CRITICAL NATIONAL NEED IDEA

WHITE PAPER: Low-cost Coal to Hydrogen for Electricity with CO2 Sequestration

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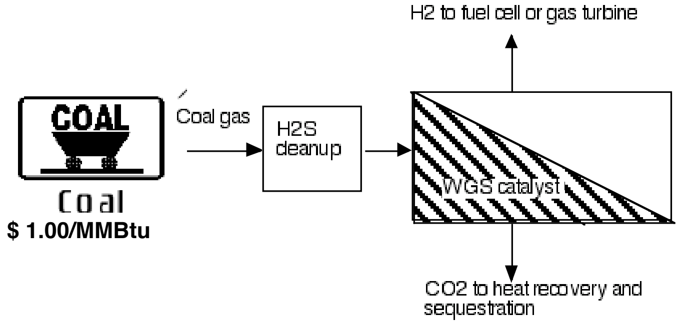
The third of the challenges President Obama highlighted in his inaugural address was that "each day brings further evidence that the ways we use energy strengthen our adversaries and threaten our planet." This white paper addresses the problem and suggests a general approach to solving it.

The average cost of electricity in Oakland county, Michigan, is 10.64¢/kwhr, or $31.17/ MMBtu. This is fairly typical for the US, as best I can tell. Much of this electricity is made from burning coal, a commodity costing $1 to $2.50/MMBtu, or less than 1/10 the price of electricity. The large difference between the cost of coal and value of the electricity produced with it supports the capital cost for electric generator building, the maintenance cost of electric distribution, and the small profit distributed to utility company stock-holders. While it is desirable to switch to a cleaner-burning alternative, like natural gas or oil, both resources are in short supply, and largely imported from outside the US. Further, their price is out of line with current electric rates. Current gas to electric generators are only about 40% efficient, and when natural gas prices rise above $12/MMBtu, as they did last summer, electric production from natural gas becomes unprofitable even at 0% financing of capital expenditures and zero dollars left for stock-holders or repair of the grid. Oil-based generation, and regenerable generation is even less cost competitive. One approach is to switch to dramatically raise the price of electricity, but I would like to suggest a particular version of clean coal that, I think, will provide major benefits at a modest price.

I would like to suggest an a new version of coal gasification that uses membrane –reactors to extract hydrogen from the coal gas, where the hydrogen is used to feed high temperature fuel cells or gas-turbine electric generators, and where the waste carbon is sequestered. The result is identical to the cancelled FutureGen project with the difference being, I believe, lower cost and higher efficiency. The general scheme is shown in the figure below. The first step shown is coal gasification. This is done by one of the several attractive coal gasification designs that are commercially mature. A particularly attractive one of these, the GE system, produces coal gas at about 800 psi., with a hydrogen content approaching 40% and a significant CO (carbon monoxide) content, and the rest, largely CO_2 (carbon dioxide). In current FutureGen designs, the CO is converted to hydrogen and CO_2 through a water-gas-shift (WGS) reactor, and the CO_2 is extracted at low pressure. For sequestration, the CO_2 is repressurized in a compressor bank. As shown below, the new approach would use the current gasification output and would then scrub the raw coal gas of H_2S. After that, we would cool it (making steam in the process), and perform the water gas shift (WGS) reaction in a membrane reactor of the sort that my company, REB Research & Consulting has been developing for the last 15 years.

A membrane reactor like the one shown below combines, in one vessel, a membrane extractor for hydrogen with the WGS catalyst that helps turn CO and steam into hydrogen and CO_2. By making the hydrogen in a membrane reactor, the equilibrium range of temperatures and pressures for hydrogen generation is expanded greatly by the extraction of hydrogen (1). Thus, fewer stages, and fewer heat exchangers would be necessary than for the ordinary reactor chain. Because there are fewer components, and less complexity, it should be possible to scale this design to smaller sizes and still maintain economical operation. Further the CO_2 is delivered at much higher pressure, and this should make for easier, cheaper sequestration.



As a good estimate, both the capital ad energy cost of sequestration will be proportional to the horse-power of the compressor bank, and this will be proportional to the volume of gas that enters. We can expect that this volume and horse-power will be decreased by quite a lot through the use of a membrane reactor because of the higher pressures of the CO_2 heading to the compressor. For the process shown, the CO_2 will be delivered to the compressor at the full gassifier pressure, about 800 psi. This high pressure CO_2 is easily compressed to 1000-2000 psi for liquefaction, transport and disposal in underground gas wells.

We believe that CO_2 disposed of in such wells will be removed from the biosphere for at least 100,000,000 years. My argument for this is that, if the gas in the wells now is over 100,000,000 years old, the wells must have at least this much retention time. Further, it seems that disposal in gas wells can have a positive value to the nation by helping to pressurize the underground reservoir, and thus helping enhance natural gas recovery from communicating well-heads. As the benefit is mostly felt by the owner of the wells, we can hope to sell the pressurized CO_2 at a profit to those owners. We will probably want to clean the CO_2 first of whatever residual hydrogen it contains, but this cleaning step should be far cheaper with high-pressure gas than with gas that begins at lower pressure. It seems possible that a simple polymeric membrane will be all that is required to strip the CO_2 of remaining hydrogen.

The hydrogen pressure from the membrane reactor will be lower than that from an ordinary gassifier. This is a slight disadvantage for use of the gas in gas turbine electric generators, but it is not a major disadvantage. Normal turbines operate at only 12 atm., approximately, or 180 psi. That is, at pressures significantly below 800 psi. The low hydrogen pressure is a major advantage for use in high temperature fuel cells. Fuel cells and turbines can be damaged by use with excessive feed pressures.

Direction, Partners, Preliminary work:

We would like to test a membrane reactor that would be about 10 feet tall and 8" in diameter for the purpose of generating the hydrogen for a 1-2 MW clean-coal electricity generator. This reactor would contain 1000- membranes, and a complete 350 MW FutureGen generator would require 250 such reactors. I have begun the process of building and testing a single disc membrane reactor that would be 8" in diameter and would have the same geometry, connections, and flow pattern as the 1000 membrane version. The development of the membranes for this reactor was done over the last 4-5 years with researchers at NETL, the National Energy Technology Laboratory, at LANL, at Iowa State University (Ames, IA) and Ames Lab, and at WRI, the Western Research Institute. We've sent the one membrane version of the membrane reactor to WRI for testing with the output from their low-pressure, 5 ton/day coal gassifier. The first results are good, but the test only lasted a few minutes before a gasket leaked. We've ordered new gaskets, and assuming this test goes well with them, we would like to test a multiple disc version on a higher-pressure coal gassifier run by NETL. In the meantime, we are continuing catalyst work that has been going on in cooperation with researchers at BASF, New Jersey (Englehard laboratories).

Our collaborators agree that this process seems like a worthwhile, evolution to the original FutureGen design. The advantages over earlier designs seem significant: we should be able to reduce the capital cost, and profitability of clean electric generation, and we should be able to make attractive generators at a lower power-generation point. We would like funding DoE to continue our development. We will probably continue developent with or without this funding, as we think the idea makes sense, but DoE funds are needed for real scale-up and for test-time on a higher-pressure gassifier.

References:

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2. R. E. Buxbaum, "Membrane Reactor Advantages for Methanol Reforming and Similar Reactions," Separation Science and Technol., 34 (1999) 2113-2123.

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