Direct Air Capture Case Studies: Sorbent System

Timothy Fout[1], Sally Homsy[2], Mark Woods[2], Alex Zoelle[2], Jessica Valentine[2], Naksha Roy[2], Aaron Kilstofte[2], Mike Sturdivan[2], Mark Steutermann[2]

[1]US Department of Energy, National Energy Technology Laboratory, Pittsburgh PA /Morgantown WV; [2]NETL Support Contractor, Pittsburgh PA/Morgantown WV

Research & Innovation Center

NATIONAL ENERGY TECHNOLOGY LABORATORY

Background

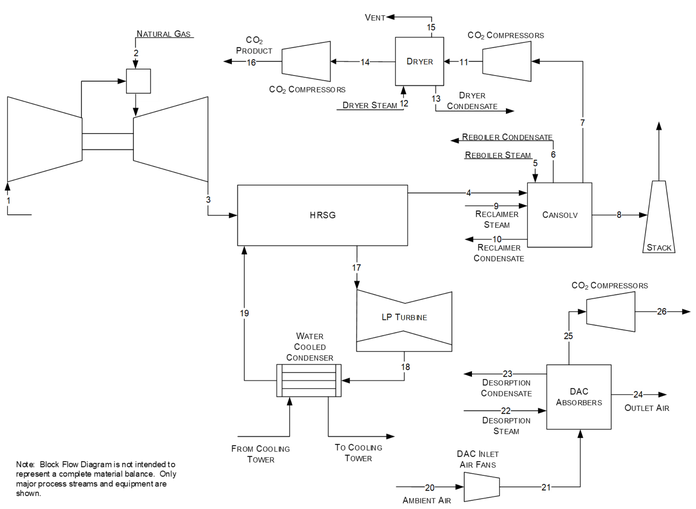
Direct air capture (DAC) technology is in the early stages of development, with a wide range of costs reported in the literature. In support of its R&D mission and to establish a reference framework for the reporting of DAC techno-economic analysis information in the literature, DOE's National Energy Technology Laboratory (NETL) has developed case studies for DAC systems. This presentation focuses on a DAC case study that examines a solid sorbent-based DAC technology and configuration.

Site Characteristics

Parameter	Value
Location	Greenfield, Midwestern U.S.
Topography	Level
Size (DAC), acres	52
Transportation	Rail or Highway
Water	50% Municipal and 50% Ground Water

Parameter	Midwest ISO	
	Bituminous Baseline Rev4[1]	Direct Air Capture
Elevation, m (ft)	0 (0)	0 (0)
Barometric Pressure, MPa (psia)	0.101 (14.696)	0.101 (14.696)
Average Ambient Dry Bulb Temperature, °C (°F)	15 (59)	15 (59)
Average Ambient Wet Bulb Temperature, °C (°F)	10.8 (51.5)	10.8 (51.5)
Design Ambient Relative Humidity, %	60	60
Cooling Water Temperature, °C (°F)[A]	15.6 (60)	15.6 (60)
Air composition based on published psychrometric data, mass %[2]		**Air composition, mole %**
N_2	75.055	74.983	77.243
O_2	22.998	23.050	20.784
Ar	1.280	1.272	0.919
H_2O	0.616	0.633	1.014
CO_2	0.050	0.062	0.040 (403.9 ppmv)
Total	100.00	100.00	100.00

Process Diagram



Note: Block Flow Diagram is not intended to represent a complete material balance. Only major process streams and equipment are shown.

Key Assumptions

- Absorber vessel outlet air exits w/o stack or dispersion considerations
- Assumed to be compliant with Effluent Limitation Guidelines
  - Water produced from DAC or NGCC w/capture
- Non-type NGCC Turbine used
  - "Rubber" turbine
- Single reciprocating compressor for CO_2 compression
- Scaled Capture System from NGCC w/ 90% capture for steam

Parameter	Assumed Value
Adsorber Vessel Type	Monolith
DAC Net Capture Rate, tonne CO_2/yr	100,000
Plant Capacity Factor, %	85
CO_2 Product Purity	Meets pipeline specification without purification
DAC System Pressure Drop, psi (in. H_2O) [A]	0.3 (7.78)
DAC System Capture Fraction	0.6
DAC Sorbent Desorption Temperature, °C (°F)	100 (212)
DAC Sorbent Regeneration Energy, GJ/tonne CO_2 (Btu/lb CO_2)	4.3 (1,847)
DAC Sorbent Adsorption Temperature	Ambient
DAC Sorbent Adsorption Capacity, mol CO_2/kg (lb CO_2/lb sorbent)	1.2 (0.053)
DAC Sorbent Lifetime, years	0.5
Sorbent Cost, $/ft^3 ($/lb)	4.0 (0.09)

