EXHIBIT A

World-Class Technology for the Newest Waste-to-Energy Plant in the United States — Palm Beach Renewable Energy Facility No. 2

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J.B. Kitto, Jr., M.D. Fick, and L.A. Hiner
The Babcock & Wilcox Company, Barberton, Ohio, U.S.A.

W.J. Arvan
Palm Beach Resource Recovery Corporation, West Palm Beach, Florida, U.S.A.

R.H. Schauer
Solid Waste Authority of Palm Beach County, West Palm Beach, Florida, U.S.A.

Abstract

On July 18, 2015, Palm Beach Renewable Energy Facility No. 2 (PBREF No. 2) began commercial operation following successful completion of the plant acceptance tests. The plant is owned by the Solid Waste Authority (SWA) of Palm Beach County and is the first greenfield waste-to-energy (WTE) facility to come online in North America in 20 years. Combining the best of U.S. and European WTE emissions control and metals recovery technologies, PBREF No. 2 is the cleanest, most efficient plant of its kind in the world today. Advanced technologies provide better than zero water discharge, emissions at or below the best natural gas turbines, better than net-zero greenhouse gas (carbon equivalent) footprint, and a Leadership in Energy and Environmental Design (LEED®) Platinum-level Education Center. This presentation begins with background on municipal solid waste (MSW) and then provides an overview of the project and plant, summary of the WTE and emissions control technologies and finally, acceptance test results and economics. PBREF No. 2 is at the forefront of renewed interest in WTE plants in North America as reliable, economical generators of renewable energy and material recycling. WTE is a key part of a comprehensive solid waste management strategy to minimize/eliminate landfilling as demonstrated in Europe and is a critical part of integrated greenhouse gas (carbon equivalent) footprint control and minimization.

Introduction and MSW Background

Municipal solid waste (MSW) or more simply, trash or garbage, is part of everyday life. How MSW is handled, processed and disposed of involves both a need to protect the environment and an opportunity to take advantage of the resource it represents to benefit society. Waste-to-energy (WTE) plants such as Palm Beach Renewable Energy Facility No. 2 (PBREF No. 2) are part of a broader comprehensive solid waste management strategy which minimizes waste, recycles resources, recovers renewable energy and ultimately minimizes or eliminates disposal of any residuals in landfills. The goal is to manage MSW in the most productive and sustainable way possible.

The PBREF No. 2 is the first greenfield plant addition to the U.S. WTE fleet in 20 years, and is the cleanest most advanced plant of its kind in the world as of this writing. The plant design builds upon U.S. technology and experience while incorporating dramatic technology advancements over the past 20 years from Europe where hundreds of new WTE plants have been (and continue to be) placed into operation as part of Europe's aggressive program to eliminate long-term landfill needs.

According to the U.S. Environmental Protection Agency (EPA)[1-4], every person in the United States (U.S.) generated an average of 4.4 lb (2 kg) of MSW each day in 2013. In typical metropolitan areas with a population of 1.5 million people, this would result in the need to manage 3300 tons per day (TPD [3000 t_m/d]) or 1,200,000 tons (1.1 Mt_m) per year. By common convention, MSW is household and commercial waste but excludes construction and demolition debris. As shown in Fig. 1, U.S. MSW contains high percentages of paper and plastics resulting in a higher heating value and lower moisture content than other MSW found around the world.

Fig. 2 illustrates an integrated strategic approach to managing MSW in a way which maximizes the benefit of the material and renewable energy recovery with minimum environmental impact. Clearly, the first stage is selfevident: minimizing generation of the waste materials to start with and reusing the materials. The level of reduction here is a matter of economics (saving money), technology (product design and material recovery) and in some cases regulations which may mandate recovery. Recycling and composting are the next steps in the strategy with curbside recycling programs and home composting combined with post-collection material separation in large-scale Material Recovery and Recycling Facilities (MRRFs) and large-scale compositing facilities. The balance between individual and community programs depends upon location, cost and willingness to participate. After recycling and compost diversion, the balance of the material is largely paper and biomass/organics that contain significant quantities of usable energy. This can be used as a fuel for modern WTE plants to generate electricity and, depending upon location, steam for industrial processes and heating purposes. WTE plants also offer the capability to recover more metals and plastics depending upon the WTE technology used, thereby increasing the overall recycle rate. Finally, the inert residue from the WTE plant can be used for a variety of applications depending upon local regulations (such as aggregate for concrete, road fill and ground cover) or disposed of in a landfill.

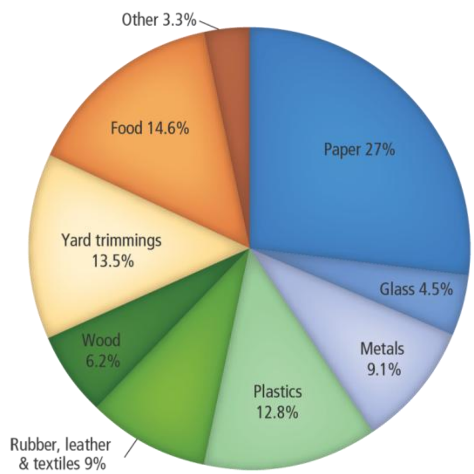

Fig. 1 U.S. MSW generation by material, 2013 (References 2 and 4). Based upon 254.1 million tons (231 million t_m) before recycling and composting.

Fig. 2 Integrated waste management strategy. (Reference 5)

In the U.S., the balance between recycle/compost, landfill and WTE varies widely by region and state.[5,6] In 2013, the U.S. recycled/composted 34.3% of its MSW while 52.8% was disposed of directly in landfills.[3] The balance of 12.9% was combusted in 77 WTE plants with a capacity to generate 2.5 GWe of electricity.[5] At the same time, Europe has made much greater progress in reducing MSW sent to landfills. In aggregate during 2013, the European Community (EC) recycled/composted 43% of its MSW and landfilled just 31% with the balance of 26% processed in 459 WTE plants (90 million tons per year).[7] In some of the most advanced countries such as Denmark, 45% of the MSW is recycled/composted and 53% is processed in 27 WTE plants, leaving just 2% of the material going to landfills. (See Fig. 3.)

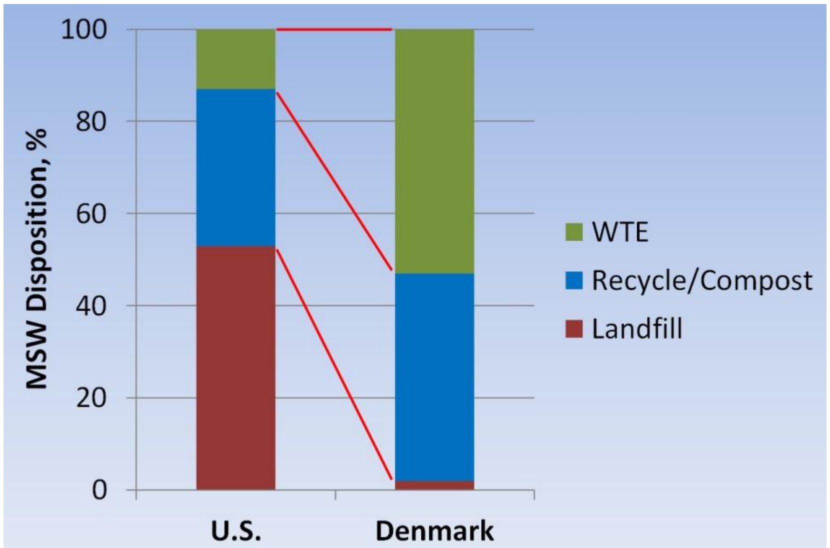

Fig. 3 Comparison of U.S. and Denmark MSW disposition (2013).

