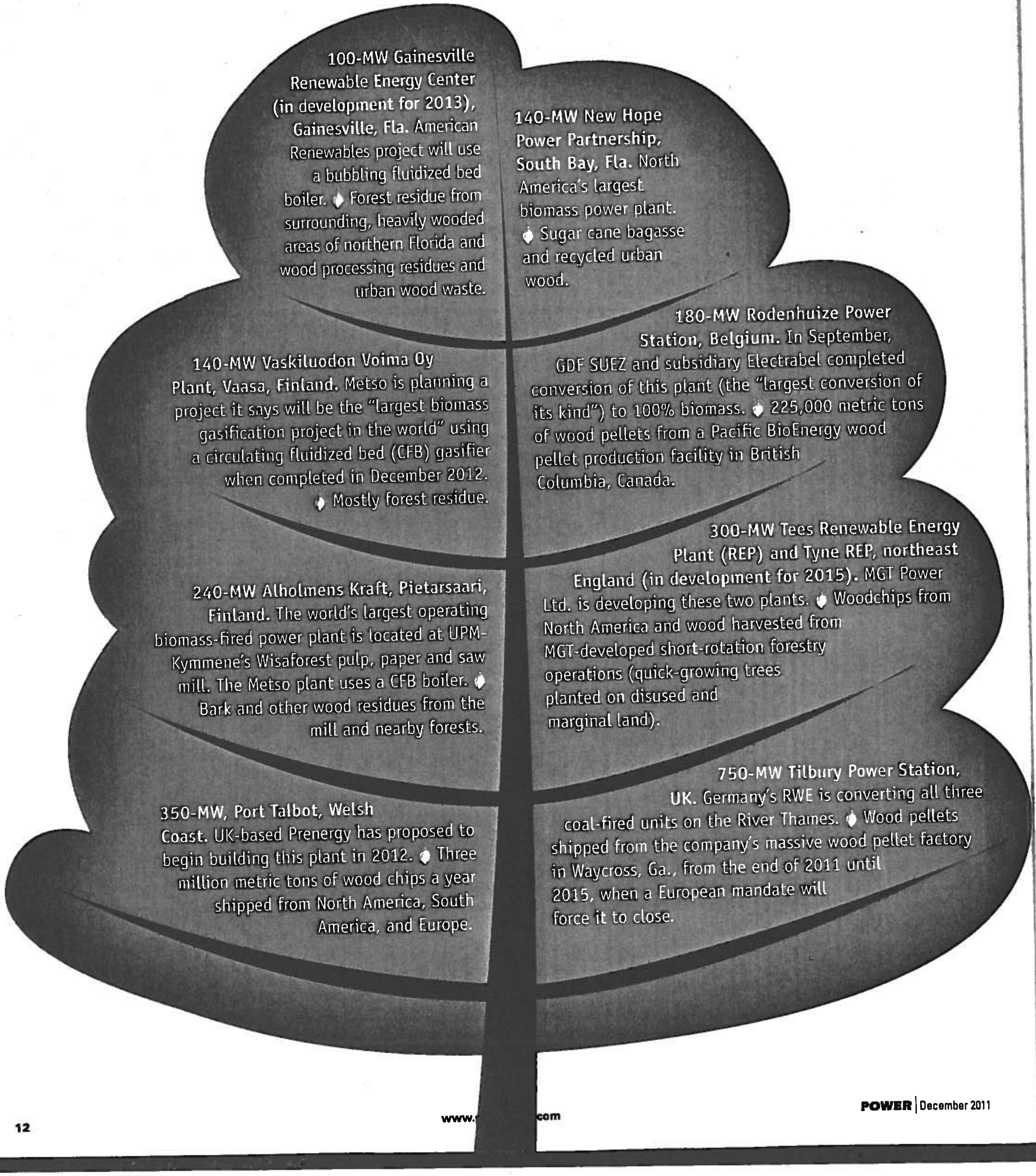
THE BIG PICTURE: Big Biomass

The world's biomass power facilities, not counting those in the pulp and paper industry, average just 18 MWe to 20 MWe. In the U.S., passage of the Public Utility Regulatory Policies Act of 1978 ignited development of many existing biomass plants. Greenhouse gas rules and renewable policies around the world have kindled a new generation of much larger biomass facilities. New announcements routinely are for plants 50 MW or larger, presumably to leverage economies of scale.

However, the biomass sector is immature and faces numerous potential threats, especially supply chain weaknesses (particularly where woody biomass is the feedstock) and high-energy, high-cost, high-impact fuel transportation concerns.

Here are some of the world's biggest existing and proposed biomass projects.

*—**Sonal Patel** and **Dr. Gail Reitenbach***



100-MW Gainesville Renewable Energy Center (in development for 2013), Gainesville, Fla. American Renewables project will use a bubbling fluidized bed boiler. ♦ Forest residue from surrounding, heavily wooded areas of northern Florida and wood processing residues and urban wood waste.

140-MW New Hope Power Partnership, South Bay, Fla. North America's largest biomass power plant. ♦ Sugar cane bagasse and recycled urban wood.

140-MW Vaskiluodon Voima Oy Plant, Vaasa, Finland. Metso is planning a project it says will be the "largest biomass gasification project in the world" using a circulating fluidized bed (CFB) gasifier when completed in December 2012. ♦ Mostly forest residue.

180-MW Rodenhuize Power Station, Belgium. In September, GDF SUEZ and subsidiary Electrabel completed conversion of this plant (the "largest conversion of its kind") to 100% biomass. ♦ 225,000 metric tons of wood pellets from a Pacific BioEnergy wood pellet production facility in British Columbia, Canada.

240-MW Alholmens Kraft, Pietarsaari, Finland. The world's largest operating biomass-fired power plant is located at UPM-Kymmene's Wisaforest pulp, paper and saw mill. The Metso plant uses a CFB boiler. ♦ Bark and other wood residues from the mill and nearby forests.

300-MW Tees Renewable Energy Plant (REP) and Tyne REP, northeast England (in development for 2015). MGT Power Ltd. is developing these two plants. ♦ Woodchips from North America and wood harvested from MGT-developed short-rotation forestry operations (quick-growing trees planted on disused and marginal land).

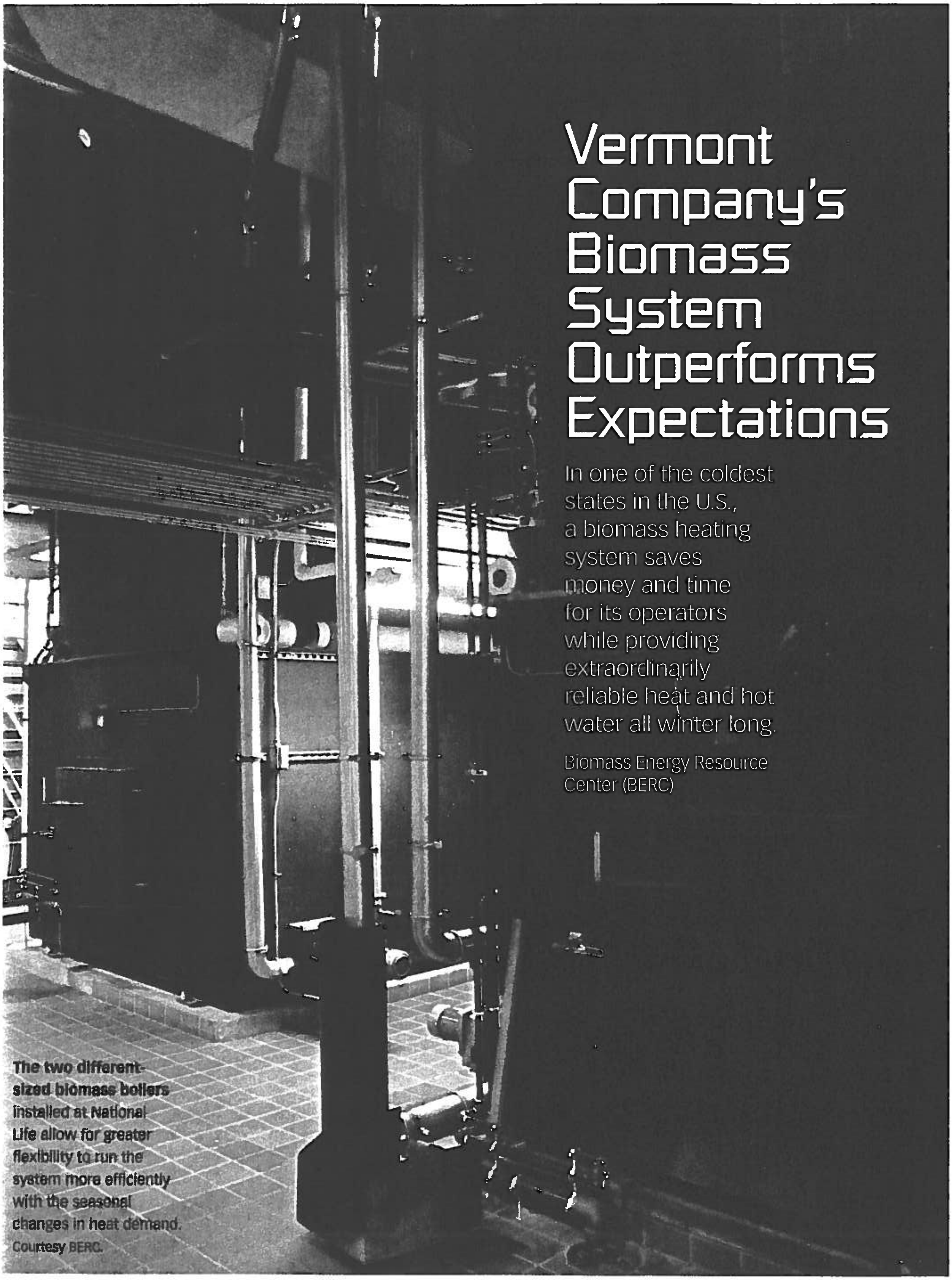
350-MW, Port Talbot, Welsh Coast. UK-based Prenergy has proposed to begin building this plant in 2012. ♦ Three million metric tons of wood chips a year shipped from North America, South America, and Europe.

750-MW Tilbury Power Station, UK. Germany's RWE is converting all three coal-fired units on the River Thames. ♦ Wood pellets shipped from the company's massive wood pellet factory in Waycross, Ga., from the end of 2011 until 2015, when a European mandate will force it to close.

Vermont Company's Biomass System Outperforms Expectations

In one of the coldest states in the U.S., a biomass heating system saves money and time for its operators while providing extraordinarily reliable heat and hot water all winter long.

