Michael J. Cicchetti
Associate Director, Government Relations

Covanta Energy Corporation
27 Castlewood Road
West Hartford, CT 06107
Tel 973-610-3547
Email mcicchetti@covantaenergy.com
Website www.covantaholding.com

Energy Policy Review Commission Comments

May 17, 2013

As the Energy Policy Review Commission continues its statutory duties to develop recommendations for the legislature regarding Massachusetts energy policies, Covanta Energy believes that the inclusion of Energy-from-Waste (EfW), also known as Waste to Energy or Resource Recovery, as a Class I energy source should be a recommendation of this study. Specifically, EfW can help the commonwealth increase in-state Class I renewable generation, create and support Massachusetts jobs, and increase reliability. Since EfW requires less financial support than intermittent renewables and it is baseload power, it could help stabilize or even reduce energy prices. At the same time, EfW is recognized internationally by climate scientists as a reducer of greenhouse gas emissions. Unfortunately, EfW is relegated to Class II in the commonwealth's RPS.

Massachusetts' RPS – Sending Jobs Out of state

According to the *Massachusetts RPS and APS Annual Compliance Report for 2011*, a full 89% of the Class I power in Massachusetts is supplied by out of state generation. As a result, Massachusetts ratepayers are subsidizing out of state companies and out of state jobs. Moving EfW to Class I will increase the Class I power being generated in the commonwealth, support and increase Massachusetts jobs, and limit the amount of Massachusetts' rate payer dollars heading out of the commonwealth. If it does not make a policy change, Massachusetts' ratepayers will continue to subsidize out of state jobs. It makes little sense to subsidize out of state energy production and jobs at the expense of in state renewable production and in state jobs.

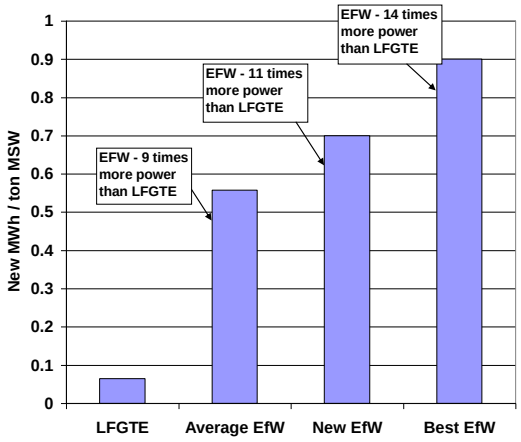
Massachusetts RPS – Encouraging the Inefficient Over the Efficient

The solid waste hierarchy has been adopted by the US EPA as well as advanced nations worldwide. It establishes clear ways to deal with solid waste. Countries, and states, that have adopted and remained true to the hierarchy have enjoyed significant reductions in landfilling while simultaneously increasing their recycling rates. Massachusetts' neighbor to the south, the State of Connecticut, adopted the hierarchy decades ago, and as a result its solid waste policies have propelled the state to the top of the list in terms of its long term sustainability. The state has all but eliminated landfilling, and is virtually self-sufficient for solid waste management.

Inexplicably, Massachusetts policy makers have refused to acknowledge this hierarchy, and as a result continue to landfill over a million tons of waste every year, mostly within the borders of the commonwealth. Unfortunately, the RPS in the commonwealth has also refused to acknowledge the fact that EfW is superior to landfilling, and as a result the RPS is subsidizing landfilling over EfW. Landfill gas plants are in Class I, while EfW is in Class II. Furthermore, in 2011, 32.1% of Massachusetts Class I target was met by these landfill gas plants, - much of which are located outside the commonwealth. Additionally, the amount of landfill gas supplying Class I power increased 15.2% from 2010, making landfill gas the second largest source of Class I power.

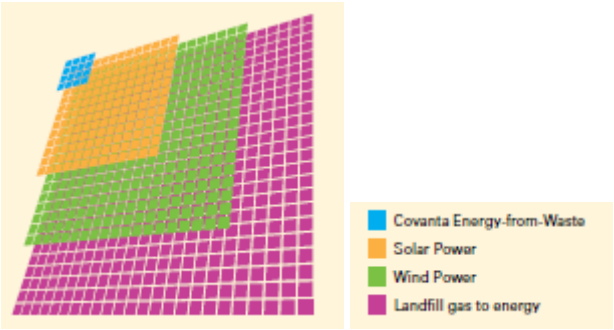
Regional states have begun to take a new view of non-recycled trash, one consistent with most parts of the industrial world: viewing it as a resource. In fact, the State of Maryland just moved EfW from Class II to Class I in its RPS. As Governor O'Malley stated upon signing the bill "After careful deliberation, I have decided to sign Senate Bill 690. Our State has an aggressive goal of generating 20% of our energy from Tier I renewable sources by 2022 and we intend to achieve that goal through as much instate energy generation as possible. This will require a diverse fuel mix including onshore and offshore wind, solar, biomass including poultry litter, and now waste-to-energy if we are to realize our 20% goal." Moving EfW from Class II to Class I would allow the six EfW facilities in Massachusetts, generating clean, in-state baseload renewable power, to help ensure that Massachusetts energy policy achieves its Class I goals while supporting in state jobs.

Landfill gas recovery systems energy efficiency is extremely low compared to EfW. The chart below compares landfill gas projects to EfW. The average existing facility generates *nine times* more power per ton of waste while the newest facilities can generate as much as *fourteen times* more power. This comparison was done using the exact same fuel, garbage.



EfW facilities produce 9 to 14 times the energy per ton compared to landfill gas.

Furthermore, EfW is one of the most efficient uses of land per megawatt (acres/MW) among the current renewable energy solutions. Covanta's facilities require an average of 0.7 acres/MW of electricity compared with 8 acres/MW for solar, 18 acres/MW for wind, and 27 acres/MW for landfill gas to energy based on average capacity over 30 years.



Land Required Per Megawatt

Landfills are one of the largest sources of manmade methane (a GHG 25 times as potent as carbon dioxide over a 100 year time frame), and only a portion of that methane is collected and converted into electricity. The rest of it escapes directly into the atmosphere. While EfW facilities are "one of the cleanest sources of electricity" according to the US EPA, landfills have significant uncontrolled emissions, including 170 air pollutants, 44 of which are air toxics, including 4 known and 13 probable carcinogens, in addition to methane. This further demonstrates the need to correct the state's energy policy and make EfW a Class I renewable.

Every ton of solid waste processed at an EfW facility offsets the need for one barrel of oil and ¼ ton of coal, reducing the state's reliance on fossil fuels. In addition, EfW facilities in Massachusetts are located near the areas of greatest electricity need, reducing the burden on our already congested transmission system and helping to alleviate congestion and capacity charges for Massachusetts ratepayers.

Energy-from-Waste is Proven in Massachusetts

Energy-from-Waste is a proven technology that converts municipal solid waste into baseload steam and/or electricity. There are currently 86 such facilities operating in the United States, including six in the commonwealth. Covanta Energy operates four of those six plants, which employ 327 people with a $33 million annual payroll. Covanta also pays $12 million in local taxes and host community fees.

The four Covanta facilities in Massachusetts are located in Pittsfield, Springfield, Rochester and Haverhill. The Haverhill facility processes approximately 1650 tons per day of municipal solid waste and produces 49 megawatts of renewable power. The Covanta SEMASS (Southeastern Massachusetts) facility in Rochester processes 3000 tons per day of solid waste and generates up to 54 megawatts of renewable power. The Springfield facility processes 408 tons per day of solid waste and generates up to 9.4 megawatts of renewable power. The Pittsfield facility, which processes up to 240 tons of solid waste each day, does not sell electricity to the grid, but instead sells steam to adjacent manufacturing operations which use this renewable power to power their operations.

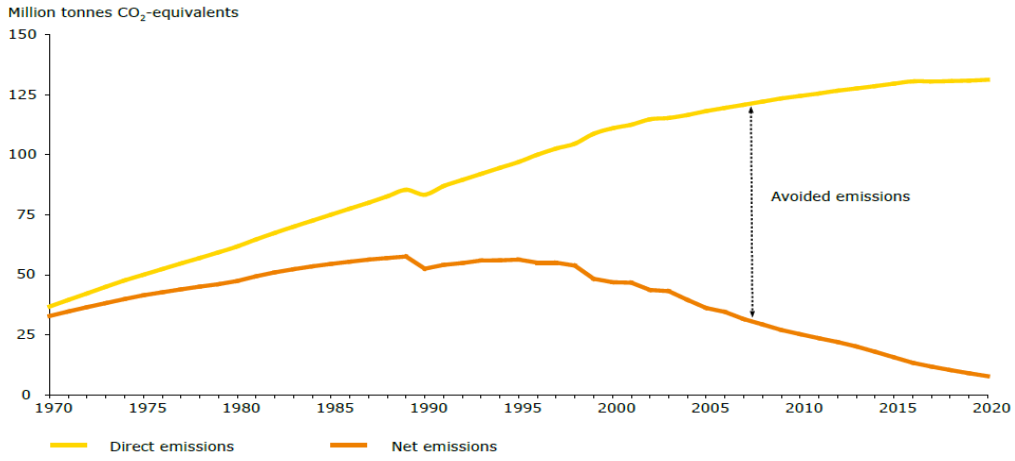
Furthermore, EfW facilities supply power 365-days-a-year, 24-hours a day and average greater than 90% availability of installed capacity. EfW power is sold as "baseload" electricity to utilities that can rely upon its supply of electricity. It is not dependent on weather conditions that make other Class I power intermittent. Additionally, because these facilities are located both where the "fuel" is and where the demand for power is, they do not require additional, interstate transmission lines. They are, in fact, distributed generation facilities.

Energy-from-Waste is the Least Subsidized Energy Source

Energy-from-Waste is one of the lowest cost renewable energy sources. Further, when the Energy Information Administration Office of Coal, Nuclear, Electric, and Alternate Fuels examined subsidies received by all energy technologies, it is clear that EfW is the least subsidized, receiving *even less than fossil fuels.* EfW provides long term price stability for rate payers for both energy and waste disposal.

Energy-from-Waste is Internationally Recognized as a Key GHG Mitigation Technology

Germany, Denmark and the rest of the EU have adopted policies that have moved to phase out landfills and increase recycling and recovery of energy from waste. As a result of the EU waste policies, the largest relative reduction in EU greenhouse gas emissions has been achieved in the waste sector, with a relative reduction of 34%. This is due largely to the avoidance of the methane that is generated by landfills. The chart below demonstrates the current and projected reduction of GHG emissions from the management of municipal waste in the EU.



Source: ETC/RWM.

The EU Landfill Directive (1999) states that member countries have to reduce the biodegradable waste going to landfill to 35% of 1995 levels by 2020. This policy has been the single most effective way to achieve increased recycling and energy recovery which allowed the waste sector to achieve the highest relative reductions of greenhouse gases at 34%. EfW facilities, through an engineered controlled combustion process, eliminate all of the potential methane from waste disposal in landfills. Recognition of EfW as a source of GHG mitigation and inclusion of EFW as an eligible source of carbon offsets follows the long established policies of the Intergovernmental Panel on Climate Change (IPCC), the Clean Development Mechanism (CDM) of the Kyoto Protocol and the European Union. Here in the United States, the recent expansion of the Lee County Resource Recovery Facility in Florida is generating carbon offset credits under the Voluntary Carbon Standard. The World Economic Forum in its 2009 Davos Report identified EfW as one of 8 technologies likely to make a significant contribution for a future low carbon global energy future. The 2010 Davos Report reiterated their findings but also included a recommendation to follow the European Union's model and increase EfW by phasing out use of landfills because to bury waste in landfill is "increasingly considered environmentally unacceptable".

Nationally, each ton of waste processed at an EfW facility leads to the reduction of a ton of carbon dioxide equivalent greenhouse gas emissions. This is predominately due to the prevention of landfill methane, a GHG 25 times as potent as carbon dioxide over a 100 year time frame. Concurrently, EfW supplies baseload renewable energy to the grid, avoiding fossil fuel combustion, and recovers ferrous and non-ferrous metals, reducing the GHG emissions associated with the production of these metals from raw materials.

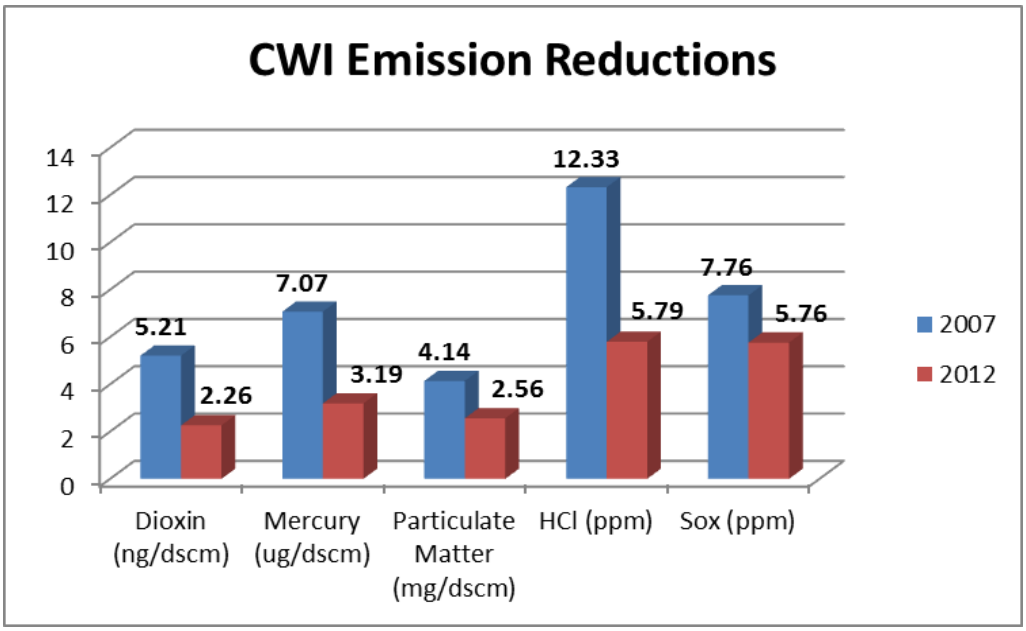
Energy-from-Waste Facilities Have a Proven Track Record of Strong Environmental Performance

The U.S. EPA states that EfW facilities produce electricity with "less environmental impact than almost any other source of electricity." Even though these facilities were built approximately 20 years ago, they employ the latest state of the art technology. The 1990 Clean Air Act included a provision that EFW facilities must comply with the Maximum Achievable Control Technology (MACT) standards. A 2007 memo from the US EPA stated that "**The performance of the MACT retrofits have been outstanding**." The table below is from that same EPA memo.