As discussed in Reference 8, there are two basic WTE plant technologies with the decision of which to use depending upon location specific parameters and economics. The first technology is *mass burn* where the MSW is fed directly to the boiler system without any significant processing. The post-combustion residual is then processed to recover and recycle remaining metals while the balance is used in a beneficial application (example road-fill) or landfilled. The second technology is *refuse derived fuel* (RDF) where the MSW is processed first to remove metals and low-Btu residue (glass, grit, foodstuffs, etc.) before being processed into a reasonably uniform-sized fuel for combustion. With the extensive curb-side recycling programs already in place as well as limited long-term landfill capacity, PBREF No. 2 was designed using mass burn technology with state-of-the-art post-combustion metals recovery.

Project Overview

In December of 2008, the Solid Waste Authority (SWA) of Palm Beach County, Florida, began the process of selecting a team to design, build and operate a new greenfield 3000 TPD (2700 t_m/d) WTE plant based upon mass burn technology with the issuance of the PBREF No. 2 comprehensive bid package and specifications. A key element in the evaluation process was a 20-year net present value analysis including capital costs, operation and maintenance costs, and beneficial revenue streams including electricity production. On April 13, 2011, SWA awarded the Design/Build contract to the Babcock & Wilcox (B&W)-led team. SWA is the owner of the facility with Arcadis serving as owner's engineer. The B&W team consisted of B&W supplying the major equipment including boilers, combustion grate systems, emissions control systems, metals recovery/processing equipment, emissions monitoring systems, and ash handling equipment, and KBR with its subcontractor CDM Smith handling the balance-of-plant material and construction. B&W also received a parallel contract for the 20-year operation and maintenance (O&M) of the new facility. PBREF No. 2 achieved commercial operation and start of the O&M contract in July of 2015 with completion of the acceptance tests.

This new plant is located adjacent to the existing SWA-owned RDF-fired WTE plant (PBREF No. 1) which B&W has operated since commercial operations began in November of 1989 (current capacity 2650 TPD [2400

t_m/d]). These facilities are the cornerstone of the SWA's Integrated Solid Waste Management System serving the 1.4 million residents of Palm Beach County and handling 100% of the MSW after the extensive curbside recycling programs.

Plant Overview

Fig. 4 provides an overview of PBREF No. 2 from June 2015 looking from the northeast to the southwest. PBREF No. 2 is located on a 24-acre site. The major operating segments of the plant are identified and include: the tipping floor, refuse pit (360 x 100 ft [110 x 30 m]), boilers, emissions control (spray dryer absorbers, fabric filters, carbon injection and SCR reactors), air-cooled steam condenser and turbine generator set. The ash management building houses the metals recovery systems as well as the ash processing equipment which mixes and conditions the material prior to shipment to the landfill.

The Education Center is an important element of the plant design. The SWA conducts extensive tours and educational sessions for the school children and citizens of the county describing the overall MSW management process as well as the WTE plant operation. To facilitate the educational experience, the Education Center incorporates some of the latest interactive educational displays and tools available. As shown in Fig. 4 an elevated walkway connects the Education Center to the WTE complex and enables the visitors to experience all phases of the WTE operation during the walking tour. Finally, the 2-million gallon rainwater retention tank is part of the water management system discussed below.

Jog Road provides site access and serves as the eastern facility boundary. At the top right is the 23 square-mile Grassy Waters Everglades Preserve, a wildlife sanctuary which also serves as the western boundary of the facility as well as the water supply for West Palm Beach and surrounding communities. At the top left of the figure, the PBREF No. 1 serves as the southern boundary.

Fig. 4 PBREF No. 2 plant overview (from June 2015 looking from northeast to southwest).

Fig. 5 provides a sectional side-view of the plant looking west and approximately to scale. There are three independent parallel boiler/grate/emissions control lines rated at 1000 TPD (907 t_m/d) each, with one line shown in the figure. The MSW is received on the tipping floor with the majority delivered by a fleet of SWA-owned tractors with walking-floor trailers which service one of six transfer stations located across the county. MSW is also delivered by local collection trucks not serviced by a transfer station, private industry vehicles and other SWA-directed sources including PBREF No. 1 process residue and out-of-county waste. The MSW is dumped into the refuse pit where it is mixed and managed by three Konecranes semi-automated refuse cranes though no more than two cranes are required at any time. The refuse cranes also deliver the MSW to a charging hopper at the inlet to the boiler. From the hopper, the MSW is fed to the grate where the combustion process begins. The combustion is completed as the flue gas passes upward through the boiler where heat is recovered to generate steam for power generation. The cooled flue gas then passes through the emissions control equipment consisting of powder activated carbon (PAC) injection, spray dryer absorber (SDA), pulse jet fabric filter (PJFF), gas-to-gas heat exchanger, and selective catalytic reduction (SCR) reactor. Finally, induced draft fans exhaust the cleaned gas to the stack. Steam generated in the three boilers powers a single General Electric steam turbine generator set nominally rated at 95 megawatts (MWe), with the power, net of parasitic load, being supplied to Florida Power & Light under a power purchase agreement. Steam is exhausted from the turbine to an SPX air-cooled steam condenser and the condensate returned to the power cycle. Not shown in Fig. 5 is the metals recovery system for the boiler bottom ash. Ferrous material (iron) is collected using a rotating drum electro-magnetic separator and other non-ferrous metals (predominately aluminum) are then collected using an eddy current separator.

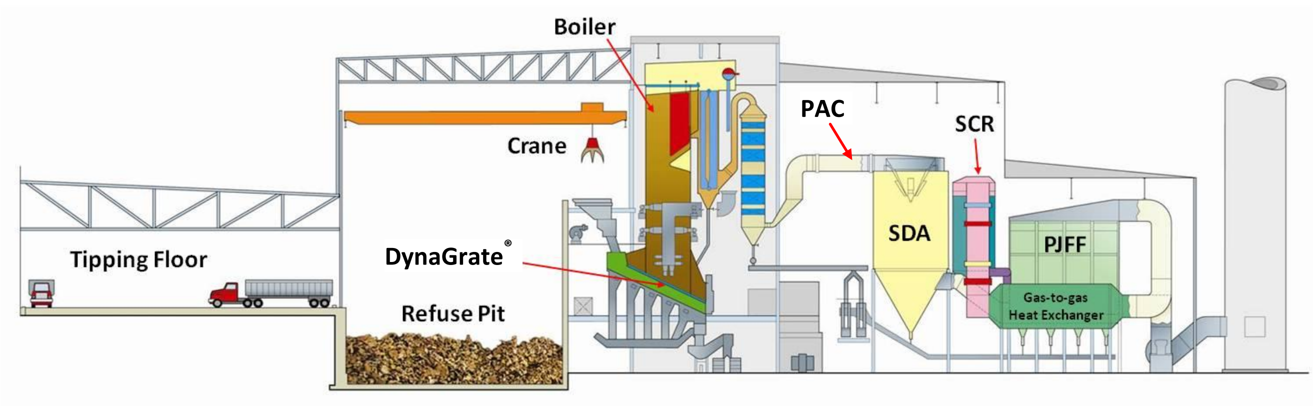

Fig. 5 Side view of PBREF No. 2 looking west showing one of three process lines. (Not shown: turbine generator behind and metals recovery/ash management in the foreground)

