It is all about energy—power generation through heat recovery in Hartford

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ABSTRACT | Wastewater solids have heat value, much like other fuel sources, and the Hartford Water Pollution Control Facility (WPCF) in Hartford, Connecticut, determined that converting biosolids to energy at the plant would be a beneficial way to use its resources. Wastewater treatment is energy intensive, and on average the Hartford WPCF uses enough electricity to light about 35,000 one-hundred-watt light bulbs. The Hartford WPCF's incineration process burned solids to turn them into inert ash, and the heat produced from incineration was not beneficially used. A heat recovery facility (HRF) was designed to use heat from the sludge incineration process to produce electricity, reducing power costs significantly. The new processes take this heat from the exhaust and turn it into steam in large boilers, where the steam spins a turbine connected to a generator that produces electricity. Use of this heat from incineration generates up to 40 percent of the facility's energy.

KEYWORDS | Heat recovery, incineration, steam turbine-generator, water pollution control facility (WPCF), training, savings, green fuel

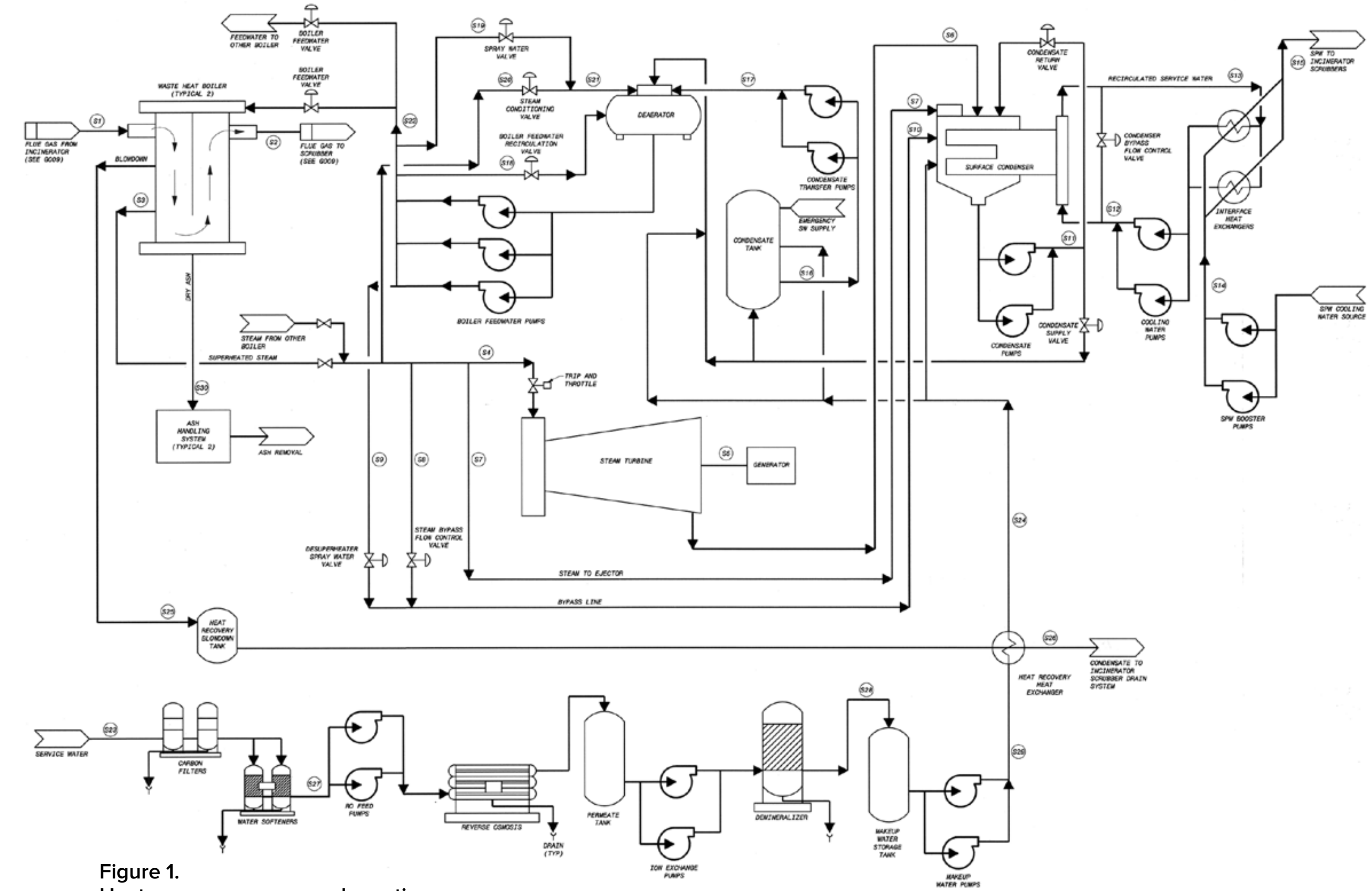

Figure 1.
Heat recovery process schematic

The Metropolitan District owns and operates the Hartford Water Pollution Control Facility (WPCF), the largest such facility in Connecticut, on an approximately 85-acre (34-hectare) site. The facility is permitted to treat 80 million gallons per day (mgd) (300 million liters per day [ML/d]) through secondary treatment processes, with a peak wet-weather capacity of 135 mgd (510 ML/d). Current daily flow averages approximately 60 mgd (230 ML/d). The facility treated more than 21 billion gallons (80 billion liters) of water in 2015. The District performs water supply and treatment, distribution and collection, water pollution control, and mapping/GIS services for Bloomfield, East Hartford, Hartford, Newington, Rocky Hill, West Hartford, Wethersfield, and Windsor. It serves a population of approximately 440,000 residents.

In 2009, a Master Plan was completed at the WPCF to identify peak flows for plant design, recommending treatment processes necessary for wet weather flows as well as processes necessary to achieve nitrogen permit limits. Another key recommendation from the Master Plan was for solids handling improvements for both wet and dry weather flows.

HEAT RECOVERY SYSTEM OVERVIEW

The Hartford WPCF uses incineration to manage its solids. The WPCF operates three multiple hearth incinerators (MHIs) that include air pollution control devices (scrubbers). Sludge enters in the third level (hearth) and follows an inside-outside pattern to the bottom, where it is rendered into inert ash after burning at approximately 1,200°F (650°C). The WPCF processes approximately 100 dry tons (90 metric tons) of solids each day. The origin of the solids includes various sources, including:

- Wastewater that flows to the Hartford WPCF
- Solids pumped from two other District WPCFs
- Solids trucked from one other District WPCF
- Solids trucked from non-District facilities, including other regional WPCFs, permitted commercial and industrial sources, and septage from residential sources not served by public sewers

Energy recovery begins with the removal of heat from a process stream. Prior to the construction of the heat recovery facility (HRF), the Hartford WPCF sent exhaust gases from the three multiple hearth incinerators directly to wet scrubber/quench vessels to remove particulates and to cool the exhaust gas to near ambient temperature. The heat in the exhaust was transferred to the quench water and not beneficially used. The HRF was designed to remove that heat and beneficially use it prior to the exhaust going to the scrubbing process. A process schematic of the heat recovery system is shown in Figure 1.

The District had discussed heat recovery since the early 2000s. However, at that time, electricity costs were too low to justify the investment required to recover heat from the MHIs. In the following years Connecticut deregulated the power sector, and energy prices began an upward trajectory that justified implementing the heat recovery project. Initial concepts for the improvements included a design-build procurement approach, and the District entered into negotiations with a supplier. Initially, the price was attractive, but with time and increased understanding of the improvements included (and not included), the project looked less attractive, and this approach was eventually abandoned. Meanwhile, energy costs continued to rise and the heat recovery concept became economically viable. Traditional design-bid-build procurement was selected.

In 2009, a federal economic stimulus program sought to support shovel-ready Green Infrastructure projects, and the Connecticut Department of Energy & Environmental Protection (DEEP) offered American Reinvestment and Recovery Act grants and low-interest loans to the District. A requirement of the grants was that the project be designed, bid, and awarded by February 2010. The project was bid in December 2009, and awarded in January 2010.

The District upgraded the incineration facility at the Hartford WPCF and installed 1.75 megawatts (MW) of electrical production capacity. The improvements reduced the Hartford WPCF's grid electricity use by approximately 40 percent. The District obtained "green funds" for this type of beneficial use project and received a $17 million grant/low-interest loan from DEEP that represented more than 60 percent of the total project cost. The project was completed in 2012.

