Coal Energy Conversion via Combustion in Supercritical Aquifer Water:
An Approach to Electric Power Generation without Atmospheric Emissions

J.R. Heberle, R.B. Bell, A.H. Berger, C.F. Edwards
Advanced Energy Systems Laboratory, Department of Mechanical Engineering, Stanford University

Motivation
Coal is a plentiful, domestic energy resource that accounts for one-half of U.S. electricity generating capacity and one-third of U.S. carbon dioxide emissions. Because of its importance, there is a critical need to find ways to use coal in a more efficient and environmentally sound manner.

System Concept
Instead of separating and sequestering CO₂, we propose to combine the energy transformation system with the sequestration medium by using aquifer water as a reaction moderator for the combustion process. Specifically, we consider using supercritical water to reform the coal into a wet supercritical fuel, combusting that fuel in a high-pressure, high-temperature environment suitable for driving a heat engine, and equilibrating the carbonated water to aquifer conditions before re-injection. Our aim is to achieve an efficient method of coal energy conversion that has no matter transfer to the atmosphere and that sequesters the carbon from the coal in the aquifer at near chemical equilibrium—and therefore non-tranquil—conditions.

System Analysis
A thermodynamic systems analysis has been performed based on the flow sheet shown below.

- ASU details are not modeled except for the high pressure liquid oxygen pump (which is not part of a standard cryogenic ASU). The work input requirement is specified according to reported state of the art values.
- Since the internal details of the SCWO system are not required for an equilibrium systems analysis, only its inlet and outlet states are considered.

The table below gives the flow rates required for a system of 500 MW scale along with the coal-specific flow rates. Of particular interest are the relative proportions of coal, oxygen, SCWO water, and the total water requirement for CO₂ dissolution. Performance of the system with 1800K combustor exit temperature is summarized in the table to the right below.

Real Solution Property Data:
Accurate thermodynamic property data are needed to calculate the flows in the supercritical water system and the amount of water needed to dissolve all of the CO₂ produced. This is being approached using a Leidenfrost-Jacobson style mixture model for the fundamental relation of the mixed CO₂-H₂O system in the single-phase region. A Peng-Robinson mixture model is used for predicting vapor-liquid equilibrium.

Isobars for a 10 mol% CO₂ solution are shown on r-T and h-T diagrams below for three property calculation methods: as a mixture of ideal gases, as an ideal solution of real fluids (as presently used in the system model), and as a real mixture of real fluids. At low temperatures (below the critical point of water) the actual specific enthalpy of the mixture is above that of an ideal solution. As a result, the specific work with respect to combuster fluid flow will be lower than in the current model, and the water flow rate through the combuster required for a chosen outlet temperature will be higher in the results shown.

Conclusion
Coal processing is divided into a reformer and combuster so that inorganic solids may be removed at a low temperature. The reformer will deliver a single-phase supercritical water solution of syntheses fuel to the combuster.

Work on this component is being performed by B. J. Kim and colleagues in the group of Professor R. E. Mitchell.

Supercritical Combustor:
The supercritical combuster accepts the synthesis fuel solution from the reformer, brings it to chemical equilibrium, and delivers the products at high temperature for use by the heat engine. Since both the fuel (ultimately coal) and the oxidizer (from the ASU) have significant costs, the combuster should operate near stoichiometric conditions and with maximum outlet temperature.

Our approach follows a gas turbine based design paradigm wherein fluid mechanics is used to achieve reaction stabilization, overall fluid mixing, and control of heat product interactions with the liner wall. Shown below is a conceptual schematic of the design currently being developed, including integration of the requisite heat exchange surface with the helium working fluid of the Brayton topping cycle.

Special thanks to the Global Climate & Energy Project (GCEP) for its continued support and funding of this research.