Pollutant	1990 Emissions (tpy)	2005 Emissions (tpy)	Percent Reduction
CDD/CDF, TEQ basis*	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%
HC1	57,400	3,200	94%
SO_2	38,300	4,600	88%
NO_x	64,900	49,500	24%

Although NO_x emissions were reduced during the period, Covanta is introducing a new technology that it is installing at its facilities. The results of this technology have further reduced nitrogen oxide (NO_X) emissions dramatically. Covanta has two patent-pending processes: LN™ (low NOx) and VLN™ (very low NOx). LN™ involves modifications to the combustion air system combined with modifications to the combustion monitoring and controls systems to achieve substantial reductions in NO_x formation.

In 2007, Covanta initiated its Clean World Initiative (CWI) in an effort to continue instituting state of the art pollution controls. The results have been very successful, with emissions being continually reduced.



As a result of these and numerous other technological emission control improvements over the years, modern EfW facilities run about as clean as a natural gas facility.

Cheap, Subsidized Landfills Compete With Recycling

Readily available data demonstrates domestically and internationally that communities that utilize EfW have much higher recycling rates when compared to those that landfill. Further, countries in Europe that have aggressively moved away from landfilling and concurrently increased their use of EfW have a vastly superior recycling rate as compared to the US overall, proving that it is the availability of cheap, state subsidized landfilling that competes with recycling, not EFW. Further, EfW facilities recover tons of ferrous and non-ferrous metals that would otherwise sit in a landfill, reducing the GHG emissions associated with the production of these metals from raw materials.

Massachusetts' Energy Future

Massachusetts is correct to undertake a review of its energy policies. Covanta Energy hopes that the commonwealth will continue on this path and embrace EfW as part of Massachusetts' energy future and recognize EfW as a Class I renewable. The commonwealth need only look to European nations to demonstrate the success of using EfW as part of a comprehensive energy plan (with the concurrent benefit of an environmentally friendly solid waste plan).

Massachusetts would prove to be at the forefront of the renewable energy discussion by moving EfW to Class 1, and reap the many benefits of this indigenous fuel source.

Additional Resources

For additional information, the following attachments provide information on the many benefits of EfW. Also, the Citizens Budget Commission (CBC) Report provides an excellent discussion of EfW.

New York Times Article: "Europe Finds Fuel In Trash; U.S. Sits Back"
World Economic Forum: "Green Investing 2010"
Kaplan, Decarolis & Thorneloe; "Is It Better to Burn or Bury Waste for Clean Electricity Generation?"
European Environment Agency Briefing: "Better management of municipal waste will reduce greenhouse gas emissions"
Center for American Progress: "Energy from Waste Can Help Curb Greenhouse Gas Emissions"

The New York Times

April 12, 2010

Europe Finds Clean Energy in Trash, but U.S. Lags

By ELISABETH ROSENTHAL

HORSHOLM, Denmark — The lawyers and engineers who dwell in an elegant enclave here are at peace with the hulking neighbor just over the back fence: a vast energy plant that burns thousands of tons of household garbage and industrial waste, round the clock.

Far cleaner than conventional incinerators, this new type of plant converts local trash into heat and electricity. Dozens of filters catch pollutants, from mercury to dioxin, that would have emerged from its smokestack only a decade ago.

In that time, such plants have become both the mainstay of garbage disposal and a crucial fuel source across Denmark, from wealthy exurbs like Horsholm to Copenhagen's downtown area. Their use has not only reduced the country's energy costs and reliance on oil and gas, but also benefited the environment, diminishing the use of landfills and cutting carbon dioxide emissions. The plants run so cleanly that many times more dioxin is now released from home fireplaces and backyard barbecues than from incineration.

With all these innovations, Denmark now regards garbage as a clean alternative fuel rather than a smelly, unsightly problem. And the incinerators, known as waste-to-energy plants, have acquired considerable cachet as communities like Horsholm vie to have them built.

Denmark now has 29 such plants, serving 98 municipalities in a country of 5.5 million people, and 10 more are planned or under construction. Across Europe, there are about 400 plants, with Denmark, Germany and the Netherlands leading the pack in expanding them and building new ones.

By contrast, no new waste-to-energy plants are being planned or built in the United States, the Environmental Protection Agency says — even though the federal government and 24 states now classify waste that is burned this way for energy as a renewable fuel, in many cases eligible for subsidies. There are only 87 trash-burning power plants in the United States, a country of more than 300 million people, and almost all were built at least 15 years ago.

Instead, distant landfills remain the end point for most of the nation's trash. New York City alone sends 10,500 tons of residential waste each day to landfills in places like Ohio and South Carolina.

"Europe has gotten out ahead with this newest technology," said Ian A. Bowles, a former Clinton administration official who is now the Massachusetts state secretary of energy.

Still, Mr. Bowles said that as America's current landfills topped out and pressure to reduce heat-trapping gases grew, Massachusetts and some other states were "actively considering" new waste-to-energy proposals; several existing plants are being expanded. He said he expected resistance all the same in a place where even a wind turbine sets off protests.

Why Americans Are Reluctant

Matt Hale, director of the Office of Resource Conservation and Recovery of the United States Environmental Protection Agency, said the reasons that waste-to-energy plants had not caught on nationally were the relative abundance of cheap landfills in a large country, opposition from state officials who feared the plants could undercut recycling programs and a "negative public perception." In the United States, individual states and municipalities generally decide what method to use to get rid of their waste.

Still, a 2009 study by the E.P.A. and North Carolina State University scientists came down strongly in favor of waste-to-energy plants over landfills as the most environmentally friendly destination for urban waste that cannot be recycled. Embracing the technology would not only reduce greenhouse gas emissions and local pollution, but also yield copious electricity, it said.

Yet powerful environmental groups have fought the concept passionately. “Incinerators are really the devil,” said Laura Haight, a senior environmental associate with the New York Public Interest Research Group.

Investing in garbage as a green resource is simply perverse when governments should be mandating recycling, she said. “Once you build a waste-to-energy plant, you then have to feed it. Our priority is pushing for zero waste.”

The group has vigorously opposed building a plant in New York City.

Even Mayor Michael R. Bloomberg, who has championed green initiatives and ranked Copenhagen’s waste-fueled heating on his list of environmental “best practices,” has shied away from proposing to get one built.

“It is not currently being pursued — not because of the technology, which has advanced, but because of the issue in selecting sites to build incinerators,” said Jason Post, the mayor’s deputy press secretary on environmental issues. “It’s a Nimby issue. It would take years of hearings and reviews.”

Nickolas J. Themelis, a professor of engineering at Columbia University and a waste-to-energy proponent, said America’s resistance to constructing the new plants was economically and environmentally “irresponsible.”

“It’s so irrational; I’ve almost given up with New York,” he said. “It’s like you’re in a village of Hottentots who look up and see an airplane — when everybody else is using airplanes — and they say, ‘No, we won’t do it, it’s too scary.’ ”

Acceptance in Denmark

Attitudes could hardly be more different in Denmark, where plants are placed in the communities they serve, no matter how affluent, so that the heat of burning garbage can be efficiently piped into homes.

Planners take pains to separate residential traffic from trucks delivering garbage, and some of the newest plants are encased in elaborate outer shells that resemble sculptures.

“New buyers are usually O.K. with the plant,” said Hans Rast, president of the homeowners’ association in Horsholm, who cut a distinguished figure in corduroy slacks and a V-neck sweater as he poured coffee in a living room of white couches and Oriental rugs.

“What they like is that they look out and see the forest,” he said. (The living rooms in this enclave of town houses face fields and trees, while the plant is roughly some 400 yards over a back fence that borders the homes’ carports). The lower heating costs don’t hurt, either. Eighty percent of Horsholm’s heat and 20 percent of its electricity come from burning trash.

Many countries that are expanding waste-to-energy capacity, like Denmark and Germany, typically also have the highest recycling rates; only the material that cannot be recycled is burned.

Waste-to-energy plants do involve large upfront expenditures, and tight credit can be a big deterrent. Harrisburg, Pa., has been flirting with bankruptcy because of a $300 million loan it took to reopen and refit an old public incinerator with the new technology.

But hauling trash is expensive, too. New York City paid $307 million last year to export more than four million tons of waste, mostly to landfills in distant states, Mr. Post said. Although the city is trying to move more of its trash by train or barge, much of it travels by truck, with heavy fuel emissions.

In 2009, a small portion of the city's trash was processed at two 1990-vintage waste-to-energy plants in Newark and Hempstead, N.Y., owned by a publicly traded company, Covanta. The city pays $65 a ton for the service — the cheapest available way for New York City to get rid of its trash. Sending garbage to landfills is more expensive: the city's costliest current method is to haul waste by rail to a landfill in Virginia.

While new, state-of-the-art landfills do collect the methane that emanates from rotting garbage to make electricity, they churn out roughly twice as much climate-warming gas as waste-to-energy plants do for the units of power they produce, the 2009 E.P.A. study found. Methane, the primary warming gas emitted by landfills, is about 20 times more potent than carbon dioxide, the gas released by burning garbage.

The study also concluded that waste-to-energy plants produced lower levels of pollutants than the best landfills did, but nine times the energy. Although new landfills are lined to prevent leaks of toxic substances and often capture methane, the process is highly inefficient, it noted.

Laws Spur New Technology

In Europe, environmental laws have hastened the development of waste-to-energy programs. The European Union severely restricts the creation of new landfill sites, and its nations already have binding commitments to reduce their carbon dioxide emissions by 2012 under the international pact known as the Kyoto Protocol, which was never ratified by the United States.

Garbage cannot easily be placed out of sight, out of mind in Europe's smaller, densely populated countries, as it so often is in the United States. Many of the 87 waste-to-energy plants in the United States are in densely populated areas like Long Island and Cape Cod.

While these plants are generally two decades old, many have been progressively retrofitted with new pollution filters, though few produce both heat and power like the newest Danish versions.

In Horsholm only 4 percent of waste now goes to landfills, and 1 percent (chemicals, paints and some electronic equipment) is consigned to "special disposal" in places like secure storage vaults in an abandoned salt mine in Germany. Sixty-one percent of the town's waste is recycled and 34 percent is incinerated at waste-to-energy plants.

From a pollution perspective, today's energy-generating incinerators have little in common with the smoke-belching models of the past. They have arrays of newly developed filters and scrubbers to capture the offending chemicals — hydrochloric acid, sulfur dioxide, nitrogen oxides, dioxins, furans and heavy metals — as well as small particulates.

Emissions from the plants in all categories have been reduced to just 10 to 20 percent of levels allowed under the European Union's strict environmental standards for air and water discharges.

At the end of the incineration process, the extracted acids, heavy metals and gypsum are sold for use in manufacturing or construction. Small amounts of highly concentrated toxic substances, forming a paste, are shipped to one of two warehouses for highly hazardous materials, in the Norwegian fjords and in a used salt mine in Germany.

"The hazardous elements are concentrated and handled with care rather than dispersed as they would be in a landfill," said Ivar Green-Paulsen, general manager of the Vestforbraending plant in Copenhagen, the country's largest.

In Denmark, local governments run trash collection as well as the incinerators and recycling centers, and laws and financial incentives ensure that recyclable materials are not burned. (In the United States most waste-to-energy plants are private ventures.) Communities may drop recyclable waste at recycling centers free of charge, but must pay to have garbage incinerated.

At Vestforbraending, trucks stop on scales for weighing and payment before dumping their contents. The trash is randomly searched for recyclable material, with heavy fines for offenders.

The homeowners' association in Horsholm has raised what its president, Mr. Rast, called "minor issues" with the plant, like a bright light on the chimney that shone into some bedrooms, and occasional truck noise. But mostly, he said, it is a respected silent neighbor, producing no noticeable odors.

The plant, owned by five adjacent communities, has even proved popular in a conservative region with Denmark's highest per-capita income. Morten Slotved, 40, Horsholm's mayor, is trying to expand it. "Constituents like it because it decreases heating costs and raises home values," he said with a smile. "I'd like another furnace."

Center for American Progress

Energy from Waste Can Help Curb Greenhouse Gas Emissions

Matt Kasper April 17, 2013

The United States currently generates 390 million tons of trash per year, or 7 pounds per person per day.[1] Municipal solid waste, or MSW, commonly known as garbage, gets picked up from homes and businesses on a weekly basis and is usually sent straight to a landfill. At the landfill, a hole is dug in the ground and then lined with a man-made liner. As trash begins to fill the hole, methane is emitted as a result of waste being broken down by anaerobic bacteria. Once the landfill is full, it is capped to limit water from seeping into it.

Although many states have the physical space for trash, it is environmentally unsustainable to take garbage and bury it in the ground at landfills, where it decomposes and releases potent greenhouse-gas pollution. What's more, some trash has to be transported by diesel trucks or trains to landfills several hundred miles away, further exacerbating its pollution footprint. Though garbage is not something we tend to actively think about on a daily basis, specifically as it relates to climate change, the United States must begin developing policies to limit the environmental consequences that result from our generation of garbage.

There are already some efforts in place to help manage trash creation. Though America's MSW generation has significantly increased over the past decades as a result of population growth, the country has also seen tremendous improvements in recycling and composting efforts, for example. In 1960 the United States recycled only 5 million tons of garbage, but today America is recycling and composting more than 90 million tons.[2] This increase is largely a result of many state and local governments introducing recycling requirements as well as recycling incentives.

But there is another alternative waste management option that America has not significantly utilized but that could help stem the flow of waste, and thus pollution emissions, in our country: energy-from-waste, or EfW, facilities. These facilities provide a means for waste disposal while also generating clean electricity. EfW plants burn garbage in a controlled environment that generates electricity, which in turn is sold to utilities and then distributed to residential, commercial, and industrial consumers.

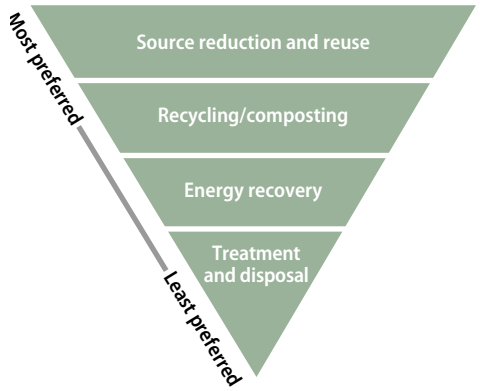
As America's population continues to increase, greenhouse-gas emissions, specifically methane from landfills, will also rise as more garbage is generated. Scientists in Hawaii found just last month that the amount of carbon dioxide in the atmosphere jumped dramatically to a new record high in 2013.[3] America's business-as-usual plan has the nation on the wrong path. Federal legislators need to begin to find more ways to decrease the amount of greenhouse gases in the atmosphere, and a plan that combines increases in EfW usage and recycling and composting would be a good start. This issue brief addresses the need for the United States to increase rates of recycling, composting, and EfW to combat climate change, explains the technology at work in an EfW facility, and makes policy recommendations that will drive down the emissions released by landfills.

