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Production of High Purity Hydrogen from Domestic Coal: Assessing the Techno-Economic Impact of Emerging Technologies

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Disclaimer

Production of High Purity Hydrogen from Domestic Coal: Assessing the Techno-Economic Impact of Emerging Technologies

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List of Acronyms and Abbreviations

AGR	Acid gas removal
AR	As received
ARR	Annual required revenue
ASU	Air separation unit
BEC	Bare erected cost
CC	Convective cooler
CCS	Carbon capture and sequestration
CGCU	Cold gas clean-up
CO	Carbon monoxide
CO_2	Carbon dioxide
DOE	Department of Energy
DSRP	Direct sulfur reduction process
EOR	Enhanced oil recovery
GAOC	Gross annual operating cost
GHG	Greenhouse gas
H_2S	Hydrogen sulfide
HHV	Higher heating value
HTHM	High temperature hydrogen membrane
M	Thousand
MM	Million
MW	Megawatt
MWh	Megawatt hour
NAOC	Net annual operating cost
NETL	National Energy Technology Laboratory
O&M	Operation and maintenance
PSA	Pressure swing adsorption
R&D	Research and development
RSC	Radiant syngas cooler
RSP	Required selling price
SCFD	Standard cubic feet per day
SCOT	Shell Claus offgas treating
SMR	Steam methane reforming
TDS	Transport desulfurizer
TPD	Ton per day
TS&M	Transportation, storage and monitoring
WGCU	Warm gas clean-up
WGS	Water-gas shift

NETL Forward

The goal of the Department of Energy's (DOE) Fossil Energy Research, Development and Demonstration is to ensure the availability of ultra-clean, abundant, low-cost, domestic electricity and energy (including hydrogen) to fuel economic prosperity and strengthen energy security. A broad portfolio of technologies is being developed within the Clean Coal Program to accomplish this objective. Ever increasing technological enhancements are in various stages of research, and multiple paths are being pursued to create a portfolio of promising technologies for development, demonstration, and eventual deployment.

Consistent with those objectives, this report assesses the improvements in cost and performance of hydrogen production from domestic coal when employing emerging technologies funded by DOE. This analysis specifically evaluates replacing conventional acid gas removal (AGR) and hydrogen purification with warm gas cleanup (WGCU) and a high-temperature hydrogen membrane (HTHM) that meets DOE's 2010 and 2015 performance and cost research and development (R&D) targets.

This report provides a detailed summary of the cost and performance for the matrix of cases shown in Table F-1. The primary value of these results is in the relative relationship to each other and to the reference state-of-the-art (SOA) Case No. 1.

Table F-1 Case Configurations

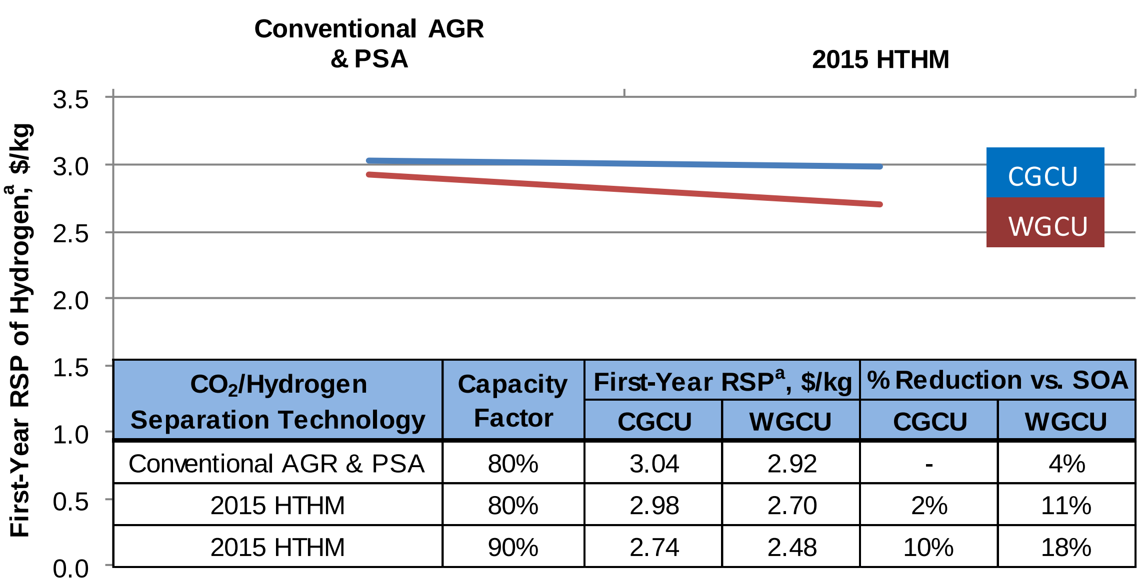
<table>
<tr><th>Case No.</th><th>Syngas Cooling</th><th>Gas Cleanup</th><th>CO_2 Removal</th><th>Hydrogen Purification</th></tr>
<tr><td>1</td><td>Quench</td><td colspan="2">Conventional 2-Stage AGR</td><td rowspan="2">Pressure Swing Adsorption</td></tr>
<tr><td>2</td><td>Radiant-Convective</td><td>WGCU</td><td>Conventional 1-Stage AGR</td></tr>
<tr><td>3</td><td>Quench</td><td>Conventional 1-Stage AGR</td><td colspan="2" rowspan="2">2010 HTHM</td></tr>
<tr><td>4</td><td>Radiant-Convective</td><td>WGCU</td></tr>
<tr><td>5</td><td>Quench</td><td>Conventional 1-Stage AGR</td><td colspan="2" rowspan="2">2015 HTHM</td></tr>
<tr><td>6</td><td>Radiant-Convective</td><td>WGCU</td></tr>
</table>

Alternate Reporting of Results

The capital cost and required selling price (RSP) of hydrogen results are heavily dependent on the assumed owner's costs, finance structure, and RSP basis. This forward provides alternate RSP of hydrogen results consistent with the costing methodology used in NETL's 2010 Baseline Hydrogen Report [1]. Key differences in the updated methodology include, but are not limited to, the following:

- Use of a high-risk fuels financing structure requiring a 20 percent return on equity
- Reporting of costs as first-year RSP of hydrogen with an assumed escalation of 3 percent per year throughout the 30-year economic life of the plant
- Expanded owner's costs
- Addition of carbon dioxide (CO_2) transport and storage costs
- Updated coal prices, CO_2 emissions cost, and escalation rates of each

Figure F-1 provides first-year RSP of hydrogen utilizing the updated costing methodology for the key cases. Also shown is the additional benefit that can be afforded if R&D and operating experience could improve plant availability from 80 percent to 90 percent with minimal impact on cost or performance. Consistent with the conclusions of the report, the benefit achieved when WGCU and the 2015 HTHM are both incorporated in the coal-to-hydrogen plant exceeds the incremental benefit provided by each technology alone.



CO_2/Hydrogen Separation Technology	Capacity Factor	First-Year RSP[a], $/kg		% Reduction vs. SOA	
		CGCU	WGCU	CGCU	WGCU
Conventional AGR & PSA	80%	3.04	2.92	-	4%
2015 HTHM	80%	2.98	2.70	2%	11%
2015 HTHM	90%	2.74	2.48	10%	18%

[a] Assuming a 3 percent increase per year in RSP over 30-year economic life of the plant
[b] Cold gas cleanup

Figure F-1 First-Year Required Selling Price of Hydrogen Utilizing Updated Costing Methodology

Executive Summary

Concerns over energy security and global climate change lead to an enhanced interest in producing more of our energy from secure domestic resources in an environmentally responsible manner. Hydrogen as an energy carrier has a major climate change advantage in that the product of hydrogen combustion is water. Therefore, if the hydrogen can be produced with little or no emissions of carbon dioxide (CO_2), the overall life cycle greenhouse gas (GHG) emissions could be almost zero. Hydrogen can be produced using electric power via electrolysis of water or by using a carbonaceous resource to reduce water. Domestic coal is a readily available carbonaceous resource for this; furthermore, the production of hydrogen from coal is a proven technology at commercial scale. However, the production of hydrogen from coal produces CO_2 at a high rate relative to other fossil fuels due to coal's low hydrogen to carbon ratio. Once viable sequestration of CO_2 is proven, this can be managed by the capture and sequestration of the CO_2 produced during the conversion of the coal into hydrogen.

The U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) commissioned Noblis to update a previous study on hydrogen from coal to assess the potential impact of using membrane technology on the performance and costs of current state-of-the-art hydrogen production.

This study analyzes six process configurations for producing hydrogen from coal. All of the processes examined are based on the gasification of Illinois No. 6 bituminous coal in an oxygen-blown entrained flow slurry gasifier in which the oxygen is produced from a cryogenic air separation unit (ASU). The syngas undergoes cleaning to remove contaminants such as hydrogen sulfide, ammonia, and mercury, and also undergoes water-gas shift to convert much of the carbon monoxide into hydrogen. The resulting gas is sent to a purification section to recover hydrogen as a product and CO_2 to be transported to a suitable sequestration site. Residual fuel gas from the purification process along with heat recovered from gas cleaning is used to generate the electric power required by the plant's unit operations.

The differences in the six case configurations are in the choices of technology for four processing areas: syngas cooling, gas cleanup, CO_2 removal, and hydrogen purification. The specific technologies used in each of the six cases are shown in Table ES-1.

Case 1 represents the conventional coal to hydrogen approach using current technologies and the performance and costs of this case are used as the benchmark to measure the performance of the other cases. Case 2 represents an advanced configuration that uses warm gas cleanup (WGCU) in place of conventional cold gas cleaning and this is analyzed to quantify the impact of the WGCU on the conventional process using the pressure swing adsorption (PSA) system. Cases 3 and 4 incorporate high-temperature hydrogen membranes (HTHM) that meet the 2010 membrane target performance of the DOE Research & Development (R&D) program in place of PSA for hydrogen separation. Cases 5 and 6 represent HTHM configurations where the HTHM meets the 2015 target performance of the DOE R&D program. These HTHM targets are shown in Table ES-2.

Table ES-1 Case Configurations

<table>
<tr><th>Case No.</th><th>Syngas Cooling</th><th>Gas Cleanup</th><th>CO_2 Removal</th><th>Hydrogen Purification</th></tr>
<tr><td>1</td><td>Quench</td><td colspan="2">Conventional 2-Stage AGR[a]</td><td rowspan="2">PSA</td></tr>
<tr><td>2</td><td>Radiant-Convective</td><td>WGCU</td><td>Conventional 1-Stage AGR</td></tr>
<tr><td>3</td><td>Quench</td><td>Conventional 1-Stage AGR</td><td colspan="2" rowspan="2">2010 HTHM</td></tr>
<tr><td>4</td><td>Radiant-Convective</td><td>WGCU</td></tr>
<tr><td>5</td><td>Quench</td><td>Conventional 1-Stage AGR</td><td colspan="2" rowspan="2">2015 HTHM</td></tr>
<tr><td>6</td><td>Radiant-Convective</td><td>WGCU</td></tr>
</table>

[a] Acid gas removal

Table ES-2 HTHM Targets

	2010 Targets	2015 Targets
Hydrogen flux[a]	200 scfh/ft^2	300 scfh/ft^2
Membrane operating temperature	300–600 °C	250–500 °C
Pressure tolerance	400 psi	800–1000 psi
Sulfur tolerance	20 ppm	100 ppm
CO tolerant	Yes	Yes
WGS activity	Yes	Yes
Hydrogen purity	99.5%	99.99%

[a] Hydrogen flux where the partial pressures of hydrogen are 150 psi and 50 psi for the non-permeate and permeate sides, respectively.

Table ES-3 summarizes the overall results of the analyses for the six cases. The reference Case 1 can produce hydrogen with an overall efficiency of 55.9 percent (HHV) at a required selling price (RSP) of $2.30/kg. Costs are in January 2008 dollars. Replacing quench with radiant cooling and cold gas cleanup (CGCU) with WGCU (Case 2) increases the efficiency to 61.7 percent and increases the RSP to $2.22/kg. In these two cases a penalty of $28/tonne of CO_2 is imposed because, although small, both plants do emit some CO_2. Replacing PSA with the 2010 target HTHM (Case 3) but still using quench and CGCU has a slight effect on efficiency compared to the reference case. In Case 4, where radiant cooling, WGCU, and the 2010 target HTHM are used, the efficiency increases because of recovery of waste heat. In Case 5, where

CGCU and the 2015 target HTHM are used, the efficiency is improved compared to Case 3 and the RSP is reduced. In Case 6, the 2015 target HTHM and WGCU are used and the efficiency is the highest of the cases and the RSP of hydrogen is the lowest. This reduction in RSP of hydrogen represents an 11 percent reduction compared to the reference PSA case.

Table ES-3 Summary of Results: Hydrogen from Coal Cases[1]

	Case 1 Reference PSA	Case 2 PSA WGCU	Case 3 2010 HTHM CGCU	Case 4 2010 HTHM WGCU	Case 5 2015 HTHM CGCU	Case 6 2015 HTHM WGCU
Coal (TPD AR)	6,000	6,000	6,000	6,000	6,000	6,000
H_2 Production (MMSCFD)	240.7	265.6	242.0	268.8	246.2	274.4
Efficiency (%HHV)	55.9	61.7	56.2	62.4	57.2	63.7
Capital Cost ($MM 2008)	1,216	1,305	1,331	1,351	1,240	1,250
Levelized RSP[a] ($/kg), Capacity Factor 80%	2.30	2.22	2.41	2.23	2.23	2.04
Plant Carbon Emissions (TPD)	335	375	0	0	0	0

[a] Includes costs associated with a CO_2 monitoring fund, but excludes CO_2 transport and storage costs.

Because of the use of oxygen-fired combustion in Cases 3, 4, 5, and 6, the carbon emissions from these cases are essentially zero.

To place these costs of hydrogen from coal in context, the costs of hydrogen from steam methane reforming (SMR) with CO_2 capture were estimated. The SMR analysis estimates that when the cost of natural gas is $7.30/MMBtu the resulting RSP of hydrogen would be $2.30/kg; that is equal to the RSP of hydrogen in the reference case. When natural gas cost is $6.20/MMBtu, the RSP of the hydrogen would be $2.04/kg; equivalent to the hydrogen RSP of Case 6.

In conclusion, this analysis indicates that domestic coal could be used as a feedstock for the production of high-purity hydrogen with resulting costs in the range $2.00 to $2.40 per kg for coal to hydrogen plants with a capacity factor of 80 percent. This cost is competitive with SMR of natural gas when the natural gas price is between $6.20 and $7.30/MMBtu. Utilization of advanced HTHM in combination with WGCU is estimated to improve the overall plant efficiency to be over 60 percent and to reduce the RSP of the hydrogen by about 11 percent compared to the reference current technology case.

Comparing reference Case 1 to Case 4 (WGCU and HTHM), there is an improvement in overall plant efficiency, with a slight decrease in hydrogen RSP. This implies that attainment of the 2010 targets for the membranes represents a break-even point to improve the overall performance compared to a PSA configuration, as long as the HTHM is coupled to gasifier waste

[1] NETL Forward to this report provides alternate reporting of RSP consistent with an updated costing methodology.

heat recovery and WGCU. Attainment of the 2015 membrane targets is projected in this analysis to further improve the efficiency and also reduce the resulting costs of hydrogen from coal when coupled with heat recovery and WGCU.

The rationale for using hydrogen as a potential energy carrier for transportation is to significantly reduce GHG emissions in the transportation sector compared to conventional petroleum. This requires that carbon capture and storage (CCS) be integrated into the coal to hydrogen conversion process. Cases 3, 4, 5, and 6 are shown with essentially zero carbon emissions, implying that 100 percent capture can be attained. Adding a cost for transportation, storage, and monitoring (TSM) of $15 per tonne of CO_2 would increase the RSP of hydrogen by about 34 cents for the six hydrogen cases.

The combination of WGCU, gasifier heat recovery, and the 2015 HTHM has a significant impact on increasing the efficiency of a coal to hydrogen plant compared to the conventional configuration. This analysis also indicates that the reduction in RSP of hydrogen between Case 1 and Case 6 at a constant capacity factor of 80 percent is over 11 percent. This result is dependent on the accuracy of estimating the costs of the advanced technologies, and there is uncertainty in this estimation because of the early stages of development of both WGCU and HTHM technologies. If the capacity factor of the advanced configurations can be increased from 80 percent to 90 percent through continuing R&D that result in improvements in gasifier refractory and burner life, for example, then the reduction in hydrogen RSP is significantly increased. In a best case scenario, with a 90 percent capacity factor for Case 6, the RSP of hydrogen is reduced to $1.87; a decrease of 19 percent compared to the base case.

Other developing technologies could also be incorporated into the hydrogen from coal configuration, including more advanced gasifiers and coal feed systems, ionic transport membranes for oxygen production, and advanced gas turbine technology. These have the potential to further improve the performance and economics of coal to hydrogen plants. Also, more detailed optimization of the HTHM configurations may positively impact the benefits of this technology. It is recommended that any additional systems studies include incorporation of these advanced technologies, better optimization of the HTHM, and more updated estimations of capital equipment costs for the developing processes.

1.0 Introduction

1.1 Background

Concerns over energy security and global climate change lead to an enhanced interest in producing more of our energy from secure domestic resources in an environmentally responsible manner. Hydrogen as an energy carrier has a major climate change advantage in that the product of hydrogen combustion is water. Therefore, if the hydrogen can be produced with little or no emissions of carbon dioxide (CO_2), the overall life cycle greenhouse gas (GHG) emissions could be almost zero.

Commercially, hydrogen is generally produced in bulk by steam reforming of natural gas. It can also be produced using electric power via electrolysis of water or by using a carbonaceous resource to reduce water. Domestic coal is a readily available carbonaceous resource for this; furthermore, the production of hydrogen from coal is a proven technology at commercial scale. However, the production of hydrogen from coal produces CO_2 at a high rate relative to other fossil fuels due to coal's low hydrogen to carbon ratio. Once viable sequestration of CO_2 is proven, this can be managed by the capture and sequestration of the CO_2 produced during the conversion of the coal into hydrogen.

The U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) commissioned Noblis to update a previous study on hydrogen from coal to assess the potential impact of using emerging technologies on the technical performance and costs of hydrogen production from domestic coal. The emerging technologies analyzed in this report are warm gas clean up (WGCU) for synthesis gas sulfur removal and high temperature hydrogen membranes (HTHM) for separation of pure hydrogen from the other species in the synthesis gas.

2.0 Approach

2.1 Scope of Systems Studies

This study analyzes six process configurations for producing hydrogen from coal. All of the processes examined are based on the gasification of Illinois No. 6 bituminous coal in an oxygen-blown entrained flow slurry gasifier, in which the oxygen is produced from a cryogenic air separation unit (ASU). The syngas undergoes cleaning to remove contaminants such as hydrogen sulfide, ammonia, and mercury, and also undergoes water-gas shift to convert much of the carbon monoxide into hydrogen. The resulting gas is sent to a purification section to recover hydrogen as a product and carbon dioxide to be transported to a suitable sequestration site. Residual fuel gas from the purification process, along with heat recovered from gas cleaning, is used to generate the electric power required by the plant's unit operations.

The differences in the six case configurations are in the choices of technology for four processing areas: syngas cooling, gas cleanup, CO_2 removal, and hydrogen purification. The specific technologies used in each of the six cases are shown in Table 1 below:

Table 1 Case Configurations

Case No.	Syngas Cooling	Gas Cleanup	CO_2 Removal	Hydrogen Purification
1	Quench	Conventional 2-Stage AGR[a]		PSA
2	Radiant-Convective	WGCU	Conventional 1-Stage AGR	
3	Quench	Conventional 1-Stage AGR	2010 HTHM	
4	Radiant-Convective	WGCU		
5	Quench	Conventional 1-Stage AGR	2015 HTHM	
6	Radiant-Convective	WGCU		

[a] Acid gas removal

For each case, a conceptual process design and cost estimate was prepared based on a steady-state process simulation done using Aspen Plus.

Case 1 represents the conventional coal to hydrogen approach using current technologies and the performance and costs of this case are used as the benchmark to measure the performance of the other cases. Case 2 represents an advanced configuration that uses WGCU in place of conventional cold gas cleaning. It also includes radiant syngas cooling and a convective cooler following the gasification, rather than a water quench. Cases 3 and 4 incorporate HTHMs that meet the 2010 target performance of the DOE Research & Development (R&D) program in place of pressure swing adsorption (PSA) for hydrogen separation. Cases 5 and 6 represent HTHM configurations where the HTHM meets the 2015 target performance of the DOE R&D program. These 2010 and 2015 HTHM performance targets are shown in Table 2.

Table 2 HTHM Performance Targets

	2010 Targets	2015 Targets
Hydrogen flux[a]	200 scfh/ft^2	300 scfh/ft^2
Membrane operating temperature	300–600 °C	250–500 °C
Pressure tolerance	400 psi	800–1000 psi
Sulfur tolerance	20 ppm	100 ppm
CO tolerant	Yes	Yes
WGS activity	Yes	Yes
Hydrogen purity	99.5%	99.99%.

[a] Hydrogen flux where the partial pressures of hydrogen are 150 psi and 50 psi for the non-permeate and permeate sides, respectively.

2.2 Conceptual Coal to Hydrogen Process Designs

Figure 1 shows a block flow schematic for the Case 1 reference plant configuration. After gasification, the syngas undergoes a water quench and raw shift. The synthesis gas is then cooled, mercury is removed, and the gas is cleaned using conventional gas cleaning technology. Two-stage physical solvent acid gas removal removes the hydrogen sulfide (H_2S) in the first stage and bulk CO_2 removal is accomplished in the second stage. The H_2S is sent to a Claus/SCOT combination for sulfur recovery and the CO_2 is dehydrated and compressed to 2,200 psi for subsequent sequestration. The cleaned syngas is sent to PSA, where the impurities in the hydrogen (mostly carbon monoxide) are retained on the adsorbent and the purified hydrogen passes through. The hydrogen, at system pressure (750 psi), is collected as the product. The PSA let-down gas is combined with a slip stream from the acid gas removal (AGR) section and sent to a boiler/superheater to produce steam that is sent to a steam turbine for electric power generation to supply all parasitic plant power requirements. The flue gas from the boiler contains CO_2 and water, and this small amount is vented to the atmosphere. Overall carbon capture is 90 percent.

Figure 2 shows a block flow diagram for the Case 2 configuration. In this configuration, after gasification, the raw syngas is passed to a radiant gas cooler and convective cooler to recover the sensible heat. Also in this configuration, the cold gas cleanup, acid gas removal, and Claus tail gas treatment processes are replaced with advanced WGCU that includes chloride removal, transport desulfurizer (TDS) and regenerator, and direct sulfur reduction (DSRP) processes [2]. Exiting the gasifier, raw syngas is cooled to approximately 950 °F in preparation for hydrogen chloride removal in a packed bed of Na_2CO_3 (trona). Hydrogen chloride is removed according to the reaction:

$$2\ HCl + Na_2CO_3\,(s) \leftrightarrow 2\ NaCl\,(s) + CO_2 + H_2O$$

The syngas is cooled in preparation for contact with zinc oxide sorbent, which reacts with H_2S and COS to remove them from the syngas. The desulfurization reactions are:

$$H_2S + ZnO\ (s) \leftrightarrow ZnS\ (s) + H_2O$$
$$COS + ZnO\ (s) \leftrightarrow ZnS\ (s) + CO_2$$

Desulfurized syngas is then sent to water gas shift (WGS). Ammonia is removed by scrubbing with water. An activated carbon filter bed is used for mercury removal. To regenerate the ZnO sorbent for the TDS, ZnS transfers to the TDS regenerator, where it contacts with oxygen and is oxidized at 1,100 °F according to the reaction:

$$ZnS\ (s) + 3/2\ O_2 \leftrightarrow ZnO\ (s) + SO_2$$

The SO_2 (sour gas) that is generated flows to the DSRP for sulfur recovery, and the regenerated sorbent is returned to the transport desulfurizer. A small portion of clean fuel gas exiting the TDS is used as reducing gas in the DSRP where sour gas is reduced, forming elemental sulfur product:

$$SO_2 + 2\ H_2 \leftrightarrow 2\ H_2O + S$$
$$SO_2 + 2\ CO \leftrightarrow 2\ CO_2 + S$$

DSRP tail gas, containing water and CO_2, is compressed and recycled to the transport desulfurizer. The transport desulfurizer has the advantage of eliminating solvent regeneration (and therefore steam heat duty) in the physical solvent reboiler. Instead, acid gas, deposited on a solid zinc oxide sorbent, is oxidized during sorbent regeneration.

The syngas, cleaned of sulfur, ammonia, and mercury, is sent to physical solvent acid gas removal (AGR) for bulk CO_2 removal. The CO_2 is dehydrated and compressed to 2,200 psi for subsequent sequestration. The hydrogen in the cleaned syngas is separated in the PSA unit. The hydrogen, at system pressure (750 psi), is collected as the product. The PSA tail gas, together with a slip stream of syngas from CO_2 separation, is sent to an atmospheric boiler/superheater where the gas is combusted in air to produce steam. This is sent to a steam turbine for electric power generation. The flue gas from the boiler is vented to the atmosphere. Overall, the configuration captures 90 percent of the carbon.

Figure 3 shows a schematic for the Case 3 configuration. This configuration uses a quench gasifier followed by COS hydrolysis, ammonia, and mercury removal. A single-stage physical solvent AGR unit is used to remove the H_2S and the syngas is then shifted. The clean shifted syngas is then expanded to conform to the HTHM operating pressure of 400 psi, which corresponds to the 2010 target. The syngas, consisting of CO_2, nitrogen, carbon monoxide (CO), and hydrogen, is then sent to three stages of HTHM for hydrogen separation. The HTHM is assumed to have WGS activity. Appendix B contains a more detailed discussion of the HTHM model.

The 100 percent pure hydrogen is collected as the HTHM permeate stream and compressed to 750 psi to be equal in final pressure to the other cases. The non-permeate HTHM stream containing CO_2, CO, and some hydrogen is sent to pressurized catalytic oxidation, where the remaining syngas is combusted with oxygen from the ASU unit. Steam is raised for plant power generation in the steam turbine. Some CO_2 is recycled for temperature control in the catalytic oxidation reactor. The flue gas exiting the catalytic oxidizer is still at system pressure and contains only CO_2 and water. This is dehydrated and compressed to 2,200 psi for sequestration. The HTHM operating temperature is assumed to be 572 °F (300 °C) and other HTHM parameters are set to comply with the 2010 targets set by NETL and shown in Table 2.

Figure 4 shows a block flow diagram for the Case 4 configuration. This configuration includes radiant and convective cooling after gasification. The synthesis gas is cleaned using the WGCU process described previously except that in this case warm gas cleaning is also used for removal of ammonia and mercury. The ammonia is removed at 350 °F by a zeolite guard bed and the mercury is removed at the same temperature using mixed metal oxides. In this way, the sensible heat is retained in the syngas before entering the HTHM separators. After cleaning and shift the syngas is then sent to three stages of HTHM. The 100 percent pure hydrogen is collected as the HTHM permeate stream and compressed to 750 psi. The non-permeate stream is sent to pressurized catalytic oxidation, where the remaining syngas is combusted with oxygen from the ASU unit and steam is raised for power generation in the steam turbine. The flue gas exiting the catalytic oxidizer is dehydrated and compressed for sequestration.

Case 5 (see Figure 5) is very similar to Case 3. The primary difference is that the HTHM parameters are based on the 2015 targets. The operating temperature is 482 °F (250 °C) and the operating pressure is 850 psi. Because of the higher pressure, the syngas is not expanded before the membrane. In all other respects, the process is the same as used in Case 3.

Similarly, Case 6 (see Figure 6) is based on Case 4, with the same HTHM performance parameters as used in Case 5 and based on the 2015 targets. As in Case 5, no syngas expander is needed. In all other respects, the process is the same as used in Case 4.

Cases 1–6 are all configured such that the plant produces only enough power to meet the parasitic plant requirements. Constraining the configurations so as not to generate excess power would probably not be practiced commercially because co-production could result in more efficient power generation. However, for the purposes of this analysis, it was decided to avoid the complexities of co-production of hydrogen and power.

