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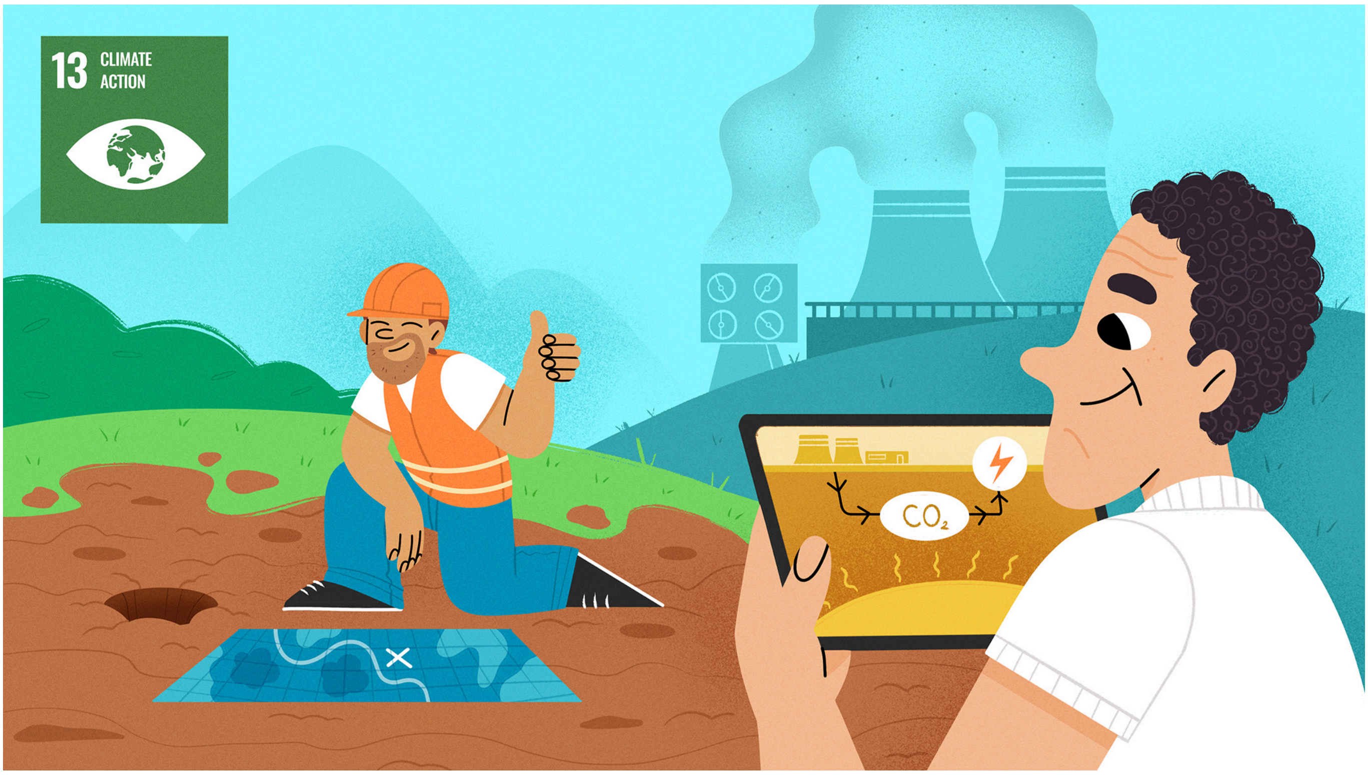


# TOWARDS SDG 13: TURNING $CO_2$ FROM A PROBLEM TO A SOLUTION USING THE EARTH'S NATURAL HEAT

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YOUNG REVIEWERS:


ANNAMARIA
AGE: 15


DEAN
AGE: 14

The United Nation's Sustainable Development Goal 13–Climate Action (SDG 13) is one of 17 Sustainable Development Goals established by the United Nations General Assembly in 2015. SDG 13 aims to limit climate change and its impacts, ensuring we take action to protect our planet. The biggest cause of climate change is the release of greenhouse gases, in particular carbon dioxide ($CO_2$). $CO_2$ is released into the air when we burn fossil fuels for energy for driving cars, running factories, and generating electricity. So how can we reduce $CO_2$ emissions while ensuring we have the energy we need? In this article, you will learn about a new technology in which $CO_2$ is captured and injected into rocks underground, and then used to create electricity for homes and buildings. By doing this, $CO_2$ can go from being a problem to being part of a solution for climate action.