Energy from waste reduces greenhouse gas emissions

States can have both EfW and recycling strategies that are compatible. Indeed, communities using EfW technology have an aggregate recycling rate above the national average.[4] Figure 1 illustrates the waste-management hierarchy created by the U.S. Environmental Protection Agency, or EPA, that states and cities have begun to follow.[5] Reducing the amount of trash generated is the most preferred and cost-effective method, followed by recycling and composting practices.

Currently, recycling and composting actions together decrease the United States' 390 million tons of MSW to 296 million tons, but a nationwide waste standard—mandatory levels of waste to be processed at EfW facilities and landfills—that incorporates recycling goals could reduce this number even further.[6] Nevertheless, waste will always be generated, and instead of disposing of it in landfills, America should be sending it to energy-from-waste facilities.

FIGURE 1
Inverted Pyramid of Waste Management



Source: Environmental Protection Agency

According to the EPA, for every ton of garbage processed at an EfW facility, approximately one ton of emitted carbon-dioxide equivalent in the atmosphere is prevented.[7] This is because the trash burned at an EfW facility doesn't generate methane, as it would at a landfill; the metals that would have been sent to the landfill are recycled instead of thrown out; and the electricity generated offsets the greenhouse gases that would otherwise have been generated from coal and natural gas plants.[8]

The European Environmental Agency, or EEA, notes that increasing rates of recycling and EfW will decrease the amount of greenhouse gases a country emits.[9] After the EEA study was released, the European Union adopted proactive waste policies, including the promotion of recycling and EfW as alternative waste-management strategies. In fact, the European waste sector achieved a 34 percent greenhouse-gas-emissions reduction from 1990 to 2007, the largest pollution reduction of any industry in the European Union.[10]

The EPA and EEA are not alone in recognizing the benefits of energy from waste. The Intergovernmental Panel on Climate Change called EfW a "key [greenhouse gas] mitigation measure," and the World Economic Forum included EfW in its list of technologies likely to make a significant contribution to a future low-carbon energy system.[11]

Trapping methane gas isn't as beneficial as EfW

Landfills in the United States are using different kinds of available technology to help decrease the amount of emissions released. One such method is to trap methane and use it as energy: Of the 1,900 landfills in the United States, all of which are covered by the EPA's air emissions and solid-waste-management regulations, approximately 560 are using techniques to capture methane gas and turn it into electricity.[12] These landfills are able to reduce the amount of methane emitted compared to the landfills that do not generate electricity,[13] but even those equipped with methane-recovery systems generate significant emissions for a number of reasons.

First, methane collection does not occur over the duration of the emitting cycle. Landfills are not obligated to collect gas immediately, nor are they required to collect it for the entire period during which methane is being generated by anaerobic decomposition. This often means that only a fraction of the gas that is produced is collected. EPA's Waste Reduction Model, which tracks greenhouse-gas emissions from different waste-management practices, estimated that when garbage in landfills begins to emit methane, only an average of 34 percent is recovered to produce electricity.[14] Another 38 percent of methane emissions in landfills are flared, which is the process of releasing gas and burning it, and the remaining 28 percent of waste experiences no recovery whatsoever.[15] Consequently, landfills are the third-largest contributor of anthropogenic methane emissions in the country, accounting for 16 percent of total methane emissions as a result of human activities in 2011 and preceded only by the natural gas and agricultural sectors, respectively.[16]

Second, the efficiency of gas collection varies over time even when gas-collection systems are active and their average performance falls short of industry claims. A 2012 report prepared by the EPA and ARCADIS U.S., Inc., an international company that provides consulting and engineering services in the fields of infrastructure, water, environment, and buildings, states that:

> *Most of the existing data that is available to evaluate fugitive emissions from landfills is based on flux box data. These measurements do not account for the majority of losses found at landfills and therefore can potentially understate the emissions that escape to the atmosphere. With the increased interest in improving greenhouse gas emission inventories and strategies for emission reductions, there is a need to better quantify landfill gas collection efficiency.*[17]

To better understand emissions from landfills, the researchers undertook source-measurement approaches and concluded that "the methane abatement efficiency [ranged] from 38 to 88 percent."[18] In other words, the landfills studied are only capturing an average of 62 percent of methane emissions, despite the 75 percent default gas-collection efficiency recommended by EPA's guidance for emission inventories.[19]

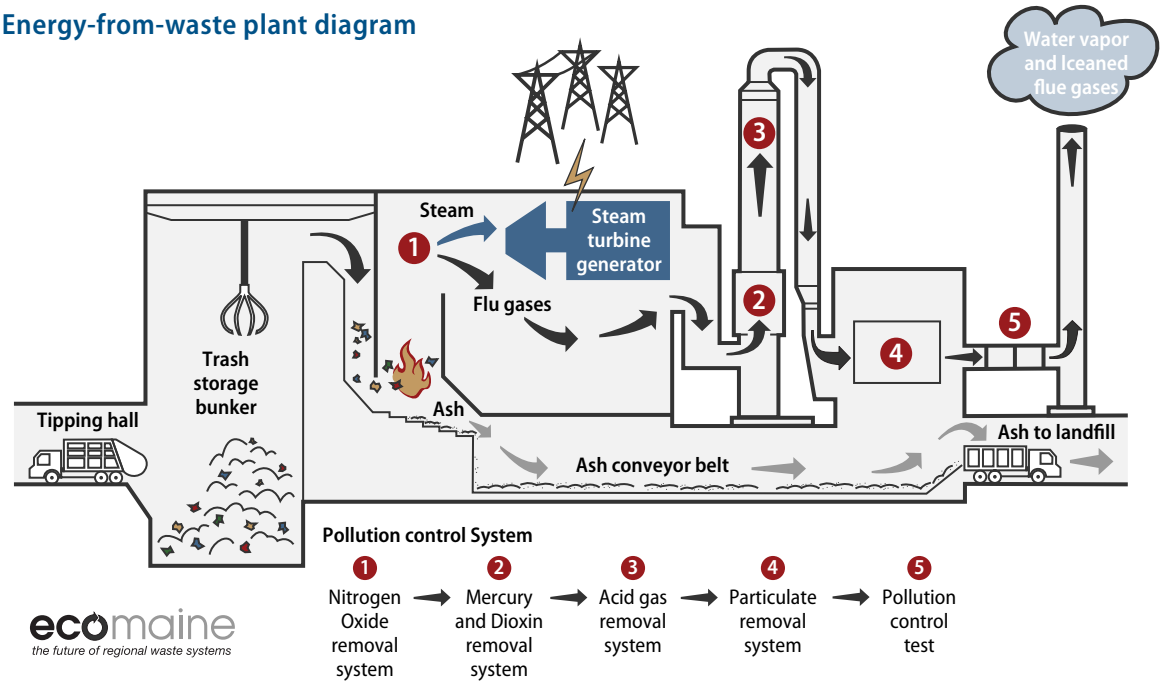
In order to reduce greenhouse-gas emissions, garbage must be diverted from landfills and sent to EfW facilities after significant recycling and composting efforts are accomplished. In fact, EPA scientists concluded that sending waste to EfW facilities is the better option not only for generating electricity, as the technology is capable of producing 10 times more electricity than landfill-gas-to-energy technology, but also because greenhouse-gas emissions from landfills—even those with optimum conditions for capturing methane and turning it into electricity—are two to six times higher than those generated from EfW facilities.[20]

How energy from waste works

Disposing of waste in landfills is the most commonly used management technique in the United States, accounting for 69 percent of total garbage disposal.[21] Some local governments, however, have begun to send their trash to EfW facilities, totaling 7 percent of total waste disposal.[22] Instead of transporting trash to the landfill, garbage trucks deliver the waste to an EfW facility, and in some cases the trash is even loaded onto railcars for delivery, which eliminates both truck traffic and diesel pollution.[23]

FIGURE 2

Energy-from-waste plant diagram



Source: ecomaine

Once the trash has been delivered to the EfW facility, it is dropped into a pit where a grapple will transfer the trash to a combustion chamber. Inside the combustion chamber, the trash is burned, causing water to boil, which will lead to the creation of steam. The steam then spins turbines to generate electricity. Throughout this process, filters are trapping fly ash, particulate matter, and metals from the trash that are not burned and are collected for recycling or even to be used in projects such as road construction and landfill-cover material. Gases from the burned waste are collected, filtered, and cleaned before being emitted. The remaining quantities of residue are collected through the filters, stored, and then sent to landfills for disposal. The electricity generated as a result of the spinning turbines goes to a switchyard and then gets transferred onto the grid for utilization and purchase.

A typical EfW plant is able to generate about 550 kilowatt-hours per ton of waste while complying with all state and federal standards.[24] This process has led many to recognize EfW facilities as a form of renewable-energy technology. In fact, the Energy Policy Act of 2005, which authorized loan guarantees, tax credits, and energy bonds for technologies that avoid greenhouse-gas pollution, included it as a renewable-energy resource.[25]

Under the Clean Air Act, EfW facilities must use the most modern air-pollution-control equipment available to ensure the smokestack emissions—carbon monoxide, nitrogen oxides, soot, and mercury—are safe for human health and the environment.[26] All facilities are specifically subject to regulations under the EPA's Maximum Achievable Control Technology Standards, which created emissions standards for industrial and commercial industries.[27] Because of the high temperatures inside the combustion chambers, most pollutants do not escape through the smokestacks, but scrubbing devices are installed in all EfW facilities as another control system to limit dangerous emissions.

EfW plants do involve large upfront expenditures, which can be a hurdle when building a new facility. A new EfW plant typically requires at least $100 million to finance construction costs, and this could be doubled or tripled depending on the size of the plant.[28] In order to finance the plant, facilities will require municipal revenue bonds, which are issued by local governments or agencies to secure revenue for essential service-infrastructure projects and are repaid with interest. Long-term contracts, however, are often developed between the facility and the county or city government that secure the facility-waste tipping fee, or the price charged for the trash received at a processing facility that is then used to pay back bonds and operating costs. Contracts are also established with utilities to receive income from the electricity generated and sold to the grid. This money is then used to pay back the bonds with interest.

Furthermore, hauling trash to landfills is expensive for large cities in America. New York City, for example, paid more than $300 million last year just to transport trash to out-of-state landfills.[29] In these cases, EfW facilities could be immediately beneficial by saving governments money while generating jobs and local revenue from an EfW facility. In

other regions of the United States, however, it can be cheaper to send trash to landfills when looking at a short-term economic analysis due to the amount of land available for trash disposal. Arkansas has an average landfill tipping fee of $35 per ton of garbage and has a reserve capacity of more than 600 years.[30] This is less than the U.S. average tipping fee of $45 per ton and also is below the average tipping fee at an EfW facility of $68 per ton.[31] But on a long-term economic basis, EfW facilities cost less than disposing of waste in landfills due to returns from the electricity sold and even the sale of recovered metals.[32] Indeed, Jeremy K. O'Brien, director of applied research for the solid-waste-management advocacy organization Solid Waste Association of North America, writes that, "Over the life of the [EfW] facility, which is now confidently projected to be in the range of 40 to 50 years, a community can expect to pay significantly less for MSW disposal at a [EfW] facility than at a regional MSW landfill."[33]

National and state recommendations

The most sustainable and cost-effective approach to limiting the amount of trash sent to landfills is avoiding waste generation entirely. Since that is hardly likely to happen at any point in the near future, however, the United States should create strong policies to increase recycling and composting efforts and implement policies to increase the amount of trash sent to EfW facilities.

The United States currently has 86 EfW plants operating in 24 states processing more than 97,000 tons of waste per day.[34] The New England region—Connecticut, Maine, Massachusetts, Maryland, New Hampshire, New Jersey, and New York—alone has 37 operating plants. Connecticut has the highest percentage of its waste going to EfW plants of any state—about 70 percent of its nonrecyclable trash—and nearly 25 percent of its waste is recycled.[35] According to Eileen Berenyi of the research and consulting firm Governmental Advisory Associates, EfW in Connecticut contributes $428 million annually to the state's revenue and has created nearly 1,000 jobs.[36]

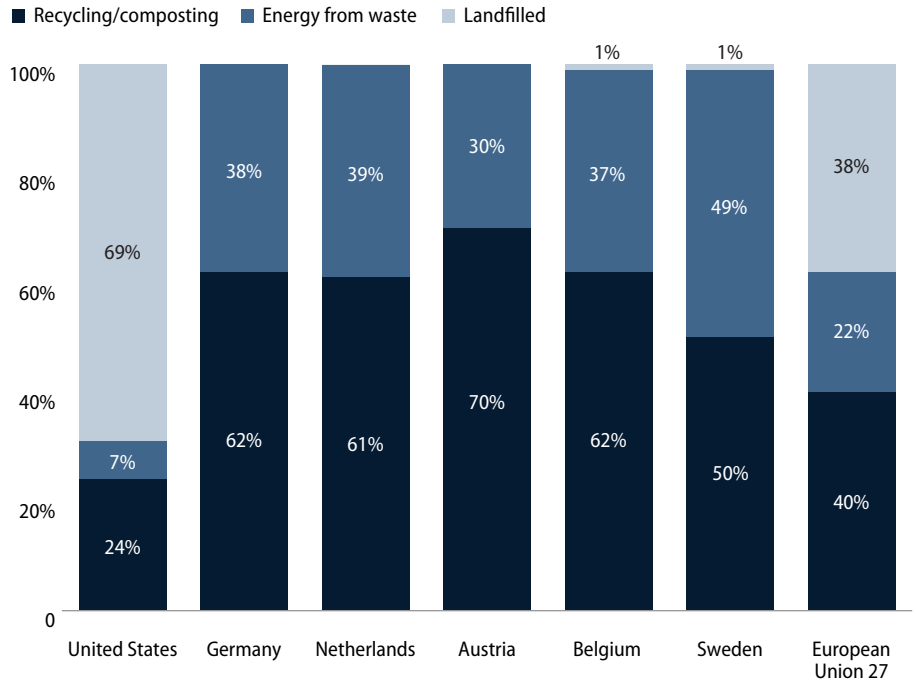
Despite the economic benefits of EfW facilities, the United States as a whole is not taking advantage of EfW technology, especially when compared to Europe. Countries such as Germany, the Netherlands, Austria, Belgium, and Sweden have proved that recycling and EfW management go hand in hand.[37] These five nations have the highest recycling rates in Europe and have reduced their dependence on landfills to 1 percent or below of waste disposal.[38] European nations have been able to achieve these rates because of the EU Landfill Directive,[39] which allows different countries to implement their own programs and policies to drive down the amount of garbage sent to landfills—whether that involves increasing landfill fees or increasing recycling-collection schemes. Nations in Europe also recognize EfW as a renewable energy source and are using this technology to help reach renewable-energy targets.[40]

Because of strong nationwide policies, the EU member states sent 19 percent less trash to landfills in 2011 compared to 2001.[41] This ultimately decreases the amount of greenhouse gases emitted from landfills and helps fight climate change. In order for the United States to begin reducing the amount of waste sent to landfills, increasing recycling rates, and generating renewable energy, a municipal-solid-waste portfolio standard must be enacted by Congress and applied nationwide in order to decrease greenhouse-gas emissions from landfills, and individual states should include EfW in current renewable-energy portfolio standards.

