Natural Gas Combined-Cycle Plant With Carbon Capture & Sequestration

Plant Overview

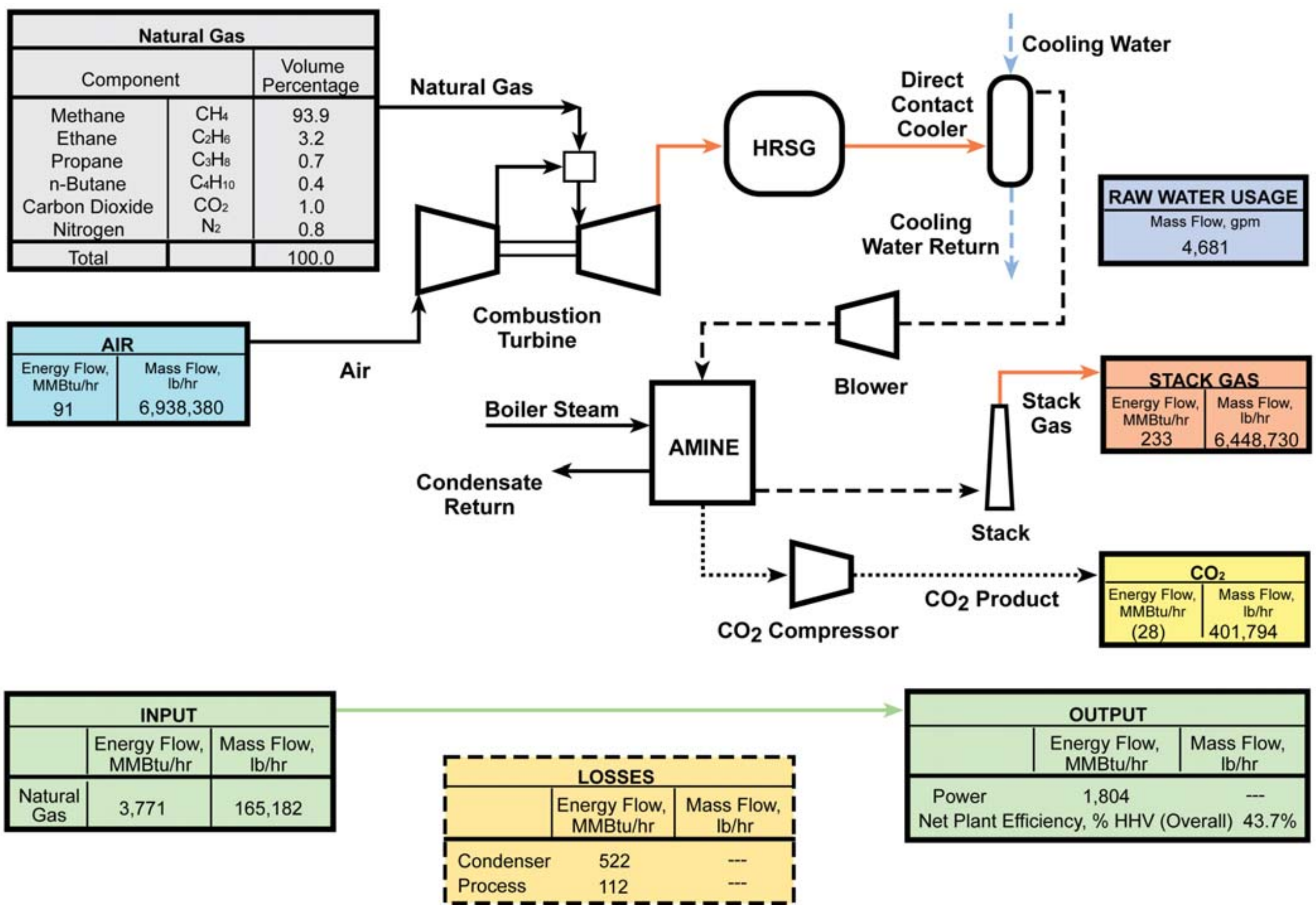
This analysis is based on a 482 MWe (net power output) natural gas combined-cycle (NGCC) plant located at a greenfield site in the midwestern United States. This plant captures carbon dioxide (CO_2) to be sequestered and is designed to meet Best Available Control Technology (BACT) emission limits. The combination process, heat, and mass balance diagram for the NGCC plant with carbon capture and sequestration (CCS) is shown in Figure 1. The primary fuel is natural gas (NG) with a higher heating value (HHV) of 22,792 Btu/lb. The plant is assumed to operate in baseload mode at a capacity factor (CF) of 85 percent without sparing for major train components. A summary of plant performance data for the NGCC plant with CCS case is presented in Table 1.

