Cogeneration/Combined Heat and Power (CHP)

Quick Facts

- Cogeneration, also known as combined heat and power (CHP), refers to a group of proven technologies that operate together for the concurrent generation of electricity and useful heat in a process that is generally much more energy-efficient than the separate generation of electricity and useful heat.
- The typical method of separate centralized electricity generation and on-site heat generation has a combined efficiency of about 45 percent whereas cogeneration systems can reach efficiency levels of 80 percent.
- In the United States, cogeneration has a long history in the industrial sector. Globally, industry sites in the chemicals, metal, oil refining, pulp and paper, and food processing sectors represent more than 80 percent of total global electric CHP capacity.
- Cogeneration is widely deployed outside the United States, with Denmark, the Netherlands, and Finland leading the world in cogeneration deployment as a fraction of total national electricity generation.
- In 2008, cogeneration accounted for 9 percent of total U.S. electricity generating capacity. A recent study by the Oak Ridge National Laboratory calculated that increasing that share to 20 percent by 2030 would lower U.S. greenhouse gas emissions by 600 million metric tons of CO_2 (equivalent to taking 109 million cars off the road) compared to “business as usual.”

Background

Cogeneration is a system of commercially available technologies that decrease total fuel consumption and related GHG emissions by generating both electricity and useful heat from the same fuel input. Cogeneration is often called combined heat and power (CHP), since most cogeneration systems are used to supply electricity and useful heat. However, the heat energy from electricity production can also be used for cooling and other non-heating purposes, so the term “cogeneration” is more inclusive. Cogeneration is a form of local or distributed generation as heat and power production take place at or near the point of consumption. For the same output of useful energy, cogeneration uses far less fuel than does traditional separate heat and power production, which means lower greenhouse gas (GHG) emissions as fossil fuel use is reduced.

While this document focuses on the GHG emission reductions, cogeneration offers other benefits that include:

- Reducing other air pollutants (e.g., SO_2, NO_X, Hg)
- Providing on-site electricity generation that is resilient in the face of grid outages thus providing power for critical services in emergencies and avoiding economic losses
- Avoiding or deferring investments in new electricity transmission and distribution infrastructure and relieving congestion constraints on existing infrastructure.

- Using existing industrial and commercial sites for incremental power generation rather than building new power plant capacity at greenfield sites

The largest potential for increased utilization of cogeneration is in the industrial sector. In the United States, the industrial sector is responsible for approximately one third of the country's total energy consumption.[1] The industrial sector's direct GHG emissions account for 20 percent of the U.S. total, and an additional 9 percent of U.S. GHG emissions come from centrally generated electricity consumed in the industrial sector.[2] Direct industrial emissions come from on-site combustion of fossil fuels and from non-energy related process emissions.

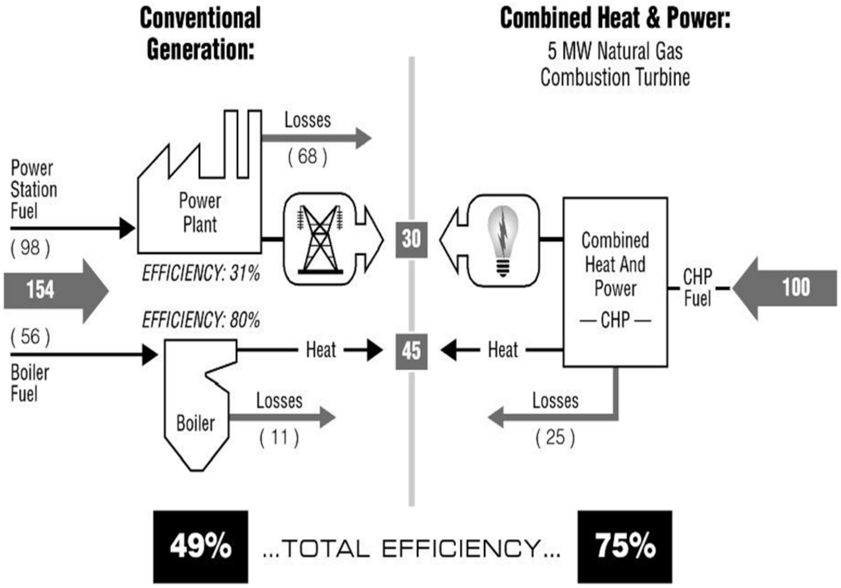
While the greatest potential for increasing cogeneration is in the industrial sector, the technology is also increasingly available for smaller-scale applications in residential and commercial facilities. Cogeneration systems appeal to business operations requiring a continuous supply of reliable power such as data centers, hospitals, universities, and industrial operations. District heating and cooling (DHC) in cities and large institutions is one established use of cogeneration (and one widely employed in Europe) in the residential and commercial sectors. District heating can meet low and medium temperature heat demands, such as space heating and hot tap water preparation, by using waste heat from electricity generation to heat water that is transported through insulated pipes. District cooling takes advantage of natural cooling from deep water resources as well as the use of waste heat to cool water via absorption chillers. About 85 urban utilities and 330 campuses in the United States use district energy to reduce costs and GHG emissions, increase efficiency, and improve reliability.[3]

