COVER STORY

Powering the future from remains of the past

Facing a boiler capacity shortage, the University of Minnesota rehabilitated a retired, antiquated steam plant into a model of modern efficiency and sustainability.

Chris Farr, PE, Project Manager, Jacobs Engineering Group Inc.

Courtesy University of Minnesota.

The University of Minnesota Twin Cities encompasses approximately 24 million gross sq ft throughout 250 buildings across two campuses – in Minneapolis and St. Paul – approximately 3 miles apart. This flagship of the University of Minnesota system comprises 19 colleges and schools, with sister campuses in Crookston, Duluth, Morris and Rochester.

Energy Management, a division of Facilities Management within University Services, oversees the production and distribution of heating, cooling and electricity services to approximately 70,000 students and staff across the Twin Cities campuses. These include

- centralized steam production and distribution systems delivering high-pressure (200-psig) steam;
- multiple district chilled-water plants providing 41,000 tons of total cooling capacity;
- five 13.8 kV switch stations (four in Minneapolis and one in St. Paul) receiving power from multiple Xcel Energy substations and distributing it to the campuses via an underground distribution network; and
- civil utility infrastructure supporting domestic water, sanitary sewer and storm water drainage that connects to city and regional systems.

Until 2017, all steam provided to the Minneapolis campus – divided by the Mississippi River into east and west bank areas – was generated at the Southeast Steam Plant (SE Plant). The plant had been acquired by the university in 1977 and received major upgrades in 2000. The upgrades included a solid-fuel circulating fluidized bed boiler and two dual-fuel (natural gas/No. 2 fuel oil) package boilers. Two older coal-fired boilers were also retained to provide backup steam capacity.

Prior to the acquisition of the SE Plant, steam for the Minneapolis campus was produced at a facility known as the Old Main Heating Plant. Originally constructed in 1912 and expanded/renovated many times over its life, this plant is located on the East Bank of the Mississippi River at the base of a former rock quarry excavation. It is highly visible to the public from the Interstate 35 river crossing and from parts of downtown Minneapolis. This building served as the primary source of campus steam energy for 88 years prior to completion of the SE Plant upgrades.

Following the SE Plant upgrade, however, the Old Main facility was largely neglected and fell into a state of disrepair. The exhaust stacks were demolished, the site was overgrown with vegetation, the roof was leaking, and the utility services to and from the building were failing. Except for the stacks, essentially all of the plant equipment was electrically disconnected and abandoned in place, including

six large coal-fired steam boilers and one gas-/oil-fired boiler. A substantial abatement effort was needed to remove asbestos, lead, mercury and other hazardous materials that were known to exist.

WITHOUT ACTION, THE ABILITY TO PROVIDE RELIABLE STEAM ENERGY TO UNIVERSITY FACILITIES WOULD BE AT SUBSTANTIAL RISK.

In 2009, a utility master plan was performed by the university to evaluate all utility systems on campus with respect to the institution's 20-year growth plans. Due to both the heating demand load growth projections and the age of the two older coal-fired boilers in the SE Plant, a shortage of firm boiler capacity was forecast to become a significant operating obstacle by 2014. Without action, the ability to provide reliable steam energy to university facilities, including a hospital and multiple research centers, would be at substantial risk.

Prompted by this assessment, and following further study, the university responded to this anticipated shortage by reinvesting in and reconfiguring its historic Old Main plant. The facility was transformed into a new 22.8 MW combined heat and power system that supplies steam and electricity to the Minneapolis campus – reducing utility grid purchases and greenhouse gas emissions in the process.

AN EFFICIENT SOLUTION

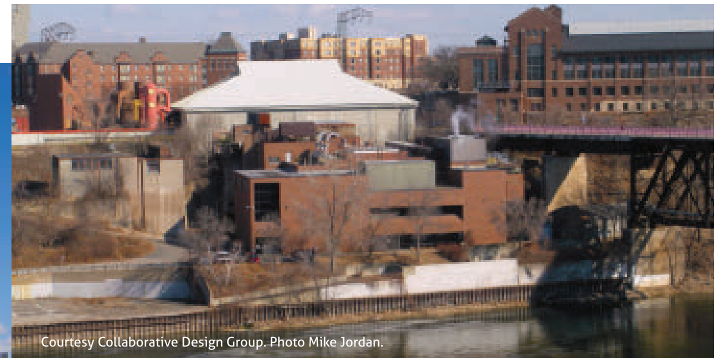
Subsequent to the completion of the master plan, the university evaluated potential solutions to address the shortage in firm boiler capacity, using reliability, sustainability and cost-effectiveness as its guiding principles. The analysis resulted in three options: adding another boiler at the SE Plant, rehabilitating the Old Main Heating Plant or building a new steam plant in the northeast area of campus.