Biomass Energy Resource Center (BERC)



The two different-sized biomass boilers installed at National Life allow for greater flexibility to run the system more efficiently with the seasonal changes in heat demand. Courtesy BERC.

To find out if a biomass heating system works smoothly or not, ask the people who really run it — day by day.

At National Life Group in Vermont, those people include Ansel Quintin, HVAC team leader. In December 2010 when the Fortune 1,000 company installed a new, twin-boiler woodchip system to provide primary heat for its 500,000 square-foot headquarters — one of Vermont's largest office buildings — the daily operation and problem-solving was turned over to Quintin and his team.

They were, to be honest, a little worried.

"Because it was something new and they'd never operated it before, most of the guys said, 'This is going to be bad,'" Quintin recalls. "It seemed like a lot of work. But you know what? That thing is awesome. We can't say enough about it, the way it operates. Very smooth."

After the first winter with biomass heat and hot water, the executive in charge of the project is just as pleased — and he's got data to back that up.

"It's been quite a success," reports Tim Shea, National Life's second vice president of purchasing and contracting. "We started the system in the latter part of December [2010]. We've got a 7 million Btu boiler and a 5 million Btu boiler, and we also put in an electrostatic precipitator (ESP) emission control. With the system up and running, we exceeded our initial projections."

The installation of two different-sized biomass boilers allows for greater flexibility to run the system more efficiently with the seasonal changes in heat demand. "We had expected to meet about 90 percent of our thermal-output needs from our biomass system," Shea says. "But from the time it was up and running, we were up over 98 percent."

With its previous, oil-fueled heating system, which it now uses as backup, National Life was consuming about 210,000 gallons of No. 4 heating oil per year. During the winter of 2010-11 — though it didn't fire up the new biomass equipment until December — the company used 2,792 tons of woodchips, averting an estimated 180,000 gallons of oil.

"This computes to over $400,000 in fuel savings from December 2010 to June 2011 for National Life Group," Shea reports.

The company vented its state-of-the-art ESP exhaust-filtration system through an existing incinerator stack that had been capped for a number of years, reducing the overall cost of the $2 million project. "We also put in an ash-collection silo that collects the ash from the combustor and the ESP," Shea says. While many other similar-sized systems use mechanical filtration, National Life's is one of the first in the Northeast to employ a far more effective ESP.

The ESP removes, on average, about 98 percent of fine particles from the system's exhaust — and "there's no manual ash removal," says Shea. "It's all done through a Grizzly vacuum system." The silo will need to be emptied about twice a year, the company expects. Its ash will be sent to a local farm, where it will be commingled with manure and spread on fields.

"There is no waste," notes Shea.

The ESP removes, on average, about 98 percent of fine particles from the system's exhaust — and "there's no manual ash removal," says Tim Shea.

Biomass Energy Resource Center's (BERC's) Senior Program Director Kamalesh Doshi (left) and National Life's Second Vice President of Purchasing and Contracting Tim Shea by a control panel of the system. Courtesy BERC.

National Life Group's Woodchip Heating System

BY THE NUMBERS:

Heating Capacity (output): 3.5 MW (12 MMBtu/hr) Total [2 Boilers = 2 MW (7 MMBtu/hr) and 1.5 MW (5 MMBtu/hr)]

Annual Wood Fuel Amount: 2,800 tons

Emissions Reduction and Combustion Control Equipment: Electrostatic Precipitator

Year Installed: December 2010

Thermal Output: Low-Pressure Steam

Estimated Annual Savings over Oil: $400,000

Estimated Time to Recover Investment: 4 years

'That Thing Took the Load'

Although biomass already heats scores of commercial facilities around Vermont, including more than 40 schools, National Life was one of the state's first commercial facilities to adopt the technology. The company used local contractors as much as possible in the installation process, and it sources its fuel from a woodchip provider about 30 miles away.

"I had thought we would have to manage the chip bin and call for deliveries, but they did all that for us," Shea says. "So that was a pleasant surprise. There were no issues with the chip delivery system."

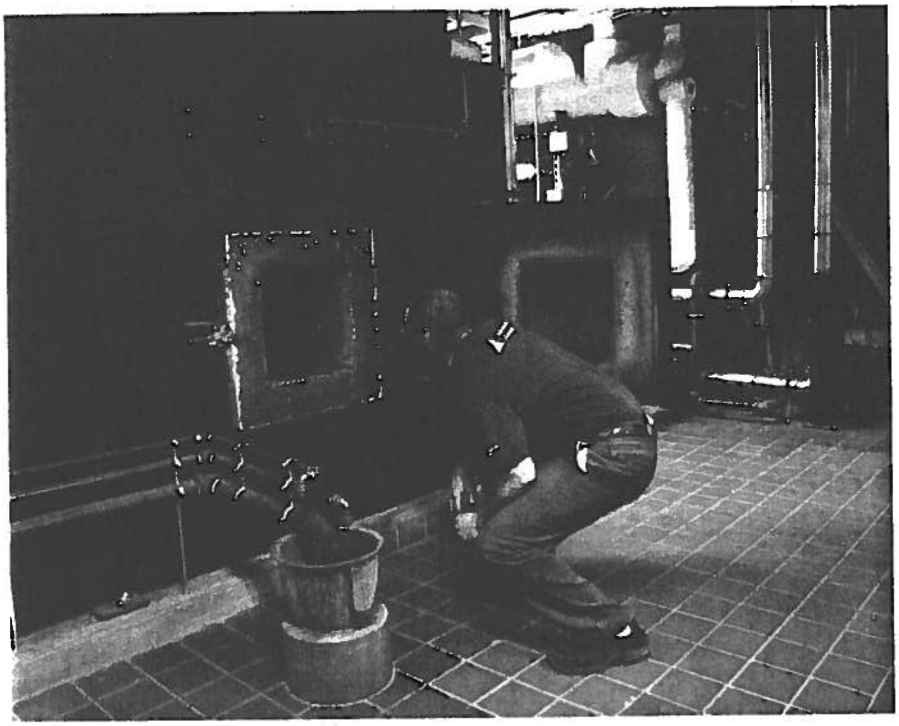
Nor were there problems with the fuel itself, reports Quintin. "The chips we got were super-clean. No plug-ups. Fed in fine.

"We were worried about when it got really cold out, that we'd be running the oil burners," he says. "But that thing took the load, and it ran right through. We used way less fuel oil than we thought we would."

A 2009 BERC feasibility study had projected that fuel cost savings would repay the biomass system's capital costs in six and a half years. But in practice, with the rise in oil prices, the system is now on track to pay for itself in four years.

"We're more than happy," Shea says. "Six years is not bad; four years is incredible. We're looking at getting 30 years out of those boilers. That's not a bad investment."

A National Life HVAC team member checks the combustion chamber of one of the biomass boilers. Courtesy BERC.



'People, Profit and Planet'

In deciding to move toward biomass heat, Shea says National Life saw three priorities: people, profit, and planet. "Economically, the system could reduce our operating costs. As for the planet, we looked at the total costs of what it takes to extract the oil, process and transport the oil, and the emissions associated with the oil, versus using a local, renewable fuel that replenishes itself within 50 years.

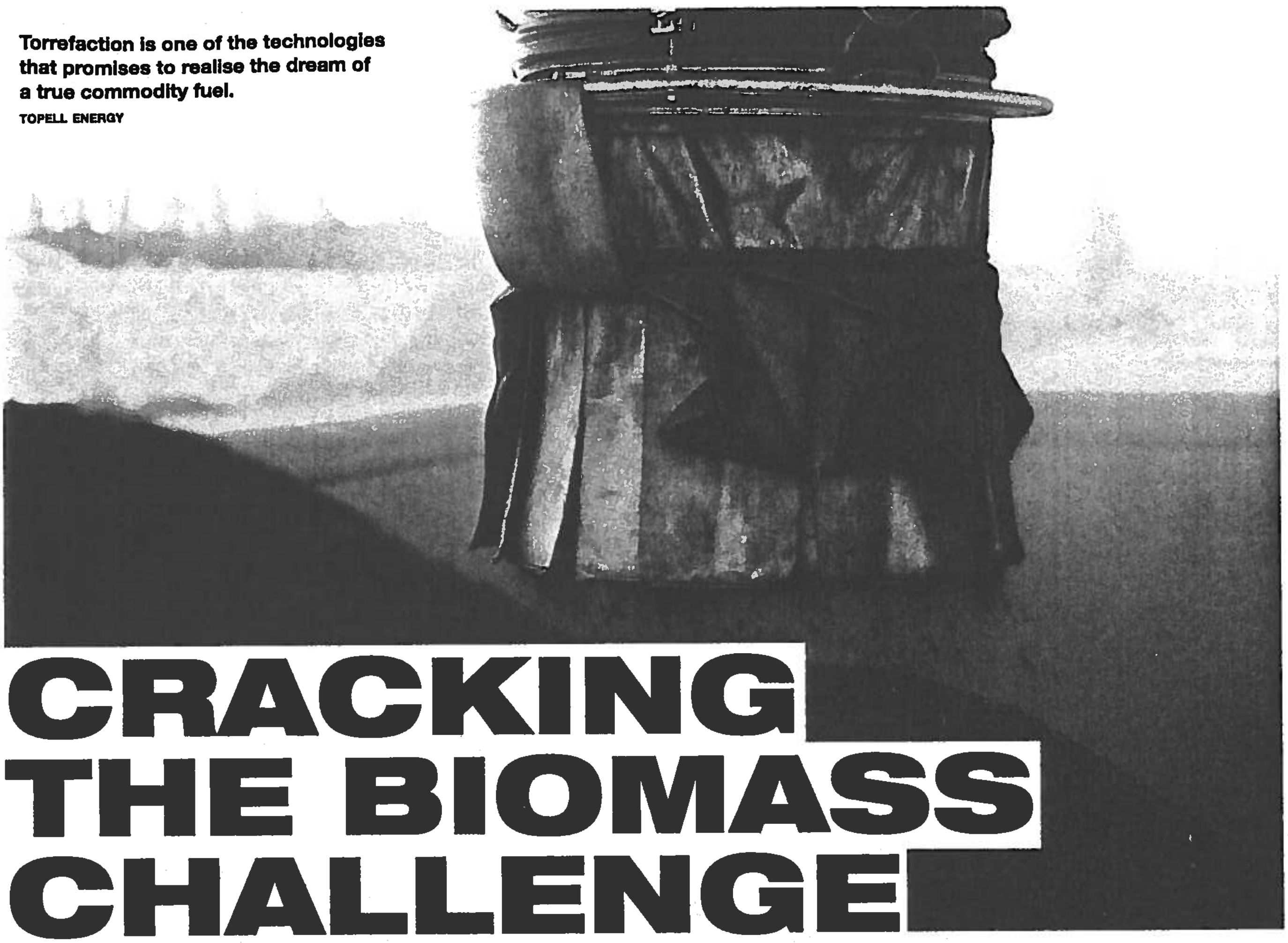
"These trees grow back naturally in Vermont — and the trees we're using are not replacing something that was going to be a fine piece of furniture," Shea adds. "Also, the emissions aspect is something we want to be mindful of, so we went with the highest technology available. And the thing just runs! I'm sure there's a lot of technology inside of it; but from our perspective, the ESP has its controller and it just does its job.

