Coal Processing Plants for Hydrogen Production with CO_2 Capture

Workshop on Production of Hydrogen from Fossil Fuels with Carbon Sequestration

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Background

- **Preparing conceptual designs, systems analysis and economics for hydrogen plants based on Oak Ridge hydrogen separation membranes**
- **Objective is to economically produce separate streams of hydrogen and CO_2**
- **Results are compared with conventional production of hydrogen and CO_2 from coal and natural gas**

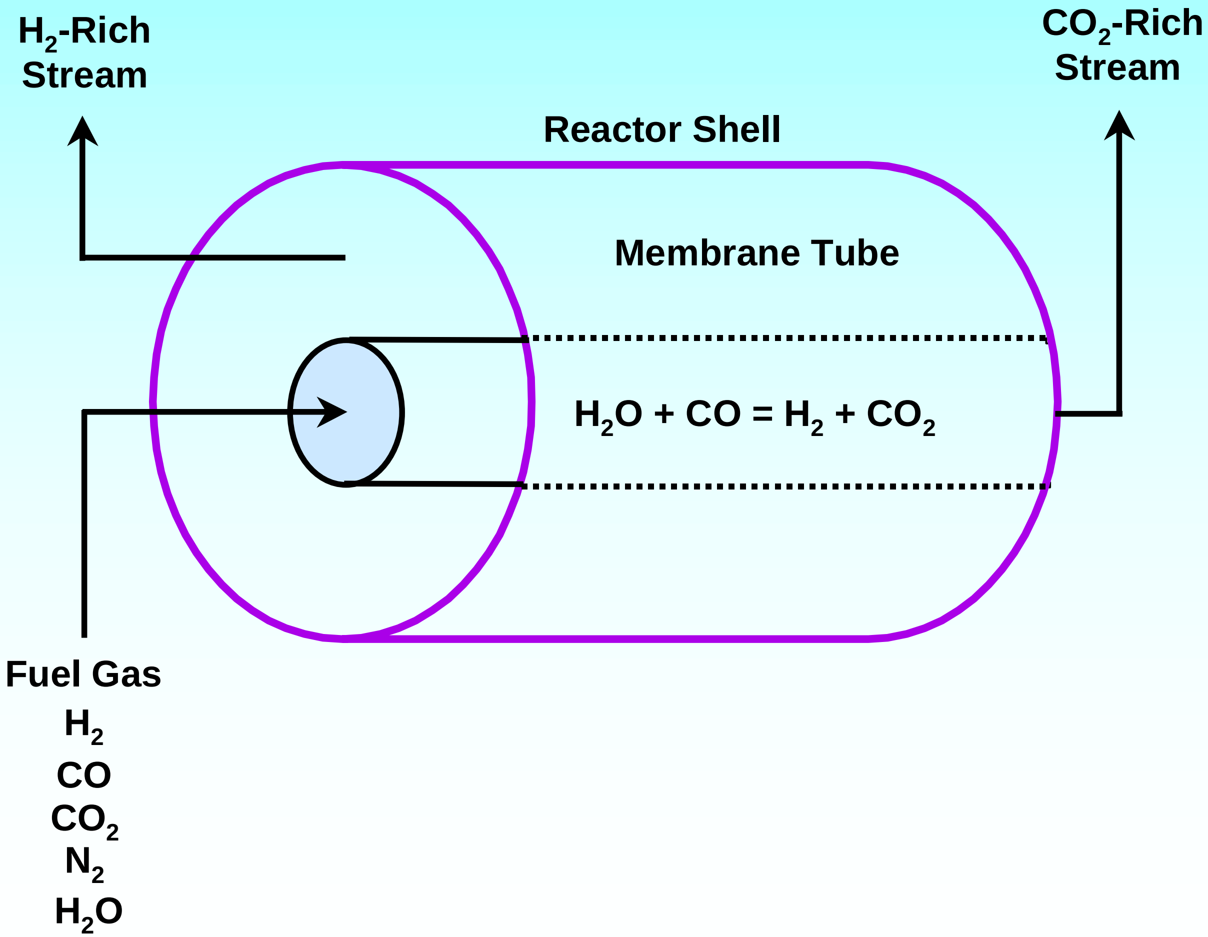
Membranes for Hydrogen Separation

- **Proton Conductive Ceramic Membrane**
- **Electrochemical Conversion Membrane**
- **Palladium-Based Membrane**
- **Inorganic Membrane**
  - **Eastern Tennessee Technology Park**
    Oak Ridge, Tennessee