Sustainability and Energy Efficiency

Superior sustainability and energy efficiency are important to SWA. A number of major plant features focus on these areas:

1. Water Conservation: PBREF No. 2 has been designed around a *better than net zero discharge* philosophy and minimum water usage. As shown in Fig. 6, the water supply for the plant includes:
    a. Harvested rainwater from the major PBREF No. 2 building roofs and the PBREF No. 1 tipping floor roof which is stored in a 2-million gallon (7.6 million liter) storage tank shown in Fig. 4. Depending upon the time of year, this source will typically supply 5 to 15% of the plant water needs.
    b. Cooling tower blowdown from PBREF No. 1 which has historically been deep well injected. This source supplies about 60% of the plant water needs — reducing the deep well injection from the **total** PBREF site below the PBREF No. 1 rate, thus providing *better than net zero discharge* for the PBREF No. 2 addition.
    c. Off-site industrial water. This source provides the balance of the water needs, seasonally ranging from 25-35% of the total plant water requirements.
    d. Neither de-chlorinated water nor potable water is required for normal plant operations.
2. Energy Recovery: PBREF No. 2 was designed to optimize the recovery of energy from the MSW to maximize **recycle of the energy** from the raw and manufactured materials back into the economic system — helping to better close the energy loop while reducing greenhouse gas emissions.

3. Materials Recovery: Ferrous and non-ferrous metals are recovered from the ash after the combustion process for recycle thus reducing needs for raw materials and reducing global greenhouse gas (GHG) emissions from virgin material processing.
4. LEED Platinum Design for the Education Center: This building was designed to U.S. Green Building Council Leadership in Energy and Environmental Design (LEED) criteria. The SWA has initiated the LEED Platinum certification process.
5. Air-Cooled Steam Condenser: This technology is used to replace the wet cooling towers which are normally used in WTE applications to reject heat from the power cycle, thus dramatically reducing the PBREF No. 2 water consumption.
6. Regenerative Braking for Refuse Cranes: When the refuse crane grapples are lowered, they use regenerative braking to generate electricity.
7. Variable Frequency Drives: The use of these drives for the induced draft and forced draft fans optimizes motor power consumption across the plant's range of operations, particularly when at less than full load operation.
8. Flora and Fauna Relocation: As part of the Design/Build contract, more than 2000 native trees, including all palm and many oak trees, were removed and replanted either on or adjacent to the site. In addition, a number of large animals, including 10 to 13 foot-long alligators were relocated from the site to the adjacent Grassy Waters Everglades Preserve.

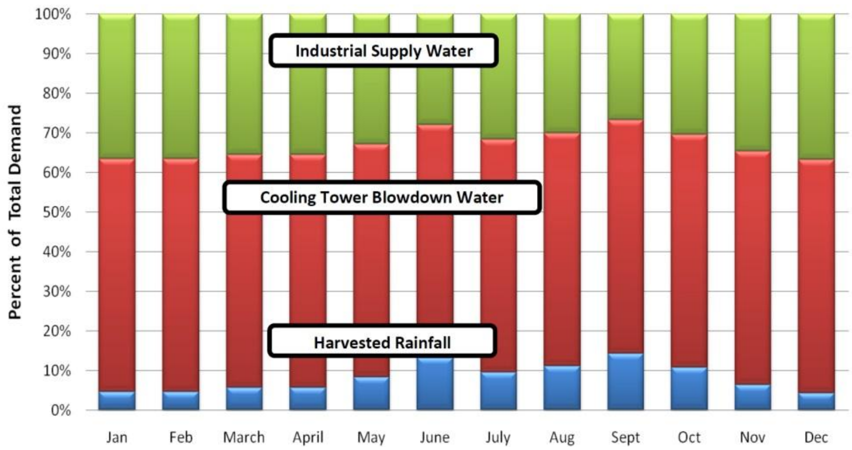

Fig. 6 Nominal water supply sources for PBREF No. 2.

Positive economic impacts on the local Palm Beach County communities were also a major goal of the SWA. As part of the construction and material supply sections of the Design/Build contract, extensive efforts were required to buy and hire locally (a win-win for the B&W team and the County). Approximately 20% of the total project value ($136 million) was spent with Palm Beach County businesses, with a quarter of that going to Small/Minority Business Enterprises (S/MBE). In addition, with a peak construction workforce of more than 1000 people, over 1.1 million construction labor hours were performed by Palm Beach County residents, exceeding the B&W team's 45% commitment.

Sustainability — Landfill Impact

The mass burn WTE process reduces the volume of material which will need landfilled by up to 90% while also effectively eliminating the residual organic compounds (combusted in the WTE process) — even potentially eliminating landfill for that portion of the residual which can be used for other beneficial applications such as road fill, concrete aggregate or ground cover. As a critical part of the project, the volume reduction significantly extends the life of the existing SWA landfill by many years. This eliminates the short-term and mid-term need for the siting, permitting, acquisition, start-up costs and operating costs of a new landfill while eliminating the environmental impact and risks of the expanded landfill footprint. As discussed later under *Greenhouse Gases*, methane gas emissions from the new landfilled MSW are eliminated and energy recovered. Odors from new landfilled MSW materials are eliminated with the destruction of the source organic compounds. Finally, the WTE process effectively eliminates new MSW landfill gaseous emissions of a variety of hazardous volatile organic and chlorinated hydrocarbons including ammonia, mercaptains/sulfides, toluenes, dichloromethane, and acetone among others.

Boiler, Grate and Combustion Technologies

Three independent parallel 1000 TPD (907 t_m/d) mass burn lines process the MSW in three B&W Stirling® power single-pass mass burn boilers shown in Fig. 7. While several boiler design options are available from B&W for mass burn applications as discussed in Reference 8, the single-pass design offered the best value proposition for PBREF No. 2. Referring to Fig. 7, MSW from the refuse storage pits is transferred to the refuse feed hopper by the refuse cranes and is then fed into the boiler/grate system by hydraulic ram actuators. The refuse combustion is begun on the B&W Volund DynaGrate® pivoting combustion grate. The combustion products or flue gases then pass vertically up through the furnace where the combustion is completed by the addition of more air through the B&W Precision Jet® overfire-air system. The furnace design in modern WTE systems is critical. Proper design permits at least two (2) seconds of residence time above 1800F (982C) to destroy dioxins (polychlorinated dibenzo-para-dioxins [PCDD]) and furans (polychlorinated dibenzofurans [PCDF]) which can be formed during the combustion of plastics in the MSW. The overfire-air system also minimizes the formation of nitrogen oxides (NO_x) and carbon monoxide (CO). Further emissions reductions are achieved in the post-combustion emissions control equipment.