FIGURE 3

European nations are a model for waste management

Management of America's waste compared to European nations



Sources: BioCycle and the Earth Engineering Center of Columbia University; Confederation of European Waste-to-Energy Plants

Municipal-solid-waste portfolio standard

The United States should set a municipal-solid-waste portfolio standard that would not only increase our nation's rates of recycling and composting but would also significantly decrease the amount of garbage destined for landfills. As many European nations have already demonstrated, recycling efforts must be included in any national policy in order to reduce the level of waste in landfills. A few U.S. states have already established MSW strategies; both California and Florida, for example, have enacted a 75 percent recycling, including composting, goal by 2020.[42] Establishing incentives for recycling, such as providing homes and businesses with free recycling containers in conjunction with free pickup for recyclables, and creating a market for recyclable materials is also paramount to achieving those standards. Specifically, an executive order requiring federal government agencies to purchase recycled-content materials will establish a market for these products.

By learning from what some states have successfully implemented, a U.S. nationwide standard should be created that mirrors what the European Union has established. Doing so will protect the environment, conserve energy, and reduce greenhouse gases.

Include EfW generation in state renewable portfolio standards

States' adoption of renewable-energy standards, which require electric-utility companies to produce a portion of their electricity from renewable resources, has considerably driven clean energy advances in recent years. The 29 states and the District of Columbia that have such standards also include landfill gas as an eligible technology, but only 21 states and the District of Columbia recognize EfW as an eligible technology.[43] Maryland has shown the most leadership in this area by raising EfW from a Tier II to a Tier I technology—the same level that solar and wind energy are on—in the renewable portfolio standard, which will increase the percentage of renewable energy from EfW plants allowed in states' portfolio standards.[44] Other states should look to Maryland and Connecticut and adopt similar policies or seek to modify existing waste-management policies so as to reduce incentives for and reliance on landfills and complement their renewable portfolio standard goals.

Importantly, states should modify their renewable programs so they are consistent with the solid-waste hierarchy. While the solid-waste hierarchy identifies landfills as the least-preferred method for managing waste, landfills including ones with methane-gas capture are typically placed on equal or higher standing in renewable programs than EfW. This unintended encouragement of the use of landfills undermines efforts to reduce that reliance, as well as state renewable and greenhouse-gas reduction goals. Such significant financial support for landfills inhibits the growth of solid-waste-management methods such as recycling and EfW further up in the hierarchy.

Conclusion

Both energy from waste and recycling and composting efforts are a win-win-win for the United States. EfW generates clean electricity, decreases greenhouse gases that would have been emitted from landfills and fossil-fuel power plants, and pairs well with increased recycling rates in states. Recycling and composting reduces trash that is destined for the landfill that would have emitted greenhouse gases while decomposing, saves energy that would have been used for the production of a virgin material, and decreases the need to mine for raw materials, which will preserve our natural resources. The United States must begin developing national policies to deal with the waste-management problem our country faces every day. Doing so will ultimately reduce emissions that cause climate change.

Matt Kasper is a Special Assistant for the Energy Policy team at the Center for American Progress.

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Is It Better To Burn or Bury Waste for Clean Electricity Generation?

P. OZGE KAPLAN,*,† JOSEPH DECAROLIS,‡ AND SUSAN THORNELOE§

National Risk Management Research Laboratory, United States Environmental Protection Agency (U.S. EPA), Research Triangle Park, North Carolina 27711, and Department of Civil Engineering, North Carolina State University, Raleigh, North Carolina 27695

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The use of municipal solid waste (MSW) to generate electricity through landfill-gas-to-energy (LFGTE) and waste-to-energy (WTE) projects represents roughly 14% of U.S. nonhydro renewable electricity generation. Although various aspects of LFGTE and WTE have been analyzed in the literature, this paper is the first to present a comprehensive set of life-cycle emission factors per unit of electricity generated for these energy recovery options. In addition, sensitivity analysis is conducted on key inputs (e.g., efficiency of the WTE plant, landfill gas management schedules, oxidation rate, and waste composition) to quantify the variability in the resultant life-cycle emissions estimates. While methane from landfills results from the anaerobic breakdown of biogenic materials, the energy derived from WTE results from the combustion of both biogenic and fossil materials. The greenhouse gas emissions for WTE ranges from 0.4 to 1.5 $MTCO_2e$/MWh, whereas the most agressive LFGTE scenerio results in 2.3 $MTCO_2e$/MWh. WTE also produces lower NO_x emissions than LFGTE, whereas SO_x emissions depend on the specific configurations of WTE and LFGTE.

Introduction

In response to increasing public concern over air pollution and climate change, the use of renewable energy for electricity generation has grown steadily over the past few decades. Between 2002 and 2006, U.S. renewable electricity generation—as a percent of total generation—grew an average of 5% annually (*1*), while total electricity supply grew by only 1% on average (*2*). Support mechanisms contributing to the growth of renewables in the United States include corporate partnership programs, investment tax credits, renewable portfolio standards, and green power markets. These mechanisms provide electric utilities, investment firms, corporations, governments, and private citizens with a variety of ways to support renewable energy development. With several competing renewable alternatives, investment and purchasing decisions should be informed, at least in part, by rigorous life-cycle assessment (LCA).

In 2005, a total of 245 million tons of MSW was generated in the United States, with 166 million tons discarded to landfills (*3*). Despite the increase in recycling and composting rates, the quantity of waste disposed to landfills is still significant and expected to increase. How to best manage the discarded portion of the waste remains an important consideration, particularly given the electricity generation options. Although less prominent than solar and wind, the use of municipal solid waste (MSW) to generate electricity represents roughly 14% of U.S. nonhydro renewable electricity generation (*1*). In this paper we compare two options for generating electricity from MSW. One method, referred to as landfill-gas-to-energy (LFGTE), involves the collection of landfill gas (LFG) (50% CH_4 and 50% CO_2), which is generated through the anaerobic decomposition of MSW in landfills. The collected LFG is then combusted in an engine or a turbine to generate electricity. A second method, referred to as waste-to-energy (WTE) involves the direct combustion of MSW, where the resultant steam is used to run a turbine and electric generator.

Clean Air Act (CAA) regulations require capture and control of LFG from large landfills by installing a gas collection system within 5 years of waste placement (*4*). The gas collection system is expanded to newer areas of the landfill as more waste is buried. Not all LFG is collected due to delays in gas collection from initial waste placement and leaks in the header pipes, extraction wells, and cover material. Collected gas can be either flared or utilized for energy recovery. As of 2005, there were 427 landfills out of 1654 municipal landfills in the United States with LFGTE projects for a total capacity of 1260 MW. It is difficult to quantify emissions with a high degree of certainty since emissions result from biological processes that can be difficult to predict, occur over multiple decades, and are distributed over a relatively large area covered by the landfill.

CAA regulations require that all WTE facilities have the latest in air pollution control equipment (*5*). Performance data including annual stack tests and continuous emission monitoring are available for all 87 WTE plants operating in 25 states. Since the early development of this technology, there have been major improvements in stack gas emissions controls for both criteria and metal emissions. The performance data indicate that actual emissions are less than regulatory requirements. Mass burn is the most common and established technology in use, though various MSW combustion technologies are described in ref *6*. All WTE facilities in the United States recover heat from the combustion process to run a steam turbine and electricity generator.

Policy-makers appear hesitant to support new WTE through new incentives and regulation. Of the 30 states that have state-wide renewable portfolio standards, all include landfill gas as an eligible resource, but only 19 include waste-to-energy (*7*). While subjective judgments almost certainly play a role in the preference for LFGTE over WTE, there is a legitimate concern about the renewability of waste-to-energy. While the production of methane in landfills is the result of the anaerobic breakdown of biogenic materials, a significant fraction of the energy derived from WTE results from combusting fossil-fuel-derived materials, such as plastics. Countering this effect, however, is significant methane leakage—ranging from 60% to 85%—from landfills (*8*). Since methane has a global warming potential of 21 times that of CO_2, the CO_2e emissions from LFGTE may be larger than those from WTE despite the difference in biogenic composition.

Although WTE and LFGTE are widely deployed and analyzed in the literature (*9*–*13*), side-by-side comparison of the life-cycle inventory (LCI) emission estimates on a mass

* Corresponding author phone: (919) 541-5069; fax: (919) 541-7885; e-mail: kaplan.ozge@epa.gov.
† On Oak Ridge Institute for Research and Education postdoctoral fellowship with U.S. EPA.
‡ North Carolina State University.
§ U.S. EPA.

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per unit energy basis is unavailable. LCI-based methods have been used to evaluate and compare solid waste management (SWM) unit operations and systems holistically to quantify either the environmental impacts or energy use associated with SWM options in the broad context of MSW management (*14–16*).

The purpose of this paper is to present a comprehensive set of life-cycle emission factors—per unit of electricity generated—for LFGTE and WTE. In addition, these emission factors are referenced to baseline scenarios without energy recovery to enable comparison of the emissions of LFGTE and WTE to those of other energy sources. While the methodology presented here is applicable to any country, this analysis is based on U.S. waste composition, handling, and disposal, with which the authors are most familiar. In addition, parametric sensitivity analysis is applied to key input parameters to draw robust conclusions regarding the emissions from LFGTE and WTE. The resultant emission factors provide critical data that can inform the development of renewable energy policies as well as purchasing and investment decisions for renewable energy projects in the prevailing marketplace.

Modeling Framework

The LFGTE and WTE emission factors are based on the composition and quantity of MSW discarded in the United States in 2005 (Table S1 of Supporting Information (SI)). We excluded the estimated quantity and composition of recycled and composted waste.

The emission factors are generated using the life-cycle-based process models for WTE (*17*) and LF/LFGTE (*18*) embedded in the municipal solid waste decision support tool (MSW-DST). The MSW-DST was developed through a competed cooperative agreement between EPA's Office of Research and Development and RTI International (*19–22*). The research team included North Carolina State University, which had a major role in the development of the LCI database, process, and cost models as well as the prototype MSW-DST. While a summary is provided here, Table S2 (SI) provides a comprehensive set of references for those interested in particular model details. The MSW-DST includes a number of process models that represent the operation of each SWM unit and all associated processes for collection, sorting, processing, transport, and disposal of waste. In addition, there are process models to account for the emissions associated with the production and consumption of gasoline and electricity. The objective of each process model is to relate the quantity and composition of waste entering a process to the cost and LCI of emissions for that process. The LCI emissions are calculated on the basis of a combination of default LCI data and user-input data to enable the user to model a site-specific system. For example, in the landfill process model, one key exogenous input is the efficiency of the LFG collection system. The functional unit in each process model is 1 ton of MSW set out for collection. The MSW includes the nonhazardous solid waste generated in residential, commercial, institutional, and industrial sectors (*3*).

Each process model can track 32 life-cycle parameters, including energy consumption, CO_2, CO, NO_x, SO_x, total greenhouse gases (CO_2e), particulate matter (PM), CH_4, water pollutants, and solid wastes. CO_2 emissions are represented in two forms: fossil and biogenic. CO_2 released from anthropogenic activities such as burning fossil fuels or fossil-fuel-derived products (e.g., plastics) for electricity generation and transportation are categorized as CO_2-fossil. Likewise, CO_2 released during natural processes such as the decay of paper in landfills is categorized as CO_2-biogenic.

The management of MSW will always result in additional emissions due to collection, transportation, and separation of waste. However, for this analysis, the configuration of the SWM system up through the delivery of the waste to either a landfill or WTE facility is assumed to be same.

TABLE 1. Inputs to the Landfill Process Model

	LFG collection system efficiency [a] (%)	oxidation rate (%)
during venting	0	15
during first year of gas collection	50	15
during second year of gas collection	70	15
during third year and on of gas collection	80	15

[a] We assumed efficiency of the collection system based on the year of the operation and the ranges stated in U.S. EPA's AP-42 (*8*).

Electricity Grids. While LFGTE and WTE provide emissions reductions relative to landfill scenarios without energy recovery, the generation of electricity from these sources also displaces conventional generating units on the electricity grid. The process models in MSW-DST can calculate total electricity generated and apply an offset analysis on the grid mix of fuels specific to each of the North American Electric Reliability Council (NERC) regions, an average national grid mix, or a user-defined grid mix. Because our focus is on the emissions differences between WTE and LFGTE technologies, the emissions factors reported here exclude the displaced grid emissions.

For reference purposes, emission factors for conventional electricity-generating technologies are reported along with the emission factors for WTE and LFGTE (*23*). These emission factors on a per megawatt hour basis include both the operating emissions from power plants with postcombustion air pollution control equipment and precombustion emissions due to extraction, processing, and transportation of fuel. The background LCI data are collected on a unit mass of fuel (*23*); when converted on a per unit of electricity generated basis, the magnitude of resultant emissions depends on the efficiency of the power plant. A sensitivity analysis was conducted on plant efficiencies to provide ranges for emission factors.

Estimating Emission Factors for Landfill Gas-to-Energy. The total LCI emissions from landfills are the summation of the emissions resulting from (1) the site preparation, operation, and postclosure operation of a landfill, (2) the decay of the waste under anaerobic conditions, (3) the equipment utilized during landfill operations and landfill gas management operations, (4) the production of diesel required to operate the vehicles at the site, and (5) the treatment of leachate (*18*). The production of LFG was calculated using a first-order decay equation for a given time horizon of 100 years and the empirical methane yield from each individual waste component (*18, 24*). Other model inputs include the quantity and the composition of waste disposed (Table S1, SI), LFG collection efficiency (Table 1), annual LFG management schedule (Figure 1), oxidation rate (Table 1), emission factors for combustion byproduct from LFG control devices (Table S3, SI), and emission factors for equipment used on site during the site preparation and operation of a landfill. While there are hundreds of inputs to the process models, we have modified and conducted sensitivity analysis on the input parameters that will affect the emission factors most significantly.

