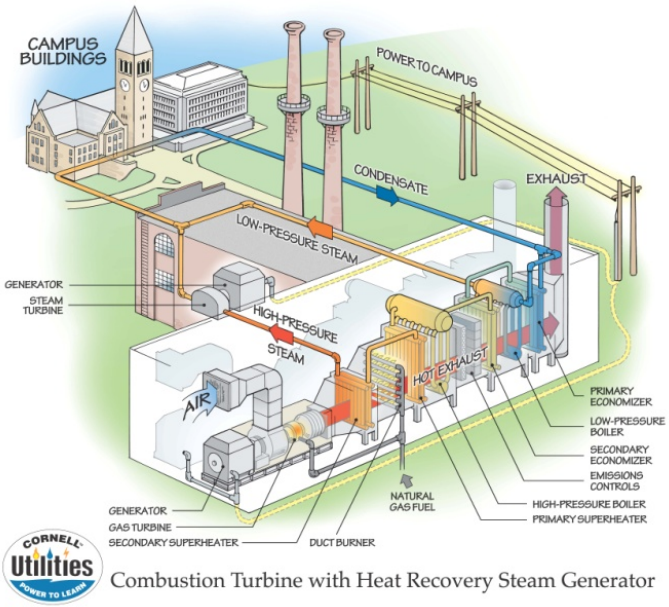
Project Summary:



Combustion Turbine with Heat Recovery Steam Generator

In 2009, Cornell University announced the release of the university's Climate Action Plan, which sets a goal of reducing the campus's net greenhouse gas emissions to zero by 2050. One of the biggest roadblocks to climate neutrality is coal. Over 40% of the United States electricity production comes from coal. Historically, Cornell University burned nearly 60,000 metric tons of coal for campus heating. Cornell's Beyond Coal Initiative was launched in 2010 in partnership with the Sierra Club. The key component in the success of this initiative is the new Combined Heat and Power Plant (CHPP), which came online in 2010. For fiscal year 2012, the plant achieved total operational efficiency of supplied heat and power to the campus of nearly 80%. Our "Beyond Coal" initiative was achieved during fiscal year 2011.
http://www.cornell.edu/video/the-end-of-coal-fuel-at-cornell
http://www.ibewhourpower.com/video/3V4wKMH7pG4

The results are **(1) an overall reduction in Central Energy Plant (CEP) greenhouse gas emissions of ~28% which equates to 55,000 metric tons/year (2) Kyoto Protocol commitments are exceeded, and (3) significant pollutant reductions are achieved by no longer combusting 60,000 metric tons per year of coal.** The easier and cheaper way would have been to install conventional natural gas boilers and continue buying most of our electricity from the grid. However, Cornell University decided that the $30 million premium (approx.) over standard practices was the right thing to do and demonstrates a real commitment to promoting sustainability by improving energy efficiency and reducing pollutants. The EPA has recently recognized this project for outstanding pollution reduction and energy efficiency qualities by presenting Cornell University with a 2011 ENERGY STAR CHP Award.

Table S.1 Emission Benefits – Central Energy Plant (metric tons)

Pollutant	Before Project	FY 2012 with CHPP	Reduction	% Reduction
CO_2	195,000	140,000	**55,000**	**28%**
NO_x	290	90	**200**	**68%**
SO_2	1,000	30	**970**	**97%**
PM	100	10	**90**	**90%**

Resulting from a rigorous energy master plan, the Cornell Combined Heat & Power Project (CCHPP) went into operation in December 2009. The $82 million CCHPP added two combustion turbine generators, totaling 30 Megawatts of electrical output with dual pressure heat recovery steam generators, totaling 300,000 lbs/hr of steam generation. This system produces ~70% of campus electrical power. This project included a major renewal of the plant electrical system and includes two 1,000 kW emergency diesel generators. A dedicated 3.2 mile high pressure natural gas pipe line was constructed to provide fuel.

