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Energy & The Environment

Gas-Fired Power Plants

As concerns over global warming and high energy prices continue to rise, the electricity sector in the United States has focused its attention on natural gas. Despite coal's dominance as the favored fuel for electricity generation in the past, most newly constructed power plants rely on natural gas as the primary energy source. Ever since 1999, natural gas power plants account for the majority of new electricity generation in the United States.[1] Furthermore, the Department of Energy forecasts 90 percent of all newly created electric power plants in the next 20 years will run off natural gas.[2]

Historical price data supports the economics behind powering electric plants with bituminous and subbituminous coal rather than natural gas. However, as environmental laws and the potential for a carbon tax become increasingly plausible, utility companies have began to shy away from coal in favor of a cleaner burning substance. As a result, while natural gas power plants have enjoyed unprecedented growth in recent years, coal's share of net electricity generation has been on the decline since it peaked in 1997 at 52 percent.[3]

Several processes exist for converting natural gas into electricity. Electricity from natural gas power plants is commonly generated via steam generation units, centralized gas turbines, combined cycle units, industrial gas fired turbines, microturbines, and gas fired reciprocating engines All methods involve combustion and vary in efficiency. Depending on the circumstances and the environment, certain methods for electricity generation are better suited than others.

Traditionally, steam power plants have relied on coal as their primary source for fuel. In a natural gas powered steam power plant, coal is replaced with natural gas to heat up a boiler containing water. As the water's temperature rises, it undergoes a phase change and turns into steam. This steam is funneled through a steam engine or turbine, which spins a shaft connect to an electrical generator. The amount of electricity produced is dependent on the rotational rate of the turbine's shaft, which is directly connected to the electrical generator. Steam generation units are typically found in large coal and nuclear power plants due to the fact that they are only up to 35 percent efficient and need to reach economies of scale to be profitable.[4] Because of heat dispersion due to steam's increased surface area and friction losses in the turbine system, steam generation units only make sense when the fuel is cheap and available in large quantities. The steam generation unit must be run around the clock to make up for the extremely low efficiency during the start up and shutdown phases, which require substantial amounts of time. As a result, power plants with steam generation units primarily serve the electrical base load power requirements.[5]

Centralized gas turbines are an alternative to the steam generation units used in some

1 Energy Information Administration. “Electric Power Annual”. Available at <http://www.eia.doe.gov/cneaf/electricity/epa/epa_sum.html>.
2 U.S. Department of Energy. “Electric Power”. Available at <http://www.energy.gov/energysources/electricpower.htm>.
3 Energy Information Administration. “Electric Power Annual”. Available at <http://www.eia.doe.gov/cneaf/electricity/epa/epa_sum.html>.
4 Natural Gas Supply Association. “Electric Generation Using Natural Gas”. Available at <http://www.naturalgas.org/overview/uses_eletrical.asp>.
5 Ibid.

natural gas power plants. Instead of relying on steam to propel the turbine, centralized gas turbines are powered by the hot gases produced from the combustion of natural gas. Single cycle centralized gas turbines can reach an efficiency of around 35%, similar to that of a steam generation unit.[6] Centralized gas turbines come in all sizes and benefit from low emissions, but suffer from poor thermal efficiency due to heat loss and friction. Furthermore, centralized gas turbines can be quickly installed and require little time to start up and come online. As a result, power plants with centralized gas turbines can be used for various types of electricity generations. They are mostly commonly relied on for peak power generation.[7] Microturbines, a form of centralized gas turbines capable of outputting less than 300 kW, are a popular option for on-site distributed power generation and are used at locations where electricity from the grid is not available.[8]

Centralized gas turbines have benefited from technical improvements through the use of recuperators, intercoolers, lean premix combustors, catalytic combustors, and brush seals developed through the Department of Energy's Advanced Turbine Systems (ATS) program.[9] The use of recuperators apply heat from a turbine's exhaust stream to the combustion air for increased efficiency.[10] The efficiency of a turbine directly depends on the firing temperature, therefore the ATS program has focused on raising turbine inlet temperatures and designing materials needed to withstand the increased heat.[11] ATS gas-path cooling systems have been incorporated into modern centralized gas turbines to increase firing temperatures by 200 degrees fahrenheit, while maintaining NOx levels.[12] Higher firing temperatures lead to a more complete combustion process and allow for more efficient overall operation. Centralized gas turbines also incorporate technological advances in aircraft turbine materials to increase efficiency. Single crystal-nickel superalloys and ceramics in turbine blades allow "an increase in the rotor inlet temperature that leads to fuel efficiency improvements and power upgrades".[13]

