine from the extended period of production would need to be disposed of. This could be done by completing a second well, not too far away from the test well, and pumping into either the Banff or Wabamun aquifers. Brine disposal into these shallower aquifers would provide additional reservoir characterization of potential brine disposal locations should pressure plume management prove to be required during a commercial CO_2 storage project.

If the Nisku Formation in the test well meets predetermined performance metrics, then a CO_2 injection pilot would be established at the site with injection of up to 100 t of CO_2 per day for a period long enough to establish important CO_2 injectivity parameters as well as provide sufficient CO_2 plume development to be observed using geophysical methods (e.g., cross-well, vertical seismic profiles and time-lapse borehole logging). In particular, geophysical tests would be used to monitor the shape of this CO_2 plume over time in order to further characterize the vertical permeability near the test well. Prior to initiation of CO_2 injection, baseline geophysical, geochemical and shallow groundwater sampling surveys would be undertaken. At least one (preferably two) fully instrumented observation well would be required for Stage IV, with both surface and subsurface monitoring programs initiated. Details about the various surveys are provided below.

Stage V If the Pilot CO_2 injection program is successful, Stage V consists of up-scaling the injection program to the 1 Mt/year target. Appropriate monitoring programs to be deployed would be designed, based on results from Stage IV of the program. Pipelining of the CO_2 from the source would be required but this is not covered in this report.

2. WASP II PROPOSED MONITORING PROGRAM

The monitoring programs recommended are specific for the Nisku target, based on WASP Phase I reports, and are also drawn from best practices recommended by the US Department of Energy National Energy Laboratory (Srivastava et al., 2009).

2.1 Stage I

Site selection would be made by the operator (i.e., TransAlta), assisted by information provided in the WASP Phase I reports. Regional characterization of the Nisku aquifer may be required over areas additional to those covered by WASP I, depending on available data.

2.2 Stage II

Once a test injection site has been selected, local site characterization should be undertaken using available well and trade seismic data (2D or 3D). It is recommended that the local characterization cover an area of up to 25 square km (5 km × 5 km) and would include the following activities:

- interpretation of 2D and 3D seismic data not previously available in WASP I;
- detailed core and log analyses from wells in the local site characterization area;

- geochemical analyses from production wells in the local site characterization area;
- groundwater sampling surveys to characterize shallow aquifers in the local site characterization area; and
- development of a local geological static model from the ground surface to the Nisku Fm.

2.3 Stages III and IV

Design of the test injection well could be undertaken by the WASP team (e.g., Runar Nygaard) or a selected engineering services company. A full well-logging suite should be run in the well, including caliper, gamma-ray, resistivity, sonic-scanner, neutron, density, and cement bond logs from base of surface casing to total depth, with FMI and formation tester logs at selected intervals. Once the well has been completed, the brine injection or production test would be undertaken to characterize the reservoir around the injection well, and if successful, this would be followed by a CO_2 injection test and pilot. During the drilling operations, a full core from the well should be obtained through the Calmar Formation (caprock) and the complete Nisku Section through to the underlying Ireton Shale. In order to refine a subsequent monitoring program, the following core analyses are required for both caprock and reservoir rocks:

- minerology;
- petrophysical properties, including static and dynamic modulii and formation factor;
- porosity and permeability measurements;
- Vp and Vs measurements on reservoir core at RTP for CO_2 saturations from 0 to 100%;
- sampling and analysis of reservoir fluids; and
- sampling and characterization of shallow aquifers intersected by the well (above Colorado Group).

Once these data have been collected, then the following tasks should be undertaken:

- update of the local-scale static geological model;
- update of the local-scale geomechanical model;
- simulation of CO_2 injection and plume development in the Nisku formation; and
- geochemical modelling of CO_2-rock interaction.

If the brine injection/production program and CO_2 injectivity tests are successful, then a number of observation wells (at least three) should be drilled to penetrate the Nisku Formation in order to monitor the CO_2 plume in the reservoir directly. These wells would all be capable of being instrumented with retrievable monitoring tools, permanent pressure and temperature gauges, and should allow sampling of the Nisku reservoir fluids as well as from deep and shallow aquifers. The location of the monitoring wells would be guided by the results of simulation of CO_2 plume development, but it is anticipated that the first observation well to be drilled should be between 200 m and 500 m from the injection well in order for microseismic monitoring and cross-well seismic surveys to be effective. If the Nisku Fm is to be stimulated in the injection well, then the first two observation wells should be completed so that the frac can be monitored with the microseismic arrays.

In conjunction with the completion of the observation wells, baseline monitoring programs should be undertaken prior to start of CO_2 injection, and these could be completed during construction of the pilot plant infrastructure. The recommended baseline surveys consist of the following.

2.3.1 Near-Surface and Atmospheric Baseline Surveys

These surveys would consist of the following.