ETTP Inorganic Membrane Characteristics

- **Porous Ceramic**
  - **Al_2O_3**
  - **5 Angstrom**
  - **Knudson diffusion**
- **Separation Factor**
  - **H_2 transport relative to retenate**
  - **Gas purity = 1 – 1/SF**
- **H_2 Transport Proportional to Partial Pressure Differential**

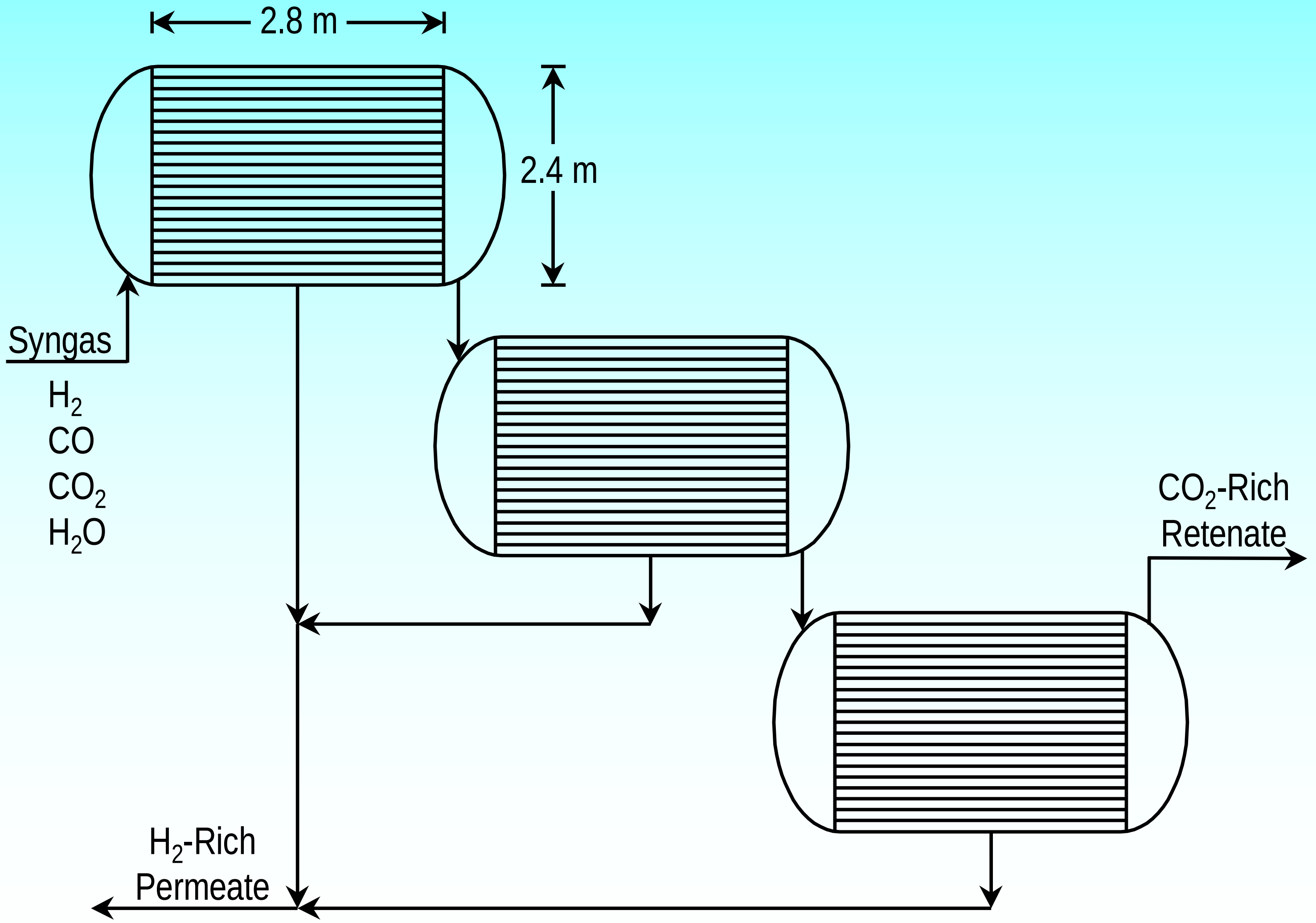
The Inorganic Membrane Separation Concept