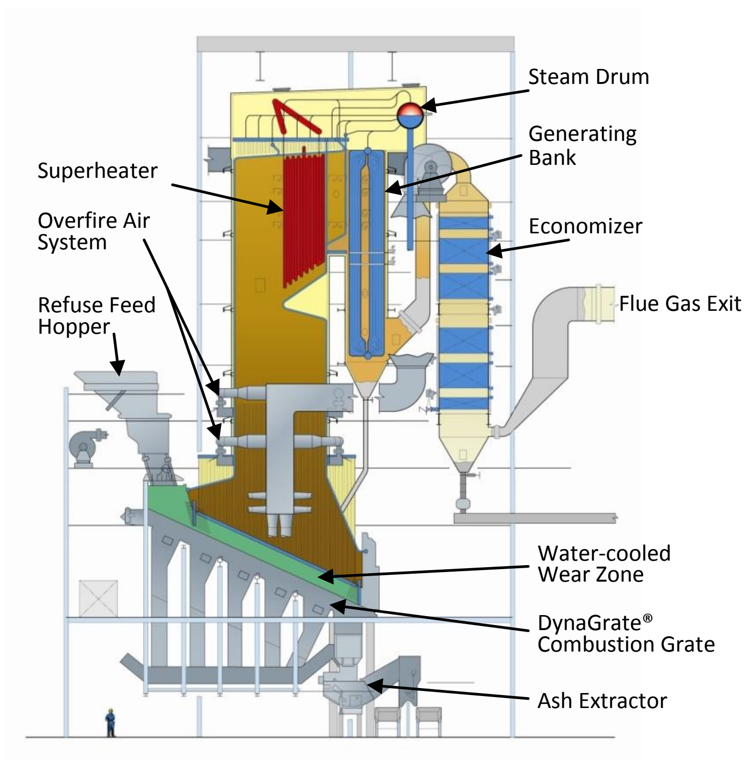

Fig. 7 B&W Stirling® mass burn power boiler schematic.

The flue gas is then cooled to recover heat as it passes through the remaining boiler furnace and heat transfer surfaces before flowing to the emissions control equipment. Each boiler provides 284,400 lb/hr (35.8 kg/s) of steam at 900 psi (6.2 MPa) and 830F (443C) to the turbine for power generation at maximum continuous rating (MCR). The boilers incorporate the best in modern U.S. and European design practice including: total Inconel® weld overlayed furnaces to provide protection from the corrosive flue gases, minimal use of refractory to reduce maintenance expense, water-cooled wear zone to minimize slagging, erosion and corrosion near the grate, and superheater heat transfer surfaces with access for easy replacement. A key advantage of B&W's combustion technology, unlike other designs, is that flue gas recirculation (combustion products recirculated to the combustion zone) is **not** required to minimize NO_x formation. Such flue gas recirculation systems result in added capital and O&M costs and reduced boiler availability.

The B&W Volund DynaGrate combustion grate shown in Fig. 8 is modular in design with two modules wide and four modules in the direction of fuel flow in each boiler. The grate consists of an alternating series of horizontal and vertical bars across each module which rotate slowly back and forth 60-degrees to create a mixing-tumbling motion. This action continuously mixes the fuel exposing fresh surface for combustion and moves the refuse continuously down the inclined grate surface from the ram charger inlet to the ash discharge. Primary combustion air is admitted from below through well-defined air gaps between the rotating grate bars. This patented rotating bar design provides very uniform air flow across the grate surface and avoids pluggage of air holes used with other grate systems. The grate speed of each module is independently controlled as is the air flow to each module permitting the integrated control system to optimize the combustion over each of the eight grate module surfaces. The overall result is a combustion system that consistently yields very low unburned carbon in the ash and very low CO concentrations in the flue gas (maximizing combustion efficiency while minimizing emissions). Lack of contact between the bars and between the bars and sidewalls minimizes wear and associated maintenance. All mechanical linkages and equipment rotating the bars are external to the grate module and boiler providing superior maintenance access.

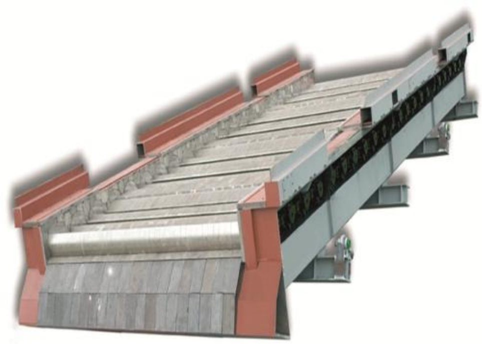

Fig. 8 B&W Volund DynaGrate® pivoting combustion grate.

Extensive computer modeling was used (Fig. 9) to design the overfire air system and to ensure maximum combustion efficiency and minimum formation of CO, NO_x and other pollutants. As shown in Fig. 9, two levels of secondary air injection nozzles are provided in the PrecisionJet system. The large low-pressure nozzles are staggered and interlaced between the front and rear walls of the boiler furnace to maximize coverage and mixing. As shown, an additional set of air nozzles is provided above the inlet to the grate for enhanced fuel drying control.

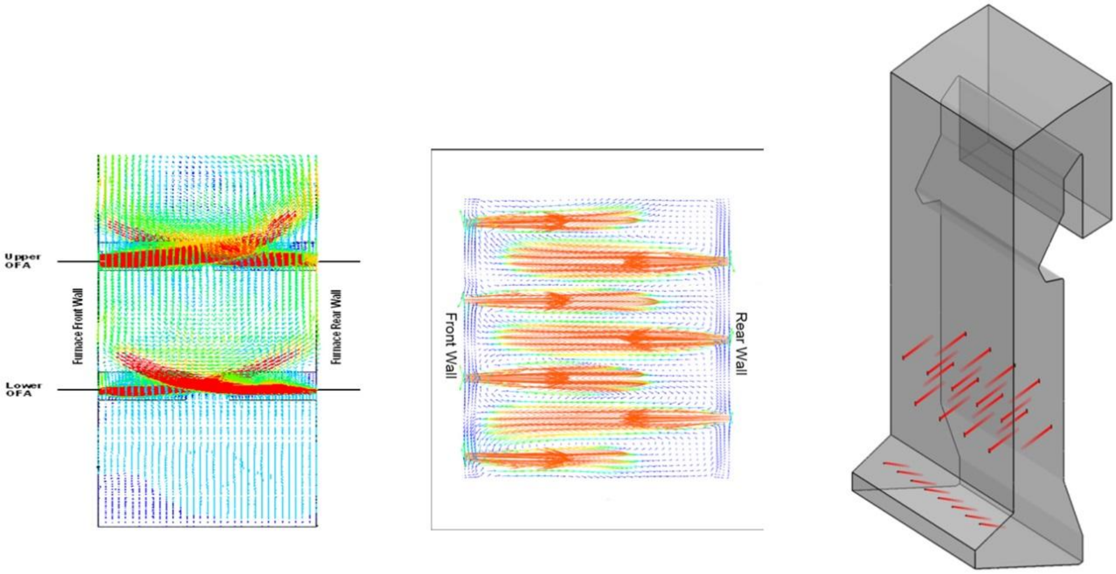

Fig. 9 Combustion modeling for PrecisionJet® air system.