"The people side is just talking about the story of Vermont — a local investment, with contractors who did the work out of area communities, plus a local fuel supply," he said. "Also the investment in the local community of reducing our emissions. We're not emitting black smoke, people are not getting soot on their lawns. This system takes into account all those aspects."

For Quintin and his HVAC team, the report is even simpler. Team members take turns being on call for winter weekends, in case the heating system needs attention. When the oil burners were the main suppliers of heat, they often required weekend maintenance. Not so with the biomass system.

"We thought, 'Oh no, we're going to be in here every day,'" Quintin says. "But I'll tell you, you talk to any of our guys, and they'll give you the same story. We've got nothing but positives to say about it." ■

The Biomass Energy Resource Center (BERC) is an independent, national nonprofit organization located in Montpelier, Vermont with a Midwest office in Madison, Wisconsin. BERC assists communities, colleges and universities, state and local governments, businesses, utilities, schools, and others in making the most of their local energy resources.



Torrefaction is one of the technologies that promises to realise the dream of a true commodity fuel.

TOPELL ENERGY

CRACKING THE BIOMASS CHALLENGE

TORREFACTION TECHNOLOGY SET TO OPEN UP NEW ERA FOR CO-FIRING

The emerging technology of torrefaction – a process by which biomass is converted into 'bio-coal' – could overcome the current limits to co-firing organic materials in existing coal-fired plants. This, argue **Mark Beekes** and **Marcel Cremers** offers a clear opportunity for increasing the renewable share of power generation.

Utilities are facing major challenges in the coming decades. Current policy envisions a transition to a sustainable energy supply, while ensuring security of supply. Therefore, current energy policy is spuring utilities to improve the sustainability of their coal-fired power plants.

Co-firing biomass is one of the major measures widely applied to reduce CO_2 emissions. Since the mid-1990s, power plants designed to burn pulverised coal have additionally been firing organic materials, such as wood and agricultural waste. However, coal-fired power plants are not designed to process biomass, which limits the co-firing percentage to some 5%–10%. With investments in dedicated supply chains and biomass pre-treatment equipment co-firing percentages of 25%–50% (thermal) have already been achieved.

WOOD PELLETS

From the fuel perspective, the ideal situation is to process the biomass so that its properties resemble those of coal. The main form of processed biomass currently in use is wood pellets – pelletised dry sawdust – because it is a relatively clean fuel that is internationally available, easy to handle (free flowing capabilities, less dust emission) and has relatively low transport cost. Wood pellets work well in coal-fired plants and are now regarded as a well-proven technology.

Nevertheless, wood pellets do have their drawbacks. Wood pellets need dedicated silo storage to avoid degradation. Co-firing wood pellets has consequences for the milling and combustion of the wood pellets. At >5% co-firing, the pellets need to be hammer milled in separate hammer mills to a typical particle size of up to 1 mm, whereas the coal mills grind the coal to a pulverised particle size of about 50 microns on average. Co-firing furthermore may influence primary air requirements, combustion behaviour, heat transfer pattern in the boiler, boiler efficiency, by-products and emissions. The various problems mean that wood pellets aren't really a commodity fuel that can be blended with coal in whatever proportions are desired.

TORREFACTION

In order to increase the co-firing percentage further, utilities are looking for innovations. To create a biomass product that has superior handling and co-firing capabilities than wood pellets, torrefaction is an option. Indeed, torrefaction is one of the technologies that promises to realise the dream of a true commodity fuel.

Torrefaction is essentially a biomass cracking technique. It's an additional pre-treatment step that heats the biomass to 260–320°C for up to one hour in an atmosphere of no or low oxygen content. After torrefaction the biomass has become brittle, due to the disintegration of hemicelluloses and to a lesser extent lignin and celluloses, which are responsible for the tough fibre structure. In other words, the fibrous structure of the biomass is partially broken down. The weakened fibre structure improves the milling properties of the biomass and enables the biomass to be processed together with coal at the power plant.

Furthermore, the calorific value of the biomass increases typically from 12–16 MJ/kg to 20–24 MJ/kg, due to the loss of volatiles and moisture. The features of torrefied biomass enable co-firing rates of more than 50% of generating output, while keeping the investments needed to a minimum.

Depending on the distance from biomass source to the co-firing site, it is economically attractive to pelletise the torrefied biomass. Torrefaction pellets have a volumetric energy density of 14.5–17.5 GJ/m^3 (bulk density of 800 kg/m^3), which is about 70%–80% higher than conventional wood pellets (8.5–10 GJ/m^3). In order to pelletise, the torrefaction temperature must stay below 300°C to keep a large part of the lignin intact, which serves as a natural binding agent for making pellets. Biomass that has been torrefied at higher temperatures might need additives to produce good quality pellets. Once the hydrophobic nature is proven, they can be stored in the open air – doing away with the need for silos. It is also considered feasibile to use particles with a size larger than the standard 8 mm pellets.

MORE ATTENTION

Torrefaction of biomass was already developed in the 1970s and 1980s. After a quiet period, the biomass market started to grow more rapidly at the beginning of this century. A number of small equipment suppliers with different technical processes started to torrefy biomass in pilot plants. The small quantities produced proved that it is possible to torrefy woody biomass. At this moment, torrefaction is attracting more and more attention. Biomass suppliers, investors, and end users are all starting up projects. There are about 30 projects currently running, mainly in Europe and North America. And, although most projects are pretty small scale, some larger ones are getting off the ground as well. The best known torrefaction unit is Topell in Duiven, the Netherlands, which is designed for 60,000 tonnes a year of product output.

PROVEN SUCCESS

A number of torrefaction reactors are being developed in parallel. It's too soon to say which approach is going to prevail with the suppliers of torrefaction technology in different stages of developing a commercial-scale installation. An inventory of the existing concepts for torrefaction, evaluating them on their technological performance, has shown that roughly all suppliers have developed an integrated concept, in which the energy efficiency is optimised by combusting the volatile rich torrefaction gases and by using the heat of the flue gases to dry and torrefy the biomass. It isn't the case that one technique is fundamentally superior to the others. Several techniques will ultimately prove successful. The idea is to have a process that can be managed easily. Cracking is an extremely complex business; it's not just one step on from drying.

INTEGRATED APPROACH

The essential thing is to have an integrated approach. It is important to think not only about the reactor itself, but also about the drying, the milling and the heat recovery. If the material isn't pre-processed properly, that has implications for how the reactor works. For example, the pre-drying step is crucial for good torrefaction conditions. Higher moisture contents of the biomass will result in 'wet' torrefaction gas, which requires energy to combust and lowers the overall energy efficiency. Seasonal aspects also play a role.

It's no good looking at everything from a purely technical viewpoint; it's about finding the most economical solution as well. Where the biomass is coming from makes a big difference to the viability of a scheme, for example. As does whether one needs to create something from scratch, or if a torrefaction unit can be added to an existing plant.

TYPES OF TORREFACTION REACTOR

Torrefaction concepts differ in reactor technology, torrefaction conditions and heat exchange methods. An overview of the major technologies is shown below.

Multiple Hearth Furnace

The Multiple Hearth Furnace (MHF) consists of six hearths, each approximately one metre in height. The biomass is fed at the top of the reactor, after which it moves down through the different levels. An 'IN hearth' passes the biomass to the next hearth by moving the biomass to a centralised passage. An 'OUT hearth' processes the biomass to the next hearth by moving it to drop holes located at the reactor's periphery. To process the biomass through the different hearths, a centralised shaft drives rabble arms at each hearth. In case of torrefaction, the reactor is operated down draft, which means that the flue gas flow follows the same direction as the product flow.

The steam injections result in very good temperature control and a high product quality with minimal energy loss, giving the process a relatively high efficiency. But they also demand gas consumption to heat the relatively wet torrefaction gasses for combustion.

A critical factor of the MHF is fuel flexibility. The particle size is limited by the space between the teeth of the rabble arm, the space between the drop holes and the quality of the product; larger particles will take more time to be torrefied.

Rotary Kiln reactor

The rotary kiln process resembles the successful concept for commercial pyrolysis units. When the rotary kiln reactor is applied to torrefaction, the biomass needs to be dried to preferably 10%–15%/wt moisture. In one concept available on the market the rotary kiln is indirectly heated by thermal oils; in another it is directly heated by superheated steam.

The rotational speed of a rotary kiln is a crucial process parameter for the product quality of torrefaction. When the rotational speed is too slow, the biomass will be carbonised instead of torrefied. When it is too high, the biomass is not fully torrefied and has low product quality. Moreover, rotational speed has a wearing effect on the biomass, leading to a reduction in particle size over the reactor's length. Variations in particle size should be avoided in a rotary kiln. The basic reactor technology has no option to differentiate in particle size, which means that these variations are critical for product quality.

The reaction time of torrefaction takes 30 minutes and the total process time is around two hours. The residence time needed for optimal torrefaction conditions primarily determines the size of the rotary kiln, which limits the upscaling possibilities of this reactor.

Torbed reactor

The principle of a Torbed reactor is the toroidal flow of the bed, which is created by injecting air with high velocity (50–80 m/s) through stationary angled 'blades'. The injection angle results in a flow with a horizontal and vertical velocity vector, which lifts and moves the fuel bed in a horizontal motion at the same time. This creates a shallow solid material bed, which circulates around a vertical axis in the centre of the reactor and around a horizontal axis in the freeboard of the reactor. The toroidal motion allows a higher air speed, which reduces the boundary layer between solid particles and gases. As a result, heat and mass transfer between gases and solids improve, which allows lower retention times and a more homogeneous product.

The commercial scale Torbed torrefaction reactor consists of a four-stage continuous updraft process. In the first stage, the biomass is completely dried and fluidised by superheated steam. The second stage increases the temperature further to 350°C and serves as a buffer for all biomass particles that have not been dried in the first stage. In the third stage, the biomass is torrefied by directly injecting hot flue gas from the combustion of torrefaction gas. The last stage functions as an additional control measure to ensure that all biomass particles have been torrefied.

The time needed to process the biomass through these four different stages is claimed to be less than five minutes, which justifies higher torrefaction temperatures than other concepts and enables higher biomass throughputs. However, excellent process control is needed to avoid a loss of chemical energy, resulting in a lower overall energy efficiency. Another disadvantage of higher torrefaction temperatures is the volatilisation of phenol, acetone and other contaminants, which makes flue gas cleaning more challenging.