The efficiency of natural gas power plants has been greatly increased through cogeneration and combined-cycle technologies. Combined-cycle and cogeneration power plants reuse the emitted waste heat from their centralized gas turbines to drive additional steam generator units. In doing so, combined-cycle and cogeneration plants leverage the inefficiencies of steam generation units and centralized gas turbines. As a result, a combined-cycle or cogeneration power plant is more capable of taking advantage of its fuel's energy content, thus raising overall efficiency to nearly 60 percent.[14] In addition to electricity, cogeneration plants have the ability to sell off the steam or heat they generate for industrial processes such as space heating, water heating, sterilization, etc... Due to increased efficiency, the total costs for a natural gas combined-cycle power plant cost anywhere between $400-500/kW, which is significantly

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6 Ann Chambers. "Natural Gas & Electric Power in Nontechnical Language". Tulsa: PennWell Books, 1999. Page 121.

7 Natural Gas Supply Association. "Electric Generation Using Natural Gas". Available at <http://www.naturalgas.org/overview/uses_eletrical.asp>.

8 Ann Chambers. "Natural Gas & Electric Power in Nontechnical Language". Tulsa: PennWell Books, 1999. Page 123.

9 Ibid. Page 120.

10 U.S. Department of Energy. "Turbines of Tomorrow. Available at <http://fossil.energy.gov/programs/powersystems/turbines/index.html>.

11 V.H. Desai, V.M. Philip, and J.Q. Zhang. "Influence of Steam Cooling on Hot Corrosion". Available at <http://www.netl.doe.gov/publications/proceedings/97/97ats/ats_pdf/ATSP-12.PDF>.

12 Ibid. Page 122.

13 Ibid. Page 123.

14 Ibid. Page 122.

less than $900-1,000/kW needed for a new coal-fired plant.[15] Furthermore, combined-cycle power plants can be constructed in less than two years, which allows for significantly faster access to reliable electricity compared to the alternatives.[16]

Various costs are associated with the life cycle of a natural gas powered combined-cycle power plant. Initial capital costs account for 10 percent of the total life cycle costs for combined-cycle power plants.[17] Of the 10 percent, 50% of the costs goes to acquiring the gas turbine-set, the heat recovery system, and the steam generator.[18] 21% accounts for the civil, arrangement, and building facilities costs along with site infrastructure costs.[19] The rest accounts for electrical infrastructure (9%) and the power island mechanical systems and control costs (20%).[20] 15 percent and 75 percent of the remaining life cycle costs for a combined-cycle power plant are attributable to maintenance on the plant and fuel costs, respectively.[21] The recent 200 percent price increase per thousand cubic feet of natural gas from 2002-2007 has resulted in significantly higher operating costs for electricity producers who rely on natural gas power plant.[22] As a result, the end consumer is faced with an "absolute cost increase of electricity [that] is 31% higher in natural gas-intensive regions than in coal-intensive ones".[23]

The current prices being charged by electricity producers that rely on natural gas power plants have risen due to the substantial run up in fuel prices. In 2006, the fuel costs for the average gas turbine power plant were 226% higher than the average fuel costs for a fossil steam plant, and 1081% higher than the average fuel costs for a nuclear power plant.[24] Fuel costs for gas turbine power plants increased by 252 percent from 1995 to 2006, which is the highest jump in fuel prices compared to other plant types.[25] As a result, continuing use of natural gas power plants for base load power requirements "could very well lead to spectacular price increases for households and industry".[26]

Natural gas combined-cycle power plants have helped minimize the environmental impact of the electricity industry. Electric utilities have been able to meet demand by constructing fewer natural gas combined-cycle power plants. As a result, utilities consume less water from municipal sources and require less access to land near high voltage transmission lines to produce the same amount of power.[27] Furthermore, higher utilization of existing natural gas

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15 Ibid. Page 138.

16 Ibid. Page 138.

17 Meherwan P. Boyce. "Handbook For Cogeneration And Combined Cycle Power Plants". New York: ASME Press, 2002. Page 452.

18 Rolf Kehlhofer, Rolf Bachmann, Henrik Nielson, and Judy Warner. "Combined-Cycle Gas & Steam Turbine Power Plants, 2nd Edition" Tusla: PennWell Books, 1999. Page 16.