Automated Refuse Crane Technology

Three Konecranes refuse cranes (see Fig. 10) with grapples are part of PBREF No. 2 fuel feed system with no more than two cranes required for routine operations at any one time. A spare crane is provided to allow for out-of-service maintenance work. The cranes provide fuel management and mixing in the refuse pit as well as transfer refuse from the pit to the boiler charging hoppers. Each crane is capable of lifting 16 t (14.5 t_m) each. Fuel management with the cranes can be executed using manual, semi-automatic or fully automatic operation. The cranes can be operated in a fully automated mode without a dedicated operator, such as at night when there are no MSW deliveries. The cranes can travel at 300 ft/min (1.5 m/s) and include anti-sway and anti-collision automation. The cranes also use regenerative braking to recover energy as the grapples are lowered to the refuse pit, reducing electricity usage.

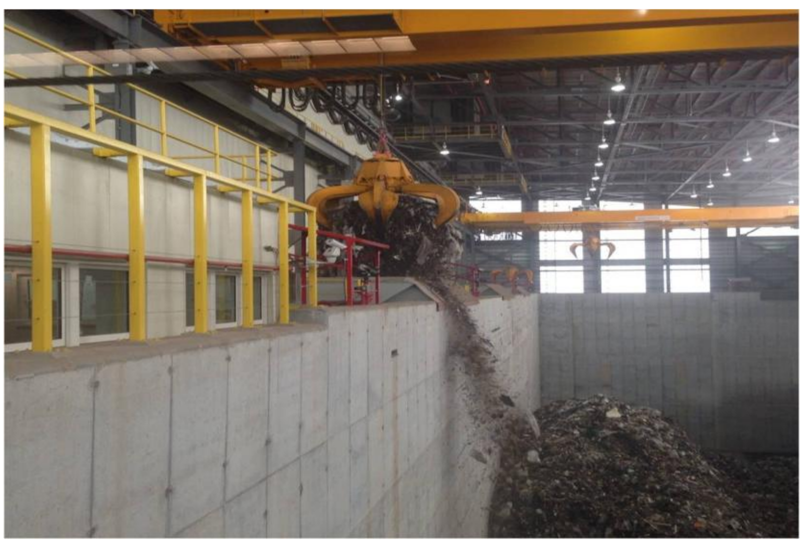

Fig 10 Automated refuse crane technology.

Post-Combustion Emissions Control Technology

The PBREF No. 2 post-combustion emissions control system, in combination with the combustion system, provides for the control of primary and secondary pollutants below permit levels. Post-combustion NO_x control is achieved by selective catalytic reduction (SCR). Acid gases (predominantly sulfur dioxide [SO_2] and hydrogen chloride [HCl]) are removed using the spray dryer absorber (SDA) in combination with the pulse jet fabric filter (PJFF). Particulate including metals and lead are controlled by the PJFF. CO, volatile organic carbons (VOCs) and dioxins/furans are primarily controlled through the combustion process, but powdered activated carbon (PAC) injection in combination with the PJFF provides additional dioxin/furan control. Finally, mercury (Hg) is controlled by the PAC injection in combination with the fabric filter.

The post-combustion emissions control system for the three MSW lines is shown in Fig. 11. Flue gas from the boilers enters on the left. PAC is injected into the flue gas before entering the vertical SDA for acid gas control and mixing of the flue gas with the PAC. The flue gas exits the SDA at the desired relative humidity, which for PBREF No. 2 typically corresponds to an SDA outlet temperature range of 280 to 290F (138 to 143C) and passes through the PJFF for particulate removal, including fly ash, unreacted lime reagent from the SDA, and reaction products from the SDA and PAC injection. Flue gas leaving the fabric filter then passes through a reheat heat transfer system to increase the flue gas temperature to ~450F (232C) before passing vertically downward through the SCR reactor to further reduce NO_x emissions. Following the SCR, the flue gas passes back through the heat exchanger system to recover energy back into the power cycle before passing through the induced draft fans and ultimately the stack. The system shown is designed for a minimum footprint for reduced capital costs and for maximum energy recovery to keep plant efficiency high.

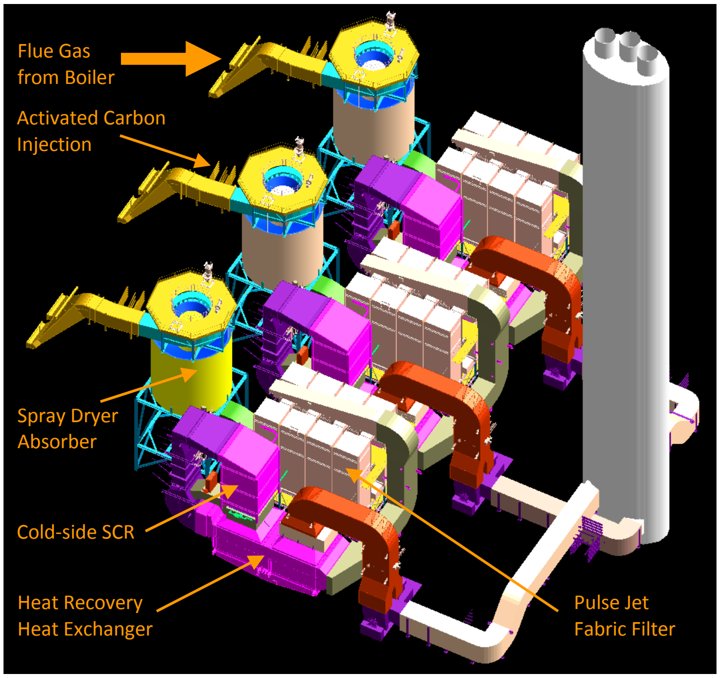

Fig. 11 Post-combustion emissions control technology.

While all of the post-combustion technologies are discussed in detail in References 8 and 9, the following material touches on some of the key elements with reference to PBREF No. 2. The PAC system provides for fine powdered carbon injection into the flue gas upstream of the SDA for control of mercury and residual dioxins and furans. The PAC is stored outside of the building in vertical silos and is pneumatically conveyed to the injection point. The SDA provides mixing to maximize contact with the flue gas. The spent and unreacted PAC is then collected in the PJFF.

Lime slurry is injected into the SDA for acid gas removal (SO_2, HCl, HF and H_2SO_4). The lime slurry is injected downward through a mechanical atomizer and mixed with the flue gas introduced into the SDA though a gas disperser assembly. Pebble lime is stored outside of the building in a vertical silo and then mixed/slaked with water to create the lime slurry for injection. For rapid load response, additional water is injected separately into the SDA to provide control of the flue gas humidity (a key performance parameter for acid gas removal and lime utilization) which is monitored at the SDA exit. The reaction products and the unreacted lime are collected in the PJFF. Additional acid gas absorption takes place as the flue gas passes through the particulate filter cake and unreacted lime on the upstream side of the filter bags.