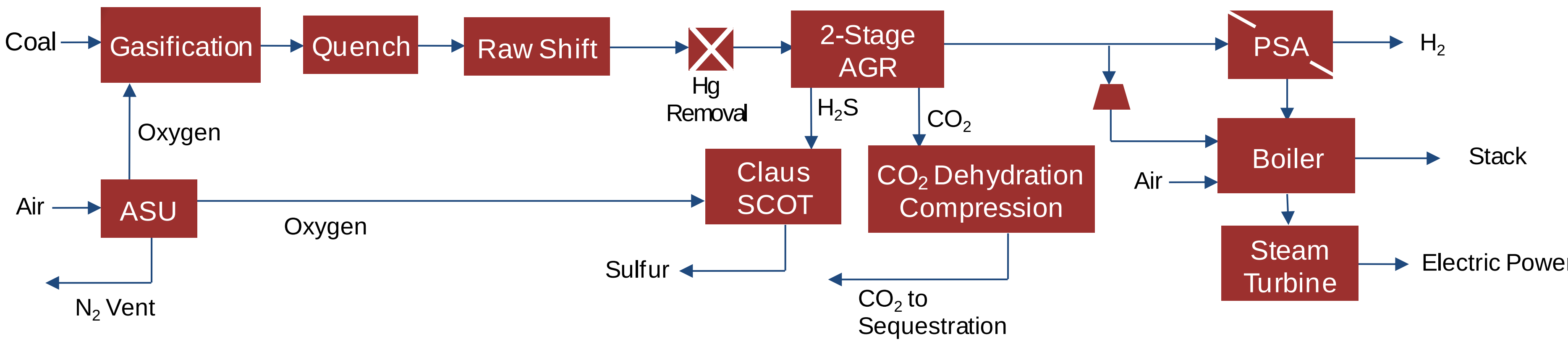


Figure 1 Case 1: GE Gasifier / Quench / CGCU / PSA

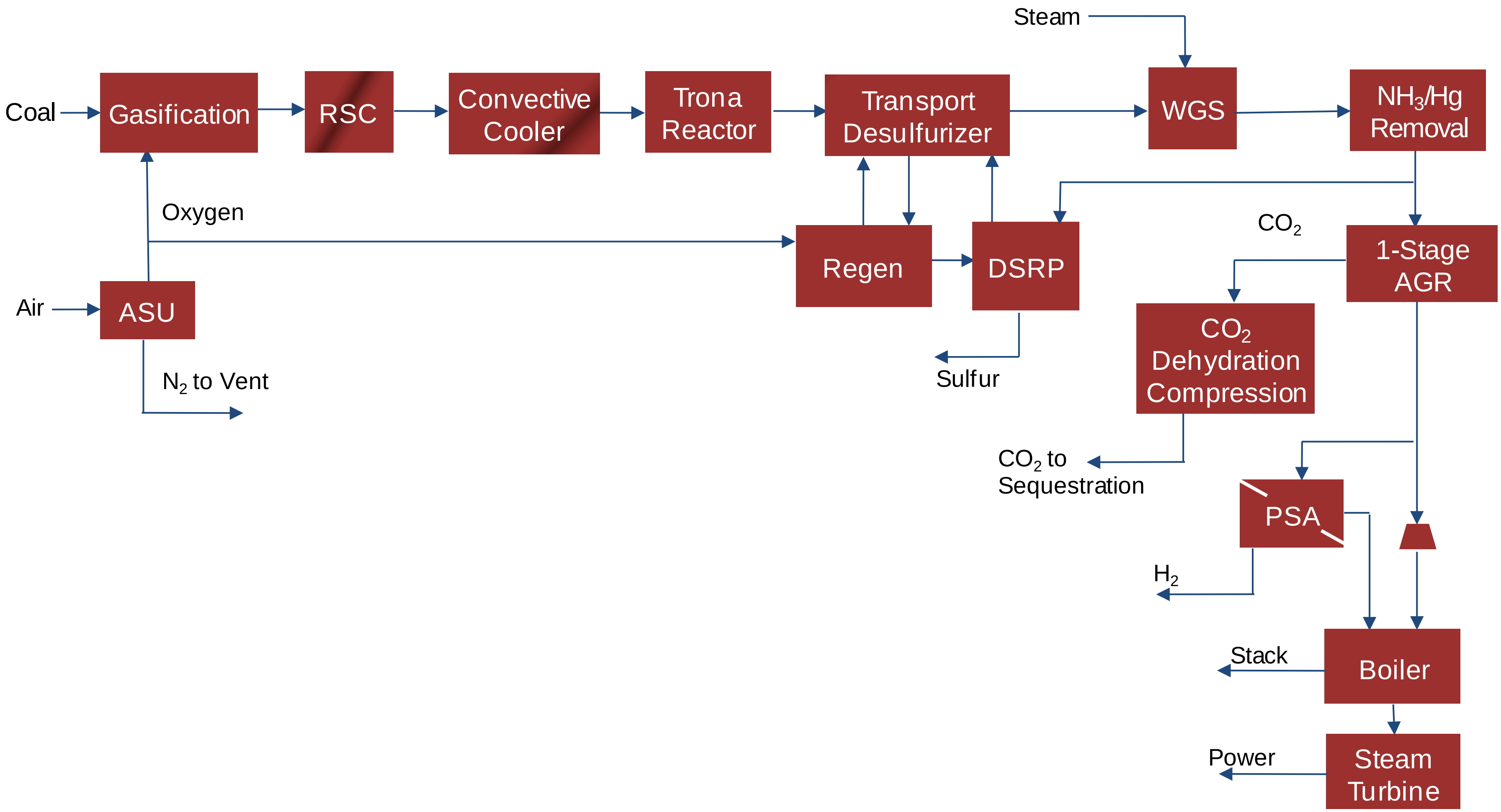


Figure 2 Case 2: GE Gasifier / RSC / CC / CGCU / PSA

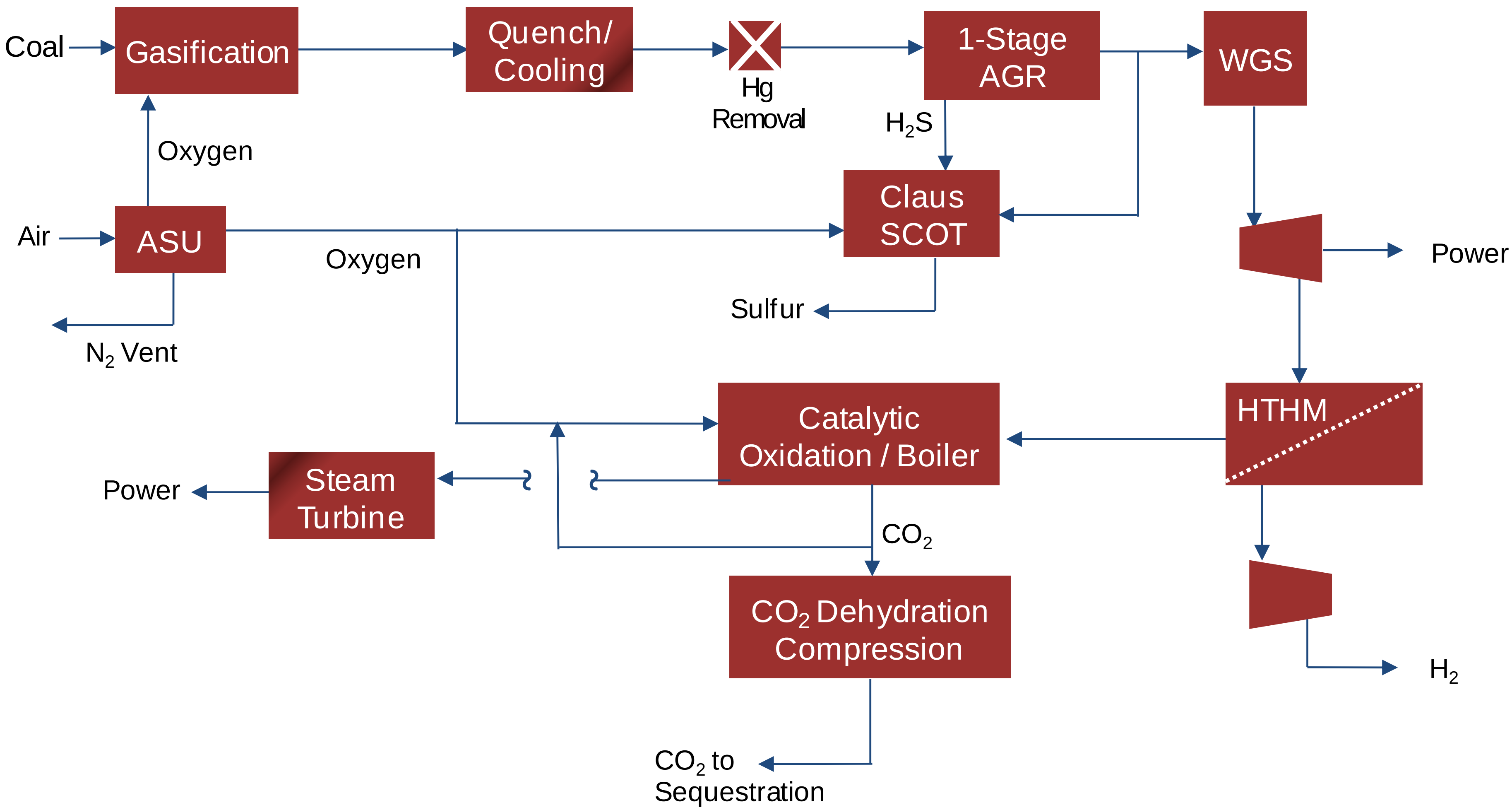


Figure 3 Case 3: GE Gasifier / Quench / CGCU / HTHM (2010)

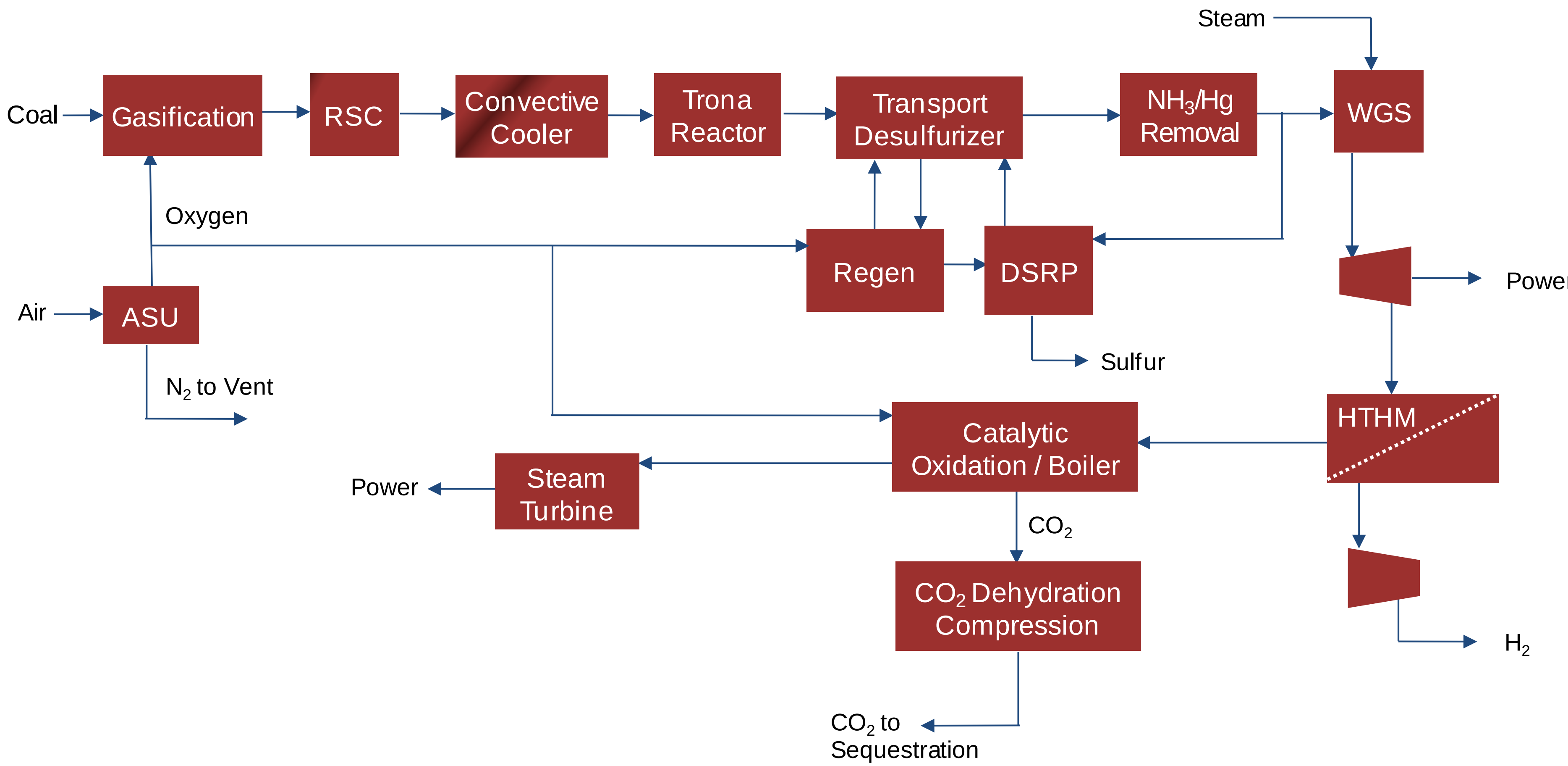


Figure 4 Case 4: GE Gasifier / RSC / CC / WGCU / HTHM (2010)

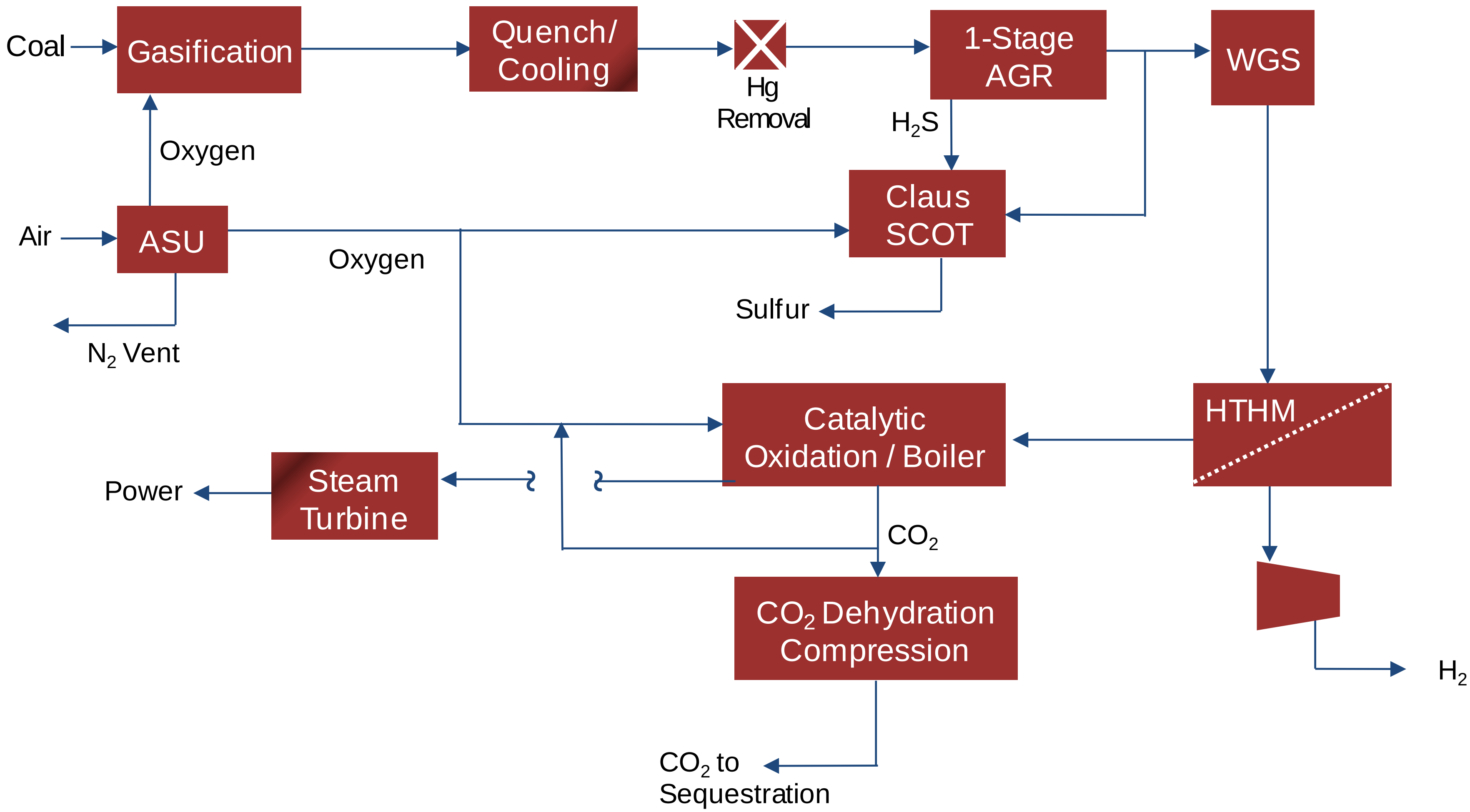


Figure 5 Case 5: GE Gasifier / Quench / CGCU / HTHM (2015)

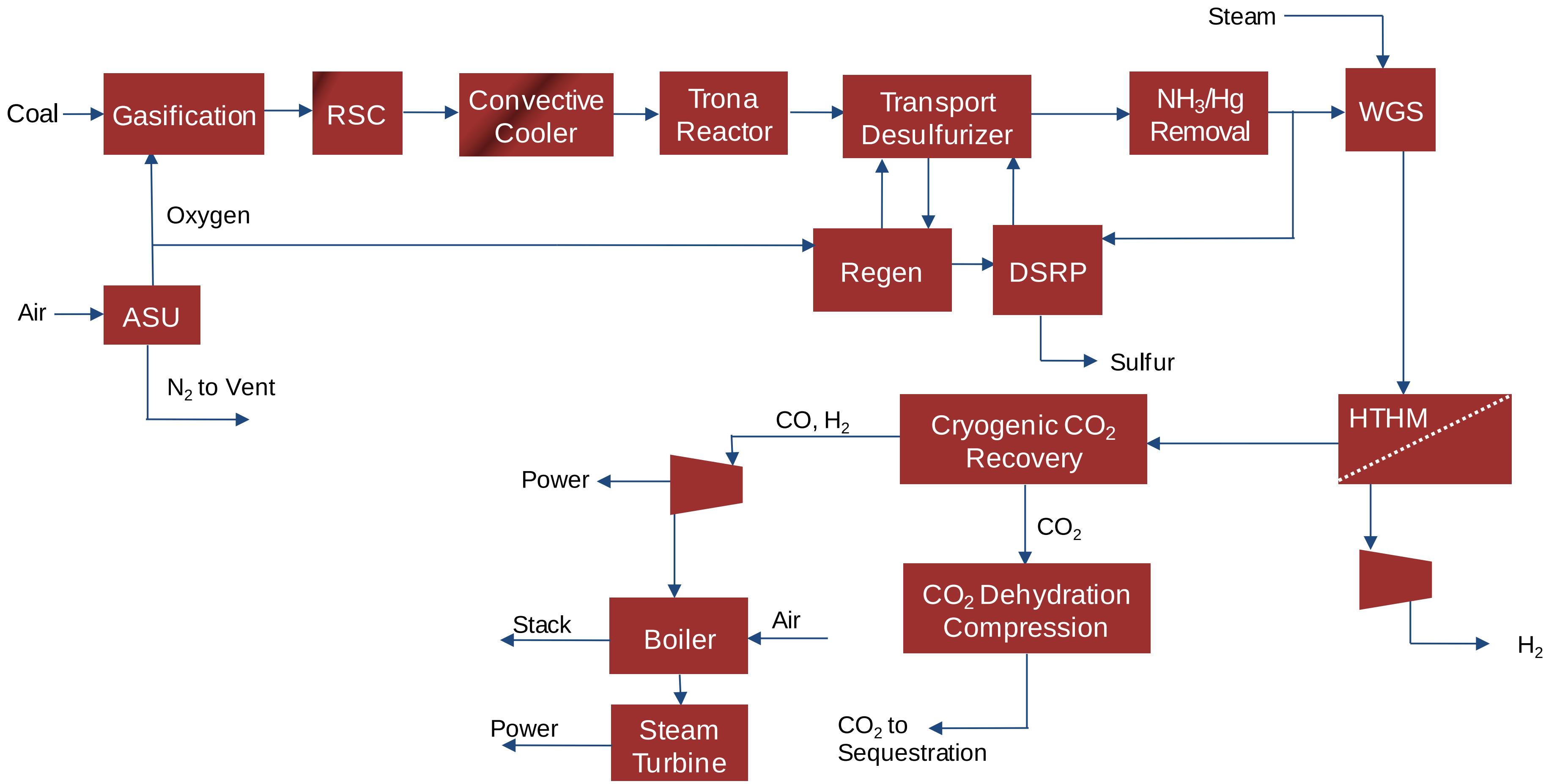


Figure 6 Case 6: GE Gasifier / RSC / CC / WGCU / HTHM (2015)

2.3 Feed Stock Coal Analysis

In all cases the same Illinois No. 6 bituminous coal was used. The coal analysis is provided in Table 3.

Table 3 Coal Analysis: Illinois No. 6 Old Ben #26 Mine [3]

Proximate Analysis
Dry Basis (wt %)

Moisture	12.51
Ash	10.91
Volatile Matter	39.37
Fixed Carbon	49.71
Total	100.00

Ultimate Analysis
Dry Basis (wt %)

Ash	10.91
Carbon	71.72
Hydrogen	5.06
Nitrogen	1.41
Chlorine	0.33
Sulfur	2.82
Oxygen	7.75
Total	100.00

Heating Value (Btu/lb)

HHV (AR)	11,666
HHV (dry basis)	13,126

2.4 Economic Analysis

In all cases, estimates were made of the capital and operating costs associated with the major process units. The basis for the estimates is described in more detail below.[2]

A 20-year levelized required selling price of hydrogen was estimated for each case. The economic assumptions used in determining the levelized RSP are given in Table 4. The total capital requirement is annualized assuming a capital charge factor of 0.175. If the plant emits CO_2, an emission cost penalty is applied based on an assumed cost of $28 per tonne. The

[2] NETL Forward to this report provides alternate reporting of RSP consistent with an updated costing methodology.

estimated RSP is levelized by using levelization factors of 1.1568 on fixed and variable operating costs, and the CO_2 emission cost, and 1.2022 on fuel cost [3].

Table 4 Assumptions and Parameters Used in Economic Analysis

Parameter	Value
Debt:Equity ratio	45:55
Interest rate on debt before tax	11% nominal
Return on equity after tax	12% nominal
Effective Income Tax Rate	38%
Repayment Term of Debt	15 years
Grace Period on Debt Repayment	0 years
Debt Reserve Fund	None
Depreciation	20 years, 150% declining balance
Working Capital	Zero for all parameters
Plant Economic Life	30 years
Investment Tax Credit	0%
Tax Holiday	0 years
All other additional capital costs ($)	0
EPC escalation	0%
Duration of Construction	3 years
Escalation rate for coal	2.35%
Escalation rate for O&M	1.87%
Coal price, delivered ($/ton)	42
Electricity price ($/MWh, 20-year levelized)	80
Sulfur credit ($/ton)	0
CO_2 emission penalty ($/tonne)	28
Capital charge factor	0.175
O&M levelization factor	1.1568
CO_2 emission cost levelization factor	1.1568
Fuel levelization factor	1.2022

3.0 Results of the Analysis

3.1 Coal to Hydrogen Cases

Cases 1–6 are for processes that produce hydrogen and just enough electric power to meet the plant parasitic power requirements. The results are summarized in Tables 5–14.

Table 5 summarizes the overall energy balance for these cases and Table 6 shows the carbon balances. Table 7 compares the amount of power produced with the individual parasitic power requirements for these cases.

Table 8 provides the estimates for the capital costs (2008 dollars) for the major plant items. The basis for the reference costs of equipment were obtained from the NETL Baseline study for fossil fuel plants [3].

Table 9 shows the remaining capital costs that make up the total capital requirement. Total capital includes bare erected cost (BEC), home office fees, process and project contingencies, legal, permitting and financing fees, and non-depreciable capital that includes owner's cost, preproduction costs, inventory costs, and a CO_2 monitoring fund for the sequestered CO_2.

Tables 10 and 11 list the major fixed and variable (at 100 percent capacity factor) O&M costs, respectively, for each case. Variable operation and maintenance (O&M) costs include coal at $42/ton ($1.81/MMBtu), and catalysts and chemicals. Fixed O&M costs include labor, taxes and insurance, maintenance materials, royalties, and disposal costs. No by-product credits are taken.

Finally, Tables 12 to 14 give the overall economic summary for each case, including the estimated required selling price (RSP) for the hydrogen product, using capacity factors of 80 percent, 85 percent, and 90 percent, respectively.[3]

3.1.1 Case 1 – GE Gasification with Quench, Cold Gas Cleaning, and PSA

This reference case (see Figure 1) represents the current state-of-the-art for the production of hydrogen from coal. The product is 240.7 MMSCFD of 99.99 percent purity hydrogen. The overall efficiency (HHV basis) is 55.9 percent and the overall carbon capture is 91 percent.

The gas cleaning and shift capital cost item (Table 8) includes two-stage AGR, Claus/SCOT acid gas treating, syngas scrubber, sour water stripper, activated carbon mercury removal, and raw water gas shift reactors. Hydrogen separation uses PSA.

The total capital cost is estimated to be 1,216 $MM and the fixed and variable (at 100 percent capacity factor) O&M costs are estimated to be $62 MM/yr and $97 MM/yr, respectively. The RSP for the hydrogen is calculated to be $2.30 per kg for 80 percent capacity factor, decreasing to $2.11 per kg at 90 percent capacity factor.

[3] NETL Forward to this report provides alternate reporting of RSP consistent with an updated costing methodology.

Table 5 Overall Energy Balance Summary for Cases 1–6

	Case 1 Reference PSA	Case 2 PSA WGCU	Case 3 2010 HTHM CGCU	Case 4 2010 HTHM WGCU	Case 5 2015 HTHM CGCU	Case 6 2015 HTHM WGCU
Inputs						
Coal Flow (ton/day AR)	6,000	6,000	6,000	6,000	6,000	6,000
Coal HHV (MMBtu/day)	140,012	140,012	140,012	140,012	140,012	140,012
Outputs						
Hydrogen (MMSCFD)	240.7	265.6	242.0	268.8	246.2	274.4
Hydrogen HHV (MMBtu/day)	78,228	86,320	78,650	87,360	80,015	89,180
Power (MW)	0	0	0	0	0	0
Power (MMBtu/day)	0	0	0	0	0	0
Total Output (MMBtu/day)	78,228	86,320	78,650	87,360	80,015	89,180
Effective Thermal Efficiency % (HHV)	**55.9**	**61.7**	**56.2**	**62.4**	**57.2**	**63.7**

Table 6 Carbon Balance for Cases 1–6

	Case 1 Reference PSA	Case 2 PSA WGCU	Case 3 2010 HTHM CGCU	Case 4 2010 HTHM WGCU	Case 5 2015 HTHM CGCU	Case 6 2015 HTHM WGCU
Carbon Inputs (TPD)						
Coal Carbon	3,825	3,825	3,825	3,825	3,825	3,825
Carbon Outputs (TPD)						
Carbon in Slag	77	77	77	77	77	77
Sequestered Carbon	3,414	3,374	3,748	3,748	3,748	3,748
Carbon in Flue Gases	335	375	0	0	0	0
Total Output Carbon	3,825	3,825	3,825	3,825	3,825	3,825
Overall Carbon Capture %	91	90	100	100	100	100

Table 7 Power Generation and Auxiliary Load Summary for Cases 1–6

	Case 1 Reference PSA	Case 2 PSA WGCU	Case 3 2010 HTHM CGCU	Case 4 2010 HTHM WGCU	Case 5 2015 HTHM CGCU	Case 6 2015 HTHM WGCU
Power Generation (MW)						
Steam Cycle	151.9	147.6	150.6	137.2	155.7	144.3
Syngas Expander	5.5	0.8	20.3	23.4		
Total	**157.4**	**148.4**	**170.9**	**160.5**	**155.7**	**144.3**
Parasitic Power Requirements (MW)						
ASU Main Air Compressor	73.6	75.2	96.0	88.3	94.7	86.7
ASU Auxiliaries	1.1	1.1	1.4	1.3	1.4	1.2
Coal Processing	2.8	2.8	2.8	2.8	2.8	2.8
CO_2 Compressor	34.6	33.6	12.7	12.8	5.8	6.0
AGR	19.9	13.5	2.8		2.8	
Oxygen Compressor	11.0	11.0	11.0	11.0	11.0	11.0
Ash	1.2	1.2	1.2	1.2	1.2	1.2
Gasifiers	0.3	0.3	0.3	0.3	0.3	0.3
Scrubber Pumps	0.3	0.3	0.3	0.3	0.3	0.3
Steam Cycle Pumps	1.7	1.5	1.9	1.8	2.0	2.0
Steam Turbine Aux	0.1	0.0	0.1	0.0	0.1	0.0
Flash Bottoms Pump	0.1	0.1	0.1	0.1	0.1	0.1
Water Circulation Pump	2.8	2.2	2.5	2.1	2.5	2.1
Cooling Tower Fan	1.4	1.1	1.3	1.1	1.3	1.1
Claus Recycle Compressor	1.9		2.1		2.1	
Claus Auxiliaries	0.2		0.2		0.2	
TDS Recycle Compressor		0.1		0.1		0.1
Regenerator O_2 Compressor		0.4		0.4		0.4
Hydrogen Compressor			29.4	33.0	21.2	24.5
Catalytic Oxidizer O_2 Compressor			1.7	0.9	2.9	1.5
Recycle CO_2 Boost Compressor			0.1			
Boiler Air Blower	1.6	0.9				
Misc	3.0	3.0	3.0	3.0	3.0	3.0
Total	**157.4**	**148.3**	**170.9**	**160.5**	**155.7**	**144.3**

Table 8 Plant Equipment Costs for Cases 1–6

Bare Erected Cost (BEC) ($MM 2008)	Case 1 Reference PSA	Case 2 PSA WGCU	Case 3 2010 HTHM CGCU	Case 4 2010 HTHM WGCU	Case 5 2015 HTHM CGCU	Case 6 2015 HTHM WGCU
Coal Handling	28	28	28	28	28	28
Prep & Feed	44	44	44	44	44	44
Plant Water Systems	36	36	36	36	36	36
Gasification	156	215	156	215	156	215
ASU	167	170	202	190	200	187
Gas Cleaning/Shift	169	167	139	94	119	71
CO_2 Removal & Compression	30	30	32	32	32	32
Steam Turbine/boiler	67	65	76	70	77	73
Ash Handling	38	38	38	38	38	38
Accessory Electric Plant	54	52	57	55	54	51
Instrument/Control	19	19	19	19	19	19
Site Improvements/Buildings	29	29	29	29	29	29
Hydrogen Separation	26	28	55	63	25	29
Hydrogen Compression			29	33	21	25
Total BEC	**863**	**920**	**940**	**947**	**878**	**877**

Table 9 Total Capital Requirement for Cases 1–6

Cost ($MM 2008)	Case 1 Reference PSA	Case 2 PSA WGCU	Case 3 2010 HTHM CGCU	Case 4 2010 HTHM WGCU	Case 5 2015 HTHM CGCU	Case 6 2015 HTHM WGCU
Bare Erected Cost	863	920	940	947	878	877
Home Office	86	92	94	95	88	88
Process Contingency	52	62	68	72	58	61
Project Contingency	130	138	141	142	132	132
Non-depreciable Capital	85	93	87	96	85	93
Total Capital Requirement	**1,216**	**1,305**	**1,331**	**1,351**	**1,240**	**1,250**

Table 10 Plant Fixed O&M Costs for Cases 1–6

Fixed O&M Cost ($MM/yr)	Case 1 Reference PSA	Case 2 PSA WGCU	Case 3 2010 HTHM CGCU	Case 4 2010 HTHM WGCU	Case 5 2015 HTHM CGCU	Case 6 2015 HTHM WGCU
Labor/Overhead	20	20	20	20	20	20
Administration	4	4	4	4	4	4
Taxes & Insurance	23	24	25	24	23	23
Maintenance Materials	9	9	9	9	9	9
Royalties/Other	9	9	9	9	9	9
Membrane Replacement			8	8	2	2
Total Fixed O&M Cost	**65**	**66**	**75**	**74**	**67**	**67**

Table 11 Plant Variable O&M Costs for Cases 1–6 at 100% Capacity Factor

Variable O&M Cost ($MM/yr)	Case 1 Reference PSA	Case 2 PSA WGCU	Case 3 2010 HTHM CGCU	Case 4 2010 HTHM WGCU	Case 5 2015 HTHM CGCU	Case 6 2015 HTHM WGCU
Coal	92	92	92	92	92	92
Catalyst/Chemicals	5	11	5	11	5	11
Total Variable O&M Cost	**97**	**103**	**97**	**103**	**97**	**103**

Table 12 Economic Summary for Cases 1–6, 80% Capacity Factor

	Case 1 Reference PSA	Case 2 PSA WGCU	Case 3 2010 HTHM CGCU	Case 4 2010 HTHM WGCU	Case 5 2015 HTHM CGCU	Case 6 2015 HTHM WGCU
Levelized Costs ($MM/yr)						
Annualized Capital Cost[a]	213	228	233	236	217	218
Coal	89	89	89	89	89	89
Non-fuel O&M	79	87	91	98	82	88
CO_2 emissions penalty	10	12				
Levelized Annual Required Revenue	391	416	412	423	388	395
Hydrogen Required Selling Price[a]						
RSP ($/MSCF)	5.56	5.36	5.83	5.39	5.39	4.93
RSP ($/MMBtu)	17.11	16.50	17.95	16.57	16.59	15.17
RSP ($/kg)	2.30	2.22	2.41	2.23	2.23	2.04

[a] Includes costs associated with a CO_2 monitoring fund, but excludes CO_2 transport and storage costs.

