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Hollow Fiber Membrane Contactors For CCS on Natural Gas Power Systems

WORKSHOP ON TECHNOLOGY PATHWAYS FORWARD FOR CARBON CAPTURE & STORAGE ON NATURAL GAS POWER SYSTEMS

Howard Meyer, R&D Director

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Introduction

- GTI and PoroGen Inc. have teamed to develop a hollow fiber membrane contactor (HFMC) technology using PoroGen's patented fiber manufacturing technology and knowhow
- CO_2 removal applications for flue gas and natural gas
- HFMC for both absorber and regenerator
- Advantages to be confirmed are lower capital and operating costs, lower weight, smaller size systems, no flooding, high turndown-ratio, modularity, shop fabrication for any capacity, insensitivity to motion for offshore operations

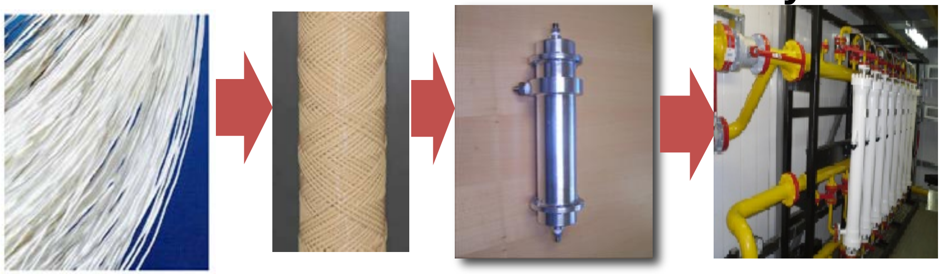
Introduction to GTI and PoroGen

- Not-for-profit research company, providing energy and natural gas solutions to the industry since 1941
- Facilities
  - 18 acre campus near Chicago
  - 250 staff

- Materials technology company commercially manufacturing products from high performance plastic PEEK (poly (ether ether ketone))
- Products ranging from membrane separation filters to heat transfer devices

Energy & Environmental Technology Center

PEEK Fiber + Cartridge + Module = Separation system



Natural Gas Flue Gas has Lower CO_2 and Higher O_2 than Coal

	PC Supercritical Power Plant	NGCC Power Plant
Plant Size, MW_e	550	474
Flue Gas Rate, kgmole/hr	102,548	113,831
CO_2, %	13.5	4
H_2O, %	15	9
O_2, %	2	12
N_2, %	68.5	74
CO_2 Captured, Tonne/hr	550	183

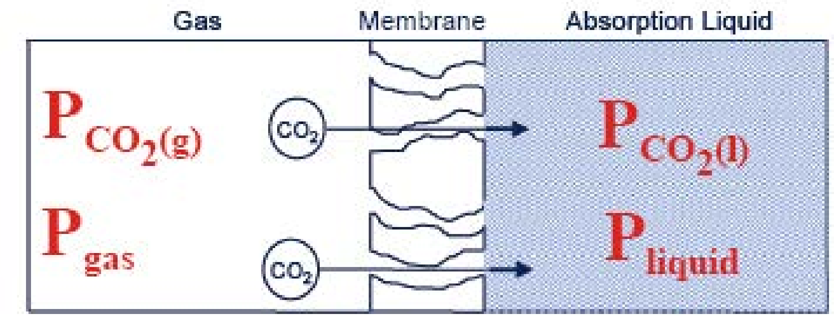
Cost and Performance Baseline for Fossil Energy Plants Volume 1: Bituminous Coal and Natural Gas to Electricity Revision 2a, September 2013, **DOE/NETL-2010/1397**

Impact of CCS on NGCC

- >Plant capital cost is ~ doubled
- >Cost of electricity increased by ~41-53%
- >Efficiency reduced by 14-16%
- >Plant net output reduced by 14-16%
- >Plant water use increases by 23-86%
- >Cost of CO_2 capture is $66-99/ton CO_2 avoided
- >Plant land area available at plant is limited

