

Natural Gas Combined-Cycle Plants With and Without Carbon Capture & Sequestration

Technology Overview

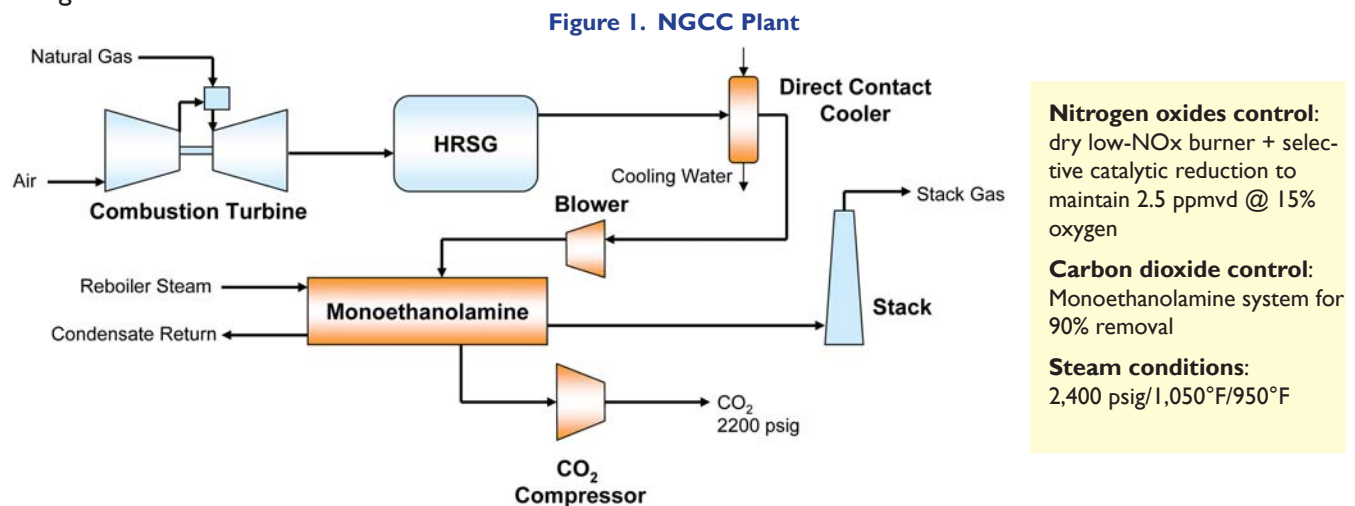
Two Natural Gas Combined-Cycle (NGCC) power plant configurations were evaluated, and the results are presented in this summary sheet. Both cases were analyzed using a consistent set of assumptions and analytical tools. The two configurations evaluated are based on an NGCC plant with and without carbon capture and sequestration (CCS).

- NGCC plant utilizing Advanced F-Class combustion turbine generators (CTGs).
- NGCC plant utilizing Advanced F-Class CTGs with CCS.

Each NGCC plant design is based on a market-ready technology that is assumed to be commercially available in time to support a 2010 startup date. The NGCC plants are built at a greenfield site in the midwestern United States and are assumed to operate in baseload mode at 85 percent capacity factor (CF) without sparing of major train components. Nominal plant size (gross rating) is 570 MWe without CCS and 520 MWe with CCS. All designs consist of two advanced F-Class CTGs, two heat recovery steam generators (HRSGs), and one steam turbine generator in a multi-shaft 2x2x1 configuration.

The NGCC cases were evaluated with and without CCS on a common thermal input basis. The case that includes CCS is equipped with the Fluor Econamine (FG) Plus™ process. The NGCC with CCS case also has a smaller plant net output resulting from the additional CCS facility auxiliary loads and steam consumption. After compression to pipeline specification pressure, the carbon dioxide (CO₂) is assumed to be transported to a nearby underground storage facility for sequestration.

The size of the NGCC designs was determined by the output of the commercially available combustion turbine. Therefore, evaluation of the NGCC designs on a common net output basis was not possible. For the cases with and without CCS, respective gross output was 520 and 570 MWe, and respective net output was 482 and 560 MWe. The natural gas (NG) flowrate was 165,182 lb/hr in both cases. See Figure 1 for a generic block flow diagram of an NGCC plant. The orange blocks in the figure represent the unit operations added to the configuration for CCS cases.



Orange blocks indicate unit operations added for CCS case.

