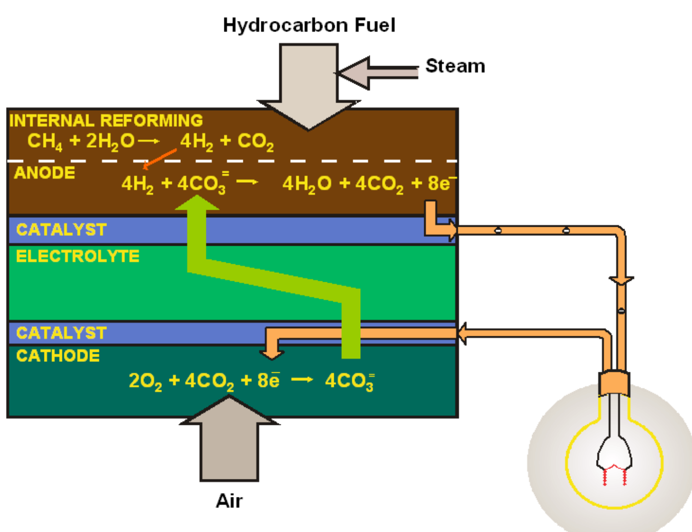
Carbon Dioxide Membrane Separation for Carbon Capture using Direct FuelCell Systems

DFC Technology Used as Electrochemical Membrane for CO_2 Purification and Capture during Power Generation

FCE's Direct FuelCell (DFC) is based on the carbonate fuel cell technology, where electrochemical reactions are supported by an electrolyte layer in which carbonate ions serve as the ion bridge that completes the electrical circuit. A side effect of this basic aspect of the technology is that carbon dioxide introduced at the air electrode is converted to carbonate ions and transferred through the electrolyte layer to the fuel electrode, where it is converted back to CO_2. This means that a DFC stack can be used as a carbon purification membrane – transferring CO_2 from a dilute oxidant stream to a more concentrated fuel exhaust stream. This has the potential to solve a problem that the US Department of Energy (and other agencies around the world) has been struggling with for years: is there a way to concentrate and capture the CO_2 in the exhaust of large coal or natural gas powerplants to avoid the harmful greenhouse effects that these exhaust gasses cause?

Conventional technologies that are being considered for carbon capture are expensive and have high power needs, consuming a significant fraction of the power output of the fossil plant they are trying to clean up. FCE is developing a carbon capture system which uses DFC stacks as CO_2 concentration systems. Instead of consuming power, the DFC Carbon Capture system produces additional clean power – an added value stream which is key to reducing the cost of the carbon capture process.