Technical and Regulatory Analysis of Adding CCS to NGCC Power Plants in California, Prepared for Southern California Edison Company by CH2M Hill, Nov. 2010

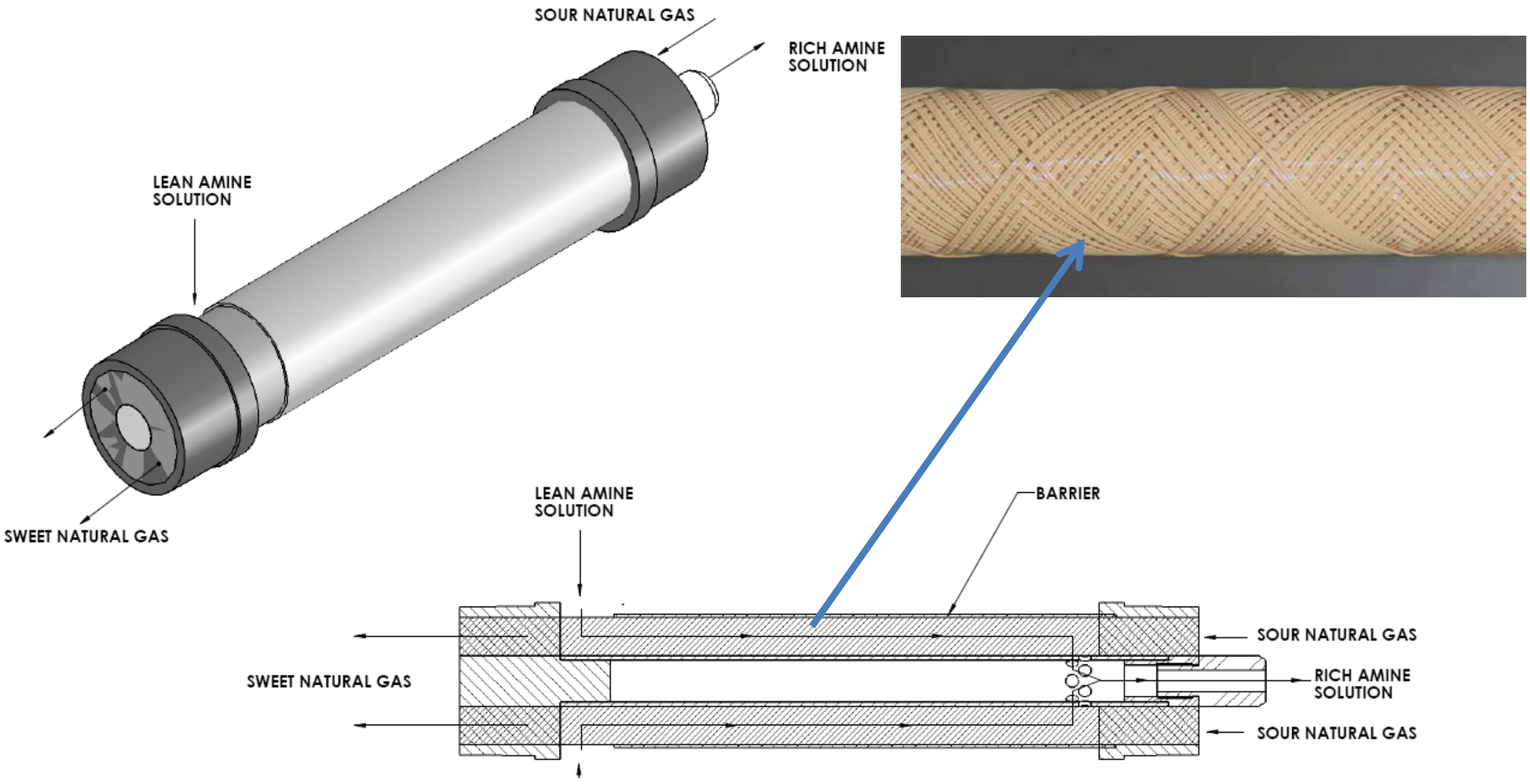
Basic Principles of HFMC Contactor



Membrane mass transfer principle

- Porous, hollow fiber membrane
- Unique membrane material , PEEK
- Membrane matrix filled with gas
- Mass transfer by diffusion reaction
- Driving force: difference in partial pressures of component to be removed/absorbed (PCO_2(g)>PCO_2(l))
- Liquid on one side, gas on the other side of the membrane
- Pressure difference between shell and tube side can be almost zero
- ($P_l \geq P_g$), i.e. the mass transfer is not pressure driven