Description

Separate heat and power (SHP) refers to the widespread practice of centrally generating electricity at large-scale power plants and separately generating useful heat onsite for applications such as industrial processes or space and water heating. SHP leads to energy losses in both processes. In the United States, conventional coal and natural gas power plants are, on average, 33 and 41 percent efficient, respectively, in converting the energy in their fuel into electricity; although, the efficiency rates vary by technology with new natural gas combined cycle plants capable of greater than 50 percent efficiency.[4] Typical SHP has a combined efficiency of about 45 percent while cogeneration systems that combine the power and heat generation processes can be up to 80 percent efficient.[5] Because cogeneration takes place on-site or close to the facility it also results in less energy lost during the transmission and distribution process (usually about 9 percent of net electricity generation).[6]

Figure 1 provides a helpful comparison of illustrative CHP and SHP systems and shows the energy inputs each would require to ultimately produce the same amount of useful energy.

Figure 1: CHP versus Separate Heat and Power (SHP) Production



Source: U.S. EPA: Combined Heat and Power Partnership, "Efficiency Benefits."
Note: This figure shows an example where cogeneration uses only 100 units of fuel to produce an amount of electricity and useful heat that would require 154 units of fuel via separate heat and power production.

Cogeneration systems can be powered by a variety of fuels, including natural gas, coal, oil, and alternative fuels such as biomass. In recent years, natural gas has been the predominant fuel for CHP systems, but biomass and "opportunity fuels" (i.e., wastes or by-products from industrial processes, agriculture, or commercial activities) are expected to gain a larger share with growing environmental and energy security concerns.[7,8] Some cogeneration technologies can operate with multiple fuel types, making the system less vulnerable to fuel availability and volatile commodity prices.

Cogeneration is appropriate in situations where a facility has a continuous demand for heating or cooling as well as demand for electrical or mechanical power. Cogeneration systems can provide electricity or mechanical power (e.g., for driving rotating equipment like compressors, pumps, and fans) and heat energy that can be used for: steam or hot water; process heating, cooling and refrigeration; and dehumidification.[9]

Cogeneration Process

There are two types of cogeneration—"topping cycle" and "bottoming cycle." The most common type of cogeneration is the "topping cycle" where fuel is first used to generate electricity or mechanical energy at the facility and a portion of the waste heat from power generation is then used to provide useful thermal energy. The less common "bottoming cycle" type of cogeneration systems first produce useful heat for a manufacturing process via fuel combustion or another heat-generating chemical reaction and recover some portion of the exhaust heat to generate electricity. "Bottoming-cycle" CHP applications are most common in process industries, such as glass and steel, that use very high temperature furnaces that would otherwise vent waste heat to the environment. The following description of cogeneration systems focus on "topping cycle" applications.

Each cogeneration system is adapted to meet the needs of an individual building or facility. System design is modified based on the location, size, and energy requirements of the site. Cogeneration is not limited to any specific type of facility but is generally used in operations with sustained heating requirements. Most CHP systems are designed to meet the heat demand of the energy user since this leads to the most efficient systems. Larger facilities generally use customized systems, while smaller-scale applications can use prepackaged units.

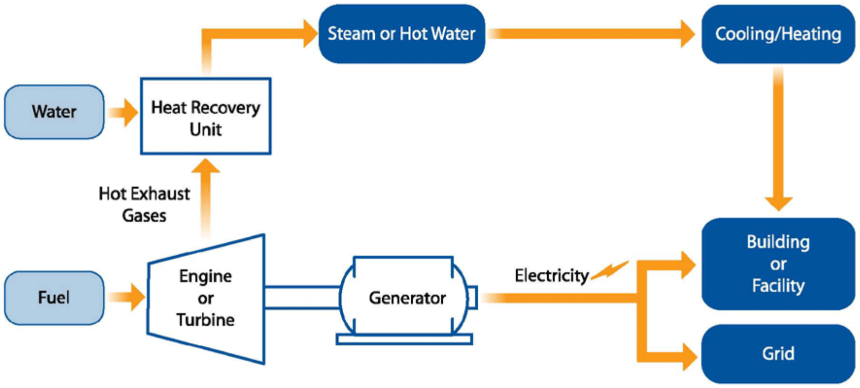
Cogeneration systems are categorized according to their prime movers (the heat engines), though the systems also include generators, heat recovery, and electrical interconnection components. The prime mover consumes (via combustion, except in the case of fuel cells discussed below) fuel (such as coal, natural gas, or biomass) to power a generator to produce electricity, or to drive rotating equipment. Prime movers also produce thermal energy that can be captured and used for other on-site processes such as generating steam or hot water, heating air for drying, or chilling water for cooling. There are currently five primary, commercially available prime movers: gas turbines, steam turbines, reciprocating engines, microturbines, and fuel cells.

