Integration of Coal Energy Conversion with Aquifer-Based Carbon Sequestration

Approach to Electric Power Generation with Zero Matter Release to the Atmosphere

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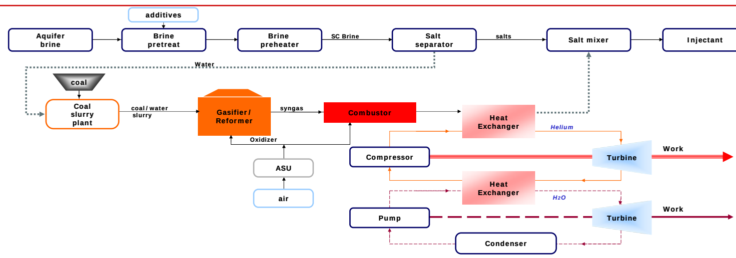
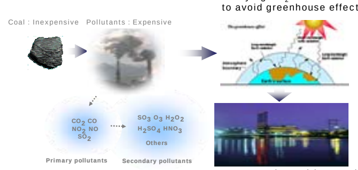
Proposed System - The Concept

- Brine from an aquifer is preheated and desalinated before introduction into the system
- Preheated and desalinated water from the aquifer is combined with pulverized coal to form a dilute slurry
- The slurry is partially oxidized in a reformer maintained at supercritical water conditions, producing compounds that are miscible in supercritical water
- Inorganic solids are separated out of the system, carbonaceous solids are recycled to the reformer, the sythesis gas is passed to a combustor
- The synthesis gas is combined with the remaining oxidizer, completing the chemical-to-sensible energy conversion
- The hot combustor products are used to drive a heat engine that produces work, cooling the hot product stream in the process
- The product stream is cooled further via heat integration with the incoming brine
- The previously separated salts are reintroduced into the cooled product stream (or sold if there is commercial value for the salt)
- The cooled solution, a fully equilibrated, single-phase brine solution carbonated to just below CO_2 saturation conditions, is injected back into the aquifer

Proposed System - Aquifer-Based Conversion System Sheme



Motivation



Objective:
To provide the understanding needed to make a coal-based power plant with no emissions a reality

Advantages of the Coal Conversion Scheme

- Maximally efficient power production while storing CO_2, indefinitely
- Feedstock flexibility
- Potential for hydrogen generation in significant quantities
- Near-zero emissions of NO_x, SO_x, trace metals, and particulates
- Size reduction of reactor vessel (compared to convention pulverized-coal fired systems

Why Coal Conversion in Supercritical Water?

- Nonpolar organic compounds and oxygen are miscible in all proportions in water above its **critical point** (647.3 K, 220.9 bar) and many salts are insoluble. Consequently,

✓ Small polar and nonpolar organic compounds released during coal extraction and devolatilization are completely miscible in SCW.
✓ Large organic compounds released during coal devolatilization hydrolyze in SCW yielding H2, CO, CO2, and low molecular weight hydrocarbons, without tar, soot or PAH formation.
✓ Sulfur, nitrogen and many trace elements in coals are oxidized to form insoluble salts in SCW.

- Coal gasification products will be dissolved in **supercritical water**, and any salts can be precipitated from the fluid mixture and removed from the system with the coal ash. There are no gaseous emissions.

Why Deep Saline Aquifers?

- Geological formations have been identified as being suitable for CO_2 storage. Estimates of the potential storage capacity at geologic sites range from 370 to 3700 billion tons of CO_2 (*Parson & Keith, Science* ***282****, 1998*).
- Deep saline aquifers are on the list of potential storage sites. Typical deep saline aquifer characteristics are:
  - Brine composition:

Chemical Species	Concentration (mass)
Water (H_2O)	92.11 %
Sodium Chloride (NaCl)	6.68 %
Calcium Chloride ($CaCl_2$)	0.757 %
Magnesium Chloride ($MgCl_2$)	0.209 %
Potassium Chloride (KCl)	0.121 %
Sodium Sulfate (Na_2SO_4)	500 ppm
Strontium Chloride ($SrCl_2$)	370 ppm
Sodium Bicarbonate ($NaHCO_3$)	250 ppm
Ammonium Chloride (NH_4Cl)	160 ppm
Total Dissolved Solids (TDS)	78900 ppm

- Temperatures: 308 - 376 K
- Pressures: 75 - 270 bar

Dissolved solids must be removed before the aquifer water is suitable for dissolving the coal conversion products.