After careful consideration, rehabilitation of the Old Main Heating Plant was identified as the best choice among these options for several reasons. First, generating steam from a second location mitigated the risks associated with having a single source of steam for the Minneapolis campus, which had been identified as one of the campus's top two risks by property insurers. Second, reusing the existing facility was perceived to be more economical than building a new steam plant in the northeast (another option that would diversify steam production locations) and installing new distribution system components required to deliver that energy to campus. And finally, the Old Main Heating Plant was considered large enough to house additional utility systems, including power generation equipment and the next district chilling plant, without requiring the construction of additional facilities. In other words, the building rehabilitation investment at Old Main would represent a down payment on future utility projects.

Once the decision was made in 2011 to rehabilitate the Old Main Heating Plant site, Energy Management, in collaboration with the university's department of Capital Planning and Project Management, took the analysis a step further. They performed a preliminary evaluation of various combinations of equipment systems including package natural gas boilers and combined heat and power equipment.

The CHP option considered in the preliminary evaluation contemplated the installation of two 7 MW dual-fuel combustion turbine generators (CTGs). Since the university maintains an interruptible gas contract with CenterPoint Energy, the equipment selected had to be capable of operating on an alternate fuel during natural gas curtailments for the heat generated to be considered as contributing toward the campus's firm boiler capacity. Using heat recovery steam generators (HRSGs) with duct burners, the two combustion turbine generators would be capable of producing up to 250,000 lb/hr of total steam, achieving the firm capacity needed to meet the projected load growth.

The analysis concluded that the corresponding reduction of total purchased utility costs (natural gas and electricity) over the life of the equipment would outweigh the higher capital investment and operations and maintenance costs of CHP equipment, making it the wisest long-term strategic decision for the university.


Courtesy Collaborative Design Group. Photo Mike Jordan.


Courtesy Jacobs Engineering Inc. Photo Dana Wheelock, ©Wheelock Photography.

Above: The University of Minnesota's Old Main Heating Plant prior to rehabilitation. Following the Southeast Steam Plant upgrade in 2000, this facility was largely neglected and fell into a state of disrepair.

Left: The rehabilitated Old Main plant, now the Combined Heat and Power Plant, began operating in 2017. Its combustion turbine generator air intake structure and heat recovery steam generator exhaust stack stand against the backdrop of the Minneapolis skyline.

In addition to lifecycle cost savings, the analysis predicted that the higher process efficiency would substantially reduce the university's carbon footprint.

OPTIMIZATION OF CHP

The University of Minnesota teamed with Jacobs Engineering Group Inc. in December 2011 to provide detailed engineering design, construction administration and commissioning services for the Combined Heat and Power Plant project to rehabilitate Old Main. The engineering effort began with a predesign phase that included a "rightsizing" analysis to confirm the findings of the preliminary CHP analysis and identify the optimal combination of plant equipment to serve the unique thermal and electrical demand profiles of the Minneapolis campus most efficiently throughout a complete year.

Jacobs' rightsizing analysis concluded that CHP did, in fact, represent the most cost-effective, reliable and sustainable solution for the university. The construction cost premium for the proposed CHP configuration, with two 7 MW CTGs and duct-fired HRSGs, was estimated to be $39 million over and above the cost of a similar package boiler solution with the same total heating capacity (250,000 lb/hr); but this configuration was expected to reduce the total cost of utilities, operation and maintenance by $69 million in the first 20 years of operation.

However, the original recommendation did not represent the optimal CHP solution. As a general rule, a plant designed around a single, larger turbine generator will typically have a lower total construction cost per kilowatt than a plant of similar capacity with multiple smaller generators. The same principle holds true for maintenance costs as well. Furthermore, because the university intended to reuse an existing facility, the site-specific challenges of trying to fit multiple CTGs and HRSGs into the existing plant created challenges with equipment layout.

