- WHITE PAPER -

FEASIBILITY OF USING GEOLOGIC FORMATIONS TO SEQUESTER CARBON DIOXIDE (CO_2)

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August 2007

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INTRODUCTION

Carbon dioxide (CO_2) is the most common greenhouse gas found in the atmosphere. The burning of fossil fuels (coal, oil, natural gas) and other fuels (wood, solid waste, ethanol, and biodiesel) is what creates CO_2 emissions. The International Panel on Climate Change (IPCC) has found that CO_2 is a major contributor to global warming (also known as global climate change).

In 2007, Governor Christine Gregoire issued Executive Order 07-02 “Washington Climate Change Challenge” to declare the state’s commitment to address climate change. [1] The Climate Advisory Team along with Technical Work Groups are working to implement the goals outlined in the Executive Order. [2]

Following the Executive Order the Washington State Legislature passed Engrossed Substitute Senate Bill (ESSB) 6001 “Climate Change — Mitigating Impacts”. The new law requires:

- Ecology to develop recommendations on the best carbon capture methods that can be used in the state to achieve our greenhouse gas reduction goals.
- New power generation plants that produce 1,100 pounds or more of greenhouse gases per megawatt-hour to develop an economical and technically feasible carbon capture plan. The plants must implement their plans within five years of operation.
- The Department of Ecology (Ecology) and the Energy Facility Site Evaluation Council (EFSEC) to adopt rules by June 30, 2008. The new rules must include the criteria that Ecology will use to evaluate carbon capture plans. Ecology must also determine whether carbon capturing or a plan for capturing will provide safe, reliable, and permanent protection against the greenhouse gases entering the atmosphere from the power plant and all auxiliary facilities.

It is critical for Washington to implement a successful carbon capture and sequestration program to achieve our goals for reducing carbon emissions. The IPCC reports that using geological sequestration methods along with rules and monitoring programs is comparable to the risks of the current methods being used. [3] Therefore, this paper focuses on geological methods for sequestering CO_2 in Washington State. It does not discuss terrestrial sequestration methods or other CO_2 controls and capture technologies.

The Climate Advisory Team with support from the Technical Working Groups is considering terrestrial carbon sequestration methods related to forest and agriculture management, and other changes in land use that can reduce CO_2 emissions. Discussion on CO_2 controls and capture technologies will be outlined in a separate paper by Ecology.

Geologic sequestration of CO_2 means injecting carbon dioxide into deep underground geological formations for permanent disposal, instead of releasing it into the air. This is sometimes referred to as carbon capture and geologic storage or disposal.

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[1] http://www.governor.wa.gov/execorders/eo_07-02.pdf

[2] http://www.ecy.wa.gov/climatechange/cat_overview.htm

[3] IPCC Special report: Carbon Dioxide Capture and Storage, Summary for Policymakers, 2005

I. Geologic Sequestration for CO_2

CO_2 that is removed from the exhaust gases of power plants and industrial boilers and heaters must be sequestered in a location where it cannot escape into the atmosphere or interfere with human activities and the environment. Typically, this means injecting captured CO_2 into a suitable geologic formation that is deeper than 3,281 feet and where pressure and temperature are above the critical point for CO_2.

Criteria that should be considered when evaluating the potential of a geological formation for sequestering captured CO_2 are:

- Tectonic setting and kinds of rock in the geologic formation.
- Geothermal regime.
- Characteristics and flow rates of waters in the proposed geologic formation.
- Potential to develop oil and gas production wells and maturity of extraction in existing oil and gas fields.
- Economic aspects relating to access.
- Infrastructure and socio–political conditions.[4]

To date, most of the technology and research for geological CO_2 injection has been done in sedimentary basins because of the extensive amount of hydrocarbon exploration and production that has occurred.

Another geologic sequestration process that does not involve injection of CO_2 below ground involves the use of ultramafic (high iron and magnesium content) rocks. Ultramafic rocks are mined from the ground and reacted with CO_2. The reaction involves the conversion of silicate minerals to carbonate minerals. This chemical conversion results in a permanent capture of CO_2.

