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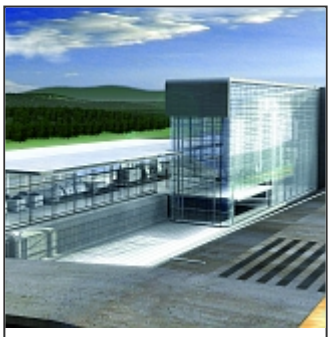

(U.S. Department of Energy)

The Job Market

Examining Carbon Capture and Storage

Carbon capture and storage (CCS) is a relatively new strategy for reducing the amount of carbon dioxide introduced into the atmosphere. Carbon dioxide released from the burning of fossil fuels in industrial power plants is captured; the gas is then "transported to a suitable storage site where it is injected deep underground to be safely stored," explains **Stuart Gilfillan**

Carbon capture and storage is a competitive, fast-paced, interdisciplinary research field involving geology, chemistry, and engineering with contributions from social science, law, and policy.

(https://web.archive.org/web/20100513022733/http://www.geos.ed.ac.uk/homes/sgilfil1/) , 30, an earth sciences postdoc at the **University of Edinburgh (https://web.archive.org/web/20100513022733/http://www.ed.ac.uk/home)** in the United Kingdom. The idea is simple, but the ability to scale up to remove enough carbon dioxide from emissions to mitigate climate change is at least a few years away.

One of the challenges of CCS technology is making sure carbon dioxide that's stored underground stays underground, and that's what Gilfillan studies. He is using noble gases and stable carbon isotopes to understand how carbon dioxide behaves underground, which is necessary to make sure storage sites are safe.

Going underground

itigating Climate Change

explored rising opportunities for natural and social scientists to study climate change and further our understanding of its likely
complements this past feature on **Careers in Climate Change Research**
)513022733/http://sciencecareers.sciencemag.org/career_magazine/previous_issues/articles/2009_11_27/caredit.a0900145)
rts aimed at actually curbing carbon dioxide emissions and reduce global warming.

e Change feature articles:

ildings
)513022733/http://sciencecareers.sciencemag.org/career_magazine/previous_issues/articles/2010_05_07/caredit.a1000046)
al writer Naomi Lubick reports on how new research in building technology aims to boost energy efficiency and reduce carbon
and homes. The research potential in the field is enormous and job prospects on the rise, Lubick found.

ngineering
)513022733/http://sciencecareers.sciencemag.org/career_magazine/previous_issues/articles/2010_05_07/caredit.a1000048)
for South Europe Elisabeth Pain looks into the controversial idea of intentionally manipulating Earth's climate. Although it remains a
reer on, there is much potentially important and rewarding work to be done in climate geoengineering.

The first demonstration of carbon dioxide capture and underground storage was at the North Sea's **Sleipner gas field (https://web.archive.org/web/20100513022733/http://www.bgs.ac.uk/science/CO2/home.html)** . Since 1996, Statoil, Norway's energy company, has been removing excess carbon dioxide from the natural gas they extract and injecting it into a 3-kilometer-deep

Sleipner well. That was followed by Canada's **Weyburn-Midale CO2 Project (https://web.archive.org/web/20100513022733/http://www.ptrc.ca/weyburn_overview.php)** in Saskatchewan in 2000. The **Texas Bureau of Economic Geology (https://web.archive.org/web/20100513022733/http://www.beg.utexas.edu/)** is now planning its fifth test site in the United States. One other CCS pilot project has started up: the **Schwarze Pumpe pilot plant (https://web.archive.org/web/20100513022733/http://www.vattenfall.com/en/ccs/pilot-plant.htm)** in Germany, which started in 2008. Currently, the world's pilot CCS projects and test sites capture about 3 megatons of carbon dioxide per year. The long-term goal is to store all of the carbon dioxide emitted by fossil fuel combustion in power plants; the United Kingdom alone emits more than 500 megatons per year. CCS is entering the scaling up stage, with large demonstration projects planned at 36 power plants worldwide.

CCS demonstration plants and pilot projects are concentrated around depleted oil and gas fields, which are considered good candidates for carbon dioxide storage. Decades of commercial oil and gas exploration have generated at least part of the needed infrastructure. These porous rock formations have stored natural gas for millions of years, so scientists reckon they can store carbon dioxide for a similar period. In the North Sea alone, there is space to store an estimated 5300 gigatons of carbon dioxide.

Guaranteeing that the carbon dioxide stays in place is crucial. Leaks are a safety concern and an issue that needs to be addressed before CCS technology is viable and accepted by the public. Concentrated carbon dioxide may cause asphyxia, and serious and widespread leaks into the atmosphere would reverse the positive effects of CCS. Recent computer models suggest that carefully selected storage sites are capable of retaining 99% of their carbon dioxide for more 1000 years. But leakage is definitely something we want to avoid, Gilfillan says, and once CCS is fully operational, storage sites will need constant monitoring.