**Watch an interview with the authors of this article to learn even more! (Video 1).**

## FIGHTING CLIMATE CHANGE AND PROTECTING OUR PLANET'S FUTURE

In 2015, the United Nations set 17 Sustainable Development Goals (SDGs) to be adopted by all member nations to improve the overall quality of life and protect the environment worldwide. SDG 13–Climate Action is one of these goals. It seeks for all nations to "take urgent action to combat climate change and its impacts". Thus, SDG 13 wants to help countries prepare for and deal with climate change and the natural disasters that come with a changing climate. SDG 13 has multiple targets to help humans to reduce their **carbon dioxide** ($CO_2$) emissions by 45% in 2030, and to reach **net zero** emissions by 2050. These targets include educating people on climate change, raising money to support developing countries in managing the effects of climate change, and ensuring that all countries have plans to protect their populations against climate disasters. SDG 13 is connected to SDG 7 (Affordable and Clean Energy) and SDG 11 (Sustainable Cities and Communities) [1]. To fight climate change, we need to use **clean energy** and pollute less. Many people still use **fossil fuels** (e.g., coal, oil, and gas) because they are cheap, but they release a lot of **greenhouse gases**. If we find affordable clean energy alternatives, fewer people will need to burn fossil fuels, which means cleaner air, less pollution, a healthier environment, and less climate change. But what is climate change and where did it come from?

**CARBON DIOXIDE ($CO_2$)**

A gas released by burning fossil fuels. It traps heat in the atmosphere, causing Earth to warm up and leading to climate change.

**NET ZERO**

A state in which the greenhouse gases going into the atmosphere are balanced by removal of gases out of the atmosphere.

**CLEAN ENERGY**

Clean energy is energy that comes from renewable, zero emission sources that do not pollute the atmosphere when used, as well as energy saved by energy efficiency measures.

**FOSSIL FUELS**

Natural fuels such as coal, oil, or gas, formed over millions of years underground from the remains of dead organisms and plants.

**GREENHOUSE GASES (GHGS)**

Gases in the atmosphere that trap heat and thus raise Earth's surface temperature.

## HOW WE GOT HERE AND WHY WE NEED TO CHANGE

For most of our history, humans used simple tools and relied on basic forms of energy like fire and wind. However, around 200 years ago, a major transition happened—the Industrial Revolution. Machines were invented to get work done more efficiently. This led to huge advances for humans, such as technology and transportation. However, these machines operate by burning fossil fuels, which releases $CO_2$ into the atmosphere where it gets trapped and increases Earth's temperature. This is known as the greenhouse effect. If not reversed, the greenhouse effect will change the climate in undesirable ways, from long-term temperature increases to extreme weather events like hurricanes, droughts, floods, and rising sea levels. We may even see heat waves in the Artic or freezing temperatures in the tropics. Global warming can also cause extinction of some animals and plants.

Science plays a major role in meeting SDG 13. For example, scientists can create climate models based on weather data to predict natural disasters. But the biggest contribution of science is to find new ways to generate clean energy. Scientists now know that **decarbonization**—reducing the amount of $CO_2$ released into the air—may reverse climate change.

**DECARBONIZATION**

The process of reducing the amount of $CO_2$ released into the air, often by using clean energy sources and capturing some of the emitted $CO_2$.

