Health, safety, and environmental risks from energy production:

A year-long reality check

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Abstract

Large-scale carbon dioxide capture and storage (CCS) offers the benefit of reducing CO₂ emissions and thereby mitigating climate change risk, but it will also bring its own health, safety, and environmental risks. Curtis M. Oldenburg, Editor-in-Chief, considers these risks in the context of the broader picture of energy production.

Over the last year, there have been major acute health, safety, and environmental (HSE) consequences related to accidents involving energy production from every major primary energy source. These are, in chronological order: (i) the Upper Big Branch (coal) Mine disaster, (ii) the Gulf of Mexico Macondo (oil) well blowout, (iii) the San Bruno (natural gas) pipeline leak and explosion, and (iv) the Fukushima (nuclear) reactor radioactivity releases.

Briefly, the Upper Big Branch Mine disaster occurred in West Virginia on April 5, 2010, when natural methane in the mine ignited, causing the deaths of 29 miners, the worst coal mine disaster in the USA since 1970.

Fifteen days later, the Macondo oil well in the Gulf of Mexico suffered a blowout, with a gas explosion and fire on the floating drilling platform that killed 11 people. The oil and gas continued to flow out of the well at the seafloor until July 15, 2010, spilling a total of approximately 5 million barrels of oil into the sea.

On September 9, 2010, a 30-inch (76-cm) buried, steel, natural gas pipeline in San Bruno, California, leaked gas and exploded in a residential neighborhood, killing 8 people in their homes and burning a total of 38 homes. Flames were up to 1000 ft (300 m) high, and the initial explosion itself reportedly measured 1.1 on the Richter scale.

Finally, on March 11, 2011, a magnitude 9.0 earthquake off the coast of Japan's main island, Honshu, caused a tsunami that crippled the backup power and associated cooling systems for six reactor cores and their spent fuel storage tanks at the Fukushima nuclear power plant. At time of

writing, workers trying to bring the crisis under control have been exposed to dangerous levels of radiation, and radioactive water and particulates have been released to the sea and atmosphere.

These four disasters, all of which occurred within the past 12 months, were not unprecedented; similar events differing only in detail have happened around the world before, and such events will occur again. Today, developed nations primarily use fossil fuels to create affordable energy for comforts such as lighting, heating and air-conditioning, refrigeration, transportation, education, and entertainment, as well as for powering manufacturing, which creates jobs and a wealth of material goods. In addition to the risks of the existing energy infrastructure that have become obvious through these recent disasters, there is also the ongoing risk of climate change that comes from the vast emissions of greenhouse gases, primarily CO₂, from the burning of fossil fuels.

The implementation of CO₂ capture and storage (CCS) will help mitigate CO₂ emissions from fossil fuel energy, but it also carries with it HSE risks. In my personal interactions with the public and with students, the main concern voiced is whether CO₂ could leak out of the deep reservoirs into which it is injected and rise up out of the ground, smothering people and animals at the ground surface. Another concern expressed is that CO₂ pipelines could fail and cause similar gaseous plumes of CO₂. The widespread concerns about CO₂ leaking out over the ground surface may be inspired by events that have happened within natural systems in equatorial Africa, in Indonesia, and in Italy.¹ Researchers have been investigating a wide variety of HSE risks of geologic CO₂ storage for some time² and have determined that wells are the main potential pathways for significant leakage from the deep subsurface.³ Below, I discuss the acute HSE risks of CO₂ leakage through wells and from pipelines, and compare the behavior of failures in CO₂ wells and pipelines with oil and gas analogues from which most of our experience derives.

Risk terminology

In the context of this discussion, risk (R) is calculated by multiplying the likelihood (L) of a given failure scenario by its consequences (C) ($R = L \times C$). By this definition, high-probability

events with small consequences may have the same level of risk as much lower probability events that have much greater consequences. Consequences can be divided into acute and chronic, where acute consequences are those that result in immediate or emergency situations involving the safety of individuals, and chronic consequences are those that may still be very serious but that occur over longer time frames. The Upper Big Branch Mine disaster and the San Bruno natural gas pipeline explosion were examples of acute consequences that caused multiple fatalities. The Macondo well blowout and Fukushima nuclear power plant meltdown disasters have both acute and chronic consequences.

CCS geologic storage and transportation infrastructure

The large-scale implementation of CCS at a level that will make a difference in mitigating fossil-fuel CO₂ emissions will involve a new infrastructure of wells and pipelines of the same approximate scale as that serving today's oil and gas industry.⁴ At this scale, thousands of deep CO₂ injection wells may be in operation, and hundreds of thousands of miles of CO₂ pipelines may be in use. Despite rigorous safety standards, high-quality materials, and monitoring and inspection protocols, failures of wells and pipelines are inevitable. Among the many causes of failures are human (operator) error, intentional disruptions and accidents, natural disasters such as earthquakes, and flaws in materials or control systems.