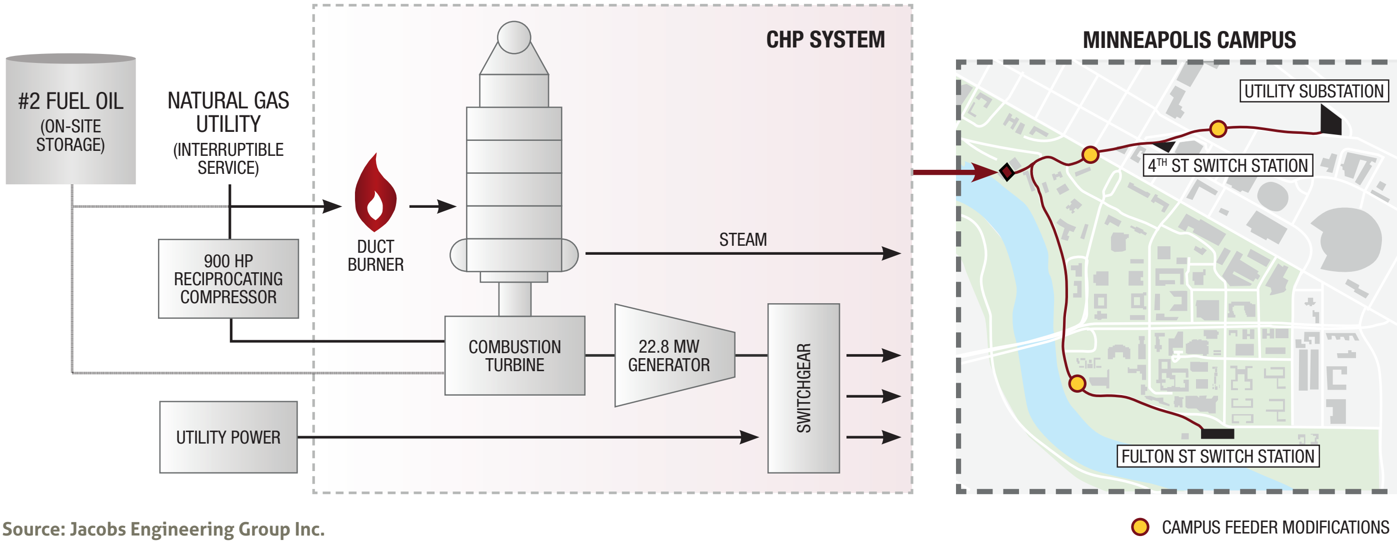
When the analysis was complete, Jacobs concluded that a plant designed around a single 22.8 MW CTG would cost only $1 million more than a plant with two 7 MW CTGs. More importantly, the cost of maintaining the single 22.8 MW CTG would actually be lower than the cost of maintaining two 7 MW CTGs. Because the single 22.8 MW CTG option provided more electrical output with a lower cost of maintenance, the single turbine solution was estimated to reduce the cost of utilities, operation and maintenance by an additional $98 million over the same 20-year period!

THE SINGLE TURBINE SOLUTION WAS ESTIMATED TO REDUCE THE COST OF UTILITIES, OPERATION AND MAINTENANCE BY AN ADDITIONAL $98 MILLION OVER 20 YEARS.

From the standpoint of sustainability, the greenhouse gas emissions attributed to consumption of steam and electricity on the Twin Cities campus were estimated to average 205,000 metric tons of carbon equivalents per year prior to the implementation of CHP. The dual-turbine option was projected to provide greenhouse gas emissions savings of approximately 22,000 metric tons annually, while the larger, single 22.8 MW CTG solution was projected to increase those savings to 32,000 metric tons.

While the single 22.8 MW generator seemed to be the most economical choice, there were challenges beyond the walls of the plant to consider. The campus distribution system was not configured to

FIGURE 1. Overview of the University of Minnesota Minneapolis campus combined heat and power system.