The CCHPP was chosen over lower-cost solutions that would have had higher environmental impacts. Some specific innovative details of the project include the following:

- Dual-pressure boiler which allows 20% more heat recovery than a conventional heat recovery steam generator.
- Investing $4 million for the capability of using gas or a liquid fuel option for the combustion turbines. This investment allows the facility to be prepared for potential biofuel options as they mature.
- Energy-recovery cascading boiler blow-down system.
- Deepwater Lake Source Cooling for turbine inlet air cooling, which increases turbine performance.
- The LEED Gold CEP office building, built as part of the project, includes an evacuated tube solar thermal heating and hot water system with under slab seasonal thermal storage system to reduce space heating requirements.
- Smart-grid technology was applied to the electrical substation.
- Cornell built a dedicated high pressure gas line, which relieves congestion on the existing NYSEG gas delivery system.
- Low emission duct burner with select catalytic reduction for NO_x reduction and separate CO catalyst.

The CCHPP is part of the Central Energy Plant (CEP) at Cornell University which provides most of the centrally produced power and district energy services such as steam and chilled water. Since 2000, chilled water has been provided via Cornell's innovative deep water Lake Source Cooling which uses water from a nearby lake to cool campus buildings with 86% less energy use than the conventional chillers it replaced. The CEP reliably serves approximately 150 buildings (13 million sqft) of the central campus and annually produces 215,000,000 kilowatt-hrs of electricity, 1,100,000 thousand pounds of steam, and 45,000,000 ton-hrs of chilled water.

Section 1: Introduction

Cornell University (Cornell), founded in 1865, is a private endowed university. It is the federal land-grant institution of New York State and a partner, through the Contract Colleges, of the State University of New York. In order to pursue its mission of teaching, research, and outreach, Cornell University must provide modern teaching, research, and outreach facilities. The Ithaca campus supports about 11,500 faculty and staff and over 19,000 students.

The Cornell Combined Heat & Power Project (CCHPP) began construction in spring 2008, and went into full operation in December 2009. The $82 million CCHPP is the result from a rigorous energy master plan and represents a major renovation of the Cornell Central Heating Plant. The Central Energy Plant (CEP) and central distribution systems are essential campus utilities. The CEP provides most of the centrally produced power and district energy services such as steam and chilled water. In addition, Cornell's 100kW hydroplant provides approximately 2% of the campus' electricity usage. The CEP reliably serves approximately 150 buildings (13 million sqft) and annually produces 215,000,000 kilowatt-hrs of electricity, 1,100,000 thousand pounds of steam, and 45,000,000 ton-hrs of chilled water. The peak steam heating load in the winter is approximately 405,000 lbs/hr with an average load of 127,000 lbs/hr.

The CCHPP added two combustion turbine generators, totaling 30 Megawatts of electrical output with heat recovery steam generators, totaling 300,000 lbs/hr of steam generation. This system produces 70% of campus electrical power. The project included a major renewal of the plant electrical system. A dedicated 3.2 mile high pressure natural gas pipe line was constructed to provide fuel.

Section 2: System Operation / Equipment

The Cornell Combined Heat and Power Project (CCHPP) involved the construction of a combined heat and power facility based on two new dual fuel Gas Turbine Generators (GTG) and natural gas duct fired Heat Recovery Steam Generators (HRSG) for the purpose of supplying the Cornell University (Ithaca, New York) campus with both electricity and heating steam. The electrical production displaces electricity previously purchased from the local utility company, New York State Electric & Gas (NYSEG) and the heating steam production displaces steam produced by the existing Central Heating Plant (CHP) boilers which were fired primarily with coal. The CCHPP also has the capability of exporting excess power production to NYSEG. The CCHPP is wholly owned, and operated by Cornell University.

