The problem is clear. There is too much carbon dioxide in the atmosphere, and every year people produce more. The gas traps the sun's heat, helping to keep our planet warm. But too much of a good thing may wreak havoc on the global climate.

World leaders agree that we need to reduce CO₂ emissions or face extreme consequences. But most CO₂ emissions come from burning fossil fuels, and the likelihood that people will drastically cut their energy use or rapidly switch to alternative fuels is slim.

"You hear an awful lot about developing alternative energy sources. But the energy infrastructure of the world is heavily reliant on fossil fuels," says Michael McKelvy, an ASU research scientist with the Center for Solid State Science (CSSS). "Currently, about 85 percent of worldwide energy comes from fossil fuels. It will be difficult to substantially replace those with alternative sources anytime soon."

Imagine if we could take all that waste CO₂ and simply throw it away. What if we could catch it, imprison it in stone, and put it back in the ground from whence it came?

The ASU Carbon Sequestration Research Team is working to make that fantasy a reality. Team members combine extensive experience in chemistry, physics, geology, mineralogy, and electron microscopy. They also know multiphase fluid flow modeling. CSSS research scientist Andrew Chizmeshya leads the computer modeling effort.

Turning CO₂ into stone is one of several potential “sequestration” technologies. The idea is to store carbon harmlessly so it cannot enter the atmosphere and contribute to the greenhouse effect.

Carbon is sequestered naturally in many forms. For instance, it is stored in trees and in deposits of fossil fuels such as coal and oil. When people burn fossil fuels, or deplete old forests, that carbon is released into the atmosphere as CO₂.

Scientists are looking at ways to sequester carbon ourselves. Some are exploring methods to pump CO₂ underground into current or abandoned oil and gas wells as well as deep saline aquifers. However, this method only works if those repositories remain sealed. Other researchers are examining ocean sequestration—storing CO₂ at the bottom of the ocean or distributing it throughout the waters. Unfortunately, no one knows how this method will impact the ocean environment.

“Our efforts are novel. We want to dispose of the CO₂ as carbonate minerals,” says McKelvy. Carbon dioxide would be collected from a power plant and separated from other waste materials. The CO₂ then would be put through a chemical reaction with serpentine or olivine, two common minerals. The reactions would form the compounds magnesite and silica.

Magnesite is widely present in nature and is similar to the limestone found in the Grand Canyon. Silica is the sand used in glassmaking. Some of this end material could be put to practical use, but not all of it, McKelvy says. Where would all that rock go?

Right back into the ground.

"Practically speaking, you'd reclaim the [olivine or serpentine] mine as well as coal mines by putting minerals back into the ground," says Chizmeshya. "The beauty of the process is that you end up with environmentally benign materials known to be stable on a geologic timescale. The important research question is can the process be made economically viable?"

So far the answer to that question has always been "no."

Scientists at other institutions have figured out how to activate, or pretreat, serpentine and olivine so they will react quickly with CO₂. The pretreated mineral is placed in a solution of water, sodium chloride, and sodium bicarbonate. Then it is reacted with CO₂ at a high temperature. This method allows for 80 percent carbonation in less than an hour.

"These are the type of reaction conditions that could be economically viable. But the current pretreatment process is too expensive for the process to be cost competitive," says McKelvy. The minerals are pretreated through heating or intense grinding. McKelvy says these methods are too energy-intensive for practical use.

The ASU Carbon Sequestration Research Team is working to develop new activation processes and modified carbonation techniques to reduce cost. To do this, they are studying the carbonation process on the atomic level. They integrate in-situ experiments with advanced computational modeling.

For example, the team is studying a promising alternative to pretreating olivine. The researchers discovered that as olivine reacts with CO₂, it forms a hard coating, kind of like the candy shell surrounding an M&M chocolate. This coating drastically slows the reaction.

Pretreating the olivine prevents the formation of this coating, but it is too expensive. Instead, the researchers will explore ways to help break up the coating as the reaction occurs.
The beauty of the process is that you end up with environmentally benign materials known to be stable on a geologic timescale.
“Our research is really on the border of fundamental and applied science. Our focus is on fundamental research that has practical benefits for society,” says McKelvy.

The scientists use a variety of techniques to study carbonation, making heavy use of the facilities at the Goldwater Center for Science and Engineering and the Center for High-Resolution Electron Microscopy in CSSS. The group has also developed a unique patent-pending microreactor, which is providing the first real-time observations of the carbonation process.

The device is basically a tiny (1/10 ml) reaction cell with windows. It can produce temperatures up to 400 degrees Celsius, and pressures up to 300 atmospheres. ASU is collaborating with the Advanced Photon Source (APS) at Argonne National Laboratories to study the precise mechanisms that govern carbonation using this reactor. To date, the researchers have conducted X-ray synchrotron studies of carbonation using the GeoSoilEnviroCARS beamline at APS. They are currently using X-ray diffraction to explore the mineral carbonation process as it occurs.

“The cell can be adapted to work with several techniques,” explains McKelvy. “It allows us to explore the solid-fluid reaction while observing the CO₂-rich fluid in intimate contact with the aqueous phase.”