## EXPLORING NEW ENERGY SOURCES

Have you ever wondered what our planet looks like from the inside and what lies deep below your feet? First of all, the Earth is layered. It consists of a very hot core in the center, a mantle surrounding the core, and a thin crust on the surface, where we all live and where valuable treasures like gold, diamonds, oil, and gas can be found (Figure 1). Earth's crust is made from different types of rocks, which have tiny channels and holes inside, much like an ant hill. While most people pay little attention to what is beneath Earth's surface, we are exploring how it can help us fight climate change and produce clean energy. You commonly hear about fossil fuel alternatives like solar and wind power, but did you know we have an enormous amount of heat energy waiting to be extracted from deep underground? Rocks deep beneath our feet can provide a solution to our energy needs and reduce $CO_2$ in the atmosphere.

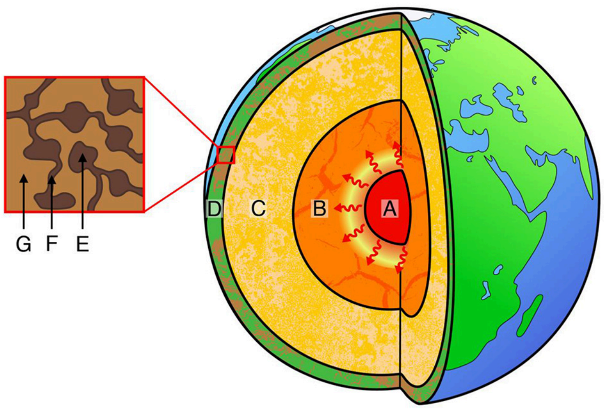


Figure 1

**Figure 1**

**(A)** At the center of Earth is the inner core, which is extremely hot and solid. **(B)** Surrounding the inner core is the outer core, which is also very hot and helps transfer heat outward because it is liquid. **(C)** The mantle is a thick layer of rock where heat slowly rises towards the surface. **(D)** The crust is the thin, solid outer layer where we live. **(G)** The crust is composed of solid rocks that contain **(E)** tiny holes, known as pores, and **(F)** connecting channels, known as throats. Pores and throats are filled with water, oil, or gasses.

Scientists are developing solutions to capture $CO_2$ from the air and store it safely underground, removing harmful emissions effectively and permanently. The tiny pores and channels in the rocks of Earth's crust may be even smaller than the thickness of a hair, but there are billions of them. Combined, they make an enormous volume of space, so large that all the $CO_2$ released by industry could easily fit inside [2]. Thus, we could inject $CO_2$ deep underground into these pores and trap it in a way that prevents it from escaping back to the surface.

But how will this $CO_2$ produce energy? Imagine Earth like a baked potato, filled with molten hot butter at its core and wrapped in aluminum foil (Earth's crust). The temperature in the core is not precisely known but believed to be around 6,000°C. This is 30 times hotter than the highest temperature of your kitchen oven [3]! Of course, the temperature is lower towards the Earth's crust. Still, this heat can be harvested from the hot rocks using fluids (typically water) and transported to the surface as a renewable energy source called **geothermal energy**.

**GEOTHERMAL ENERGY**

Energy created from the natural heat stored inside the Earth. It is a clean and renewable source of power.

Scientists have proposed a new technology called **$CO_2$-plume geothermal (CPG)**, in which $CO_2$ stored underground is transported back to the surface to extract Earth's heat and generate electricity.

**$CO_2$-PLUME GEOTHERMAL (CPG)**

A method that uses $CO_2$ to create clean energy by heating it in underground hot rocks and using it to generate electricity.

## FROM PROBLEM TO SOLUTION

Our research at KAUST studies how CPG can be made affordable. This approach pumps $CO_2$ underground through the deep holes into hot rocks, where temperatures can reach 150–250°C [4]. The $CO_2$ will heat up as it moves through the rock pores and channels. It then reaches another hole that pumps it back to the surface as a hot fluid. We extract that heat as geothermal energy to produce electricity, which can be sold. The cooled $CO_2$ goes back underground, and the cycle starts all over again (Figure 2). This is a great approach because one of the biggest challenges of storing $CO_2$ underground is the high cost of drilling deep holes. But using this dual-purpose method, we can reduce the costs of $CO_2$ storage by generating clean energy that can be sold!