Hydrogen Separation Device Design Assumptions

- **Hydrogen Separation Factor**
  - **~ 200 @ 99.5% hydrogen**
- **Hydrogen Transport Rate**
  - **0.1 cm^3/minute/cm^2/cmHgΔP**
- **Operating Temperature and Pressure**
  - **600°C, 65 bar exit gas conditions**
  - **300°C, 65 bar exit gas conditions**
- **Cost**
  - **$1,076/$m^2$ membrane**
- **Design Configuration**
  - **Tube side pressurization**
- **Tube Dimensions**
  - **16 mm OD x 2.8 m long**

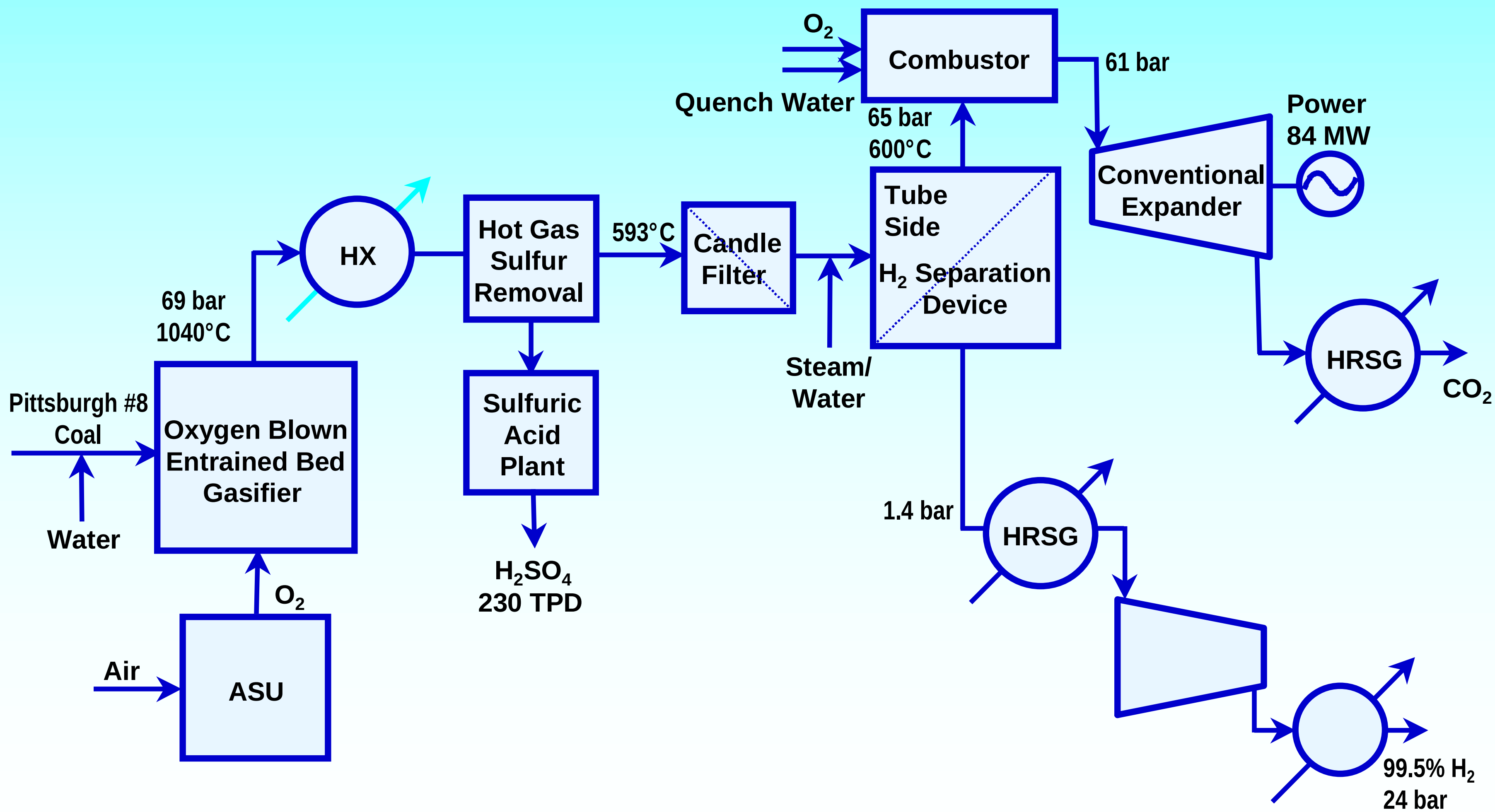
Hydrogen Separation Device Concept



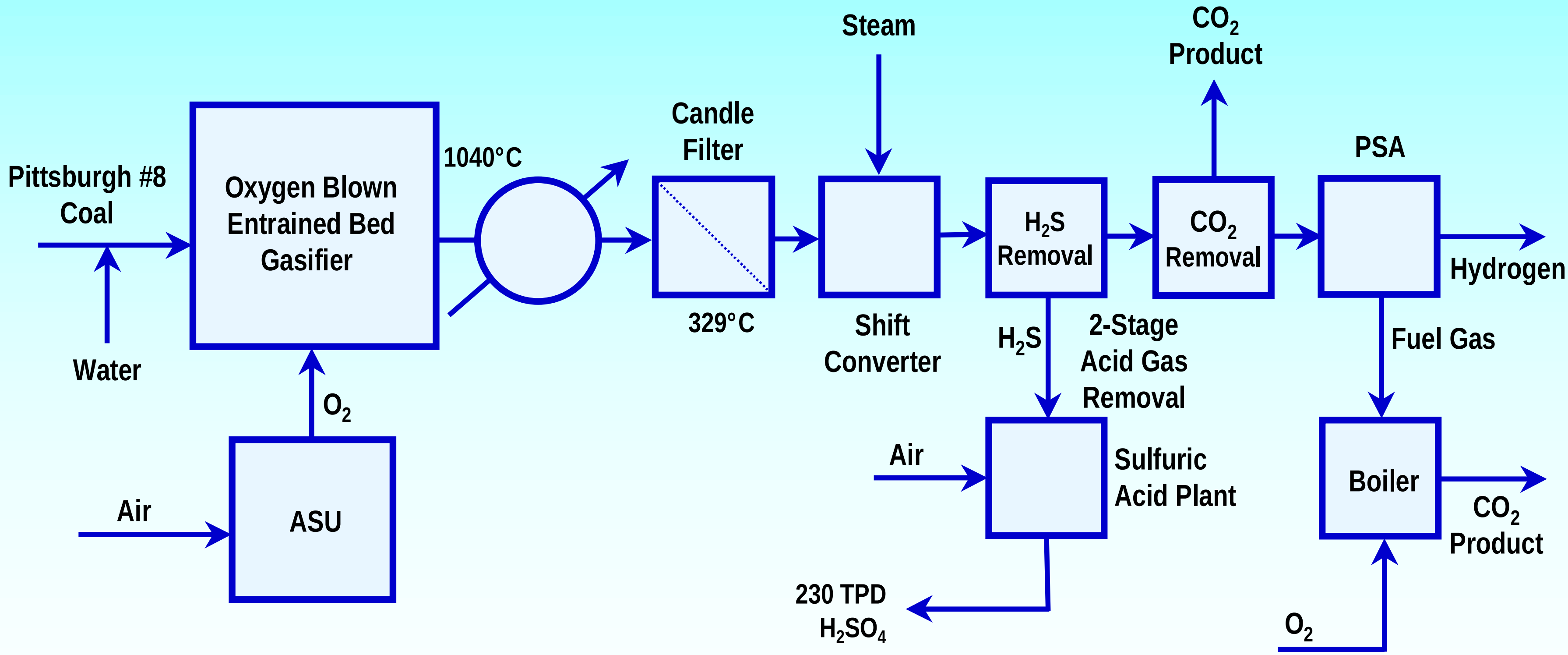
Design Basis for Advanced Hydrogen Plant