Improvements included upgrades to all three incinerators with connections for heat recovery, ducts, and diversion dampers as well as induced draft fans with variable frequency drives (VFDs) and instrumentation/SCADA controls as needed. Incinerator No. 3 was significantly upgraded and included a Venturi scrubber, air pollution controls, and a flue gas recirculation system as well as major refractory brickwork modifications. The 1.75-MW

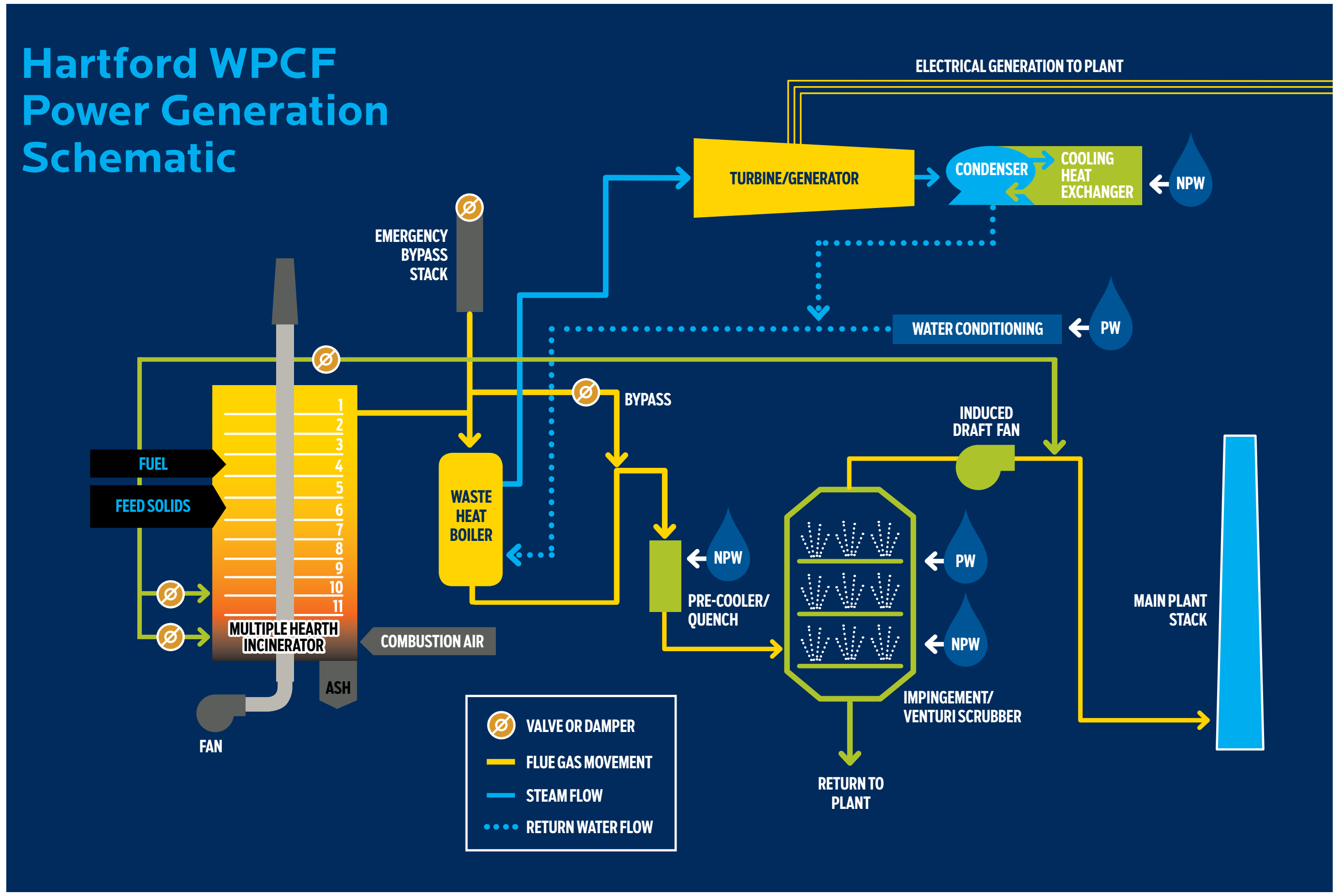

Figure 2. Power generation system schematic

electricity production system was also installed to convert the heat energy to power. The electricity generation system consisted of boilers, a steam turbine-generator, and an associated water treatment system. A schematic of the power generation system is shown in Figure 2.

HEAT RECOVERY SYSTEM

The heat recovery system has three main processes:

1. Heat recovery in the boilers to generate steam from the hot incineration exhaust
2. Steam turbine-generator to convert the steam to electricity
3. Condenser, deaerator, and feed water pumps combined to convert the spent steam back to usable boiler feedwater

In addition to these three main processes, several other processes at the HRF include compressed air, a cooling water system, chemical treatment to produce boiler quality water, and ash handling. These systems are described below.