Compact moving bed reactor

In a moving bed reactor the biomass is fed at the top and moves slowly down to the bottom where the product is discharged. The length of the reactor is, in large part, determined by the retention time needed to produce the desired product. When applied for torrefaction the retention time is 25–30 minutes. The biomass is directly heated to 250–300°C by a partial recycle of the torrefaction gases. From the remaining torrefaction gases the tar is separated and the cleaned gas combusted in an afterburner, where it is combined with the gas of a biomass gasification unit and the resulting flue gases directly fed into the torrefaction gas recycle stream. The recycle consists of repressurisation of the torrefaction gas to compensate for the pressure drop in the recycle loop, and of the heating of the recycle gas to deliver the required heat in the torrefaction reactor.

A typical phenomenon in moving bed reactors is the unequal heating of the fuel bed, due to limited mixing possibilities. This effect becomes more severe in larger moving bed reactors, which limits the upscaling potential of this reactor technology.

Screw conveyor reactor

The screw reactor is heated by the flue gases after combustion of the torrefaction gases, as in the other concepts. However, heat transfer in a screw reactor is less efficient than fluidisation technology and, due to the transport capabilities of the screw, the biomass feed is limited to particles with a size smaller than 10 mm. Moreover, biomass with a very low bulk density and high moisture content needs to be pre-treated before feeding it to the screw reactor. In order to have a good product quality, the screw diameter is limited, which limits the upscaling potential.

CHALLENGES

As can be seen, various torrefaction concepts exist. All concepts have been tested to at least a pilot-scale size. Some concepts are currently being implemented or have already been implemented in a torrefaction plant. The typical size of realised plants or plants under construction is on the order of 20–60 kt/year on product output. Apart from the upscaling challenges, all suppliers of torrefaction technology struggle to find feasible solutions for a number of issues, such as:

- Flue gas cleaning: In order to avoid permit problems, additional flue gas cleaning is needed after combustion of the torrefaction gas. An alternative would be to inject the torrefaction gas in a coal-fired boiler to completely oxidise all organic compounds;
- Process control: The challenge is to control the biomass feed, torrefaction temperature and retention time in such a way that all biomass is completely torrefied without being carbonised;
- Fuel flexibility: European and national legislation is restricting biomass available for co-firing. A different type of biomass will change the process conditions significantly and thereby also the choice of optimal reactor technology and integrated concept;
- Sustainability: Concepts with relatively low efficiencies and relatively high emissions will fall off.

The co-firing rate will still be limited by the chemical composition of the biomass because components like alkaline metals, phosphor and chlorine will still be present after torrefaction and affect boiler integrity (corrosion, fouling), byproducts and emissions. Site-specific bottlenecks will be present in most cases, and may include dust emissions, health and safety, operational limits of primary air fans, operational limits of the coal mills, and shifting of the heat balance in the boiler. Models can calculate and predict these bottlenecks.

Torrefaction's performance is highly dependent on the pre-treatment of biomass. And a large part of its added value will be allocated before the power plant gate. Nonetheless, we foresee that torrefaction will play an important role in co-firing biomass at coal-fired power plants. At the moment, torrefaction technology is making its first careful steps towards commercialisation, while the technology and product quality are still surrounded by uncertainties.

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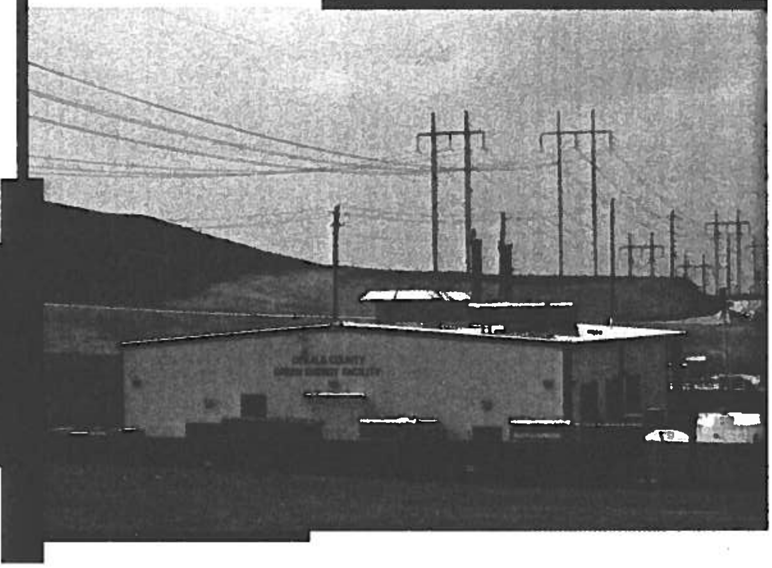
GARBAGE TO GAS TO ENERGY



The 3.2 megawatt Landfill Gas to Energy power building at Dekalb County, Georgia's Seminole Landfill in suburban Atlanta. The Southern Company's Georgia Power subsidiary buys 100 percent of the electricity generated here.

How utilities are tapping into landfill gases for conversion to energy.

Bruce Dorminey, Contributor

Landfill Gas to Energy (LFGTE) isn't likely to win any beauty prizes in the renewable energy sweepstakes — wind and solar continue to garner all the glamour. But this unsung method of harvesting landfill methane for conversion to electricity (or for direct use as a fuel for industry or vehicles) continues to prove that LFGTE is a scrappy long-term contender in the war on man-made greenhouse gases.

The technology is now fully mature. Of some 2,400 landfills in the U.S., more than 500 landfill gas conversion plants are operating today, with another 500 sites under consideration.

"People have been commercially recovering landfill gas since 1975," said Jean Bogner, a 2007 Nobel Peace Prize laureate and geochemist at the University of Illinois at Chicago. "Compared to biomass, the good thing about municipal solid waste is there's a good, established collection system for it."

Landfill methane gas is generated by decomposing organic material in municipal solid waste like food, leaves, grass, paper, and lumber and accounts for about a quarter of total man-made U.S. methane emissions. Even so, LFGTE projects still amount to only a fraction of a percent of the country's total energy production.

"We're starting to more and more view waste as a valuable product that we can either reuse or that has organic content that we can extract," said Mikhail Chester, a civil engineer at Arizona State University.

The U.S.' Clean Air Act dictates that at the very least, landfill owners capture gases and periodically flare them off to prevent dangerous buildup.

Beyond the landfill gas' local volatility, due to methane's heat trapping ability, this greenhouse gas warms the earth 23 times more than carbon dioxide. Thus, it only makes sense to use this landfill gas to either directly run an industrial boiler or kiln, or run a turbine that can generate electricity.

Landfill gas is extracted using a series of wells, pipes and vacuums that collect upwards of 95 percent of an average landfill's gas. The gas is oxidized during the burning process to produce water and carbon dioxide, then used directly to replace fossil fuels in industrial and manufacturing operations, or cleaned of impurities so that it can be used in pipelines and vehicles. But electricity from LFGTE still makes up about 70 percent of the U.S. projects that do more than just flare the gas.

Suburban Atlanta's Seminole landfill in DeKalb County became Georgia Power's first green project in 2006. Since 2010, the utility has also been buying electricity from Savannah's Superior Landfill to energy project, set up by Houston-based Waste Management Inc.

Georgia Power only pays the landfill operators what it would cost the utility to generate the equivalent amount of electricity. Although combined both these plants have a total capacity of about 10 megawatts (MW) — a fraction of the utility's total electrical capacity of almost 16,000 MW — Georgia Power spokesperson Lynn Wallace says the company is considering other such partnerships.

For its part, Waste Management is currently operating 131 such plants in the U.S. and Canada with 10 more now under construction or scheduled to break ground this year and another 30 in development.

"Our goal is to quadruple the amount of energy we produce from waste," said Waste Management's spokesperson Lynn Brown. "We've upgraded our turbine technology in the last 5 years to make it more efficient. But each landfill has its own characteristics. Even climate can dictate how much gas you get out of a landfill. In dry climates you don't get much; if you get a lot of rain you might get more."

Installation costs average $1.2 million to $1.8 million per megawatt with a typical urban project running between $5 million and $10 million.

But to be effective, the smallest LFGTE project requires at least half a million tons of solid waste. This isn't an option for home recyclers or even fiercely independent large-scale ranchers. (For every one million tons of municipal solid waste that is collected, a 780-kW capacity electricity plant could be built.)

The EPA's landfill methane outreach program notes that LFGTE projects generated more than 15 million megawatt-hours last year, with the biggest single U.S. project being the 50-MW Puente Hills landfill project.

At the other end of the spectrum, in 2010, Green kW Energy installed a project on the site of a landfill closed in 2001 in Montgomery County, Virginia. With an estimated 15 years of gas left to capture, electricity from its 265-kW generating system is being sold back on the grid.

"OUR GOAL IS TO QUADRUPLE THE AMOUNT OF ENERGY WE PRODUCE FROM WASTE,"

— LYNN BROWN,
WASTE MANAGEMENT INC.

"Green kW put up the capital and we just put in additional piping and meters," said Alan Cummins, executive director of Montgomery Regional Solid Waste Authority in Christiansburg, Va.

As a result, Montgomery Regional Solid Waste Authority should soon start receiving about a $1,000 a month, which they will put into a fund for a future local green energy education/training facility.

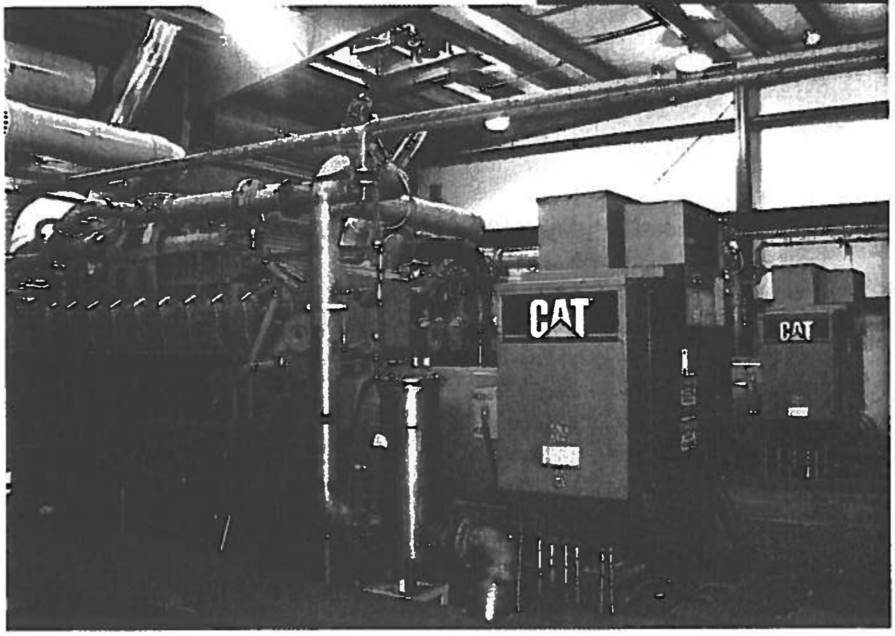
"More and more we're seeing landfills outfitted with these systems," said Chester. "That tells me that the economics are working. And it's cost effective even when you have to go back and rip up the landfill to put it in."