The PJFF collects particulate on the outside of vertically hung tubular filter bags within the fabric filter enclosure as the flue gas passes vertically upward outside and then through the PTFE (polytetrafluoroethylene) membrane-coated bag material. A filter cake consisting of ash, reaction products, unreacted lime and PAC collect on the outside of the bags. The filter cake is periodically removed from the bag by periodic bursts of high pressure air directed down the bags and collected in the bottom hoppers for transfer to the ash management building. The filter cake also removes additional pollutants as the flue gas passes through the unreacted reagents.

The SCR NO_x reduction system is the first such system installed on a WTE application in North America. This is a low dust (after PJFF) and low temperature system. Vaporized aqueous ammonia is injected through a manifold and injection grid system into the flue gas upstream of the catalyst reactor. The flue gas then passes vertically downward through the Ceram ceramic catalyst blocks where NO_x is converted to nitrogen (N_2) and water vapor (H_2O) through reaction with the ammonia (NH_3) in the presence of the catalyst. The catalyst consists primarily of titanium oxide with small amounts of other material to enhance low temperature performance and resist degradation. The 19% aqueous ammonia solution is stored outside of the building in a contained storage tank. The reactor is designed to accept a number of different catalysts when the catalyst is ultimately removed because of deactivation. The reactor is also positioned within the emissions control building to permit rapid catalyst replacement. The SCR system also has the added benefit of further reducing the emissions of any remaining dioxins and furans in the presence of the catalyst.

Finally, the SCR flue gas reheat/heat recovery system provides the critical flue gas temperature necessary for optimal catalyst operation without firing natural gas or penalizing the power plant efficiency as shown in Fig. 12. After the flue gas leaves the PJFF it passes first though a gas-to-gas heat exchanger which heats the flue gas close to the required temperature by using the waste heat in the flue gas leaving the SCR reactor. The flue gas then passes through a steam coil gas heater which uses steam extracted from the boiler drum to achieve the target ~450F (~232C) flue gas temperature. After the SCR reactor, the flue gas then passes back through the gas-to-gas heat exchanger to recover part of the energy in the flue gas. It then passes through a finishing heat exchanger which utilizes low temperature boiler feedwater to extract the last of the energy and reduce the gas temperature to the desired stack temperature (~295F [146C]). Thus the reheat/heat recovery system is fully integrated into the power cycle to maximize plant thermal efficiency.

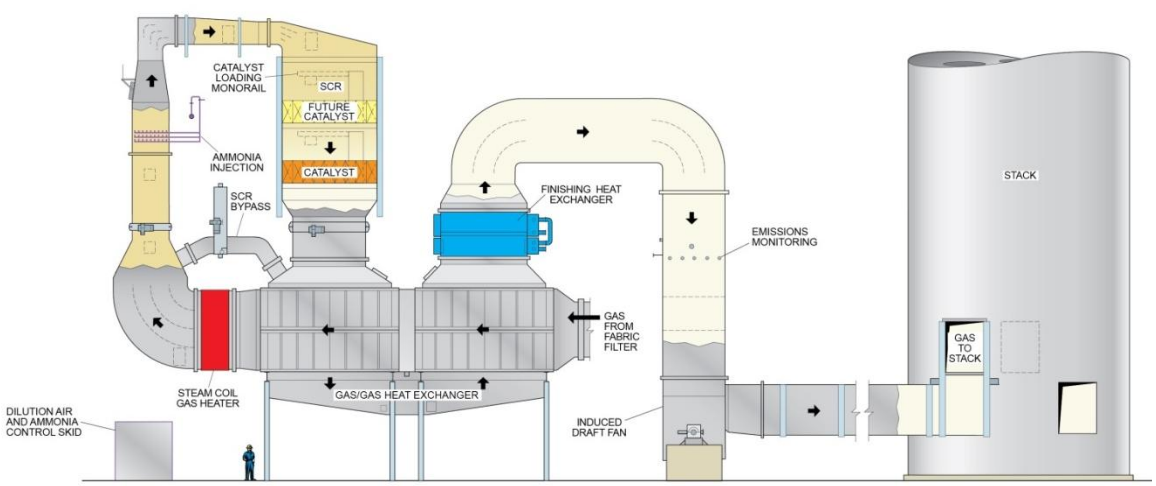

Fig. 12 SCR reheat and heat recovery system.

Power, Metals Recovery and Emissions Acceptance Test Results

MSW throughput, thermal performance, metals recovery, noise, plant reliability and emissions tests were conducted in the summer of 2015 as part of the formal PBREF No. 2 acceptance. Acceptance tests were conducted over a 30-day period where continuous operation was required and a number of individual heat rate (thermal efficiency) and emissions tests were conducted. PBREF No. 2 exceeded all MSW throughput requirements.

During the continuous operation test period, three 8-hour thermal efficiency performance tests were conducted in accordance with ASME PTC-34 Performance Test Code.[10] The B&W team guaranteed an electrical generation rate of 625 kWh per ton of reference MSW with 5000 Btu/lb heat content. This is equivalent to a more conventional power plant heat rate of 16,000 Btu/kWh which is at the lower end (higher efficiency) of state-of the art WTE facilities. During the performance tests, the three measured heat rates (as corrected by PTC-34) ranged from 666 to 677 kWh/reference ton or 6 to 8% higher than the guarantee value making PBREF No. 2 one of the best in class for modern mass burn units of its kind.

Tests were also conducted to verify the guarantees for ferrous and non-ferrous metal recovery from the bottom ash of the three units. The ferrous recovery rate guarantee was 90%. Over the test period, the ferrous recovery system recovered 97.2% of ferrous metals. The non-ferrous recovery rate guarantee was 85%. Over the test period, the non-ferrous recovery system recovered 88.6% of the non-ferrous metals.

Three 4-hour emissions tests were also conducted on each of the three units by an independent contractor over the continuous operation acceptance test period providing nine total sets of emissions results. The results for the primary pollutants are summarized in Table 1. This table also provides the PBREF No. 2 permit emissions limits as well as the emissions from natural gas turbines for comparison purposes. Key results include:

1. PBREF No. 2 achieved all of its permit emissions guarantees in every case with values significantly below the permitted levels.
2. The PBREF No. 2 emissions results are at the low end of or below the emissions of natural gas-fired turbines.