Table 13 Economic Summary for Cases 1–6, 85% Capacity Factor

	Case 1 Reference PSA	Case 2 PSA WGCU	Case 3 2010 HTHM CGCU	Case 4 2010 HTHM WGCU	Case 5 2015 HTHM CGCU	Case 6 2015 HTHM WGCU
Levelized Costs ($MM/yr)						
Annualized Capital Cost[a]	213	229	233	236	217	219
Coal	94	94	94	94	94	94
Non-fuel O&M	80	88	92	99	82	89
CO_2 emissions penalty	11	13				
Levelized Annual Required Revenue	397	423	418	429	394	402
Hydrogen Required Selling Price[a]						
RSP ($/MSCF)	5.32	5.14	5.57	5.15	5.15	4.72
RSP ($/MMBtu)	16.38	15.80	17.15	15.84	15.86	14.51
RSP ($/kg)	2.20	2.12	2.30	2.13	2.13	1.95

[a] Includes costs associated with a CO_2 monitoring fund, but excludes CO_2 transport and storage costs.

Table 14 Economic Summary for Cases 1–6, 90% Capacity Factor

	Case 1 Reference PSA	Case 2 PSA WGCU	Case 3 2010 HTHM CGCU	Case 4 2010 HTHM WGCU	Case 5 2015 HTHM CGCU	Case 6 2015 HTHM WGCU
Levelized Costs ($MM/yr)						
Annualized Capital Cost[a]	213	229	233	237	218	219
Coal	100	100	100	100	100	100
Non-fuel O&M	80	89	91	99	82	89
CO_2 emissions penalty	12	13				
Levelized Annual Required Revenue	404	430	425	436	400	408
Hydrogen Required Selling Price[a]						
RSP ($/MSCF)	5.11	4.93	5.34	4.94	4.94	4.53
RSP ($/MMBtu)	15.73	15.18	16.43	15.19	15.21	13.93
RSP ($/kg)	2.11	2.04	2.21	2.04	2.04	1.87

[a] Includes costs associated with a CO_2 monitoring fund, but excludes CO_2 transport and storage costs.

3.1.2 Case 2 – GE Gasification with Radiant Syngas Cooling, WGCU and PSA

This case is analyzed to assess the impact of WGCU and heat recovery from the syngas using radiant and convective syngas cooling on the performance and economics of the reference Case 1. In this case (see Figure 2) the TDS and DSRP processes replace the first stage of the physical solvent AGR and Claus/SCOT units. Clean shift is used in place of raw shift and the chlorine is removed at high temperature in the trona reactor. The syngas is cooled and scrubbed to remove ammonia and mercury before the physical solvent bulk CO_2 removal process. In all other respects, Case 2 uses the same process as Case 1.

This case produces 265.6 MMSCFD of 99.99 percent purity hydrogen at an overall efficiency of 61.7 percent (HHV) while attaining 90 percent carbon capture and sequestration (CCS).

The gas cleaning and shift item cost includes hot chloride removal, TDS/DSRP, WGS, syngas scrubbing and cooling, sour water stripping, activated carbon mercury removal, and bulk CO_2 removal using physical solvent AGR.

The total capital cost for the Case 2 plant is estimated to be $1,305 MM, approximately 8 percent higher than for Case 1. This is because of the higher gasification cost as a result of the heat recovery. Gas cleaning costs are not reduced because of the necessity for a physical solvent AGR system for bulk CO_2 removal. The RSP for the hydrogen at 80 percent capacity factor is calculated to be $2.22/kg and $2.04/kg at 90 percent capacity factor. The replacement of the cold gas cleaning with WGCU and the addition of syngas heat recovery via radiant and convective syngas cooling has improved the overall plant efficiency compared to Case 1 by 5.8 percentage points. However, there is only a 3 percent reduction in the estimated RSP of hydrogen.

3.1.3 Case 3 – GE Gasification with Quench, CGCU, 2010 HTHM

This case is analyzed to assess the impact of the HTHM using 2010 membrane performance targets, in combination with cold gas clean up (CGCU) and quench cooling, on the performance and economics of coal to hydrogen production.

The product is 242.0 MMSCFD of essentially 100 percent purity hydrogen. The overall efficiency is 56.2 percent (HHV). Referring to Appendix B, the HTHM has an estimated required area of 110,959 ft^2.

The stack gas from the oxygen-fired pressurized catalytic oxidation unit contains only water and CO_2. In this way essentially 100 percent carbon sequestration can be attained.

Gas cleaning and shift includes COS hydrolysis, scrub and low temperature cooling, sour water stripping, mercury removal, single-stage AGR, Claus/SCOT, shift, and expander. The CO_2 in this case is from the pressurized catalytic oxidation reactor and the flue gas and is assumed to be at system pressure. The hydrogen separation is the cost of the three-stage HTHM system and the cost of the compression is to compress the hydrogen from the three-stages to 750 psi delivery pressure. The cost for the membrane is $\$100/ft^2$ (2010 goal) and the cost of the installed HTHM separator is estimated to be $\$500/ft^2$ ($\$100/ft^2$ for the membrane plus $\$100/ft^2$ for the support times 2.5 for module construction and installation [4].

The total capital cost is estimated to be $1,331 MM, almost 10 percent higher than Case 1. This is because of the higher costs for the ASU (because of additional oxygen for catalytic oxidation), and higher hydrogen separation and compression costs. The O&M cost includes replacement of the membrane every 3 years. The RSP for the hydrogen is calculated to be $2.41/kg for 80 percent capacity factor, reducing to $2.21/kg at 90 percent capacity factor.

3.1.4 Case 4 – GE Gasification, WGCU, 2010 HTHM

This case is analyzed to assess the impact of the 2010 target HTHM in combination with WGCU and radiant and convective syngas cooling on the performance and economics of coal to hydrogen production. In this case (see Figure 4) the full WGCU system is incorporated into the configuration that includes chloride removal, TDS and DSRP, WGS, and warm mercury and ammonia removal.

The product is 268.8 MMSCFD of hydrogen at an overall efficiency of 62.4 percent (HHV). The required membrane surface area for this case is estimated to be 125,950 ft^2 (see Appendix B). As in Case 3, 100 percent carbon sequestration is attained.

Gas cleaning and shift includes hot chloride removal, TDS/DSRP, WGS, and warm gas mercury and ammonia removal. The total capital cost is estimated to be $1,351 MM, almost 11 percent higher than for Case 1. While this case has a smaller cost of gas cleaning than Case 1, it is more than compensated for by the larger gasifier cost (because of heat recovery), and the larger ASU, and hydrogen separation and compression costs. The RSP for the hydrogen becomes $2.23/kg at 80 percent capacity factor and reduces to $2.04/kg at 90 percent capacity factor; very close to the values obtained for Cases 1 and 2.

The net result of replacing the PSA unit with a HTHM is a slight increase in process efficiency and essentially no impact on hydrogen RSP (comparing cases 2 and 4). The relative increase in hydrogen RSP was smaller for Case 4 than Case 3 because Case 4 had a higher relative increase in process efficiency and the HTHM eliminated the bulk CO_2 removal AGR unit.

3.1.5 Case 5 – GE Gasification with Quench, CGCU, 2015 HTHM

This case is analyzed to assess the impact of the 2015 target HTHM in combination with CGCU on the performance and economics of coal to hydrogen production (see Figure 5). For the higher operating pressures of the 2015 HTHM, expansion of the syngas is not needed. The ability of the membrane to operate at a lower temperature (250 °C versus 300 °C) facilitates shift in the shift reactor and within the membranes. The higher pressure, enhanced shift, and higher reference permeability of the 2015 membrane results in a significant reduction in the required membrane area. The required membrane area for this case is estimated to be 56,552 ft^2. The assumed membrane module cost for the 2015 membrane is $450/$ft^2$ (assuming the membrane cost is $90/$ft^2$).

The product is 246.2 MMSCFD of pure hydrogen at an overall efficiency of 57.2 percent (HHV). As with the other HTHM cases, 100 percent carbon sequestration is attained.

Total capital cost is estimated to be $1,240 MM which is less than 2 percent higher than for Case 1. The O&M costs include a cost to replace the membrane every 5 years. The RSP for the hydrogen is calculated to be $2.23/kg for 80 percent capacity factor and $2.04/kg for 90 percent capacity factor.

3.1.6 Case 6 – GE Gasification, WGCU, 2015 HTHM

This case is analyzed to assess the impact of the 2015 target HTHM in combination with WGCU and radiant and convective syngas cooling on the performance and economics of coal to hydrogen production. This configuration is shown in Figure 6.

As in Case 5, syngas expansion is not necessary because the membrane can withstand the full system pressure. The required membrane area is estimated to be 64,361 ft^2, almost half that required in Case 4.

The product is 274.4 MMSCFD of pure hydrogen at an overall efficiency of 63.7 percent (HHV) with 100 percent carbon capture and sequestration. This high efficiency is the result of higher hydrogen recovery and lower parasitic power requirement because of lower CO_2 compression. The total capital cost is estimated to be $1,250 MM which is 10 percent higher than for Case 1. The RSP for the hydrogen is calculated to be $2.04/kg for 80 percent capacity factor and $1.87 for 90 percent capacity factor. These estimates are over 11 percent lower than the estimates for reference Case 1.

3.2 Discussion of Coal to Hydrogen Cases

The six coal to hydrogen cases examine the impact of variations in four components of the coal to hydrogen process: syngas heat recovery, desulfurization, hydrogen separation, and CO_2 separation. Case 2 uses high-temperature syngas heat recovery and warm gas cleanup versus quench and cold gas cleanup for Case 1. While Case 2 has significantly higher process efficiency, the RSP estimates for the two cases differ by about 3 percent. The results indicate that warm gas cleanup coupled with high-temperature syngas cooling only slightly improves the economic performance of a conventional sequestering coal to hydrogen process that does not export electric power. This is because of the higher cost of the gasifiers that have heat recovery equipment and, although WGCU was used for sulfur removal, physical absorption was needed for bulk CO_2 removal.

Cases 3–6 use an HTHM and oxy-fired combustor to effect hydrogen and CO_2 separation, compared to a PSA and solvent physical adsorption for Cases 1 and 2. For an HTHM that meets the 2010 performance goals, there is a slight improvement in process efficiency for both Case 3 and Case 4 compared to Case 1 and Case 2. There was essentially no difference in the estimated RSP for Case 4 versus Case 2, but a 4–5 percent RSP increase for Case 3 versus Case 1. The 2010 HTHM represents a near break-even point. A membrane that does not meet the 2010 targets is unlikely to offer a significant improvement over conventional PSA-based technology.

For a HTHM that meets 2015 performance targets, as shown in Cases 5 and 6, these is a significant improvement in both process efficiency and the estimated RSP of hydrogen compared to conventional PSA-based technology. For plants with 80 percent capacity factor, in Case 6 the RSP of hydrogen is approximately 11 percent lower than for Case 1. If future R&D can improve plant reliability and availability resulting in a capacity factor of 90 percent, then hydrogen could be produced for an RSP 19 percent lower than Case 1.

The component flow summaries for the three stages of the HTHM reactors in Cases 1 through 6are shown in Appendix B. Summaries of the component flows and conditions for the major streams and detailed process flow diagrams for Cases 1 through 6 are shown in Appendix A.

3.3 Hydrogen Production from Natural Gas

Commercially, hydrogen is usually produced by steam reforming of natural gas—so-called steam methane reforming (SMR). A simplified conceptual model of SMR with carbon capture was developed to estimate the RSP of hydrogen as a function of the price of natural gas feed. Figure 7 shows the results of this analysis. The SMR capital is estimated to be $413.5 MM for a hydrogen production rate of 215 MMSCFD. Overall plant efficiency was estimated to be 70 percent HHV.

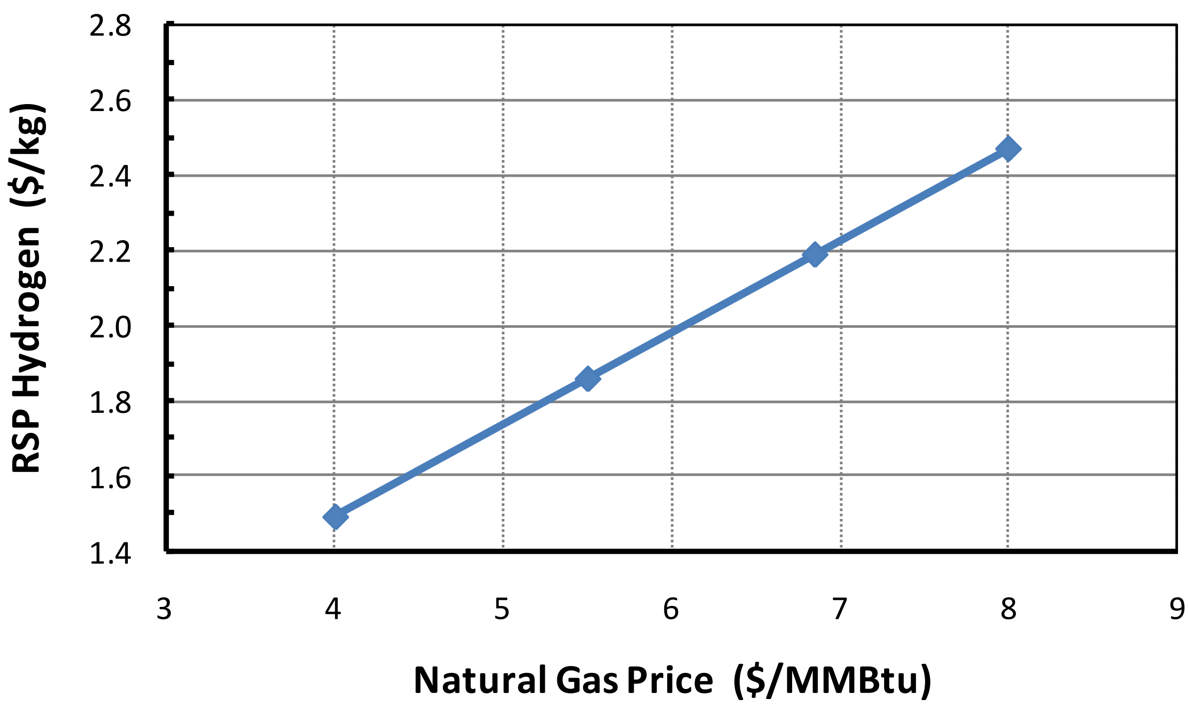


Figure 7 RSP of Hydrogen with Natural Gas Cost

A natural gas price of $7.30/MMBtu is estimated to give an RSP of hydrogen of $2.30/kg the RSP for the coal to hydrogen reference Case 1 at 80 percent capacity factor. A natural gas price of $5.50/MMBtu would give a hydrogen RSP equivalent to the RSP in Case 6 at 90 percent capacity factor; $1.87/kg.

3.4 Sensitivity Analyses

Sensitivity analyses were performed to quantify the potential impact on the RSP of hydrogen of the following parameters:

- Capital cost
- Coal price
- CO_2 value

Figures 8–10 show the RSP as a function of the capital cost, coal price, and CO_2 value, respectively, for Cases 1 and 6 with capacity factors of 80 percent. The sensitivity variables are shown over an arbitrary but reasonable range reflecting potential uncertainty or possible changes over time.

Figure 8 shows the impact of capital cost on the RSP of hydrogen for the Case 1 and 6 plants. In this graph the assumptions are: levelized costing, coal price of $42/ton (equivalent to $1.80/MMBtu), and CO_2 value of zero. If the capital cost estimated in this report were to be 30 percent higher for the reference Case 1 plant, then the RSP of hydrogen would increase from $2.30 to $2.67/kg, an increase of 16 percent. For the Case 6 plant the RSP would increase from $2.04 to $2.38/kg.

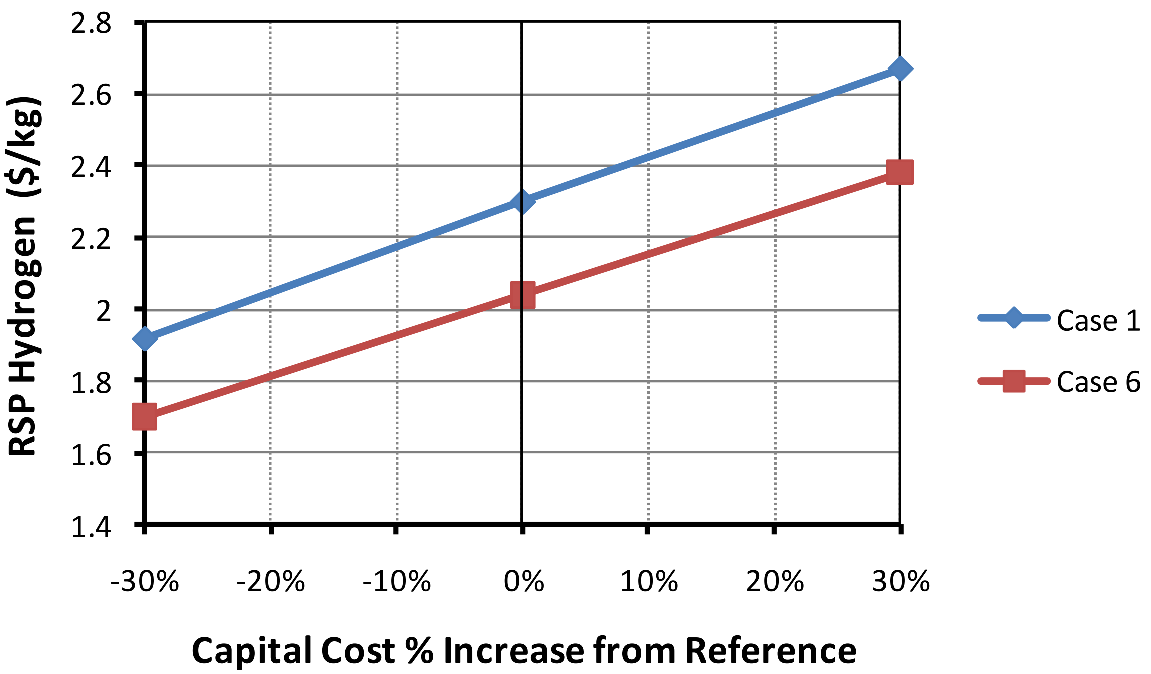


Figure 8 Sensitivity of Hydrogen RSP to Capital Cost

Figure 9 shows the sensitivity of hydrogen RSP to the coal price for the reference Case 1 and Case 6 plants. In this analysis the base coal price was assumed to be $42/ton, equivalent to

\$1.80/MMBtu. However, if the coal price were to be 30 percent greater than the reference price (\$55/ton) the RSP of hydrogen for the Case 1 plant would increase to \$2.46/kg. A 30 percent lower coal price (\$30/ton) would reduce the RSP of hydrogen to \$2.15/kg. For the Case 6 plant the RSP of hydrogen would increase from \$2.04 to \$2.18/kg for coal at \$55 per ton.

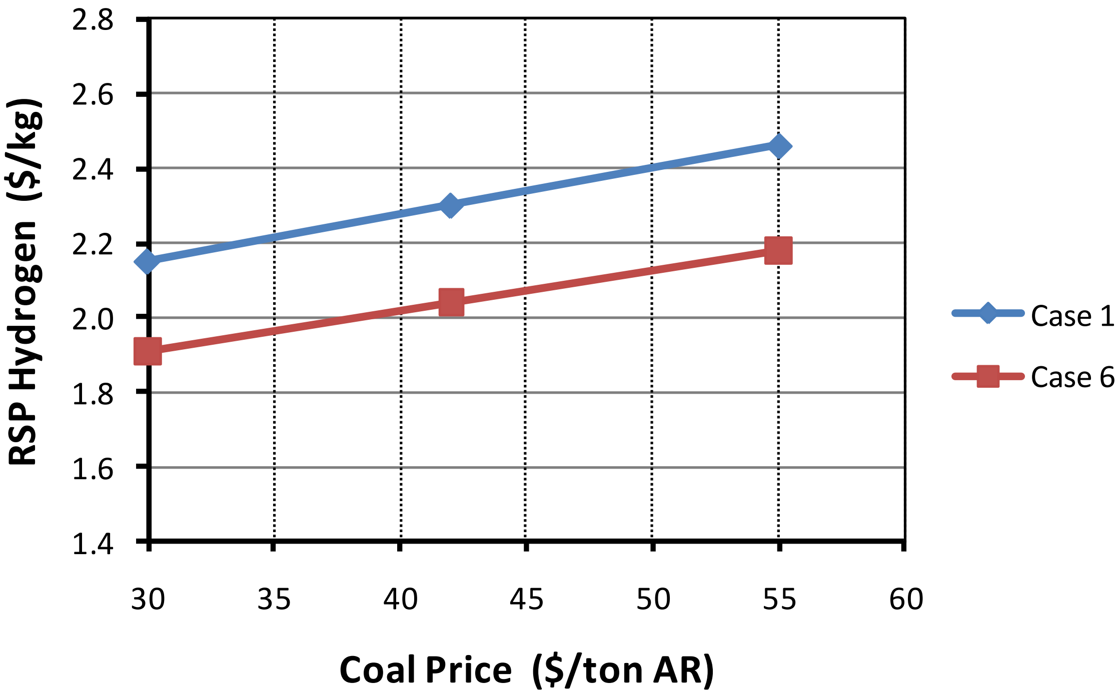


Figure 9 Sensitivity of Hydrogen RSP to Coal Price

Figure 10 shows the sensitivity of hydrogen RSP to the value of the CO_2 captured during conversion of coal to hydrogen in the plants. This value can be either positive or negative. If positive, it is assumed that the captured CO_2 can be sold for purposes such as enhanced oil recovery (EOR). This would then add an additional value product to the plant output. If negative, it is assumed that an additional cost is associated with the transportation, storage, and monitoring (TS&M) of the CO_2. With no value for the CO_2 in the Case 1 plant, the RSP of hydrogen is \$2.30/kg. If it costs \$15 per tonne for TS&M of the CO_2 in a saline aquifer or other formation, the RSP of the hydrogen would increase to \$2.64/kg. If a credit of \$15 per tonne can be obtained for the CO_2 for EOR, for example, then the RSP would decrease to \$1.96/kg. For the Case 6 plant, if the CO_2 is valued at \$15 per tonne, the RSP of hydrogen would decrease from \$2.04 to \$1.71/kg.

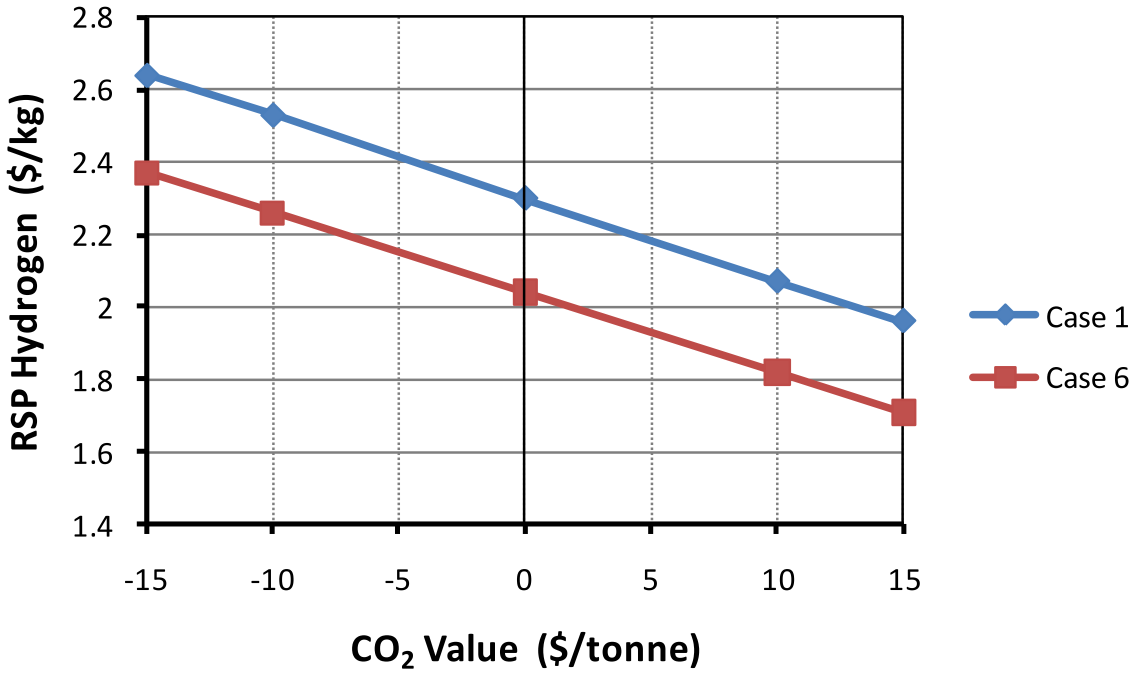


Figure 10 Sensitivity of Hydrogen RSP to CO_2 Value

All three of the sensitivity variables can potentially have a significant impact on the RSP. Based on the variable ranges used, the value of the captured CO_2 would have the potential for the largest impact on the RSP, followed by the capital cost, and then the coal price.

4.0 Summary of Results

Table 16 summarizes the overall results. The cost of hydrogen from coal using the base case current technology configuration (Case 1) and assuming a capacity factor of 80 percent is estimated to be $2.30 per kilogram, equivalent to $2.30 on a gallon of gasoline equivalent basis. Incorporating warm gas cleaning, in place of conventional cold syngas cleaning, and using radiant cooling of the gasifier effluent gas, in place of quench (Case 2), improves the overall efficiency by 5.8 efficiency points and reduces the RSP.

Replacing PSA with the 2010 target HTHM, but still using quench and cold gas cleaning, as in the Case 3 configuration, has a small effect on efficiency. In addition, the RSP of hydrogen has increased compared to Case 1 because of higher ASU, hydrogen separation, and hydrogen compression costs.

In Case 4, where radiant and convective cooling, WGCU, and 2010 target HTHM are used, the efficiency increases to 62.4 percent and the RSP is $2.23/kg, approximately 3 percent lower than Case 1. This implies that the 2010 membrane targets, especially for flux rate, are close to a break-even point compared to conventional technology.

In Case 5, where CGCU and the 2015 target HTHM are used, the efficiency is estimated to be 57.2 percent and the RSP is $2.23/kg. In Case 6, where WGCU and the 2015 HTHM are used, the greatest improvement in overall efficiency is found at 63.7 percent and the lowest RSP at $2.04/kg. This is an 11 percent reduction in RSP compared to the reference case plant. This analysis indicates that attainment of the 2015 membrane program targets in a configuration that includes WGCU and gasifier waste heat recovery will result in both an improvement in overall efficiency and a reduction in the RSP of hydrogen. If future R&D can improve the capacity factor from 80 percent to 90 percent, then the RSP of hydrogen would decrease to $1.87/kg; a 19 percent decrease compared to Case 1.

The processes considered in this study included CO_2 capture and compression. However, no charge was made for the actual sequestration or storage of the CO_2. There is a wide variation of estimated costs for this depending on the studies and on the type of sequestration formation considered. A sensitivity calculation was performed to determine the impact on the RSP if up to $15 per tonne of CO_2 was charged for TS&M. This sequestration cost adds about 34 cents per kilogram to the costs of the hydrogen. If, however, the CO_2 could be sold for EOR and a value of $15/tonne was realized, the RSP of the hydrogen would be reduced by about 34 cents per kilogram.

Table 15 Summary of Results for Coal to Hydrogen Cases 1–6[4]

	Case 1 Reference PSA	Case 2 PSA WGCU	Case 3 2010 HTHM CGCU	Case 4 2010 HTHM WGCU	Case 5 2015 HTHM CGCU	Case 6 2015 HTHM WGCU
Coal (TPD AR)	6,000	6,000	6,000	6,000	6,000	6,000
H_2 Production (MMSCFD)	240.7	265.6	242.0	268.8	246.2	274.4
Efficiency (%HHV)	55.9	61.7	56.2	62.4	57.2	63.7
Capital Cost ($MM 2008)	1,216	1,305	1,331	1,351	1,240	1,250
Levelized RSP[a] ($/kg), 80% CF	2.30	2.22	2.41	2.23	2.23	2.04
Plant Carbon Emissions (TPD)	335	375	0	0	0	0

[a] Includes costs associated with a CO_2 monitoring fund, but excludes CO_2 transport and storage costs.

[4] NETL Forward to this report provides alternate reporting of RSP consistent with an updated costing methodology.

5.0 Conclusions

The results of this analysis indicate that inclusion of the HTHM can be beneficial to the overall efficiency of coal to hydrogen plants if the membrane is integrated with both gasifier heat recovery and WGCU. Very little efficiency improvement is found when the 2010 membrane is integrated with conventional CGCU and no gasifier heat recovery. WGCU and heat recovery also greatly improve the efficiency of the hydrogen plant with PSA for hydrogen separation, but the greatest efficiency gain, almost 8 points, is found with the combination of the advanced 2015 membrane, heat recovery, and WGCU.

In the conceptual Cases 3, 4, 5, and 6 the HTHM is assumed to be coupled to a pressurized oxygen-fired boiler/superheater so that advantage can be taken of the non-permeate system pressure. This device is not commercially available technology. If such a system is unavailable, then the CO_2 would have to be recovered from the non-permeate stream using an auto refrigeration process for separation of the CO_2 from the residual CO and hydrogen in the non-permeate stream. This sensitivity was examined for Case 6 and it was found to have a 1.2 percentage point reduction in plant efficiency and essentially no impact on the RSP of the hydrogen.

Although this study has attempted to use the most current literature cost information for the major equipment items, there is still uncertainty in the actual capital costs of coal to hydrogen plants, especially those that incorporate novel technologies that have not been commercially deployed. Because of this concern, a sensitivity to capital cost variation was conducted that showed that if the capital was 30 percent higher, then the RSP of hydrogen would increase by about 16 percent.