Steam turbines and gas, or combustion, turbines are the prime movers (heat engines) best suited for industrial processes due to their large capacity and ability to produce the medium- to high-temperature steam typically needed in industrial processes.[10]

Gas Turbines

Gas turbines typically have capacities between 500 kilowatts (kW) and 250 megawatts (MW), can be used for high-grade heat applications, and are highly reliable.[11] Gas turbines operate similarly to jet engines—natural gas is combusted and used to turn the turbine blades and spin an electrical generator. The cogeneration system then uses a heat recovery system to capture the heat from the gas turbine's exhaust stream. This exhaust heat can be used for heating (e.g., for generating steam for industrial processes) or cooling (generating chilled water through an absorption chiller). About half of the CHP capacity in the United States consists of large combined cycle systems that include two electricity generation steps (the combustion turbine and a steam turbine powered by heat recovered from the gas turbine exhaust) that supply steam to large industrial or commercial users and maximize power production for sale to the grid. Figure 2 shows how a simple-cycle gas turbine cogeneration system recovers heat from the gas turbine's hot exhaust gases to produce useful thermal energy for the site.

Figure 2: Gas Turbine or Engine with Heat Recovery Unit

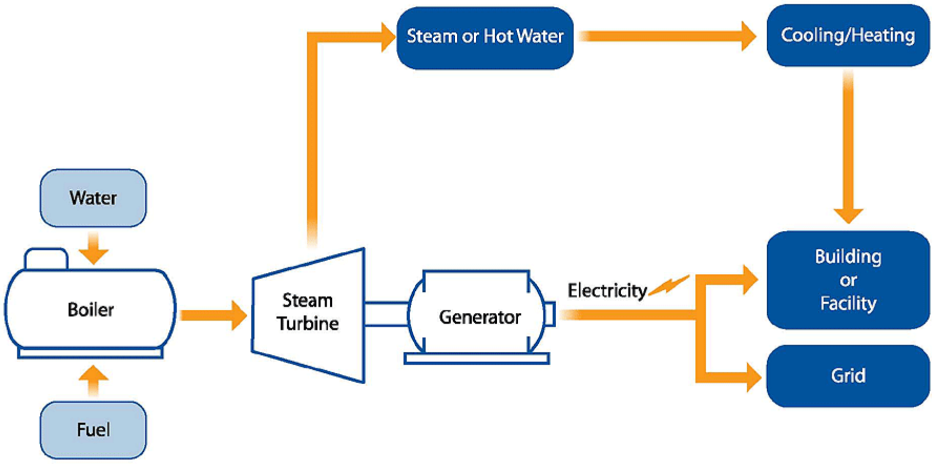


Source: U.S. EPA – Combined Heat and Power Partnership: Basic Information.
Note: Figure 2 shows a gas turbine cogeneration system, with the heat recovery unit capturing exhaust heat from the turbine, and converting that to thermal energy for other uses.

Steam Turbines

Steam turbines systems can use a variety of fuels, including natural gas, solid waste, coal, wood, wood waste, and agricultural by-products. Steam turbines are highly reliable and can meet multiple heat grade requirements. Steam turbines typically have capacities between 50 kW and 250 MW and work by combusting fuel in a boiler to heat water and create high-pressure steam, which turns a turbine to generate electricity.[12] The low-pressure steam that subsequently exits the steam turbine can then be used to provide useful thermal energy, as shown in Figure 3. Ideal applications of steam turbine-based cogeneration systems include medium- and large-scale industrial or institutional facilities with high thermal loads and where solid or waste fuels are readily available for boiler use.

Figure 3: Steam Boiler with Steam Turbine



Source: US EPA – Combined Heat and Power Partnership: Basic Information.
Note: Figure 3 shows how a cogeneration system that is primarily heat based, can also be used to generate electricity.

Reciprocating Engines

In terms of the number of units, reciprocating internal combustion engines are the most widespread technology for power generation, found in the form of small, portable generators as well as large industrial engines that power generators of several megawatts; however, because of their small size, reciprocating engines account for only a small share (about 2 percent) of total U.S CHP capacity.[13] Spark ignition (SI) engines are the most common types of reciprocating engines used for CHP in the United States. SI engines (available in capacities up to 5 MW) are similar to gasoline-powered automobile engines, but they generally run on natural gas, though they can also run on propane or landfill and biogas.

Reciprocating engines start quickly, follow load well, have good efficiencies even when operating at partial load, and generally have high reliabilities.[14] Reciprocating engines are well suited for CHP in commercial and light industrial applications of less than 5 MW. Smaller engine systems produce hot water. Larger systems can be designed to produce low-pressure steam. Multiple reciprocating engines can be used to increase system capacity and enhance overall reliability.