To better understand what makes a storage site safe, Gilfillan has been investigating the deep terrestrial carbon cycle. "I am trying to find out how long carbon dioxide has been stored naturally and, more importantly, how it is stored," Gilfillan says. Carbon dioxide may be stored in deep rocks as it emerges from the natural degassing of magmas, or it may get trapped on Earth's surface in sedimentary rocks like limestone, which mainly contain carbonateminerals. By tracing noble gases, Gilfillan has been able to distinguish the origin -- magmatic or sedimentary -- of carbon dioxide. He has also been able to track the migration of carbon dioxidethrough faults and cracks within Earth's crust using stable carbon isotopes. The lessons learned from these natural analogs can then "be used to choose suitable engineered storage sites and monitor how the carbon dioxide is being stored," Gilfillan says.

Gilfillan's work has demonstrated that in underground natural gas fields, carbon dioxide is mainly stored through dissolution in water inside tiny pores in reservoir rocks. Because water with dissolved carbon dioxide is denser than water without the gas, it will sink to the bottom of the reservoir where it can be stored safely, he explains. But this means it's important to make sure that the carbon dioxide–rich water does not move out over time. "The flow of water around sites chosen for engineered storage needs to be fully understood before carbon dioxide is injected, to reduce the possibility of leaks," Gilfillan says.

An expanding field

Carbon capture and storage is a competitive, fast-paced, interdisciplinary research field involving geology, chemistry, and engineering, with contributions from social science, law, and policy. That broad scope means that CCS offers many opportunities for science and engineering graduates.

"CCS is a very good topic to learn; it gives you very good transferable skills," says Howard Herzog, senior research scientist at the Massachusetts Institute of Technology's (MIT's) **Carbon Capture and Sequestration Technologies Program (https://web.archive.org/web/20100513022733/http://sequestration.mit.edu/index.html)** in Cambridge. Because CCS researchers need to work with a diverse crowd, including people from social sciences and policy, they gain skills that can help them land a job in academia, government, and industry, he says.

The MIT program focuses mainly on the technical issues of CCS, and Herzog normally recruits students with engineering backgrounds. But other labs hire scientists from a wider range of fields. Herzog is looking for students who have the skills to work with models and do quantitative analysis, "but also strong team workers with communication skills," he says. Graduates from the MIT program usually go to work in private industry because they are trained to tackle the applied side of CCS, but some find careers in the public sector or academia. For scientists choosing academia, the field gives you plenty of opportunities to get your name on a paper, Herzog adds.

Despite international negotiations to reduce carbon emissions, fossil fuel combustion in power plants is likely to remain an important energy source for decades, and there are signs that opportunities in CCS are expanding. The American Recovery and Reinvestment Act provides $3.4 billion for CCS demonstration projects, and in 2009, the U.K. government announced that new coal plants must have CCS demonstration in place when they go online.

A solid background

Gilfillan, a keen mountain biker, decided to study earth sciences at the **University of Glasgow (https://web.archive.org/web/20100513022733/http://www.gla.ac.uk/)** in the United Kingdom because it would allow him to combine a career in science with his love for the outdoors. He chose to focus on geochemistry because it's a field that provides "definite answers." He gained fieldwork experience working for the British Geological Survey. During two summers, he collected soil

(Jason Heath, New Mexico Tech)

Stuart Gilfillan samples a natural carbon dioxide geyser in Green River, Utah.

and river sediment samples for the **Geochemical Baseline Survey of the Environment**

(https://web.archive.org/web/20100513022733/http://www.bgs.ac.uk/gbase/) , a project that documents the natural chemical composition of soils and sediments across the United Kingdom.

Gilfillan started his Ph.D. at the **University of Manchester (https://web.archive.org/web/20100513022733/http://www.manchester.ac.uk/)** in the United Kingdom in 2002, under the supervision of Christopher Ballentine. Gilfillan sought the source of the carbon dioxide found in natural reservoirs and springs in Utah, figuring out how to track carbon dioxide in natural reservoirs using noble gases and stable carbon isotopes. He soon became aware of the possibility of applying his research to CCS. "I was attracted by the possibility of doing something positive to address rising carbon dioxide emissions from fossil fuel combustion," he says. CCS was then taking its first steps. "I knew that there was a potential for my research to [make] a significant contribution."

When he finished his Ph.D. in 2006, Gilfillan moved to Edinburgh, first with a 3-year postdoc position and then, starting in 2009, with a research fellowship funded by the Natural Environment Research Council. His postdoctoral research has allowed him to apply the geochemical-monitoring techniques he learned during his Ph.D. to carbon capture and storage. The project involves 2 or 3 weeks of fieldwork per year at U.S. testing sites in Mississippi. Back in the lab, he processes the samples and then spends most of his time at his desk analyzing the data and modeling the mobility of carbon dioxide in and around the test sites.

