FREQUENTLY ASKED QUESTIONS ABOUT CARBON SEQUESTRATION AND EARTHQUAKES

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Q. What is Carbon Sequestration?
A. Carbon sequestration is a key technology to reduce greenhouse gas emissions and climate change impacts. The process takes carbon dioxide (CO_2) from a fossil energy power plant or large emission source, compresses the CO_2 to a near liquid state, transports it via pipeline to a site where it is injected deep underground. The deep geological formations that receive and hold CO_2 are far below fresh water aquifers and below an impermeable cap rock or seal. Ideal geological formations for sequestration include depleted oil and gas fields, where oil and gas has been sequestered naturally for millions of years. For the most part, sequestration involves putting CO_2 back into the same formations formerly occupied by oil and gas before they were extracted, more than half a mile below the earth's surface.

Q. What causes earthquakes to occur?
A. Slow movement deep in the Earth causes stresses to build up within its brittle outer crust. An earthquake occurs when the stress that has accumulated over perhaps hundreds to thousands of years is relieved in a few seconds by causing failure and slip on a fault. A fault is a narrow zone of weakness within the crust. Friction prevents slip along this zone until the crustal stress exceeds its frictional strength. The crust is composed of a mosaic of tectonic plates, and earthquakes occur most frequently along the giant fault zones - such as the San Andreas fault system in California - that form the boundaries of the plates. Earthquakes also occur within plate interiors, but generally at a much lower rate. The size of an earthquake, measured by the Richter magnitude scale, depends on the size of the fault break. For example, the1906 magnitude 7.8 San Francisco earthquake broke about 300 miles of the San Andreas fault, whereas a magnitude 4 earthquake would break a fault patch only about 500 yards long (magnitude 3 earthquakes or less often are not felt at the surface). The largest earthquake that can occur in a particular region is therefore limited by the maximum length of the faults there, but there is no lower limit to earthquake size. On average, in a particular region, earthquakes of a given magnitude occur about 10 times less frequently than earthquakes one magnitude unit smaller. For example, if a magnitude 7 earthquake occurs in a plate boundary region every 200 years, then we would expect a magnitude 6 about every 20 years, a magnitude 5 every 2 years, and 5,000 magnitude 1 earthquakes per year.

Q. Can human activity cause earthquakes to occur?
A. Yes. Human activity such as building dams, mining, nuclear weapons testing, oil and gas extraction, and fluid injection can induce seismic events. These activities can change the stress within the crust and cause slip along faults. Earthquakes induced by fluid injection are caused by increasing the fluid pressure at depth. This lowers the frictional resistance on faults and may cause them to slip under the existing stress loading, which would normally be too low to cause failure. Deformation of a pressurized reservoir can also induce stresses in the surrounding rock that add to the existing stress loading on faults or fractures causing them to slip (commonly, these faults are small). Like naturally-occurring (tectonic) earthquakes, the vast majority of induced earthquakes are much too small (less than magnitude 3) to be felt or to cause damage, and can be detected only by sensitive instruments. On rare occasions, however, fluid injection has induced moderate (magnitude 3.5 to 5.5) felt earthquakes that in a few cases have caused damage. Most of these cases have been studied in detail, and shown to be due to circumstances that can be avoided through proper site selection and injection design and operation.

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The oil and gas industry has injected billions of tons of water, gas, and CO_2 in to the Earth's crust over the decades to enhance oil production, for natural gas storage, or for environmental management. This experience has taught that the level of seismic activity induced by fluid injection can be limited and controlled, and that earthquakes large enough to have adverse consequences can be prevented altogether. A few key steps are critical:

- First of all, detailed geological and tectonic characterization of a potential injection field and the surrounding region is essential. This enables operators to determine the existing stress conditions in the crust and to locate and characterize active and potentially active faults and fracture zones.
- Injection wells must be located to avoid fault zones which show a high potential for failure and slip. Injection operations should be carefully designed to keep fluid pressures low enough to avoid adverse events.
- Large injection operations should be carefully monitored. A variety of hydrological and geophysical techniques, including downhole pressure measurements and sensitive seismic instruments exist to detect and characterize small microearthquakes and stress changes. Continuous monitoring during and after injection allows operators to make timely adjustments that can mitigate potential problems and improve site performance.