Microturbines

Microturbines are small, compact, lightweight combustion turbines that typically have power outputs of 30 to 300 kW. A heat exchanger recovers thermal energy from the microturbine exhaust to produce hot water or low-pressure steam. The thermal energy from the heat recovery system can be used for potable water heating, absorption cooling, dessicant dehumidification, space heating, process heating, and other building uses. Microturbines can burn a variety of fuels including natural gas and liquid fuels.

Fuel Cells

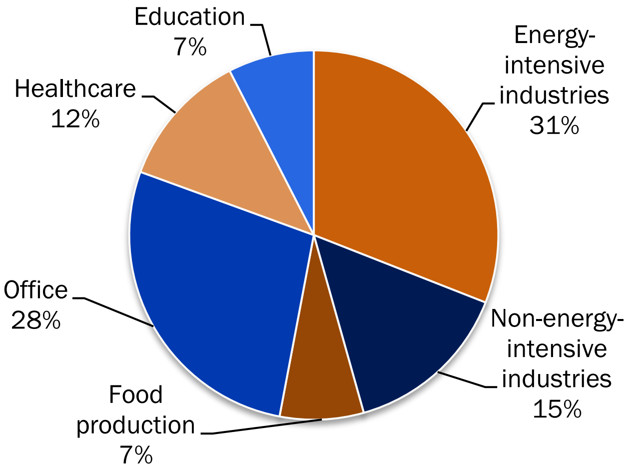
Fuel cells are an emerging technology with the potential to serve power and thermal needs with very low emissions and with high electrical efficiency. Fuel cells use an electrochemical or battery-like process to convert the chemical energy of hydrogen into water and electricity. The hydrogen can be obtained from processing natural gas, coal, methanol, and other hydrocarbon fuels. As a less mature technology, fuel cells have high capital costs, an immature support infrastructure, and technical risk for early adopters. However, the advantages of fuel cells include low emissions and low noise, high power efficiency over a range of load factors, and modular design. A variety of fuel cell technologies are under development, with some targeted for small commercial markets, and other technologies focused on larger, industrial CHP applications.

Environmental Benefit / Emission Reduction Potential

Cogeneration offers multiple environmental benefits. Since less fuel is burned per unit of useful energy output, cogeneration reduces GHG emissions and decreases air pollution compared to SHP systems. Currently installed cogeneration systems avoid the equivalent of 1.8 percent of annual U.S. energy consumption and annual CO_2 emissions of 248 million metric tons (equal to 3.5 percent of total U.S. GHG emissions in 2007).[15,16] A recent study by the Oak Ridge National Laboratory (ORNL) calculated that increasing cogeneration's share of total U.S. electricity generation capacity to 20 percent by 2030 (which ORNL estimated would require deploying 156 GW of new cogeneration capacity compared to about 85 GW today) would lower U.S. GHG emissions by 600 million metric tons of CO_2 (equivalent to taking 109 million cars off the road) compared to "business as usual."[17]

While the ORNL analyzed an ambitious goal for expanding cogeneration by 2030, a 2009 study by McKinsey & Company sought to estimate the cost-effective potential for expanding cogeneration by 2020 (i.e., the potential to make NPV-positive investments in cogeneration).[18] McKinsey estimated that the potential exists in the United States for an additional 50.4 GW of cogeneration capacity by 2020, which would avoid an estimated 100 million metric tons of CO_2 per year compared to "business as usual." McKinsey found that the cost-effective incremental cogeneration capacity consisted primarily (70 percent) of large-scale (greater than 50 MW) industrial cogeneration systems. Figure 4 shows McKinsey's estimates of the composition of cost-effective cogeneration potential for 2020.

Figure 4: McKinsey's Estimates of Cost-Effective Cogeneration Potential for 2020 by Sector[19]



Cost

Cogeneration systems are major investments. For example, the capital cost of a 50 MW gas turbine cogeneration system might be on the order of $45 million, and such a cogeneration system might take 6-18 months to construct.[20] A 1 MW reciprocating engine cogeneration system (e.g., for a hospital) might have a capital cost of roughly $1.6 million.[21] The cost of a cogeneration system depends on the level of complexity of features beyond the basic prime mover – such as the heat recovery or emissions monitoring systems (as well as location, labor, and the financial carrying costs during construction). Generally, with the same fuel and configuration, costs for cogeneration systems per kilowatt of capacity decrease as size increases. Given the efficiency gains from cogeneration, some analysts estimate that GHG emission reductions can be achieved at a "negative cost" via cogeneration in many instances since cost savings from reduced expenditures on fuel (due to the higher efficiency of cogeneration compared to separate heat and power generation) will outweigh the capital and other costs of cogeneration projects.[22]