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

Technical Description

The combined-cycle plant was based on two CTGs. The CTG is representative of the advanced F-Class CTGs with an International Standards Organization base rating of 184,400 kWe (when firing NG). This machine is an axial flow, single-shaft, constant-speed unit, with variable inlet guide vanes and Multi-Nozzle Quiet Combustor dry low-NOx (DLN) burner combustion system. Additionally, a selective catalytic reduction (SCR) system further reduces the nitrogen oxides (NOx) emissions. The Rankine cycle portion of both designs uses a single-reheat 16.5 MPa/566°C/510°C (2,400 psig/1,050°F/950°F) cycle. Recirculating evaporative cooling systems are used for cycle heat rejection. The efficiency of the case without CCS is almost 51 percent, with a gross rating of 570 MWe.

The CCS case requires a significant amount of auxiliary power and extraction steam for the process, which reduces the output of the steam turbine. This results in a lower net plant output for the CCS cases of about 482 MWe for an average net plant efficiency of almost 44 percent higher heating value (HHV).

The CCS case is equipped with the Fluor Econamine Flue Gas (FG) Plus™ technology, which removes 90 percent of the CO₂ in the FG exiting the HRSG unit. Once captured, the CO₂ is dried and compressed to 15.3 MPa (2,215 psia). The compressed CO₂ is transported via pipeline to a geologic sequestration field for injection into a saline formation, which is located within 50 miles of the plant. Therefore, CO₂ transport, storage, and monitoring costs are included in the analyses.

Fuel Analysis and Costs

The design NG characteristics are presented in Table 1. Both NGCC cases were modeled with the design NG.

A NG cost of \$6.40/MMkj (\$6.75/MMBtu) (January 2007 dollars) was determined from the Energy Information Administration AEO2007 for an eastern interior high-sulfur bituminous coal.

Environmental Design Basis

The environmental design for this study was based on evaluating both of the NGCC cases using the same regulatory design basis. The environmental specifications for a greenfield NGCC plant are based on the pipeline-quality NG specification in Table 1 and EPA 40 CFR Part 60, Subpart KKKK. Table 2 provides details of the environmental design basis for NGCC plants built at a midwestern U.S. location. The emissions controls assumed for each of the two NGCC cases are as follows:

- Dry low-NOx burners in conjunction with SCR for NOx control in both cases.
- Econamine process for CO₂ capture in the CCS case.

NGCC plants produce negligible amounts of SO₂, particulate matter (PM), and mercury (Hg); therefore, no emissions controls equipment or features are required for these pollutants.

Table 1. Fuel Analysis

Natural Gas		
Component		Volume Percentage
Methane	CH ₄	93.9
Ethane	C ₂ H ₆	3.2
Propane	C ₃ H ₈	0.7
n-Butane	C ₄ H ₁₀	0.4
Carbon dioxide	CO ₂	1.0
Nitrogen	N ₂	0.8
Total		100.0
	LHV	HHV
kJ/kg	47,764	52,970
kJ/scm	35	39
Btu/lb	20,552	22,792
Btu/scf	939	1,040

Table 2. Environmental Targets

Pollutant	NGCC
SO ₂	Negligible
NOx	2.5 ppmvd @ 15% Oxygen
PM (filterable)	Negligible
Hg	N/A

Major Economic and Financial Assumptions

For the NGCC cases, capital cost, production cost, and levelized cost-of-electricity (LCOE) estimates were developed for each plant based on adjusted vendor-furnished and actual cost data from recent design/build projects and resulted in determination of a revenue-requirement 20-year LCOE based on the power plant costs and assumed financing structure. Listed in Table 3 are the major economic and financial assumptions for the two NGCC cases.

Project contingencies were added to each of the cases 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 10.6 percent for the NGCC case without CCSTPC and roughly 13.3 percent for the NGCC case with CCS.

Process contingency is intended to compensate for uncertainties arising as a result of the state of technology development. Process contingencies have been applied to the estimates as follows:

- CO₂ 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.

For the NGCC case that features CCS, capital and operating costs were estimated for transporting CO₂ to an underground storage field, associated storage in a saline aquifer, and for monitoring beyond the expected life of the plant. These costs were then levelized over a 20-year period.

Results

The results of the analysis of the two NGCC cases are presented in the following subsections.