The rationale for using hydrogen as a potential energy carrier for transportation is to significantly reduce GHG emissions in the transportation sector compared to the use of conventional petroleum. This requires that CCS be integrated into the coal to hydrogen conversion process. Cases 3, 4, 5, and 6 are shown with essentially zero carbon emissions, implying that 100 percent capture could be attained during the coal to hydrogen conversion process, provided that CO_2 sequestration becomes a proven and viable technology option. This implies that the overall life cycle GHG emissions would be very low. Only the coal mining and transport emissions and the emissions associated with transport of the hydrogen to the end user would apply. Adding a TS&M cost of $15 per tonne of CO_2 increases the costs of hydrogen by about 34 cents per kilogram for the six cases.

The combination of WGCU, gasifier heat recovery, and the 2015 HTHM has a significant impact on increasing the efficiency of a coal to hydrogen plant compared to the conventional configuration. This analysis also indicates that the reduction in RSP of hydrogen between Case 1 and Case 6 at a constant capacity factor of 80 percent is about 11 percent. This result is dependent on the accuracy of estimating the costs of the advanced technologies, and there is uncertainty in this estimation because of the early stages of development of both WGCU and HTHM technologies. If the capacity factor of the advanced configurations can be increased from 80 percent to 90 percent through continuing R&D that result in improvements in gasifier refractory and burner life, for example, then the reduction in hydrogen RSP is significantly increased. In a best case scenario, with a 90 percent capacity factor for Case 6 the RSP of hydrogen is reduced to \$1.87, a decrease of 19 percent compared to the base case.

Other developing technologies could also be incorporated into the hydrogen from coal configuration, including more advanced gasifiers and coal feed systems, ionic transport membranes for oxygen production, and advanced gas turbine technology. These have the potential to further improve the performance and economics of coal to hydrogen plants. Also, more detailed optimization of the HTHM configurations may positively impact the benefits of this technology. It is recommended that any additional systems studies include incorporation of these advanced technologies, better optimization of the HTHM, and more updated estimations of capital equipment costs for the developing processes.

6.0 References

1. NETL. "Assessment of Hydrogen Production Plants with CO_2 Capture, Volume 1: Baseline State-of-the-Art Plants," August 2010.
2. Gray, D., Plunkett, J., Salerno, S., White, C., Tomlinson, G. "Current and Future IGCC Technologies: A Pathway Study Focused on Non-Capture Advanced Power Systems R&D Using Bituminous Coal – Volume I," report prepared by Noblis for NETL; October 16, 2008.
3. NETL. "Cost and Performance Baseline for Fossil Energy Plants. Volume I: Bituminous Coal and Natural Gas to Electricity Final Report," Revision I, August 2007, DOE/NETL-2007/1281.
4. Personal communication from Paul Grimmer of Eltron, October 7, 2009.

Appendix A: Aspen Plus Stream Tables

Figure 11 below shows a process flow diagram and abbreviated stream table for Case 1. Table 16 provides a more detailed stream table for this case.

Figure 12 below shows a process flow diagram and abbreviated stream table for Case 2. Table 17 provides a more detailed stream table for this case.

Figure 13 below shows a process flow diagram and abbreviated stream table for Case 3. Table 18 provides a more detailed stream table for this case.

Figure 14 below shows a process flow diagram and abbreviated stream table for Case 4. Table 19 provides a more detailed stream table for this case.

Figure 15 below shows a process flow diagram and abbreviated stream table for Case 5. Table 20 provides a more detailed stream table for this case.

Figure 16 below shows a process flow diagram and abbreviated stream table for Case 6. Table 21 provides a more detailed stream table for this case.

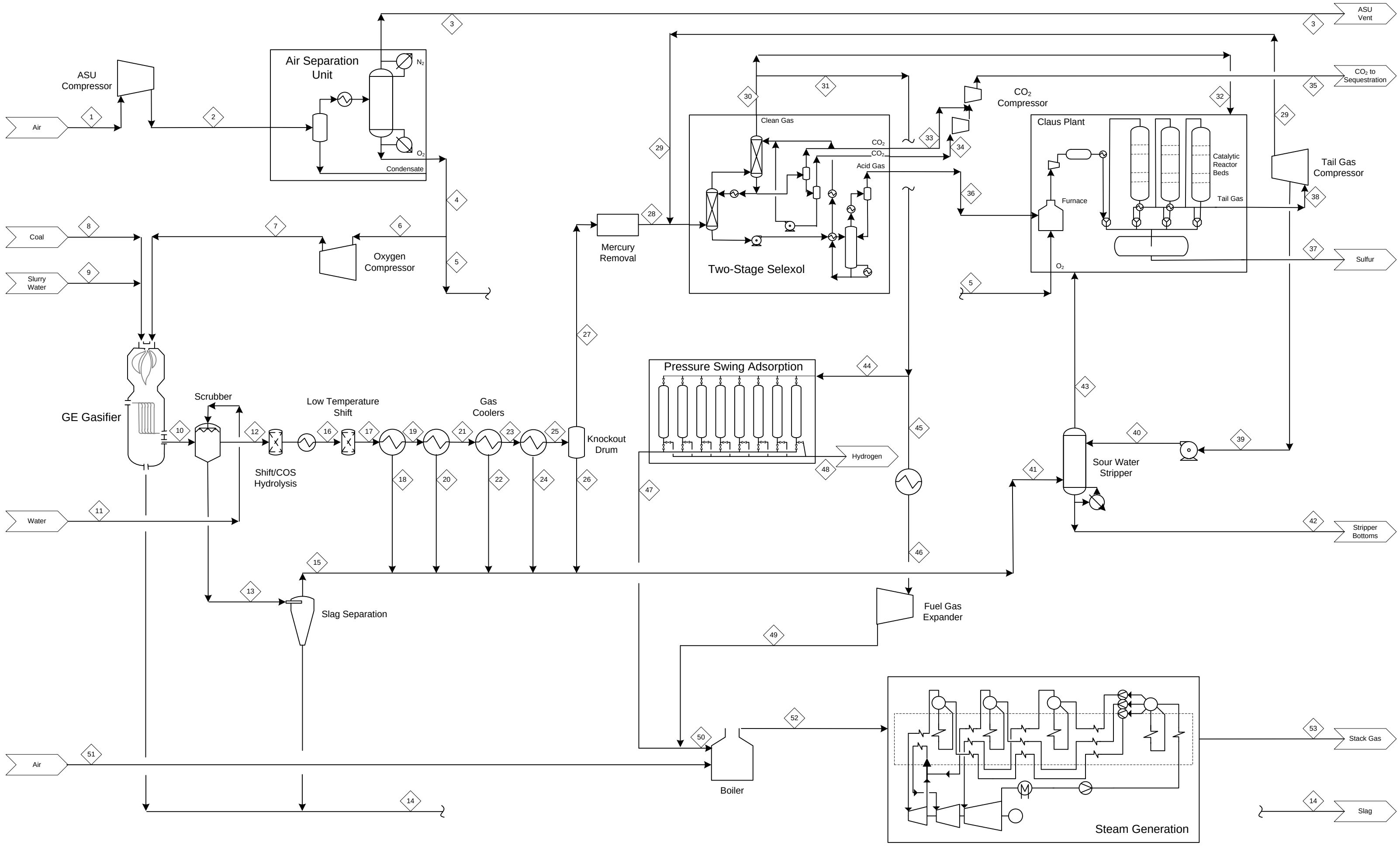


Figure 11 Process Flow Diagram for Case 1

Table 16 Detailed Stream Table for Case 1

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
		AMBAIR	ASUFEED	ASUXS	O2PRODCT	O2CLAUS	GASIF-O2	OXYGEN	WTCOAL	SLRYWT	RXPROD2	QWNCHW	RAW-GAS	QWNCHBTM	SLAG	SLAGWATR	TOLTSHFT	FRLTSHFT	CLR1LIQ	CLR1VAP	COND1	QNCHCHLL	CLR3LIQ	CLR3VAP	COND2	CHILLED	NH3OUT	TOMERCRY
Mass Flow	lb/hr	1,916,984	1,916,984	1,472,799	436,263	10,089	426,174	426,174	500,000	194,375	1,120,549	931,091	1,978,117	18,665	54,859	16,802	1,978,117	1,978,117	528,532	1,449,585	81,256	1,368,328	89,422	1,278,906	31,360	1,247,546	1,872	1,245,674
Mole Flow	lbmol/hr	66,624	66,624	52,465	13,719	317	13,402	13,402		10,789	51,863	51,683	102,511	1,035		932	102,511	102,511	29,291	73,221	4,504	68,717	4,959	63,758	1,741	62,018	63	61,954
Temp	F	59.0	281.5	88.0	90.0	90.0	90.0	232.7	59.0	59.0	2,500.3	246.7	454.9	454.9	2,500.3	454.9	425.0	448.8	332.0	332.0	300.0	300.0	225.0	225.0	100.0	100.0	100.0	100.0
Pressure	psia	14.7	190.3	16.4	145.0	145.0	145.0	1,024.7	14.7	14.7	900.0	840.0	838.0	838.0	900.0	838.0	813.0	812.5	811.5	811.5	810.5	810.5	810.5	810.5	809.5	809.5	808.5	808.5
Enthalpy	MMBtu/hr	-54.3	48.4	3.8	0.7	0.0	0.7	12.7	-505.4	-1,337.7	-1,886.7	-6,216.3	-7,977.8	-119.9	-5.3	-107.9	-8,297.1	-8,297.7	-3,470.2	-5,394.6	-536.5	-4,951.5	-597.8	-4,483.2	-213.1	-4,370.6	-2.4	-4,368.5

		28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53
		TO-AGR	TGOUT	TREATED	TO-PSA	REDUCEIT	HPCO2FL	LPCO2FL	P-HPCO2	TOCLAUS	SULFUR	TGRCY	TOTGRWR	TGWATRCY	QNCHSOUR	SWSBOT	SWSVAP	PSAFEED	PSABYP	HTDFG	PSABTM	H2PROD	EXPFG	FGB	COMBAIR	HRSGIN	HRSGOUT
Mass Flow	lb/hr	1,245,674	29,629	191,732	191,642	89	402,923	640,428	1,043,127	40,220	12,513	41,361	11,731	11,731	749,245	757,543	3,433	167,650	23,992	23,992	114,218	53,432	23,992	138,211	1,369,787	1,507,997	1,507,997
Mole Flow	lbmol/hr	61,954	699	37,678	37,660	18	9,261	14,587	23,836	1,127	49	1,350	651	651	41,489	42,008	132	32,945	4,715	4,715	6,440	26,505	4,715	11,155	47,606	54,636	54,636
Temp	F	99.7	110.0	87.0	87.0	87.0	60.0	42.0	245.8	119.0	320.0	337.1	110.1	110.5	309.2	247.0	80.0	87.0	87.0	620.0	85.0	85.0	69.2	65.6	59.0	1,999.8	260.0
Pressure	psia	807.5	808.5	792.5	792.5	792.5	149.7	16.7	2,200.0	23.7	21.7	21.0	21.0	75.0	808.5	35.0	35.0	792.5	792.5	792.5	771.5	750.0	29.4	29.4	14.7	16.1	16.1
Enthalpy	MMBtu/hr	-4,368.7	-109.0	-352.1	-352.0	-0.2	-1,551.3	-2,468.4	-4,017.7	-106.3	0.7	-173.1	-80.1	-80.1	-4,927.9	-5,048.1	-9.2	-307.9	-44.1	-25.9	-310.1	1.4	-44.5	-354.6	-38.8	-405.4	-1,180.6

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
		AMBAIR	ASUFEED	ASUXS	O2PRODCT	O2CLAUS	GASIF-O2	OXYGEN	WTCOAL	SLRYWT	RXPROD2	QWNCHW	RAW-GAS	QWNCHBTM	SLAG	SLAGWATR
CONVENTIONAL																
	Temperature F	59	281.5	88	90	90	90	232.7		59	2500.3	246.7	454.9	454.9		454.9
	Pressure psia	14.7	190.3	16.4	145	145	145	1024.7	14.7	14.7	900	840	838	838		838
	Vapor Frac	1	1	1	1	1	1	1		0	1	0	1	0		0
	Mole Flow lbmol/hr	66623.8	66623.8	52465	13719.1	317.3	13401.9	13401.9	0	10789.5	51863.3	51683.4	102511.3	1035.5	0	932.1
	Mass Flow lb/hr	1916983.6	1916983.6	1472799	436263	10088.9	426174.1	426174.1	0	194375	1065690.7	931090.9	1978116.5	18665	0	16802.3
	Volume Flow cuft/hr	25212399.7	2792792.8	18797501.8	554322.2	12819.1	541503.1	97055.6	0	3647.1	1847712.9	18954.4	1101170.1	448.7	0	405.7
	Enthalpy MMBtu/hr	-54.3	48.4	3.8	0.7	0	7.00E-01	12.7		-1337.7	-1881.4	-6216.3	-7977.8	-119.9		-107.9
	Mass Flow lb/hr															
	H2O	7921.6	7921.6	0	0	0	0	0	0	194375	168000.1	931090.9	1080464.6	18626.4	0	16763.7
	CO2	0	0	0	0	0	0	0	0	0	271601.8	0	271581	20.8	0	20.8
	O2	441726	441726	24670.4	417055.6	9644.7	407410.9	407410.9	0	0	0	0	0	0	0	0
	N2	1467336	1467336	1448128.6	19207.4	444.2	18763.2	18763.2	0	0	24085.5	0	24085.3	0.3	0	0.3
	CH4	0	0	0	0	0	0	0	0	0	153.8	0	153.8	0	0	0
	CO	0	0	0	0	0	0	0	0	0	555066.3	0	555060.3	6.1	0	6.1
	COS	0	0	0	0	0	0	0	0	0	471.7	0	471.6	0.1	0	0.1
	H2	0	0	0	0	0	0	0	0	0	30603.4	0	30602.6	0.8	0	0.8
	H2S	0	0	0	0	0	0	0	0	0	13052.3	0	13046.7	5.6	0	5.6
	HCL	0	0	0	0	0	0	0	0	0	1508.2	0	1507.8	0.4	0	0.4
	NH3	0	0	0	0	0	0	0	0	0	1147.5	0	1143	4.5	0	4.5
	SO2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	S8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CISOLID																
	Temperature F															
	Pressure psia	14.7	190.3	16.4	145	145	145	1024.7	14.7	14.7	900	840	838	838		838
	Vapor Frac															
	Enthalpy MMBtu/hr															
	Mass Flow lb/hr															
NC SOLID																
	Temperature F								59		2500.3				2500.3	
	Pressure psia	14.7	190.3	16.4	145	145	145	1024.7	14.7	14.7	900	840	838	838	900	838
	Vapor Frac								0		0				0	
	Mass Flow lb/hr	0	0	0	0	0	0	0	500000	0	54858.5	0	0	0	54858.5	0
	Enthalpy MMBtu/hr								-505.4		-5.3				-5.3	
	Mass Flow lb/hr															
	BIT-COAL	0	0	0	0	0	0	0	499994.9	0	0	0	0	0	0	0
	SLAG	0	0	0	0	0	0	0	0	0	54858.5	0	0	0	54858.5	0
	ASH	0	0	0	0	0	0	0	5.1	0	0	0	0	0	0	0
TOTAL																
	Mass Flow lb/hr	1916983.6	1916983.6	1472799	436263	10088.9	426174.1	426174.1	500000	194375	1120549.2	931090.9	1978116.5	18665	54858.5	16802.3
	Enthalpy MMBtu/hr	-54.3	48.4	3.8	0.7	0	0.7	12.7	-505.4	-1337.7	-1886.7	-6216.3	-7977.8	-119.9	-5.3	-107.9

Table 16 Detailed Stream Table for Case 1, cont.

		16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
		TOLTSHFT	FRLTSHFT	CLR1LIQ	CLR1VAP	COND1	QNCHCHLL	CLR3LIQ	CLR3VAP	COND2	CHILLED	NH3OUT	TOMERCRY	TO-AGR	TGOUT	TREATED
CONVENTIONAL																
	Temperature F	425	448.8	332	332	300	300	225	225	100	100	100	100	99.7	110	87
	Pressure psia	813	812.5	811.5	811.5	810.5	810.5	810.5	810.5	809.5	809.5	808.5	808.5	807.5	808.5	792.5
	Vapor Frac	1	1	0	1	0	1	0	1	0	1	0	1	1	1	1
	Mole Flow lbmol/hr	102511.3	102511.3	29290.5	73220.7	4503.8	68716.9	4958.6	63758.3	1740.6	62017.7	63.2	61954.5	61954.5	698.8	37677.7
	Mass Flow lb/hr	1978116.5	1978116.5	528532	1449584.6	81256.4	1368328.2	89422.1	1278906.1	31360.4	1247545.7	1871.8	1245673.9	1245673.9	29629	191731.9
	Volume Flow cuft/hr	1127273.3	1167983.6	1.14E+04	7.44E+05	1707.8	674133.9	1799.7	5.63E+05	5.98E+02	435083.8	42.8	435283.9	435574.6	3943.5	282547.1
	Enthalpy MMBtu/hr	-8297.1	-8297.7	-3.47E+03	-5.39E+03	-536.5	-4951.5	-597.8	-4483.2	-213.1	-4370.6	-2.4	-4368.5	-4368.7	-109	-352.1
	Mass Flow lb/hr															
	H2O	755001.7	729253.5	526420.7	202832.9	80946.3	121886.6	89088.6	32798	31085.6	1712.5	0	1712.5	1712.5	32.9	78.7
	CO2	1066659.3	1129559.8	1.60E+03	1.13E+06	216.4	1127745	160.4	1.13E+06	2.23E+01	1127562.3	0	1127562.3	1127562.3	28150.2	87834.1
	O2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	N2	24085.3	24085.3	2.3	24083	0.2	24082.7	0.1	24082.6	0	24082.6	0	24082.6	24082.6	1153.6	25137.8
	CH4	153.8	153.8	0.1	153.7	0	153.7	0	153.7	0	153.7	0	153.7	153.7	0.1	149.5
	CO	49244.9	9211.3	0.9	9210.4	0.1	9210.3	0	9210.3	0	9210.3	0	9210.3	9210.3	4.2	9085.5
	COS	2.4	2.4	0	2.3	0	2.3	0	2.3	0	2.3	0	2.3	2.3	0	0
	H2	67005.6	69886.8	19.8	69866.9	2.2	69864.7	1	69863.7	0	69863.6	0	69863.6	69863.6	16.2	69439.6
	H2S	13312.9	13312.9	167.5	13145.4	25.7	13119.7	26.1	13093.6	7	13086.6	0	13086.6	13086.6	271.8	6.7
	HCL	1507.8	1507.8	11.4	1496.4	1.7	1494.7	1.8	1492.9	0.5	1492.4	1492.4	0	0	0	0
	NH3	1143	1143	310.8	832.1	63.7	768.4	143.9	624.5	245	379.4	379.4	0	0	0	0
	SO2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	S8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CISOLID																
	Temperature F															
	Pressure psia	813		811.5	811.5	810.5	810.5	810.5	810.5	809.5	809.5	808.5	808.5	807.5		792.5
	Vapor Frac															
	Enthalpy MMBtu/hr															
	Mass Flow lb/hr															
NC SOLID																
	Temperature F															
	Pressure psia	813		811.5	811.5	810.5	810.5	810.5	810.5	809.5	809.5	808.5	808.5	807.5		792.5
	Vapor Frac															
	Mass Flow lb/hr	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Enthalpy MMBtu/hr															
	Mass Flow lb/hr															
	BIT-COAL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	SLAG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	ASH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL																
	Mass Flow lb/hr	1978116.5	1978116.5	528532	1449584.6	81256.4	1368328.2	89422.1	1278906.1	31360.4	1247545.7	1871.8	1245673.9	1245673.9	29629	191731.9
	Enthalpy MMBtu/hr	-8297.1	-8297.7	-3470.2	-5394.6	-536.5	-4951.5	-597.8	-4483.2	-213.1	-4370.6	-2.4	-4368.5	-4368.7	-109	-352.1

Table 16 Detailed Stream Table for Case 1, cont.

	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
	TO-PSA	REDUCEIT	HPCO2FL	LPCO2FL	P-HPCO2	TOCLAUS	SULFUR	TGRCY	TOTGRWR	TGWATRCY	QNCHSOUR	SWSBOT	SWSVAP	PSAFEED	PSABYP
CONVENTIONAL															
Temperature F	87	87	60	42	245.8	119	320	337.1	110.1	110.5	309.2	247	80	87	87
Pressure psia	792.5	792.5	149.7	16.7	2200	23.7	21.7	21	21	75	808.5	35	35	792.5	792.5
Vapor Frac	1	1	1	1	1	1	0	1	0	0	0	0	1	1	1
Mole Flow lbmol/hr	37660.1	17.6	9261.5	14586.7	23835.7	1127.5	48.8	1350	651.2	651.2	41488.9	42007.7	132.3	32945.3	4714.8
Mass Flow lb/hr	191642.5	89.5	402922.7	640428.4	1043126.9	40219.9	12513	41361.3	11731.3	11731.3	749245	757543.2	3433.1	167650	23992.5
Volume Flow cuft/hr	282415.3	131.8	323251.8	4667057.3	59738.6	293465.9	39.2	547488.1	224.3	224.3	15877.4	48815.1	21582	247058.6	35356.7
Enthalpy MMBtu/hr	-352	-0.2	-1551.3	-2468.4	-4017.7	-106.3	0.7	-173.1	-80.1	-80.1	-4927.9	-5048.1	-9.2	-307.9	-44.1
Mass Flow lb/hr															
H2O	78.7	0	168	946.2	890.4	552.5	0	11763.1	11730.2	11730.2	744304.8	756035	0	68.8	9.9
CO2	87793.2	41	402419.1	639455.7	1041874.4	26003.5	0	28151.8	0.7	0.7	2018.4	0	2019	76802	10991.2
O2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N2	25126.1	11.7	44.3	1.1	45.4	53	0	1153.6	0	0	2.9	0	2.9	21980.5	3145.6
CH4	149.4	0.1	2.8	0.2	3	1.3	0	0.1	0	0	0.1	0	0.1	130.7	18.7
CO	9081.3	4.2	77.6	5.3	82.9	46.1	0	4.2	0	0	7.1	0	7.1	7944.4	1136.9
COS	0	0	0	1.1	1.1	1.3	0	0	0	0	0.1	0	0.1	0	0
H2	69407.2	32.4	209.1	7.6	216.6	223.6	0	16.2	0	0	24	0	24	60717.8	8689.4
H2S	6.7	0	1.7	11.3	13	13338.7	0	272.2	0.4	0.4	231.9	0	232.3	5.8	0.8
HCL	0	0	0	0	0	0	0	0	0	0	1508.2	1508.2	0	0	0
NH3	0	0	0	0	0	0	0	0	0	0	1147.5	0	1147.5	0	0
SO2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S8	0	0	0	0	0	0	12513	0	0	0	0	0	0	0	0
CISOLID															
Temperature F															
Pressure psia	792.5	792.5	149.7	16.7	2200	23.7	21.7	21	21	75	808.5	35		792.5	792.5
Vapor Frac															
Enthalpy MMBtu/hr															
Mass Flow lb/hr															
NC SOLID															
Temperature F															
Pressure psia	792.5	792.5	149.7	16.7	2200	23.7	21.7	21	21	75	808.5	35		792.5	792.5
Vapor Frac															
Mass Flow lb/hr	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Enthalpy MMBtu/hr															
Mass Flow lb/hr															
BIT-COAL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SLAG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ASH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL															
Mass Flow lb/hr	191642.5	89.5	402922.7	640428.4	1043126.9	40219.9	12513	41361.3	11731.3	11731.3	749245	757543.2	3433.1	167650	23992.5
Enthalpy MMBtu/hr	-352	-0.2	-1551.3	-2468.4	-4017.7	-106.3	0.7	-173.1	-80.1	-80.1	-4927.9	-5048.1	-9.2	-307.9	-44.1

Table 16 Detailed Stream Table for Case 1, cont.

		46	47	48	49	50	51	52	53
		HTDFG	PSABTM	H2PROD	EXPFG	FGB	COMBAIR	HRSGIN	HRSGOUT
CONVENTIONAL									
	Temperature F	620	85	85	69.2	65.6	59	1999.8	260
	Pressure psia	792.5	771.54	750	29.39	29.39	14.7	16.14	16.14
	Vapor Frac	1	1	1	1	1	1	1	1
	Mole Flow lbmol/hr	4714.8	6439.9	26505.4	4714.8	11154.7	47606.2	54636.3	54636.3
	Mass Flow lb/hr	23992.5	114218.3	53431.7	23992.5	138210.8	1369786.5	1507997.3	1507997.3
	Volume Flow cuft/hr	69927.7	47431.2	210371.2	910690.5	2137853.9	18020566.6	89366283.2	26132001.6
	Enthalpy MMBtu/hr	-25.9	-310.1	1.4	-44.5	-354.6	-38.8	-405.4	-1180.6
	Mass Flow lb/hr								
	H2O	9.9	68.8	0	9.9	78.7	5660.4	148846.2	148846.2
	CO2	10991.2	76802	0	10991.2	87793.2	0	102471.6	102471.6
	O2	0	0	0	0	0	315636.6	183051.5	183051.5
	N2	3145.6	21980.5	0	3145.6	25126.1	1048489.4	1073615.5	1073615.5
	CH4	18.7	130.7	0	18.7	149.4	0	0	0
	CO	1136.9	7944.4	0	1136.9	9081.3	0	0	0
	COS	0	0	0	0	0	0	0	0
	H2	8689.4	7286.1	53431.7	8689.4	15975.5	0	0	0
	H2S	0.8	5.8	0	0.8	6.7	0	0	0
	HCL	0	0	0	0	0	0	0	0
	NH3	0	0	0	0	0	0	0	0
	SO2	0	0	0	0	0	0	12.5	12.5
	S8	0	0	0	0	0	0	0	0
CISOLID									
	Temperature F								
	Pressure psia	792.5	771.54	750	29.39	29.39	14.7	16.14	16.14
	Vapor Frac								
	Enthalpy MMBtu/hr								
	Mass Flow lb/hr								
NC SOLID									
	Temperature F								
	Pressure psia	792.5	771.54	750	29.39	29.39	14.7	16.14	16.14
	Vapor Frac								
	Mass Flow lb/hr	0	0	0	0	0	0	0	0
	Enthalpy MMBtu/hr								
	Mass Flow lb/hr								
	BIT-COAL	0	0	0	0	0	0	0	0
	SLAG	0	0	0	0	0	0	0	0
	ASH	0	0	0	0	0	0	0	0
TOTAL									
	Mass Flow lb/hr	23992.5	114218.3	53431.7	23992.5	138210.8	1369786.5	1507997.3	1507997.3
	Enthalpy MMBtu/hr	-25.9	-310.1	1.4	-44.5	-354.6	-38.8	-405.4	-1180.6

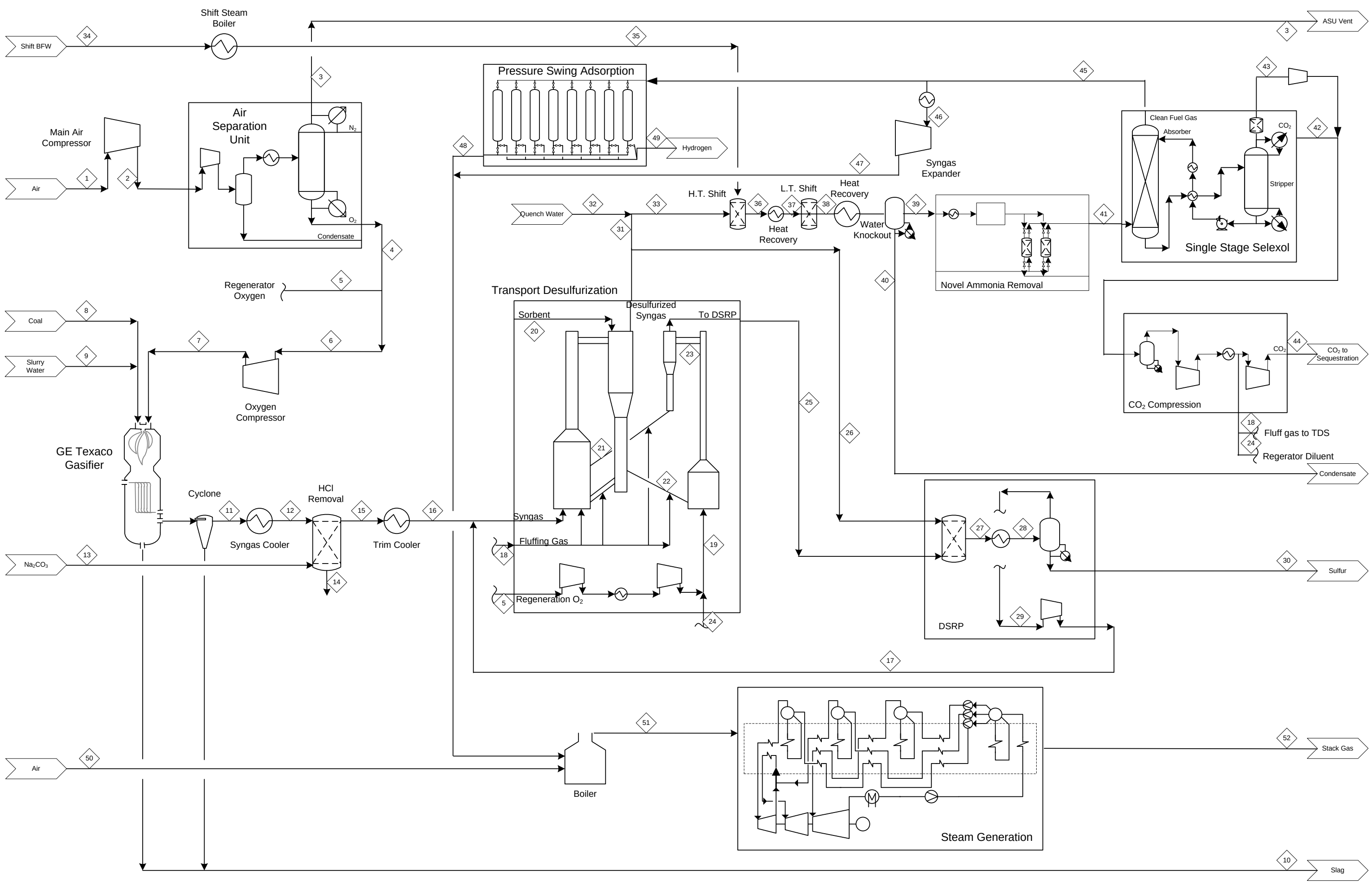


Figure 12 Process Flow Diagram for Case 2

Table 17 Detailed Stream Table for Case 2

		1	2	3	4	5	6	7	8	9	10	11	12	13
		AMBAIR	ASUFEED	ASUXS	O2PRODCT	TO-REGEN	GASIF-O2	OXYGEN	WTCOAL	SLRYWT	SLAG	GASTOCLR	SW4	SW35
Mass Flow	lb/hr	1,958,477	1,958,477	1,504,678	445,706	19,556	426,150	426,150	500,000	194,375	54,859	1,065,666	1,065,666	8,769
Mole Flow	lbmol/hr	68,066	68,066	53,601	14,016	615	13,401	13,401		10,789		51,863	51,863	83
Temp	F	59.0	281.5	88.0	90.0	90.0	90.0	232.7	59.0	59.0	1,250.0	1,250.0	950.0	60.0
Pressure	psia	14.7	190.3	16.4	145.0	145.0	145.0	1,024.7	14.7	14.7	900.0	900.0	896.0	800.0
Enthalpy	MMBtu/hr	-55.5	49.5	3.9	0.7	0.0	0.7	12.7	-505.4	-1,337.7	-28.1	-2,475.9	-2,609.0	-40.2