Current Status of Cogeneration

Cogeneration currently accounts for roughly 12 percent of total U.S. electricity generation and comprises about 9 percent (85 gigawatts at about 3,300 sites) of total generating capacity.[23] Figures 5-8 show how existing cogeneration capacity is distributed across different applications, system technology types, and fuel inputs. Only about 12 percent of existing cogeneration capacity is deployed at commercial or institutional facilities (as opposed to industrial or manufacturing facilities). Nearly three quarters of cogeneration capacity uses natural gas for fuel, and gas-fired combustion turbines and combined cycle systems dominate cogeneration capacity even though nearly half of all cogeneration sites use reciprocating engines (the reciprocating engines are much smaller in terms of capacity than the other systems). Large cogeneration systems (100 megawatts or more in capacity) account for roughly 65 percent of total cogeneration capacity.[24]

Figure 5: Existing Cogeneration Capacity by Application[25]

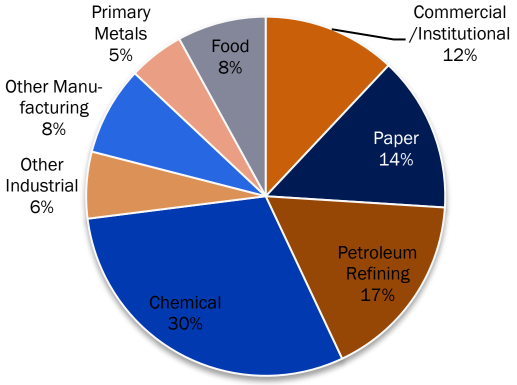


Figure 6: Existing Cogeneration Sites by System Type[26]

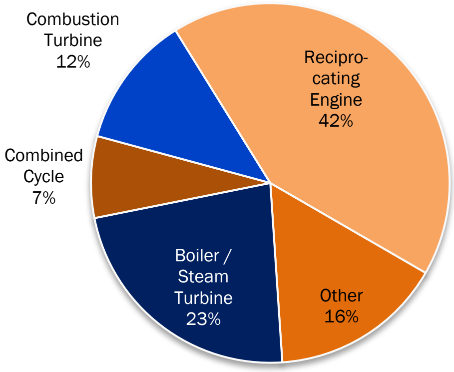


Figure 7: Existing Cogeneration Capacity by System Type[27]

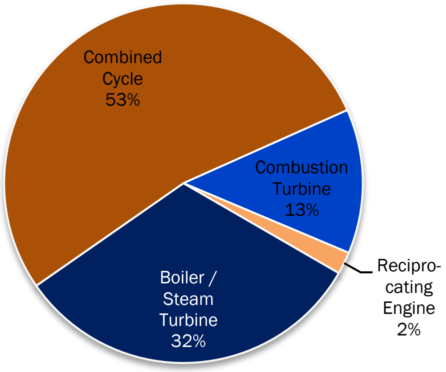
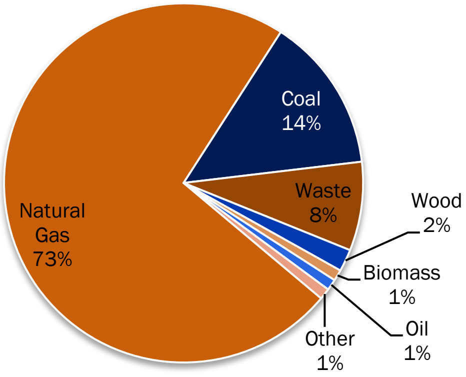


Figure 8: Existing Cogeneration Capacity by Fuel Type[28]



Current U.S. cogeneration capacity is largely concentrated in states with large industrial heat consumption (see Table 1), such as for petrochemical and petroleum refining operations. Texas alone has one fifth of the total U.S. cogeneration installed capacity, and the top five states in terms of installed capacity account for half of the U.S. total.[29] State air pollution regulations that use output-based standards and state-level incentives for cogeneration also promote cogeneration in certain states.

Cogeneration projects multiplied in the United States following the passage of the Public Utilities Regulatory Policies Act (PURPA) in 1978. PURPA required utilities to interconnect with and purchase electricity from "qualified facilities" like cogeneration systems thus giving industrial and institutional users access to the grid and the ability to sell back excess electricity. Shortly after enactment of PURPA, Congress also created federal tax credits for CHP investments. Following the enactment of PURPA and the CHP tax credits, cogeneration grew dramatically with capacity increasing more than three-fold in two decades (from about 20 gigawatts in 1978).[30] 2006 through 2009 saw much lower levels of cogeneration deployment than historical growth rates owing in part to higher natural gas prices and economic uncertainty.[31] One factor affecting the growth of CHP was the change to PURPA regulations that resulted from the Energy Policy Act of 2005. As instructed by the act, the Federal Energy Regulatory Commission (FERC) issued new rules that no longer required utilities to buy electricity from larger "qualified facilities" when those facilities have access to competitive electricity markets, and FERC issued rules to ensure that new CHP "qualified facilities" were not mainly electricity-generating facilities taking advantage of the incentives offered to CHP facilities (so-called "PURPA machines").[32]