A number of criteria are available to define permanent geologic sequestration of CO_2. The simplest criterion is that the duration of sequestration must exceed the availability of the resource generating the CO_2 emissions.

Options for Sequestering CO_2

There are two options for CO_2 disposal, subsurface sequestration and above ground sequestration. The main methods for the subsurface sequestration of CO_2 (Figure 1) are saline aquifers, depleted oil and gas fields, coal, and basalt. The option for the above ground sequestration of CO_2 is reaction with ultramafic rocks.

[4] Bachu, 2000

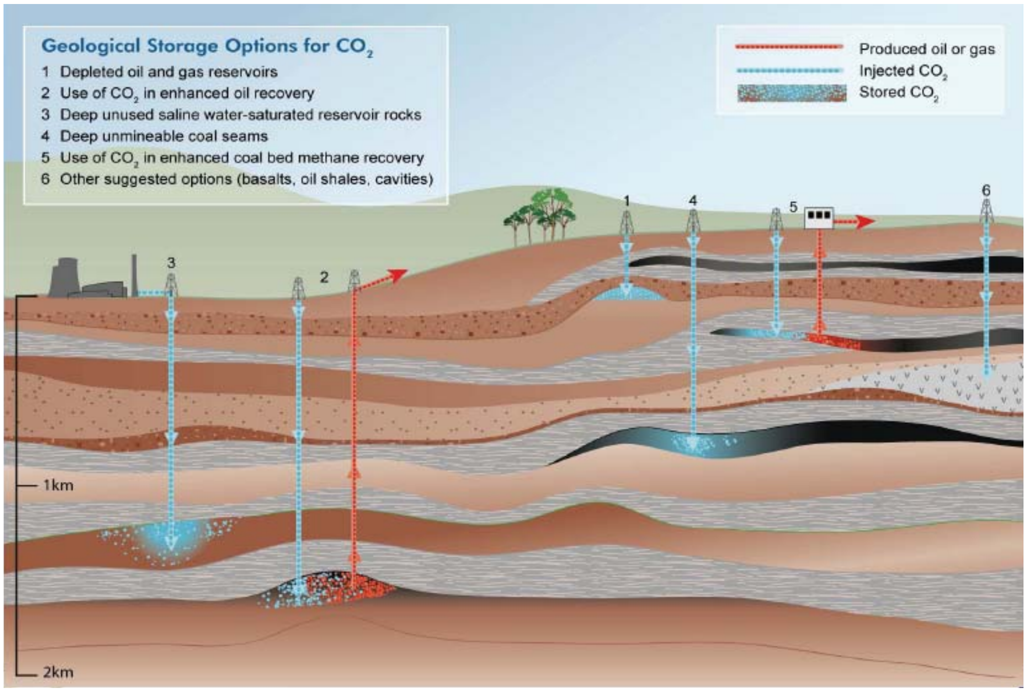

Figure 1: The main options for the subsurface sequestration of CO2.[5]

Subsurface Sequestration

Saline Aquifers

CO_2 can be sequestered in saline aquifers by injecting it into the pore spaces of the aquifer where it will replace or dissolve into the saline fluids. Saline waters contain high levels of salts and minerals that make the water unsuitable for drinking or irrigation.

When CO_2 is injected into a geologic formation that contains saline water, up to 29 percent will dissolve into the water initially. Under reservoir conditions, CO_2 is more buoyant compared to water so it tends to move upwards through the pore system of the aquifer. Once the maximum amount of CO_2 dissolves into the water, a process of migration and trapping begins. For liquid CO_2 sequestration to occur, it has to become trapped. The CO_2 that dissolves into the saline aquifer may react with the rocks within the geologic formation and form carbonate minerals which could allow for a much higher percentage of the CO_2 to dissolve into the formation water.