HFMC Technology Description



Mass Transfer Performance

Comparison to Other Contacting Technologies

Gas-liquid contactor	Specific surface area, (m^2/m^3)	Volumetric mass transfer coefficient, $(sec)^{-1}$
Packed column (Countercurrent)	10 – 350	0.0004 – 0.07
Bubble column (Agitated)	100 – 2,000	0.003 – 0.04
Spray column	10 – 400	0.0007 – 0.075
Membrane contactor	**100 – 7,000**	**0.3 – 4.0**

Pilot Test of a Nanoporous, Super-hydrophobic Membrane Contactor Process for Post-combustion CO_2 Capture

DOE Contract No. DE-FE0012829

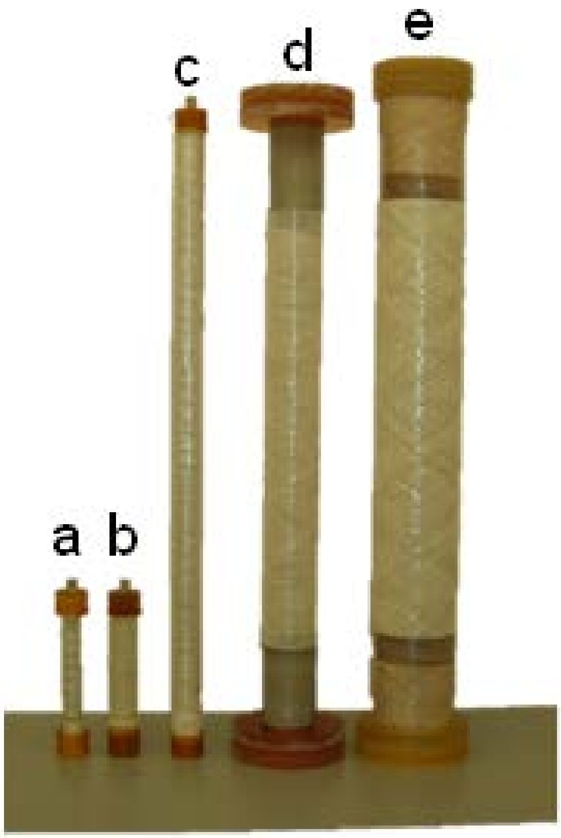
Bench-scale Technical Goals Achieved

Parameters	Goal	Achievement
CO_2 removal in one stage	≥ 90%	90%
Gas side ΔP, psi	≤ 2	1.6
Mass transfer coefficient,$(sec)^{-1}$	≥ 1	1.7
CO_2 purity	≥ 95%	97%
Continuous operation time in integrated absorber/desorber	≥ 100 h	104 h with >90% CO_2 removal
Mass transfer coefficient of the 4” 2,000 GPU module in the field	>1.0 $(sec)^{-1}$	1.2 $(sec)^{-1}$

Module Scale Up

4-inch diameter module in 8-inch shell

2-inch diameter module for lab testing



Field Experiment Testing Rig

Flue Gas Composition

Element	Concentration
CO_2	7.4-9.6 vol%
NO_x	40-60 ppmv
SO_2	0.4-0.6 ppmv
CO	100-600 ppmv
O_2	8.5-11 vol%
Balance: N_2 , water vapor and trace elements	

- Slipstream removing ~ 100 - 135 lb/day CO_2
- Modules with ~100 ft^2 of area
- Tests of aMDEA and H3-1 (Hitachi solvent)