Table 1. Plant Performance Summary

Plant Type	NGCC
Carbon capture	Yes
Net power output (kWe)	481,890
Net plant HHV efficiency (%)	43.7
Primary fuel (type)	Natural gas
Levelized cost-of-electricity (mills/kWh) @ 85% capacity factor	97.4
Total plant cost ($ x 1,000)	$564,628
Cost of CO_2 avoided[1] ($/ton)	83

[1]The cost of CO_2 avoided is defined as the difference in the 20-year levelized cost-of-electricity between controlled and uncontrolled like cases, divided by the difference in CO_2 emissions in kg/MWh.

Figure 1. Process Flow Diagram
NGCC With CCS



Note: Diagram is provided for general reference of major flows only. For complete flow information, please refer to the final report.

Technical Description

The analysis for the NGCC plant with CCS is based on two advanced F-Class combustion turbine generators (CTGs) that are assumed to be commercially available to support startup in 2010, two heat recovery steam generators (HRSGs), and one steam turbine generator (STG) in a multi-shaft 2x2x1 configuration with a recirculating wet cooling tower for cycle heat rejection. A performance summary for the advanced CTG for the NGCC plant with CCS is presented in Table 2. The unit consists of an NG system that feeds NG at the required pressure and temperature to the two axial-flow, constant-speed CTGs with variable inlet guide vanes and a dry low-NOx (DLN) burner combustion system. Each CTG exhausts to an HRSG configured with high-, intermediate-, and low-pressure steam systems, including drum, superheater, reheater, and economizer sections. Steam flows from both HRSGs to a conventional STG for power generation. The Rankine cycle consists of a single reheat system with steam conditions of 16.5 MPa/566°C/510°C (2,400 psig/1,050°F/950°F). Nitrogen oxides emissions are controlled to 25 ppmvd (referenced to 15 percent oxygen (O_2) by the DLN combustion system and then further reduced by a selective catalytic reduction (SCR) system. The SCR system was designed for 90 percent nitrogen oxides (NOx) reduction. The DLN burner, together with the SCR system, achieves the emission limit of 2.5 ppmvd (referenced to 15 percent O_2). All other support systems and equipment are typical for a conventional NGCC plant. Plant performance is based on the properties of pipeline-quality NG.

Table 2. Advanced Gas Turbine Performance[1]

	Advanced F-Class
Net output, MWe	185
Pressure ratio	18.5
Airflow, kg/s (lb/s)	431 (950)
Firing temperature, °C (°F)	>1,371 (>2,500)

[1]At International Standards Organization conditions firing natural gas.

Flue gas (FG) exiting the HRSGs is directed to the Fluor Econamine FG Plus™ process, where CO_2 is absorbed in a monoethanolamine-based solvent. A booster blower is required to overcome the process pressure drop. Carbon dioxide removed in the Econamine FG Plus™ process is dried and compressed for subsequent pipeline transport and sequestration. The CO_2 is delivered to the plant fence line at 15.3 MPa (2,215 psia). The compressed CO_2 is transported via pipeline to a geologic sequestration field for injection into a saline aquifer, which is located within 50 miles of the plant.

Achieving a nominal 482 MWe net output with the above plant configuration results in an HHV thermal input requirement of 1,103,363 kWt (3,766 MMBtu/hr basis). This thermal input is achieved by burning NG at a rate of 165,182 lb/hr, which yields an HHV net plant heat rate of 7,813 Btu/kWh (HHV efficiency of 43.7 percent). The gross power output of 520 MWe is produced from the advanced CTGs and the STG. With an auxiliary power requirement of 38 MWe, the net plant output is 482 MWe. The summary of plant electrical generation performance is presented in Table 3.

Table 3. Plant Electrical Generation

	Electrical Summary
Advanced gas turbine x 2, MWe	370.2
Steam turbine, MWe	149.9
Gross power output, MWe	520.1
Auxiliary power requirement, MWe	(38.2)
Net power output, MWe	481.9

Environmental Performance

This study assumes the use of BACT to meet the emission requirements of the 2006 New Source Performance Standards.