Table 1: Cogeneration Installed Capacity by State, 200633

Rank	State	Total Capacity (MW)	% of U.S. Total
1	TX	17,240	20%
2	CA	9,220	11%
3	LA	6,959	8%
4	NY	5,789	7%
5	FL	3,545	4%
6	NJ	3,493	4%
7	AL	3,362	4%
8	PA	3,242	4%
9	MI	3,104	4%
10	OR	2,523	3%
Rest of U.S.		26,523	31%

Recent federal legislation, including the Energy Improvement and Extension Act of2008 (EIEA) and the American Recovery and Reinvestment Act of 2009 (ARRA), encourages wider deployment of cogeneration with tax incentives for cogeneration projects (the CHP investment tax credit and accelerated depreciation) and substantial funding for select CHP projects.[34]

Globally, cogeneration is in widespread use, especially in the European Union (EU). Five EU countries rely on cogeneration for between 30 to 50 percent of their total power generation, and cogeneration has contributed to 57 million metric tons of CO_2e, or 15 percent, of Europe's overall GHG emission reductions from 1990 to 2005.[35,36] Globally, industry sites in the chemicals, metal, oil refining, pulp and paper, and food processing sectors represent more than 80 percent of total global CHP capacity.[37] Cogeneration currently accounts for approximately 13 and 5 percent of total electricity generation capacity in China and India, respectively.[38] The International Energy Agency (IEA) projects that by 2030, Chinese and Indian cogeneration penetration could rise to 28 and 26 percent, respectively, with adequate policy and market incentives.[39] In China, cogeneration has significant growth potential given the country's large industrial base. IEA projected that under aggressive international efforts to reduce GHG emissions, global industrial cogeneration could quadruple from 2005 to 2050 as compared to merely doubling under "business as usual."[40]

Obstacles to Further Development or Deployment of Cogeneration

- Capital Constraints

  Cogeneration systems are large capital investments. Firms may be unwilling to undertake such significant capital investments even when they may offer positive returns. Another cost consideration for firms is business uncertainty. If a firm is not confident that it will continue operations for many years at a given facility, it may not invest in the high upfront costs of cogeneration since a project's economic viability can depend on cost savings realized over several years. In addition, there can be costs associated with manufacturing downtime and siting and permitting issues. Also, seamless integration of components beyond the basic equipment can necessitate specialized parts and increase the cost of a cogeneration system.[41]

- Utility Business Practices

  Many cogeneration systems maintain their connection to the utility grid for supplemental power needs beyond their self generation capacity and/or for standby and back-up service during routine maintenance or unplanned outages. Utility charges for these services (standby rates) can significantly reduce the money-saving potential of cogeneration.[42] However, cogeneration and other types of distributed energy allow the grid to function more efficiently by reducing baseload and peak demand, as well as reducing the need for transmission and distribution upgrades and construction. Pricing arrangements between utilities and cogeneration system operators that fairly account for utilities' obligation to supply backup power as well as the benefits to the grid of cogeneration (e.g., avoided costs of building new generation and transmission capacity) can encourage cogeneration investments.

- Utility Interconnection

  The economic viability of cogeneration systems depends on their ability to safely, reliably, and economically interconnect with the existing grid. Interconnection standards, including technical specifications as well as application processes and fees, between utilities and cogeneration systems are often state mandated and vary regionally. This lack of uniformity makes it difficult for manufacturers of cogeneration technologies to produce modular components and can make cogeneration system deployment more complicated and expensive. Improved interconnection policies could increase deployment of cogeneration systems.[43,44]

- Environmental Permitting Regulations

  By generating both electricity and heat onsite, cogeneration can increase a facility's onsite air emissions even as it reduces total emissions associated with the facilities heat and electricity consumption. Current environmental permitting regulations do not always recognize this overall emissions reduction benefit. For example, the Clean Air Act's New Source Review (NSR) requires large, stationary sources to install best available pollution control equipment during construction or major modifications that increase onsite emissions. In some circumstances NSR requirements can discourage installation of CHP systems even when they would improve environmental outcomes.[45] The adoption of output-based emission standards, which allows cogeneration systems to benefit from their increased efficiency, is one way to encourage more cogeneration systems.