		14	15	16	17	18	19	20	21	22	23	24	25	26
		SW31	SW29	ABSFEED	SW41	CO2FLUFF	SYNAIR	NEWZNO	SW1	SW9	SW30	FLFGAS	SW21	RDUCEGAS
Mass Flow	lb/hr	8,994	1,065,441	1,065,441	101,186	44	81,095	1,701	1,711,459	1,717,717	1,798,811	61,539	87,353	26,361
Mole Flow	lbmol/hr	103		51,863	2,678	1	2,025	21	20,874	20,874	22,704	1,410	1,830	1,238
Temp	F	946.7	946.7	769.4	519.5	100.0	189.8	60.0	1,100.0	900.0	1,100.0	211.3	1,100.0	900.0
Pressure	psia	798.0	798.0	796.0	825.0	850.0	800.0	795.0	786.0	793.0	786.0	1,100.0	786.0	788.0
Enthalpy	MMBtu/hr	-35.0	-2,614.2	-2,690.9	-392.2	-0.2	-235.5	-3.2	-2,836.3	-2,866.4	-3,101.9	-236.1	-265.6	-69.3

		27	28	29	30	31	32	33	34	35	36	37	38	39
		SW26	SW27	SW38	P-SULFUR	SW18	QWTR	SHFTMX	SHFTWTR1	SHFTSTM	FRHTSHFT	TOLTSHFT	FRLTSHFT	CHILLED
Mass Flow	lb/hr	113,715	113,715	101,186	12,528	1,135,752	231,634	1,367,386	200,000	200,000	1,565,706	1,565,706	1,565,706	1,286,169
Mole Flow	lbmol/hr	3,068	3,068	2,678	390	53,325	12,858	66,183	11,102	11,102	77,264	77,264	77,264	61,764
Temp	F	1,016.1	500.0	500.0	100.0	900.0	59.0	397.7	60.0	519.0	777.9	390.1	459.6	100.0
Pressure	psia	763.0	758.0	755.0	14.7	788.0	800.0	787.0	815.0	815.0	786.5	785.0	784.5	781.5
Enthalpy	MMBtu/hr	-335.0	-361.0	-392.7	30.5	-2,986.2	-1,593.6	-4,524.0	-1,375.7	-1,126.5	-5,647.5	-5,918.7	-5,918.7	-4,542.8

		40	41	42	43	44	45	46	47	48	49	50	51	52
		QNCHSOUR	AGFEED	HPCO2FL	LPCO2FL	P-HPCO2	TREATED	HTDFG	FGB	PSABTM	H2PROD	COMBAIR	HRSGIN	HRSGOUT
Mass Flow	lb/hr	279,537	1,283,912	406,659	645,488	1,030,088	192,286	3,636	3,636	129,686	58,964	771,978	905,300	905,300
Mole Flow	lbmol/hr	15,500	61,637	9,339	14,671	23,601	36,626	693	693	6,684	29,250	26,830	31,828	31,828
Temp	F	264.1	105.0	60.0	42.0	112.6	87.0	620.0	72.5	85.0	85.0	59.0	2,000.0	260.0
Pressure	psia	781.5	776.5	149.7	16.7	2,200.0	761.5	761.5	29.4	771.5	750.0	14.7	16.1	16.1
Enthalpy	MMBtu/hr	-1,855.8	-4,529.3	-1,565.1	-2,486.1	-4,046.4	-332.0	-3.6	-6.3	-328.1	1.5	-21.9	-363.6	-822.9

Table 17 Detailed Stream Table for Case 2, cont.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	AMBAIR	ASUFEED	ASUXS	O2PRODCT	TO-REGEN	GASIF-O2	OXYGEN	WTCOAL	SLRYWT	SLAG	GASTOCLR	SW4	SW35	SW31	SW29
CONVENTIONAL															
Temperature F	59	281.5	88	90	90	90	232.7		59		1250	950			946.7
Pressure psia	14.7	190.3	16.4	145	145	145	1024.7	14.7	14.7		900	896	800	798	798
Vapor Frac	1	1	1	1	1	1	1		0		1	1			1
Mole Flow lbmol/hr	68065.9	68065.9	53600.6	14016.1	615	13401.1	13401.1	0	10789.5	0	51863.2	51863.2	0	0	51863.2
Mass Flow lb/hr	1958476.5	1958476.5	1504677.6	445705.9	19556	426149.8	426149.8	0	194375	0	1065666.4	1065666.4	0	0	1065441
Volume Flow cuft/hr	25758119.8	2853242.5	19204372	566320.4	24848.2	541472.2	97050.1	0	3647.1	0	1071144.1	886615.7	0	0	991752.3
Enthalpy MMBtu/hr	-55.5	49.5	3.9	0.7	0	0.7	12.7		-1337.7		-2475.9	-2609			-2614.2
Mass Flow lb/hr															
H2O	8093.1	8093.1	0	0	0	0	0	0	194375	0	167971.3	167971.3	0	0	168343.9
CO2	0	0	0	0	0	0	0	0	0	0	271609.1	271609.1	0	0	272519.4
O2	451287.1	451287.1	25204.4	426082.7	18695	407387.6	407387.6	0	0	0	0	0	0	0	0
N2	1499096.4	1499096.4	1479473.2	19623.2	861	18762.2	18762.2	0	0	0	24083.3	24083.3	0	0	24083.3
CH4	0	0	0	0	0	0	0	0	0	0	154.1	154.1	0	0	154.1
CO	0	0	0	0	0	0	0	0	0	0	555061.2	555061.2	0	0	555061.2
COS	0	0	0	0	0	0	0	0	0	0	471.5	471.5	0	0	471.5
H2	0	0	0	0	0	0	0	0	0	0	30606.3	30606.3	0	0	30606.3
H2S	0	0	0	0	0	0	0	0	0	0	13052.4	13052.4	0	0	13052.4
HCL	0	0	0	0	0	0	0	0	0	0	1508.2	1508.2	0	0	0
NH3	0	0	0	0	0	0	0	0	0	0	1148.9	1148.9	0	0	1148.9
SO2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CISOLID															
Temperature F													60	946.7	
Pressure psia	14.7	190.3	16.4	145	145	145	1024.7	14.7	14.7			896	800	798	798
Vapor Frac													0	0	
Mole Flow lbmol/hr	0	0	0	0	0	0	0	0	0	0	0	0	82.7	103.4	0
Mass Flow lb/hr	0	0	0	0	0	0	0	0	0	0	0	0	8768.6	8993.9	0
Volume Flow cuft/hr	0	0	0	0	0	0	0	0	0	0	0	0	55.7	60.8	0
Enthalpy MMBtu/hr													-40.2	-35	
Mass Flow lb/hr															
ZNO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ZNS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NA2CO3	0	0	0	0	0	0	0	0	0	0	0	0	8768.6	6576.4	0
NACL	0	0	0	0	0	0	0	0	0	0	0	0	0	2417.5	0
NC SOLID															
Temperature F								59		1250					
Pressure psia	14.7	190.3	16.4	145	145	145	1024.7	14.7	14.7	900		896	800	798	798
Vapor Frac								0		0					
Mass Flow lb/hr	0	0	0	0	0	0	0	500000	0	54858.5	0	0	0	0	0
Enthalpy MMBtu/hr								-505.4		-28.1					
Mass Flow lb/hr															
BIT-COAL	0	0	0	0	0	0	0	499994.9	0	0	0	0	0	0	0
SLAG	0	0	0	0	0	0	0	0	0	54858.5	0	0	0	0	0
ASH	0	0	0	0	0	0	0	5.1	0	0	0	0	0	0	0
TOTAL															
Mass Flow lb/hr	1958476.5	1958476.5	1504677.6	445705.9	19556	426149.8	426149.8	500000	194375	54858.5	1065666.4	1065666.4	8768.6	8993.9	1065441
Enthalpy MMBtu/hr	-55.5	49.5	3.9	0.7	0	0.7	12.7	-505.4	-1337.7	-28.1	-2475.9	-2609	-40.2	-35	-2614.2

Table 17 Detailed Stream Table for Case 2, cont.

	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
	ABSFEED	SW41	CO2FLUFF	SYNAIR	NEWZNO	SW1	SW9	SW30	FLFGAS	SW21	RDUCEGAS	SW26	SW27	SW38	P-SULFUR
CONVENTIONAL															
Temperature F	769.4	519.5	100	189.8		1100	900	1100	211.3	1100	900	1016.1	500	500	100
Pressure psia	796	825	850	800	795	786	793	786	1100	786	788	763	758	755	14.7
Vapor Frac	1	1	1	1		1	1	1	1	1	1	0.9	0.8	1	0
Mole Flow lbmol/hr	51863.2	2677.9	1	2024.9	0	0	0	1830.2	1409.9	1830.2	1237.2	3067.4	3067.4	2677.9	389.5
Mass Flow lb/hr	1065441	101186.4	44	81094.7	0	0.7	0.9	87353.3	61538.7	87353.3	26322.4	113675.6	113675.6	101186.4	12489.2
Volume Flow cuft/hr	867339.3	32780.7	4.7	15916.2	0	0.3	0.4	39382.7	7443.3	39382.7	23142.1	59566.9	34311.1	35069.2	304.5
Enthalpy MMBtu/hr	-2690.9	-392.2	-0.2	-235.5		0	0	-265.6	-236.1	-265.6	-69.2	-334.9	-360.9	-392.7	30.6
Mass Flow lb/hr															
H2O	168343.9	10299.1	0	0	0	0	0	0	0	0	4208.8	10299.1	10299.1	10299.1	0
CO2	272519.4	89107	44	61489.9	0	0.7	0.9	61490.8	61489	61490.8	8211.9	89107	89107	89107	0
O2	0	0	0	18694.6	0	0	0	0	0	0	0	0	0	0	0
N2	24083.3	1446.3	0	867.2	0	0	0	867.2	5.5	867.2	579.1	1446.3	1446.3	1446.3	0
CH4	154.1	3.8	0	0.2	0	0	0	0.2	0.2	0.2	3.6	3.8	3.8	3.8	0
CO	555061.2	265.6	0	18.6	0	0	0	18.6	19.8	18.6	12597	265.6	265.6	265.6	0
COS	471.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H2	30606.3	37.5	0	23.9	0	0	0	23.9	23.9	23.9	695.1	37.5	37.5	37.5	0
H2S	13052.4	0.5	0	0.3	0	0	0	0.3	0.3	0.3	0.1	0.5	0.5	0.5	0
HCL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NH3	1148.9	26.7	0	0	0	0	0	0	0	0	26.7	26.7	26.7	26.7	0
SO2	0	0	0	0	0	0	0	24952.3	0	24952.3	0	0	0	0	0
S	0	0	0	0	0	0	0	0	0	0	0	12489.2	12489.2	0	12489.2
CISOLID															
Temperature F					60	1100	900	1100			900	1016.1	500		100
Pressure psia	796	825	850	800	795	786	793	786	1100		788	763	758	755	14.7
Vapor Frac					0	0	0	0			0	0	0		0
Mole Flow lbmol/hr	0	0	0	0	20.9	20874.2	20874.2	20874.2	0	0	0.5	0.5	0.5	0	0.5
Mass Flow lb/hr	0	0	0	0	1700.6	1711458	1717715.7	1711458	0	0	39	39	39	0	39
Volume Flow cuft/hr	0	0	0	0	4.8	4994.4	5092	4994.4	0	0	0.1	0.1	0.1	0	0.1
Enthalpy MMBtu/hr					-3.2	-2836.3	-2866.4	-2836.3			-0.1	-0.1	-0.1		-0.1
Mass Flow lb/hr															
ZNO	0	0	0	0	1700.6	1635542.6	1603842.6	1635542.6	0	0	36.4	36.4	36.4	0	36.4
ZNS	0	0	0	0	0	75915.4	113873.1	75915.4	0	0	2.6	2.6	2.6	0	2.6
NA2CO3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NACL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NC SOLID															
Temperature F															
Pressure psia	796	825	850	800	795	786	793	786	1100		788	763	758	755	14.7
Vapor Frac															
Mass Flow lb/hr	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Enthalpy MMBtu/hr															
Mass Flow lb/hr															
BIT-COAL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SLAG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ASH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL															
Mass Flow lb/hr	1065441	101186.4	44	81094.7	1700.6	1711458.7	1717716.6	1798811.3	61538.7	87353.3	26361.4	113714.6	113714.6	101186.4	12528.2
Enthalpy MMBtu/hr	-2690.9	-392.2	-0.2	-235.5	-3.2	-2836.3	-2866.4	-3101.9	-236.1	-265.6	-69.3	-335	-361	-392.7	30.5

Table 17 Detailed Stream Table for Case 2, cont.

	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
	SW18	QWTR	SHFTMX	SHFTWTR1	SHFTSTM	FRHTSHFT	TOLTSHFT	FRLTSHFT	CHILLED	QNCHSOUR	AGFEED	HPCO2FL	LPCO2FL	P-HPCO2	TREATED
CONVENTIONAL															
Temperature F	900	59	397.7	60	519	777.9	390.1	459.6	100	264.1	105	60	42	112.6	87
Pressure psia	788	800	787	815	815	786.5	785	784.5	781.5	781.5	776.5	149.7	16.7	2200	761.5
Vapor Frac	1	0	1	0	1	1	1	1	1	0	1	1	1	1	1
Mole Flow lbmol/hr	53304.9	12857.6	66162.5	11101.7	11101.7	77264.2	77264.2	77264.2	61763.9	15500.3	61637.1	9338.8	14670.6	23600.7	36626.5
Mass Flow lb/hr	1134071.7	231634	1365705.7	200000	200000	1565705.7	1565705.7	1565705.7	1286168.6	279537.1	1283912.5	406659.1	645487.6	1030088.1	192285.7
Volume Flow cuft/hr	997054	4343.6	744043.9	3751.7	115537.6	1306005.7	869516.9	954588.8	448305.7	5757.6	455653.4	325967.4	4694007.8	23893.8	285824.7
Enthalpy MMBtu/hr	-2983.4	-1593.6	-4521.1	-1375.7	-1126.5	-5647.5	-5918.7	-5918.7	-4542.8	-1855.8	-4529.3	-1565.1	-2486.1	-4046.4	-332
Mass Flow lb/hr															
H2O	181330.6	231634	412964.6	200000	200000	332452.8	332452.8	279998.2	1744.3	278253.9	0.2	0	0.1	0.2	0
CO2	353802.9	0	353802.9	0	0	1039069.3	1039069.3	1167211.6	1166572.4	639.1	1166572.4	406200.5	645464.5	1029256.2	75827.2
O2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N2	24950.5	0	24950.5	0	0	24950.5	24950.5	24950.5	24949.8	0.7	24949.8	43.8	1.1	91.8	24852.5
CH4	154.3	0	154.3	0	0	154.3	154.3	154.3	154.3	0	154.3	2.8	0.2	4	150
CO	542729.8	0	542729.8	0	0	106586.3	106586.3	25029.1	25028.4	0.7	25028.4	210.9	14.4	330.6	24678
COS	0.1	0	0.1	0	0	0.1	0.1	0.1	0.1	0	0.1	0	0	0.1	0
H2	29948.7	0	29948.7	0	0	61337.5	61337.5	67207.1	67201.3	5.7	67201.3	201.1	7.3	399.5	66778
H2S	6	0	6	0	0	6	6	6	5.9	0	5.9	0	0	5.6	0
HCL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NH3	1148.9	0	1148.9	0	0	1148.9	1148.9	1148.9	512	636.9	0	0	0	0	0
SO2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CISOLID															
Temperature F	900		397.7												
Pressure psia	788	800	787	815	815	786.5	785		781.5	781.5	776.5	149.7	16.7	2200	761.5
Vapor Frac	0		0												
Mole Flow lbmol/hr	20.4	0	20.4	0	0	0	0	0	0	0	0	0	0	0	0
Mass Flow lb/hr	1680.4	0	1680.4	0	0	0	0	0	0	0	0	0	0	0	0
Volume Flow cuft/hr	5	0	5	0	0	0	0	0	0	0	0	0	0	0	0
Enthalpy MMBtu/hr	-2.8		-2.9												
Mass Flow lb/hr															
ZNO	1569	0	1569	0	0	0	0	0	0	0	0	0	0	0	0
ZNS	111.4	0	111.4	0	0	0	0	0	0	0	0	0	0	0	0
NA2CO3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NACL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NC SOLID															
Temperature F															
Pressure psia	788	800	787	815	815	786.5	785		781.5	781.5	776.5	149.7	16.7	2200	761.5
Vapor Frac															
Mass Flow lb/hr	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Enthalpy MMBtu/hr															
Mass Flow lb/hr															
BIT-COAL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SLAG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ASH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL															
Mass Flow lb/hr	1135752.1	231634	1367386.1	200000	200000	1565705.7	1565705.7	1565705.7	1286168.6	279537.1	1283912.5	406659.1	645487.6	1030088.1	192285.7
Enthalpy MMBtu/hr	-2986.2	-1593.6	-4524	-1375.7	-1126.5	-5647.5	-5918.7	-5918.7	-4542.8	-1855.8	-4529.3	-1565.1	-2486.1	-4046.4	-332

Table 17 Detailed Stream Table for Case 2, cont.

	46	47	48	49	50	51	52
	HTDFG	FGB	PSABTM	H2PROD	COMBAIR	HRSGIN	HRSGOUT
CONVENTIONAL							
Temperature F	620	72.5	85	85	59	2000	260
Pressure psia	761.5	29.39	771.54	750	14.7	16.14	16.14
Vapor Frac	1	1	1	1	1	1	1
Mole Flow lbmol/hr	692.6	692.6	6684.3	29249.6	26829.7	31827.9	31827.9
Mass Flow lb/hr	3636.3	3636.3	129685.8	58963.6	771977.5	905299.6	905299.6
Volume Flow cuft/hr	10687	134639.7	49252.1	232151.5	10155941.9	52063749.3	15224312.6
Enthalpy MMBtu/hr	-3.6	-6.3	-328.1	1.5	-21.9	-363.6	-822.9
Mass Flow lb/hr							
H2O	0	0	0	0	3190.1	73361.3	73361.3
CO2	1434	1434	74393.2	0	0	115012.7	115012.7
O2	0	0	0	0	177884.9	101170.5	101170.5
N2	470	470	24382.5	0	590902.5	615755	615755
CH4	2.8	2.8	147.2	0	0	0	0
CO	466.7	466.7	24211.3	0	0	0	0
COS	0	0	0	0	0	0	0
H2	1262.8	1262.8	6551.5	58963.6	0	0	0
H2S	0	0	0	0	0	0	0
HCL	0	0	0	0	0	0	0
NH3	0	0	0	0	0	0	0
SO2	0	0	0	0	0	0	0
S	0	0	0	0	0	0	0
CISOLID							
Temperature F							
Pressure psia	761.5	29.39	771.54	750	14.7	16.14	16.14
Vapor Frac							
Mole Flow lbmol/hr	0	0	0	0	0	0	0
Mass Flow lb/hr	0	0	0	0	0	0	0
Volume Flow cuft/hr	0	0	0	0	0	0	0
Enthalpy MMBtu/hr							
Mass Flow lb/hr							
ZNO	0	0	0	0	0	0	0
ZNS	0	0	0	0	0	0	0
NA2CO3	0	0	0	0	0	0	0
NACL	0	0	0	0	0	0	0
NC SOLID							
Temperature F							
Pressure psia	761.5	29.39	771.54	750	14.7	16.14	16.14
Vapor Frac							
Mass Flow lb/hr	0	0	0	0	0	0	0
Enthalpy MMBtu/hr							
Mass Flow lb/hr							
BIT-COAL	0	0	0	0	0	0	0
SLAG	0	0	0	0	0	0	0
ASH	0	0	0	0	0	0	0
TOTAL							
Mass Flow lb/hr	3636.3	3636.3	129685.8	58963.6	771977.5	905299.6	905299.6
Enthalpy MMBtu/hr	-3.6	-6.3	-328.1	1.5	-21.9	-363.6	-822.9

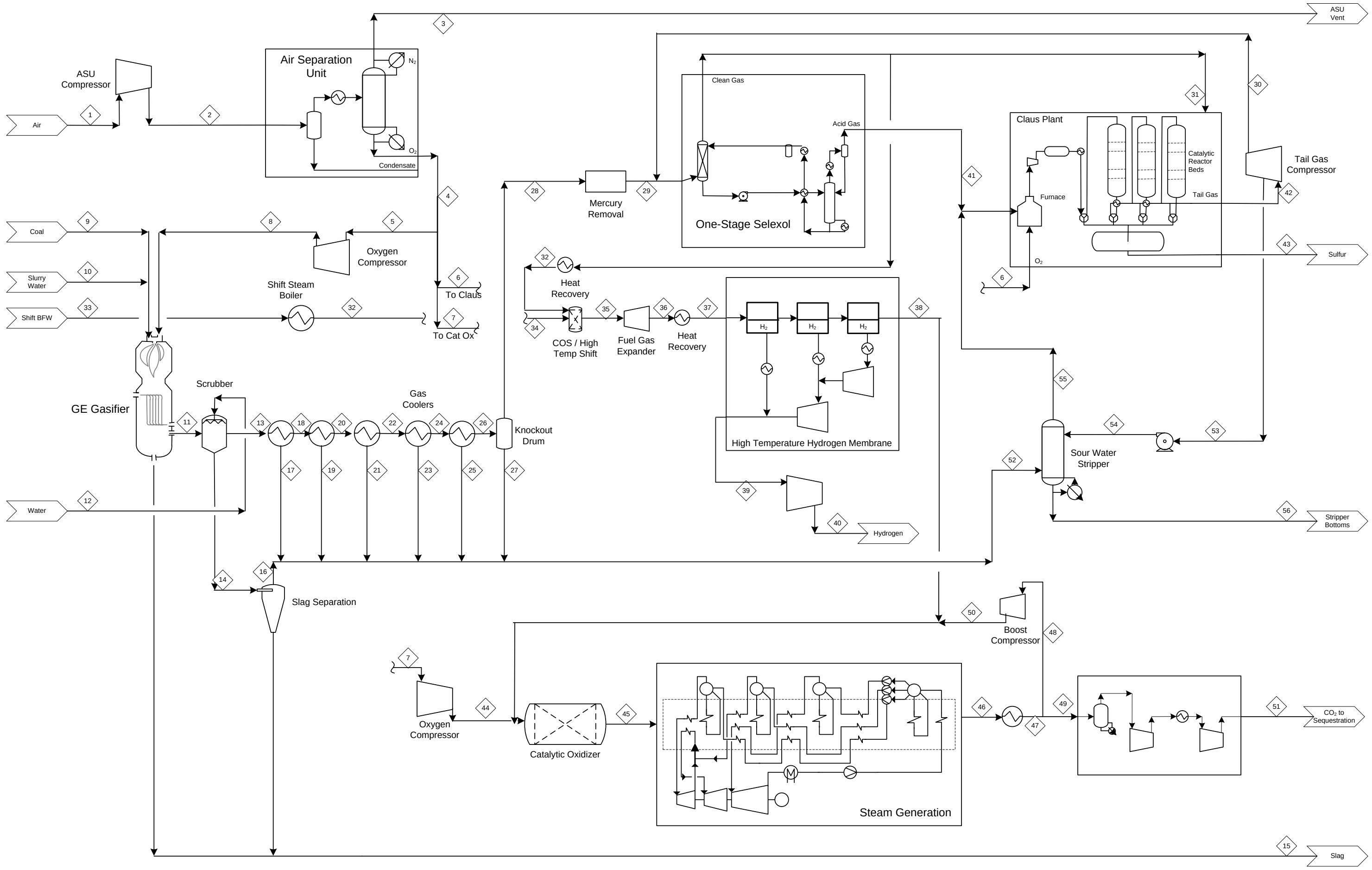


Figure 13 Process Flow Diagram for Case 3

Table 18 Detailed Stream Table for Case 3

		1	2	3	4	5	6	7	8	9	10	11	12	13	14
		AMBAIR	ASUFEED	ASUXS	O2PRODCT	GASIF-O2	O2CLAUS	TO-CATOX	OXYGEN	WTCOAL	SLRYWT	GASTOCLR	QWNCHW	RAW-GAS	QWNCHBTM
Mass Flow	lb/hr	2,504,506	2,504,506	1,924,186	569,970	425,969	5,775	138,226	425,969	500,000	194,375	1,065,486	929,979	1,976,811	18,654
Mole Flow	lbmol/hr	87,043	87,043	68,545	17,924	13,395	182	4,347	13,395		10,789	51,862	51,622	102,449	1,035
Temp	F	59.0	281.5	88.0	90.0	90.0	90.0	90.0	232.7	59.0	59.0	2,498.0	246.7	454.8	454.8
Pressure	psia	14.7	190.3	16.4	145.0	145.0	145.0	145.0	1,024.7	14.7	14.7	900.0	840.0	838.0	838.0
Enthalpy	MMBtu/hr	-71.0	63.3	5.0	0.9	0.7	0.0	0.2	12.7	-505.4	-1,337.7	-1,881.4	-6,208.9	-7,970.4	-119.8

		15	16	17	18	19	20	21	22	23	24	25	26	27	28
		SLAG	SLAGWATR	CLRALIQ	CLRAVAP	CLR1LIQ	CLR1VAP	COND1	QNCHCHLL	CLR3LIQ	CLR3VAP	COND2	CHILLED	NH3OUT	TOMERCRY
Mass Flow	lb/hr	54,859	16,792	179,324	1,797,487	678,685	1,118,802	84,825	1,033,976	117,625	916,352	20,402	895,950	1,755	894,195
Mole Flow	lbmol/hr		932	9,948	92,501	37,645	54,856	4,705	50,151	6,526	43,625	1,133	42,492	57	42,435
Temp	F	2,498.0	454.8	446.3	446.3	365.5	365.5	335.0	335.0	225.0	225.0	100.0	100.0	100.0	100.0
Pressure	psia	900.0	838.0	837.5	837.5	837.0	837.0	836.0	836.0	836.0	836.0	835.0	835.0	834.0	834.0
Enthalpy	MMBtu/hr	-5.3	-107.8	-1,153.4	-6,964.0	-4,431.9	-3,168.0	-556.9	-2,698.8	-786.4	-2,067.9	-138.5	-1,993.0	-2.3	-1,991.0

		29	30	31	32	33	34	35	36	37	38	39	40	41	42
		TO-AGR	TGOUT	REDUCEIT	TOWGS	SHFTWTR1	SHFTSTM	FRSHIFT	MEXP	TOHTHM	MEMFG	H2COLD	H2PROD	TOCLAUS	TGRCY
Mass Flow	lb/hr	894,195	31,582	3,460	883,849	229,639	229,639	1,113,488	1,113,488	1,113,488	1,098,491	53,710	53,710	38,467	42,920
Mole Flow	lbmol/hr	42,435	794	164	42,014	12,747	12,747	54,761	54,761	54,761	30,266	26,644	26,644	1,051	1,423
Temp	F	99.7	110.0	100.0	412.0	60.0	518.9	761.3	611.7	572.0	640.7	110.0	100.0	100.0	365.2
Pressure	psia	833.0	808.5	803.5	796.5	815.0	815.0	791.0	426.2	426.2	414.2	79.8	749.5	803.5	21.0
Enthalpy	MMBtu/hr	-1,991.1	-110.5	-7.8	-1,892.2	-1,579.6	-1,293.4	-3,185.6	-3,254.9	-3,273.3	-3,638.5	6.0	4.2	-100.3	-172.0

		43	44	45	46	47	48	49	50	51	52	53	54	55	56
		SULFUR	PCATOX	HRSGIN	HRSGOUT	HPCO2-1	RECCO2	CO2TOCMP	RECCO2P	P-HPCO2	QNCHSOUR	TOTGRWR	TGWATRCY	SWSVAP	SWSBOT
Mass Flow	lb/hr	12,505	138,225	1,412,558	1,412,558	1,352,627	175,842	1,176,786	175,842	1,176,744	1,099,408	11,336	11,336	3,128	1,107,616
Mole Flow	lbmol/hr	49	4,347	34,565	34,565	31,240	4,061	27,178	4,061	27,176	60,945	629	629	135	61,440
Temp	F	320.0	163.7	2,683.7	260.0	90.0	90.0	90.0	101.9	100.0	359.0	110.1	110.5	80.0	247.0
Pressure	psia	33.0	381.1	381.1	381.1	381.1	381.1	381.1	411.1	2,200.0	834.0	21.0	75.0	35.0	35.0
Enthalpy	MMBtu/hr	0.7	2.3	-4,314.7	-5,361.9	-5,074.9	-659.7	-4,415.2	-659.4	-4,511.0	-7,177.3	-77.4	-77.4	-6.6	-7,386.0

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	AMBAIR	ASUFEED	ASUXS	O2PRODCT	GASIF-O2	O2CLAUS	TO-CATOX	OXYGEN	WTCOAL	SLRYWT	GASTOCLR	QWNCHW	RAW-GAS	QWNCHBTM	SLAG
CONVENTIONAL															
Temperature F	59	281.5	88	90	90	90	90	232.7		59	2498	246.7	454.8	454.8	
Pressure psia	14.7	190.3	16.4	145	145	145	145	1024.7	14.7	14.7	900	840	838	838	
Vapor Frac	1	1	1	1	1	1	1	1		0	1	0	1	0	
Mole Flow lbmol/hr	87,043	87,043	68,545	17,924	13,395	182	4,347	13,395	0	10,790	51,862	51,622	102,449	1,035	0
Mass Flow lb/hr	2,504,506	2,504,506	1,924,186	569,970	425,969	5,775	138,226	425,969	0	194,375	1,065,486	929,979	1,976,811	18,654	0
Volume Flow cuft/hr	3.29E+07	3.65E+06	24558610.7	724212.3	5.41E+05	7337.7	175631.6	97009	0	3647.1	1.85E+06	18931.8	1100512.1	448.3	0
Enthalpy MMBtu/hr	-71	63	5	1	1	0	0	13		-1,338	-1,881	-6,209	-7,970	-120	
Mass Flow lb/hr															
H2O	10349.5	10349.5	0	0	0	0	0	0	0	194375	1.68E+05	929978.8	1079120.9	18615	0
CO2	0	0	0	0	0.00E+00	0	0	0	0	0	271664.1	0	271643.2	20.8	0
O2	577107.3	577107.3	32231.4	544875.9	407215.1	5520.7	132140	407215.1	0	0	0	0	0	0	0
N2	1917049.1	1917049.1	1891954.9	25094.2	18754.2	254.3	6085.7	18754.2	0	0	24066.7	0	24066.4	0.3	0
CH4	0.00E+00	0	0	0	0.00E+00	0	0	0	0	0	156.3	0	156.3	0	0
CO	0	0	0	0	0	0	0	0	0	0	555023	0	555016.9	6.1	0
COS	0	0	0	0	0	0	0	0	0	0	470.3	0	470.1	0.1	0
H2	0	0	0	0	0	0	0	0	0	0	30627.8	0	30627	0.8	0
H2S	0	0	0	0	0	0	0	0	0	0	13053.1	0	13047.5	5.6	0
HCL	0	0	0	0	0	0	0	0	0	0	1508.2	0	1507.8	0.4	0
NH3	0	0	0	0	0	0	0	0	0	0	1159.4	0	1154.9	4.6	0
SO2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CISOLID															
Temperature F															
Pressure psia	14.7	190.3	16.4	145	145	145	145	1024.7	14.7	14.7		840	838	838	
Vapor Frac															
Enthalpy MMBtu/hr															
Mass Flow lb/hr															
NC SOLID															
Temperature F									59						2498
Pressure psia	14.7	190.3	16.4	145	145	145	145	1024.7	14.7	14.7		840	838	838	900
Vapor Frac									0						0
Mass Flow lb/hr	0	0	0	0	0	0	0	0	500000	0	0	0	0	0	54858.5
Enthalpy MMBtu/hr									-505.4						-5.3
Mass Flow lb/hr															
BIT-COAL	0	0	0	0	0	0	0	0	499994.9	0	0	0	0	0	0
SLAG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	54858.5
ASH	0	0	0	0	0	0	0	0	5.1	0	0	0	0	0	0
TOTAL															
Mass Flow lb/hr	2504505.9	2504505.9	1924186.3	569970	425969.4	5775	138225.7	425969.4	500000	194375	1065485.9	929978.8	1976811.1	18653.6	54858.5
Enthalpy MMBtu/hr	-71	63.3	5	0.9	0.7	0	0.2	12.7	-505.4	-1337.7	-1881.4	-6208.9	-7970.4	-119.8	-5.3

Table 18 Detailed Stream Table for Case 3, cont.