NGCC plants use NG as their fuel, which creates negligible emissions of sulfur dioxide (SO_2), particulate matter (PM), and mercury (Hg); therefore, NGCC plants require no emissions control equipment or features to reduce these emissions. Nitrogen oxides emissions are controlled to 25 ppmvd (referenced to 15 percent O_2) by the DLN combustion system and then further reduced by an SCR system. The SCR system was designed for

90 percent NOx reduction while firing NG. The low NOx burner, together with the SCR, achieves the emission limit of 2.5 ppmvd (referenced to 15 percent O_2).

CO_2 capture is designed to recover 90 percent of the CO_2 in the FG stream by the Econamine FG Plus™ process.

A summary of the resulting air emissions is presented in Table 4.

Table 4. Air Emissions Summary @ 85% Capacity Factor

Pollutant	NGCC With CCS
CO_2	
• tons/year	166,172
• lb/MMBtu	11.9
• cost of CO_2 avoided ($/ton)	83
SO_2	
• tons/year	Negligible
• lb/MMBtu	Negligible
NOx	
• tons/year	127
• lb/MMBtu	0.009
PM (filterable)	
• tons/year	Negligible
• lb/MMBtu	Negligible
Hg	
• tons/year	Negligible
• lb/TBtu	Negligible

Cost Estimation

Plant size, primary/secondary fuel type, construction time total plant cost (TPC) basis year, plant CF, plant heat rate, fuel cost, plant book life, and plant in-service date were used as inputs to develop capital cost, production cost, and levelized cost-of-electricity (LCOE) estimates. Costs for the plant were based on adjusted vendor-furnished and actual cost data from recent design/build projects. Values for financial assumptions and a cost summary are shown in Table 5.

Project contingencies were added to each case to cover project uncertainty and the cost of any additional equipment that could result from detailed design. The project contingencies represent costs that are expected to occur. Project contingency was 13.3 percent of the TPC.

Process contingency is intended to compensate for uncertainties arising as a result of the state of technology development. Process contingencies represent 5 percent of the NGCC CCS case TPC and have been applied to the estimates as follows:

- CO_2 Removal System – 20 percent on all NGCC CCS cases.
- Instrumentation and Controls – 5 percent on the NGCC CCS cases.

This study assumes that each new plant would be dispatched any time it is available and would be capable of generating maximum capacity when online. Therefore, CF is assumed to equal availability and is 85 percent for NGCC cases. The assumed CF for NGCC cases is 85 percent.

For the NGCC cases that feature CCS, capital and operating costs were estimated for transporting CO_2 to an underground storage area, associated storage maintenance, and for monitoring beyond the expected life of the plant. These costs were then levelized over a 20-year period.

The calculated cost of transport, storage, and monitoring for CO_2 is $7.00/short ton, which adds 2.9 mills/kWh to the LCOE.

The 482 (net) MWe NGCC plant with CCS was projected to have a TPC of $1,172/kWe, resulting in a 20-year LCOE of 97.4 mills/kWh.

Table 5. Major Financial Assumptions and Resulting Cost Summary[1]

Major Assumptions					
Case:	1x482 MWe net NGCC with CCS				
Plant Size:	481.9	(MWe, net)	Heat Rate:	7,813	(Btu/kWh)
Primary/Secondary Fuel (type):	Natural Gas		Fuel Cost:	6.75	($/MMBtu)
Construction Duration:	3	(years)	Plant Life:	30	(years)
Total Plant Cost[2] Year:	2007	(January)	Plant in Service:	2010	(January)
Capacity Factor:	85	(%)	Capital Charge Factor:	17.5	(%)
Resulting Capital Investment (Levelized 2007 dollars)					**Mills/kWh**
Total Plant Cost					27.5
Resulting Operating Costs (Levelized 2007 dollars)					**Mills/kWh**
Fixed Operating Cost					2.6
Variable Operating Cost					3.0
Resulting Fuel Cost (Levelized 2007 dollars) @ $1.80 / MMBtu					**Mills/kWh**
					61.4
Resulting Levelized CO_2 Cost (2007 dollars)					**Mills/kWh**
					2.9
Total Levelized Busbar Cost of Power (2007 dollars)					**Mills/kWh**
					97.4

[1]Costs shown can vary ± 30%.

[2]Total plant cost includes all equipment (complete with initial chemical and catalyst loadings), materials, labor (direct and indirect), engineering and construction management, and contingencies (process and project). Owner's costs are not included.

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Reference: Cost and Performance Baseline for Fossil Energy Plants, Vol. 1, DOE/NETL-2007/1281, May 2007.
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