If the scientists can economize the carbonation process, they will have a promising method for large-scale CO₂ disposal. Olivine and serpentine are readily available in huge quantities.

“Global olivine reserves can carbonate a substantial amount of the CO₂ that could be generated from known coal reserves. Serpentine could cover all of it,” says Chizmeshya.

Mining, milling, and transporting the minerals would carry a cost, of course. Fortunately, serpentine and olivine mines already exist. The minerals cost about $5 per ton to mine and mill. The materials are found all over the world, which can help keep transportation costs low.

“Ideally, the mine and the power plant would be in close proximity,” says Chizmeshya. CO₂ could be shipped to the reaction plant via pipeline, the same way gas is transported.

Mineral sequestration may offer side benefits, as well. For example, it could help eliminate other dangerous substances. Asbestos is a form of serpentine that could be used to react with CO₂. Carbonation destroys asbestos, rendering it harmless to humans.

The process would integrate with the Department of Energy’s Vision 21 program. That program’s goal is to develop high-efficiency fossil fuel power plants that emit virtually no pollutants by 2015. It could also help the United States reduce its dependency on foreign oil.

“The United States has enough coal reserves to support our energy needs well into the next century,” says McKelvy. “That coupled with advances in power plant and transportation efficiency, hydrogen generation, and fuel cell technology could allow us to be energy independent with our own reserves. Carbon sequestration can enable us to use that in an environmentally sound way.”

ASU is a member of the CO₂ Mineral Sequestration Working Group, managed by the Fossil Fuels Division of the U.S. Department of Energy. ASU team members include McKelvy, Chizmeshya, Ray Carpenter, Renu Sharma, Hamdallah Bearat, and Jason Diefenbacher from CSSS, George Wolfe, Brandon Doss, and Susan Weinstein from Chemistry and Biochemistry; Michael Kocher and Robert Marshak from Physics and Astronomy; Dersin Gormley, Ryan Nunez, and Youngchul Kim from the Science and Engineering of Materials Graduate Program; and Kyle Squires and Kirigan Saha from Mechanical and Aerospace Engineering. For more information, contact Michael McKelvy, Ph.D., 480.965.4535. Send e-mail to: Michael.Mckelvy@asu.edu

Diane Boudreau

Algal sequestration research is supported by Arizona Public Service and Universal Enotech. For more information, contact Milton Sommerfeld, Ph.D., School of Life Sciences, 480.965.3391. Send e-mail to: Milton.Sommerfeld@asu.edu

Growing Solutions

Rocks are not the only place to store carbon. All green plants are carbon-based. They are natural carbon sinks. Old-growth forests are well-known repositories of carbon, but smaller organisms can do the job, too—perhaps even better. Some ASU researchers are now exploring the microscopic world, looking at algae as a way to sequester CO₂. “Algae are much more productive than higher plants,” explains Milton Sommerfeld, a professor in the School of Life Sciences. “They can produce more biomass over a short time.”

Sommerfeld is working with Qiang Hu to develop large-scale bioreactors that will remove CO₂ from smokestacks and use it in growing algae. Hu is a research assistant professor and bioreactor expert.

In effect, the bioreactors would be algal farms producing a crop that could be used for a variety of purposes. Algae have nutritional value that makes them useful for fertilizer, animal feed, fine chemicals, and even human food supplements.

The first task the researchers faced was finding a suitable species to use for sequestration. They needed to find algae that tolerates high levels of CO₂, has a high growth rate, and serves as a useful product once grown.

The researchers isolated many species of algae from natural water environments. During laboratory testing they found several good candidates for the job. The next step will be to set up an actual bioreactor in a power plant as a pilot study. “It’s been a small project at this point. The next level of scale will be bigger. Right now we use a synthetic gas mix. In the pilot study we will use real flue gas,” says Sommerfeld.

The flue gas will agitate the mix as well as provide CO₂. It also will provide heat to maintain a suitable culture temperature, which will help the algae grow outdoors all year round. The pilot study will help scientists learn how the algae thrive in a real-life situation compared to a highly controlled laboratory. Sommerfeld says that using multiple species is an important strategy.

The productiveness of each type of algae may vary depending on external factors such as temperature, solar light intensity, or nutrient availability.

If it proves effective, this technique could be an excellent and inexpensive way to reduce point-source CO₂ emissions. Hu says that the process is environmentally friendly and sustainable over the long term.

“The process is driven by solar energy, not electricity. This generates more CO₂. And our by-product is renewable,” he adds.

Algal biomass generated from the process can make it commercially profitable, as well. The researchers hope the bioreactors will eventually cover their own operating costs. There certainly will be no shortage of product to sell. According to Hu, the CO₂ from a single power plant could help generate about 10 million tons of algal biomass per year.

Diane Boudreau

Algal sequestration research is supported by Arizona Public Service and Universal Enotech. For more information, contact Milton Sommerfeld, Ph.D., School of Life Sciences, 480.965.3391. Send e-mail to: Milton.Sommerfeld@asu.edu