In ranking how best to use the landfill gas once it's extracted, Bogner puts direct use in existing gas-fired industrial boilers first. Landfill gas methane also has the advantage of being more efficient than conventional natural gas, because it burns at a lower temperature.

"If you have a factory or a sewage treatment plant next to a landfill site," said Bogner, "you can run the gas right there without the expense of electrical generation equipment."

Conversion to electricity, she ranks second, followed by the third option of injecting the gas into pipelines or compressing or liquefying it for use in vehicles. But Bogner says this third option is the most costly. That's because before use, the gas first has to be stripped of impurities, which for the moment, makes it the least attractive. ◥

Bruce Dorminey, a science journalist and author of "Distant Wanderers: The Search for Planets beyond the Solar System," is an active member of the Society of Environmental Journalists (SEJ). Twitter: @bdorminey


Electrical generators inside the Power building at the Dekalb County, Georgia Seminole Landfill.

Waste-to-Energy Technology Options Increase but Remain Underutilized

WTE technologies offer cost-effective, near-term solutions for producing baseload electric power, meeting renewable energy targets, and reducing greenhouse gas emissions in the U.S. and other countries. They also present opportunities for improving resource management practices, increasing energy security, enhancing environmental quality, and supporting climate policy goals around the world.

By Stan Rosinski, Electric Power Research Institute Inc.

Courtesy: HDR Inc.

Waste-to-energy (WTE) technologies convert the chemical energy stored in residues associated with human activities into heat, steam, and electricity. Primary fuel sources include municipal solid waste (MSW) and other materials diverted from disposal facilities as well as gases rich in methane that are generated when organic substances decompose in the absence of oxygen.

Among the many available fuel-processing and energy conversion technologies, incineration of MSW and derived fuels in boilers is commercially mature and in common use around the world, as are combustion-based systems that fire gases resulting from uncontrolled anaerobic decomposition of waste buried in landfills and from controlled processing of organic materials in purpose-built digesters. Advanced thermal conversion technologies such as gasification and pyrolysis—which transform MSW into versatile fuels suitable for high-efficiency energy production or direct end use—are finding increasing application but are not yet proven.

Overview of Technologies

State-of-the-art WTE technologies are widely recognized by government agencies as effective resource management solutions and renewable generation options. When incorporated within integrated MSW plans emphasizing reduction, reuse, recycling, and composting, they provide an environmentally sound means of recovering energy from the residual wastes while decreasing the volume of material that must be landfilled by roughly 90%. At landfills, agricultural facilities, and wastewater treatment plants, they generate useful energy while substantially reducing emissions of methane, a greenhouse gas (GHG) with high global warming potential.

Globally, WTE capacity has expanded significantly in recent years, driven largely by policy considerations. First and foremost, many nations have forsaken landfilling as inefficient and environmentally undesirable, leading to a steady increase in the annual tonnage of MSW subjected to energy recovery. For example, a 1999 European Union directive essentially banned the landfilling of combustible MSW fractions in order to control methane emissions, avoid nonproductive use of land and other resources, and prevent water and soil contamination.

In Europe, Asia, and elsewhere, such policies—along with climate change mitigation and renewable energy targets—have motivated the construction of hundreds of mass-burn incinerators, the early commercial application of various advanced thermal conversion technologies, and the proliferation of smaller-scale landfill gas (LFG) and digester gas systems. Frequently, these WTE plants supply heat or are combined heat and power (CHP) facilities; in fact, 18% of the district heating load in Denmark is served by MSW combustion. Across Europe, WTE facilities produced 56 terawatt-hours (TWh) of renewable energy in 2006, including 31 TWh of heat and 25 TWh of power.

A far different situation exists in the U.S., where public concern over pollutant emissions from incinerators has yet to dissipate, despite the stringent air quality control requirements imposed more than 15 years ago by the U.S. Environmental Protection Agency (EPA). No new MSW energy recovery plants have been constructed since the mid-1990s, and no commercial-scale MSW gasification or pyrolysis facilities have been built. The modest WTE capacity additions—largely of LFG facilities—have been motivated by federal air quality regulations and, more recently, state renewable portfolio standard (RPS) requirements, rather than by waste management policies.

According to data from the U.S. Energy Information Administration (EIA), load-serving WTE capacity exceeded 4.1 GW in 2008, but the amount running on MSW has declined slightly since 2003, falling to 2.2 GW. However, recent growth in LFG deployment helped to keep WTE's share of nonhydro renewable capacity near 11%, third-largest behind wind and wood biomass.

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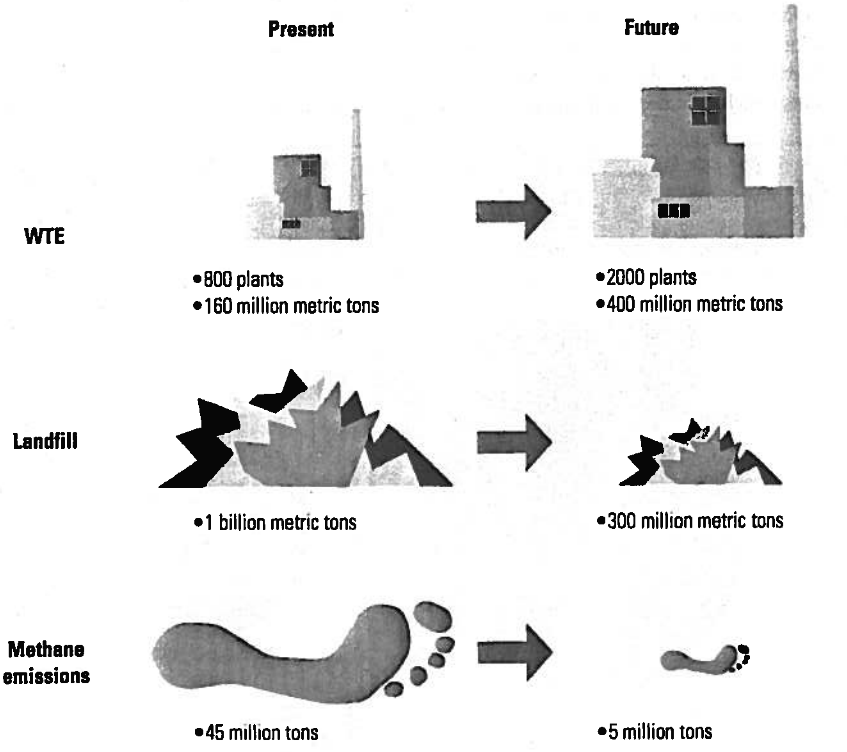
As baseload, dispatchable units, WTE plants continue to play an important role in U.S. renewable energy generation, even accounting for the fact that capacity has stagnated and the EIA includes only the fraction of output attributable to biogenic sources such as green power. WTE technologies supplied 15.4 TWh of renewable energy to the grid in 2008, equivalent to 16% of nonhydro renewable generation, second only to wind. Of this total, MSW incinerators and fluidized bed combustion (FBC) units produced 7.2 TWh from biogenic fuels, which make up roughly 55% of the total U.S. waste stream by heat input. Counting output attributable to the combustion of plastics and other nonbiogenic materials, these plants produced roughly 13 TWh, pushing overall generation from WTE technologies above 20 TWh.

1. Turning trash into treasure. At waste treatment facilities, the tipping fees offset the operation, maintenance, labor, and capital costs of the facility along with the final disposal costs of any unusable residues. The fee can be charged per load, per ton, or per item, depending on the source and type of waste. This photo shows the Lee County waste-to-energy facility's tipping floor, which is the designated receiving area where waste collection vehicles discharge their loads. *Courtesy: HDR Inc.*

Independent power producers—among them waste management firms and municipalities—own the majority of load-serving WTE capacity, while more than half of the methane-rich fuel produced at U.S. landfills, agricultural operations, and wastewater treatment plants is applied to generate on-site heat and power.

Conventional incinerators typically collect MSW from a broad area, operate on must-run status, and offer availabilities exceeding 90%. LFG and digester gas facilities—collectively referred to as anaerobic-digestion-to-energy (ADTE) plants—are distributed resources sited, sized, and run according to fuel availability and production rate. Both MSW-derived fuels and digester gases may be cofired in fossil plants, but this may have operational and regulatory implications.

2. Benefits of expanding WTE deployment. Global adoption of integrated resource management strategies could dramatically increase deployment of incinerators and advanced conversion technologies. This development would reduce landfilling and associated emissions of methane, while expanded landfill gas capture and energy production could further reduce the carbon footprint of waste management practices. *Source: Lauber & Themelis, 2010*



MSW projects have a unique attribute: As an alternative to landfilling, they typically charge a tipping fee to municipalities and other entities (Figure 1). This translates into a negative fuel cost—and a revenue source—that may help offset the high capital costs associated with fuel handling and environmental control systems and the high operations and maintenance (O&M) costs attributable to the variable composition, high moisture and ash content, high contaminant level, and low energy density of waste materials. ADTE plants also require a steady supply of no-cost fuel to justify the expense of collection, treatment, and conversion systems.

The economics of WTE plants are extremely site-specific, depending on tipping fees, MSW characteristics, environmental regulations, byproduct management practices, and many other factors. WTE installations often benefit from the investment and production tax credits granted to renewable energy sources. However, MSW plants sometimes are granted no, or partial, incentives because a significant percentage of their energy production results from the combustion of plastics and other nonbiogenic materials.

The economic viability of ADTE installations is strongly influenced by policy drivers. Policies requiring control of air pollutant and greenhouse gas emissions from landfills, agricultural operations, and wastewater treatment plants improve economics by reducing the incremental cost of adding generating capacity. Depending on site-specific circumstances, these projects also may yield revenue streams in the form of marketable renewable energy certificates and carbon credits.

Globally, more than 1 billion tons of post-recycling MSW continues to be disposed of in landfills each year, including more than 130 million tons in the U.S. While European, Asian, and other nations move forward with strong commitments to energy recovery, the U.S. faces mounting MSW management challenges, including the declining capacity of existing landfills, growing opposition to new disposal sites, high per-capita waste generation rates, low recycling rates, and air and water pollution concerns.