■ **Plant Size**	**H_2 production from** **2,270 metric tpd dry coal feed** **Excess power sold offsite**
■ **Gasifier**	**Oxygen-blown entrained bed** **1040°C, outlet pressure 68 bar**
■ **Gas Cleanup**	**593°C desulfurization with transport reactor** **Sulfur recovery as sulfuric acid** **Ceramic candle particulate filter**
■ **Hydrogen Separation**	**95% separation, 99.5% pure H_2**
■ **Hydrogen Utilization**	**Compress to 24 bar**
■ **Retenate Gas**	**5% of fuel value remaining @ 65 bar** **Fire with oxygen and expand to 1.4 bar**

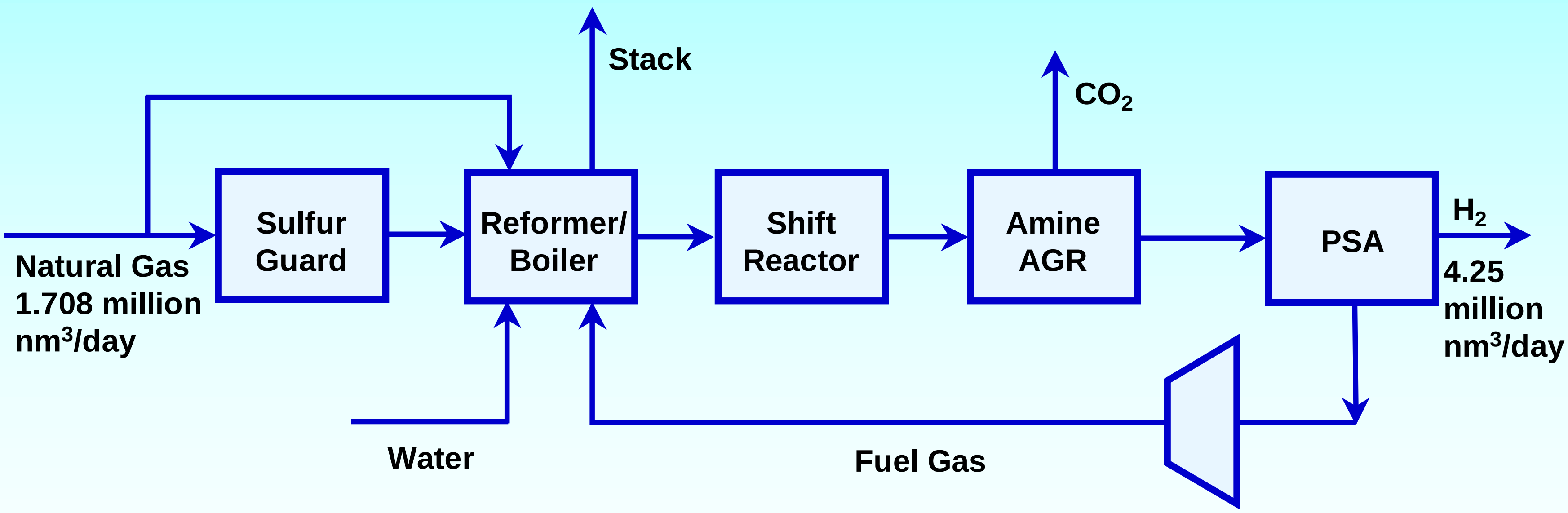
Hydrogen Plant with Hot Gas Desulfurization and Conventional Turbine Expander



