AN OVERVIEW OF HYDROGEN PRODUCTION FROM KRW OXYGEN-BLOWN GASIFICATION WITH CARBON DIOXIDE RECOVERY*

by

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All the process elements are commercially available to operate coal gasification so that it can produce electricity, hydrogen, and carbon dioxide while delivering the same quantity of power as without H_2 and CO_2 recovery. To assess the overall impact of such a scheme, a full-energy cycle must be investigated (Figure 1). Figure 2 is a process flow diagram for a KRW oxygen-blown integrated gasification combined-cycle (IGCC) plant that produces electricity, H_2, and supercritical CO_2. This system was studied in a full-energy cycle analysis, extending from the coal mine to the final destination of the gaseous product streams [Doctor et al. 1996, 1999], on the basis of an earlier study [Gallaspy et al. 1990]. We report the results of updating these studies to use current turbine performance.

The location chosen, in the midwestern United States, is 160 km from Old Ben #26 mine, which ships 3,866 tonnes of Illinois #6 coal daily by diesel locomotive. Three parallel gasifier trains, each capable of providing 42% of the plant's 456-MW nominal capacity, use a combined total of 3,488 tonne/d of ¼-in. prepared coal. The plant produces a net 134 MW of power directly, plus 3.71×10^6 Nm^3/d of a hydrogen stream that contains all the inert argon but otherwise is 99.999% pure. This hydrogen product is sent 100 km away (by pipeline, at 34 bar), where it is used to generate 330 MW of additional power, for a net production of 455 MW with all the losses in the cycle accounted for accurately. The plant also produces 3.18×10^6 Nm^3/d of supercritical CO_2 at 143 bar; the CO_2 is sequestered in enhanced oil recovery (EOR) operations 500 km away.

A 100-km hydrogen pipeline design was prepared, and costs were estimated for a high-purity hydrogen flow of 3.71×10^6 Nm^3/d through a 343-mm pipe at 30 bar. There appears to be no economic justification for going to higher pipeline pressures. An internal study of the costs for delivering energy as methane vs. energy as H_2 showed a 13% advantage for methane at 500 psi, rising to a 46% advantage at 800 psi. Economic assumptions were for an availability of 95% and capital recovery of 12%, to yield transmission costs of $\$0.171/10^3$ std. ft^3, or \$0.564/GJ. It is very important to observe that the high costs of a dedicated pipeline dictate the need for high availabilities.

Separating the hydrogen for fuel cells and then using an optimistic, but technically achievable, performance efficiency yields an impressive gain in overall process efficiency. This gain offsets the losses in efficiency from the recovery of CO_2. Hence, measured against a base case with no CO_2 recovery, consumers receive the identical amount of power (in MW) from a given input of coal.

Carbon dioxide as a supercritical product (143 bar) can be recovered from coal gasification and power production. Where there is an EOR market, this is actually profitable. Hydrogen can be recovered from coal gasification at high purity (99.999%) for sale; however, the need for high pipeline utilization is critical. Pressures of 35 bar are optimal. Fuel-cell conversion efficiencies must approach 77% to match the base-case output. At present, solid-oxide fuel cell (SOFC) efficiencies are 53-58%, while alkaline fuel cell efficiencies are near 70%.

For this study, the three major greenhouse gases — CO_2, CH_4, and N_2O — were followed throughout the cycle. A CO_2 emission rate of 1 kg CO_2/kWh was assumed for power purchases outside the fence of the IGCC plant to estimate the impact of these emissions (see summary in Table 1). While the base-case IGCC plant with no modifications is nearly 28% lower in CO_2 emissions than current U.S. grid emissions, a reduction from 0.72 kg CO_2/kWh down to 0.16 kg CO_2/kWh is technically feasible with this scheme. This low-greenhouse-impact strategy is not without a high economic cost; uncertainty about the impact is linked to uncertainty about the sales value of hydrogen and future disposal charges for CO_2.