Table 1
PBREF No. 2 Emissions – As Good as or Better Than a Gas Turbine

Pollutant	Natural Gas Turbine Exhaust [Note 1]	PBREF No. 2 Emissions Permit	PBREF No. 2 Actual Emissions Test [Notes 2, 3]
Nitric Oxide	20 – 220 ppm	< 50 ppm	30 – 31 ppm
Nitrogen Dioxide	2 – 20 ppm	Included above	Included above
Carbon Monoxide	5 – 330 ppm	< 100 ppm	15 – 24 ppm
Sulfur Dioxide	Trace – 100 ppm	< 24 ppm	10 – 21 ppm
Sulfur Trioxide	Trace – 4 ppm	Not required	Not detectable/Trace
Unburned Hydrocarbons	5 – 300 ppm	< 7 ppm	0.2 – 2.7 ppm
Particulate Matter	Trace – 25 ppm	12 mg/dscm	0.6 – 2.5 mg/dscm

- All data shown for typical concentration (parts per million volume) except where noted
Note 1: Natural gas data source: *Gas Turbine Emissions and Control*, GE Power Systems white paper
Note 2: PBREF No. 2, data source: Babcock & Wilcox
Note 3: Actual emissions test conducted during compliance test, three 4 hr. test per unit – 9 total tests with range showing high and low measurement under stable full load testing

Table 2 provides the results for emissions that are of particular concern for WTE facilities. The PBREF No. 2 permit emissions limits are provided for comparison.

1. PBREF No. 2 achieved results below all of its permit emission limits.
2. Many of the PBREF No. 2 results are an order of magnitude below the emissions limits making it the best in class of WTE facility in the U. S. and the world.

Table 2
Emissions of WTE-Sensitive Pollutants – Best of Class for WTE Systems

Pollutant	PBREF No. 2 Emissions Permit	PBREF No. 2 Actual Emissions Test Notes 2, 3
Dioxin/Furan	< 10 ng/dscm	0.23 – 0.36 ng/dscm
Trace Metals (Hg)	< 25 µg/dscm	0.55 – 0.62 µg/dscm
Trace Metals (Cd)	< 10 µg/dscm	0.26 – 2.54 µg/dscm
Trace Metals (Pb)	< 125 µg/dscm	0.51 – 8.05 µg/dscm
HCl	< 20 ppm_{dv}	1.5 – 2.1 ppm_{dv}
HF	No limit set Note 1 (<10 ng/dscm)	<0.1 ng/dscm; not detectable

Note 1: Predicted value < 10 ng/dscm, testing only to verify
Note 2: PBREF No. 2, data source: Babcock & Wilcox
Note 3: Actual emissions test conducted during compliance test, three 4 hr. test per unit – 9 total tests with range showing high and low measurement under stable full load testing

To put these results into perspective and to understand the major advancements of today's modern WTE facilities as compared to the original emissions results of WTE plants constructed thirty years ago, it is worthwhile to consider the emissions of dioxins/furans. During the 1980s before the importance of WTE facility dioxin/furan emissions were fully understood, WTE facilities had dioxin/furan emissions equivalent to over 10,000 ng/DSCM. The cause was primarily due to small hot combustion furnaces (for low initial capital cost) without the volume or flue gas residence time at elevated temperatures (1800F [982C] or higher) to control pollutant formation and destruction, as well as the lack of post-combustion controls. In contrast, PBREF No. 2 dioxin/furan emission results of 0.36 ng/dscm are more than four orders of magnitude below the results in the 1980s for a reduction of more than 99.996%. The EPA has indicated that WTE industry retrofits and compliance measures to meet current emissions regulations have reduced annual emissions from all U.S. WTE plants in aggregate from an estimated 18 lb (8.2 kg) of dioxin toxic equivalents in 1987 to an aggregate total of less than 0.5 oz (14 g) per year today.[11,12] PBREF No. 2 measured emissions (Table 2) are more than an order of magnitude less than today's stringent emissions limits. The EPA has also recognized dramatic emissions reductions in other WTE plants as indicated in Table 3.

Table 3
Emissions Reductions from Large and Small WTE Units from 1990 to 2005 As Reported by the U.S. EPA (Reference 11)

Pollutant	1990 Emissions (t/yr)	2005 Emissions (t/yr)	Percent Reductions
CDD/CDF, TEQ basis Note 1	4400	15	99+%
Mercury	57	2.3	96%
Cadmium	9.6	0.4	96%
Lead	170	5.5	97%
Particulate Matter	18,600	780	96%
HCl	57,400	3200	94%
SO_2	38,300	4600	88%

Note 1: Toxic equivalent (sum of substance amounts multiplied by toxicity equivalency factors)

Finally, even when MSW is buried directly in a state-of-the-art sanitary landfill, landfill gas (in addition to methane and CO_2 discussed below) contains a variety of VOCs and chlorinated hydrocarbons.[13] These include ammonia, mercaptains/sulfides, toluenes, dichloromethane, and acetone among others, in significant concentrations which adversely impact the environment. 3000 TPD (2700 t_m/d) MSW disposed of in a landfill, instead of employing WTE, would produce 58 to 93 t/yr (53 to 84 t_m/yr) of these compounds based upon the rates discussed by Reference 13.

Greenhouse Gas (GHG) Emission Avoidance though WTE

WTE facilities significantly reduce the global greenhouse gas emissions footprint. In general terms, this includes three major elements:

1. Renewable Component Impact on Net CO_2 Emissions: Approximately two-thirds of MSW falls under categories considered by the U.S. EPA as renewable fuel assuming that rubber, leather and textiles categories are approximately evenly split between natural and manmade products (see References 3 and 4). The bulk of the renewables is paper/board products, wood, food waste and yard trimmings. Recent EPA analyses of municipal solid waste combustion indicate that WTE facilities produce lower net GHG emissions than fossil fuel sources as shown in Fig. 13.[12] This figure clearly shows the impact of the renewable component in MSW on the net GHG emissions (1016 pounds of CO_2/MWh) compared to coal, oil and natural gas fossil fuels. Calculations from the PBREF No. 2 performance tests are consistent with this. The MSW renewable portion at PBREF No. 2 is relatively high because of the higher proportion of yard and other biomass waste present.

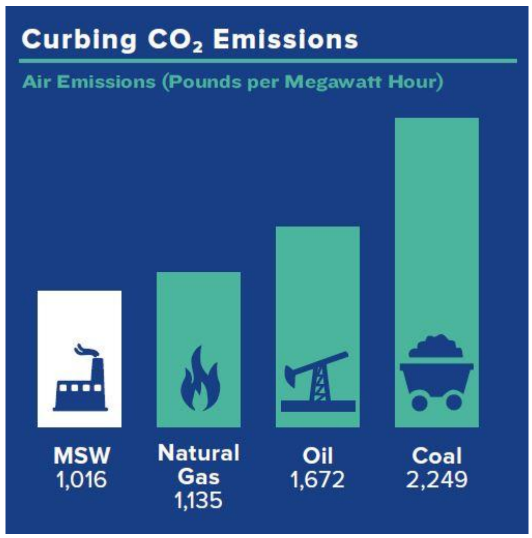

Fig. 13 Waste-to-energy produces lower CO_2 emissions than fossil fuel sources. (Reference 12)