Little is known about deep saline aquifers or geological structures in Washington due to the lack of deep drilling. There have only been:

- Four water wells drilled deeper than 3,281 feet.
- Less than 20 wells drilled deeper than 2,624 feet.
- Less than 90 drilled deeper than1969 feet.

[5] IPCC and modified by BigSky Carbon Sequestration Partnership.

Most of the deeper wells have been drilled in eastern Washington.

Location of Washington saline aquifers are shown in figure 2.[6] The water that comes from the deeper aquifers in eastern Washington contains minerals that eliminate the ability to use them for domestic purposes and they reach such high temperatures that they cannot be used for irrigation. Therefore, there are few waters rights issues over the use of these aquifers for storing CO_2.[7]

Western Washington saline aquifers may not be prime candidates for storing CO_2 because of the increased risk of earthquakes, extensive faulting and fracturing, and their proximity to volcanoes. In other words, CO_2 injected into these aquifers and not chemically converted to carbonates may move out of the saline aquifers through faults back into the atmosphere. However, more characterization studies are needed to evaluate the actual geologic sequestration potential of the region west of the Cascades.

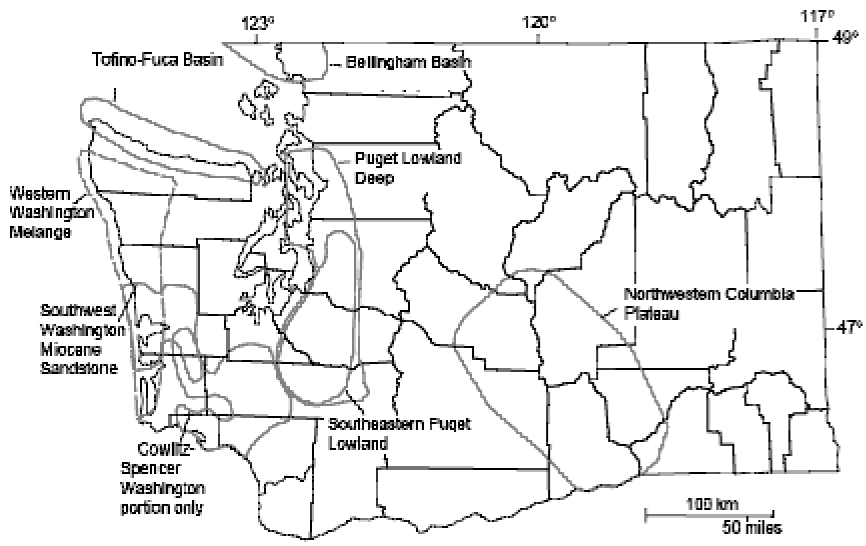

Figure 2: location of saline aquifers in Washington

Depleted Oil and Gas Fields

Oil and gas fields are natural underground traps for buoyant fluids and generally occur in porous and permeable sandstone and carbonate formations. In some areas of the world, oil and gas has been trapped for hundreds of thousands or millions of years and has not leaked. Therefore, these natural underground traps may make excellent reservoirs for CO_2 also.

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[6] Johnson and others, 1997

[7] Reidel and others, 2002

However, Washington has produced little oil and gas in the past and currently produces none. A small amount of oil (12,000 barrels) was produced in 1962 along the western edge of the Olympic Peninsula near Ocean City in Grays Harbor County. This was from a 4,140 foot deep well.[8] This area is not suitable for sequestering CO_2 because of the complex faulting and geology in the area.

Washington also produced a small amount of gas (1.3 billion cubic feet) from 1929 to 1941 from the Rattlesnake Hills Gas Field in eastern Washington. The gas was trapped in Columbia River basalt flows at depths between 700 and 1,300 feet.[9] This abandoned gas field is not suitable for storing CO_2 because it is too shallow. The ideal depth for injecting CO_2 should be more than 3,281 feet.

Little is known about the deep basins in Washington that might be used to sequester CO_2 because there has not been very much exploration for oil and gas in the state. Frequently gas is detected in wells but it is limited and has not been proven cost effective.