The emission factors are calculated under the following scenario assumptions: (1) A regional landfill subject to CAA is considered. (2) A single cell in the regional landfill is modeled. (3) Waste is initially placed in the new cell in year 0. (4) The landfill already has an LFG collection network in place. (5) An internal combustion engine (ICE) is utilized to generate electricity. (6) The offline time that is required for

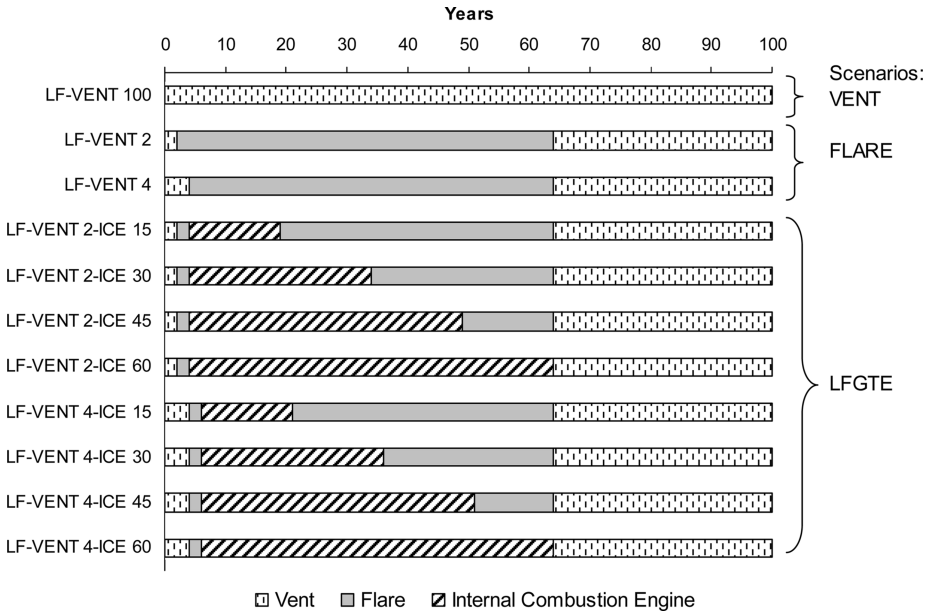

FIGURE 1. Annual landfill gas management schedule assumed for alternative scenarios.

the routine maintenance of the ICE is not considered. (7) The LFG control devices are assumed to have a lifetime of 15 years. (8) The LFG will be collected and controlled until year 65. This assumption is based on a typical landfill with an average operating lifetime of 20 years in which LFG production decreases significantly after about 60 years from initial waste placement. This is based on the use of a first-order decay equation utilizing empirical data from about 50 U.S. LFG collection systems.

The timing of LFG-related operations has significant variation and uncertainty that will influence the total emissions from landfills as well as the emission factors per unit of electricity generated. To capture these uncertainties and variation, several different management schemes were tested. Figure 1 presents the different cases considered for LFGTE projects. Each case differs according to the management timeline of the LFG. For instance, LF-VENT 2-ICE 15 corresponds to no controls on LFG for the first two years, after which the LFG is collected and flared in the third and fourth years. From year 5 until year 19, for a period of 15 years, the LFG is processed through an ICE to generate electricity, after which the collected gas is flared until year 65. Finally from year 65 on, the LFG is released to the atmosphere without controls.

To quantify the emissions benefit from LFGTE and WTE, landfill emissions occurring in the absence of an energy recovery unit can serve as a useful comparison. Thus, three baseline scenarios without electricity generation were defined for comparison to the energy recovery scenarios: LF-VENT 100 (LFG is uncontrolled for the entire lifetime of the LF), LF-VENT 2 (LFG is uncontrolled for the first two years, and then the LFG is collected and flared until year 65), LF-VENT 4 (LFG is uncontrolled for the first four years, and then the LFG is collected and flared until year 65). Since emissions are normalized by the amount of electricity generated (MW h) to obtain the emission rates, an estimate of hypothetical electricity generation for the baseline scenarios must be defined. The average electricity generation from a subset of the energy recovery scenarios is used to calculate the baseline emission rates. For example, emission factors [g/(MW h)] for LF-VENT 2 are based on the average of electricity generated in LF-VENT 2-ICE 15, LF-VENT 2-ICE 30, LF-VENT 2-ICE 45, and LF-VENT 2-ICE 60. Additional sensitivity analysis was conducted on oxidation rates where scenarios were tested for a range of 10−35%.

Estimating Emission Factors for Waste-to-Energy. The total LCI emissions are the summation of the emissions associated with (1) the combustion of waste (i.e., the stack gas (accounting for controls)), (2) the production and use of limestone in the control technologies (i.e., scrubbers), and (3) the disposal of ash in a landfill (*17*).

Emissions associated with the manufacture of equipment such as turbines and boilers for the WTE facility are found to be insignificant (<5% of the overall LCI burdens) and, as a result, were excluded from this analysis (*25*). In addition, WTE facilities have the capability to recover ferrous material from the incoming waste stream and also from bottom ash with up to a 90% recovery rate. The recovered metal displaces the virgin ferrous material used in the manufacturing of steel. The emission offsets from this activity could be significant depending on the amount of ferrous material recovered. Total LCI emissions for WTE were presented without the ferrous offsets; however, sensitivity analysis was conducted to investigate the significance.

In the United States, federal regulations set limits on the maximum allowable concentration of criteria pollutants and some metals from MSW combustors (*5*). The LCI model calculates the controlled stack emissions using either the average concentration values at current WTE facilities based on field data or mass emission limits based on regulatory requirements as upper bound constraints. Two sets of concentration values (Table S4, SI) are used in calculations to report two sets of emission factors for WTE (i.e., WTE-Reg and WTE-Avg). The emission factors for WTE-Reg were based on the regulatory concentration limits (*5*), whereas the emission factors for WTE-Avg were based on the average concentrations at current WTE facilities.

The CO_2 emissions were calculated using basic carbon stoichiometry given the quantity, moisture, and ultimate analysis of individual waste items in the waste stream. The LCI model outputs the total megawatt hour of electricity production and emissions that are generated per unit mass of each waste item. The amount of electricity output is a function of the quantity, energy, and moisture content of the individual waste items in the stream (Table S1, Supporting Information), and the system efficiency. A lifetime of 20 years and a system efficiency of 19% [18000 Btu/(kW h)] were assumed for the WTE scenarios. For each pollutant, the following equation was computed:

$$\text{LCI_WTE}_i = \sum_j \{(\text{LCI_Stack}_{ij} + \text{LCI_Limestone}_{ij} + \text{LCI_Ash}_{ij}) \times \text{Mass}_j\}/\text{Elec} \quad \text{for all } i \quad (1)$$

where LCI_WTE_i is the LCI emission factor for pollutant i [g/(MW h)], LCI_Stack_{ij} is the controlled stack gas emissions for pollutant i (g/ton of waste item j), $\text{LCI_Limestone}_{ij}$ is the allocated emissions of pollutant i from the production and use of limestone in the scrubbers (g/ton of waste item j), LCI_Ash_{ij} is the allocated emissions of pollutant i from the disposal of ash (g/ton of waste item j), Mass_j is the amount of each waste item j processed in the facility (ton), and Elec is the total electricity generated from MSW processed in the facility (MW h). In addition, the sensitivity of emission factors to the system efficiency, the fossil and biogenic fractions of MSW, and the remanufacturing offsets from steel recovery was quantified.

Results and Discussion

The LCI emissions resulting from the generation of 1 MW h of electricity through LFGTE and WTE as well as coal, natural gas, oil, and nuclear power (for comparative purposes) were calculated. The sensitivity of emission factors to various inputs was analyzed and is reported. Figures 2−4 summarize the emission factors for total CO_2e, SO_x, and NO_x, respectively.

Landfills are a major source of CH_4 emissions, whereas WTE, coal, natural gas, and oil are major sources of CO_2-fossil emissions (Table S5, SI). The magnitude of CH_4 emissions strongly depends on when the LFG collection system is installed and how long the ICE is used. For example, LF-VENT 2-ICE 60 has the least methane emissions among LFGTE alternatives because the ICE is operated the longest (Table S5, SI). CO_2e emissions from landfills were significantly higher than the emissions for other alternatives because of the relatively high methane emissions (Figure 2, Table S5).

The use of LFG control during operation, closure, and postclosure of the landfill as well as the treatment of leachate contributes to the SO_x emissions from landfills. SO_x emissions from WTE facilities occur during the combustion process and are controlled via wet or dry scrubbers. Overall, the SO_x emissions resulting from the LFGTE and WTE alternatives are approximately 10 times lower than the SO_x emissions resulting from coal- and oil-fired power plants with flue gas controls (Figure 3). The SO_x emissions for WTE ranged from 140 to 730 g/(MW h), and for LFGTE they ranged from 430 to 900 g/(MW h) (Table 2, Table S5). In a coal-fired power plant, average SO_x emissions were 6900 g/(MW h) (Table S6 and S7, SI). Another important observation is that the majority of the SO_x emissions from natural gas are attributed to processing of natural gas rather than the combustion of the natural gas for electricity-generating purposes.

The NO_x emissions for WTE alternatives ranged from 810 to 1800 g/(MW h), and for LFGTE they ranged from 2100 to 3000 g/(MW h) (Figure 4, Table 2, Table S5). In a coal-fired power plant, average NO_x emissions are 3700 g/(MW h) (Tables S6 and S7, Supporting Information). The emission factors for other criteria pollutants were also calculated. Besides CO and HCl emissions, the emission factors for all LFGTE and WTE cases are lower than those for the coal-fired generators (Tables S5−S8, SI).

While we have provided a detailed, side-by-side comparison of life-cycle emissions from LFGTE and WTE, there is an important remaining question about scale: How big an impact can energy recovery from MSW make if all of the discarded MSW (166 million tons/year) is utilized? Hypothetically, if 166 million tons of MSW is discarded in regional landfills, energy recovery on average of ∼10 TW h or ∼65 (kW h)/ton of MSW of electricity can be generated, whereas a WTE facility can generate on average ∼100 TW h or ∼600 (kW h)/ton of MSW of electricity with the same amount of MSW (Table 3). WTE can generate an order of magnitude more electricity than LFGTE given the same amount of waste. LFGTE projects would result in significantly lower electricity generation because only the biodegradable portion of the MSW contributes to LFG generation, and there are significant inefficiencies in the gas collection system that affect the quantity and quality of the LFG.

Moreover, if all MSW (excluding the recycled and composted portion) is utilized for electricity generation, the WTE alternative could have a generation capacity of 14000 MW, which could potentially replace ∼4.5% of the 313000 MW of current coal-fired generation capacity (*26*).

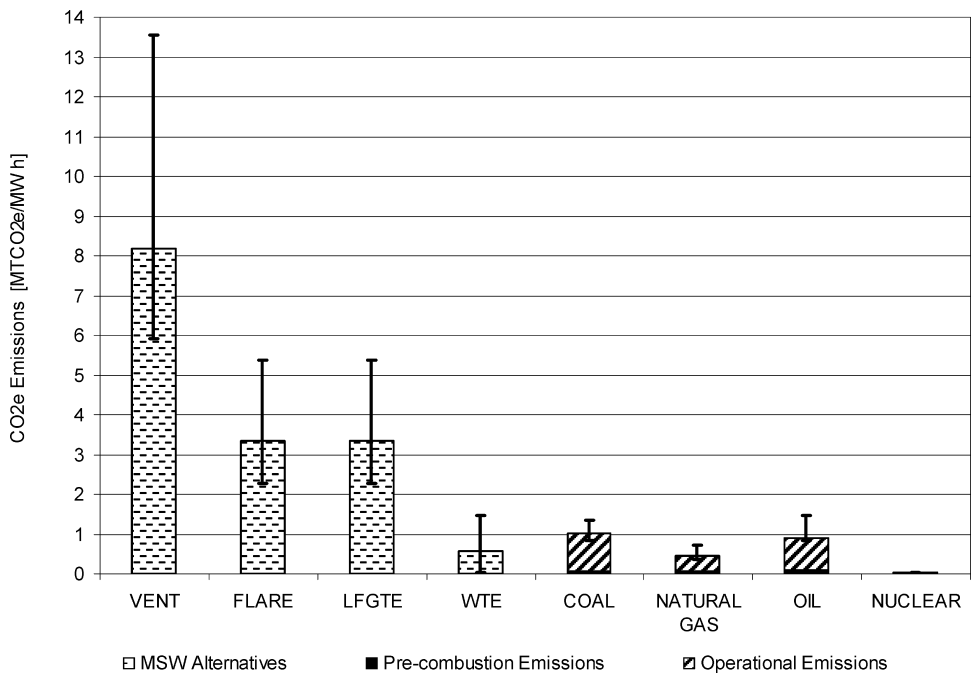

FIGURE 2. Comparison of carbon dioxide equivalents for LFGTE, WTE, and conventional electricity-generating technologies (Tables S5−S8, Supporting Information, include the full data set).

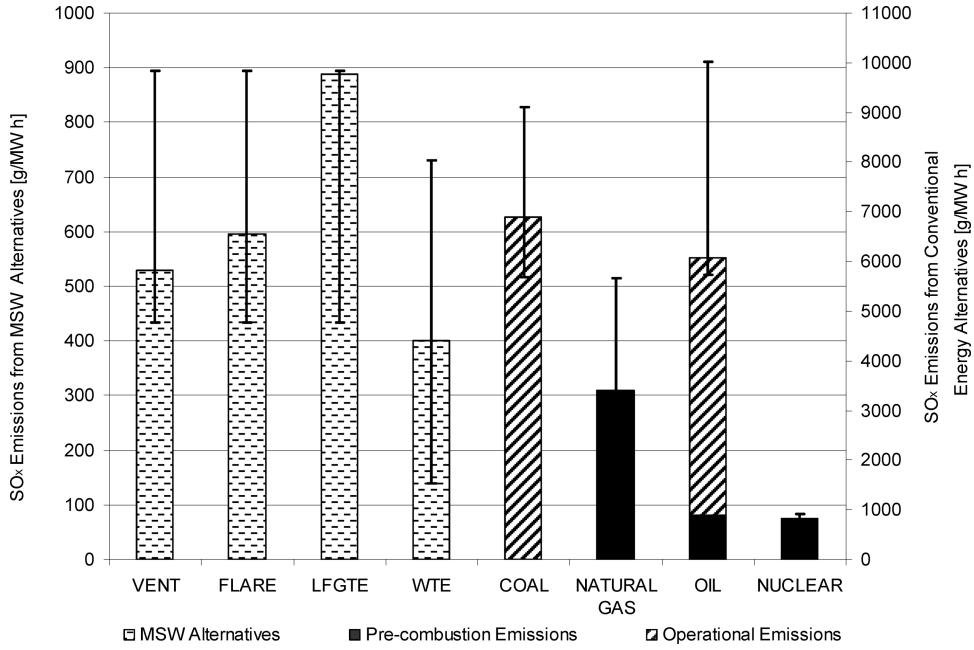

FIGURE 3. Comparison of sulfur oxide emissions for LFGTE, WTE, and conventional electricity-generating technologies (Tables S5−S8, Supporting Information, include the full data set).