Source: Jacobs Engineering Group Inc.

easily distribute this level of on-site generation from a single generation source. Connecting power to campus loads without compromising reliability required substantial reconfiguration of the medium-voltage system. These reconfigurations included a new utility connection and several new connections from the generation equipment to the distribution buses at the university's existing Fourth Street and Fulton switching stations (fig. 1).

These changes would allow the university to utilize all of the generated electricity behind the meter during the majority of the year while keeping the CTG running at full capacity for thermal optimization. Modifications to the electrical system also accounted for increased short-circuit current and allowed for system operation without exceeding the ratings of the existing equipment. After these considerations were taken into account, the additional cost of the 22.8 MW solution was more than $9 million in comparison to the original recommendation.

The design team also considered issues of reliability for a unit trip. The instantaneous loss of power and steam generation from a single larger unit tripping off line would have a more profound impact than losing one of two smaller units. To address this risk, the project team implemented strategies for quick response to prevent electric outages or excessive drops in steam pressure to campus. These strategies resulted in major modifications to the physical infrastructure and operation of the campus power distribution network as well as new operational procedures that keep a standby boiler warm and ready to respond quickly if steam production from the HRSG is lost unexpectedly.

The new "flying duct bank" contains feeders that bring utility power into the new plant 13.8 kV switchgear and distribute power back to campus switching stations.

FROM CONCEPT TO CONSTRUCTION

The University of Minnesota Board of Regents agreed that the additional lifecycle cost savings and greenhouse gas avoidance of a 22.8 MW plant justified the additional investment. In February 2013, additional funds were allocated, and the project team proceeded with detailed design.

Through competitive solicitation, a GE LM2500 dual-fuel CTG, equipped with dry low-emission technology, was chosen to power the rehabilitated plant. Unlike the standard industrial package, a single-lift model was purchased. This option includes a steel torque tube base structure

Courtesy Jacobs Engineering Inc. Photo Rodney Carpenter.

Heat recovery steam generator modules entered Old Main through a roof penetration in September 2015.

System snapshot: University of Minnesota Minneapolis campus

	Steam/Combined heat and power system
Startup year	1912 – Old Main Heating Plant built, began steam service 1977 – Southeast Steam Plant (SE Plant) acquired from Northern States Power 2017 – Combined Heat and Power Plant (CHP Plant) started up in renovated Old Main plant facility
Number of buildings served	Approximately 150
Total square footage served	Approximately 19 million sq ft (steam); 16 million sq ft (electricity)
Plant capacity	CHP Plant: 250,000 lb/hr steam, 22.8 MW electricity SE Plant: 650,000 lb/hr steam, 16 MW electricity (nameplate)
Number of boilers	CHP Plant: 1 combustion turbine generator, 1 heat recovery steam generator SE Plant: 3 boilers
Fuel types	Natural gas, ultralow-sulfur No. 2 fuel oil
Distribution network length	7 miles
Piping type	Carbon steel
Piping diameter range	2 inches to 24 inches
System pressures	CHP Plant: 200 psi SE Plant: 900 psi and 200 psi
System temperatures	CHP Plant: 420 F SE Plant: 950 F

Source: Jacobs Engineering Group Inc.

with a three-point mount on which both the combustion turbine and electric generator are factory-mounted prior to shipment. While the engineered base adds cost to the CTG equipment, its stiffness is designed to absorb the torque reaction between the engine and generator during normal and fault conditions that would otherwise need to be resisted by the equipment foundation. Since this unit was to be installed on an elevated pedestal, the additional cost of the torque tube base was offset by savings in the supporting structure. Conversely, this option exacerbated the challenge of delivery to the site. The weight of the package as shipped by road from Houston to Minneapolis was more than 225,000 lb.

Installation of the combustion turbine generator packages and heat recovery steam generators began in August 2015. The HRSG included duct burners sized to boost steam output to 250,000 lb/hr, burning either natural gas or ultralow-sulfur No. 2 fuel oil, as well as carbon monoxide and nitrogen oxide catalysts to further reduce the emissions. The HRSG was shipped in modules of various sizes up to 37 ft tall, 14 ft wide and 12 ft long and weighing up to 140,000 lb. Each module was sequentially lowered through an opening in the roof that would eventually house the 127-ft-tall exhaust stack.