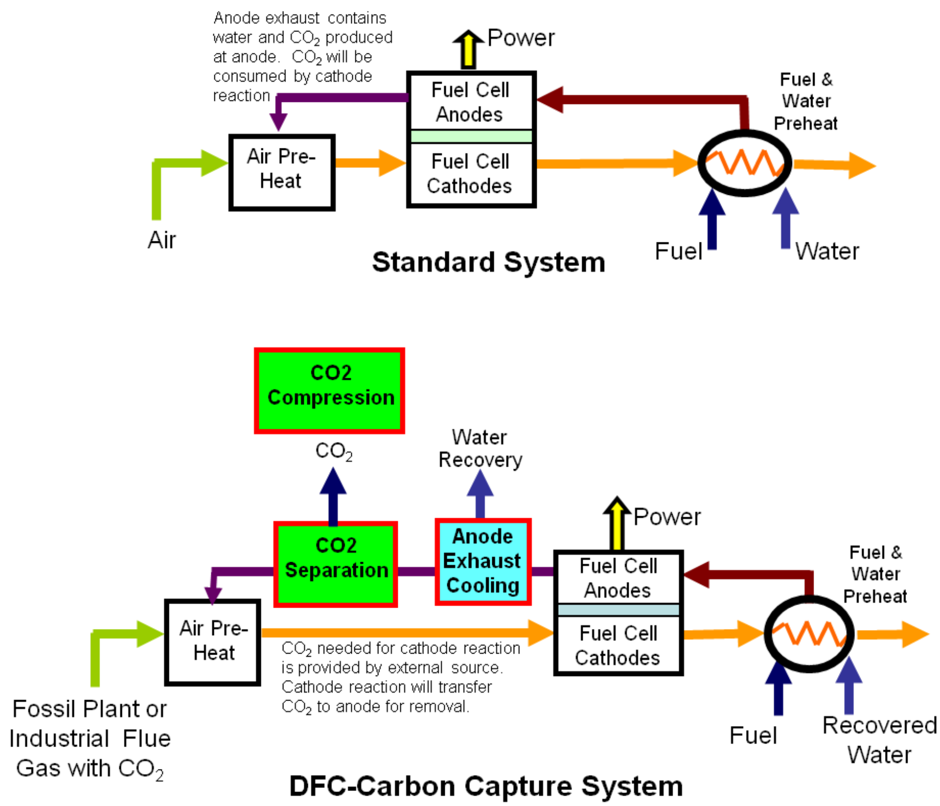


Direct FuelCell Electrochemical Reactions

Carbonate ion transfer supports electrochemical reaction of hydrogen at anodes and oxygen at cathodes, creating cycle of CO_2 production at anode and CO_2 consumption at cathode

The DFC Carbon Capture concept is an extension of the standard DFC system design, as illustrated below. In a standard DFC powerplant, CO_2 produced at the anode is recycled back to the cathode by mechanical systems in the balance of plant. If the concentrated CO_2 in the anode exhaust stream is extracted from the system and not recycled back to the cathode, an external source of CO_2 can support the cathode reaction. This external source can be the exhaust from another powerplant or an industrial source. The dilute CO_2 in the external flue gas will be reacted at the DFC cathodes and transferred to the anode stream, from which it can be easily separated for sequestration or utilization.

In the standard system, a hydrocarbon fuel (e.g. natural gas or biogas) is sent to the anodes and reformed to hydrogen. Most of the hydrogen is consumed in the anode power production reaction. The anode exhaust contains residual hydrogen, any CO_2 from the input fuel, and the CO_2 produced as a result of the carbonate ion transfer. The anode exhaust is mixed with fresh air and sent to a catalytic oxidizer, where the residual hydrogen is used to heat the oxidant stream up to the stack temperature. The cathode consumes oxygen from the air and the CO_2 from the carbonate ion transfer. Water vapor, residual oxygen, nitrogen and the CO_2 from the input fuel pass through the cathode to the system exhaust.