- soil and vadose zone surveys to determine baseline CO_2 concentrations and isotopic compositions in the near-surface soil and shallow groundwater;
- flux accumulation chambers to determine background CO_2 flux from the soil near the proposed injection well and observation wells;
- groundwater surveys to determine baseline chemical and isotopic composition of groundwater in the local site characterization area. Samples would be obtained from available wells; the drilling of additional groundwater monitoring wells may be necessary;
- surface tiltmeter array to measure transient ground motion during injection (if warranted by geomechanical modelling);
- surface monuments for high-accuracy differential GPS measurements and for microgravity surveys; and
- establishment of a network of INSAR reflectors for baseline surface strain state. Areal coverage should be no less than 50 km^2.

2.3.2 Subsurface Baseline Surveys

These surveys would consist of the following.

- Instrumentation of the observation wells, including the following.
  - Pressure and temperature gauges at reservoir level in the overlying Wabamun Formation and at the top of the Colorado Formation.
  - Microseismic arrays, either permanent or retrievable. The recommended array is made up of sixteen three-component geophones spaced at 15 m intervals, with the deepest geophone assembly just below the base of the Nisku Formation.
  - In-situ down-hole sampling of fluids from the reservoir, from formations above the caprock and shallower aquifers (above Colorado Gp) for baseline aqueous geochemistry.
- Well logs to establish near-well resistivity and porosity characteristics. If steel casing is used, resistivity measurements may be problematic, so pulsed-neutron logs may need to be used instead. If fiberglass casing is used, standard oilfield induction resistivity measurements are the resistivity measurement of choice.
- 3D multi-component seismic survey to fully map the subsurface structure and stratigraphy within the local site characterization area and to detect faults or other possible natural leakage paths to shallow aquifers or the ground surface. All surface shots of the survey should also be recorded by the downhole array in the observation well.
- Walkaway vertical seismic profiles (VSPs) to provide high-resolution baseline images of the Nisku Formation around the injection well (retrievable array). Walkaway shotlines should extend up to 2 km south and east of the well with shot spacing of 50 m. The VSP surveys should be run from base of surface casing to total depth, with a shuttle interval of 15 m. This is important since the WASP I geophysical program indicates that surface seismic data will be challenged to track the CO_2 plume within the Nisku reservoir.
- A baseline cross-well seismic survey to characterize the in-situ seismic properties of the Nisku Formation between the injection and at least one of the observation wells.

2.4 Stage IV

Monitoring undertaken during fluid production and injection would consist of continuous and periodic programs. Those programs are as follows.

2.4.1 Continuous Monitoring

Continuous monitoring would consist of the following.

- Pressure and temperature monitoring in the injection and observation wells, with automated data logging and cell-based transmission to monitoring office;
- Microseismic monitoring from the downhole geophone arrays in the observation wells, with automated event detection and transmission to monitoring office;
- Tiltmeter array monitoring for mapping transient surface deformation associated with fracture development in the injection reservoir.

2.4.2 Periodic Monitoring

Over the two-year Stage IV program, time-lapse or periodic surveys are proposed:

- Induction resistivity (depending on the casing type) and neutron logs in the observation wells from surface to TD.
- Multicomponent surface seismic survey at the end of Stage IV to assess effectiveness of surface seismic surveys to monitor the CO_2 plume and detect any upward migration of the CO_2 into shallower zones.
- Walkaway VSP surveys at the end of Stage IV to monitor CO_2 plume behavior around the injection well.
- Time-lapse geochemical surveys from the observation wells to investigate plume migration and breakthrough, study rock-fluid interactions in the reservoir, and the geochemistry of fluids from the Wabamun Formation which overlies the caprock.
- Time-lapse geochemical surveys of shallow groundwater wells to monitor for changes in groundwater chemistry including CO_2 contents and dissolved carbon species.
- Time-lapse geophysical logging of the observation well closest to the injector to map the vertical distribution of CO_2 within the Nisku Formation and to indentify possible microchannel leakage paths through the well casing.
- Time-lapse INSAR surveys (recommended each year) to monitor surface strain resulting from pressure plume associated with CO_2 injection in the Niksu Formation.
- Differential GPS and microgravity surveys at fixed monuments every six months (four surveys in total) to monitor ground strain and subsurface density changes.
- Time-lapse soil, casing gas and flux accumulation surveys to monitor for CO_2 leakage into the vadose zone.
- Time-lapse atmospheric CO_2 monitoring surveys, particularly near existing wells in the Pilot site area.

2.5 Stage V

If the Pilot Project is successful then a full review of the monitoring programs conducted in Stage IV should be undertaken before the monitoring program for Stage V is designed. The review should include updating the geomechanical and geochemical models of the test site area and reservoir performance simulation to history match CO_2 breakthrough at the observation wells. Results of the review will indicate which monitoring programs should either be discontinued or enhanced for scale-up.

REFERENCES

Srivastava, R.D., Brown, B., Carr, T.R., Vikara, D., McIlvried, H., 2009, Monitoring, Verification and Accounting of CO_2 stored in deep geological formations: DOE/National Energy Technology Laboratory-311/081508, 132 pp.