	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
	SLAGWATR	CLRALIQ	CLRAVAP	CLR1LIQ	CLR1VAP	COND1	QNCHCHLL	CLR3LIQ	CLR3VAP	COND2	CHILLED	NH3OUT	TOMERCRY	TO-AGR	TGOUT
CONVENTIONAL															
Temperature F	454.8	446.3	446.3	365.5	365.5	335	335	225	225	100	100	100	100	99.7	110
Pressure psia	838	837.5	837.5	837	837	836	836	836	836	835	835	834	834	833	808.5
Vapor Frac	0	0	1	0	1	0	1	0	1	0	1	0	1	1	1
Mole Flow lbmol/hr	932	9,948	92,501	37,645	54,856	4,705	50,151	6,526	43,625	1,133	42,492	57	42,435	42,435	794
Mass Flow lb/hr	16,792	179,324	1,797,487	678,685	1,118,802	84,825	1,033,976	117,625	916,352	20,402	895,950	1,755	894,195	894,195	31,582
Volume Flow cuft/hr	405.4	4.27E+03	995049.8	14961.6	5.69E+05	1.83E+03	506388.5	2.37E+03	3.84E+05	3.89E+02	301216.2	40	301245	301418.8	4819
Enthalpy MMBtu/hr	-108	-1,153	-6,964	-4,432	-3,168	-557	-2,699	-786	-2,068	-139	-1,993	-2	-1,991	-1,991	-111
Mass Flow lb/hr															
H2O	16753.5	178933.8	900187.1	676995.5	223191.7	84612.5	138579.2	117271.4	21307.7	2.02E+04	1101.4	0	1101.4	1101.4	35.9
CO2	20.8	209.3	271433.9	820.8	270613.1	9.41E+01	270519	77.2	270441.9	5.4	270436.5	0	270436.5	270436.5	27593.7
O2	0	0.00E+00	0	0	0	0	0	0	0	0	0	0	0	0	0
N2	0.3	2.5	24063.9	6	24058	0.6	24057.4	0.2	24057.2	0	24057.2	0	24057.2	24057.2	1207.1
CH4	0	0.1	156.3	0.2	156.1	0.00E+00	156.1	0.00E+00	156.1	0	156.1	0	156.1	156.1	0.6
CO	6.1	58.2	554958.7	141	554817.6	13.3	554804.3	4.8	554799.5	0.1	554799.4	0	554799.4	554799.4	2169.1
COS	0.1	1.3	468.8	5.4	463.5	0.6	462.9	0.5	462.4	0	462.4	0	462.4	462.4	0
H2	0.8	7.9	30619	21.8	30597.3	2.1	30595.2	0.9	30594.3	0	30594.3	0	30594.3	30594.3	59.5
H2S	5.6	58.2	12989.3	304.8	12684.5	39.2	12645.3	50.5	12594.9	6.8	12588.1	0	12588.1	12588.1	515.6
HCL	0.4	4.2	1503.6	21.5	1482.1	2.7	1479.4	3.5	1475.9	0.5	1475.4	1475.4	0	0	0
NH3	4.6	48.9	1106	368.3	737.7	60.1	677.6	215.6	462	182.4	279.6	279.6	0	0	0
SO2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CISOLID															
Temperature F															
Pressure psia	838	837.5	837.5	837	837	836	836	836	836	835	835	834	834	833	
Vapor Frac															
Enthalpy MMBtu/hr															
Mass Flow lb/hr															
NC SOLID															
Temperature F															
Pressure psia	838	837.5	837.5	837	837	836	836	836	836	835	835	834	834	833	
Vapor Frac															
Mass Flow lb/hr	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Enthalpy MMBtu/hr															
Mass Flow lb/hr															
BIT-COAL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SLAG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ASH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL															
Mass Flow lb/hr	16792.1	179324.4	1797486.8	678685.2	1118801.6	84825.3	1033976.3	117624.6	916351.7	20401.5	895950.2	1755	894195.2	894195.2	31581.5
Enthalpy MMBtu/hr	-107.8	-1153.4	-6964	-4431.9	-3168	-556.9	-2698.8	-786.4	-2067.9	-138.5	-1993	-2.3	-1991	-1991.1	-110.5

Table 18 Detailed Stream Table for Case 3, cont.

		31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
		REDUCEIT	TOWGS	SHFTWTR1	SHFTSTM	FRSHIFT	MEXP	TOHTHM	MEMFG	H2COLD	H2PROD	TOCLAUS	TGRCY	SULFUR	PCATOX	HRSGIN
CONVENTIONAL																
	Temperature F	100	412	60	518.9	761.3	611.7	572	640.7	110	100	100	365.2	320	163.7	2683.7
	Pressure psia	803.5	796.5	815	815	791	426.18	426.18	414.18	79.8	749.5	803.5	21	33	381.07	381.07
	Vapor Frac	1	1	0	1	1	1	1	1	1	1	1	1	0	1	1
	Mole Flow lbmol/hr	165	42,014	12,747	12,747	54,761	54,761	54,761	30,266	26,644	26,644	1,051	1,424	49	4,347	34,565
	Mass Flow lb/hr	3,460	883,849	229,639	229,639	1,113,488	1,113,488	1,113,488	1,098,491	53,710	53,710	38,467	42,920	12,506	138,225	1,412,558
	Volume Flow cuft/hr	1213.9	500876.8	4307.6	132659.1	9.18E+05	1484393.5	1428569.9	864385.6	2044935.8	2.17E+05	5328.8	598191.5	39.1	75749.6	3.07E+06
	Enthalpy MMBtu/hr	-8	-1,892	-1,580	-1,293	-3,186	-3,255	-3,273	-3,639	6	4	-100	-172	1	2	-4,315
	Mass Flow lb/hr															
	H2O	2	514	229639	229639	59309	59309	59309	13410.8	0	0.00E+00	621.3	11370.6	0	0	61083.1
	CO2	1070.8	273525.7	0	0	690883	690883	690883	897581.8	0	0	23433.7	27596.6	0	0	1315492.4
	O2	0	0	0	0	0	0	0	0	0	0	0	0	0	132139.2	0
	N2	98.5	25165.8	0	0	25165.8	25165.8	25165.8	25165.8	0	0	0	1207.1	0	6085.6	35921.2
	CH4	0.6	154.3	0	0	1.54E+02	154.3	154.3	154.3	0	0	1.8	0.6	0	0	0
	CO	2169	554041.6	0	0	288428.8	288428.8	288428.8	156873.7	0	0	757.8	2169.1	0	0	0
	COS	0.1	38.3	0	0	0.2	0.2	0.2	0.2	0	0	423.9	0	0	0	0
	H2	119	30403.2	0	0	49519.1	49519.1	49519.1	5276.6	53710.4	53710.4	131.5	59.5	0	0	0
	H2S	0	6.5	0	0	28.2	28.2	28.2	28.2	0	0	13097.2	516.3	0	0	0
	HCL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	NH3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	SO2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	61
	S8	0	0	0	0	0	0	0	0	0	0	0	0	12505.5	0	0
CISOLID																
	Temperature F															
	Pressure psia	803.5	796.5	815	815		426.18	426.18	414.18	79.8	749.5	803.5	21	33	381.07	381.07
	Vapor Frac															
	Enthalpy MMBtu/hr															
	Mass Flow lb/hr															
NC SOLID																
	Temperature F															
	Pressure psia	803.5	796.5	815	815		426.18	426.18	414.18	79.8	749.5	803.5	21	33	381.07	381.07
	Vapor Frac															
	Mass Flow lb/hr	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Enthalpy MMBtu/hr															
	Mass Flow lb/hr															
	BIT-COAL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	SLAG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	ASH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL																
	Mass Flow lb/hr	3460.1	883849.4	229639	229639	1113488.4	1113488.4	1113488.4	1098491.3	53710.4	53710.4	38467.2	42919.8	12505.5	138224.8	1412557.7
	Enthalpy MMBtu/hr	-7.8	-1892.2	-1579.6	-1293.4	-3185.6	-3254.9	-3273.3	-3638.5	6	4.2	-100.3	-172	0.7	2.3	-4314.7

Table 18 Detailed Stream Table for Case 3, cont.

	46	47	48	49	50	51	52	53	54	55	56
	HRSGOUT	HPCO2-1	RECCO2	CO2TOCMP	RECCO2P	P-HPCO2	QNCHSOUR	TOTGRWR	TGWATRCY	SWSVAP	SWSBOT
CONVENTIONAL											
Temperature F	260	90	90	90	101.9	100	359	110.1	110.5	80	247
Pressure psia	381.07	381.07	381.07	381.07	411.07	2200	834	21	75	35	35
Vapor Frac	1	1	1	1	1	1	0	0	0	1	0
Mole Flow lbmol/hr	34,565	31,240	4,061	27,179	4,061	27,176	60,945	629	629	135	61,440
Mass Flow lb/hr	1,412,558	1,352,627	175,842	1,176,786	175,842	1,176,744	1,099,408	11,336	11,336	3,128	1,107,616
Volume Flow cuft/hr	6.60E+05	4.18E+05	54392.6	3.64E+05	51480.6	26726.3	24127.6	216.8	216.8	22011.8	52649.9
Enthalpy MMBtu/hr	-5,362	-5,075	-660	-4,415	-659	-4,511	-7,177	-77	-77	-7	-7,386
Mass Flow lb/hr											
H2O	61083.1	1198.6	155.8	1042.8	155.8	1001.5	1094773.1	11334.7	11334.7	0	1106107.7
CO2	1315492.4	1.32E+06	171008.1	1144438.6	171008.1	1144438.5	1227.6	0.6	0.6	1228.2	0
O2	0	0	0	0	0	0	0	0	0	0	0
N2	35921.2	35921.2	4669.8	31251.4	4669.8	31251.4	9.5	0	0	9.5	0
CH4	0	0	0	0.00E+00	0	0	0.2	0	0	0.2	0
CO	0	0	0	0	0	0	223.6	0	0	223.6	0
COS	0	0	0	0	0	0	7.9	0	0	7.9	0
H2	0	0	0	0	0	0	33.5	0	0	33.5	0
H2S	0	0	0	0	0	0	465	0.7	0.7	465.7	0
HCL	0	0	0	0	0	0	1508.2	0	0	0	1508.2
NH3	0	0	0	0	0	0	1159.4	0	0	1159.4	0
SO2	61	60.8	7.9	52.9	7.9	52.9	0	0	0	0	0
S8	0	0	0	0	0	0	0	0	0	0	0
CISOLID											
Temperature F											
Pressure psia	381.07	381.07		381.07	411.07	2200	834	21	75		35
Vapor Frac											
Enthalpy MMBtu/hr											
Mass Flow lb/hr											
NC SOLID											
Temperature F											
Pressure psia	381.07	381.07		381.07	411.07	2200	834	21	75		35
Vapor Frac											
Mass Flow lb/hr	0	0	0	0	0	0	0	0	0	0	0
Enthalpy MMBtu/hr											
Mass Flow lb/hr											
BIT-COAL	0	0	0	0	0	0	0	0	0	0	0
SLAG	0	0	0	0	0	0	0	0	0	0	0
ASH	0	0	0	0	0	0	0	0	0	0	0
TOTAL											
Mass Flow lb/hr	1412557.7	1352627.2	175841.6	1176785.7	175841.5	1176744.3	1099408	11335.9	11335.9	3128	1107615.9
Enthalpy MMBtu/hr	-5361.9	-5074.9	-659.7	-4415.2	-659.4	-4511	-7177.3	-77.4	-77.4	-6.6	-7386

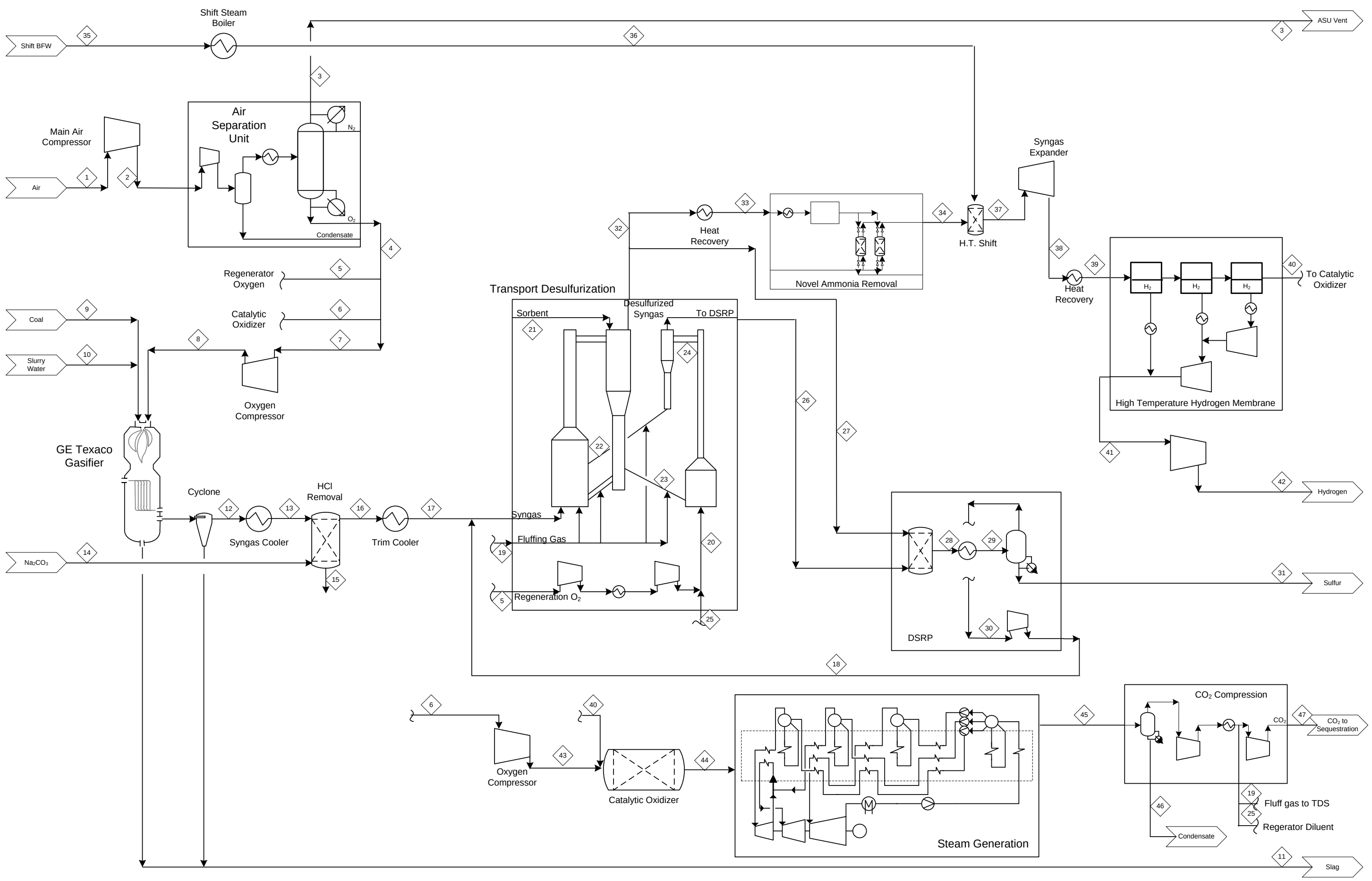


Figure 14 Process Flow Diagram for Case 4

Table 19 Detailed Stream Table for Case 4

		1	2	3	4	5	6	7	8	9	10	11	12
		AMBAIR	ASUFEED	ASUXS	O2PRODCT	TO-REGEN	TOCATOXY	GASIF-O2	OXYGEN	WTCOAL	SLRYWT	SLAG	GASTOCLR
Mass Flow	lb/hr	2,301,248	2,301,248	1,768,025	523,713	19,556	78,008	426,150	426,150	500,000	194,375	54,859	1,065,666
Mole Flow	lbmol/hr	79,979	79,979	62,982	16,469	615	2,453	13,401	13,401		10,789		51,863
Temp	F	59.0	281.5	88.0	90.0	90.0	90.0	90.0	232.7	59.0	59.0	1,250.0	1,250.0
Pressure	psia	14.7	190.3	16.4	145.0	145.0	145.0	145.0	1,024.7	14.7	14.7	900.0	900.0
Enthalpy	MMBtu/hr	-65.2	58.1	4.6	0.9	0.0	0.1	0.7	12.7	-505.4	-1,337.7	-28.1	-2,475.9

		13	14	15	16	17	18	19	20	21	22	23	24
		SW4	SW35	SW31	SW29	ABSFEED	SW41	CO2FLUFF	SYNAIR	NEWZNO	SW1	SW9	SW30
Mass Flow	lb/hr	1,065,666	8,769	8,994	1,065,441	1,065,441	101,194	44	81,093	1,672	1,682,467	1,688,725	1,769,817
Mole Flow	lbmol/hr	51,863	83	103	51,863	51,863	2,688	1	2,035	21	20,518	20,518	22,358
Temp	F	950.0	60.0	946.7	946.7	770.6	519.6	100.0	141.2	60.0	1,100.0	900.0	1,100.0
Pressure	psia	896.0	800.0	798.0	798.0	796.0	825.0	850.0	800.0	795.0	786.0	793.0	786.0
Enthalpy	MMBtu/hr	-2,609.0	-40.2	-35.0	-2,614.2	-2,690.4	-386.6	-0.2	-231.0	-3.1	-2,787.0	-2,816.1	-3,047.2

		25	26	27	28	29	30	31	32	33	34	35	36
		FLFGAS	SW21	RDUCEGAS	SW26	SW27	SW38	P-SULFUR	SW18	TOWGS	TOHTSHFT	SHFTWTR1	SHFTSTM
Mass Flow	lb/hr	61,537	87,351	26,370	113,721	113,721	101,194	12,528	1,135,722	1,135,722	1,132,911	196,110	196,110
Mole Flow	lbmol/hr	1,419	1,840	1,238	3,078	3,078	2,688	390	53,335	53,335	53,246	10,886	10,886
Temp	F	157.9	1,100.0	900.0	1,015.9	500.0	500.0	100.0	900.0	412.0	412.0	60.0	518.9
Pressure	psia	1,100.0	786.0	788.0	763.0	758.0	755.0	14.7	788.0	777.0	772.0	815.0	815.0
Enthalpy	MMBtu/hr	-231.7	-260.2	-69.2	-329.4	-355.4	-387.1	30.5	-2,980.7	-3,198.2	-3,194.1	-1,348.9	-1,104.6

		37	38	39	40	41	42	43	44	45	46	47
		FRSHIFT	MEXP	TOHTHM	MEMTG	H2COLD	H2PROD	PCATOX	HRSGIN	HRSGOUT	COND	P-HPCO2
Mass Flow	lb/hr	1,329,021	1,329,021	1,329,021	1,321,893	59,669	59,669	77,978	1,399,871	1,399,871	163,597	1,174,694
Mole Flow	lbmol/hr	64,132	64,132	64,132	37,449	29,600	29,600	2,452	37,591	37,591	9,077	27,092
Temp	F	789.0	645.7	572.0	617.5	110.0	100.0	163.7	1,721.5	260.0	90.0	114.6
Pressure	psia	771.5	426.2	426.2	414.2	80.0	749.5	381.1	381.1	381.1	381.1	2,200.0
Enthalpy	MMBtu/hr	-4,298.7	-4,378.5	-4,419.8	-4,893.3	6.7	4.6	1.3	-4,902.0	-5,534.9	-1,119.8	-4,502.5

Table 19 Detailed Stream Table for Case 4, cont.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	AMBAIR	ASUFEED	ASUXS	O2PRODCT	TO-REGEN	TOCATOXY	GASIF-O2	OXYGEN	WTCOAL	SLRYWT	SLAG	GASTOCLR	SW4	SW35	SW31
CONVENTIONAL															
Temperature F	59	281.5	88	90	90	90	90	232.7		59		1250	950		
Pressure psia	14.7	190.3	16.4	145	145	145	145	1024.7	14.7	14.7		900	896	800	798
Vapor Frac	1	1	1	1	1	1	1	1		0		1	1		
Mole Flow lbmol/hr	79,979	79,979	62,982	16,469	615	2,453	13,401	13,401	0	10,790	0	51,863	51,863	0	0
Mass Flow lb/hr	2,301,248	2,301,248	1,768,025	523,713	19,556	78,008	426,150	426,150	0	194,375	0	1,065,667	1,065,667	0	0
Volume Flow cuft/hr	3.03E+07	3352615.1	2.26E+07	665437.5	2.48E+04	9.91E+04	5.41E+05	97050.1	0	3.65E+03	0.00E+00	1.07E+06	886615.7	0.00E+00	0.00E+00
Enthalpy MMBtu/hr	-65	58	5	1	0	0	1	13		-1,338		-2,476	-2,609		
Mass Flow lb/hr															
H2O	9509.5	9509.5	0	0	0.00E+00	0.00E+00	0	0.00E+00	0	194375	0	167971.4	167971.4	0.00E+00	0
CO2	0	0	0	0	0	0	0	0	0.00E+00	0	0.00E+00	271609.1	271609.1	0	0
O2	530271	530271	29615.6	500655.4	18694.6	74573.1	407387.7	4.07E+05	0	0.00E+00	0	0	0	0	0
N2	1761467.2	1761467.2	1738409.6	23057.6	861	3434.5	18762.2	18762.2	0	0	0	24083.3	24083.3	0	0
CH4	0	0	0	0	0	0	0	0	0	0	0	154.1	154.1	0	0
CO	0.00E+00	0	0	0	0	0	0.00E+00	0	0	0	0	5.55E+05	555061.2	0	0
COS	0	0	0	0	0	0	0	0	0	0	0	471.5	471.5	0	0
H2	0	0	0	0	0	0	0	0	0	0	0	30606.3	30606.3	0	0
H2S	0	0	0	0	0	0	0	0	0	0	0	13052.4	13052.4	0	0
HCL	0	0	0	0	0	0	0	0	0	0	0	1508.2	1508.2	0	0
NH3	0	0	0	0	0	0	0	0	0	0	0	1148.9	1148.9	0	0
SO2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CISOLID															
Temperature F														60	946.7
Pressure psia	14.7	190.3	16.4	145	145	145	145	1024.7	14.7	14.7			896	800	798
Vapor Frac														0	0
Mole Flow lbmol/hr	0	0	0	0	0	0	0	0	0	0	0	0	0	82.7	103.4
Mass Flow lb/hr	0	0	0	0	0	0	0	0	0	0	0	0	0	8768.6	8993.9
Volume Flow cuft/hr	0	0	0	0	0	0	0	0	0	0	0	0	0	55.7	60.8
Enthalpy MMBtu/hr														-40.2	-35
Mass Flow lb/hr															
ZNO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ZNS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NA2CO3	0	0	0	0	0	0	0	0	0	0	0	0	0	8768.6	6576.4
NACL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2417.5
NC SOLID															
Temperature F									59		1250				
Pressure psia	14.7	190.3	16.4	145	145	145	145	1024.7	14.7	14.7	900		896	800	798
Vapor Frac									0		0				
Mass Flow lb/hr	0	0	0	0	0	0	0	0	500000	0	54858.5	0	0	0	0
Enthalpy MMBtu/hr									-505.4		-28.1				
Mass Flow lb/hr															
BIT-COAL	0	0	0	0	0	0	0	0	499994.9	0	0	0	0	0	0
SLAG	0	0	0	0	0	0	0	0	0	0	54858.5	0	0	0	0
ASH	0	0	0	0	0	0	0	0	5.1	0	0	0	0	0	0
TOTAL															
Mass Flow lb/hr	2301247.8	2301247.8	1768025.2	523713	19555.5	78007.6	426149.9	426149.9	500000	194375	54858.5	1065666.5	1065666.5	8768.6	8993.9
Enthalpy MMBtu/hr	-65.2	58.1	4.6	0.9	0	0.1	0.7	12.7	-505.4	-1337.7	-28.1	-2475.9	-2609	-40.2	-35

Table 19 Detailed Stream Table for Case 4, cont.

	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
	SW29	ABSFEED	SW41	CO2FLUFF	SYNAIR	NEWZNO	SW1	SW9	SW30	FLFGAS	SW21	RDUCEGAS	SW26	SW27	SW38	P-SULFUR
CONVENTIONAL																
Temperature F	946.7	770.6	519.6	100	141.2		1100	900	1100	157.9	1100	900	1015.9	500	500	100
Pressure psia	798	796	825	850	800	795	786	793	786	1100	786	788	763	758	755	14.7
Vapor Frac	1	1	1	1	1		1	1	1	1	1	1	0.9	0.8	1	0
Mole Flow lbmol/hr	51,863	51,863	2,688	1	2,035	0	0	0	1,840	1,419	1,840	1,238	3,078	3,078	2,688	390
Mass Flow lb/hr	1,065,441	1,065,441	101,194	44	81,093	0	1	1	87,351	61,537	87,351	26,332	113,683	113,683	101,194	12,489
Volume Flow cuft/hr	9.92E+05	868223.6	3.30E+04	4.7	1.43E+04	0	3.00E-01	0.4	3.96E+04	6279.8	39600.8	2.32E+04	5.98E+04	3.45E+04	3.52E+04	3.05E+02
Enthalpy MMBtu/hr	-2,614	-2,690	-387	0	-231		0	0	-260	-232	-260	-69	-329	-355	-387	31
Mass Flow lb/hr																
H2O	1.68E+05	168344	1.04E+04	0.00E+00	5.19E+01	0.00E+00	0.00E+00	0.00E+00	5.19E+01	52.3	5.19E+01	4211.4	1.04E+04	1.04E+04	1.04E+04	0
CO2	272519.4	272519.4	87582.2	44	59990.6	0	0.7	0.9	59991.5	59997.8	59991.5	8180.2	87582.2	87582.2	87582.2	0
O2	0	0	0	0	18694.1	0	0	0	0	0	0	0.00E+00	0	0	0	0
N2	24083.3	24083.3	2959.4	0	2345.7	0	0	0	2345.7	1486.5	2345.7	6.14E+02	2959.4	2959.4	2959.4	0.00E+00
CH4	154.1	154.1	3.6	0	0	0	0	0	0	0	0	3.6	3.6	3.6	3.6	0
CO	555061.2	555061.2	247.1	0	0	0	0.00E+00	0	0	0	0	12601.1	247.1	247.1	247.1	0
COS	471.5	471.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H2	30606.3	30606.3	13.6	0	0	0	0	0	0	0	0	694.8	13.6	13.6	13.6	0
H2S	13052.4	13052.4	0.1	0	0	0	0	0	0	0	0	0.1	0.1	0.1	0.1	0
HCL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NH3	1148.9	1148.9	36.6	0	9.7	0	0	0	9.7	0	9.7	26.9	36.6	36.6	36.6	0
SO2	0	0	0	0	0.6	0	0	0	24952.2	0.6	24952.2	0	0	0	0	0
S	0	0	0	0	0	0	0	0	0	0	0	0	12489.2	12489.2	0	12489.2
CISOLID																
Temperature F						60	1100	900	1100			900	1015.9	500		100
Pressure psia	798	796	825	850	800	795	786	793	786	1100		788	763	758	755	14.7
Vapor Frac						0	0	0	0			0	0	0		0
Mole Flow lbmol/hr	0	0	0	0	0	20.5	20518	20518	20518	0	0	0.5	0.5	0.5	0	0.5
Mass Flow lb/hr	0	0	0	0	0	1671.6	1682466.4	1688723.9	1682466.4	0	0	38.4	38.4	38.4	0	38.4
Volume Flow cuft/hr	0	0	0	0	0	4.7	4912.5	5010.1	4912.5	0	0	0.1	0.1	0.1	0	0.1
Enthalpy MMBtu/hr						-3.1	-2787	-2816.1	-2787			-0.1	-0.1	-0.1		-0.1
Mass Flow lb/hr																
ZNO	0	0	0	0	0	1671.6	1606552.9	1574853.7	1606552.9	0	0	35.8	35.8	35.8	0	35.8
ZNS	0	0	0	0	0	0	75913.5	113870.2	75913.5	0	0	2.6	2.6	2.6	0	2.6
NA2CO3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NACL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NC SOLID																
Temperature F																
Pressure psia	798	796	825	850	800	795	786	793	786	1100		788	763	758	755	14.7
Vapor Frac																
Mass Flow lb/hr	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Enthalpy MMBtu/hr																
Mass Flow lb/hr																
BIT-COAL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SLAG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ASH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL																
Mass Flow lb/hr	1065441.1	1065441.1	101193.7	44	81092.6	1671.6	1682467	1688724.8	1769817.4	61537.1	87351.1	26370.2	113721.3	113721.3	101193.7	12527.6
Enthalpy MMBtu/hr	-2614.2	-2690.4	-386.6	-0.2	-231	-3.1	-2787	-2816.1	-3047.2	-231.7	-260.2	-69.2	-329.4	-355.4	-387.1	30.5

Table 19 Detailed Stream Table for Case 4, cont.