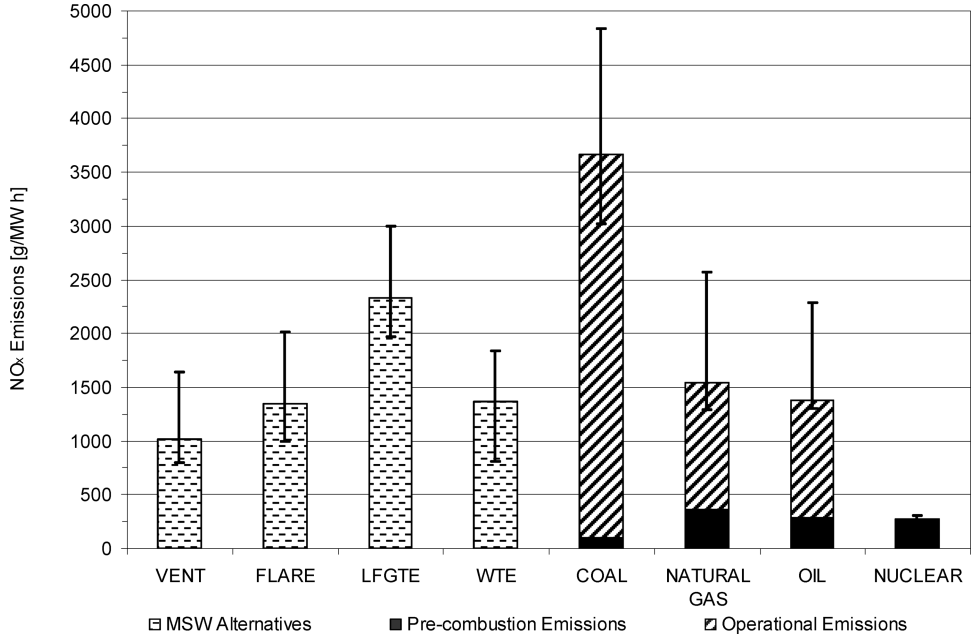

FIGURE 4. Comparison of nitrogen oxide emissions for LFGTE, WTE, and conventional electricity-generating technologies (Tables S5−S8, Supporting Information, include the full data set).

A significant portion of this capacity could be achieved through centralized facilities where waste is transported from greater distances. The transportation of waste could result in additional environmental burdens, and there are clearly limitations in accessing all discarded MSW in the nation. Wanichpongpan studied the LFGTE option for Thailand and found that large centralized landfills with energy recovery performed much better in terms of cost and GHG emissions than small, localized landfills despite the increased burdens associated with transportation (*13*). To quantify these burdens for the United States, emission factors were also calculated for long hauling of the waste via freight or rail. Table S9 (SI) summarizes the emission factors for transporting 1 ton of MSW to a facility by heavy-duty trucks and rail.

Sensitivity analysis was also conducted on key inputs. With incremental improvements, WTE facilities could achieve efficiencies that are closer to those of conventional power plants. Thus, the system efficiency was varied from 15% to 30%, and Table 2 summarizes the resulting LCI emissions. The variation in efficiencies results in a range of 470−930 kW h of electricity/ton of MSW, while with the default heat rate; only 600 (kW h)/ton of MSW can be generated. The efficiency also affects the emission factors; for example, CO_2-fossil emissions vary from 0.36 to 0.71 Mg/(MW h).

The emission savings associated with ferrous recovery decreased the CO_2e emissions of the WTE-Reg case from 0.56 to 0.49 $MTCO_2e$/(MW h). Significant reductions were observed for CO and PM emissions (Table 2).

TABLE 2. Sensitivity of Emission Factors for WTE to Plant Efficiency, Waste Composition, and Remanufacturing Benefits of Steel Recovery

	baseline factors		Sensitivity on: system efficiency	Sensitivity on: waste composition		Sensitivity on: steel recovery	
Input Parameters Varied[a]							
heat rate [Btu/(kW h)]	18000	18000	*[11000, 23000]*	18000	18000	18000	18000
efficiency (%)	19	19	*[15, 30]*	19	19	19	19
composition	default	default	default	*all biogenic*	*all fossil*	default	default
stack gas limits	reg	avg	*reg/avg*	reg	reg	*reg*	*avg*
steel recovery	excludes	excludes	excludes	excludes	excludes	*includes*	*includes*
Results: Criteria Pollutants							
CO [g/(MW h)]	790	790	[500,1000]	740	880	−110	−110
NO_x [g/(MW h)]	1300	1500	[810, 1800]	1200	1400	1200	1400
SO_x [g/(MW h)]	578	221	[140, 730]	550	620	450	90
PM [g/(MW h)]	181	60	[38, 230]	180	190	−190	−310
Results: Greenhouse Gases							
CO_2-biogenic [Mg/(MW h)]	0.91	0.91	[0.58, 1.2]	1.5	0.03	0.91	0.91
CO_2-fossil [Mg/(MW h)]	0.56	0.56	[0.36, 0.71]	0.02	1.5	0.49	0.49
CH_4 [Mg/(MW h)]	1.3E−05	1.3E−05	[8.1E−06, 1.6E−05]	1.6E−05	7.9E−06	−5.0E−05	−5.0E−05
CO_2e [$MTCO_2e$/(MW h)]	0.56	0.56	[0.36, 0.71]	0.02	1.45	0.49	0.49
Results: Electricity Generation							
TW h [b]	98	98	[78, 160]	61	37	98	98
(kW h)/ton	590	590	[470, 930]	470	970	590	590
GW [c]	12	12	[9.7, 20]	7.6	4.7	12	12

[a] For each sensitivity analysis scenario, the input parameters in italics were modified and resultant emission factors were calculated and are reported. [b] The values represent the TWh of electricity that could be generated from all MSW disposed into landfills. [c] 1 TWh/8000 h = TW; a capacity factor of approximately 0.91 was utilized.

TABLE 3. Comparison of Total Power Generated

	total electricity generated from 166 million tons of MSW, TW h	total power [a], GW	electricity generated from 1 ton of MSW, (kW h)/ton
waste-to-energy	78−160	9.7−19	470−930
landfill-gas-to-energy	7−14	0.85−1.8	41−84

[a] 1 TW h/8000 h = TW; a capacity factor of approximately 0.91 was utilized.

The composition of MSW also has an effect on the emission factors. One of the controversial aspects of WTE is the fossil-based content of MSW, which contributes to the combustion emissions. The average composition of MSW as discarded by weight was calculated to be 77% biogenic- and 23% fossil-based (Table S1, SI). The sensitivity of emission factors to the biogenic- vs fossil-based waste fraction was also determined. Two compositions (one with 100% biogenic-based waste and another with 100% fossil-based waste) were used to generate the emission factors (Table 2). The CO_2e emissions from WTE increased from 0.56 $MTCO_2e$/(MW h) (WTE-Reg) to 1.5 $MTCO_2e$/(MW h) when the 100% fossil-based composition was used (Table 2, Figure 2). However, the CO_2e emissions from WTE based on 100% fossil-based waste were still lower than the most aggressive LFGTE scenario (i.e., LF-VENT 2-ICE 60) whose CO_2e emissions were 2.3 $MTCO_2e$/(MW h).

The landfill emission factors include the decay of MSW over 100 years, whereas emissions from WTE and conventional electricity-generating technologies are instantaneous. The operation and decomposition of waste in landfills continue even beyond the monitoring phases for an indefinite period of time. Reliably quantifying the landfill gas collection efficiency is difficult due to the ever-changing nature of landfills, number of decades that emissions are generated, and changes over time in landfill design and operation including waste quantity and composition. Landfills are an area source, which makes emissions more difficult to monitor. In a recent release of updated emission factors for landfill gas emissions, data were available for less than 5% of active municipal landfills (*27*). Across the United States, there are major differences in how landfills are designed and operated, which further complicates the development of reliable emission factors. This is why a range of alternative scenarios are evaluated with plausible yet optimistic assumptions for LFG control. For WTE facilities, there is less variability in the design and operation. In addition, the U.S. EPA has data for all the operating WTE facilities as a result of CAA requirements for annual stack testing of pollutants of concern, including dioxin/furan, Cd, Pb, Hg, PM, and HCl. In addition, data are available for SO_2, NO_x, and CO from continuous emissions monitoring. As a result, the quality and availability of data for WTE versus LFGTE results in a greater degree of certainty for estimating emission factors for WTE facilities.

The methane potential of biogenic waste components such as paper, food, and yard waste is measured under optimum anaerobic decay conditions in a laboratory study (*24*), whose other observations reveal that some portion of

the carbon in the waste does not biodegrade and thus this quantity gets sequestered in landfills (*28*). However, there is still a debate on how to account for any biogenic "sequestered" carbon. Issues include the choice of appropriate time frame for sequestration and who should be entitled to potential sequestration credits. While important, this analysis does not assign any credits for carbon sequestered in landfills.

Despite increased recycling efforts, U.S. population growth will ensure that the portion of MSW discarded in landfills will remain significant and growing. Discarded MSW is a viable energy source for electricity generation in a carbon-constrained world. One notable difference between LFGTE and WTE is that the latter is capable of producing an order of magnitude more electricity from the same mass of waste. In addition, as demonstrated in this paper, there are significant differences in emissions on a mass per unit energy basis from LFGTE and WTE. On the basis of the assumptions in this paper, WTE appears to be a better option than LFGTE. If the goal is greenhouse gas reduction, then WTE should be considered as an option under U.S. renewable energy policies. In addition, all LFTGE scenarios tested had on the average higher NO_x, SO_x, and PM emissions than WTE. However, HCl emissions from WTE are significantly higher than the LFGTE scenarios.

Supporting Information Available

MSW composition, physical and chemical characteristics of waste items, detailed LCI tables and sensitivity results, and emission factors for long haul of MSW. This material is available free of charge via the Internet at http://pubs.acs.org.

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Better management of municipal waste will reduce greenhouse gas emissions

- The amount of municipal waste is expected to grow by 25 % from 2005 to 2020.
- Increased recovery of waste, and diverting waste away from landfill play a key role in tackling the environmental impacts of increasing waste volumes.
- As recycling and incineration with energy recovery are increasingly used, net greenhouse gas emissions from municipal waste management are expected to drop considerably by 2020.
- Limiting or avoiding growth in waste volumes would further reduce greenhouse gas emissions from the waste sector and deliver other benefits to society and the environment.

Growing waste volumes

On average, each European citizen generated 460 kg municipal waste in 1995. This amount rose to 520 kg per person in 2004, and a further increase to 680 kg per person is projected by 2020. In total, this corresponds to an increase of almost 50 % in 25 years. This projected continuing increase in waste volumes is primarily due to an assumed sustained growth in private final consumption (i.e. an average growth in the EU-15 and EU-12 respectively of 2 % and 4 % per year by 2020 (EC, 2006)) and a continuation of current trends in consumption patterns.

However, as shown in Figure 1, there are significant differences between EU-15 ([1]) and EU-12 ([2]) Member States. While an EU-15 citizen generated 570 kg on average in 2004, the figure was only 335 kg for an EU-12 citizen. Nevertheless, as EU-12 economies further develop and consumption patterns evolve, waste volumes are likely to increase over the next 15 years and approach current EU-15 levels. Looking forward, municipal waste volumes within the EU-15 and EU-12 are expected to grow by 22 % and 50 % by 2020, respectively. Over the entire period, more than 80 % of the total municipal waste is generated in the EU-15.

If we were simply to spread all EU municipal waste generated in 2020 (i.e. about 340 million tonnes) on the ground, it would cover an area the size of Luxembourg 30 cm thick or Malta 2.5 m thick!

These results indicate that efforts to prevent the generation of waste should be significantly reinforced, if the aim of the Sixth Environment Action Programme of a significant reduction in volumes of waste is to be achieved.

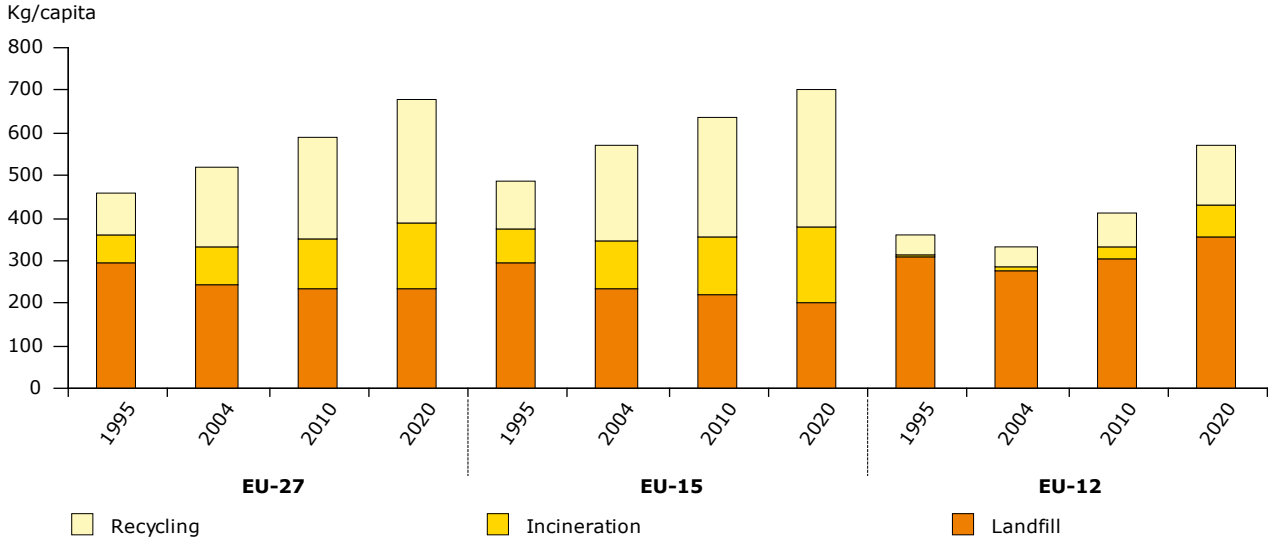
Increasing recovery and diversion of waste from landfill

Historically, disposal by landfilling has been the predominant treatment method for municipal waste, but over the last two decades considerable reductions in landfilling have taken place. In 2004, 47 % of total EU municipal waste was landfilled

([1]) Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden and the United Kingdom.
([2]) Bulgaria, Czech Republic, Cyprus, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Romania, Slovenia and the Slovak Republic.