Heat Recovery from Incinerators to Boilers
The boilers used at the HRF are vertical, two-pass units with a top entry and exit. Ducts with control valves transfer the multiple hearth incinerator's hot exhaust gas from the incinerators to the boiler inlets. The boilers are operated by using damper valves to inlet and remove incinerator exhaust gas, thus allowing the boiler to extract heat and produce steam. Water movement and steam movement are controlled by valves operated by the main plant control system. The hot gas is directed into the superheater section of the boiler and then on through the length of the boiler. The first pass is downward through the boiler, and the second pass is upward through the boiler to the exit. After exiting the boiler at the economizer section, the now much-cooler exhaust gas is carried in warm ducts back to the entrance of the MHI quench process.

Each incinerator has a hot gas damper valve, a warm gas damper valve, and a breech damper valve to control the exhaust gas flow from the MHI. In the normal configuration, MHI exhaust will flow out the incinerator breech into the incinerator quench system. In energy-recovery mode, exhaust gas will flow out of the hot duct into and through the boiler and return through the warm duct to the MHI quench system. The boiler transfers the heat from the MHI exhaust to the water in the boiler thus creating steam, the working fluid used to drive the steam turbine-generator. These boilers produce steam at 500-pounds-per-square-inch-gauge (PSIG) (3,450-kiloPascals [kPa]) internal pressure and 700°F (370°C) temperature; however, normal operations are 385 PSIG (2,650 kPA) steam pressure and 600°F (315°C) steam temperature. Ash brought into the boilers from the MHI is collected in the bottom of the boiler and removed via a lock hopper. Ash is removed continuously during normal operations and carried by the ash handling system.

Ash Handling System—The incinerator exhaust carries some fly ash from the sludge incineration process. This fine ash settles out on the boiler tubes and inside walls. Denser particles and larger ash particles may also fall out of the exhaust stream as the ash is lifted up the vertical flow section of the boiler. This ash collects at the bottom of the boiler in an ash hopper. A rotary valve at the bottom of this hopper allows removal of ash without a loss of vacuum seal in the boiler. Currently, the ash falls into a temporary dumpster, which is moved and emptied periodically into a larger container for ultimate disposal. Eventually, a fully automated ash handling system will be installed using cooled augers to take the ash to a storage and handling location.

Steam Turbine-Generator—The steam system starts as the produced steam leaves the boiler and enters the high-pressure steam piping. At this time the steam piping carries fully pressurized and high-temperature steam to several points of use. The turbine is the main facility steam user, and because the amount of steam produced will vary widely over time, the steam flow to the turbine is based on steam header pressure. The amount of steam fed to the turbine may vary, but the flow control valve will throttle turbine intake to keep the steam header at a constant 385 PSIG (2,650 kPa) pressure. The generator maintains constant output voltage but the kW output varies.

The steam turbine-generator has a local control cabinet that provides for local operation of the equipment. The main facility control system can also operate the steam turbine-generator system remotely from the control room location. The electric generator output is directly controlled by the amount of steam flow to the steam turbine.

Water Treatment System—The boiler feed water starts with city supply water. This supply water is carbon filtered, softened, filtered, processed through reverse osmosis, and polished through ion exchange before arriving at a storage tank ready for process use. Various boiler chemicals are added to maintain the high quality and protect the boiler piping. Treated water is pumped from the storage tank to the points of use as supply valves open at the various equipment skids. If there is no demand, the water is circulated in the tank.


Steam turbine

TRAINING AND STARTUP

Training and startup of Hartford's heat recovery process began during design. The Water Pollution Control (WPC) division of the District has long-employed the strategy of operator and maintenance staff engagement in all phases of design, and heat recovery was certainly no different. From the very early stages of Basis of Design through post startup operation, staff engagement was encouraged. Site visits were critical, and all levels of staff participated in these trips. Many valuable "lessons learned" were gained from other facilities, and that knowledge was incorporated into the Hartford facility. During the design of a project, staff are encouraged to ask questions and offer insight into design details. For example, maintenance staff are present to ensure adequate access to equipment is included; instrumentation and controls staff are present to ensure data is gathered effectively and incorporated correctly into the plant's SCADA system; electrical staff are present to ensure uniform breakers and panels are provided and set-up per standard. Staff engagement at this level creates an atmosphere of trust and facilitates buy-in, removing the dated approach of "engineer designs, contractor builds, staff operates."