19 Ibid.

20 Ibid.

21 Meherwan P. Boyce. "Handbook For Cogeneration And Combined Cycle Power Plants". New York: ASME Press, 2002. Page 452.

22 Energy Information Administration. "Natural Gas Prices". Available at <http://tonto.eia.doe.gov/dnav/ng/ng_pri_sum_a_EPG0_PEU_DMcf_a.htm>.

23 DOE/NETL-2008/1320. "Natural Gas and Electricity Costs and Impacts on Industry". National Energy Technology Laboratory. April 28, 2008. Available at <http://www.netl.doe.gov/energy-analyses/pubs/NatGasPowerIndWhitepaper.pdf>. Page 10.

24 Energy Information Administration. "Average Operating Expenses for Major U.S. Investor-Owned Electric Utilities". Available at <http://www.eia.doe.gov/cneaf/electricity/epa/epat8p2.html#_ftn2>.

25 Ibid.

26 DOE/NETL-2008/1320. "Natural Gas and Electricity Costs and Impacts on Industry". National Energy Technology Laboratory. April 28, 2008. Available at <http://www.netl.doe.gov/energy-analyses/pubs/NatGasPowerIndWhitepaper.pdf>. Page 11.

27 Northwest Power Planning Council. "Natural Gas Combined-Cycle Turbine Power Plants". Western Governors'

combined-cycle units has the potential to displace up to a third of the nation's coal kilowatt-hours.[28] By relying on natural gas as a fuel source, combined-cycle power plants release 43% less carbon dioxide, 82% less carbon monoxide, 90% less nitrogen oxides, 99.99% less sulfur dioxides, 99.7% less particulate matter, and close to 100 percent less mercury per billion BTU when compared with coal.[29] As a result, natural gas power plants benefit the environment by reducing coal's negative foothold in the electric industry.

Concerns have arose over high levels of methane present in natural gas. Methane's ability to trap heat is significantly greater than that of carbon dioxide, and thus poses a threat to global warming. However, a major study conducted by the Environmental Protection Agency and the Gas Research Institute concluded that the reduction in carbon dioxide offset a potential increase in methane into the atmosphere as a result of natural gas combustion.[30] Natural gas's gas property enables it to mix well with oxygen in the air, providing for a more complete combustion process. As a result, the chances for high methane emissions from natural gas combustion are low.

Pollution from natural gas power plants can be eliminated using existing technologies found in modern coal power plants. Water injection and selective catalytic reduction are used to remove 78 percent of NOx emissions from flue gas.[31] Natural gas combined-cycle power plants can also incorporate carbon capture technology through the use of chemical absorption by amine solutions to reduce CO2 output by 90%.[32] However, carbon capture technologies for combined cycle natural gas power plants require expensive hardware and increase operating cost as well as the fuel costs due to the reduced operating efficiency.[33] Carbon capture technology is not considered to be a cost effective solution for dealing with natural gas's low CO2 emissions.[34] The same logic also applies for controlling SO2 emissions from natural gas power plants. The low levels of SO2 from the combustion of natural gas has significantly reduced the generation of sludge and eliminated the need for scrubbers in the flue stack.[35]

Association. August 8, 2002. Available at <http://www.westgov.org/wieb/electric/Transmission%20Protocol/SSG-WI/pnw_5pp_02.pdf>.

28 DOE/NETL-2008/1320. “Natural Gas and Electricity Costs and Impacts on Industry”. National Energy Technology Laboratory. April 28, 2008. Available at <http://www.netl.doe.gov/energy-analyses/pubs/NatGasPowerIndWhitepaper.pdf>. Page 6.

29 Natural Gas Supply Association. “Natural Gas and the Environment”. Available at <http://www.naturalgas.org/environment/naturalgas.asp>.

30 Ibid.

31 Pamela L. Spath and Margaret K. Mann. “Life Cycle Assessment of a Natural Gas Combined-Cycle Power Generation System”. National Renewable Energy Laboratory. September 2000. Available at <http://www.nrel.gov/docs/fy00osti/27715.pdf>.

32 Olav Bolland and Henriette Undrum. “A novel methodology for comparing CO2 capture options for natural gas-fired combined cycle plants”. Advances in Environmental Research. Volume 7, Issue 4. June 2003. Available at <http://www.sciencedirect.com/science/article/B6W75-46X2K64-1/2/65829d8cd00a8b2f61c2f3b88d5cc90b>.

33 Ibid.

34 Ibid.

35 Natural Gas Supply Association. “Natural Gas and the Environment”. Available at <http://www.naturalgas.org/environment/naturalgas.asp>.