- Need for Further Research, Development, and Demonstration (RD&D)

  To improve the performance of cogeneration technologies and reduce investment costs, further RD&D is warranted, specifically in the areas of: high-temperature CHP, small-scale systems (e.g., improving the efficiency of micro-turbines and their cost through improved manufacturing techniques), fuel cell research, heat & cold storage system optimization and integration, and medium-scale systems (e.g., increased demonstration of medium-scale turbines in various industrial settings).[46]

Policy Options to Help Promote Cogeneration

- Price on Carbon

  Policies that set a price on GHG emissions, such as a GHG cap-and-trade program (see Climate Change 101: Cap and Trade), can encourage investment in energy-efficient technology such as cogeneration. Carbon pricing policies (e.g., cap and trade allowance allocation) can be designed so as not to create disincentives for cogeneration.[47]

- Renewable Portfolio and Energy Efficiency Resource Standards

  Renewable Portfolio Standards and Energy Efficiency Standards require that energy providers meet a specific portion of their electricity demand through renewable energy and/or energy efficiency measures. Such policies specify eligible energy sources and technologies that count towards the requirements. More than a dozen states allow cogeneration to count toward renewable/alternative energy and efficiency standards.48

- Financial Incentives for Cogeneration

  Certain states already offer investment tax credits (ITC), which are a form of subsidy to help offset the upfront capital cost of investments, for cogeneration, and the federal government also offers a 10 percent ITC for cogeneration (enacted in 2008) and accelerated depreciation.49 Some states offer production incentives, which provide a financial benefit based upon the annual useful energy output of the cogeneration system.

- Interconnection Standards

  Coordination among state and federal regulators, utilizes, and stakeholder groups regarding best practices in cogeneration interconnection with the electric grid can help ensure cogeneration interconnection contributes to a safe and reliable grid and minimize the cost and complexity facing cogeneration technology providers and users designing and deploying systems for interconnection.

- Environmental Permitting

Cogeneration is more readily deployed when environmental regulations do not penalize cogeneration systems that increase onsite air emissions (by using more fuel onsite to generate both electricity and heat) while also decreasing net air emissions by having higher efficiency (and thus less total fuel use) than separate heat and power generation.50

- **Research, Development, and Demonstration (RD&D)**
  Continued and increased funding for programs such as the Department of Energy's Industrial Technologies Program (ITP)51 would support RD&D for cogeneration technologies to improve reliability and efficiency and reduce costs. ITP's public-private partnerships help future deployment of both integrated energy systems and component technologies (for upgrading and retrofits).
- **Technical Assistance for Potential Cogeneration Users**
  Many companies (especially small and medium-sized businesses) that would benefit from cogeneration systems are not aware of their financial or technical options. Expanding programs that work with companies such as the U.S. Environmental Protection Agency's Combined Heat and Power Partnership,52 the National Institute of Standards Manufacturing Extension Partnership,53 and DOE's Industrial Assessment Centers and CHP Regional Application Centers54 would help further promote cogeneration.

Related Business Environmental Leadership Council (BELC) Company Activities

ABB

Air Products

Alstom

Baxter Healthcare

Cummins

Dow Chemical Company

GE

PG&E

Weyerhaeuser

Related Pew Center Resources

The U.S. Electric Power Sector and Climate Change Mitigation, 2005

Corporate Energy Efficiency Project

Further Reading / Additional Resources

American Council for an Energy Efficient Economy (ACEEE), "Combined Heat and Power (CHP)"

Gas Technology Institute (GTI)

Hedman, Bruce, ICF International, "CHP: The State of the Market," presentation to the U.S. EPA Combined Heat and Power Partnership 2009 Partners Meeting, 1 October 2009.

International Energy Agency, "Combined Heat and Power: Evaluating the Benefits of Greater Global Investment," 2008.

McKinsey & Company

- *Reducing U.S. Greenhouse Gas Emissions: How Much at What Cost?*, 2007
- *Unlocking Energy Efficiency in the U.S. Economy*, 2009

New York State Energy Research and Development Authority (NYSERDA), "Combined Heat and Power Program Guide."

Oak Ridge National Laboratory, *Combined Heat & Power: Effective Energy Solutions for a Sustainable Future*, 2008

U.S. Combined Heat and Power Association (USCHPA)

U.S. Department of Energy

- Case Studies Database
- Combined Heat and Power (CHP) Regional Application Centers (RACs)
- Industrial Distributed Energy

U.S. Environmental Protection Agency

- Catalog of CHP Technologies
- CHP Partnership Program

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[1] U.S. Energy Information Administration (EIA), Annual Energy Review 2009, Table 1.2a: Energy Consumption by Sector, Selected years 1949 – 2008.

[2] U.S. Environmental Protection Agency (EPA), *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2007*, Table ES-7, 2009.

[3] Environmental and Energy Study Institute, "The Role of District Energy/Combined Heat and Power in Energy and Climate Policy Solutions," 2009.

[4] EIA, *Electric Power Annual*, 2010, see Table 5.3 and Table 5.4. New natural gas combined cycle plant efficiency estimate comes from EIA's *Assumptions to the Annual Energy Outlook 2010* (see table 8.2).