There have been only 216 wells drilled for oil and gas purposes that were deeper than 2,624 feet for the entire state. Of that number, only 11 wells, drilled in the Columbia Basin, were deeper than 5,500 feet. This gives a very incomplete understanding of our deeper geology, so more work and deeper drilling must be done to determine sequestration potential. The deep sediments below the Columbia River basalts in Eastern Washington that are targets for natural gas may also be the most promising sequestration target in the state. The sediments themselves may have significant sequestration potential with the basalts overlying them acting as a reactive barrier.

Coal

Washington has large coal deposits (Figure 3) mostly in areas along the western foothills of the Cascade Mountains.[10] The coal deposits are found in a discontinuous string of fields from near the Canadian border on the north, to the South near Longview in Cowlitz County and the Columbia River. Other large deposits are found on the eastern flanks of the Cascade Range near Roslyn in Kittitas County.

Deep coal beds can be significant reservoirs for natural gas and may be used for storing CO_2 also. Unfortunately little is known about Washington's deep coal deposits, but there is ongoing exploration for coal bed methane with 35 holes drilled recently and more planned. Before we can use Washington coal beds to sequester CO_2 we will need to learn more about the deeper coals thicknesses, continuity, capping formations, and permeability. The areas that have been mined are too shallow to use for storing CO_2. Currently, the West Coast Regional Carbon Sequestration Partnership (WESTCARB) and TransAlta are investigating the deeper coal beds in the Centralia area for the potential to sequester CO_2.