Capital Cost

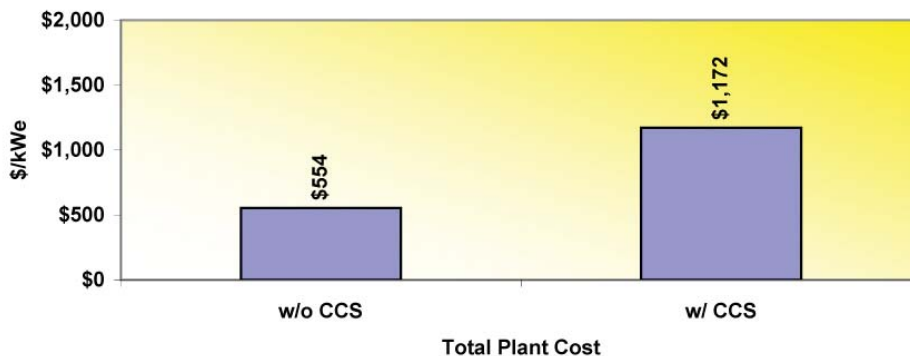
The total plant cost (TPC) for each of the two NGCC cases is compared in Figure 2. The TPC includes all equipment (complete with initial chemical and catalyst loadings), materials, labor (direct and indirect), engineering and construction management, and contingencies (process and project). Owner’s costs are not included.

The results of the analysis indicate that an NGCC costs \$554/kWe, and that an additional \$618/kWe is needed for the NGCC plant with CCS.

Table 3. Major Economic and Financial Assumptions for NGCC Cases

Major Economic Assumptions	
Capacity factor	85%
Costs year in constant U.S. dollars	2007 (January)
Natural gas delivered cost	\$6.75/MMBtu
Construction duration	3 Years
Plant startup date	2010 (January)
Major Financial Assumptions	
Depreciation	20 years
Federal income tax	34%
State income tax	6%
Low risk cases	
After-tax weighted cost of capital	8.79%
Capital structure:	
Common equity	50% (Cost = 12%)
Debt	50% (Cost = 9%)
Capital charge factor	16.4%
High risk cases	
After-tax weighted cost of capital	9.67%
Capital structure:	
Common equity	55% (Cost = 12%)
Debt	45% (Cost = 11%)
Capital charge factor	17.5%

Figure 2. Comparison of TPC for the Two NGCC Cases

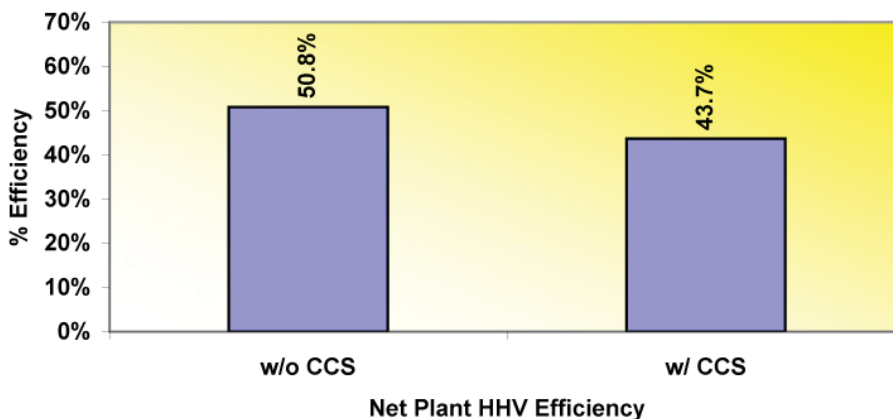


All costs are in January 2007 U.S. dollars.

Efficiency

The net plant HHV efficiencies for the two NGCC cases are compared in Figure 3. This analysis indicates that adding CCS to the NGCC reduces plant HHV efficiency by more than 7 percentage points, from 50.8 percent to 43.7 percent.