Table 1. Materials flow for O_2-blown IGCC (glycol, CO_2, and H_2S recovery; PSA hydrogen recovery; turbine topping cycle; solid oxide fuel cell @ 65%; basis: electric power delivery 100 km from station)

Flow Parameter	Nm^3/d	ton/d	kg/h	Power MW	CO_2 kg/h	CH_4 kg/h	N_2O kg/h
MINING AND TRANSPORT							
Coal methane emissions						566	
Mining operations and preparation				-2.61	2,614		0.00003
Transport by rail (161 km)				-0.21	905		0.66265
Subtotal				**-2.82**	**3,520**	**566**	**0.66267**
POWER PLANT							
Coal preparation (0 in. × ¼ in.)		3,845	145,341	-0.85			
O_2 by cryogenic separation	8,937,000	2,347	88,717	-29.29			
Steam from heat recovery steam generator			17,254				
Gasifier island				-2.90			
Solid waste		492	18,598				
Sulfur		78	2,948				
SO_2 (gasifier only)		6.92	262		6,157		**unknown**
Glycol circulation				-5.80	320,383		
Glycol refrigeration				-4.50			
Power recovery turbines				3.40			
CO_2 compression to pipeline (143 bar)	3,178,000			-17.30	-260,055		
H_2 PSA purification to pipeline (31 bar)	3,710,000			-3.18			
H_2 cryo-storage for pipeline				-0.92			
Power island				-3.09			
Miscellaneous (5%)				-3.07			
Subtotal				**-67.50**	**66,485**	**0**	**unknown**
Power							
Gas turbine				501.78			
Air compressor and losses				-347.77			
Steam turbine				47.80			
Gross Power Subtotal				**201.81**			
Net Power				**134.30**			
CO_2 PIPELINE AND SEQUESTERING	3,178,000				260,055		
Pipeline booster stations				-1.64	1,637		0.00002
Geological reservoir (1% loss)					-257,454		
Subtotal				**-1.64**	**4,238**	**0**	**0.00002**
H_2 PIPELINE OUTLET (21 bar)	3,710,000						
H_2 3-stage SOFC (65% of 460.0 MW)				299.00			
Steam generator (85% of 36.8 MW)				31.28			
Subtotal				**330.28**	**0**	**0**	**0.00000**
POWER TRANSM'N LOSS (-3.5%)				**-4.70**			
NET ENERGY CYCLE		**0.163**	**kg CO_2/kWh**	**455.42**	**74,242**	**566**	**0.66269**
NET ENERGY CYCLE (Base Case)		**0.723**	**kg CO_2/kWh**	**456.46**	**330,060**	**566**	**0.66267**