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12. Natural Gas Supply Association. “Natural Gas and the Environment”. Available at <http://www.naturalgas.org/environment/naturalgas.asp>.
13. Northwest Power Planning Council. “Natural Gas Combined-Cycle Turbine Power Plants”. Western Governors' Association. August 8, 2002. Available at <http://www.westgov.org/wieb/electric/Transmission%20Protocol/SSG-WI/pnw_5pp_02.pdf>.
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15. U.S. Department of Energy. “Electric Power”. Available at <http://www.energy.gov/energysources/electricpower.htm>.
16. U.S. Department of Energy. “Turbines of Tomorrow. Available at

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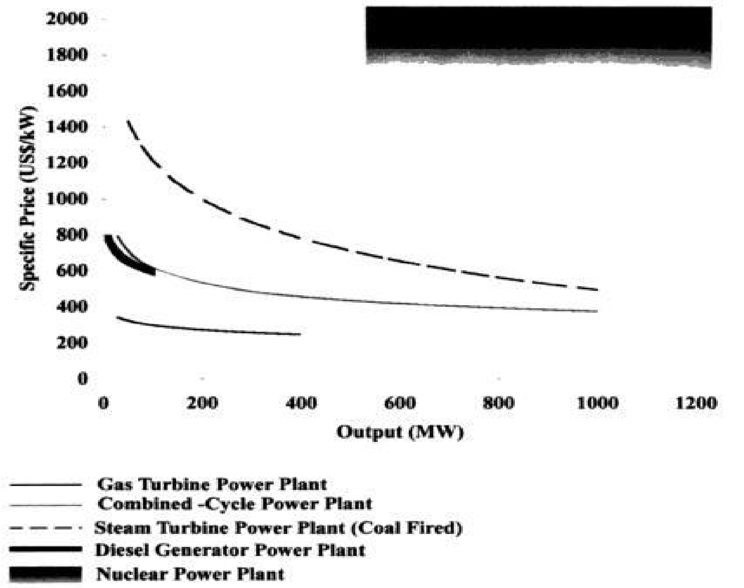


Figure 2-2 Comparison of Different Turnkey Power Plants in Terms of Specific Price and Output

The cost for various power plants given their potential output

Kehlhofer, Rolf, Bachmann, Rolf, Nielson, Henrik, and Warner, Judy. "Combined-Cycle Gas & Steam Turbine Power Plants, 2nd Edition" Tusla: PennWell Books, 1999.