[8] McFarland, 1983

[9] McFarland, 1983

[10] Schasse, 2003

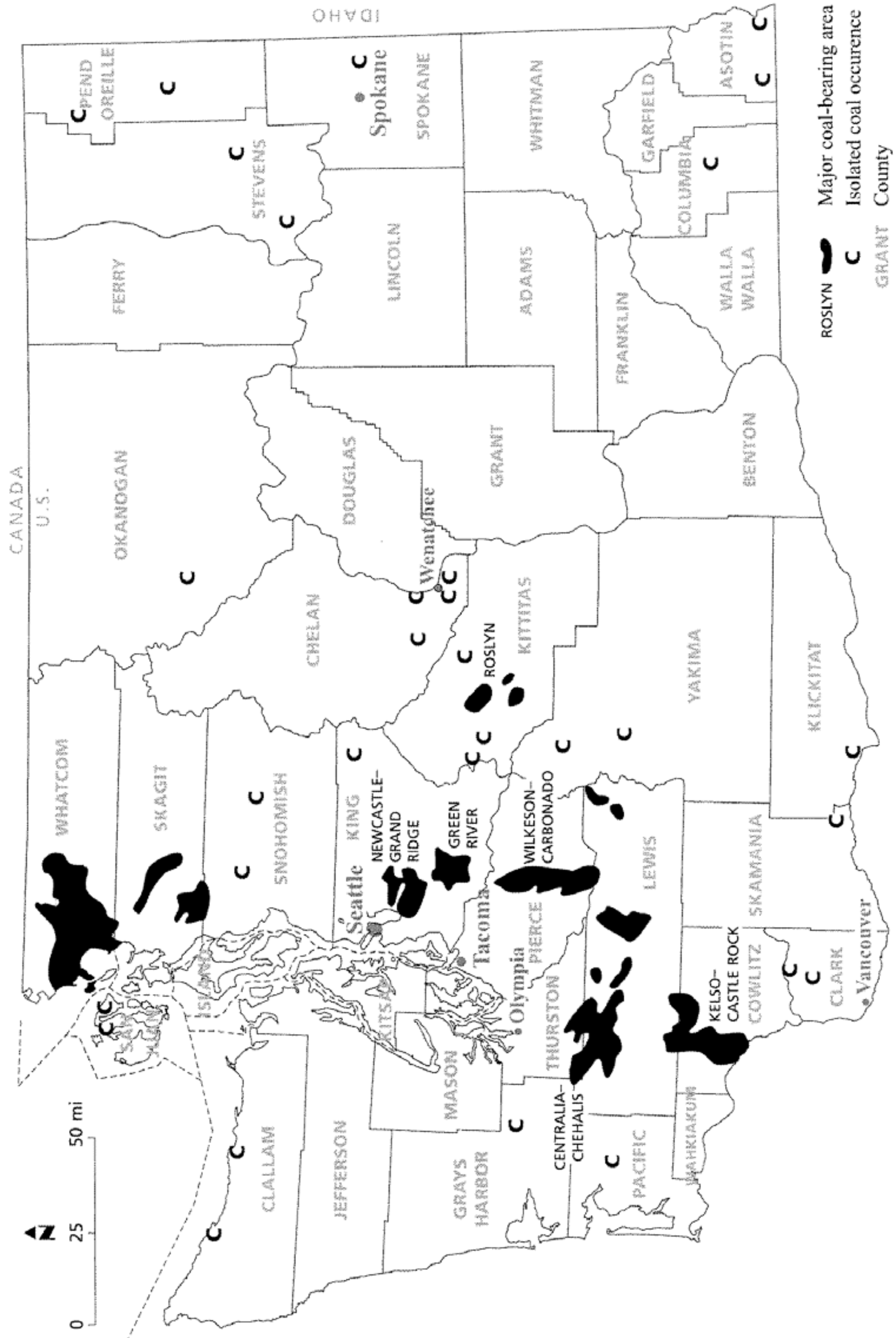

Figure 3: Coal-bearing areas of Washington

Basalt

Basalt is a volcanic rock found in many areas in eastern Washington. These areas have the potential to sequester CO_2 because CO_2 will react with the minerals to create stable carbonates. Using basalt flows to sequester CO_2 is a very different approach than the previous methods. Rather than sequestering it in a reservoir, this method relies on the reaction of the CO_2 with the calcium, iron, and magnesium silicate minerals in the basalt to form stable carbonate minerals. CO_2 is therefore more permanently stored (in terms of "geological" time).

In eastern Washington, some basalt formations appear to have the necessary characteristics of extent, capacity, permeability, and permanency to support geologic sequestration of CO_2. Figure 4 shows areas that are most favorable for natural gas storage in Columbia River Basalt Group lava flows.[11] Reidel and others (2002) concluded that the same areas were also candidates for sequestering CO_2.

There has been extensive drilling of the Columbia River basalts in the Hanford area. A systematic and quantitative evaluation of basalts as potential geologic sequestration for carbon dioxide has not been developed. [12] Currently, Pacific North West Labs and the Big Sky Carbon Sequestration Partnership are proposing to demonstrate the potential to sequester CO2 underground in eastern Washington.