CO₂ storage infrastructure failure

So what could the hypothetical geologic CO₂ storage accidents of the future look like? We do not have to rely solely on speculation to address this question, since both CO₂ well blowouts and CO₂ pipeline accidents have happened in the past.⁵

CO₂ well blowout

A blowout is defined as any uncontrolled upward flow of reservoir fluid in the well. In general, deep wells drilled for CO₂ injection or monitoring must be carefully managed to avoid blowouts. The reason for this susceptibility to blowout is that like oil and gas, CO₂ in the formation may be at hydrostatic or higher pressure, whereas the pressure contributed by the column of CO₂ in the wellbore itself is less than hydrostatic because CO₂ is not as dense as water. During drilling, heavy drilling fluids (so-called muds) are used to achieve whatever bottom-hole pressure is desired to control the upward flow of formation fluids. And blowout preventers (BOPs) are installed on finished wells to avoid blowouts. In general, new and improved technology have made blowouts of all kinds very rare today,⁶ although disasters still can occur for a variety of reasons, as evidenced by the Macondo well.

A CO₂ well blowout occurred in 1982, at Sheep Mountain, Colorado.⁷ Sheep Mountain is a large, natural CO₂ reservoir that provides CO₂ for enhanced oil recovery. Over the course of the 17 days of the blowout before engineers could kill the well, CO₂ flowed freely out of the well and out of fissures in the ground. Grapefruit-sized chunks of dry ice, formed by Joule-Thomson cooling, were thrown high into the air by the pressure of the release. The energy of the discharge tended to disperse the CO₂ gas, and there were no reports of hazardous accumulations of CO₂ gas near the ground. Because CO₂ is not flammable, there was also no hazard from fire or explosion.

This example at Sheep Mountain provides a close analogue of what a CO₂ blowout from a geologic CO₂ storage site might look like. In short, a CO₂ blowout would be a rapid, uncontrolled release most likely with enough energy to dissipate the CO₂ cloud above the ground surface, with no chance of causing a fire or explosion. Acute health and safety hazards would include loud noise from the rapidly discharging gas and possible local projectiles of dry ice. It would be possible (but not likely) for high concentrations of CO₂ to accumulate in topographic depressions and present an inhalation hazard (e.g. during the sublimation of a dry-ice bank), but only under enclosed conditions with little or no wind.⁸

CO₂ pipeline leakage

Rapid discharge of CO₂ from an above-ground pipeline or one in the shallow subsurface would outwardly resemble a CO₂ well blowout insofar as both involve rapid depressurization and high flow rates of CO₂ with potential for dry ice to form. The main difference is that a pipeline has emergency shut-off valves located at intervals along its route, which means the flow would be stopped upon activation of the valves. Nevertheless, noise and blowing chunks of dry ice are a hazard as long as the leak occurs. As in the well blowout, the energy associated with the discharge tends to enhance dispersion of the leaking CO₂.⁹ In contrast to a natural gas pipeline, there would be no hazard that the leaking CO₂ would catch on fire or explode, because CO₂ is not flammable – in fact it is commonly used as a fire suppressant.

Closing thoughts

As much effort as is spent trying to minimize HSE risk related to the world's existing energy infrastructure, there will always be the chance of failure. Large-scale CCS offers the benefit of reducing CO₂ emissions and thereby mitigating climate change risk, but it will also bring its own HSE risk. The fact that CO₂ is not flammable decreases the acute HSE risks associated with geologic CO₂ storage relative to the analogous infrastructure for the oil and gas industry (i.e. wells and pipelines). Furthermore, because CO₂ is a gas at ambient conditions, it will tend to mix with the atmosphere and dissipate, and not pose a chronic HSE hazard, assuming the source of leakage is stopped.

Large-scale CO₂ discharge by well blowouts and pipeline leakage are not the only HSE risks associated with CCS. Research is ongoing to evaluate consequences of CO₂ and brine migrating into groundwater resources, and to evaluate the likelihood and consequence of CO₂ injection causing induced seismicity, a well-known consequence of fluid injection. These research efforts need to be expanded and accelerated to fully evaluate the risks and benefits of large-scale CCS, including long-term risks.

Arguably, the biggest long-term risk to global HSE is the vast climate change experiment we are at present carrying out through unmitigated emissions of greenhouse gases into the atmosphere from burning fossil fuels. Mitigating climate change risk through implementation of CCS entails some level of HSE risk, but recent experience points to the CCS risks being much less than the acute risks we assume today that are associated with fossil fuel and nuclear energy production.

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