The main difficulty of working in CCS is "to make sure you are doing work that someone else has not thought of yet," Gilfillan says. "You need to be self-motivated and adaptable because things change quite quickly, and you have to react to that," he says.

The field is competitive, but Gilfillan believes it has room for him. "Good research has an impact" in his field, "and that is a great motivator," he says. In April 2009, he published in ***Nature* (https://web.archive.org/web/20100513022733/http://www.nature.com/nature/journal/v458/n7238/full/nature07852.html)** his study demonstrating that carbon dioxide is stored in natural reservoirs through dissolution in water. He was the primary author. "I was amazed at the impact it had," he says. "The day before it was published I was called by journalists all over the world."

CCS needs to be deployed at an industrial scale to mitigate carbon emissions effectively, so its implementation depends on the commitment of governments and industry partners -- and on huge investments. So the pace is inevitably slow, which, given the urgency of the problem, Gilfillan finds frustrating. "If we are to significantly reduce carbon dioxide emissions by 2020, CCS needs to start happening as soon as possible," he says.

Further Resources

CCS research centers with training opportunities

In the United States:

- **Carbon Capture and Sequestration Technologies Program (https://web.archive.org/web/20100513022733/http://sequestration.mit.edu/index.html)** -- MIT

- **The Global Climate and Energy Project (https://web.archive.org/web/20100513022733/http://gcep.stanford.edu/)** -- Stanford University

- **Carbon Mitigation Initiative (https://web.archive.org/web/20100513022733/http://cmi.princeton.edu/)** -- Princeton University

- **Geologic Carbon Sequestration Program (https://web.archive.org/web/20100513022733/http://esd.lbl.gov/research/programs/gcs/)** -- Lawrence Berkeley National Laboratory

- **Carbon Sequestration Program (https://web.archive.org/web/20100513022733/http://csp.unl.edu/Public/index.html)** -- University of Nebraska, Lincoln

- **Gulf Coast Carbon Center (https://web.archive.org/web/20100513022733/http://www.beg.utexas.edu/gccc/)** -- University of Texas, Austin

In the United Kingdom:

- **Scottish Centre for Carbon Storage (https://web.archive.org/web/20100513022733/http://www.geos.ed.ac.uk/sccs/)** (Offers a master's degree program solely dedicated to CCS)

- **Carbon Capture and Storage (https://web.archive.org/web/20100513022733/http://www3.imperial.ac.uk/carboncaptureandstorage)** -- Imperial College London

- **Centre for Innovation in Carbon Capture and Storage (https://web.archive.org/web/20100513022733/http://www.nottingham.ac.uk/carbonmanagement/index.php)** -- University of Nottingham

- **Centre for Energy, Petroleum and Mineral Law and Policy (https://web.archive.org/web/20100513022733/http://www.dundee.ac.uk/cepmlp/)** -- University of Dundee

- **Carbon Capture Legal Programme (https://web.archive.org/web/20100513022733/http://www.ucl.ac.uk/cclp/)** -- University College London

Europe:

- **Gas Technology Centre (https://web.archive.org/web/20100513022733/http://www.ntnu.no/gass/)** -- Norwegian University of Science and Technology

- **Institute of Combustion and Power Plant Technology (https://web.archive.org/web/20100513022733/http://www.ifk.uni-stuttgart.de/index.en.html)** -- University of Stuttgart (Germany)

- **Combustion and Harmful Emission Control Research Centre (https://web.archive.org/web/20100513022733/http://www.chec.kt.dtu.dk/)** -- Danish Technical University (Denmark)

- **Politics and Policy of Carbon Capture and Storage (https://web.archive.org/web/20100513022733/http://www.ccs-politics.se/index.html)** (Sweden)

- **European CO2 Technology Center Mongstad (https://web.archive.org/web/20100513022733/http://www.tcmda.com/?language=UK)** (Norway)

More About CCS:

- **Global Carbon Capture and Storage Institute (https://web.archive.org/web/20100513022733/http://www.globalccsinstitute.com/)**

- **UK Carbon Capture and Storage Community (https://web.archive.org/web/20100513022733/http://www.co2storage.org.uk/)** (Comprehensive information and list of related Web sites)

- **Carbon Sequestration Research Program (https://web.archive.org/web/20100513022733/http://www.fossil.energy.gov/programs/sequestration/index.html)** of the U.S. Department of Energy

Image *(top):* Artist's drawing of the proposed FutureGen coal-fueled, near-zero emissions power plant in Matoon, Illinois that captures and sequesters the carbon dioxide generated in the production process.

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