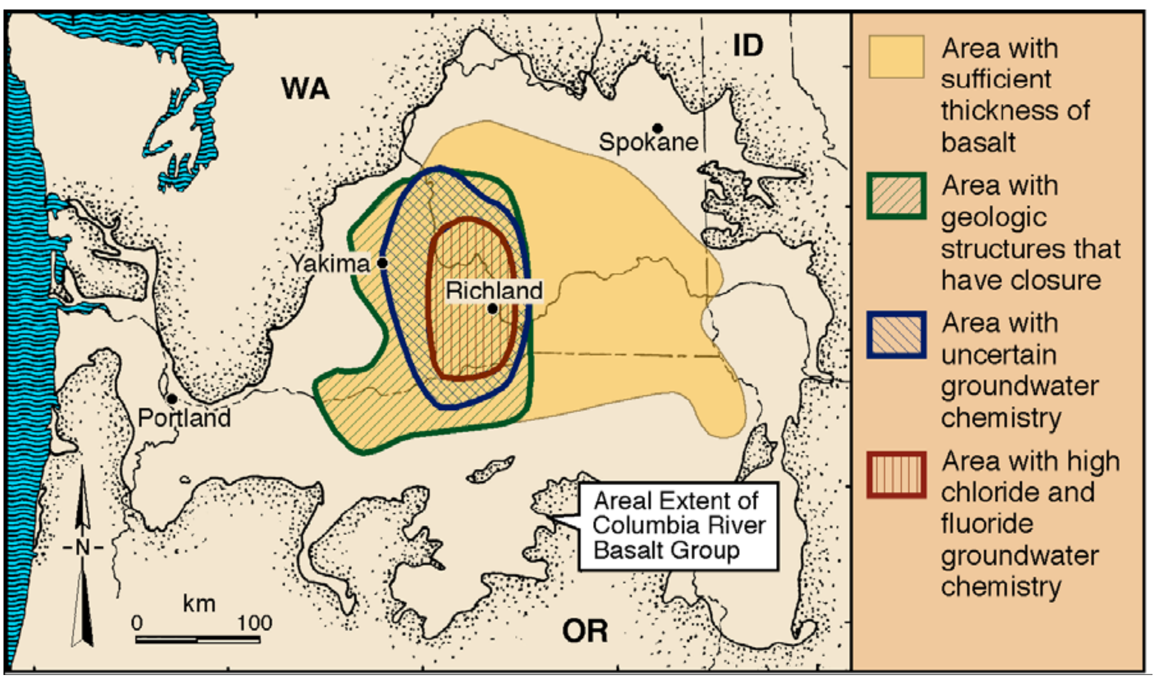

Figure 4: Most favorable areas that may be suitable to sequester CO2.

[11] Reidel and others (2002)

[12] McGrail, 2006

Surface Sequestration

Ultramafic rocks

Using ultramafic rocks to sequester CO_2 is similar to using basalts because it relies on a chemical reaction between CO_2 and magnesium rich silicate minerals to form stable carbonates (carbonation). Injecting CO_2 underground into ultramafic rocks is not feasible because these types of rocks are not very porous or permeable. Therefore, it is necessary to mine the ultramafic rocks such as olivine or serpentine and transport them to a facility where the chemical reaction process can take place.

The good thing about this technique is that it sequesters the CO_2 permanently (in terms of "geological" time). The downside is that it takes 2 to 2.6 tons of ultramafic rocks to bind 1 ton of CO_2.[13] Since the CO_2 emissions are huge in amount, using this technique will require mining on a very large scale.

Washington has abundant deposits of ultramafic rocks such as the Twin Sisters mountains located in the North Cascades of Washington. There is enough material in the Twin Sisters alone to get rid of 19 years of U.S. CO_2 emissions and ~5 years of global emissions. However, open pit mining on such a scale would have significant environmental impacts, be more expensive, and very labor intensive. Disposal of the resulting carbonate mineral would be equally daunting since you would have a greater volume of material than you started with.[14]

II. Risk Management

There is little experience with geologic sequestration of CO_2; but, experience and scientific knowledge gained from the oil and gas industry can help develop risk management strategies for CO_2. Key components of a risk management strategy for geologic sequestration of CO_2 include:

- Appropriate site selection based on thorough geologic characterization.
- A monitoring program to detect problems during or after injection.
- Appropriate remediation measures, if necessary.
- A regulatory system to protect human health and the environment.
- Determine an acceptable leakage standard.

Potential Risks

After CO_2 is injected and sequestered into geologic formations there is the potential for it to migrate or leak from the targeted formation into shallower aquifers degrading ground water quality or into the air. Ground water quality is degraded either by CO_2 leaking directly into an

[13] Goff and Lackner (1998)

[14] (Goff and Lackner, 1998)

aquifer or by the displacement of saline ground water from the deep target aquifer into a shallower aquifer used for irrigation or drinking water supplies.

These risks can be managed with thorough site characterization that includes:

- Identifying the most promising geologic formations.
- Identifying low permeable caprock or other mechanisms for retention.
- Detecting potential pathways for leaks.
- Conduct flow and transport modeling.

