Oxygen-separation membranes could aid in CO2 reduction

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It may seem counterintuitive, but one way to reduce carbon dioxide emissions to the atmosphere may be to produce pure carbon dioxide in powerplants that burn fossil fuels. In this way, greenhouse gases — once isolated within a plant — could be captured and stored in natural reservoirs, deep in Earth's crust.

Such "carbon-capture" technology may significantly reduce greenhouse gas emissions from cheap and plentiful energy sources such as coal and natural gas, and help minimize fossil fuels' contribution to climate change. But extracting carbon dioxide from the rest of a powerplant's byproducts is now an expensive process requiring huge amounts of energy, special chemicals and extra hardware.

Now researchers at MIT are evaluating a system that efficiently eliminates nitrogen from the combustion process, delivering a pure stream of carbon dioxide after removing other combustion byproducts such as water and other gases. The centerpiece of the system is a ceramic membrane used to separate oxygen from air. Burning fuels in pure oxygen, as opposed to air — a process known as oxyfuel combustion — can yield a pure stream of carbon dioxide.

The researchers have built a small-scale reactor in their lab to test the membrane technology, and have begun establishing parameters for operating the membranes under the extreme conditions found inside a conventional powerplant. The group's results will appear in the *Journal of Membrane Sciences*, and will be presented at the International

Symposium on Combustion in August.

Ahmed Ghoniem, the Ronald C. Crane Professor of Engineering at MIT, says ceramic-membrane technology may be an inexpensive, energy-saving solution for capturing carbon dioxide.

"What we're working on is doing this separation in a very efficient way, and hopefully for the least price," Ghoniem says. "The whole objective behind this technology is to continue to use cheap and available fossil fuels, produce electricity at low price and in a convenient way, but without emitting as much CO_2 as we have been."

Ghoniem's group is working with other colleagues at MIT, along with membrane manufacturers, to develop this technology and establish guidelines for scaling and implementing it in future powerplants. The research is in line with the group's previous work, in which they demonstrated a new technology called pressurized oxyfuel combustion that they have shown improves conversion efficiency and reduces fuel consumption.

Streaming pure oxygen

The air we breathe is composed mainly of nitrogen (78 percent) and oxygen (21 percent). The typical process to separate oxygen from nitrogen involves a cryogenic unit that cools incoming air to a temperature sufficiently low to liquefy oxygen. While the freezing technique produces a pure stream of oxygen, the process is expensive and bulky, and consumes considerable energy, which may sap a plant's power output.

Ghoniem says using ceramic membranes that supply the oxygen needed for the combustion process may operate much more efficiently, using less energy to produce pure oxygen and ultimately capture carbon dioxide. He envisions the technology's use both in new powerplants and as a retrofit to existing plants to reduce greenhouse gas emissions.

Ceramic membranes are selectively permeable materials through which only oxygen can flow. These membranes, made of metal oxides such as lanthanum and iron, can withstand extremely high temperatures — a big advantage when it comes to operating in the harsh environment of a powerplant. Ceramic membranes separate oxygen through a mechanism called ion transport, whereby oxygen ions flow across a membrane, drawn to the side of the membrane with less oxygen.

A two-in-one solution

Ghoniem and his colleagues built a small-scale reactor with ceramic membranes and studied the resulting oxygen flow. They observed that as air passes through a membrane, oxygen accumulates on the opposite side, ultimately slowing the air-separation process. To avert this buildup of oxygen, the group built a combustion system into their model reactor. They found that with this two-in-one system, oxygen passes through the membrane and mixes with the fuel stream on the other side, burning it and generating heat. The fuel burns the oxygen away, making room for more oxygen to flow through. Ghoniem says the system is a "win-win situation," enabling oxygen separation from air while combustion takes place in the same space.

"It turns out to be a clever way of doing things," Ghoniem says. "The system is more compact, because at the same place where we do separation, we also burn. So we're integrating everything, and we're reducing the complexity, the energy penalty and the economic penalty of burning in pure oxygen and producing a carbon dioxide stream."

The group is now gauging the system's performance at various temperatures, pressures and fuel conditions using their laboratory setup.

They have also designed a complex computational model to simulate how the system would work at a larger scale, in a powerplant. They've found that the flow of oxygen across the membrane depends on the membrane's temperature: The higher its temperature on the combustion side of the system, the faster oxygen flows across the membrane, and the faster fuel burns. They also found that although the gas temperature may exceed what the material can tolerate, the gas flow acts to protect the membrane.

"We are learning enough about the system that if we want to scale it up and implement it in a powerplant, then it's doable," Ghoniem says. "These are obviously more complicated powerplants, requiring much higher-tech components, because they can much do more than what plants do now. We have to show that the [new] designs are durable, and then convince industry to take these ideas and use them."

Provided by Massachusetts Institute of Technology

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