Integrated Flue Gas Carbon Capture Field Experiment

- > Attained target CO_2 removal (> 90%) with both solvents
- > 200 - 300 hours of operation logged
- > Presence of SO_2 (up to ~500 ppmv) did not affect CO_2 removal
- > Mass transfer coefficients >1 s^{-1} obtained (with 2,000 GPU module) [conventional contactors: 0.0004-0.075 $(sec)^{-1}$]
- > H3-1 has better mass transfer coefficient by ~17%

Slipstream Project Objectives and Goal

- **Objectives**:
  - Build a 1 MW_e equivalent pilot-scale CO_2 capture system (20 ton/day) using PEEK hollow fibers in a membrane contactor and conduct tests on flue gas at the NCCC
  - Demonstrate a continuous, steady-state operation for a minimum of two months
  - Gather data necessary for process scale-up
- **Goal**
  - Achieve DOE's Carbon Capture performance goal of 90% CO_2 capture rate with 95% CO_2 purity at a cost of \$40/tonne of CO_2 captured by 2025

NCCC= National Carbon Capture Center (Southern Company, Wilsonville, AL)

Timeline and scope

Oct, 2013

BP1: Design of the 1 MW equivalent scale system

Oct 2014

BP2: Procurement of parts, and construction

Oct 2015

BP3: System installation and shakedown

Oct 2016

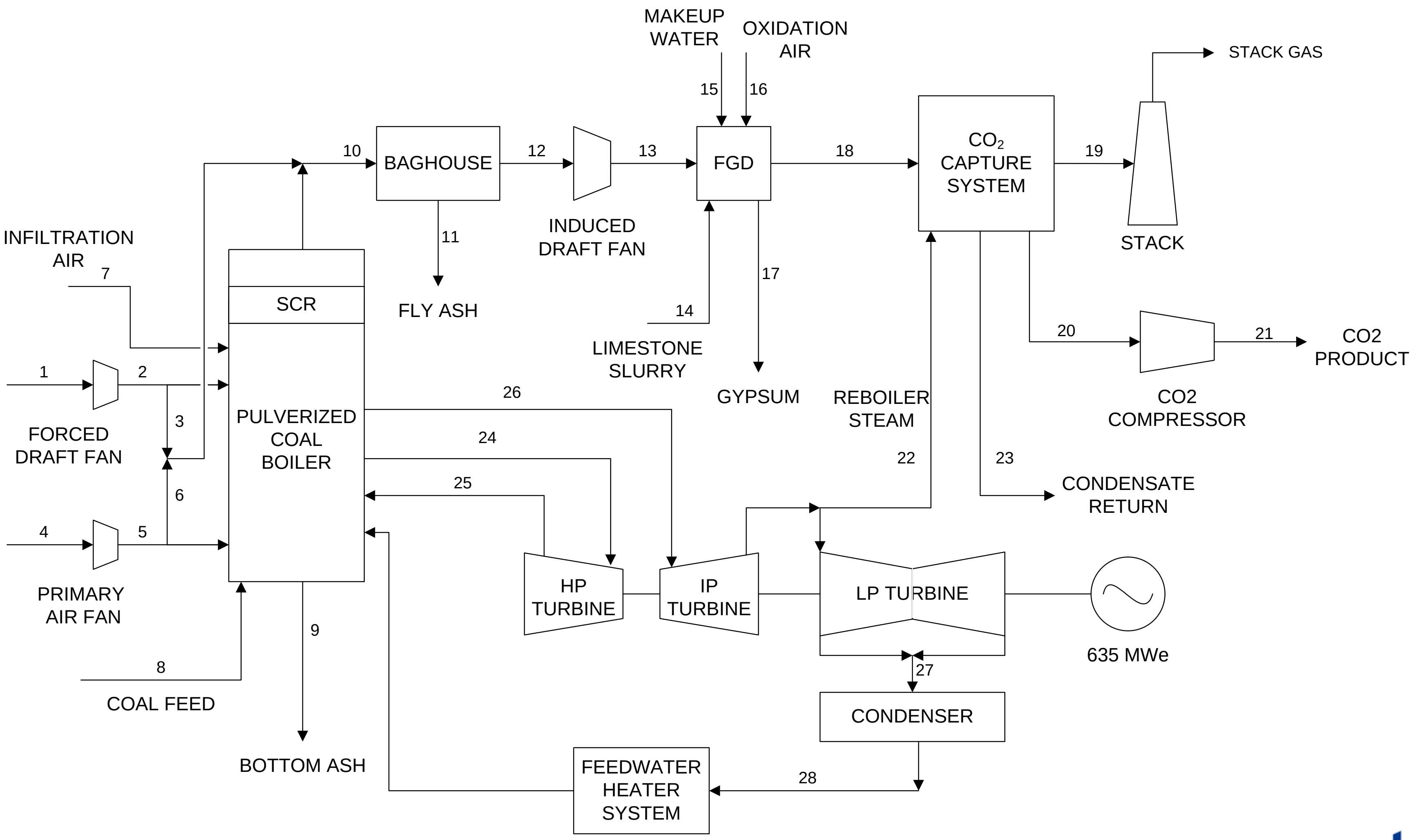
BP4: Parametric and continuous tests

Sep 2017

Anticipated Slipstream Feed Conditions at NCCC

Parameter	Condition
Capacity, MW_e	1
CO_2 Capture, ton/day	20
Pressure	~ atmospheric pressure
Temperature	~ 40 °C (100 °F)
Gas composition	CO_2 concentration: ~13 vol%
Water vapor in feed stream	Fully saturated
Contaminant levels	SO_2 level: 20-30 ppm or ~1 ppm