Case Description

- Case 0B
  - Monolithic DAC Sorbent System with NGCC supplied power and steam
  - 90% Post Combustion Capture on NGCC
  - Sized to account for 100,000 tonnes CO_2 / year net removed from atmosphere
- Case 0B-EB
  - Monolithic DAC Sorbent System with Electric Boiler for steam
  - Carbon footprint of electricity considered to be zero
  - Included in report but not highlighted due to time

Performance Results

Case 0B Monolith Performance

Parameter	Case 0B
Superficial Velocity (ft/s)	8.18
Bed Depth (ft)	2
Cell Diameter (ft)	0.0048
Bed Pressure Drop (Pa)	625
System Pressure Drop, including ducting (Pa)	1,935
Reynold's Number	249
Vessel Diameter (ft)	60
Number of Vessels	20
Sorbent Loading (g-mol/kg sorbent)	1.20
Sorbent Density (lb/ft^3)	24
Adsorption Time (hr)	3
Desorption Time (hr)	0.3

Case 0B Performance Summary

Combustion Turbine Power, MWe	36
Steam Turbine Power, MWe	2
Total Gross Power, MWe	**37**
Auxiliary Loads	
NGCC CO_2 Capture/Removal Auxiliaries, kWe	800
NGCC CO_2 Compression, kWe	1,290
DAC Air Fans, kWe	32,810
DAC CO_2 Compression, kWe	1,690
Balance of Plant, kWe	780
Total Auxiliaries, MWe	**37**
Net Power, MWe	**0**
Natural Gas Feed Flow, kg/hr (lb/hr)	6,988 (15,405)
HHV Thermal Input, kWt	101,503
LHV Thermal Input, kWt	91,617
CO_2 Balance	
NGCC Flue Gas CO_2 Captured, tonne/yr	125,090
DAC CO_2 Removed from Air (Gross), tonne/yr	113,900
NGCC Flue Gas CO_2 Emitted to Air, tonne/yr	13,900
Net CO_2 Removed from Air, tonne/yr	**100,000**

Cost Considerations

- **Capital Cost Estimates**
  - DAC -50/+50, Class 5 AACE Classification
  - Concept Screening
- **Not FOAK or NOAK Costs**
  - Consistent methodology applied as for commercial systems
  - Detailed depiction of assumptions and design
  - Capital costs and scaling parameters for the DAC system components were developed by Black & Veatch using in-house cost estimating references
- **Other Factors**
  - Site/project specific (Scale, Capacity Factor, Financing, Labor Rates, Regulations, etc.)
- **Future Cost Trends**
  - Effect of R&D

Cost Results

DEFINITIONS

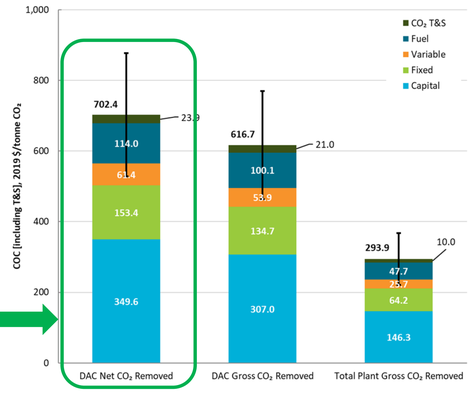
Gross = All CO_2 captured and stored

DAC Gross = Gross – CO_2 Captured and Stored from NGCC

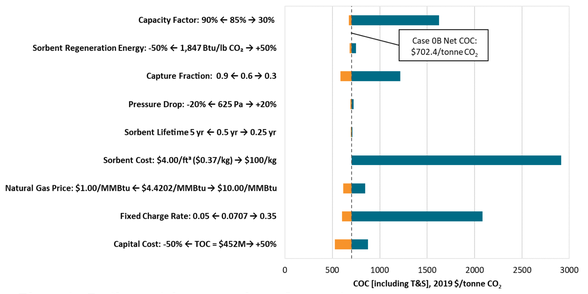
DAC Net = DAC Gross – CO_2 Captured by DAC to account for NGCC emissions not captured

Preferred Metric for DAC

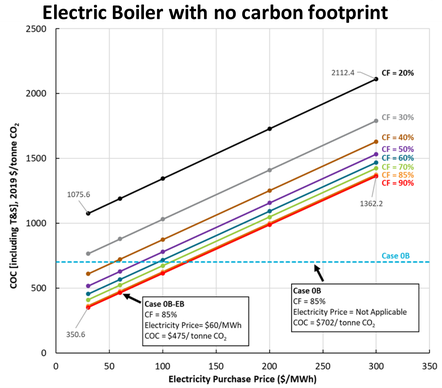
Cost of Capture



Cost Sensitivities



Electric Boiler with no carbon footprint



IMPORTANT ASSUMPTIONS

- Cost of Capture in Electric Boiler Sensitivity DOES NOT include carbon footprint of electricity used
- COC shown in NOT equivalent to COC_{net} unless electricity is 100% carbon free