2. Recovered/Recycled Metals: Post-combustion recovery of metals from PBREF No. 2 also reduces the GHG footprint by avoiding the net energy difference between recycling metals and producing metals from virgin ore. For ferrous metals recovered, 56% of the energy for virgin ore production is avoided.[14] The typical 2000 t/month (1814 t_m/month) of ferrous metal recovered from PBREF No. 2 avoids the use of 16,800 t (15,241 t_m) of coal and 14,400 t (13,063 t_m) of limestone on an annual basis. For the non-ferrous metals recovered (assuming aluminum), 90% of the energy to produce aluminum ingots from virgin ore production is avoided.[14] The typical 100 t/month (90.7 t_m/month) of non-ferrous metal recovered from PBREF No. 2 avoids the equivalent use of 1.5 million gallons (5.7 million liters) of gasoline per year. Combining ferrous and non-ferrous results, post-combustion metals recovery at PBREF No. 2 further reduces the GHG footprint by 170 pounds of CO_2/MWh.
3. Methane (CH_4) Offset: When MSW is landfilled, anaerobic biodegradation of the organic components in MSW generates CO_2 and CH_4 in approximately equal proportions[15,16], with methane produced at a rate between 0.03 and 0.04 ton CH_4 per ton of MSW on a dry basis.[15] This is equivalent to 0.02 and 0.03 on a wet basis using typical as-delivered moisture content of 31%.[8] These landfill emission rates result in 61 to 83 t (55 to 75 t_m) of landfill methane emissions per day being avoided by using a 3000 TPD (2700 t_m/d) WTE facility such as PBREF No. 2. Methane in the atmosphere is relatively short-lived compared to CO_2, and therefore the exact global warming potential (GWP, conversion to CO_2 equivalent on a mass basis) declines over time with the value highly variable depending upon the analysis assumptions and the life-cycle time. The U.S. EPA indicates that for 100 years, the GWP for methane is 28 to 36 and for 20 years, it is 84 to 87.[17] To provide some level of consistency from year-to-year and to reflect the relatively short-term

nature of GHG emissions targets being considered, many GHG analyses (example in Reference 18) use the 20-year United Nations Intergovernmental Panel on Climate Change Assessment Report No. 4 global warming potential of 72 for methane.[19] Using this global warming potential, the 61 to 83 t/d (55 to 75 t_m/d) of methane avoided is equivalent to avoiding 4000 to 6000 pounds of CO_2 emissions per MWh of WTE generated power.

From this simplified analysis, the renewable fuel portion of MSW, the emissions impact of the post-combustion metals recycle, and the avoidance of landfill methane emissions provides a significant net reduction in GHG emissions with WTE technology, and thus, a negative GHG footprint.

More comprehensive integrated life-cycle analyses of GHG emissions from MSW have been conducted under a broad range of scenarios using the U.S. EPA's municipal solid waste decision support tool (MSW-DST) by Thorneloe et al.[20] This analysis was based upon a 481,700 t/yr (437,000 t_m/yr) MSW stream or 1320 TPD (1200 t_m/d) with an average U.S. MSW composition. A 75% gas collection efficiency is assumed for cases based upon landfill gas collection. The annual GHG results for five important cases are shown in Fig. 14. The general conclusion is that **WTE with recycling provides a net GHG reduction** compared to the net positive **GHG emissions for just landfill with recycle**. Again referencing the U.S. EPA, approximately one ton of net GHG emissions are reduced for each ton of MSW combusted in a WTE plant.[12]

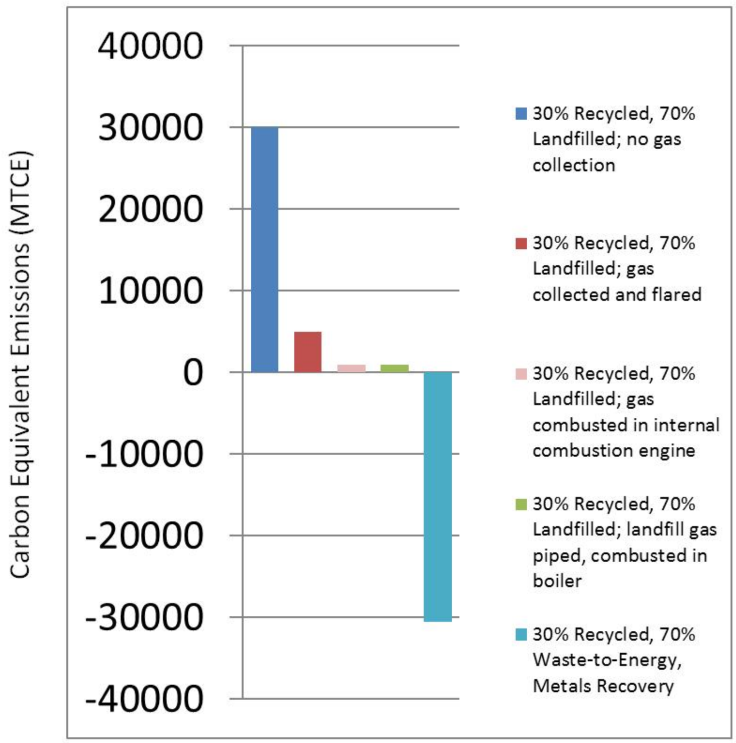

Fig. 14 Net impact of WTE plant on greenhouse gases. (Reference 20)

Economics

Clearly, capital cost and levelized cost per ton of WTE play important roles in wider acceptance and utilization in the U.S. Economic benefits of WTE plants include:

- Revenue from energy recovery
  - Electricity sales

  - Steam sales (combined heat and power applications)
  - Localized energy recovery credits as a renewable portfolio contributor
- Revenue from metal recovery
- Reduced landfill costs
  - Mass burn technology reduces volume to the landfill by up to 90%
  - Further cost reduction when the remaining ash is utilized as concrete aggregate, road fill or cover material
- Reduced costs for future landfills
  - Reduced need by extending the current landfill life
  - Elimination of future landfill permitting costs
- Community employment
  - Temporary construction jobs and job training
  - Permanent plant operations, maintenance and administrative careers
- Local community services impact
  - Hotels, restaurants, etc.
  - Local goods and services suppliers

The SWA has reported that the total amended cost of the PBREF No. 2 was $674,000,000.[21] Based upon the 3000 TPD (2700 t_m/d) facility capacity, the unit price is $224,700 per TPD capacity. This value is less than the inflation-adjusted WTE plants built 20 years ago, demonstrating the impact of current state-of-the-art technology and major efforts to modularize many plant components to reduce construction cost and time. However, more important than capital cost in the long run is the tipping fee (amount paid to dispose of a ton of MSW) and how it compares to landfilling alone. Clearly, landfill costs vary widely by region. For Palm Beach County Florida, current SWA analysis concludes that the PBREF No. 2 WTE plant has about the same cost as the direct landfilling at approximately $25/ton. This analysis excludes the problems and costs of landfilling in the future and should only improve as depressed commodity prices stabilize and renewable energy credits become available.

Conclusion

After groundbreaking in April of 2012, the Palm Beach Renewable Energy Facility No. 2 has transitioned to commercial operation following successful completion of formal acceptance testing in July of 2015. (See Fig. 15.) The facility incorporates the latest advanced technologies from the U.S. and Europe to provide the cleanest and most advanced efficient WTE facility of its kind in the world today — generating renewable energy and reducing net greenhouse emissions.

Fig. 15 PBREF No. 2 at twilight.

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