Overall Project Objective and Tasks

The overall project objective is to provide the information needed to develop and commercialize the proposed coal-to-electricity scheme with *in situ* CO_2 sequestration.

- **Task I. Supercritical Water Coal Reforming**
  Research efforts are aimed at characterizing coal conversion rates under SCW conditions and determining the conditions that maximize the amount of chemical energy from the coal in the synthesis fluid.
- **Task II. Synthesis Fluid Oxidation**
  Research efforts center around the design and operation of the oxidation reactor and the heat exchanger needed to transfer energy to the heat engine.
- **Task III. Aquifer Interactions**
  Research activities are concerned with characterizing the impact of dissolved constituents in the water being returned to the aquifer on aquifer ecology.

Task I. Supercritical Coal Reforming

- Experimental activities will be undertaken to characterize the rates of extraction, devolatilization, gasification, and oxidation of coals in supercritical water conditions.
- The amount of oxygen required to just drive the endothermic gasification reactions will be determined.
- Conditions that maximize the amount of chemical energy from the coal in the synthesis fluid will be identified.
- Models for predicting thermodynamic and transport properties of key species in SCW media will be developed.
- Models for coal extraction and devolatilization and char gasification and oxidation in SCW environments will be developed.

Preliminary Analysis - Fuel Analysis

Coal composition

	As received %-wt	Dry basis %-wt
Moisture	1.97	-
Carbon	78.10	79.67
Hydrogen	4.12	4.20
Nitrogen	1.44	1.47
Chlorine	0.01	0.01
Sulfur	1.37	1.40
Ash	10.11	10.31
Oxygen (diff)	2.89	2.95
LHV (kJ/kg)		**23,475**

Mineral composition

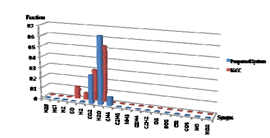
Oxidized species	wt-% of ash
SiO_2	42.7
Al_2O_3	39.0
Fe_2O_3	10.7
CaO	1.71
MgO	0.57
TiO_2	1.86
K_2O	1.61
Na_2O	0.43
P_2O_5	0.94

This analysis is for Lower Kittanning coal, a lv-bituminous coal from Pennsylvania

The temperature-dependent specific heats of the ash components are used to determine the specific heat of the ash.

Preliminary Analysis - Synfuel Properties

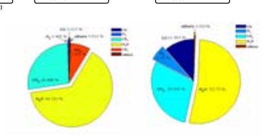
- 20% solids slurry, sufficient oxygen added to gasifier to maintain the system temperature



- The gasifier in the aquifer-based system is maintained at 221 atm, 650 °C
- The gasifier in the IGCC system is maintained at 29 atm and 1427 °C

Preliminary Analysis - Synfuel Properties

	Aquifer-Based conversion system	Typical IGCC system
States	221 atm, 650 K	29 atm, 1700 K
LHV [MJ/100Kg of coal]	1263.29	778.98

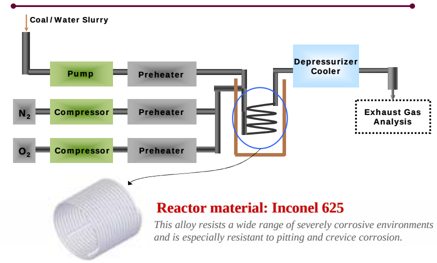


Preliminary Analysis - System Comparison

	Aquifer-Based conversion system	Typical IGCC system
Fraction solid in the slurry	0.295	0.425
Moles O_2 added to the gasifier	4.492 kmol	6.171 kmol
Moles of O_2 added to the combustor	3.373 kmol	1.534 kmol
Maximum system efficiency*	42.0 %	43.9 %

* *Not including work for pumps and compressors*
Ideal devices

Experimental Setup for Coal Reforming Studies



Reactor material: Inconel 625
This alloy resists a wide range of severely corrosive environments and is especially resistant to pitting and crevice corrosion.

Conclusions

Advantages of the proposed aquifer-based, supercritical water coal conversion scheme for electric power generation relative to current and other proposed power generation systems include:

- maximally efficient power production while storing CO_2 products in indefinitely stable forms,
- near-zero traditional air pollutant emissions, and
- size reduction of reactor vessel (compared to conventional pulverized coal-fired systems).

This investigation aims to lay the foundation for an efficient coal energy option with no matter release to the atmosphere and in which all combustion products, in particular, carbon dioxide, are pre-equilibrated in aquifer water before injection into the subsurface.