Electric Power Research Institute (EPRI) modeling studies of the U.S. electric sector performed using the National Electric System Simulator & Integrated Evaluator (NESSIE) project a fourfold increase in load-serving MSW capacity to almost 9 GW and a threefold expansion in load-serving LFG capacity to more than 4 GW over the next two decades under market-based climate policies.

Other countries that have not yet incorporated energy recovery as a key component in

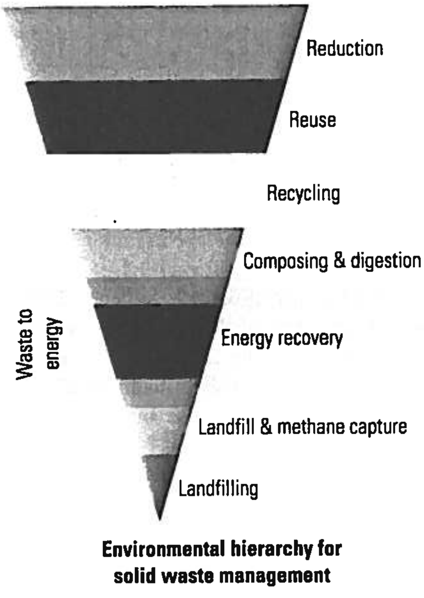
MSW management provide analogous deployment potential. China, for example, has indicated that WTE technologies will be employed to handle more than 30% of its MSW by 2030, a huge increase over current practice.

Figure 2 illustrates how a global transformation in MSW management—encompassing increases in recycling, energy recovery, and other practices to levels already being achieved in many countries—could lead to more than double current WTE capacity while decreasing the amount of MSW being landfilled by more than two-thirds (despite the growing waste volume associated with a growing population). If this transformation were to include expanded energy recovery from LFG, then a ninefold reduction in methane emissions also could be realized. To grow the role of WTE in meeting energy needs, advances are required in resource management, fuel processing, power generation systems, O&M techniques, and environmental controls. Supportive policies and incentives, and greater public acceptance, also are needed.

Resource Management

Waste differs from other energy sources in that MSW management practices, along with producer and consumer behavior, determine the volume and characteristics of fuels suitable for conversion by individual technologies. Figure 3 displays a solid waste management hierarchy, with environmental efficacy declining from top to bottom.

3. Greening up MSW management. Incineration and advanced thermal conversion of the residual waste remaining after recycling and composting represent environmentally sound municipal solid waste (MSW) management options. Digestion-based waste-to-energy technology also may be deployed to extract useful energy from compostable materials and from landfill gas that is captured to reduce pollutant and greenhouse gas emissions. *Source: EPRI*



Traditionally, integrated MSW management plans have focused on decreasing the amount of material that must be disposed of via incineration or landfilling. More recently, "zero waste" strategies have come to the fore, emphasizing prevention and materials recovery but also sharpening the focus on energy recovery as an approach for securing additional environmental benefits, including reductions in land use and emissions. In fact, the small physical footprint of incinerators and other WTE plants, relative to landfilling, is an important driver behind their widespread deployment for MSW disposal in heavily populated European and Asian countries.

Furthermore, although modern landfills are engineered and operated to avoid or minimize environmental releases of methane, volatile organic compounds, hazardous air pollutants, and leachate, control systems are nonexistent or inadequate at many locations, while even new landfills may capture as little as 60% of life-cycle methane emissions. Globally and in the U.S., landfills thus remain the second-largest anthropogenic source of methane, which has a global warming potential many times that of carbon dioxide (CO_2). WTE plants avoid methane and leachate production, and flue gases generally are subject to stringent air quality controls.

On average, modern, electricity-only incinerators also yield roughly an order of magnitude more net energy per ton of MSW than LFG plants. Energy recovery from MSW thus is capable of displacing larger amounts of fossil generation. Additional emission reductions occur when materials removed from the incoming fuel feed and/or metals recovered from combustion byproducts are recycled. This avoids emissions attributable to the extraction and processing of virgin materials.

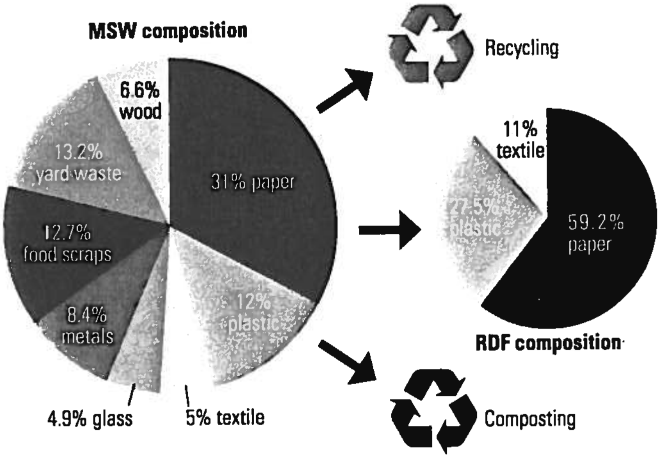
A frequently cited resource management concern is that WTE facilities may undermine recycling programs, but the European experience shows that countries with high energy recovery rates also exhibit higher-than-average recycling rates. In 2006, 41% of the MSW stream across Europe was recycled or composted, 19% was delivered to more than 400 WTE plants, and 40% was landfilled. In 2008, the U.S. recycling rate was 33%, 13% of MSW was delivered to a total of 87 WTE incinerators and FBC units, and 54% was landfilled, according to the EPA. Similarly, the post-recycling energy recovery rate is more than 30% across Europe, less than 20% for the U.S., and even lower in China and many other nations. By contrast, this rate ranges from 70% to 80% in Japan and exceeds 90% in Denmark and the Netherlands, highlighting the potential for increased WTE deployment.

Fuels and Processing Methods

As a fuel, MSW poses a number of challenges. It is produced on a distributed basis, and its composition is highly variable, including a mix of organic and inorganic constituents. Hazardous and toxic waste stream components pose health and safety risks. Low energy density and high moisture, chlorine, and ash content lead to handling, combustion, slagging and fouling, corrosion, and byproduct management issues.

Lightly processed, post-recycling MSW received at mass-burn WTE plants has a heating value in the range of 4,500 to 5,500 Btu/lb. High-intensity processing yields refuse-de-

4. From refuse to electrons. When raw municipal solid waste (MSW) is transformed into refuse-derived fuel (RDF) that can be used to generate electricity, large amounts of inorganic and organic materials are recovered for recycling and composting. The end result is a higher-quality fuel with more uniform content and significantly improved handling and combustion performance. RDF also may be pelletized to improve transport. *Sources: EPA and Scoullos et al., 2008*



rived fuel (RDF)—also known as solid recovered fuel—which is more amenable to firing in FBC units and advanced thermal conversion systems and offers the potential for high-rate cofiring in pulverized coal plants.

Mechanical, magnetic, thermal, biological, and other techniques may be applied to isolate and process combustible fractions. Residual waste—mainly a mixture of paper and plastics—is pulverized and dried to form a fluffy material of relatively uniform consistency with a heating value of roughly 5,500 to 6,500 Btu/lb (Figure 4). RDF may be packed as cubes or pellets for easy storage and transportation.

Processed engineered fuel (PEF) refers to higher-grade RDF produced from sorted and mechanically processed wastes, such as packaging materials and tires, and from custom blends of paper, plastic, and other materials.

The higher energy density, improved handling characteristics, and reduced moisture and ash content of derived fuels translate into lower heat rates and O&M costs. Of course, realizing these benefits has impacts, in that installing and operating fuel-processing systems at the plant site imposes energy and cost penalties. Centralized manufacturing of higher-grade fuels offers potential economies of scale, while source-based production creates opportunities to reduce hauling costs and facilitate long-distance trade. RPS eligibility remains an issue for individual fuel formulations.

For ADTE technologies, the digestion process relies on anaerobic bacteria that break down organic materials into sugars, acids, and then gases, leaving behind liquid and solid residues. Decomposition occurs over years to decades in landfills and days to weeks in purpose-built digesters.

Produced at atmospheric pressure and saturated with water, digester gas typically must be compressed, dehydrated, and treated. Depending on the fuel and power generation option, extensive pretreatment may be required to remove siloxane, hydrogen sulfide, and other constituents with potential to cause corrosion, erosion, environmental control, and odor problems. Further cleaning and purification are necessary to achieve the quality required for injection of pipeline-quality renewable fuel in natural gas delivery systems.

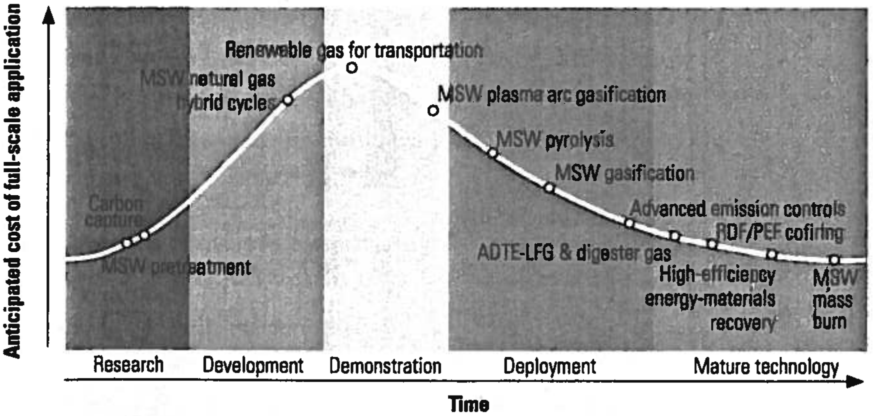
Generation Technologies

WTE technologies come in different forms, offer a variety of outputs, and are in various stages of development, but they have two common objectives: to both manage waste and generate energy. Conventional combustion-based processes transform solid wastes into heat for direct use or further conversion into steam and electricity, while advanced conversion processes convert solids into gaseous or liquid fuels offering broader utility. Figure 5 displays the status of a broad range of WTE technologies, showing the extent to which public-private investment is required to yield commercially mature systems.

Comparing the economic, energy, and environmental performance of individual WTE technologies on a consistent basis is extremely difficult. Traditionally, incineration and other options have been evaluated on the basis of \$/ton of MSW disposed in comparison to the cost of landfilling or on their ability to meet the objectives of integrated resource management plans, rather than on the \$/kW and \$/MWh metrics commonly used in the power industry.

