

Energy Futures Lab

Clean Fossil Fuels

Research Overview



Burning issue

This Research Overview highlights the diverse range of approaches and technologies developed by scientists and engineers at Imperial that will be needed to minimise emissions of carbon dioxide, a greenhouse gas, from the use of fossil fuels over the coming few decades. Research includes developing techniques to remove carbon dioxide from the flue gases of power plants and chimneys, as well as methods to burn the fuel in pure oxygen, which results in a flue gas that consists entirely of water vapour and carbon dioxide that can then be captured relatively easily. It addresses how to remove the carbon from the fuel before it is burned. Researchers are also studying how to store carbon dioxide safely in repositories deep underground.

Clearing the air

Work to develop clean fossil fuels is vital for the UK to ensure that its energy supply is affordable and secure as the country tries to minimise the consequences of climate change. Professor Tim Green, Director of the Energy Futures Lab, says, “The UK has set itself very ambitious targets to deliver an 80% cut in carbon emissions by 2050. However fossil fuels are likely to remain an important part of the energy mix for the next 20 or 30 years so we have to think hard about how we manage carbon emissions from them. Provided we address the carbon capture and storage question, then we can use fossil fuels to produce low carbon content electricity or low carbon content fuels such as hydrogen.”

Scrub the smoke

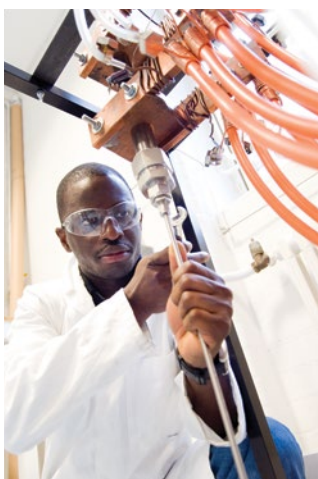
In the UK fossil fuels such as coal and gas are mostly used to generate power. Carbon dioxide from power stations accounts for about 40% of all emissions. Coal is the dirtiest fuel in the nation’s energy mix; its use to generate electricity has roughly halved since 1990 but it still accounts for more than half of the carbon emissions from power generation. But rushing to close all these existing fossil-fuel power plants would plunge the country into darkness and risk devastating an already weak economy. So researchers at the Energy Futures Labs are working to make existing technologies cleaner and affordable while the country makes the transition to greener power generation.



Burn and raze

Adding a device that captures carbon dioxide to the top of a chimney is probably the most straightforward way to create clean fossil fuels. However it adds an energy penalty: because it takes effort to scrub the effluent gases of carbon dioxide, the plant has about 20% less power available to generate electricity. Thus more fuel must be burned and more carbon dioxide emitted—and subsequently captured—in order to maintain the same power output.

An alternative approach spearheaded by Dr Paul Fennell, Senior Lecturer in Clean Energy at Imperial, is to place solid material that can withstand high temperatures, such as natural limestone, close to the combustion chamber. The limestone not only absorbs the carbon dioxide more efficiently than a chemical scrubber, it could also be used to manufacture cement at the end of its useful life in the furnace. Dr Fennell's team is conducting research to identify whether the carbonated limestone will prove suitably durable for use in the building trade. If so, such material could create a synergy between power generation and cement making, both of which are normally significant generators of carbon-dioxide emissions.



(Top) Stefan Iglauer and Puneet Sharma are investigating the injection of CO₂ into porous rocks.

(Mid) Imperial students participate in the Constructionarium in Norfolk, learning how to position oil rig structures.

(Left) Egwono Okpono, a PhD student, investigates the extraction of CO₂ from exhaust gases produced by burning fossil fuels.

Pure oxygen

If fossil fuels were burned in a stream of pure oxygen, the waste gas would be mainly carbon dioxide and water vapour, which is very easy to separate by condensation. Because burning fuels in pure oxygen increases the temperature of combustion, in practice some of the carbon dioxide is recycled through the system to reduce the heat. Burning fuel using mostly oxygen has several advantages over using air: the volume of flue gases is greatly reduced, so less heat is lost up the chimney. Because nitrogen, the main component of air, is removed from the process, no nitrogen oxides—which cause smog and acid rain—are formed during combustion. However it also has an energy penalty: separating oxygen from the air can add 15% to the power required to maintain a steady output. So researchers at Imperial led by Dr Fennell are also examining an alternative combustion technique that uses the oxides of iron, nickel or copper to transfer the oxygen needed to burn the fuel.