At the onset of startup there was no collective experience in running a steam turbine power plant. While this could have been daunting, one positive was that "we were all in this together, learning" and no bad operational habits could be present. Unlike a plant receiving a pump or clarifier that mirrors existing equipment, we were starting with a new facility, so training was especially important. In all, more than 20 equipment-specific training sessions were held. Because operations staff are present 24 hours per day, 7 days per week, four sessions of each training were offered. This was

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done to accommodate staff schedules with training held immediately prior to the start of a shift or immediately after a shift ended. Separate training was also conducted for mechanical, electrical and instrumentation and controls staff, dictated by the maintenance requirements for each piece of equipment.


Deaerator

Significant effort went into developing specifications in the bid documents that detailed the requirements for each training class, as well as trainer qualifications and submittal requirements. Each vendor had to provide a resume of its proposed trainer. Vendors were also required to provide a copy of each presenter's materials (PowerPoint, handouts, etc.) for District review and approval in advance of training. Training classes were timed so that equipment was already installed and and functionally tested. WPCF staff also participated in all functional testing and were encouraged to visit the construction site regularly to view installation of equipment.

In addition to vendor training, the design engineer also delivered training sessions. This included system-wide training and standard operating procedure (SOP) training. The system-wide training tied together all vendor training and offered insight into how the equipment worked together as a system. The designer also developed SOPs that were validated in the field, under actual conditions. This training ensured that all operators had an accurate set of instructions available for operating the facility.

The contractor and design engineer were required to video each training class (one per topic) and provide the video to the District. The District has an on-line operations and maintenance (O&M) system that contains all training videos, SOPs, training handouts, drawings, equipment manuals, etc. The material can be accessed by all staff. As new operators are hired, they can "attend" heat recovery training and have the same handouts and other materials as those who attended the classes.

The District also brought in a power plant operator with more than 40 years of experience to help guide startup and training. This individual was a sounding board for ideas and encouraged operators to ask a lot of "how" and "why" questions. Having a veteran of the power production business on "our side" helped balance things for staff and relieved some of the startup decision-making pressure. This expert was also relied on after startup for regular conference calls and data review/analysis and troubleshooting, and to help ensure that the process was operating correctly.

During startup and initial WPCF operations, brief daily meetings ensured everyone knew what was going on, what happened overnight, and what the day's goals were. This regular communication was vital to keeping everyone informed; it also allowed rapid response to changing conditions and prevented the project from getting too far outside acceptable operating conditions.

DESIGN AND CONSTRUCTION LESSONS LEARNED

In addition to the startup and training recommendations discussed above, several beneficial lessons that were learned from this project can be of use to agencies and consultants implementing similar projects:

- Design the system for full automation through SCADA.
- Design a robust water treatment system, as this is critical to the boiler tube longevity and heat transfer.
- Insulate supply and return ducts to boilers to reduce temperatures in the upper reaches of the room, and carefully design the building with proper ventilation.
- Install the HVAC system to use heat from upper floors to heat lower floors in the winter. This helps to supplement any heat that would need to be added to lower floors for operator comfort.
- Provide redundancy in design for critical equipment that supports the turbine and boilers.
- Leave time in the construction schedule for functional testing of interconnect safety relays and functional testing of all equipment before and during startup. Clearly spell out functional testing in the specifications to prove it was properly tested.
- Design the facility to operate continuously, 24 hours per day, 7 days per week, because a lot of effort and skill is required for startup and shutdown. Most problems occur during startup and shutdown. The process works best when the facility is in steady-state-mode operation.
- Any facility that supports heat recovery (such as incineration, dewatering, and thickening) should be reviewed prior to startup to ensure reliability to support the heat recovery facility. Any issues in these areas will affect heat recovery.
- Install all instruments used to measure boiler drums away from the steam drum. The steam drums emit a lot of localized heat (150°F, 66°C) and can affect electronics longevity and operation.
- Install local displays on instruments for ease of calibration/ troubleshooting.
- Incorporate into design the ability to maintain boiler tube temperature above 300°F (149°C) when boiler is off line to minimize condensation, which will form sulfuric acid and corrode the boiler tubes.

RESULTS

The main driver in designing and constructing the heat recovery process at the Hartford WPCF was to ultimately save the District's ratepayers money by generating electricity. Significant environmental benefits also come from the process, and safety is a paramount concern.