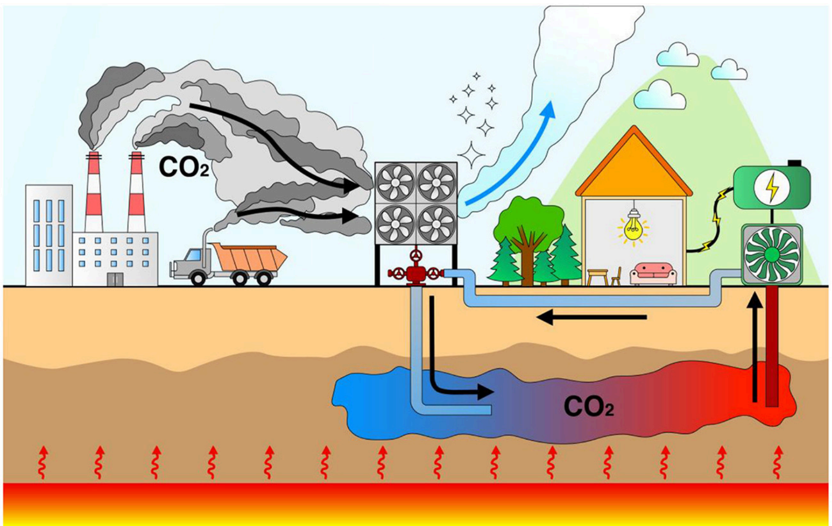


Figure 2

**Figure 2**

The CPG process captures $CO_2$ and turns it into a liquid to generate geothermal energy. Several holes, called wells, are drilled several km deep into Earth's subsurface. An injector well pumps cold $CO_2$ down (blue well), where hot rocks heat it up. Then, a producer well (red well) transports the $CO_2$ back to surface, carrying the energy in form of heat. This heat is extracted to generate electricity to power homes. After heat extraction, the cold $CO_2$ is re-injected underground. Once a reservoir is filled with $CO_2$, the system continues to produce geothermal heat and generates electricity through continued $CO_2$ circulation.

For CPG to work, selecting the right underground location and understanding how $CO_2$ flows underground is essential. Our team's research at KAUST showed that it is possible to use $CO_2$ in this dual-purpose way. By using this method, we remove $CO_2$ from the atmosphere and create a cost-effective way to fight climate change and support a clean-energy future (Figure 3) [5].