From an energy recovery perspective, producing hot water for direct use in district heating is the simplest and highest-efficiency approach for MSW, with a net level exceeding 60%. Generating steam for district or industrial process heating or CHP applications is somewhat less efficient, while cofiring RDF and PEF in coal plants further reduces conversion efficiency to around 30%. Steam-electric power generation in a dedicated incinerator or FBC plant offers low efficiency—around 20% or less—due primarily to fuel properties, boiler design and size, and heat losses, as well as reduced net power export due to parasitic energy consumption required by environmental control systems. MSW conversion processes yielding gaseous fuels suitable for firing in combustion turbines and combined-cycle plants offer potential for substantial gains in electricity production efficiency.

5. Maturing at different rates. WTE technologies are at varying stages of development and commercial maturity, as shown by this Grubb curve. *Source: EPRI*



Notes: ADTE= anaerobic digestion to energy, LFG= landfill gas, MSW= municipal solid waste, RDF= refuse-derived fuel, PEF= process-engineered fuel.

Conventional Thermal Conversion

Mass-burn incineration, the simplest and lowest-cost option for electricity production, also accounts for the overwhelming majority of installed WTE capacity.

FBC technology offers higher conversion efficiency and lower pollutant emissions, but its application has been constrained by the limited availability and higher cost of RDF. Higher-quality fuel is required to maintain stable combustion conditions in these systems because they have a much shorter residence time.

For both types of plants, steam serves a turbine-generator train, and power flows through a transmission-class substation onto the grid, as shown in Figure 6. Net electrical output is roughly 550 to 600 kWh/ton of MSW. Turbine exhaust is directed to a condenser for cooling, but in cogeneration applications heat may be extracted and water or steam fed to a distribution system for district or process heating. Conventional wet cooling systems may require significant amounts of water. Air-cooled condensers can reduce water consumption by up to 90% while imposing parasitic loads that increase generation costs.

Advanced Thermal Conversion

For advanced thermal conversion technologies, design goals are to increase materials recovery and recycling rates, improve the quality of recyclables, simplify flue gas cleanup, and reduce the quantity and improve the quality of solid byproducts that must be disposed of via landfill. There are three advanced thermal conversion processes of importance:

- *Pyrolysis* involves energy-assisted heating of MSW in the absence of oxygen within a range of about 400C to 800C. Byproducts include volatile liquids and syngas—with relative proportions determined by process temperature—plus a blend consisting primarily of metals that may be recycled and char that may be used for energy recovery or beneficial applications.

- *Gasification* involves heating of mixed MSW or derived fuels at temperatures exceeding 700C in the presence of sufficient oxygen to allow partial oxidation, but not enough for full combustion. This energy-assisted process yields a syngas mixture of hydrogen, carbon monoxide, water vapor, methane, and other constituents.
- *Plasma arc gasification* is a technology developed for hazardous waste incineration. It involves the use of a gasification reactor in combination with high-voltage electrodes that create a plasma torch. The torch operates at about 1,200C, well below the temperatures employed to destroy hazardous waste but sufficient to transform the complex gas mixture into a simpler syngas.

Once treated, MSW-derived syngas may be fired in internal combustion engines sized in 1-MW increments or, far less commonly, in steam-electric boilers. With additional processing, it may be used in combustion turbines or combined cycle units. Units generally are sized at 20 MW or less, and electric generation efficiencies of 25% to 40% are achievable. Energy recovery may yield recyclable slag, residual material that must be landfilled, or both.

Biological Conversion

Digestion relies on biological processes to produce gaseous fuels exhibiting considerable utility and energy density. Processes occurring within landfills generally are uncontrolled, while those occurring in enclosed plastic, concrete, or metal structures may be managed by altering feed characteristics and rates, controlling physical conditions, and making chemical and biological additions.

LFG is commonly collected and used to serve on-site needs for energy. At wastewater treatment plants, digester gas arising from processing of the solid fraction of domestic sewage traditionally has been fired for process heating, but a growing number of plants are using it for CHP applications. Manure from large-scale cattle, pig, and poultry operations increasingly is being employed to generate fuel for energy production consistent with some RPS mandates.

Digestion of biogenic MSW fractions is an emerging approach to solid waste management. For this application, mechanical pretreatment may be used to separate out residual recyclables and noncombustibles and isolate the organic materials to be introduced to the digester.

Reciprocating engines—the most commonly employed generation option for digester gas—may be installed in 1-MW increments to match the on-site fuel supply. Both smaller and larger engines are available. Small combustion turbines may be deployed in the range of 1 to 5 MW or at microturbine scale, while fuel cells may be employed for fuel meeting tight quality standards. Steam-electric and combined cycle plants are suited only to sites with fuel supplies capable of supporting central-station generation. In many cases, ADTE installations are backed by natural gas or propane firing capability to ensure consistent energy production.

Cofiring and Hybrid Cycles

MSW-derived solid fuels, syngas, and digester gas may be cofired in fossil plants, and hybrid cycles involving distinct waste and fossil fuel feeds are being explored. Depending on the fuel characteristics and policy environment, these approaches may provide options for reducing fuel costs and GHG emissions as well as generating renewable energy.

Proper fuel specifications are critical for successful MSW cofiring applications. Experience indicates that PEF with heating values in the range of 8,500 to 11,500 Btu/lb (wet weight basis) may successfully contribute up to 30% of the input energy in coal-fired boilers.

Renewable Gas

LFG, digester gas, and syngas may be upgraded and injected into natural gas networks for direct use in heating or transportation applications. LFG from the Fresh Kills Landfill in New York, for example, has been treated to increase methane concentrations, meet other pipeline-quality criteria, and feed the local gas distribution system for more than 30 years.

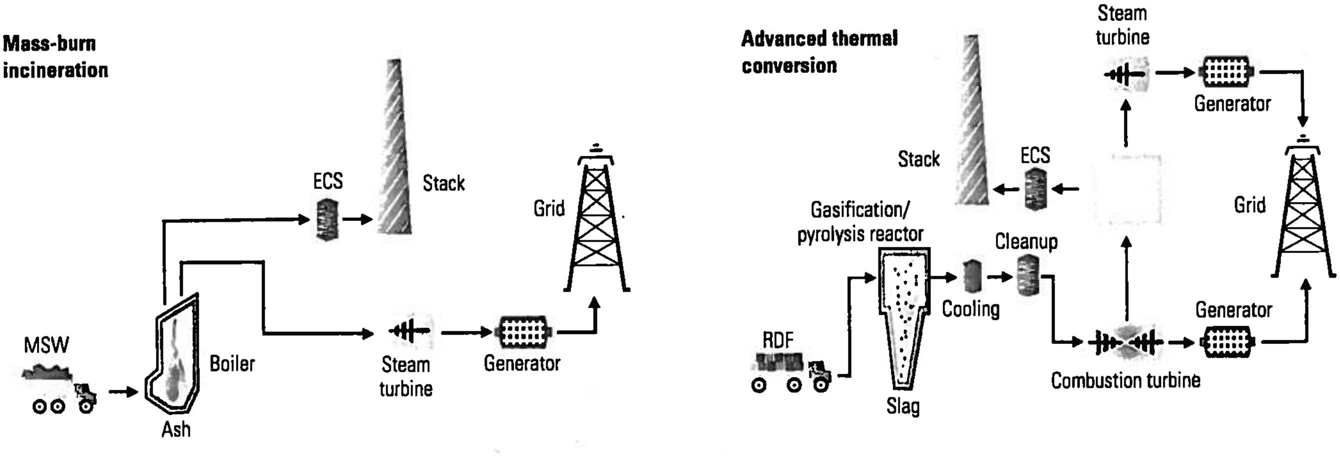
A number of utilities and agencies are exploring renewable gas production as an option for GHG mitigation and enhanced energy recovery because modern heating systems achieve efficiencies of 80% to 90% and higher—far above those achieved in power generation applications.

Operations and Maintenance

Modern WTE plants offer availabilities exceeding 90%, comparable to those of other baseload generating options. Sensor and control systems, operating environments, degradation mechanisms, and maintenance needs also are generally similar. Many of the O&M challenges unique to WTE capacity arise from the characteristics of MSW as a fuel source.

Difficulties in MSW handling and feeding increase labor and maintenance requirements and, along with variations in fuel quality, complicate process control in incinerators.

6. Conventional and advanced thermal conversion technologies. Conventional mass-burn incinerators typically operate on as-received or lightly processed municipal solid waste and are based on mature steam-electric generation systems. In contrast, advanced thermal technologies require higher-quality refuse-derived fuel or processed engineered fuel and involve a multi-step process, whereby solid fuel is transformed into syngas that must be cooled, cleaned, and then fired to generate electricity. *Source: EPRI*



Notes: ECS= environmental control systems, HRSG= heat recovery system generator, RDF= refuse-derived fuel.

High slagging and fouling rates necessitate frequent removal of ash deposits, while noncombustible materials and aggressive chemical conditions lead to accelerated rates of erosion and corrosion.

Environmental Controls

Modern incinerators have lower life-cycle pollutant and GHG emissions than landfilling. In general, WTE plants have output-based emission rates for conventional air pollutants roughly comparable to those of existing coal-fired capacity but higher than those of gas-fired units. On a per-MWh basis, overall CO_2 emissions from incinerators typically exceed those of coal-fired plants due to high moisture content, other fuel properties, and low conversion efficiencies. However, the substantial percentage of these releases attributable to combustion of biogenic fuel fractions is commonly subtracted from the total under conventional life-cycle analysis frameworks.

Stack emissions and other releases from WTE plants generally are subject to stringent regulation, such as the maximum available control technology mandate under the Clean Air Act that required large U.S. incinerators to install dry flue gas desulfurization (FGD) scrubbers, fabric filter baghouses, activated carbon injection, selective noncatalytic reduction, and other measures by 2000. This largely has eliminated harmful emissions from existing MSW capacity, at the cost of increased parasitic energy consumption and higher O&M costs.

Figure 7 illustrates the dramatic reduction in dioxin and furan releases—from 8,877 toxic equivalents (TEQ) in 1987, when incinerators accounted for more than 60% of total U.S. airborne emissions, to 12 TEQ in 2002. This 99.9% decrease was complemented by absolute reductions in emissions of mercury, lead, cadmium, and hydrochloric acid of more than 90% and of sulfur dioxide and particulate matter by more than 85%. For some contaminants, source reduction has made important contributions. Many mercury-containing products have been phased out, and recycling programs in communities served by WTE facilities are keeping mercury out of the MSW stream.

Capturing and recovering energy from LFG substantially reduces pollutant and GHG emissions, relative to landfilling. Limited data are available on air emissions associated with energy recovery from digester gas generated from wastewater, manure, MSW organics, and other biogenic wastes. A variety of pretreatment, combustion-based, and post-combustion technologies are available. Odor management measures include enclosures, filters and treatment methods at air intakes and exhausts, and negative pressure control.