THE STRUCTURAL RENOVATIONS WERE COMPLICATED BY THE HIGH CARBON CONTENT OF THE 1911-TO-1915-ERA STEEL, NOT CONSIDERED WELDABLE USING MODERN-DAY WELDING PROCEDURES.

Because none of the old equipment in the plant was viable for reuse, all balance of plant systems required for a complete and integrated power plant were also provided. Since it was not possible to procure a high-pressure natural gas delivery service to the site, this included a 900 HP electric-drive reciprocating gas compressor. Major structural and architectural changes were also required to reconfigure the space inside the building for the new equipment systems and code compliance. The structural renovations were greatly complicated by the high carbon content of the 1911-to-1915-era steel, which was originally installed using riveted construction and was not considered weldable using modern-day welding procedures.

The team achieved coordination of steam generation, condensate return and other shared duties between the Combined Heat and Power Plant and the existing SE Plant via a modern programmable logic controller-based control system with new fiber optic communication lines between the two facilities. Electrically, the plant control system was designed to include a load-shedding scheme, and the switching stations were enhanced with source transfer schemes to improve reliability and operational flexibility.

In addition to the utility savings realized through the primary CHP process, the system collects waste heat from all available sources throughout the plant, including the blowdown system and process coolers. This energy is used for preheating condensate, producing heating hot water and anti-icing heat for turbine combustion air and more. Many other sustainability enhancements were also implemented in accordance with the State of Minnesota B3 Guidelines (i.e., Buildings, Benchmarks & Beyond), formerly the Minnesota Sustainable Buildings Guidelines.

Finally, the design includes provisions and infrastructure for the future addition of a 5,800-ton steam turbine-driven chilled-water plant and a 250,000-lb/hr package boiler.

THE FUTURE IS NOW

In addition to offering dramatic utility cost savings, the new Combined Heat and Power Plant's ability to generate all steam required to meet campus demand for a significant portion of the year provides operational flexibility to perform long-overdue maintenance activities to systems in the SE Plant – a task that was previously difficult to accomplish while meeting campus thermal needs.

Now a beacon of efficiency and sustainability, the new CHP plant has revolutionized the production of energy on the University of Minnesota's Minneapolis campus. In the first year of steady operation, which began in 2017, the university expects to reduce the consumption of purchased power from the utility grid by more than 60 percent, while also reducing greenhouse gases caused by the consumption of all heat and power on the Minneapolis campus by at least 10 percent.

These results are not made possible simply because a CHP system was installed. Rather, the biggest success of this project was taking the time to make sure that the optimal solution was implemented. Just as no two campuses are completely alike, the best utility solutions must be tailored to suit the unique needs of each owner. In the case of the University of Minnesota, Energy Management is now well-suited to showcase its principles of reliability, sustainability and cost-effectiveness for many years to come.

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STEAM PRODUCTION FROM A SECOND PLANT PROVIDES IMMEDIATE VALUE

On March 9, 2017, most of the combined heat and power systems in the University of Minnesota's new plant had been started and successfully operated, if only for short periods of time. However, functional performance testing and commissioning were far from complete.

On this particularly cold morning, and unbeknownst to the university, a contractor was working to pump grout into the ground to fill voids beneath a city-owned tunnel. This location was adjacent to the university's primary steam tunnel carrying the main steam line from the Southeast Steam Plant (SE Plant) to campus. Much by accident, this material migrated from the intended void area to below the floor of the university's steam tunnel, causing the floor to heave up and break some live steam piping. The first indication of trouble was a fire pump starting due to a sprinkler line in the tunnel. Opening a tunnel access door revealed large amounts of steam blowing inside the tunnel plus visible equipment damage, forcing the SE Plant to begin an immediate shutdown to inspect the header and make repairs.

At any other time over the past 25 years, this event would have been catastrophic. On this occasion, however, the project team, including plant operations staff, carefully evaluated their options and determined that the Combined Heat and Power Plant could be safely operated for a day, prior to substantial completion, to provide steam to the Minneapolis campus while allowing the primary steam header from the SE Plant to be de-energized for repairs. The project team immediately transitioned from testing activities to live operation and made sure that the campus, which includes many critical buildings such as a hospital and research labs, was kept warm. In doing so, the team demonstrated just how valuable a second source of campus steam production can be.