The major equipment in the CCHPP is two dual fuel (natural gas and no.2 ultra low sulfur diesel fuel) gas turbine generators (GTGs). Each GTG is completed with an innovative dual pressure natural gas duct fired Heat Recovery Steam Generator (HRSG) which uses the hot exhaust gases of the GTG to generate steam. The nominal output for each gas turbine generator is 15 MW (ISO rating). Each HRSG is capable of providing approximately 46,000 lb/hr of HP steam (400 psig, 600^{o}F) and 14,000 lb/hr of LP steam (50 psig nominal, saturated) with no duct firing, and

approximately 135,000 lb/hr of HP steam and 18,000 lb/hr of LP steam at the maximum duct firing temperature of 1800 ^{o}F. The high pressure steam passes through two backpressure turbines producing more electricity as the steam is supplied to campus.

When the Cornell power system is isolated from the grid in the event of a grid outage, transformer failure, or other reason, the GTGs will operate in islanded operation to supply power to the campus. The GTGs will follow the campus load up to their base load capability and control the system frequency. On return to normal parallel operation, the Cornell power system can be synchronized to the grid without having to adjust GTG output or campus loads.

NOx and CO emissions are minimized via state-of–the–art catalysts in the HRSG. A new ammonia supply system provides ammonia to the Selective Catalytic Reduction (SCR) units of the two new HRSGs for the control of NOx emissions. The ammonia equipment including unloading skid, 12,000 gallon storage tank, forwarding skid, process control unit, manifold and injection grid provide the vaporized ammonia needed.

Two (2) 480 V Emergency Diesel Generators (EDGs) are sized to provide sufficient auxiliary power to blackstart both gas turbine generator sets and CCHPP and CHP auxiliary loads. The EDGs are also capable of operating in a Peak Shaving mode where they can operate in parallel with the normal utility supply.

The gas turbines have dual fuel capability, operating either with 100% natural gas fuel or 100% Ultra Low Sulfur (ULS) No.2 fuel oil. The fuel oil serves as back up fuel for the gas turbines during interruption of natural gas supply or during times of high natural gas pricing. An advantage of the dual fuel system is that the turbines are able to utilize liquid bio-fuel options if they become readily available and feasible. The fuel oil supply system allows continuous operation of the two gas turbines at full electric load at any site ambient temperature. The fuel supply system allows for switching of fuel sources to be initiated automatically or manually at any turbine load and running condition. The fuel oil system also supplies fuel to the two new emergency diesel generators.

Central Energy Plant Equipment

Equipment Type and Year Installed	Production / Output Information
Rentech HRSG 1 and 2 with Duct Burner 2009	Fuel: Natural Gas High Pressure Steam 135klbs/hr Low Pressure Steam: 18klb/hr
Solar Titan 130 GTG 1 and 2 2009	Fuel: Natural Gas / #2 Ultra low sulfur diesel Electric Output: 15MW (ISO Rating)

Equipment Type and Year Installed	Production / Output Information
Boiler No. 5: D Type Package Boiler 1965	Fuel: Natural Gas Steam Capacity: 100klb/hr Steam Parameters: 200psig @ 550F
Boiler No. 6 and 7: D Type Package Boiler 1992	Fuel: Natural Gas Steam Capacity: 108klb/hr Steam Parameters: 400psig @ 640F

Equipment Type and Year Installed	Production / Output Information
Turbodyne Steam Backpressure Turbine No. 1 (TG-1) 1986	Steam Backpressure turbine generator Power Generation Capacity: 1,700 kw (nominal capacity)
Turbodyne Steam Backpressure Turbine No. 2 (TG-2) 1986	Steam Backpressure turbine generator Power Generation Capacity: 5,800 kw (nominal capacity)
Steam Condenser 2009	Max Condensing Capacity: 90,000 lb/hr Allows both GTG units to operate at full output with HRSG unfired. Excess low pressure steam generated in the HRSG is routed directly to the steam condensing system.

Section 3: Distribution network

The steam distribution system consists of approximately 62,000 linear feet of underground piping.

Section 4: System Energy Efficiency

For FY 2012, the efficiency of the central energy plant was 78%. Fossil fuel energy input was 2,405,000 MMBtu, with over 99.9% of the fuel energy input natural gas. The remainder was #2 ultra-low sulfur fuel oil. Energy output was 1,881,000 MMBtu. Approximately 62% of the energy output is steam and 38% is electric. Detailed energy input and output is provided in the following table.