European Environment Agency

Figure 1 Generation and management of municipal waste in Europe *(per capita)*



Source: Eurostat and ETC/RWM.

(see Figure 1). This is expected to decrease further to around 35 % by 2020. Recycling and other material-recovery operations are expected to increase from the current level of 36 % to around 42 % by 2020. Finally incineration was used for 17 % of municipal waste in 2004 and is likely to increase to about 25 % by 2020.

These past and expected trends are in part the result of dedicated policies which aim to increase the recycling and recovery of packaging waste (e.g. 1994 Packaging Directive) and to divert biodegradable municipal waste away from landfill (e.g. 1999 Landfill Directive). Overall, a further reduction of the quantity of municipal waste going to landfill is projected, which reflects the efforts made at national and European levels to achieve, among other things, the objectives set in the Sixth Environment Action Programme.

An EEA publication (2007) illustrates patterns in Member States approaches to waste management, particularly in the context of the Landfill Directive.

Falling net greenhouse gas emissions from municipal waste management

In 2005, greenhouse gas emissions from waste management represented about 2 % of the total emissions in the European Union.

Emissions of methane, one of the six greenhouse gases controlled by the Kyoto Protocol, are especially linked to agriculture (particularly cattle) and landfill operations. The EU Landfill Directive can therefore help in achieving EU targets on greenhouse gas emissions reductions, for example through methane recovery and diversion of biodegradable municipal waste from landfill. Another interface between waste management and climate change policies is the consumption of energy (giving rise to greenhouse gas emissions) in the collection, treatment and manufacturing use of waste.

Net emissions of greenhouse gases from the management of municipal waste are projected to decline from a peak of around 55 million tonnes CO_2-equivalents per year in the late 1980s to 10 million tonnes CO_2-equivalents by 2020 (Figure 2).

This is due to two separate developments. On the one hand, waste quantities that enter management facilities are projected to continue to grow as waste generation *per capita* increases and waste collection is further improved. This pushes direct emissions of greenhouse gases from the waste management sector up. Landfilling represents 60 % of the total in 2020, and recycling and incineration about 20 % each.

On the other hand, recycling and incineration will be increasingly used. This represents savings (or avoided greenhouse gas emissions) that offset direct emissions. Recycling contributes 75 % of total avoided emissions by 2020 and incineration almost 25 %.

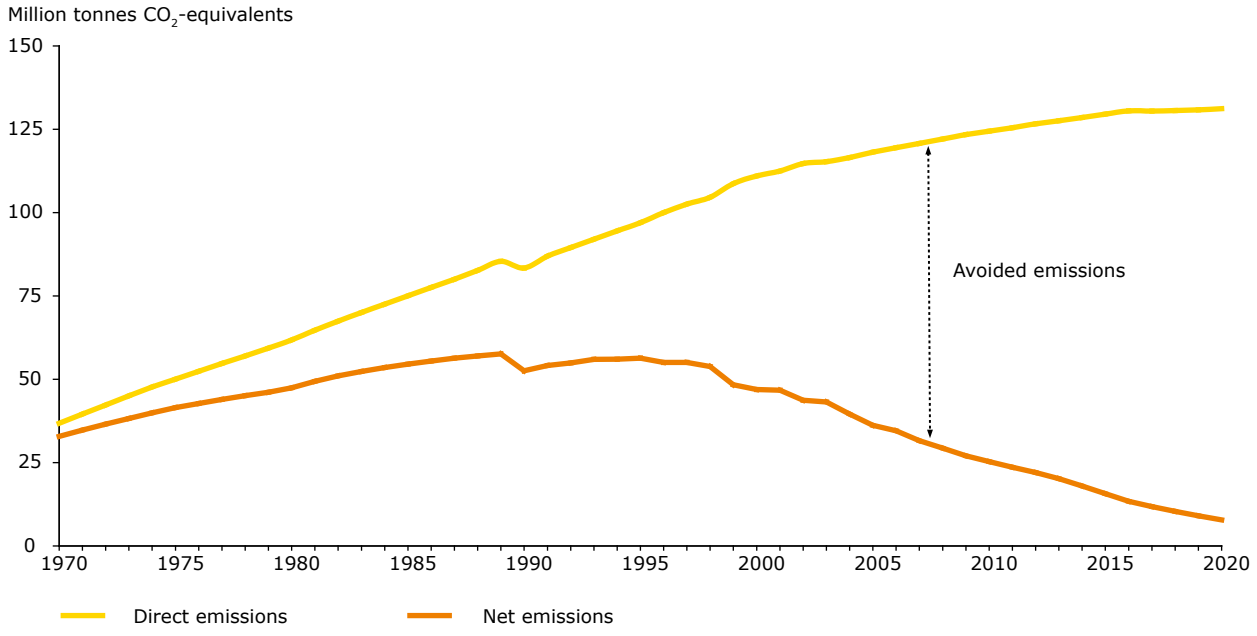
Overall, therefore, the projections show that better management of municipal waste will reduce greenhouse gas emissions in Europe, decoupling environmental pressures from economic growth as called for in the Sixth Environment Action Programme. Furthermore, with an expected further development of recycling and waste being increasingly used as a resource, the projections point towards achieving the long-term goal of becoming a recycling society as stated in the Thematic Strategy on Prevention and Recycling.

The projections used in this study assume that waste management capacity grows to match demand. However, if investment in new and improved management capacity does not keep up with the increasing waste quantities, net greenhouse gas emissions can be higher due to inefficient management.

Further benefits from limiting or avoiding growth in waste volumes

While the projections show that net emissions of greenhouse gases will fall despite increasing volumes of waste, action to limit or avoid the projected growth in waste volumes will further reduce net greenhouse gas emissions from the waste management sector. The collection and transport of waste, closely linked to waste volumes, is estimated to account for less than 5 % of the direct greenhouse gas

Figure 2 Trends and projections of greenhouse gas emissions from management of municipal waste in the European Union



Source: ETC/RWM.

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emissions of the waste sector, primarily due to the short distances over which municipal waste is usually transported. However, this figure represents 40 % of the net emissions in 2020.

Limiting waste volumes will also deliver other benefits such as reduced costs of waste management, and reduced air pollution (with particles and oxides of nitrogen) and noise related to the collection and transport of waste. The costs of waste management can otherwise increase significantly as volumes grow. The cost of collection and treatment of waste is particularly onerous, and generating waste is by definition a loss of resources.

In conclusion, Europe cannot become complacent with regard to the continuing growth in waste — reflecting our current unsustainable consumption and production patterns — as this in the long term may outweigh the improvements taking place in the waste management sector.

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European Environment Agency
Kongens Nytorv 6
1050 Copenhagen K
Denmark

Tel.: +45 33 36 71 00
Fax: +45 33 36 71 99

Web: eea.europa.eu
Enquiries: eea.europa.eu/enquiries

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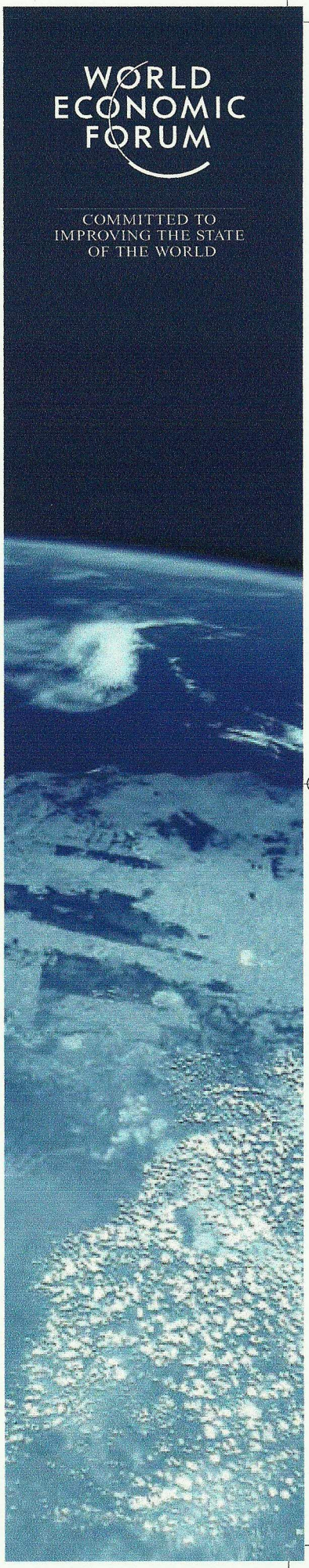
Green Investing 2010

Policy Mechanisms to Bridge the Financing Gap



World Economic Forum
January 2010

WORLD ECONOMIC FORUM

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1. Executive Summary

In this report, we provide an update on the status of investment volumes in clean energy and an overview of the different technologies that will contribute significantly to a future low-carbon energy infrastructure, as well as the key enablers that are required in order to allow those technologies to get to scale. We also highlight developments in the carbon markets and global negotiations (in Copenhagen and beyond) which affect clean energy and greenhouse gas emissions as a whole. Finally, we provide an analytical framework to evaluate 35 different types of policy mechanisms designed to unleash private capital to facilitate the shift to a low-carbon economy.

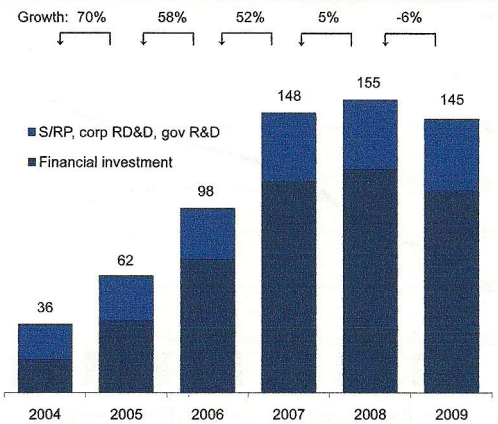
When we published the first Green Investing report, Green Investing: "Towards a Low-Carbon Energy Infrastructure", the world was in the midst of the credit crisis. Our main concern was that climate change would slip down policy-makers' agendas as they grappled with the immediate threat to the world's financial system. As we put it at the time:

> "At the very time when commentators are branding green investing as a luxury the world cannot afford, enormous investment in the world's energy infrastructure is required in order to address the twin threats of energy insecurity and climate change. Waiting for economic recovery, rather than taking decisive action now, will make the future challenge far greater. The investment demand is substantial. Despite the recent turmoil, the world's financial markets are up to the financing challenge, but they will need continued action from the world's policy-makers and leading corporations."

A year later, and the world is a very different place. On the macroeconomic stage, the concern is no longer about the collapse of our financial system, but about a protracted recession and the risk of a slow recovery. In clean energy, after stalling in the first quarter of 2009, investment activity rebounded, and in fact total investment activity will finish the year at US$ 145 billion, down only 6.5% on the total for 2008 (see Figure 1).

For much of the year it looked as though investment would be down by a much greater amount. In part, its healthy recovery was supported by the arrival of the first tranches of stimulus funding targeted at the sector around the world. HSBC estimated that governments allocated more than US$ 430 billion in fiscal stimulus globally to "climate change themes". However, this total includes rail, water and electricity infrastructure that is not specifically dedicated to clean energy. Once these are stripped out, we estimate a total of US$ 177 billion of stimulus funding has been allocated to renewable energy, energy efficiency, smart grid, advanced transportation and other core clean energy technologies (see Figure 2).

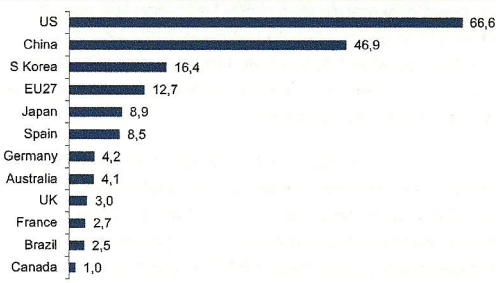
Figure 1: Total Global Annual Investment in Clean Energy 2004 to 2009, US$ billions



Note: S/RP = small/residential projects. New investment volume adjusts for re-invested equity. Total values include estimates for undisclosed deals.

Source: New Energy Finance

Figure 2: Clean Energy Stimulus by Country 2009, US$ billions

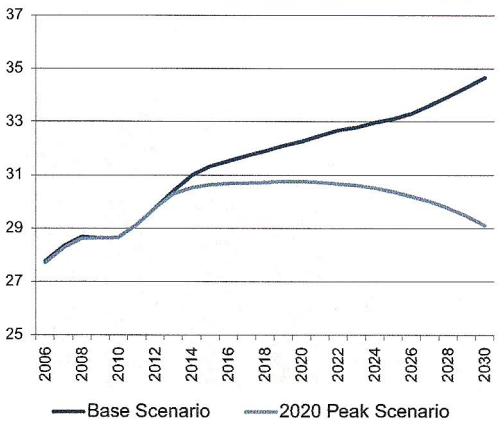


Note: Total announced by the 12 economies is US$ 177.3 billion. Includes only stimulus measures targeted specifically at clean energy; excludes general rail, water, power infrastructure

Source: New Energy Finance

Of the US$ 177 billion, only around US$ 25 billion actually reached the front line in terms of clean energy technology providers or projects during 2009. We estimate the flow of stimulus spending will strengthen to around US$ 60 billion during 2010, which will almost certainly drive overall investment in clean energy into record territory, perhaps reaching as much as US$ 200 billion. Stimulus funding will then remain at around US$ 60 billion for 2011, before receding. One of most urgent questions

Figure 3: CO_2 Emissions from Energy, Base and 2020 Peak Scenarios, GTonnes



Source: New Energy Finance, GE2M

facing policy-makers in clean energy as elsewhere is how to stop the stimulus funding in due course without causing the industry to collapse.