Conventional Hydrogen Plant with Maximum CO_2 Removal



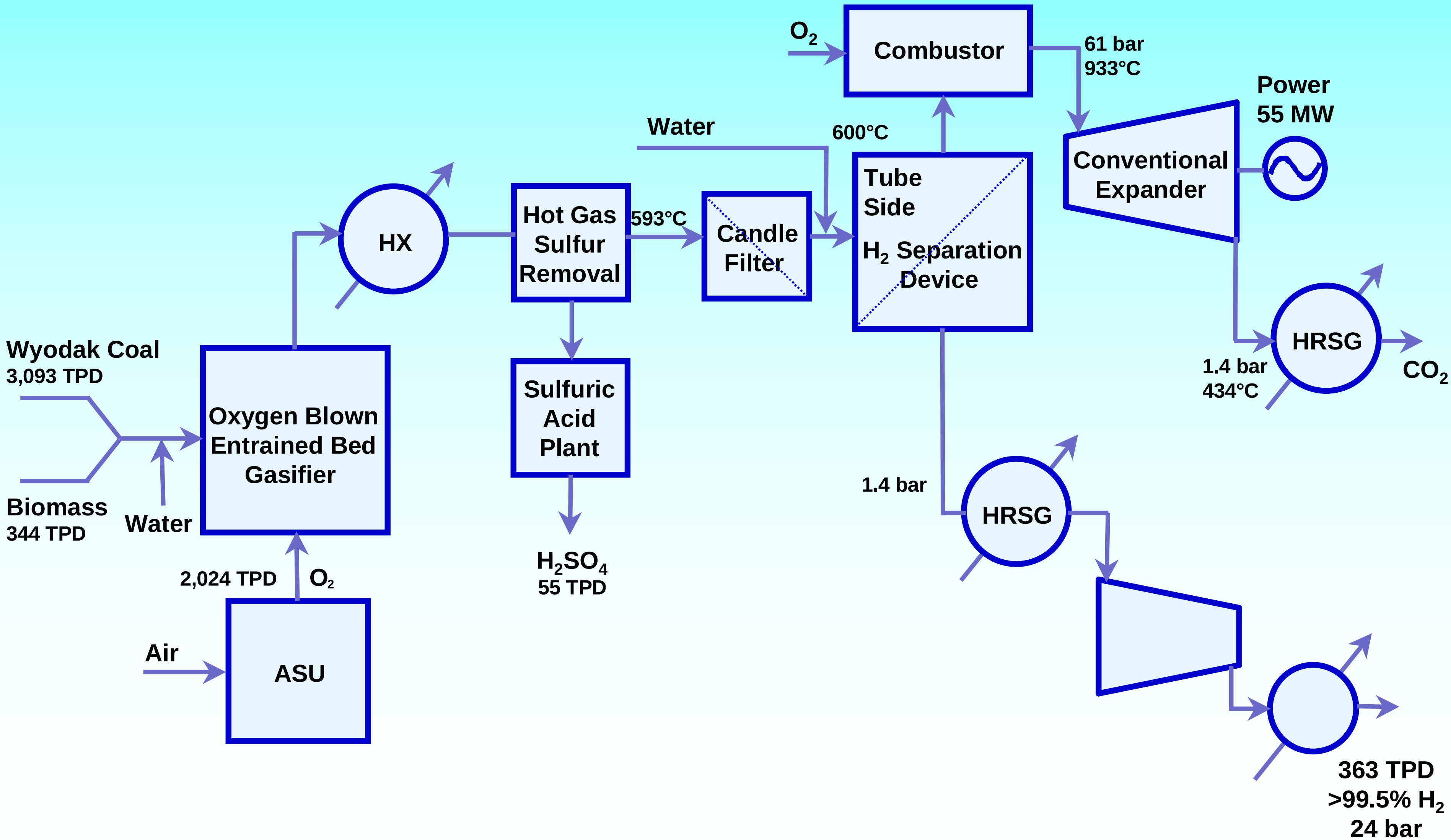
Steam Reforming Natural Gas with CO_2 Removal