Decarbonised fuel

Removing carbon from the fuel before it is burned would prevent carbon dioxide from forming. In this process, the fuel is burned in an atmosphere that has insufficient oxygen for full combustion to take place, which produces a mix of carbon monoxide, methane, hydrogen and carbon dioxide. Professor Peter Lindstedt of the Department of Mechanical Engineering uses a series of reactions to convert the mixture into hydrogen and carbon dioxide while keeping pollutants to a minimum, and to separate the two gases so the hydrogen can be used as fuel and the carbon dioxide can be stored. Because the separation is relatively easy, the process does not carry as significant an energy penalty as post-combustion techniques. It is also much easier to integrate the capture of the carbon dioxide with the generation of power from the fuel.

The quest to sequester

Carbon dioxide is routinely pumped into underground reservoirs as part of normal oil extraction, to enhance the oil recovery by squeezing out more of the precious fluid. If depleted reservoirs where the oil formed were refilled with carbon dioxide, it might be possible to store it for thousands of years. Ample offshore storage exists in porous sandstone rocks below the North Sea that is nevertheless close to many power stations where carbon dioxide is generated. Professor Geoffrey Maitland of the Department of Chemical Engineering is part of an Energy Futures Lab team that studies how carbon dioxide behaves when it mixes with oil and brine in these underground reservoirs at different temperatures and pressures. He uses both experiments and computer models to identify how it might move within the confined pore space of various different types of sedimentary rock including the carbonate reservoirs found in the Middle East.

Smouldering embers

Underground fires that start in coal seams can burn for many decades. At present such fires are mostly uncontrolled, but Professor Maitland reckons that underground controlled combustion of fossil fuels could eventually offer the opportunity to create power without ever releasing carbon dioxide. Coal could also be transformed into gas or liquid fuels while remaining underground. Instead of drilling for oil and mining for coal and then pumping or shipping the fuel to a power station, power could be generated on the site of the fuel supply. He says, "Much of the downstream fossil-fuel processing currently carried out on surface could be relocated underground, transforming the subterranean well network from a passive, fluid-transportation conduit to an active, continuous-processing plant. A large part of the carbon will remain underground, captured and stored in the reservoirs without release."

In context

Some people worry that carbon dioxide could escape from reservoirs, which could badly affect animal and plant life. Addressing these concerns will be crucial if carbon capture and storage are to make a significant contribution towards mitigating climate change. There are also other political implications: any project to pump carbon dioxide along oil pipelines and inject it into aquifers, for example, is likely to require local, regional or international agreements. Staff at the Centre for Environment Policy at Imperial are working with the Energy Futures Lab to identify and address such issues.

A pilot plant for carbon capture and storage

A klaxon pierces the air and an orange light pulsates. "There is an emergency," repeats an insistent voice. In the power plant's control room, where its operators have jumped to their feet at news of the impending crisis, the desks rise to present their computer terminals at standing height. The large screens that cover the walls now display powerful camera shots of the plant alongside technical plans, data garnered from sensors over the past hour and a live link to the company's headquarters many thousands of miles away.

Thankfully the crisis is not real. But the plant itself is a true facility that captures carbon dioxide from a mix of gases—before mixing the separated gases back together again in a continuous demonstration cycle. Rising four storeys through the core of the chemical engineering department at Imperial, the gleaming stainless steel pipes and vessels are placed under the control of small teams of second-year undergraduates for a fortnight at a time, as they learn how to operate a state-of-the-art facility.

The carbon-capture process is relatively straightforward. A solution containing monoethanolamine is sprinkled onto the mixture of gases from which the carbon dioxide is to be removed. The liquid solution absorbs the carbon dioxide, leaving the nitrogen as a gas. At the base of this absorber column, the carbon-dioxide rich solution is collected and pumped to a nearby stripper column, which heats the fluid to a sufficiently high temperature for it to release the carbon dioxide as a gas for collection. Undergraduates can thus run the plant as it cycles through the process, as well as in the simulated crisis mode.

The plant has more than 250 sensors, some of which are wirelessly connected to the control room and powered by heat generated by the plant that would otherwise be wasted. The set up is thus being used not only to test which technologies work best at different points in the process of carbon capture but also to train the next generation of engineers.





Energy Futures Lab Research Overviews explore the key issues that must be addressed if we are to develop more secure and sustainable energy supplies, and explain how research at Imperial College London paves the way to meeting these challenges. Our staff and students conduct multidisciplinary energy research to cut carbon emissions. With strong links to industry, they develop an integrated view of energy supply, demand and distribution that takes into account technological, environmental, economic and security considerations.

Further articles in the Energy Futures Lab Research Overview series:

- Low Carbon Transport
- Sustainable Power
- Energy Infrastructure
- Policy and Innovation

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