Central Energy Plant Component	Energy Input (MMBtu)	Energy Output (MMBtu)	Energy Output Type
Combined Heat & Power Equipment			
Combustion Turbines 1 and 2:	2,038,000	623,000	**Electric**
HRSG 1 and 2 with Duct Burner	277,000	1,108,000	**Steam**
Total Combined Heat & Power Equipment	**2,315,000**	**1,731,000**	
Boilers	89,000	68,000	**Steam**
Steam Turbine Generators	**NA**	**82,000**	**Electric**
Central Energy Plant Totals	**2,404,000**	**1,881,000**	
Overall Central Energy Plant Efficiency	**78%**		

Section 5: Measurable Environmental Benefits

The Cornell Combined Heat and Power project has achieved significant emission reductions compared with pre-project emissions for both greenhouse gases and regulated pollutants. The reductions are from the following:

(1) Better efficiency: The CCHPP significantly increased the efficiency of the central energy plant. More specifically, the CCHPP offsets grid power that is generated at a much lower thermal efficiency due to the lack of a steam host. Generally speaking, when accounting for typical grid power efficiencies, the CCHPP improves efficiency from 50% for separate heat and power systems to approximately 75% for the combined heat and power configuration. For fiscal year 2012 the efficiency of the central energy plant was 78%.

(2) Beyond Coal: Coal emissions are significantly higher than natural gas for carbon dioxide (CO2) and priority pollutants oxides of nitrogen and oxides of sulfur. Displacing coal with

natural gas provides emission reductions for these pollutants as well as for heavy metals, a major regulatory focus area within the Great Lakes watershed, of which Cornell is part. In addition, eliminating coal also eliminated the emissions associated with transportation of the coal (approximately 2,500 truck trips per year) from Kentucky/West Virginia.

Section 5.1 Greenhouse Gas Reductions: The integration of combined heat and power with the elimination of coal reduced CO2 emissions by 55,000 metric tons. Emissions associated with on-site natural gas consumption increased significantly; however, emissions associated with coal are eliminated and the emissions associated with grid purchased electricity are reduced since electric is now produced on-site. The emission reductions for FY 2012 are summarized in the table below.

Fuel Type	CO_2 Emissions Before CCHPP metric tons	CO_2 Emissions With CCHPP (metric tons)	CO_2 Reduction (metric tons)
Coal	141,000	-	141,000
Natural Gas	5,400	127,000	(121,600)
Totals	**146,400**	**127,000**	**19,400**
Grid Electric	49,000	12,700	36,300
Total CO_2		**CO_2 Reductions**	55,700

Section 5.2 Regulated Pollutants: Emissions for regulated pollutants sulfur dioxide (SO_2), oxides of nitrogen (NOx) and particulate matter have been reduced by 97%, 68% and 90% respectively. The dramatic reductions in regulated pollutants have allowed Cornell to revise their classification from a Major Source of Hazardous Air Pollutants to a Minor Source. In addition, no longer burning coal eliminates bottom ash waste and emissions associated with transportation of the coal.

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Section 5.3 Sustainable Future: The project's combustion turbines have dual-fuel capability to allow them to run on distillate fuel oil. If future bio-fuels become economically available in sufficient capacity to warrant use, these could be blended (or, depending on their characteristics, potentially burned "straight"). Similarly, a clean bio-gas, such as that promoted

by faculty on campus for farm applications, could supplement, or substitute for, the natural gas available now by pipeline.

Finally, the solid-fuel boilers could be modified to burn renewable solid fuels if a reliable supply were locally available. Renewable fuels in every form continue to be explored. The overall system was designed to allow their use as they become economically and technologically feasible. These design elements allow Cornell's CEP to be a pro-active component of Cornell's Climate Action Plan to achieve net carbon neutrality by 2050.