[5] Oak Ridge National Laboratory (ORNL), Combined Heat & Power: Effective Energy Solutions for a Sustainable Future, 2008.

[6] IEA, "Combined Heat and Power: Evaluating the Benefits of Greater Global Investment," 2008.

[7] ORNL, 2008.

[8] For more information on "opportunity fuels," see Resource Dynamics Corporation, 2004, *Combined Heat and Power Market*

Potential for Opportunity Fuels, prepared for the Department of Energy.

[9] ORNL, 2008.

[10] EPA, "Catalog of CHP Technologies."

[11] EPA, "Catalog of CHP Technologies: Gas Turbines."

[12] EPA, "Catalog of CHP Technologies: Steam Turbines."

[13] ORNL, 2008.

[14] Part-load efficiency refers to the efficiency when equipment is running below its rated level of output.

[15] DOE, *Powering Progress in Combined Heat and Power (CHP)*.

[16] EPA, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2007*.

[17] DOE, *Powering Progress in Combined Heat and Power (CHP)*.

[18] McKinsey & Company, *Unlocking Energy Efficiency in the U.S. Economy*, 2009. NPV refers to net present value, which, for a cogeneration project in McKinsey's analysis, is the discounted value of future cost savings (e.g., from avoided electricity generation by utilities) net of incremental costs associated with cogeneration (e.g., up-front capital and installation costs, ongoing maintenance costs, and fuel costs).

[19] McKinsey & Company, *Unlocking Energy Efficiency in the U.S. Economy*, 2009.

[20] EPA, "Catalog of CHP Technologies: Gas Turbines," 2008, see Table 3.

[21] EPA, "Catalog of CHP Technologies: Reciprocating Engines," 2008, see Table 3.

[22] McKinsey & Company, *Reducing U.S. Greenhouse Gas Emissions: How Much at What Cost?*, 2007.

[23] ORNL, 2008.

[24] ORNL, 2008.

[25] ORNL, 2008.

[26] ORNL, 2008.

[27] ORNL, 2008.

[28] ORNL, 2008.

[29] ORNL, 2008.

[30] ORNL, 2008.

[31] Hedman, Bruce, ICF International, "CHP: The State of the Market," presentation to the U.S. EPA Combined Heat and Power Partnership 2009 Partners Meeting, 1 October 2009.

[32] Stoel Rives LLP, "Energy Law Alert: New FERC Order Weakens PURPA's QF 'Must Buy' Provisions," 23 October 2006.

[33] ORNL, 2008.

[34] EPA, "Federal Incentives for Developing Combined Heat and Power Projects."

[35] Denmark, Finland, Russia, Latvia, and the Netherlands, IEA, "Combined Heat and Power," 2008.

[36] IEA, "Combined Heat and Power: Evaluating the Benefits of Greater Global Investment," 2008.

[37] IEA, *Energy Technology Perspectives 2008: Scenarios & Strategies to 2050*, 2008.

[38] IEA, "Combined Heat and Power: Evaluating the Benefits of Greater Global Investment," 2008.

[39] IEA, Cogeneration and District Energy – Sustainable Energy Technologies for Today and Tomorrow

[40] IEA, *Energy Technology Perspectives 2008: Scenarios & Strategies to 2050*, 2008.

[41] The necessitated tailoring of cogeneration systems due to a lack of factory-integrated components requires extensive project engineering, which adds to the costs and increases risk of assimilation errors. Site-specific priorities determine the design-basis for sizing a CHP system. NYSERDA, "Public Policy Issues and Hurdles to Implementing CHP in NYS."

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[42] ACEEE, “Standby Rates.”

[43] California Energy Commission (CEC), “Exploring Feed-in Tariffs for California.”

[44] *The Economist*, “Building the Smart Grid,” 4 June 2009.

[45] ORNL, 2008.

[46] IEA, “Combined Heat and Power: Evaluating the Benefits of Greater Global Investment,” 2008.

[47] For example, investing in cogeneration will increase a facility’s direct GHG emissions even though it will reduce total emissions due to the improved efficiency of cogeneration. For a discussion of how to avoid creating disincentives for cogeneration under cap and trade, see Colvin, Michael, “Combined Heat and Power and Cap & Trade,” California Public Utilities Commission, presentation materials for ARB public meetings, 9 September 2009.

[48] For more information on such state policies, see the Pew Center’s “Renewable and Alternative Energy Portfolio Standards.”

[49] For more information on the federal ITC for cogeneration and relevant state incentives, see the Database of State Incentives for Renewables and Efficiency (DSIRE).

[50] For more information on this topic, see EPA’s *Output-Based Regulations: A Handbook for Air Regulators*, 2004.

[51] DOE, Industrial Technologies Program web site.

[52] EPA, Combined Heat and Power Partnership web site.

[53] Manufacturing Extension Partnership web site.

[54] See the CHP Regional Application Centers web site.