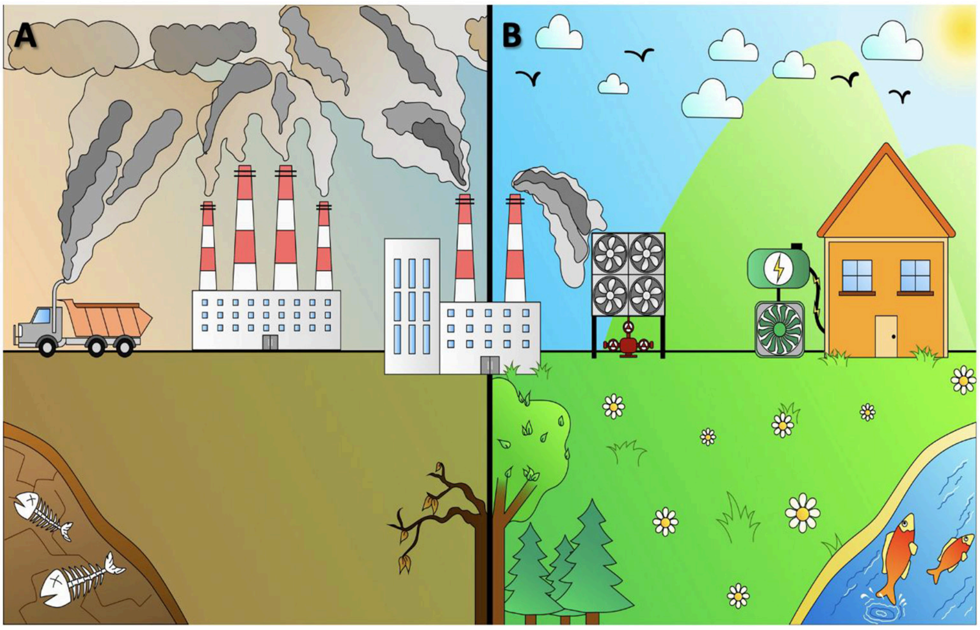


Figure 3

**Figure 3**

**(A)** A world where we release a lot of pollution, including $CO_2$, into the air without capturing it. As a result, climate change makes trees and animals struggle, and the environment suffers. **(B)** A cleaner world, where we capture $CO_2$ before it harms the planet. This captured $CO_2$ helps generate renewable energy and keeps the air clean, allowing plants, animals, and people to live healthier lives.

For our study location, CPG could generate an average of about 164 megawatts of power every year [5]. This is enough electricity to power thousands of homes every day, or the equivalent of about 2,300 electric cars! Furthermore, we calculated that this clean energy system is price competitive: it could produce electricity at an average cost of about $77 per megawatt-hour—cheaper than electricity from nuclear energy and about the same as wind power, solar power, or pumped hydropower [5].

Another exciting aspect is how much $CO_2$ this method can store. CPG systems could hold around 1.15 gigatons of $CO_2$ over 11.5 years [5]. This is approximately equal to the emissions from 230 million cars in 1 year. If you lined up all those cars, they would circle the Earth almost 30 times! Safely storing this much $CO_2$ underground would be a game changer for fighting climate change. Hopefully, our geologists can find many places underground to store and use $CO_2$ in this way.

## TO SUM IT UP

In this article, you learned that energy is vital for our society, but that we are relying on sources that are bad for the environment because they cause climate change. SDG 13 aims to find clean energy sources to reduce the buildup of $CO_2$ in our atmosphere. By capturing $CO_2$ and injecting it into hot rocks underground, we transform this harmful gas into a source of renewable energy. This dual-purpose approach reduces global warming and at the same time supports a sustainable energy future. $CO_2$ becomes part of the solution instead of just being a problem. However, while this is a big step forward, more work is needed to put this method within reach. Also, geothermal energy should not be the only renewable energy source we use in the future—we need *all* available solutions to tackle climate change. In fact, you can do your part! You can support SDG 13 by saving energy in your house or school (like by turning off the lights when they are not needed), learning and teaching others about climate change, and encouraging your community to use renewable energy sources. Even small actions can help create a healthier planet!

## ACKNOWLEDGMENTS

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**CONFLICT OF INTEREST:** The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.



## YOUNG REVIEWERS

**ANNAMARIA, AGE: 15**

Hi, my name is Annamaria, and I currently go to The KAUST School. I enjoy swimming, love the beach, adore reading, and have an orange cat named Tiger.

**DEAN, AGE: 14**

My name is Dean and I am a student in The KAUST School–in 9th Grade. I enjoy reading books, watching TV, studying, and playing with my cat. I am creative and a visual learner.

## AUTHORS

**SIMON ZOUGHEIB**

My name is Simon Zougheib, and I am a PhD student at KAUST, where I study energy and how we can get and use it more wisely. My work focuses on finding better ways to manage water in oil production and to store $CO_2$ safely underground to help protect our planet. I enjoy both experiments and computer models to test new ideas. My goal is to create sustainable solutions for energy challenges, so future generations can enjoy a cleaner world. I believe that science can help us solve big problems, and I love being part of that journey!