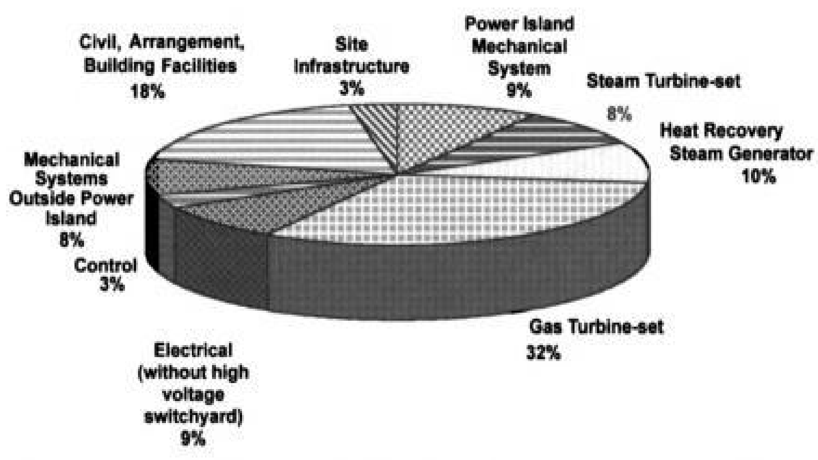


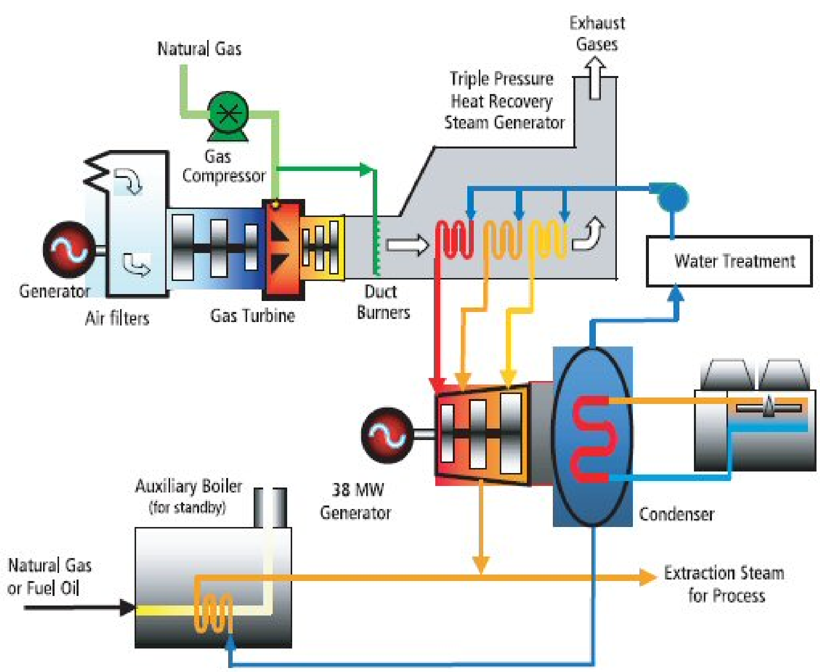
Figure 2-3 The Cost Percentage of the Different Plant Areas for a Typical 400 MW Turnkey Combined Cycle Plant

Kehlhofer, Rolf, Bachmann, Rolf, Nielson, Henrik, and Warner, Judy. "Combined-Cycle Gas & Steam Turbine Power Plants, 2nd Edition" Tusla: PennWell Books, 1999.

Table 8.2. Average Power Plant Operating Expenses for Major U.S. Investor-Owned Electric Utilities, 1995 through 2006
(Mills per Kilowatthour)

Plant Type	2006	2005	2004	2003	2002	2001	2000	1999	1998	1997	1996	1995
Operation												
Nuclear	8.93	8.39	8.3	8.86	8.54	8.3	8.41	8.93	9.98	11.02	9.47	9.43
Fossil Steam	3.23	2.97	2.68	2.5	2.54	2.4	2.31	2.21	2.17	2.22	2.25	2.38
Hydroelectric[1]	5.11	5.26	5.05	4.5	5.07	5.79	4.74	4.17	3.85	3.29	3.87	3.69
Gas Turbine and Small Scale[2]	3	2.97	2.73	2.76	2.72	3.15	4.57	5.16	3.85	4.43	5.08	3.57
Maintenance												
Nuclear	5.68	5.23	5.38	5.23	5.04	5.01	4.93	5.13	5.79	6.9	5.68	5.21
Fossil Steam	3.19	2.96	2.96	2.73	2.68	2.61	2.45	2.38	2.41	2.43	2.49	2.65
Hydroelectric[1]	3.44	3.6	3.64	3.01	3.58	3.97	2.99	2.6	2	2.49	2.08	2.19
Gas Turbine and Small Scale[2]	2.29	2.15	2.16	2.26	2.38	3.33	3.5	4.8	3.43	3.43	4.98	4.28
Fuel												
Nuclear	4.85	4.54	4.58	4.6	4.6	4.67	4.95	5.17	5.39	5.42	5.5	5.75
Fossil Steam	23.17	21.77	18.21	17.35	16.11	18.13	17.69	15.62	15.94	16.8	16.51	16.07
Hydroelectric[1]	–	–	–	–	–	–	–	–	–	–	–	–
Gas Turbine and Small Scale[2]	52.46	53.73	45.2	43.91	31.82	43.56	39.19	28.72	23.02	24.94	30.58	20.83
Total												
Nuclear	19.46	18.16	18.26	18.69	18.18	17.98	18.28	19.23	21.16	23.33	20.65	20.39
Fossil Steam	29.59	27.69	23.85	22.59	21.32	23.14	22.44	20.22	20.52	21.45	21.25	21.11
Hydroelectric[1]	8.54	8.86	8.69	7.51	8.65	9.76	7.73	6.77	5.86	5.78	5.95	5.89
Gas Turbine and Small Scale[2]	57.75	58.85	50.1	48.93	36.93	50.04	47.26	38.68	30.3	32.8	40.64	28.67

Energy Information Administration. "Average Operating Expenses for Major U.S. Investor-Owned Electric Utilities". Available at <http://www.eia.doe.gov/cneaf/electricity/epa/epat8p2.html#_ftn2>.



A diagram of a combined cycle and cogeneration plant that can sell off steam.

Epcor. "Castleton Power Plant: New York". Available at <http://www.epcorpowerlp.ca/operations/usa/castleton.asp>.