PC Process Flow Diagram



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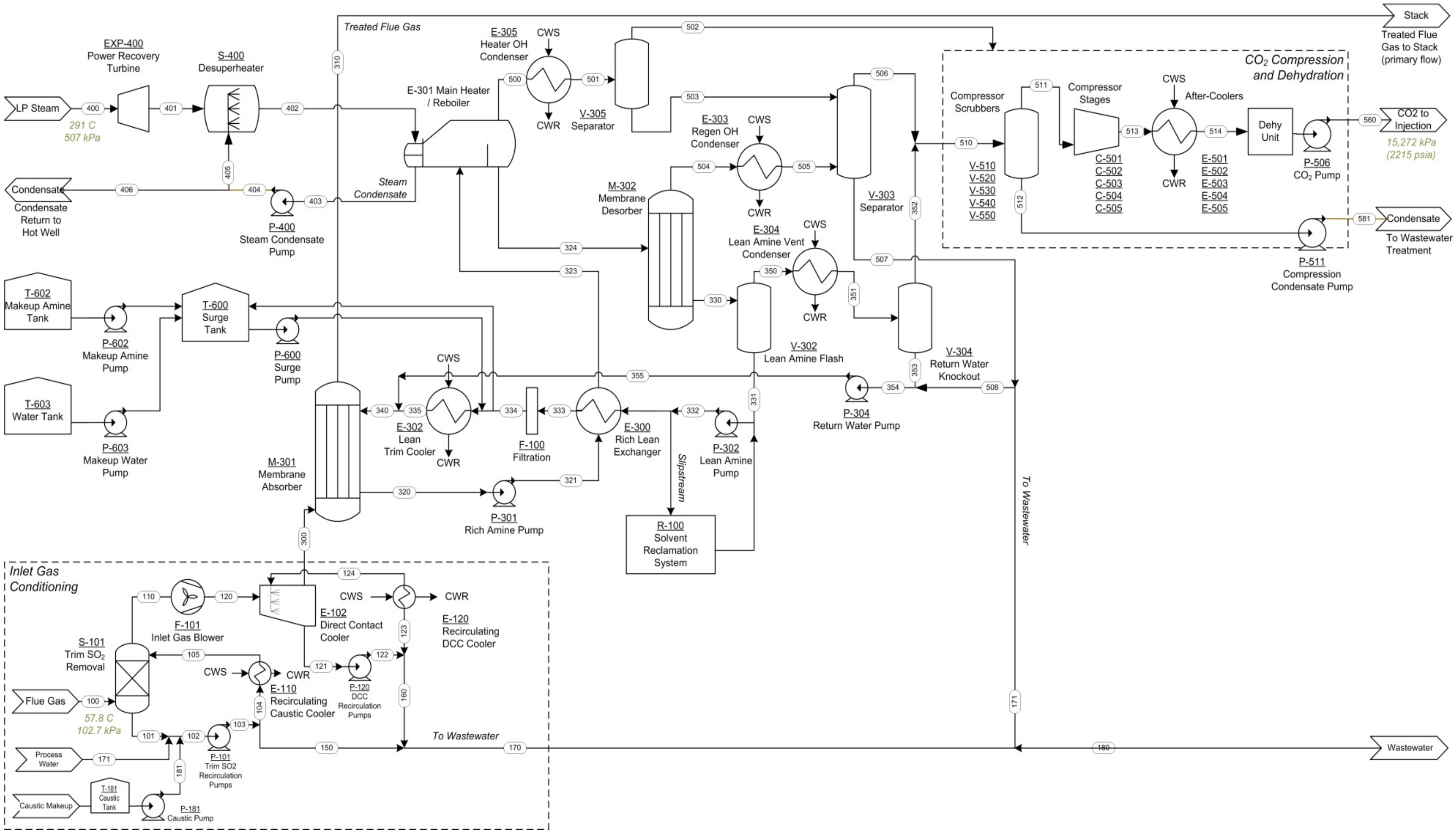
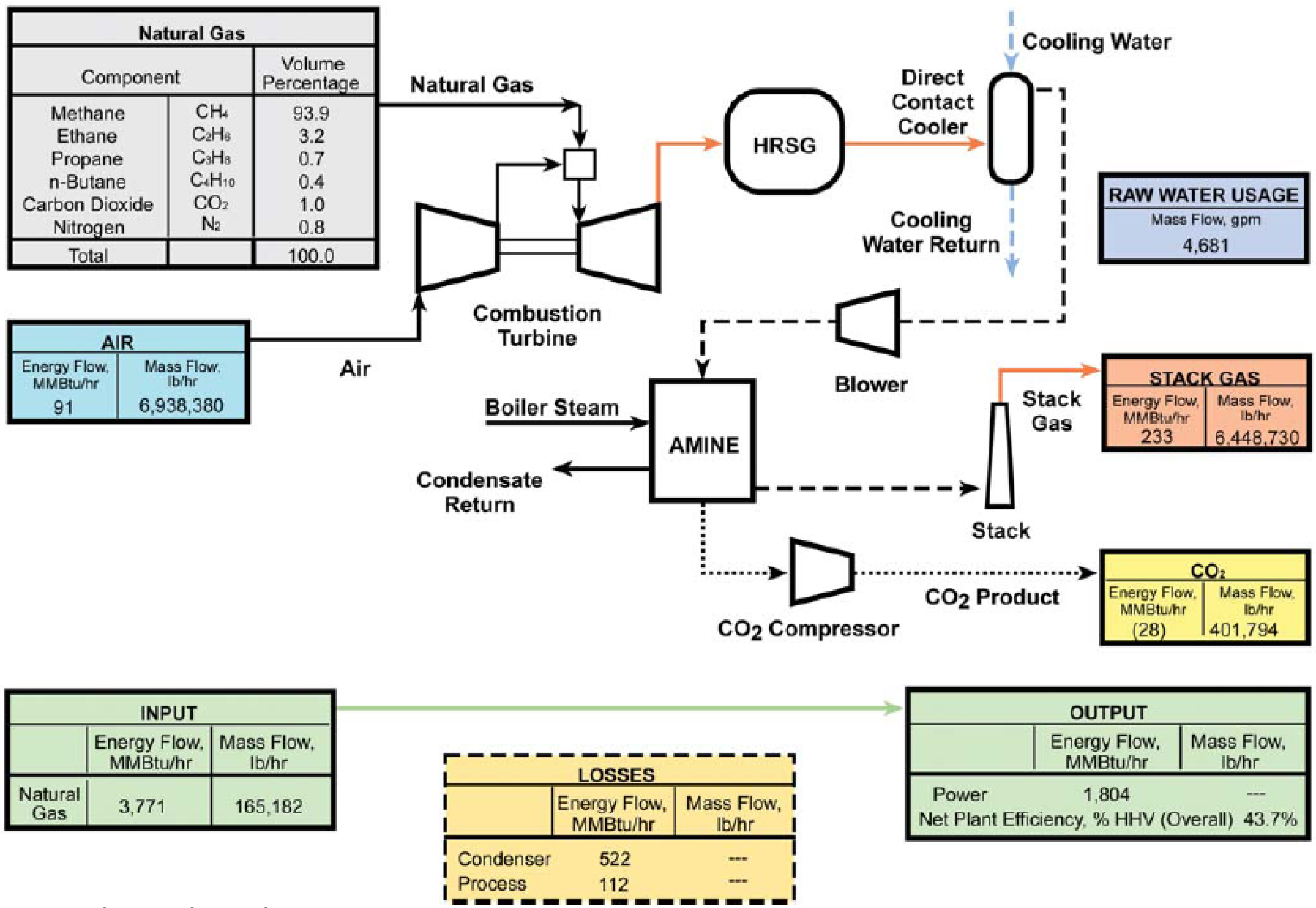
Capture System PFD