**MARTIN HOECHERL**

My name is Martin Hoecherl, and I am a Ph.D. student in petroleum engineering at KAUST. Given the continued importance of oil and gas in the future global energy mix, I made it my goal to contribute to a more sustainable and responsible hydrocarbon production. My research focuses on improving our understanding of fluid flow in the subsurface by experimentally investigating how liquids flow through tiny pores smaller than human hair. The laboratory is my playground, and I am passionate about interdisciplinary research to unlock creative solutions for today's energy challenges.

**HUSSAIN ALQAHTANI**

Hussain Alqahtani is a Ph.D. student at KAUST University with a background in petroleum engineering and geology. With over 15 years of experience in the oil and gas industry, he brings practical insight to research focused on subsurface energy systems. His work explores the intersection of geology, engineering, and innovative energy solutions. Outside of research, Hussain enjoys exploring the natural world, sharing science with others, and staying curious about how Earth's hidden processes shape our everyday lives.

**P. MARTIN MAI**

Professor P. Martin Mai is a geophysicist by training, interested in all aspects of earthquake phenomena. He and his team of students, researchers, and global collaborators work to better understand the "earthquake machine" and how it causes strong shaking and tsunamis. Their goal is to help mitigate future earthquake disasters. In addition, Martin is interested in geothermal energy systems and how to make them an economically viable pillar for the future sustainable renewable energy mix. And when Martin is not working, you can find him enjoying outdoor activities (biking, running, swimming, hiking) with friends and family.

**HUSSEIN HOTEIT**

I am Professor **Hussein Hoteit**, and I research Earth's underground energy systems at KAUST. My work focuses on understanding how fluids, such as oil, gas, and water, move through rocks deep beneath the surface. For the past 25 years, I have been tackling complex challenges at the intersection of energy and the environment. One of my key projects involves turning carbon dioxide into stone, replicating the natural process of carbon mineralization to help mitigate climate change. Beyond research, I enjoy teaching students how to build computer models that simulate fluid behavior under extreme temperatures and pressures of the subsurface. I am passionate about finding smarter, more sustainable ways to use our planet's resources while protecting the environment.

**VOLKER VAHRENKAMP**

Volker Vahrenkamp is Professor of Earth Systems Sciences & Engineering at KAUST. He loves rocks AND the holes in the rocks through which fluids are flowing. He and his students try to find out how limestones and the holes in them are created. For that they search in the sea and visit many mountain areas. Through his research he wants to help securing future energy supply because much of oil, gas and hot water needed for geothermal energy are found in the pores of limestones. Before coming to KAUST, he spent 28 years searching for hydrocarbons in wild places—from off-shore atolls to the jungles of Borneo and the deserts of Arabia. In 2016, he co-founded and became Managing Director of Nordic Geothermal LLC, a Dubai based company promoting the use of geothermal energy in Arabia. Volker earned his bachelor degree in Germany, his Master Degree in Geology at the University of Michigan, USA, and his PhD in Marine Geology at the University of Miami in Florida.

**JUSTIN EZEKIEL**

Dr. Justin Ezekiel is an Assistant Professor at the University of Calgary, jointly appointed in the Department of Earth, Energy, and Environment and the School of Public Policy. With over 12 years of teaching and research experience, he works at the intersection of geoscience, energy innovation, and sustainable transitions. His research focuses on integrated modeling of geothermal energy, underground carbon, hydrogen, and energy storage—turning complex subsurface data into practical solutions. Committed to global decarbonization, Justin bridges science, engineering, and policy to tackle urgent energy challenges with curiosity, creativity, and a collaborative spirit.

**THOMAS FINKBEINER**

Thomas Finkbeiner is Research Professor with a PhD degree in geophysics. All of his career he has worked in the area of geomechanics investigating the stresses arising from tectonic forces in the Earth's crust and how these affect the failure of rocks. Rock failure can occur around borehole walls (causing problems while drilling), in and above reservoirs (impacting production of gases and liquids), and along faults (inducing mostly small earthquakes). Understanding when these failures occur makes energy production and storage safer and cleaner. In his private life, Thomas enjoys sports, camping, and spending time with his family and friends. *thomas.finkbeiner@kaust.edu.sa