In addition, the project includes a small office building for plant staff. The office building has achieved a LEED Gold rating by the United States Green Building Council (USGBC) in recognition of the buildings sustainable elements. The design seeks to provide good stewardship through a highly-efficient envelope and equipment; utilizing renewable energy (solar thermal) for heating with under slab seasonal energy storage; conserving and energy consumption via heat recovery and employing occupancy-based controls.

Section 6: Innovations

The project is an innovative solution to Cornell's long term heat and power needs coupled with the desire to significantly reduce the associated environmental impacts. The standard practice would be to continue buying electric off the grid and installing natural gas boilers to generate steam. Combined heat and power goes beyond standard techniques. As noted by the Oak Ridge National Laboratory in their report **"Combined Heat and Power: Effective Energy Solutions for a Sustainable Future**" on Dec. 1, 2008.

"Combined Heat and Power (CHP) solutions represent a proven and effective near-term energy option to help the United States enhance energy efficiency, ensure environmental quality, promote economic growth, and foster a robust energy infrastructure. Using CHP today, the United States already avoids more than 1.9 Quadrillion British thermal units (Quads) of fuel consumption and 248 million metric tons of carbon dioxide (CO_2) emissions annually compared to traditional separate production of electricity and thermal energy. This CO_2 reduction is the equivalent of removing more than 45 million cars from the road."

The CCHPP was chosen over lower-cost solutions that would have had higher environmental impacts and would have limited future renewable fuel flexibility. Some specific innovative details of the project include the following:

- Dual-pressure boiler which allows 20% more heat recovery than a conventional heat recovery steam generator.
- Investing $4 million for the capability of using gas or a liquid fuel option for the combustion turbines. This investment allows the facility to be prepared for potential biofuel options as they mature.
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Section 7: Outreach efforts & related benefits

As an institution committed to education, research, and outreach, Cornell University is committed to the goal of providing useful technological information to the wider community. Outreach efforts regarding the project are many, cover a broad range and include the following:

Local Approvals / State Environmental Quality Review (SEQR): The project was subject to State Environmental Quality Review, which included numerous information meetings to educate the community about the project and the related benefits.

Media Events: In January of 2010, Cornell held a media event to formally announce the Beyond Coal Initiative. Speaking in recognition of the importance of this effort was Bruce Nilles, Director of the Sierra Club's Beyond Coal Campaign.

Facility Tours: Over a hundred tours and presentations have been provided to students and faculty, the community, state representatives, facilities professionals looking to implement this technology elsewhere, and environmental leaders to inform, educate, and transfer Cornell's experience.

Web Accessibility: Performance information for the project is publicly available via the New York State Energy Research and Development Agency (NYSERDA) website on distributed generation / combined heat and power at

http://chp.nyserda.org/home/index.cfm Project information is also available at

http://energyandsustainability.fs.cornell.edu/util/districtenergy.cfm

Cornell's Climate Action Plan is available at

http://www.sustainablecampus.cornell.edu/initiatives/climate-action-plan.cfm

National Recognition/Support: The U.S. Environmental Protection Agency awarded the project a 2011 ENERGY STAR CHP award in February 2011. In addition, Cornell University was awarded the Second Nature's 1st Annual Climate Leadership Award for Institutional Excellence in Climate Leadership.
http://secondnaturebos.wordpress.com/2010/10/11/cornell/

Articles: Published articles on the project have occurred in "Combined Cycle Journal", Nov. 2010 and "Turbomachinery Magazine", June 2009, and the District Energy Magazine, 2012 in addition to multiple local press feature articles.

Technology Transfer: Detailed reports regarding Monitoring, Cost Performance, Project Commissioning, and Project Operations are being provided to NYSERDA for technology transfer.

Technical Presentations: Provided in-depth technical presentations on CHP concepts and the benefits to numerous industry and institutional groups including the International District Energy Association, American Society of Heating, Refrigerating and Air Conditioning Engineers, Manufacturers Association of Central New York, Dormitory Authority of the State of New York and, and Big Ten & Friends.