Q. Why should we put fluids underground?
A. The energy industry, including oil, gas, and power companies, has been injecting fluids such as water, steam, CO_2 and nitrogen for many decades. Some of this injection goes into oil and gas fields to increase production, a process known as Enhanced Oil Recovery (EOR). In addition, injection is used to prevent ground subsidence due to oil and gas withdrawal and to avoid discharge of produced brines at the surface. Other fluids such as natural gas are injected underground for storage for use during peak power demand periods. The purpose of sequestering CO_2 underground permanently is to prevent CO_2 from entering the atmosphere and thereby contributing to global climate change. CO_2 stripped from oil or gas as it is pumped out can be injected back into depleted section of the reservoir, serving both to store the CO_2 and to enhance recovery of the remaining oil or gas.

Q. What happens to sequestered CO_2 during an earthquake: Can it escape quickly?
A. Once in the deep formations, CO_2 stays in a liquid (supercritical) state due to high pressure. CO_2 in this state is trapped in the very small (less than 1 millimeter) pore spaces between the grains of rock that make up underground reservoir formations. An overlying impermeable layer of "cap rock" serves as a barrier to prevent CO_2 from escaping.

Even in highly active region like California the vast bulk of the original oil and gas reserves has remained in place over millions of years through many earthquake cycles. As an example, the Elk Hills oilfield currently holds gas volumes roughly ten times larger than the proposed CO_2 injection volume at that site. Except for an earthquake that involves fault slip actually within the overburden, the rock deforms elastically during an earthquake so that its integrity is not compromised. For example, monitoring of the sequestration site in Nagaoka, Japan revealed no evidence for leakage following a recent magnitude 6.8 earthquake 14 miles from the site. The small potential for slip (tectonic or induced) on faults in the overburden to create leakage pathways to the surface can be minimized by careful siting and operational design.

The most likely potential CO_2 leakage paths would be injection wells. However, these are carefully designed to prevent leakage.

Q. How does an earthquake affect oil and gas production wells and injection wells?
A. Modern wells are designed to withstand seismic deformations. They are constructed from flexible steel casing designed to deform but not rupture from distortions much larger than those caused by the passage of seismic waves from earthquakes except very close to the earthquake source. Several oil and gas fields throughout Southern California and the San Joaquin basin have experienced major nearby earthquakes with relatively few problems. For example, only 14 of 1,725 active wells within the oilfields close to the 1983 magnitude 6.8 Coalinga earthquake suffered collapsed or parted well casings.

Q. Can oil wells be repaired after an earthquake?
A. In some cases, damaged oil wells can be recompleted (repaired) and reused even after a large earthquake. In other cases, the well cannot be repaired, but can be plugged (sealed). It is common to plug or recomplete wells that have failed due to crustal deformation, and there are many companies in the US and abroad who are experienced in recompleting wells in seismically active regions.

Q. At what depth in the earth's crust do tectonic earthquakes occur and how far is this from where CO_2 will be injected?
A. Most moderate or large tectonic earthquakes nucleate many miles beneath the Earth's surface. Major earthquakes (magnitude 6 and above) in California, for example, occur primarily in strong, brittle basement rock at depths on the order of 6 miles or more (although very small earthquakes occur at depths as shallow as 2 miles). Earthquakes in other some regions on Earth can occur at much greater depths. The oil and gas reservoirs to be used for CO_2 sequestration projects are typically located at depths less than 15,000 feet (3 miles) and no injection is made into basement rocks, which generally have low permeability. Since the strength of seismic waves decreases with distance, the large vertical separations between the sources of significant earthquakes and injection reservoirs is a major factor preventing well damage. In-depth research (notably into the 1983 Coalinga earthquake) indicates that it is highly unlikely that fluid injection or extraction can trigger major tectonic earthquakes.

Q. What threat does sequestered CO_2 pose to humans and the environment, especially in regards to an earthquake?
A. CO_2 is a non-toxic, non-flammable and otherwise harmless gas that we breathe in and out every day. It is a basic compound that sustains life on Earth by nourishing plant life by photosynthesis. Food grade CO_2 is found in carbonated drinks and is used in flash-freezing . The only direct risk of harm from CO_2 is when a high concentration resulting from inadequate ventilation displaces oxygen and causes asphyxiation.

In recorded history there have been rare, natural occurrences of rapid, high volume releases of CO_2 due to volcanic activity and volcanic lake processes that have harmed plants, animals, and people. However, the circumstances under which these releases occurred are quite different from those of industrial carbon sequestration. Commercial carbon sequestration sites are selected on the basis of careful study, and by design lack pathways that can bring CO2 quickly to the surface. Sequestration sites are also subject to extensive monitoring and oversight. Therefore, a large, threatening release of CO_2 is extremely unlikely and in many cases demonstrably not possible.

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