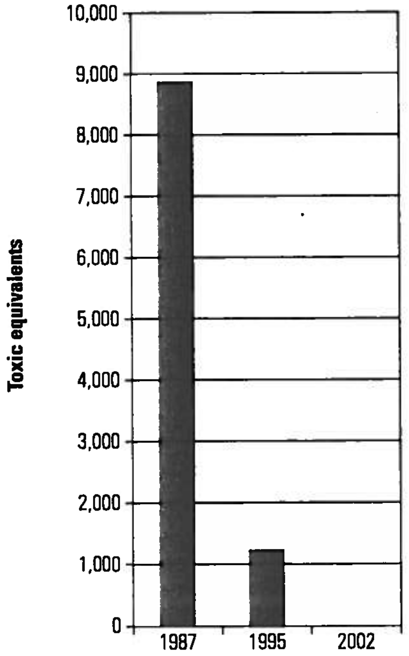
Solid byproducts from MSW combustion and control processes include fly ash, bottom ash, slag, and FGD solids. Ferrous and nonferrous metals typically are extracted from bottom ash as recyclables, and the remaining ash then may be recycled as an aggregate material. Fly ash and FGD solids often contain relatively high concentrations of heavy metals and other contaminants. This may limit opportunities for beneficial reuse in concrete, fill, gypsum, and other applications and require disposal in a dedicated landfill, at significant cost.

Conventional treatment technologies are available for liquid wastes and thermal discharges generated during fuel storage, dewatering, steam-electric conversion, environmental control, and cooling operations associated with WTE capacity.

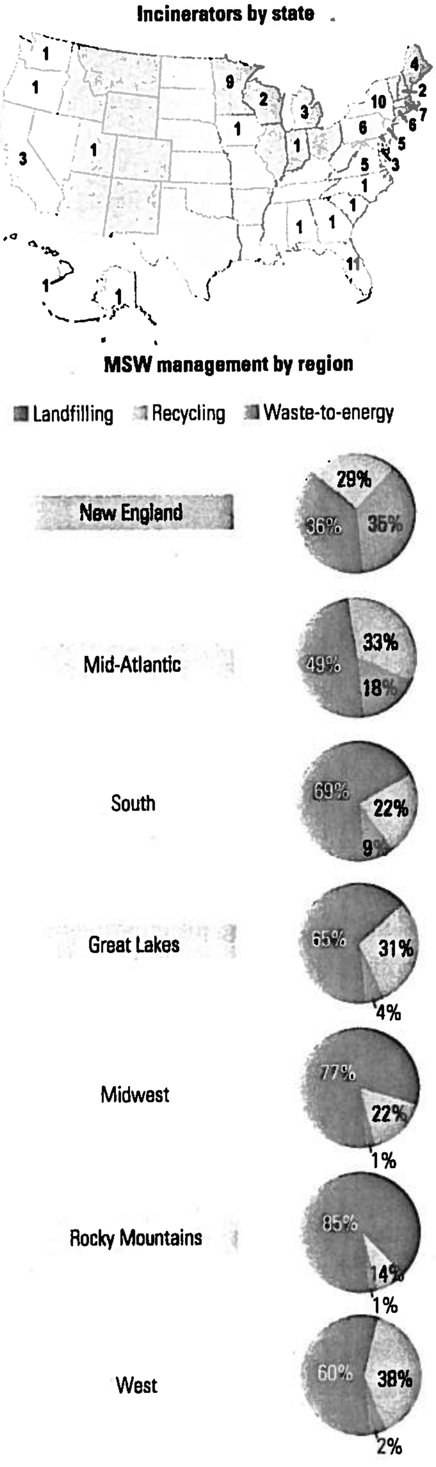
Future Directions in the Development of WTE Technologies

Many European and Asian nations have high energy recovery rates, while mature WTE technologies have experienced relatively modest application in the U.S. and many other countries. To expand deployment in the U.S. and elsewhere, common misconceptions regarding the environmental performance of WTE technologies must be eliminated, and decision-makers must treat post-recycling MSW as an asset for energy recovery, emission reduction, and baseload renewable energy production rather than as a liability for disposal.

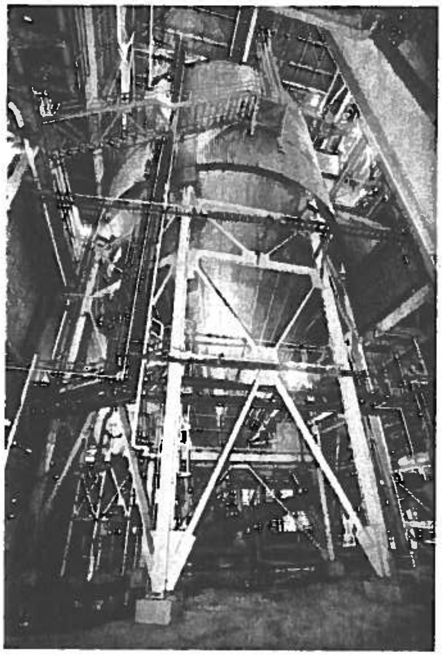
7. Cutting out dioxins and furans. State-of-the-art environmental control systems have reduced dioxin and furan emissions from U.S. incinerators by 99.9% since the mid-1980s, and they allow these facilities to routinely comply with air quality standards tighter than those faced by coal-fired plants. *Source: Psomopoulos et al., 2009*



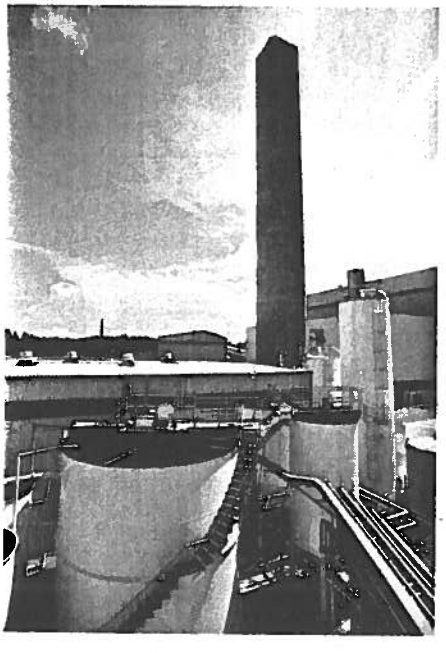
8. Untapped potential. Given the very low energy recovery rates and high landfilling rates in many regions of the country, the U.S. has many promising prospects for successful WTE deployment. *Sources: Michaels, 2007; Simmons et al., 2006*



9. Leading the way. The Lee County waste-to-energy (WTE) and recovered material processing plant, one of the most advanced solid waste management systems in the U.S., burns waste at more than 1,800F. The plant is equipped with extensive air-pollution control systems, such as the scrubber shown in the photo. The Lee County WTE plant is the first U.S. plant built with a permanent activated carbon injection system for controlling mercury emissions. *Courtesy: HDR Inc.*



10. Once is not enough. Adding an additional layer of sustainability, the Lee County WTE plant operates as a zero-discharge facility. The clarifier at the plant is used to treat recycled wastewater from a nearby municipal wastewater treatment plant. *Courtesy: HDR Inc.*



In addition, the costs and risks of existing and emerging WTE options must be reduced through investments in research, development, and demonstration (RD&D) to improve cost-performance characteristics and through consistent policy and market frameworks that account for their attributes as renewable energy and climate mitigation options.

As shown in Figure 8, most U.S. regions continue to landfill much more than 50% of their solid waste. Almost half of the existing MSW-firing plants are sited in densely populated northeast states, where landfill space is at a premium. Since 1996, no new incinerators have been deployed in the U.S., leading to an increase in intrastate MSW transport from sending areas lacking landfill capacity to more rural receiving areas. Despite the fact that long-distance hauling and landfilling result in higher levels of pollutant and GHG emissions than would energy recovery from a nearby WTE facility, this trend may continue as existing disposal sites are closed and challenges associated with permitting new landfills in developed areas grow.

Countering this trend is the recent expansion of a WTE plant in Lee County, Fla. (Figures 9 and 10), where generating capacity was augmented from 40 MW to 60 MW to handle the increasing MSW volume from Ft. Myers and nearby communities. Efforts to expand existing facilities are under way elsewhere, and new plants are being considered across the country. However, a number of U.S. states maintain bans on new MSW incinerators and are considering extending these bans to include advanced WTE technologies such as gasification and pyrolysis.

Relative to landfilling, energy recovery offers much lower GHG emissions, requires much less land, and boosts recycling rates. Stringent regulations, advanced control technologies, and other measures hold pollutant emissions from modern incinerators below the permit limits established to protect environmental and human health. Handling practices—such as using rail rather than truck transport, employing covered containers, and unloading MSW inside buildings with negative pressure control—help address noise, litter, and odor concerns. WTE technologies deployed at landfills, treatment plants, and farms offer an advantage in that they may be seen as part of an ongoing municipal or agricultural operation.

Comprehensive life-cycle analyses evaluating energy recovery within waste management, energy supply, and climate mitigation contexts are needed to document the benefits of WTE technologies, while proactive communication with decision-makers, stakeholder groups, and the public is required to address concerns and increase acceptance for individual projects as elements within integrated resource management strategies. Science-based information and educational outreach also are necessary to help ensure that WTE options are eligible for the investment and production incentives granted to renewable energy sources and are designated as qualifying technologies under RPS mandates and other directives.

Cost reduction and further improvement in environmental performance represent additional RD&D priorities. At present, MSW incinerators are much more costly to build and operate than coal-fired steam electric capacity and other baseload generation, and most WTE plants are economically viable only because their fuel provides a source of revenue in the form of tipping fees.

New source separation and MSW processing technologies are needed to remove potentially harmful constituents and to produce derived and engineered fuels offering improved handling characteristics, increased energy density, and decreased moisture and ash content, and reduced emissions of pollutants and GHGs. These advances would reduce the capital investment required for fuel feed and environmental control systems, as well as lower heat rates and O&M costs for incinerators. In addition, they would facilitate long-distance fuel transport, potentially leading to the siting and construction of larger, more cost-efficient WTE facilities in rural areas. Improved fuels also would enable high-rate MSW cofiring in coal-fired plants, a potentially low-cost approach for reducing carbon emissions from existing capacity while generating renewable energy.

To support deployment of advanced conversion processes and hybrid plant concepts, successful commercial-scale demonstrations are needed to confirm the ability of individual technologies to handle large amounts of waste on a reliable basis, in an environmentally sound manner, over an extended period.

Current EPRI projects address several key areas for growing the role of WTE technologies in meeting U.S. needs for clean, affordable, reliable, and sustainably produced electricity. EPRI plans to continue collaborative work with utilities, agencies, and other stakeholders to identify and pursue near-, mid-, and long-term RD&D needs and opportunities. ■

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