	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47
	SW18	TOWGS	TOHTSHFT	SHFTWTR1	SHFTSTM	FRSHIFT	MEXP	TOHTHM	MEMTG	H2COLD	H2PROD	PCATOX	HRSGIN	HRSGOUT	COND	P-HPCO2
CONVENTIONAL																
Temperature F	900	412	412	60	518.9	789	645.7	572	617.5	110	100	163.7	1721.5	260	90	114.6
Pressure psia	788	777	772	815	815	771.5	426.18	426.18	414.18	79.98	749.5	381.07	381.07	381.07	381.07	2200
Vapor Frac	1	1	1	0	1	1	1	1	1	1	1	1	1	1	0	1
Mole Flow lbmol/hr	53,315	53,315	53,247	10,886	10,886	64,132	64,132	64,132	37,449	29,600	29,600	2,452	37,591	37,591	9,077	27,093
Mass Flow lb/hr	1,134,070	1,134,070	1,132,911	196,110	196,110	1,329,021	1,329,021	1,329,021	1,321,893	59,669	59,669	77,978	1,399,871	1,399,871	163,597	1,174,694
Volume Flow cuft/hr	9.97E+05	6.36E+05	6.40E+05	3.68E+03	1.13E+05	1.12E+06	1788445.2	1666284.7	1038269.5	2266486	2.42E+05	42733.3	2320999.8	706047.9	3.10E+03	29548.4
Enthalpy MMBtu/hr	-2,978	-3,195	-3,194	-1,349	-1,105	-4,299	-4,379	-4,420	-4,893	7	5	1	-4,902	-5,535	-1,120	-4,503
Mass Flow lb/hr																
H2O	1.81E+05	1.81E+05	1.81E+05	196109.8	196109.8	151734.6	1.52E+05	151734.6	1.01E+05	0.00E+00	0	0	164565.6	164565.6	163471	9.99E+02
CO2	352309.8	3.52E+05	352309.8	0.00E+00	0.00E+00	9.04E+05	903810.2	903810.2	1156366.7	0	0.00E+00	0	1205431.5	1205431.5	125.5	1145308.6
O2	0	0	0	0	0	0	0	0	0	0	0	7.45E+04	0	0	0	0.00E+00
N2	26429	26429	26429	0	0	26429	26429	26429	26429	0	0	3433.1	29862.2	29862.2	0.00E+00	28375.7
CH4	154.1	154.1	154.1	0	0	154.1	154.1	154.1	154.1	0	0	0	0	0	0	0
CO	542707.2	542707.2	542707.2	0	0.00E+00	1.92E+05	191700.3	191700.3	30958.6	0	0.00E+00	0	0	0	0	0
COS	0.1	0.1	0.1	0	0	0.1	0.1	0.1	0.1	0	0	0	0	0	0	0
H2	29925.1	29925.1	29925.1	0	0	55186.7	55186.7	55186.7	7085.9	59669.2	59669.2	0	0	0	0	0
H2S	6	6	6	0	0	6	6	6	6	0	0	0	0	0	0	0
HCL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NH3	1158.6	1158.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SO2	0	0	0	0	0	0	0	0	0	0	0	0	11.3	11.3	0.1	10.6
S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CISOLID																
Temperature F	900	412														
Pressure psia	788	777	772	815	815		426.18	426.18	414.18	79.98	749.5	381.07	381.07	381.07	381.07	2200
Vapor Frac	0	0														
Mole Flow lbmol/hr	20.1	20.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mass Flow lb/hr	1652.1	1652.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Volume Flow cuft/hr	4.9	4.9	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Enthalpy MMBtu/hr	-2.8	-2.9														
Mass Flow lb/hr																
ZNO	1540.7	1540.7	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ZNS	111.4	111.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NA2CO3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NACL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NC SOLID																
Temperature F																
Pressure psia	788	777	772	815	815		426.18	426.18	414.18	79.98	749.5	381.07	381.07	381.07	381.07	2200
Vapor Frac																
Mass Flow lb/hr	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Enthalpy MMBtu/hr																
Mass Flow lb/hr																
BIT-COAL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SLAG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ASH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL																
Mass Flow lb/hr	1135721.8	1135721.8	1132911.1	196109.8	196109.8	1329021	1329021	1329021	1321892.6	59669.2	59669.2	77978	1399870.6	1399870.6	163596.6	1174693.8
Enthalpy MMBtu/hr	-2980.7	-3198.2	-3194.1	-1348.9	-1104.6	-4298.7	-4378.5	-4419.8	-4893.3	6.7	4.6	1.3	-4902	-5534.9	-1119.8	-4502.5

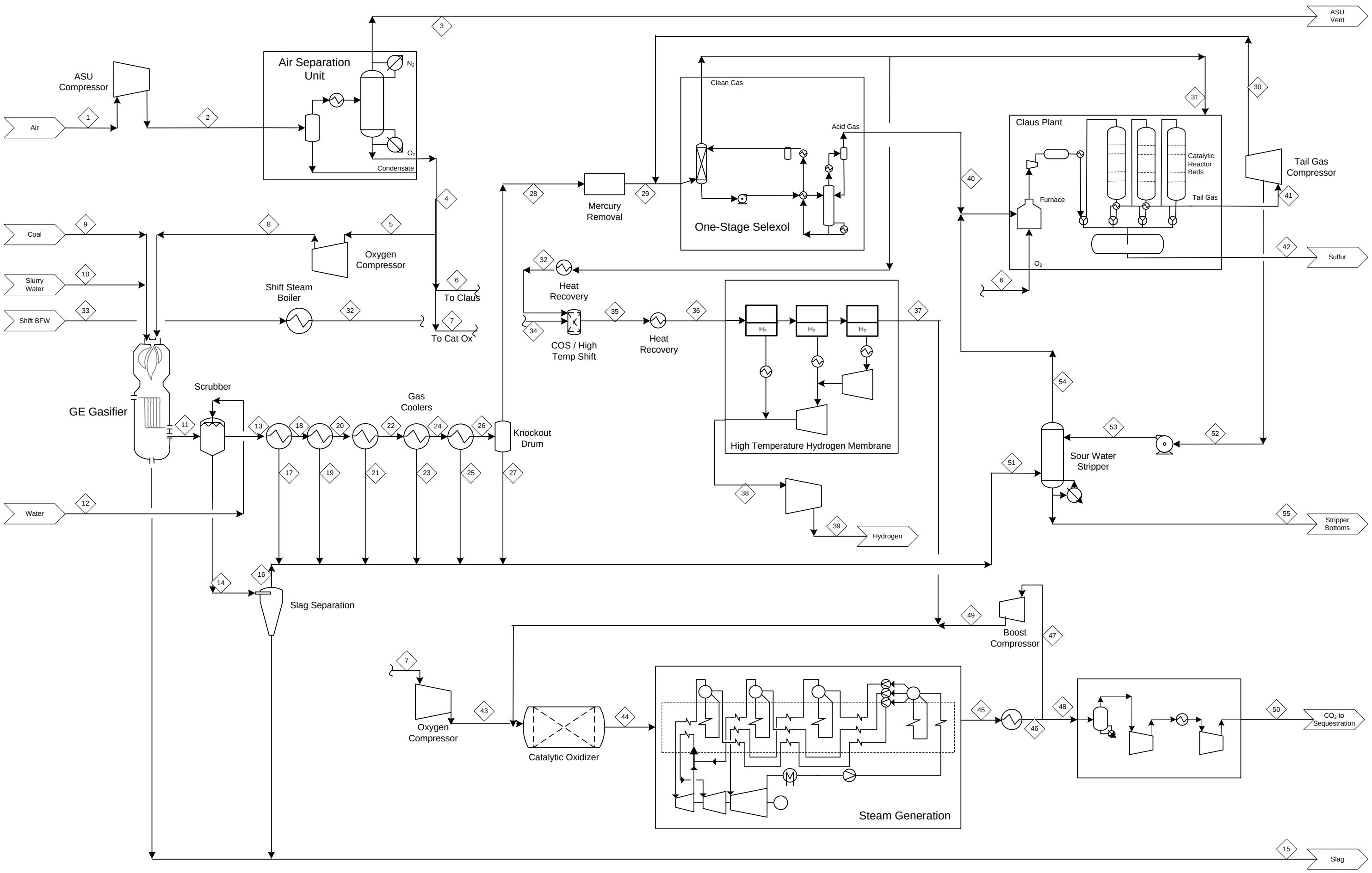


Figure 15 Process Flow Diagram for Case 5

Table 20 Detailed Stream Table for Case 5

		1	2	3	4	5	6	7	8	9	10	11	12	13	14
		AMBAIR	ASUFEED	ASUXS	O2PRODCT	GASIF-O2	O2CLAUS	TO-CATOX	OXYGEN	WTCOAL	SLRYWT	GASTOCLR	QWNCHW	RAW-GAS	QWNCHBTM
Mass Flow	lb/hr	2,471,411	2,471,411	1,898,760	562,438	426,153	5,775	130,510	426,153	500,000	194,375	1,065,670	930,978	1,977,984	18,664
Mole Flow	lbmol/hr	85,893	85,893	67,639	17,687	13,401	182	4,104	13,401		10,789	51,863	51,677	102,505	1,035
Temp	F	59.0	281.5	88.0	90.0	90.0	90.0	90.0	232.7	59.0	59.0	2,500.0	246.7	454.9	454.9
Pressure	psia	14.7	190.3	16.4	145.0	145.0	145.0	145.0	1,024.7	14.7	14.7	900.0	840.0	838.0	838.0
Enthalpy	MMBtu/hr	-70.1	62.4	4.9	0.9	0.7	0.0	0.2	12.7	-505.4	-1,337.7	-1,881.4	-6,215.5	-7,977.1	-119.8

		15	16	17	18	19	20	21	22	23	24	25	26	27	28
		SLAG	SLAGWATR	CLRALIQ	CLRAVAP	CLR1LIQ	CLR1VAP	COND1	QNCHCHLL	CLR3LIQ	CLR3VAP	COND2	CHILLED	NH3OUT	TOMERCRY
Mass Flow	lb/hr	54,859	16,801	180,762	1,797,223	656,388	1,140,835	90,823	1,050,012	133,704	916,308	20,394	895,914	1,750	894,164
Mole Flow	lbmol/hr		932	10,028	92,477	36,408	56,069	5,038	51,031	7,418	43,613	1,132	42,481	57	42,424
Temp	F	2,500.0	454.9	446.3	446.3	371.5	371.5	342.0	342.0	225.0	225.0	100.0	100.0	100.0	100.0
Pressure	psia	900.0	838.0	837.5	837.5	837.0	837.0	836.0	836.0	836.0	836.0	835.0	835.0	834.0	834.0
Enthalpy	MMBtu/hr	-5.3	-107.9	-1,162.7	-6,962.6	-4,281.7	-3,290.5	-595.6	-2,787.2	-894.0	-2,067.7	-138.5	-1,992.8	-2.2	-1,990.9

		29	30	31	32	33	34	35	36	37	38	39	40	41	42
		TO-AGR	TGOUT	REDUCEIT	TOWGS	SHFTWTR1	SHFTSTM	FRSHIFT	TOHTHM	MEMFG	H2COLD	H2PROD	TOCLAUS	TGRCY	SULFUR
Mass Flow	lb/hr	894,164	31,602	3,470	883,821	229,150	229,150	1,112,971	1,112,971	1,105,716	54,624	54,624	38,476	42,928	12,505
Mole Flow	lbmol/hr	42,424	795	165	42,003	12,720	12,720	54,723	54,723	30,256	27,097	27,097	1,051	1,423	49
Temp	F	99.7	110.0	100.0	412.0	60.0	518.9	761.2	482.0	554.6	110.0	100.0	100.0	365.3	320.0
Pressure	psia	833.0	808.5	803.5	796.5	815.0	815.0	791.0	785.0	773.0	156.2	749.5	803.5	21.0	33.0
Enthalpy	MMBtu/hr	-1,990.9	-110.6	-7.8	-1,892.1	-1,576.2	-1,290.7	-3,182.7	-3,313.6	-3,724.9	6.1	4.3	-100.3	-172.0	0.7

		43	44	45	46	47	48	49	50	51	52	53	54	55
		PCATOX	HRSGIN	HRSGOUT	HPCO2-1	RECCO2	CO2TOCMP	RECCO2P	P-HPCO2	QNCHSOUR	TOTGRWR	TGWATRCY	SWSVAP	SWSBOT
Mass Flow	lb/hr	130,466	1,411,928	1,411,928	1,351,884	175,745	1,176,139	175,745	1,176,139	1,100,622	11,324	11,324	3,125	1,108,821
Mole Flow	lbmol/hr	4,103	34,537	34,537	31,207	4,057	27,150	4,057	27,150	61,013	629	629	135	61,507
Temp	F	185.8	2,496.1	259.9	90.0	90.0	90.0	96.1	100.0	361.2	110.1	110.5	80.0	247.0
Pressure	psia	800.0	773.0	773.0	773.0	773.0	773.0	803.0	2,200.0	834.0	21.0	75.0	35.0	35.0
Enthalpy	MMBtu/hr	2.5	-4,402.2	-5,372.2	-5,092.8	-662.1	-4,430.7	-661.9	-4,509.3	-7,182.5	-77.3	-77.3	-6.6	-7,394.1

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	AMBAIR	ASUFEED	ASUXS	O2PRODCT	GASIF-O2	O2CLAUS	TO-CATOX	OXYGEN	WTCOAL	SLRYWT	GASTOCLR	QWNCHW	RAW-GAS	QWNCHBTM	SLAG
CONVENTIONAL															
Temperature F	59	281.5	88	90	90	90	90	232.7		59	2500	246.7	454.9	454.9	
Pressure psia	14.7	190.3	16.4	145	145	145	145	1024.7	14.7	14.7	900	840	838	838	
Vapor Frac	1	1	1	1	1	1	1	1		0	1	0	1	0	
Mole Flow lbmol/hr	85,893	85,893	67,639	17,687	13,401	182	4,104	13,401	0	10,790	51,863	51,677	102,505	1,035	0
Mass Flow lb/hr	2,471,411	2,471,411	1,898,760	562,438	426,153	5,775	130,510	426,153	0	194,375	1,065,670	930,978	1,977,984	18,664	0
Volume Flow cuft/hr	32504290	3600519.9	2.42E+07	714642.4	541476.3	7337.7	165828.4	97050.8	0	3647.1	1847566	18952.1	1101103.3	448.6	0
Enthalpy MMBtu/hr	-70	62	5	1	1	0	0	13		-1,338	-1,881	-6,216	-7,977	-120	
Mass Flow lb/hr															
H2O	10212.7	10212.7	0.00E+00	0	0	0	0	0	0	194375	167975	930978.3	1080328.2	18625.2	0
CO2	0	0	0	0	0	0	0	0	0	0	271608.2	0	271587.4	20.8	0
O2	569481.2	569481.2	31805.5	537675.7	407390.7	5520.7	124764.3	407390.7	0	0	0	0	0	0	0
N2	1891716.6	1891716.6	1866954	24762.6	18762.3	254.3	5746	18762.3	0	0	24083.6	0	24083.3	0.3	0
CH4	0	0	0	0	0	0	0	0	0	0	154.1	0	154.1	0	0
CO	0	0	0	0	0	0	0	0	0	0	555061.9	0	555055.8	6.1	0
COS	0	0	0	0	0	0	0	0	0	0	471.6	0	471.4	0.1	0
H2	0	0	0	0	0	0	0	0	0	0	30605.9	0	30605.1	0.8	0
H2S	0	0	0	0	0	0	0	0	0	0	13052.4	0	13046.8	5.6	0
HCL	0	0	0	0	0	0	0	0	0	0	1508.2	0	1507.8	0.4	0
NH3	0	0	0	0	0	0	0	0	0	0	1148.7	0	1144.2	4.5	0
SO2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CISOLID															
Temperature F															
Pressure psia	14.7	190.3	16.4	145	145	145	145	1024.7	14.7	14.7		840	838	838	
Vapor Frac															
Enthalpy MMBtu/hr															
Mass Flow lb/hr															
NC SOLID															
Temperature F									59						2500
Pressure psia	14.7	190.3	16.4	145	145	145	145	1024.7	14.7	14.7		840	838	838	900
Vapor Frac									0						0
Mass Flow lb/hr	0	0	0	0	0	0	0	0	500000	0	0	0	0	0	54858.5
Enthalpy MMBtu/hr									-505.4						-5.3
Mass Flow lb/hr															
BIT-COAL	0	0	0	0	0	0	0	0	499994.9	0	0	0	0	0	0
SLAG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	54858.5
ASH	0	0	0	0	0	0	0	0	5.1	0	0	0	0	0	0
TOTAL															
Mass Flow lb/hr	2471410.5	2471410.5	1898759.5	562438.3	426153	5775	130510.3	426153	500000	194375	1065669.6	930978.3	1977984	18663.9	54858.5
Enthalpy MMBtu/hr	-70.1	62.4	4.9	0.9	0.7	0	0.2	12.7	-505.4	-1337.7	-1881.4	-6215.5	-7977.1	-119.8	-5.3

Table 20 Detailed Stream Table for Case 5, cont.

	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
	SLAGWATR	CLRALIQ	CLRAVAP	CLR1LIQ	CLR1VAP	COND1	QNCHCHLL	CLR3LIQ	CLR3VAP	COND2	CHILLED	NH3OUT	TOMERCRY	TO-AGR	TGOUT
CONVENTIONAL															
Temperature F	454.9	446.3	446.3	371.5	371.5	342	342	225	225	100	100	100	100	99.7	110
Pressure psia	838	837.5	837.5	837	837	836	836	836	836	835	835	834	834	833	808.5
Vapor Frac	0	0	1	0	1	0	1	0	1	0	1	0	1	1	1
Mole Flow lbmol/hr	932	10,028	92,477	36,408	56,069	5,038	51,031	7,418	43,613	1,132	42,481	57	42,424	42,424	795
Mass Flow lb/hr	16,801	180,762	1,797,223	656,388	1,140,835	90,823	1,050,012	133,704	916,308	20,394	895,914	1,750	894,164	894,164	31,602
Volume Flow cuft/hr	405.7	4.30E+03	9.95E+05	14541.2	5.84E+05	1966	518872.6	2.69E+03	383407.7	389.3	301135.4	39.9	301165.7	301342.8	4821.7
Enthalpy MMBtu/hr	-108	-1,163	-6,963	-4,282	-3,291	-596	-2,787	-894	-2,068	-139	-1,993	-2	-1,991	-1,991	-111
Mass Flow lb/hr															
H2O	16762.7	180368.2	899960	654754.3	245205.6	90595.6	154610.1	133306.7	21303.4	20202.1	1101.3	0	1101.3	1101.3	35.9
CO2	20.8	211	271376.3	803.8	270572.5	103	270469.5	87.7	270381.8	5.4	270376.4	0	270376.4	270376.4	27615.9
O2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
N2	0.3	2.50E+00	24080.8	6.1	24074.7	0.6	24074.1	2.00E-01	24073.9	0	24073.9	0	24073.9	24073.9	1198.8
CH4	0	0.1	154	0.2	153.8	0	153.8	0	153.8	0	153.8	0	153.8	153.8	0.6
CO	6.1	58.7	554997.1	143.5	554853.6	15.2	554838.4	5.5	554832.9	0.1	554832.8	0	554832.8	554832.8	2175.2
COS	0.1	1.3	470.1	5.2	464.9	0.7	464.2	0.6	463.7	0	463.6	0	463.6	463.6	0
H2	0.8	8	30597.1	21.9	30575.2	2.4	30572.8	1	30571.8	0	30571.7	0	30571.7	30571.7	59.6
H2S	5.6	58.7	12988.1	292	12696.1	41.8	12654.3	57.4	12596.9	6.8	12590.2	0	12590.2	12590.2	516.3
HCL	0.4	4.2	1503.6	20.6	1483	2.9	1480	4	1476	0.5	1475.6	1475.6	0	0	0
NH3	4.5	48.8	1095.4	339.9	755.4	60.9	694.5	240.8	453.7	179.2	274.5	274.5	0	0	0
SO2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CISOLID															
Temperature F															
Pressure psia	838	837.5	837.5	837	837	836	836	836	836	835	835	834	834	833	
Vapor Frac															
Enthalpy MMBtu/hr															
Mass Flow lb/hr															
NC SOLID															
Temperature F															
Pressure psia	838	837.5	837.5	837	837	836	836	836	836	835	835	834	834	833	
Vapor Frac															
Mass Flow lb/hr	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Enthalpy MMBtu/hr															
Mass Flow lb/hr															
BIT-COAL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SLAG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ASH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL															
Mass Flow lb/hr	16801.3	180761.5	1797222.5	656387.6	1140834.9	90823.2	1050011.7	133703.9	916307.9	20394.1	895913.8	1750.1	894163.7	894163.7	31602.3
Enthalpy MMBtu/hr	-107.9	-1162.7	-6962.6	-4281.7	-3290.5	-595.6	-2787.2	-894	-2067.7	-138.5	-1992.8	-2.2	-1990.9	-1990.9	-110.6

Table 20 Detailed Stream Table for Case 5, cont.

	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
	REDUCEIT	TOWGS	SHFTWTR1	SHFTSTM	FRSHIFT	TOHTHM	MEMFG	H2COLD	H2PROD	TOCLAUS	TGRCY	SULFUR	PCATOX	HRSGIN	HRSGOUT
CONVENTIONAL															
Temperature F	100	412	60	518.9	761.2	482	554.6	110	100	100	365.3	320	185.8	2496.1	259.9
Pressure psia	803.5	796.5	815	815	791	785	773	156.23	749.5	803.5	21	33	800	773	773
Vapor Frac	1	1	0	1	1	1	1	1	1	1	1	0	1	1	1
Mole Flow lbmol/hr	165	42,003	12,720	12,720	54,723	54,723	30,256	27,097	27,097	1,051	1,423	49	4,103	34,538	34,538
Mass Flow lb/hr	3,470	883,821	229,150	229,150	1,112,971	1,112,971	1,105,716	54,624	54,624	38,476	42,928	12,505	130,466	1,411,928	1,411,928
Volume Flow cuft/hr	1216.9	500747.3	4298.5	132376.6	9.17E+05	708131.3	425150.4	1064101.5	221126.2	5329	598184.1	39.1	35219.7	1431237.9	305167.2
Enthalpy MMBtu/hr	-8	-1,892	-1,576	-1,291	-3,183	-3,314	-3,725	6	4	-100	-172	1	3	-4,402	-5,372
Mass Flow lb/hr															
H2O	2	513.8	229150	229150	59074.3	59074.3	10053.2	0	0	621.4	11359.1	0	0	60838.9	60838.9
CO2	1073.6	273479.9	0	0	690215.6	690215.6	925688.2	0	0	23438.9	27617.3	0	0	1315489.4	1315489.4
O2	0	0	0	0	0	0	0	0	0	0	0	0	124722.3	0	0
N2	98.8	25173.8	0	0	2.52E+04	25173.8	25173.8	0	0	0	1198.8	0	5744.1	35538.1	35538.1
CH4	0.6	152	0	0	152	152	152	0	0	1.8	0.6	0	0	0	0
CO	2175.1	554075.5	0	0	288858.5	288858.5	138990	0	0	757.3	2175.2	0	0	0	0
COS	0.2	38.4	0	0	0.2	0.2	0.2	0	0	425.1	0	0	0	0	0
H2	119.3	30380.7	0	0	49468.1	49468.1	5630.3	54623.7	54623.7	131.4	59.6	0	0	0	0
H2S	0	6.5	0	0	28.2	28.2	28.2	0	0	13099.9	517	0	0	0	0
HCL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NH3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SO2	0	0	0	0	0	0	0	0	0	0	0	0	0	61.2	61.2
S8	0	0	0	0	0	0	0	0	0	0	0	12505.4	0	0	0
CISOLID															
Temperature F															
Pressure psia	803.5	796.5	815	815		785	773	156.23	749.5	803.5	21	33	800	773	773
Vapor Frac															
Enthalpy MMBtu/hr															
Mass Flow lb/hr															
NC SOLID															
Temperature F															
Pressure psia	803.5	796.5	815	815		785	773	156.23	749.5	803.5	21	33	800	773	773
Vapor Frac															
Mass Flow lb/hr	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Enthalpy MMBtu/hr															
Mass Flow lb/hr															
BIT-COAL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SLAG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ASH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL															
Mass Flow lb/hr	3469.6	883820.7	229150	229150	1112970.7	1112970.7	1105715.9	54623.7	54623.7	38475.8	42927.6	12505.4	130466.4	1411927.6	1411927.6
Enthalpy MMBtu/hr	-7.8	-1892.1	-1576.2	-1290.7	-3182.7	-3313.6	-3724.9	6.1	4.3	-100.3	-172	0.7	2.5	-4402.2	-5372.2

Table 20 Detailed Stream Table for Case 5, cont.

	46	47	48	49	50	51	52	53	54	55
	HPCO2-1	RECCO2	CO2TOCMP	RECCO2P	P-HPCO2	QNCHSOUR	TOTGRWR	TGWATRCY	SWSVAP	SWSBOT
CONVENTIONAL										
Temperature F	90	90	90	96.1	100	361.2	110.1	110.5	80	247
Pressure psia	773	773	773	803	2200	834	21	75	35	35
Vapor Frac	1	1	1	1	1	0	0	0	1	0
Mole Flow lbmol/hr	31,207	4,057	27,150	4,057	27,150	61,013	629	629	135	61,507
Mass Flow lb/hr	1,351,884	175,745	1,176,139	175,745	1,176,139	1,100,622	11,325	11,325	3,125	1,108,821
Volume Flow cuft/hr	166442.8	21637.6	1.45E+05	21096.7	26709.3	24196.9	216.5	216.6	21998.6	52663.1
Enthalpy MMBtu/hr	-5,093	-662	-4,431	-662	-4,509	-7,183	-77	-77	-7	-7,394
Mass Flow lb/hr										
H2O	873.1	113.5	7.60E+02	113.5	759.6	1095989.6	11323.2	11323.2	0	1107312.8
CO2	1315412.2	171003.6	1144408.6	171003.6	1144408.6	1231.7	0.6	0.6	1232.4	0
O2	0	0	0	0	0	0	0	0	0	0
N2	35538.1	4620	30918.1	4619.9	30918.1	9.7	0	0	9.7	0
CH4	0	0	0	0	0	0.2	0	0	0.2	0
CO	0	0	0	0	0	229.1	0	0	229.1	0
COS	0	0	0	0	0	7.9	0	0	7.9	0
H2	0	0	0	0	0	34.2	0	0	34.2	0
H2S	0	0	0	0	0	462.2	0.7	0.7	462.9	0
HCL	0	0	0	0	0	1508.2	0	0	0	1508.2
NH3	0	0	0	0	0	1148.7	0	0	1148.7	0
SO2	60.9	7.9	53	7.9	53	0	0	0	0	0
S8	0	0	0	0	0	0	0	0	0	0
CISOLID										
Temperature F										
Pressure psia	773		773	803	2200	834	21	75		35
Vapor Frac										
Enthalpy MMBtu/hr										
Mass Flow lb/hr										
NC SOLID										
Temperature F										
Pressure psia	773		773	803	2200	834	21	75		35
Vapor Frac										
Mass Flow lb/hr	0	0	0	0	0	0	0	0	0	0
Enthalpy MMBtu/hr										
Mass Flow lb/hr										
BIT-COAL	0	0	0	0	0	0	0	0	0	0
SLAG	0	0	0	0	0	0	0	0	0	0
ASH	0	0	0	0	0	0	0	0	0	0
TOTAL										
Mass Flow lb/hr	1351884.2	175745	1176139.3	175744.9	1176139.3	1100621.6	11324.5	11324.5	3125.1	1108821
Enthalpy MMBtu/hr	-5092.8	-662.1	-4430.7	-661.9	-4509.3	-7182.5	-77.3	-77.3	-6.6	-7394.1