Safety—The District has operated for decades with a "Safety First" philosophy, and heat recovery is no exception. Safety was considered in every phase of heat recovery design, startup, and ongoing operations, and remains the highest priority. To date no reportable injuries have occurred in the facility. Every operator is authorized to implement an "emergency stop" to the facility at any time for any reason. There are many ways to do this, including use of SCADA and physical "Stop" buttons in the production area. The SCADA system monitors many different points within the systems and can automatically shut the system down if warranted or deliver alarms indicating a trend or an instance that needs attention.

Savings—Since WPCF staff took over operational responsibilities for the heat recovery process on January 1, 2014, results have exceeded expectations. In 2014, the heat recovery facility produced 7.6 million kilowatt hours (kWhs) (27.4 million megajoules [MJ]), valued at around $1 million (using $0.13 per kWh [$0.036 per MJ] as an "all in" rate). Performance in 2015 was even better, producing 9.7 million kWhs (34.9 million MJ), valued at around $1.3 million. Results for 2016 to date indicate a production rate (and savings) that will surpass the 2015 values. The project was designed to produce up to 40 percent of the plant's total electricity needs. In 2014, heat recovery produced 25 percent of the WPCF's electricity needs. In 2015, this increased to approximately 30 percent. Figure 3 shows a monthly comparison of energy production for 2014 and 2015.

Environmental Benefits—Heat recovery at the Hartford WPCF has numerous environmental benefits. The HRF system has reduced thermal waste to the environment, as the heat is now converted to electricity. Producing power onsite also reduces electricity line losses associated with the power produced far away from the WPCF that must travel many miles before being used. One hundred percent of the power generated onsite is used onsite. Pollution emitted at the generation source has been reduced, as less power is needed to satisfy the plant's electrical demand. A renewable source of fuel (biosolids) is now beneficially used. This "green" form of fuel is continuously produced at the WPCF from the sewage received 24 hours per day, 7 days per week.

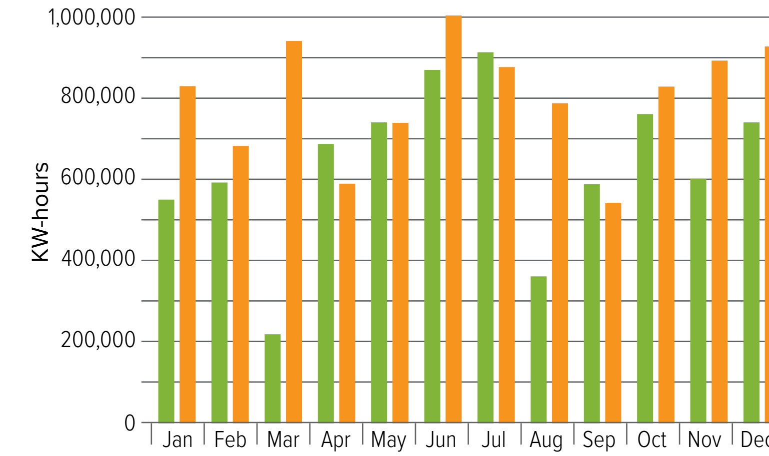

Figure 3. 2014 – 2015 Turbine KW-hours

LONG-TERM OPERATIONS

As the District winds down on the third year of heat recovery operations, long-term planning for plant rehabilitation is underway. Boilers must be inspected annually. This requires a plant shutdown, and while this time needs to be minimized due to lost power production, it creates an opportunity to complete minor maintenance, repairs, and modifications not possible during production. Long-term rehabilitation of major systems (boilers, turbine, high voltage electrical gear, and other systems) will be handled through specification development and bidding. This work is beyond in-house capabilities due to the expertise required. The main goal is keep the system running safely for the full design life to maximize power production.

CONCLUSIONS

The Hartford WPCF has successfully converted biosolids to energy to beneficially use its resources. The new HRF uses excess heat from sludge incineration to produce electricity, reducing power costs significantly. Use of this heat from incineration can generate up to 40 percent of the facility's energy. In the first two years of operation, the new heat recovery and power generation system produced 7,600 MWh and 9,600 MWh (27,000 MJ and 34,500 MJ), respectively, equating to cost savings of $1.1 million to $1.3 million annually.

From an operations perspective, the District's wastewater treatment facility has become a resource recovery facility. This has required operators to add power plant operations and maintenance to their set of skills. Grooming operators who have the interest and proficiency in the system is critical to its success.

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Thomas Tyler, P.E., manages water pollution control for the Metropolitan District in Hartford, Connecticut. Jeffrey Bowers, Hartford WPCF superintendent, and Michael Zabilansky, facility engineer, contributed to this article and to the project's success.