Plant Efficiency Summary

Item	Unit	Case 11 (no capture)	Case 12 (Econ-amine™)	GTI HFC - H3-1
HHV Thermal Input	kWh_{th}	1,409,162	1,934,519	1,816,984
Net Plant HHV Effic.	%	39.3	28.4	30.3
Net Plant HHV Heat Rate	Btu/ kWh	8,687	12,002	11,271
COE - Total	mills/ kWh	81	147	130-135
Increase in COE - Total	%	-	82	59-67
Cost of CO_2 Capture - Total	$/tonne	-	66	50-57

DOE Cost & Performance Comparison of Fossil Power Plants



DOE/NETL-2007/1281 (2007)

Model Predicts Higher Plant Efficiency and Lower COE for NGCC with HFMC

Basis	DOE		IECM		
	Case 13	Case 14	Base	Capture	Capture
CO_2 Capture Technology	No	Conv. Column	No	Conv. Column	**HFMC**
Gross Power Output (kW_e)	570,200	520,900	516,840	516,840	516,840
Auxiliary Power Requirement (kW_e)	9,840	38,200	10,340	84,540	55,000
Net Power Output (kW_e)	560,360	481,890	506,500	432,300	461,900
Natural Gas Flowrate (lb/h)	165,182	165,182	148,740	148,740	148,740
Net Plant HHV Efficiency (%)	50.8	43.7	50.15	42.8	45.73
% Decrease in HHV Efficiency		**14.0**		**14.7**	**8.8**
Net Plant HHV Heat Rate (Btu/kW-h)	6,719	7,813	6,803	7,972	7,461
Total Plant Cost ($x1000)	310,710	564,628	359,500	500,400	449,800
Total Plant Cost ($/kW)	554	1,172	554	1,158	974
LCOE (mills/kWh)	68.4	97.4	52.76	77.02	68.22
% Increase in LCOE (mills/kWh)		**42.4**		**46.0**	**29.3**
CO_2 Emissions (lb/MWh)	783	85.8	809.9	9.49	8.89

DOE/NETL-2007/1281 (2007)

HFMC Reduces Costs of CO_2 Capture

- ✓ Improved membrane material and membrane performance to lower capital costs
- ✓ Improved solvent regeneration using mild heat and higher pressure (even more when combined with a solvent requiring lower regeneration energy).
- ✓ Improved process performance results from increased flexibility in solvent selection
- ✓ Reduced system size and footprint by up to 70% enables retrofit application to many existing power plants
- ✓ Reduced materials of construction costs since membrane modules are constructed from plastic materials and are not subject to corrosion
- ✓ Reduced parasitic fan loads due to lower pressure and pressure drop requirements compared to conventional membranes and columns
- ✓ Reduced solvent degradation

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