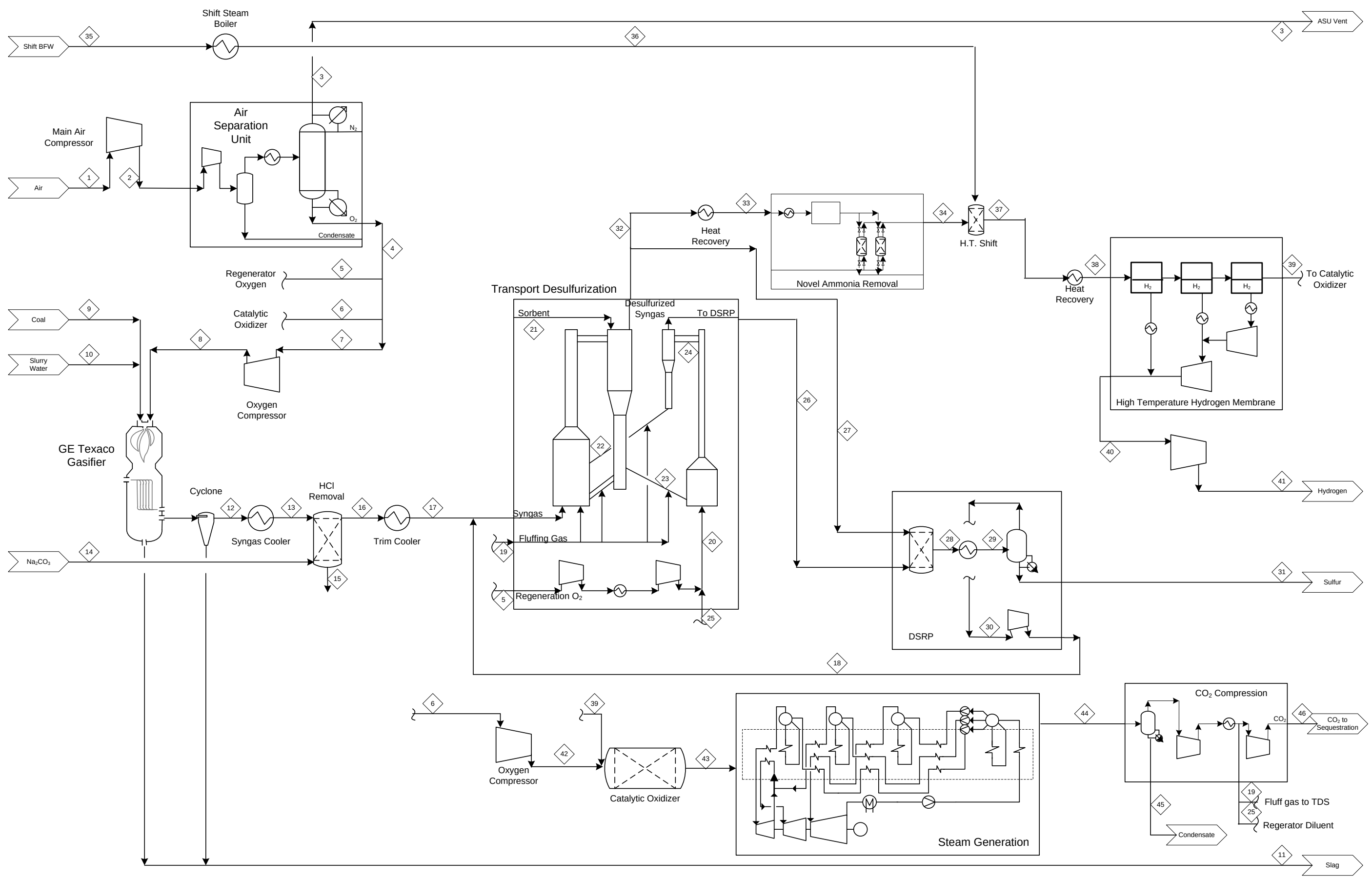


Figure 16 Process Flow Diagram for Case 6

Table 21 Detailed Stream Table for Case 6

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
		AMBAIR	ASUFEED	ASUXS	O2PRODCT	TO-REGEN	TOCATOXY	GASIF-O2	OXYGEN	WTCOAL	SLRYWT	SLAG	GASTOCLR	SW4	SW35	SW31	SW29	ABSFEED	SW41	CO2FLUFF	SYNAIR	NEWZNO	SW1	SW9
Mass Flow	lb/hr	2,251,479	2,251,479	1,729,789	512,387	19,556	66,696	426,135	426,135	500,000	194,375	54,859	1,065,652	1,065,652	8,769	8,994	1,065,426	1,065,426	101,193	44	81,093	1,671	1,682,343	1,688,601
Mole Flow	lbmol/hr	78,249	78,249	61,620	16,113	615	2,097	13,401	13,401		10,789		51,863	51,863	83	103	51,863	51,863	2,688	1	2,035	21	20,517	20,517
Temp	F	59.0	281.5	88.0	90.0	90.0	90.0	90.0	232.7	59.0	59.0	1,250.0	1,250.0	950.0	60.0	946.7	946.7	768.4	519.6	100.0	141.2	60.0	1,100.0	900.0
Pressure	psia	14.7	190.3	16.4	145.0	145.0	145.0	145.0	1,024.7	14.7	14.7	900.0	900.0	896.0	800.0	798.0	798.0	796.0	825.0	850.0	800.0	795.0	786.0	793.0
Enthalpy	MMBtu/hr	-63.8	56.9	4.5	0.8	0.0	0.1	0.7	12.7	-505.4	-1,337.7	-28.1	-2,475.9	-2,608.9	-40.2	-35.0	-2,614.1	-2,691.3	-386.6	-0.2	-231.0	-3.1	-2,786.7	-2,815.9

		24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46
		SW30	FLFGAS	SW21	RDUCEGAS	SW26	SW27	SW38	P-SULFUR	SW18	TOWGS	TOHTSHFT	SHFTWTR1	SHFTSTM	FRSHIFT	TOHTHM	MEMTG	H2COLD	H2PROD	PCATOX	HRSGIN	HRSGOUT	COND	P-HPCO2
Mass Flow	lb/hr	1,769,694	61,537	87,351	26,369	113,720	113,720	101,193	12,528	1,135,707	1,135,707	1,132,896	196,231	196,231	1,329,127	1,329,127	1,332,547	61,030	61,030	66,694	1,399,242	1,399,242	163,843	1,173,862
Mole Flow	lbmol/hr	22,356	1,419	1,840	1,238	3,078	3,078	2,688	390	53,334	53,334	53,246	10,892	10,892	64,139	64,139	37,442	30,275	30,275	2,097	37,566	37,566	9,088	27,060
Temp	F	1,100.0	119.7	1,100.0	900.0	1,015.9	500.0	500.0	100.0	900.0	412.0	412.0	60.0	518.9	789.3	482.0	515.5	110.0	100.0	185.8	1,465.3	260.0	90.0	114.6
Pressure	psia	786.0	1,100.0	786.0	788.0	763.0	758.0	755.0	14.7	788.0	777.0	772.0	815.0	815.0	771.5	765.5	753.5	154.7	749.5	800.0	753.5	753.5	753.5	2,200.0
Enthalpy	MMBtu/hr	-3,046.9	-232.6	-260.2	-69.2	-329.4	-355.4	-387.1	30.5	-2,980.6	-3,198.1	-3,194.0	-1,349.8	-1,105.3	-4,299.1	-4,474.1	-5,015.3	6.9	4.8	1.3	-5,022.5	-5,549.0	-1,121.1	-4,500.6

Table 21 Detailed Stream Table for Case 6, cont.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	AMBAIR	ASUFEED	ASUXS	O2PRODCT	TO-REGEN	TOCATOXY	GASIF-O2	OXYGEN	WTCOAL	SLRYWT	SLAG	GASTOCLR	SW4	SW35	SW31
CONVENTIONAL															
Temperature F	59	281.5	88	90	90	90	90	232.7		59		1250	950		
Pressure psia	14.7	190.3	16.4	145	145	145	145	1024.7	14.7	14.7		900	896	800	798
Vapor Frac	1	1	1	1	1	1	1	1		0		1	1		
Mole Flow lbmol/hr	78,249	78,249	61,620	16,113	615	2,097	13,401	13,401	0	10,790	0	51,863	51,863	0	0
Mass Flow lb/hr	2,251,479	2,251,479	1,729,789	512,387	19,556	66,696	426,135	426,135	0	194,375	0	1,065,652	1,065,652	0	0
Volume Flow cuft/hr	2.96E+07	3.28E+06	22077490.3	651046.2	24847.6	84744.9	541453.7	97046.8	0	3647.1	0	1.07E+06	886614.6	0	0
Enthalpy MMBtu/hr	-64	57	5	1	0	0	1	13		-1,338		-2,476	-2,609		
Mass Flow lb/hr															
H2O	9.30E+03	9.30E+03	0.00E+00	0	0	0	0.00E+00	0	0	194375	0	167954	167954	0	0
CO2	0	0	0.00E+00	0	0	0	0	0	0	0	0	2.72E+05	271613.5	0	0
O2	518803	518803	28975.1	489827.9	18694.6	63759.6	407373.7	407373.7	0	0	0	0.00E+00	0	0	0
N2	1723372.4	1723372.4	1700813.5	22558.9	861	2936.4	18761.5	18761.5	0	0	0	24082	24082	0	0
CH4	0	0	0	0	0	0	0	0	0	0	0	154.3	154.3	0	0
CO	0	0	0	0	0	0	0	0	0	0	0	555058.1	555058.1	0	0
COS	0	0	0	0	0	0	0	0	0	0	0	471.4	471.4	0	0
H2	0	0	0	0	0	0	0	0	0	0	0	30608	30608	0	0
H2S	0	0	0	0	0	0	0	0	0	0	0	13052.5	13052.5	0	0
HCL	0	0	0	0	0	0	0	0	0	0	0	1508.2	1508.2	0	0
NH3	0	0	0	0	0	0	0	0	0	0	0	1149.7	1149.7	0	0
SO2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CISOLID															
Temperature F														60	946.7
Pressure psia	14.7	190.3	16.4	145	145	145	145	1024.7	14.7	14.7			896	800	798
Vapor Frac														0	0
Mole Flow lbmol/hr	0	0	0	0	0	0	0	0	0	0	0	0	0	82.7	103.4
Mass Flow lb/hr	0	0	0	0	0	0	0	0	0	0	0	0	0	8768.6	8993.9
Volume Flow cuft/hr	0	0	0	0	0	0	0	0	0	0	0	0	0	55.7	60.8
Enthalpy MMBtu/hr														-40.2	-35
Mass Flow lb/hr															
ZNO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ZNS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NA2CO3	0	0	0	0	0	0	0	0	0	0	0	0	0	8768.6	6576.4
NACL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2417.5
NC SOLID															
Temperature F									59		1250				
Pressure psia	14.7	190.3	16.4	145	145	145	145	1024.7	14.7	14.7	900		896	800	798
Vapor Frac									0		0				
Mass Flow lb/hr	0	0	0	0	0	0	0	0	500000	0	54858.5	0	0	0	0
Enthalpy MMBtu/hr									-505.4		-28.1				
Mass Flow lb/hr															
BIT-COAL	0	0	0	0	0	0	0	0	499994.9	0	0	0	0	0	0
SLAG	0	0	0	0	0	0	0	0	0	0	54858.5	0	0	0	0
ASH	0	0	0.00E+00	0	0	0	0	0	5.1	0	0	0	0	0	0
TOTAL															
Mass Flow lb/hr	2251479.3	2251479.3	1729788.6	512386.8	19555.5	66696	426135.3	426135.3	500000	194375	54858.5	1065651.8	1065651.8	8768.6	8993.9
Enthalpy MMBtu/hr	-63.8	56.9	4.5	0.8	0	0.1	0.7	12.7	-505.4	-1337.7	-28.1	-2475.9	-2608.9	-40.2	-35

Table 21 Detailed Stream Table for Case 6, cont.

	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
	SW29	ABSFEED	SW41	CO2FLUFF	SYNAIR	NEWZNO	SW1	SW9	SW30	FLFGAS	SW21	RDUCEGAS	SW26	SW27	SW38
CONVENTIONAL															
Temperature F	946.7	768.4	519.6	100	141.2		1100	900	1100	119.7	1100	900	1015.9	500	500
Pressure psia	798	796	825	850	800	795	786	793	786	1100	786	788	763	758	755
Vapor Frac	1	1	1	1	1		1	1	1	1	1	1	0.9	0.8	1
Mole Flow lbmol/hr	51,863	51,863	2,688	1	2,035	0	0	0	1,840	1,419	1,840	1,238	3,078	3,078	2,688
Mass Flow lb/hr	1,065,427	1,065,427	101,193	44	81,093	0	1	1	87,351	61,537	87,351	26,331	113,682	113,682	101,193
Volume Flow cuft/hr	991751.1	866615.9	32951	4.70E+00	14268.9	0	0.3	0.4	39600.8	5.11E+03	39600.8	23154.4	59790.2	34485.2	35246.8
Enthalpy MMBtu/hr	-2,614	-2,691	-387	0	-231		0	0	-260	-233	-260	-69	-329	-355	-387
Mass Flow lb/hr															
H2O	168326.6	168326.6	10350.8	0	51.9	0	0	0	51.9	3.99E+01	51.9	4210.9	10350.8	10350.8	10350.8
CO2	272523.8	272523.8	87581.6	44	59990.6	0	0.7	0.9	59991.5	60034	59991.5	8180.2	87581.6	87581.6	87581.6
O2	0	0	0	0	18694.1	0	0	0	0	0	0	0	0	0	0
N2	24082	24082	2959.3	0	2345.7	0	0	0	2345.7	1462.7	2345.7	613.6	2959.3	2959.3	2959.3
CH4	154.3	154.3	3.6	0	0	0	0	0	0	0	0	3.6	3.6	3.6	3.6
CO	555058.1	555058.1	247.1	0	0	0	0	0	0	0	0	12600.7	247.1	247.1	247.1
COS	471.4	471.4	0	0	0	0	0	0	0	0	0	0	0	0	0
H2	30608	30608	13.6	0	0	0	0	0	0	0	0	694.9	13.6	13.6	13.6
H2S	13052.5	13052.5	0.1	0	0	0	0	0	0	0	0	0.1	0.1	0.1	0.1
HCL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NH3	1149.7	1149.7	36.6	0	9.7	0	0	0	9.7	0	9.7	26.9	36.6	36.6	36.6
SO2	0	0	0	0	0.6	0	0	0	24952.2	0.6	24952.2	0	0	0	0
S	0	0	0	0	0	0	0	0	0	0	0	0	12489.2	12489.2	0
CISOLID															
Temperature F						60	1100	900	1100			900	1015.9	500	
Pressure psia	798	796	825	850	800	795	786	793	786	1100		788	763	758	755
Vapor Frac						0	0	0	0			0	0	0	
Mole Flow lbmol/hr	0	0	0	0	0	20.5	20516.5	20516.5	20516.5	0	0	0.5	0.5	0.5	0
Mass Flow lb/hr	0	0	0	0	0	1671.5	1682342.5	1688600.1	1682342.5	0	0	38.4	38.4	38.4	0
Volume Flow cuft/hr	0	0	0	0	0	4.7	4912.1	5009.7	4912.1	0	0	0.1	0.1	0.1	0
Enthalpy MMBtu/hr						-3.1	-2786.7	-2815.9	-2786.7			-0.1	-0.1	-0.1	
Mass Flow lb/hr															
ZNO	0	0	0	0	0	1671.5	1606429.1	1574729.9	1606429.1	0	0	35.8	35.8	35.8	0
ZNS	0	0	0	0	0	0	75913.4	113870.2	75913.4	0	0	2.6	2.6	2.6	0
NA2CO3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NACL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NC SOLID															
Temperature F															
Pressure psia	798	796	825	850	800	795	786	793	786	1100		788	763	758	755
Vapor Frac															
Mass Flow lb/hr	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Enthalpy MMBtu/hr															
Mass Flow lb/hr															
BIT-COAL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SLAG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ASH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL															
Mass Flow lb/hr	1065426.5	1065426.5	101192.8	44	81092.6	1671.5	1682343.2	1688601	1769693.6	61537.1	87351.1	26369.3	113720.4	113720.4	101192.8
Enthalpy MMBtu/hr	-2614.1	-2691.3	-386.6	-0.2	-231	-3.1	-2786.7	-2815.9	-3046.9	-232.6	-260.2	-69.2	-329.4	-355.4	-387.1

Table 21 Detailed Stream Table for Case 6, cont.

		31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46
		P-SULFUR	SW18	TOWGS	TOHTSHFT	SHFTWTR1	SHFTSTM	FRSHIFT	TOHTHM	MEMTG	H2COLD	H2PROD	PCATOX	HRSGIN	HRSGOUT	COND	P-HPCO2
CONVENTIONAL																	
	Temperature F	100	900	412	412	60	518.9	789.3	482	515.5	110	100	185.8	1465.3	260	90	114.6
	Pressure psia	14.7	788	777	772	815	815	771.5	765.5	753.5	154.73	749.5	800	753.5	753.5	753.5	2200
	Vapor Frac	0	1	1	1	0	1	1	1	1	1	1	1	1	1	0	1
	Mole Flow lbmol/hr	390	53,314	53,314	53,246	10,893	10,893	64,139	64,139	37,442	30,275	30,275	2,097	37,566	37,566	9,088	27,060
	Mass Flow lb/hr	12,489	1,134,055	1,134,055	1,132,896	196,231	196,231	1,329,127	1,329,127	1,332,547	61,030	61,030	66,694	1,399,242	1,399,242	163,843	1,173,862
	Volume Flow cuft/hr	304.5	997242.6	636450	639840.8	3681	113359.8	1122610.6	843115.1	507177.9	1.20E+06	2.47E+05	18004.3	1040040	328109.9	3105.4	29506.7
	Enthalpy MMBtu/hr	31	-2,978	-3,195	-3,194	-1,350	-1,105	-4,299	-4,474	-5,015	7	5	1	-5,023	-5,549	-1,121	-4,501
	Mass Flow lb/hr																
	H2O	0	181362.7	181362.7	181362.7	196231.1	196231.1	151872.3	151872.3	104529.5	0.00E+00	0.00E+00	0	164434.8	1.64E+05	163634.3	760.6
	CO2	0	352313.7	352313.7	352313.7	0	0	903732.2	903732.2	1176833.7	0	0	0	1205431.5	1205431.5	208.3	1145189.2
	O2	0	0	0	0	0	0	0	0	0	0	0	63758	0	0	0	0
	N2	0	26427.7	26427.7	26427.7	0	0	26427.7	26427.7	26427.7	0	0	2936.4	29364.1	29364.1	0.1	27901.3
	CH4	0	154.3	154.3	154.3	0	0	154.3	154.3	154.3	0	0	0	0	0	0	0
	CO	0	542704.5	542704.5	542704.5	0	0	191749.6	191749.6	17931.9	0	0	0	0	0	0	0
	COS	0	0.1	0.1	0.1	0	0	0.1	0.1	0.1	0	0	0	0	0	0	0
	H2	0	29926.8	29926.8	29926.8	0	0	55184.7	55184.7	6664.2	61030	61030	0	0	0	0	0
	H2S	0	6	6	6	0	0	6	6	6	0	0	0	0	0	0	0
	HCL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	NH3	0	1159.4	1159.4	0	0	0	0	0	0	0	0	0	0	0	0	0
	SO2	0	0	0	0	0	0	0	0	0	0	0	0	11.3	11.3	0.1	10.6
	S	12489.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CISOLID																	
	Temperature F	100	900	412													
	Pressure psia	14.7	788	777	772	815	815		765.5	753.5	154.73	749.5	800	753.5	753.5	753.5	2200
	Vapor Frac	0	0	0													
	Mole Flow lbmol/hr	0.5	20.1	20.1	0	0	0	0	0	0	0	0	0	0	0	0	0
	Mass Flow lb/hr	38.4	1651.9	1651.9	0	0	0	0	0	0	0	0	0	0	0	0	0
	Volume Flow cuft/hr	0.1	4.9	4.9	0	0	0	0	0	0	0	0	0	0	0	0	0
	Enthalpy MMBtu/hr	-0.1	-2.8	-2.9													
	Mass Flow lb/hr																
	ZNO	35.8	1540.5	1540.5	0	0	0	0	0	0	0	0	0	0	0	0	0
	ZNS	2.6	111.4	111.4	0	0	0	0	0	0	0	0	0	0	0	0	0
	NA2CO3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	NACL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NC SOLID																	
	Temperature F																
	Pressure psia	14.7	788	777	772	815	815		765.5	753.5	154.73	749.5	800	753.5	753.5	753.5	2200
	Vapor Frac																
	Mass Flow lb/hr	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Enthalpy MMBtu/hr																
	Mass Flow lb/hr																
	BIT-COAL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	SLAG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	ASH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL																	
	Mass Flow lb/hr	12527.6	1135707	1135707	1132895.6	196231.1	196231.1	1329126.7	1329126.7	1332547.3	61030	61030	66694.4	1399241.7	1399241.7	163842.8	1173861.7
	Enthalpy MMBtu/hr	30.5	-2980.6	-3198.1	-3194	-1349.8	-1105.3	-4299.1	-4474.1	-5015.3	6.9	4.8	1.3	-5022.5	-5549	-1121.1	-4500.6

Appendix B: Component Flow Summary for HTHM Cases

B-1 Methodology for Hydrogen Product Cases

Figure 17 is a schematic of the hypothesized 3-stage membrane and Aspen Plus model.

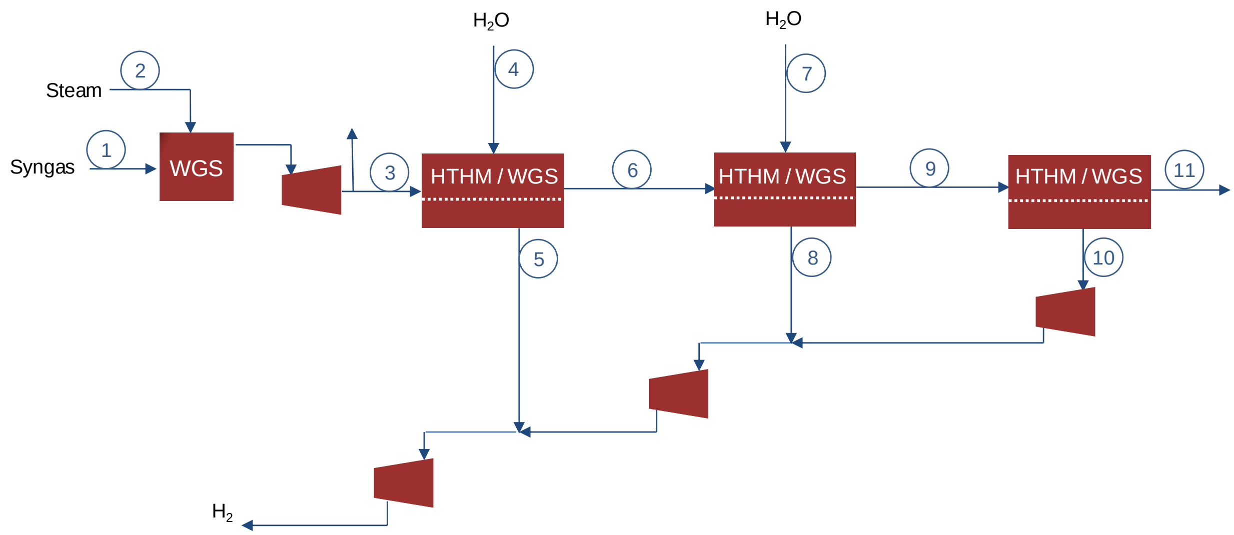


Figure 17 HTHM Configuration for Hydrogen Production

The clean gas is mixed with steam and the mixture is shifted. For Cases 3 and 4, the shifted product is expanded because the 2010 target limits the pressure across the 2010 membrane to 400 psi.

More shift is assumed to continue within the HTHM as the hydrogen permeates through the membrane and is removed from the input gas. This removal of hydrogen product pushes the shift equilibrium towards production of more hydrogen.

The calculation procedure first assumes a quantity of hydrogen required to be removed in the membrane. It is then possible to compute the restricted equilibrium conditions of the non-permeate exiting the membrane, and hence the partial pressure of the remaining hydrogen. The assumption here is that the gases will be in near equilibrium at these temperature conditions. A temperature approach of 100 °F was used.

B-2 Case 3 – GE Gasification with Quench, CGCU, 2010 HTHM

Table 22 is a summary of the component flows and conditions through the stages. Shifting continues in the membrane. Water is added to the membranes to reduce the temperature to the minimum membrane temperature of 572 °F (300 °C). The added moisture also facilitates shift in the membrane. Water was not added to the third membrane stage as the amount of shift was relatively small and it was found that the addition of water reduced the process efficiency slightly.

The area for each membrane stage was based on the flux at the average driving force within the membrane stage, which was estimated as the linear average of the driving forces at the inlet and exit of the stage. For Cases 3 and 4, the flux was based on the 2010 program goal of 200 scfh/ft^2 when the partial pressures of hydrogen are 150 psi and 50 psi for the non-permeate and permeate sides, respectively. Assuming Sievert's law holds, this yielded a hydrogen flux (scfh/ft^2) expression of:

$$F = 0.465\,\delta$$

where δ is the difference in the square roots of the non-permeate and permeate hydrogen partial pressures (psia).

Once the simulation was set up to proceed as above for the three membranes, it was possible to vary the hydrogen recovery and permeate pressure in each stage to determine the ultimate effect on total membrane area and hydrogen compression required. The overall results were fairly insensitive to these changes, since conditions that reduced membrane area resulted in a corresponding increase in the compression requirement.

Permeate pressures assumed are believed to be a near optimum compromise between membrane area and compression capital and power costs. Three stages of HTHM are necessary.

Table 22 Component Flow Analysis for HTHM for Case 3

MEMBRANE STREAM AND OPERATING DATA											
STREAM #	1	2	3	4	5	6	7	8	9	10	11
CH4 (LB MOLES/HR)	10		10			10			10		10
H2O (LB MOLES/HR)	28	12,747	3,292	1,084		2,592	1,065		2,059		744
H2 (LB MOLES/HR)	15,082		24,565		17,195	9,153		6,407	4,345	3,041	2,618
CO (LB MOLES/HR)	19,780		10,297			8,513			6,915		5,601
CO2 (LB MOLES/HR)	6,216		15,698			17,482			19,081		20,395
N2 (LB MOLES/HR)	898		898			898			898		898
TOTAL (LB MOLES/HR)	42,013	12,747	54,760	1,084	17,195	38,649	1,065	6,407	33,307	3,041	30,265
H2 RECOVERY					17,195			6,407		3,041	
TEMPERATURE (F)	412		572			572			572		572
PRESSURE (PSIA)	792		426			422			418		414
H2 PARTIAL PRESSURE (PSIA)			191			100			55		36
H2 RECOVERY PRESSURE (PSIA)					82			45		29	
H2 FLUX (SCF/HR/FT2)					113			79		51	
MEMBRANE AREA FT2					57,819			30,781		22,360	
SHIFT (LB MOLES/HR)			9,483			1,784			1,599		1,314
TOTAL MEMBRANE AREA (FT2)				110,959							

B-3 Case 4 – GE Gasification, WGCU, 2010 HTHM

The schematic of the three stages of the HTHM reactor is the same as shown in Figure 17, and a summary of the component flows and conditions through the stages is shown in Table 23. The same methodology was used to estimate the HTHM area required in this case as used in the previous Case 3.

Table 23 Component Flow Analysis for HTHM for Case 4

MEMBRANE STREAM AND OPERATING DATA											
STREAM #	1	2	3	4	5	6	7	8	9	10	11
CH4 (LB MOLES/HR)	10		9			9			9		9
H2O (LB MOLES/HR)	10,068	10,869	8,141	1,657		7,120	1,269		6,447		5,328
H2 (LB MOLES/HR)	14,845		26,517		18,562	10,633		7,443	5,132	3,592	2,658
CO (LB MOLES/HR)	19,375		6,628			3,950			2,008		890
CO2 (LB MOLES/HR)	8,005		19,892			22,570			24,512		25,631
N2 (LB MOLES/HR)	943		914			914			914		914
TOTAL (LB MOLES/HR)	53,246	10,869	62,101	1,657	18,562	45,196	1,269	7,443	39,023	3,592	35,430
H2 RECOVERY					18,562			7,443		3,592	
TEMPERATURE (F)	412		572			572			572		619
PRESSURE (PSIA)	772		426			422			418		414
H2 PARTIAL PRESSURE (PSIA)			182			99			55		31
H2 RECOVERY PRESSURE (PSIA)					82			45		25	
H2 FLUX (SCF/HR/FT2)					106			78		58	
MEMBRANE AREA FT2					66,353			36,283		23,313	
SHIFT (LB MOLES/HR)			12,532			2,678			1,942		1,119
TOTAL MEMBRANE AREA (FT2)					125,950						

B-4 Case 5 – GE Gasification with Quench, CGCU, 2015 HTHM

The only difference in the membrane model between Case 3 and Case 5 is in the correlation for the flux. For this case, the membrane flux was assumed to attain the 2015 program goal of 300 scfh/ft^2 when the partial pressures of hydrogen are 150 psi and 50 psi for the non-permeate and permeate sides, respectively. Assuming Sievert's law holds, this yielded a hydrogen flux (scfh/ft^2) expression of:

$$F = 0.700\,\delta$$

A summary of the component flows and conditions through the stages is shown in Table 24.

Table 24 Component Flow Analysis for HTHM for Case 5

MEMBRANE STREAM AND OPERATING DATA											
STREAM #	1	2	3	4	5	6	7	8	9	10	11
CH4 (LB MOLES/HR)	10		10			10			10		10
H2O (LB MOLES/HR)	28	12,713	3,276	1,396		2,496	1,207		1,935		548
H2 (LB MOLES/HR)	15,083		24,548		17,184	9,540		6,678	4,630	3,241	2,776
CO (LB MOLES/HR)	19,779		10,314			8,139			6,371		4,984
CO2 (LB MOLES/HR)	6,216		15,681			17,857			19,625		21,012
N2 (LB MOLES/HR)	898		898			898			898		898
TOTAL (LB MOLES/HR)	42,015	12,713	54,727	1,396	17,184	38,940	1,207	6,678	33,468	3,241	30,227
H2 RECOVERY					17,184			6,678		3,241	
TEMPERATURE (F)	412		482			482			482		554
PRESSURE (PSIA)	792		785			781			777		773
H2 PARTIAL PRESSURE (PSIA)			352			191			107		71
H2 RECOVERY PRESSURE (PSIA)					159			89		57	
H2 FLUX (SCF/HR/FT2)					222			159		108	
MEMBRANE AREA FT2					29,328			15,850		11,374	
SHIFT (LB MOLES/HR)			9,465			2,176			1,768		1,387
TOTAL MEMBRANE AREA (FT2)					56,552						

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The schematic of the three stages of the HTHM reactor is the same as shown in Figure 17, and a summary of the component flows and conditions through the stages is shown in Table 25. The same methodology was used to estimate the HTHM area required in this case as used in the previous Case 5.

Table 25 Component Flow Analysis for HTHM for Case 6

MEMBRANE STREAM AND OPERATING DATA											
STREAM #	1	2	3	4	5	6	7	8	9	10	11
CH4 (LB MOLES/HR)	10		9			9			9		0
H2O (LB MOLES/HR)	10,068	10,888	8,165	2,183		7,053	1,369		6,414		5,526
H2 (LB MOLES/HR)	14,845		26,527		18,569	11,253		7,877	5,385	3,769	2,503
CO (LB MOLES/HR)	19,375		6,633			3,338			1,329		441
CO2 (LB MOLES/HR)	8,005		19,900			23,195			25,204		26,091
N2 (LB MOLES/HR)	943		914			914			914		0
TOTAL (LB MOLES/HR)	53,246	10,888	62,148	2,183	18,569	45,763	1,369	7,877	39,255	3,769	34,562
H2 RECOVERY					18,569			7,877		3,769	
TEMPERATURE (F)	412		482			482			482		517
PRESSURE (PSIA)	772		766			762			758		754
H2 PARTIAL PRESSURE (PSIA)			327			187			104		55
H2 RECOVERY PRESSURE (PSIA)					157			86		43	
H2 FLUX (SCF/HR/FT2)					203			159		129	
MEMBRANE AREA FT2					34,573			18,708		11,080	
SHIFT (LB MOLES/HR)			12,530			3,295			2,009		888
TOTAL MEMBRANE AREA (FT2)					64,361						