Plant Summaries

	Coal to Hydrogen with 600°C Inorganic Membrane	Conventional Coal to Hydrogen w/CO_2 Recovery	Natural Gas-Steam Reforming w/CO_2 Recovery
Feedstock Rate	100,620 kg/h	100,620 kg/h	1.708 MM nm^3/day
Oxygen Feed (95%)	101,932 kg/h	128,714 kg/h	N/A
Hydrogen Production	16,300 kg/h	12,025 kg/h	16,600 kg/h
CO_2 Recovery (% of total)	240,421 kg/h (94%)	235,818 kg/h (92%)	98,707 kg/h (71%)
Gross Power Production	84 MW	64 MW	0 MW
Auxiliary Power Requirement	77 MW	52 MW	6 MW
Net Power Production	7 MW	12 MW	(6 MW)
Effective Thermal Efficiency	80.4%	60.1%	78.6%
Capital Cost, $1,000 (Yr 2000)	$362,994	$374,906	$142,370
Feedstock Cost Delivered	$0.95/GJ	$0.95/GJ	$3.00/GJ
Hydrogen Product Cost	$4.80/GJ	$6.55/GJ	$5.62/GJ

Hydrogen Plant with Wyodak Coal/Biomass



Performance and Cost Comparisons Pittsburgh No. 8 and Wyodak/Biomass

	Inorganic Membrane Pittsburgh No. 8	Inorganic Membrane Wyodak/Biomass
Coal Feed	100,620 kg/h	128,860 kg/h
Biomass Feed	N/A	14,317 kg/h
Oxygen to Gasifier	75,281 kg/h	84,739 kg/h
Oxygen to Retenate Combustor	26,650 kg/h	11,486 kg/h
Hydrogen Product Stream	16,300 kg/h	15,135 kg/h
Sulfuric Acid Byproduct	8,845 kg/h	2,296 kg/h
Net Power Production	7 MW	14 MW
Effective Thermal Efficiency	80.4%	79.8%
Capital Cost, $1,000	$359,791	$365,662
Feedstock Cost, Delivered	$0.95/GJ	$0.62/GJ
Hydrogen Product Cost	$4.95/GJ	$4.80/GJ

CO_2 Emissions Comparisons
Pittsburgh No. 8 and Wyodak/Biomass

	Inorganic Membrane Pittsburgh No. 8	Inorganic Membrane Wyodak/Biomass
Total CO_2 Produced	255,897 kg/h	262,491 kg/h
Biomass Credit	N/A	26,143 kg/h
Net CO_2 Produced	255,897 kg/h	236,348 kg/h
CO_2 Recovered	240,421 kg/h	235,845 kg/h
CO_2 Emissions	15,476 kg/h	503 kg/h
Ton CO_2 Emissions/Ton H_2	0.95	0.0331

Conclusions

Hydrogen Fuel:

- **Can be produced from coal in a cost-competitive manner with advances in materials and separation technologies**
- **Can be produced while efficiently capturing CO_2**
- **Will play an important role in meeting market and environmental challenges**
- **Can be made available to meet regional challenges for sustainable growth and economic prosperity**