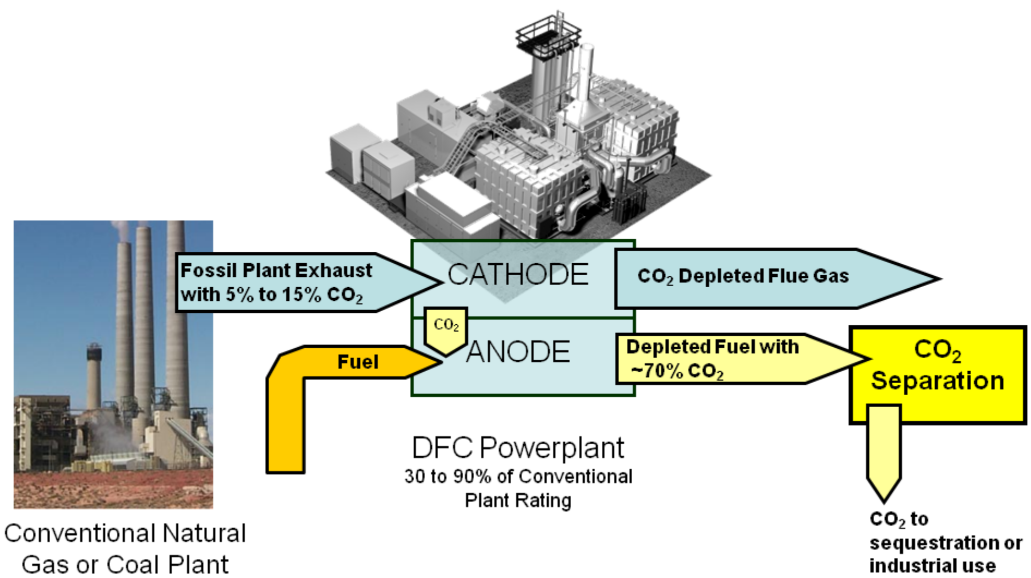
System Comparisons

CO_2 from powerplant or industrial source is sent to cathode, transferred and concentrated in anode, and removed from anode exhaust

The modification for carbon capture involves cooling the anode exhaust and separating most of the CO_2 from the exhaust stream. Since most of the CO_2 is removed from the anode exhaust, the CO_2 needed for the cathode reaction is provided by the exhaust of the external source. If this source is a conventional coal fired plant the CO_2

concentration will be in the range of 12 to 15 percent. An advanced Integrated Gasification Combined Cycle coal plant will have 7 to 8% CO_2 in its exhaust. A large scale combined cycle natural gas powerplant will have as little as 5% CO_2 in its exhaust. Separating CO_2 from these dilute streams is difficult, but once the CO_2 is sent to the fuel cell cathodes it is transferred to the anode exhaust stream, which has a CO_2 concentration of about 70%, and most of the balance is water, so it is very easy to remove CO_2 from this stream.

Using DFC powerplant stacks for this purpose has ancillary benefits beyond the CO_2 capture. One benefit is that since the fuel cell product water is condensed and removed while separating CO_2 from the anode exhaust, the DFC powerplant is a net water producer. This can reduce cost and environmental impact since many of the CO_2 source systems are significant water consumers. Another benefit is that a large percentage of any NOX in the source powerplant will be destroyed as it flows through the DFC stacks. While NOX is usually not present in the cathode inlet stream (which is mostly fresh air), it has been shown that if flue gas containing NOX is used instead of fresh air, most of the NOX will be reduced to nitrogen through chemical and electrochemical mechanisms as it flows over the cathodes.