In addition to careful site selection, a monitoring program will ensure that CO_2 does not escape from the sequestration site. A monitoring system must be able to detect the movement of CO_2 into shallower ground water.

III. Existing Rules and Permits that Cover CO_2 Sequestration Projects

Rules

Ecology has the authority to regulate CO_2 sequestration projects through the following rules:

- Chapter 173-218 WAC, Underground Injection Control (UIC) Program - Regulates the injection of fluid, including gas, but there are no specific standards for CO_2 injection in the rule.
- Chapter 173-216 WAC, State Waste Discharge Permit Program - Requires permits for any discharge of polluting materials into waters of the state, including ground water, and requires compliance with WAC 173-200. Carbon dioxide injection is a discharge of polluting materials.
- Chapter 173-200 WAC, Water Quality Standards for Ground Waters - Requires the protection of the existing quality of all ground water. Ecology can require geologic characterization and monitoring under this rule.

State Waste Discharge Permit

A state waste discharge permit is a permit required for geologic sequestration of CO_2 in Washington State. All permits issued for a CO_2 sequestration project will include site-specific requirements depending on the scope of the proposed project and the site geology. Permit applicants may also be required to meet the conditions below:

- Adequate well construction to ensure the CO_2 reaches the target geologic formation.
- Geologic investigations that indicate the injected CO_2 will stay in the target geologic formation.
- A monitoring program designed to identify movement of sequestered CO_2 beyond the target formation.

As stated earlier, the current rules do not include specific standards for approving permits for these types of projects. Therefore, there is the potential that people will appeal the permits issued for geologic sequestration projects. Also, the state waste discharge permit rules do not address the following:

- Requirements for project closure and post closure monitoring.
- Requirements for mitigation if a CO_2 injection project leaks or fails to perform as expected.

All state waste discharge permits issued for these projects will also include conditions that ensure the project meets the ground water quality standards of WAC 173-200. The permit will include specific well construction standards that are stricter than the current ones outlined in WAC 173-160, Minimum Standards for Construction and Maintenance of Wells. The standards under WAC 173-160 are designed for water wells and environmental monitoring wells and not for wells used for CO_2 injection.

CO_2 injection wells must withstand high injection pressures and reactive fluids. The standards for injection wells must address how deep they are and the risks involved in using them. A routine testing program should be required to ensure that the integrity of the well's casing remains intact through the lifetime of the injection project.

IV. Improving Rules and Technical Guidance for CO_2 Sequestration Projects

In response to the Climate Change –Mitigating Impacts Act (ESSB 6001) Ecology will establish clear rules for CO_2 injection projects with the help of a technical workgroup that consists of interested industry, regulators, and citizens. They will define the issues, develop the direction, and propose improvements to current rules for geologic CO_2 injection projects. The workgroup would need to consider the following:

UIC standards - Ecology has started the process to amend WAC 173-218 to establish specific UIC standards for CO_2 sequestration projects that will provide a clear road map of the requirements to project proponents and citizens.

Well construction - Because wells used for injecting CO_2, are more like oil and gas wells (regulated by Department of Natural Resources (DNR)). Ecology will work with the DNR to develop the requirements for well construction design and operations. These requirements will be stricter than WAC 173-160 and could be included in individual state waste discharge permit conditions or the amended UIC rules.

Guidance - Develop guidance documents for CO_2 geologic sequestration projects that outline the geologic characterization and monitoring necessary to approve state waste discharge permits.

Formalizing Ecology and DNR working relationship - Ecology and DNR will formally define their working relationship on CO_2 storage projects. This agreement could be in the form of a memorandum of understanding between the two agencies.

V. Conclusion

Currently, geological sequestration of CO_2 represents the only large scale solution in Washington for reducing the greenhouse gases that contribute to global warming. There are several efforts underway to evaluate the feasibility of using this technology. These efforts may provide useful information as the state develops the rules and technical guidance that will ensure we protect our underground sources of drinking water while we are reducing our contribution to greenhouse gases.

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