Figure 3. Comparison of Net Plant Efficiency for the Two NGCC Cases



Levelized Cost-of-Electricity

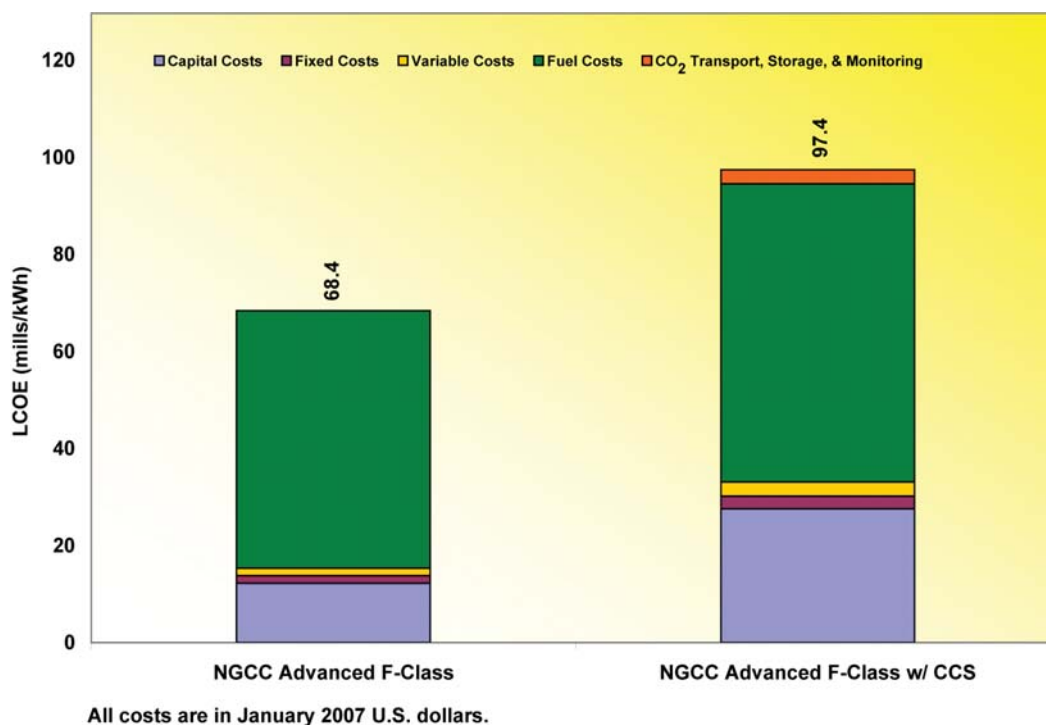
The LCOE is a measurement of the coal-to-busbar cost of power, and includes the TPC, fixed and variable operating costs, and fuel costs levelized over a 20-year period. The calculated cost of transport, storage, and monitoring for CO₂ is about \$7.00/short ton, which adds roughly 3 mills to the LCOE.

The NGCC without CCS plant generates power at an LCOE of 68.4 mills/kWh at a CF of 85 percent. When CCS is included, the increased TPC and reduced efficiency result in a higher LCOE of 97.4 mills/kWh.

Environmental Impacts

Listed in Table 4 is a comparative summary of emissions from the two NGCC cases. Mass emission rates and cumulative annual totals are given for sulfur dioxide (SO₂), NO_x, PM, Hg, and CO₂.

Figure 4. Comparison of Levelized Cost-of-Electricity for the Two NGCC Cases



The emissions from both NGCC plants evaluated meet or exceed Best Available Control Technologies requirements for the design NG specification and EPA 40 CFR Part 60, Subpart KKKK. The CO₂ is reduced by 90 percent in the capture case, resulting in less than 167,000 tons/year of CO₂ emissions. The cost of CO₂ avoided is defined as the difference in the 20-year LCOE between controlled and uncontrolled like cases, divided by the difference in CO₂ emissions in kg/MWh. In this analysis, the cost of CO₂ avoided is about \$83/ton. Sulfur dioxide, Hg, and PM emissions are negligible. Raw water usage in the CCS case is over 85 percent greater than for the case without CCS primarily because of the large Econamine process cooling water demand.

Table 4. Comparative Emissions for the Two NGCC Cases @ 85% Capacity Factor

Plant Type	NGCC	
	Without CCS	With CCS (90%)
CO₂		
• tons/year	1,661,720	166,172
• lb/MMBtu	119	11.9
• cost of avoided CO ₂ (\$/ton)	N/A	83
SO₂		
• tons/year	N/A	N/A
• lb/10 ⁶ Btu	N/A	N/A
NO_x		
• tons/year	127	127
• lb/MMBtu	0.009	0.009
PM (filterable)		
• tons/year	N/A	N/A
• lb/MMBtu	N/A	N/A
Hg		
• tons/year	N/A	N/A
• lb/TBtu	N/A	N/A
Raw water usage, gpm	2,511	4,681

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