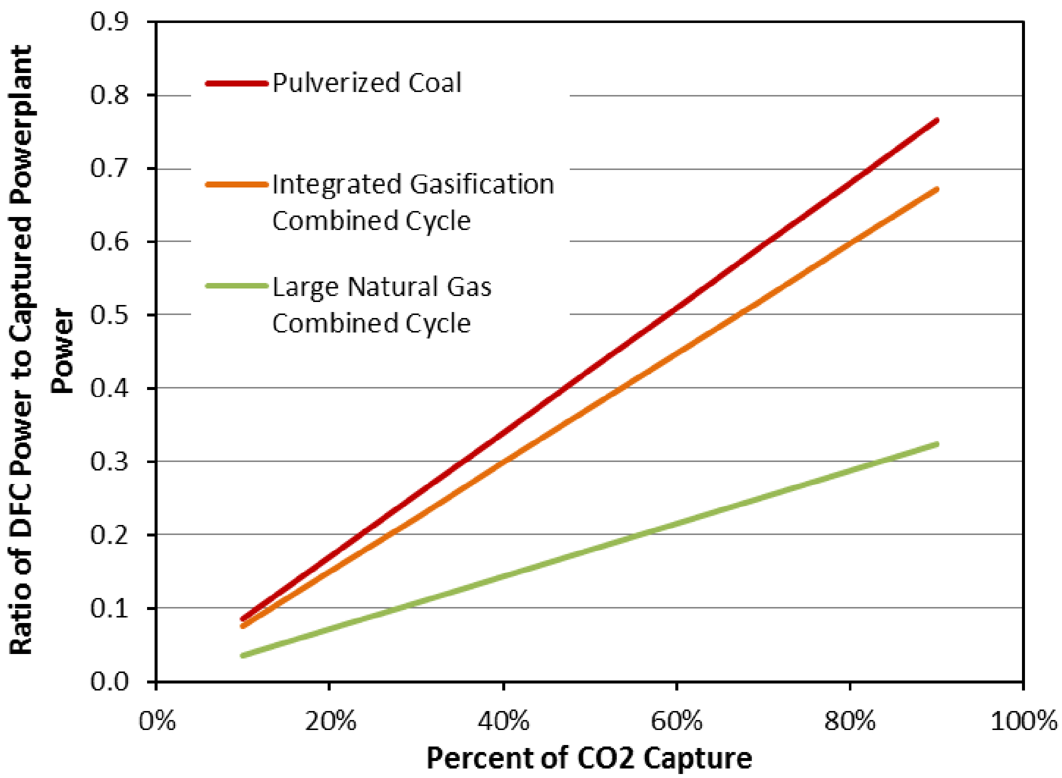


DFC Carbon Capture Concept

Exhaust from fossil powerplant or thermal source is sent to DFC oxidant inlet. DFC power generation process transfers CO2 from fossil plant to anode exhaust for easy separation

The size of the DFC powerplant required to capture CO_2 from a specific source depends on the size of the source and the CO_2 emission rate. A 2.8MW DFC3000 powerplant during normal power operation is transferring about 3200 kg of CO_2 per hour from the cathode to anode streams in the stack modules. In carbon capture mode, this system could capture and purify about 2300 kg per hour of external CO_2 in addition to the CO_2 exhaust of the DFC powerplant.

When used to capture CO_2 from a fossil fueled powerplant, the ratio of DFC power to captured plant power depends on the CO_2 emission rate of the source power plant. A conventional pulverized coal power plant with a typical CO_2 emission rate of 820 kg/MWh would require a larger capture system than a large scale natural gas combined cycle plant with a CO_2 emission rate of 360 kg/MWh. The size of the capture plant would also depend on the desired capture percentage. An illustration of these relationships is given in the following chart, which shows the ratio of DFC to captured plant power as a function of CO_2 capture ratio for three types of source plants.



DFC Carbon Capture Relative Plant Size Requirements

The size of the DFC capture system depends on the CO2 emission rate of the source plant and the desired level of capture efficiency

A 500 MW pulverized coal plant requires almost as large a DFC capture plant (about 400 MW) for a 90% carbon capture rate. A less carbon-intensive 500 MW natural gas combined cycle plant would require a DFC plant of about 200 MW (40% of the captured plant rating) for the same carbon capture ratio.

These large-scale DFC capture plants will ultimately be specially designed with larger scale balance of plant systems than today's commercial products. In the near term, capture systems can be configured as multiple-unit systems based on the largest DFC plant currently available, the 2.8MW DFC3000. DFC capture plants based on multiple smaller units can be installed in modular increments, providing an increasing level of carbon capture over time and limiting any perceived new-technology risk. Commercial DFC based powerplants have been available since 2003, and large fuel cell parks based on multiple DFC3000 systems are becoming more common in bulk power generation applications. The largest such system so far is a 59 MW system consisting of twenty one DFC3000 powerplants, below.

FCE's DFC-based carbon capture concept has been studied analytically and in single cell tests with internal funds and support from the US Environmental Protection Agency. FCE is currently being funded by the US Department of Energy to conduct detailed system cost and performance studies, as well as bench scale stack tests to demonstrate to concept. The next step after these tests will be to demonstrate the technology at MW scale with a capture system based on one of FCE's MW-scale products. FCE is exploring various opportunities to establish this type of demonstration project.

59 MW Powerplant based on Twenty One DFC3000 Systems
Project developed by POSCO, Korea Hydro Nuclear Power Co. (KHNP) and Samchully Gas Co in South Korea is an example of large systems based on 2.8MW DFC3000