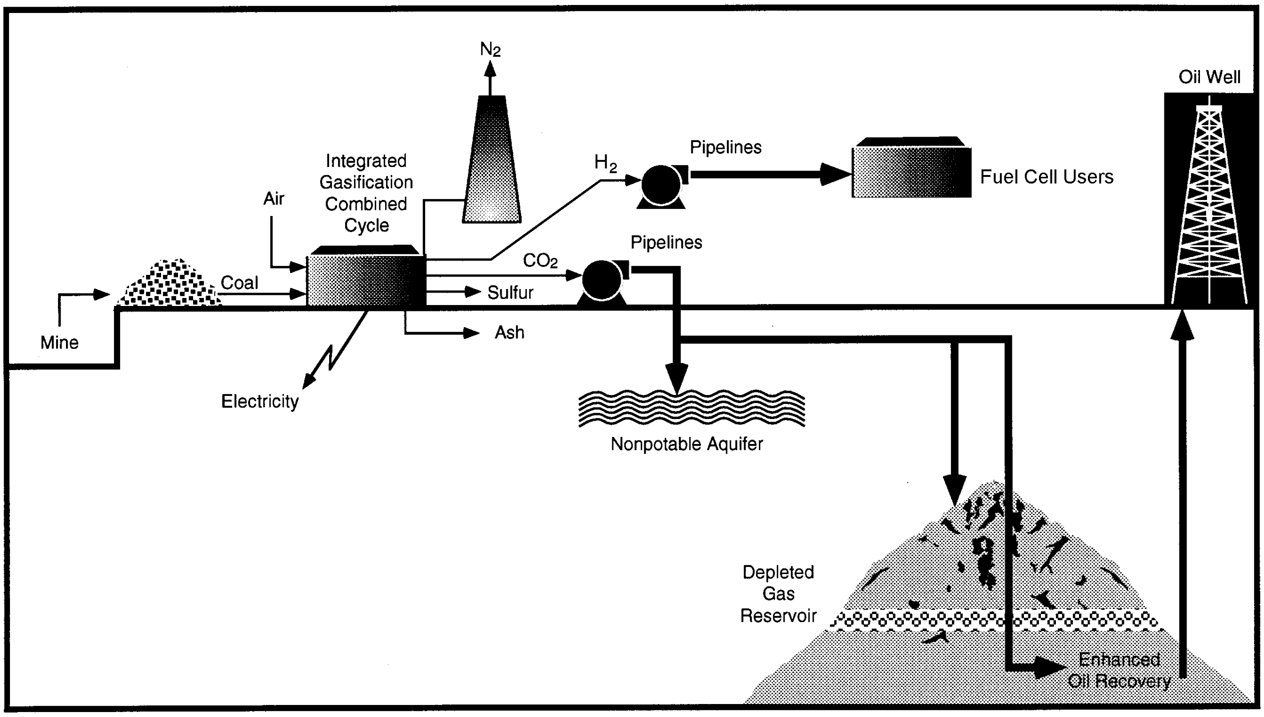

Figure 1. Full-energy cycle for the production of electricity, hydrogen, and carbon dioxide.

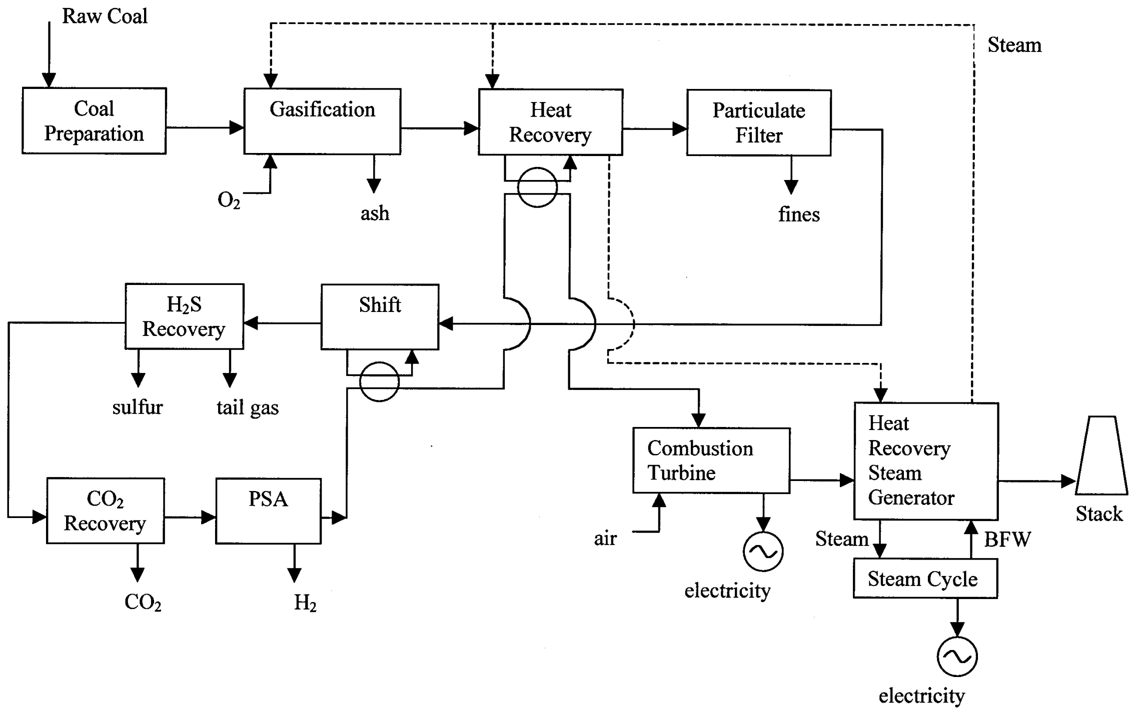

Figure 2. Integrated gasification combined-cycle plant for producing electricity, CO_2, and H_2.

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