Clean energy investment has survived the crisis and dropped only marginally to US$ 145 billion last year. It looks set to rise to US$ 200 billion in 2010, and to continue growing beyond that. However, this still falls far short of the investment volumes required to transform the world's energy infrastructure.

Last year we reported that if the world is to see energy-related CO_2 emissions peak by 2020 (see Figure 3) – scientists say is necessary to restrict the increase in global average temperatures to 2°C – global investment in clean energy must reach US$ 500 billion per annum by 2020. At the time New Energy Finance and others estimated that without a major new initiative to drive the shift to clean energy, the figure would likely only reach US$ 350 billion per annum. Nothing that has happened in the intervening 12 months has changed those estimates significantly.

The International Energy Agency World Energy Outlook 2009 (WEO 2009) contains a "450 Scenario", describing one way of meeting the world's energy needs while restricting emissions to a level consistent with a 2°C temperature increase. In it, renewable energy (including large hydro) grows by a total of just under 110% between now and 2030 to meet 22% of primary energy and nearly 37% of electricity needs worldwide. The IEA estimates that the 450 Scenario would require the investment between now and 2030 of US$ 38 trillion, equivalent to 2.0% of global gross domestic product; this is US$ 10.5 trillion more than required under its business-as-usual "Reference Scenario".

Regardless of which model or source is used, there is a gap between the funding flowing into clean energy and what is needed to bring emissions under control. And it is sobering to note what the IEA itself says about continuing with business as usual:

> "The Reference Scenario corresponds to a long-term concentration of 1000ppm CO_2 equivalent. The consequences of the world following the 1000 ppm trajectory implied by following the Reference Scenario to 2030 and beyond, would, based on central estimates, result in a global mean temperature rise of around 6°C. At this level, studies indicate that the environmental impacts would be severe."

While the financial crisis and resulting recession have depressed investment activity, the past year has at least brought very good news on the cost front. In previous years, soaring demand for equipment from project developers meant that manufacturers were able to maintain high margins throughout the technology supply chain. Cost reductions were not passed on to clients: turbine prices were on an upward trend, and solar module costs did not drop between 2005 and 2008, despite the steep experience curve along the sector's whole value chain.

All of that changed in 2009. The levelized cost of renewable energy – i.e. the cost per unit before taking into account any subsidies or support mechanisms – fell by an average of 10% across most sectors, including the most mature, onshore wind. In the solar sector, the fall was far more dramatic, with the price of photovoltaic modules coming down by 50% in the course of the year. This is good news for the sector, although it comes at a time when the cost of fossil-based fuel has also been dropping. The difference is that as the economy and financial markets recover, oil and gas costs will bounce back. Clean energy costs, however, will fall further, as debt spreads for projects return to long-term trend levels.

In last year's report we took an in-depth look at eight renewable energy technologies which will contribute substantially to the clean energy infrastructure of the future. This year we have added two new sectors which have also shown great promise. Of our ten chosen sectors, eight are power-generating technologies, the other two produce liquid biofuels. Between them they are expected to absorb cumulative investment of US$ 7.5 trillion between now and 2030 (see Figure 4). The ten technologies are as follows:

1: Onshore wind
2: Offshore wind
3: Solar photovoltaic power
4: Solar thermal electricity generation
5: Biomass
6: Municipal solid waste-to-energy
7: Geothermal power
8: Small-scale hydro
9: Sugar-based first-generation biofuel
10: Cellulosic, algal and other second-generation biofuels
These may be the frontrunners but they are by no means the only possible contributors to a cleaner energy future: many other emerging technologies have potential in the longer term. Nuclear power will be a major part of the future energy system, but it is beyond the remit of this report.

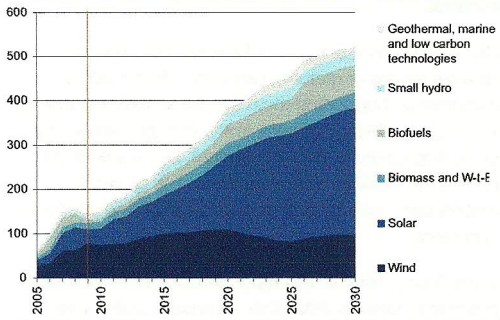
Last year we also identified a number of key enablers, where investment is essential if the energy system is to be able to absorb and use all of the renewable energy it can produce, and still meet the world's energy needs. These key enablers are energy efficiency, smart grid, power storage and carbon capture and sequestration. This year we have added advanced transportation as a key enabler, and upgraded energy efficiency to its own section.

Almost all models of future energy supply demonstrate that energy efficiency must be responsible for half or more of all reductions in CO_2 emissions between now and 2030. A lot of work has been done in the past few years by McKinsey and others on the opportunity to improve energy efficiency at very low – or even negative cost. Yet the paradox remains: persuading energy users to avail themselves of all these opportunities to save money continues to prove extremely difficult. We look here at the reasons why this is so, and what can be done about it.

The COP 15 meeting in Copenhagen could probably never have lived up to the world's expectations. As things turned out, it was neither the success that some may to claim, nor was it the failure depicted by its detractors.

The Copenhagen Accord, "noted" by the Plenary on the final day of the 15th Conference of the meeting enshrines the continuation of the Kyoto Protocol and contains a long-awaited commitment to mobilise resources to control deforestation. It recognises the need to limit temperature increases to 2°C, and contains a promise to look at the science behind a 1.5°C limit by 2015. On the financing front, developed countries committed themselves to "a goal of mobilizing jointly US$ 100 billion a year by 2020 to address the needs of developing countries", but left the mechanics to be agreed later.

Figure 4: Expected Clean Energy Investment per annum 2007 to 2030, US$ billions



Source: New Energy Finance

The only concrete financial commitment that was forthcoming at Copenhagen was a pledge by developed countries to provide developing countries with US$ 10 billion per year for three years in the form of "Quick Start" funds, to be shared between clean energy, REDD (Reducing Emissions from Deforestation and Forest-Degradation) and adaptation initiatives. Even if leveraged five-to-one with private funding, the scale of the pledge is an order of magnitude less than required. The IEA estimates that subsidies for fossil fuels in the largest 20 non-OECD economies alone amount to US$ 310 billion per annum.

The world's carbon markets spent 2009 somewhat in limbo, waiting for the outcome of Copenhagen and for progress on domestic cap-and-trade in the US and Australia. They were disappointed on all three fronts. Nevertheless, the existing markets persevered, with around US$ 120 billion of trading activity in 2009, and the US's Regional Greenhouse Gas Initiative provided the success story: it started operation and in its first year raised over US$ 400m from the auctioning of credits to be invested in renewable energy projects in the North-East and mid-Atlantic states.

Attention on the international climate scene now switches to the task of trying to build a legally binding agreement around the Copenhagen Accord. Negotiations will resume during 2010, first in Bonn in June, and then in Mexico City at COP 16 in December.

Meanwhile, Copenhagen did not deliver a binding global deal and hence will have the inevitable effect of shifting the focus of policy-makers to the national and local level. Over the past four years, there have been no fewer than 696 pieces of legislation in favour of clean energy – renewable energy and energy efficiency – around the

world, many in anticipation of a global deal. Over the coming four years, we will no doubt see the trend continue.

Clean energy is a story of multiple technologies, at different stages of maturity, requiring different policy instruments. Supporting them can be achieved in multiple ways: by modifying the rules of the energy markets, by promoting equity or debt investment, by means of tax rules or by creating carbon markets. The choice of mechanism must depend on local political and economic conditions.

In the final chapter of this report we look at 35 different policy mechanisms that either have been used or are under discussion to promote the world's shift to a low-carbon energy system. We map the mechanisms against the sectors and situations in which they are most likely to be productively used. We also provide a rating, indicating how well we think they are likely to perform on three key questions: whether they scale; whether they are economically efficient; and whether they can catalyse private investment over and above their cost to the public purse.

We do not expect our evaluation of the policy mechanisms to be the final word on how to maintain and accelerate the world's progress towards a clean energy infrastructure. However, we hope it provides a useful framework and fuels a vital debate.

Last year's inaugural Green Investing report was subtitled "Towards a Clean Energy Infrastructure". Looking back a year later, the good news is that the world has continued to make progress towards a clean energy infrastructure in the midst of a period of unprecedented financial and economic turmoil. The bad news is that progress may not been fast enough, and is not accelerating at the rate required to address the critical issue of climate change. While, the world's investors may be ready to invest in clean energy companies and projects, they still have questions over the policy environment in which they operate.

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4. Ten Emerging Large-Scale Renewable Energy Sectors

In last year's Green Investing Report, we asserted that "any future low-carbon energy infrastructure will have to include a significant proportion of energy generated from renewable sources". Nothing that happened during 2009 has changed this. The impact of the recession will reduce the long-term growth in energy demand somewhat, but any analysis of how that demand can be met shows that renewable energy will play a much expanded role.

The 2009 edition of the IEA's World Energy Outlook (*WEO* 2009) contains the usual Reference Scenario, showing the future of the world's energy system under business-as-usual conditions – not taking into account any future policy measures to shift to low-carbon energy. This shows renewable energy's contribution growing by 57% in absolute terms between 2007 and 2030, and from 12.6% of primary energy to 14.2%. In terms of electricity generation, the growth of clean energy is even more pronounced: renewable power (including large-scale hydro) is expected to grow by nearly 140%, and from 18.1% of consumption in 2007 to 22.3% in 2030.

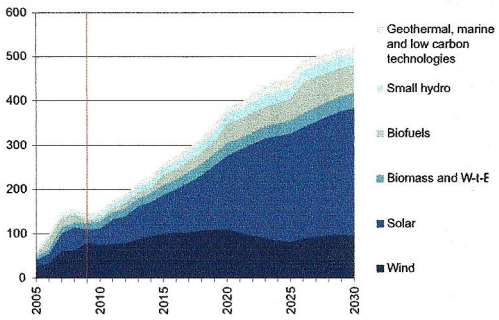
However, the IEA itself admits: "The Reference Scenario corresponds to a long-term concentration of 1000ppm CO_2 equivalent. The consequences of the world following the 1000 ppm trajectory implied by following the Reference Scenario to 2030 and beyond, would, based on central estimates, result in a global mean temperature rise of around 6°C. At this level, studies indicate that the environmental impacts would be severe."

The IEA's release of *WEO* 2009 came around the same time as the breaking of "Climategate", the release of thousands documents stolen from the server of the Climatic Research Unit of the United Kingdom's University of East Anglia.

WEO 2009 also contains a "450 Scenario", describing one way of meeting the world's energy needs while restricting emissions to a level consistent with a 2°C temperature increase. The figures are even more dramatic: renewable energy grows by just under 110% to meet 22% of primary energy demand by 2030, supplying nearly 37% of all electricity needs worldwide.

In terms of finance, the IEA estimates that the Reference Scenario would require the investment of US$ 26 trillion between now and 2030, equivalent to 1.4% of global gross domestic product. The 450 Scenario entails additional investment of US$ 10.5 trillion. This is, however, offset by a reduction in energy bills of US$ 8.6 trillion globally in the period 2008-2030 alone, with more savings resulting thereafter. There are also benefits in terms of public health, as the level of pollutants under the 450 Scenario is significantly lower.

Figure 18: Clean Energy Asset Finance by sector 2007 to 2030, US$ billions



Source: New Energy Finance, GE2M

These figures are broadly in line with scenarios from other sources, including New Energy Finance's Global Energy & Emissions Model (GE2M). This model predicts investment in clean energy growing to US$ 384 billion by 2020, an increase of approximately 180% over 2009, but still not sufficient to achieve peak CO_2 emissions by 2020. In terms of asset finance, the model shows that the recession will reduce investment growth in the near term, but the long-term trend looks even healthier than in last year's report, due to the reductions in the cost of clean energy and new legislation supporting the sector around the world (see).

In last year's Green Investing Report we highlighted eight renewable energy technologies which we believed would prove to be major contributors to the energy supply of the future, based on their potential scale and cost competitiveness with conventional energy. This was not intended to be an exhaustive list, and this year we are pleased to add two more: small hydro and the broader biomass sector beyond municipal solid waste. Both have demonstrated good technical and economic progress in the past year.

This year's report, therefore, looks in more detail at ten promising clean energy sectors. The first eight are power generating technologies, the last two produce liquid biofuels. These leading sectors are described in Appendix 1 and their details are summarised below:

1 Onshore wind
2 Offshore wind
3 Solar photovoltaic power
4 Solar thermal electricity generation
5 Biomass
6 Municipal solid waste-to-energy
7 Geothermal power
8 Small-scale hydro
9 Sugar-based first-generation biofuel
10 Cellulosic, algal and other second-generation biofuels

Table 1. Summary Table of Emerging Large-Scale Renewable Energy Sectors (See Appendix 1 for further details)

	Installed Capacity Worldwide, 2009	Potential Capacity by 2030	Market Readiness / Levelized Cost of Energy	Technology Gaps	Potential Bottlenecks	Policy Requirement
1. Onshore wind	140GW	800GW	$68-109/MWh	• Existing technology adequate, drive train improvements required to increase reliability and decrease costs • Larger turbines • Power storage (to reduce impact of intermittency)	• Short term: capital availability and slow speed of planning applications • Long term: geographic isolation of wind resource areas	• Stable implementation of existing policies • Modest rate support in the form of Renewable Portfolio Standard, feed-in tariff or green certificates • Accelerated planning processes • Incentives / regulation to require integration and remove grid bottlenecks
2. Offshore wind	2.2-2.4GW	120GW	$109-205/MWh	• Reliability of offshore turbines still a key concern • New dedicated "marinized" technology at larger scale being rolled out over next five years	• Short term: capital availability, offshore wind may fall in investment priorities of utilities due to low returns • Long term: innovation in and industrial supply of turbines, potentially slow due to uncertainty of demand	• Continued, stable support in Germany and United Kingdom, growing support in Nordic markets, Benelux, China and US • Increased support from export credit agencies and government backed banks to reduce the cost and increase the availability of financing • Incentives / funding for grid development • Accelerated planning processes
3. Solar PV (Grid scale and Residenti al)	20GW	1000GW	$170-450/MWh)	• Continued scale-up of entire crystalline silicon supply chain; process engineering to reduce costs • Mass manufacture of scalable, high-efficiency thin film	• Capital • Access to transmission grid and net metering for residential customers. Capped incentive regimes • Planning permission	• Substantial support, long-term but declining over time and easily adjusted to falls in technology price • Mandatory net metering by utilities • Attractive tax treatment of R&D • Public research funds
4. Solar thermal electricity generation (STEG)	616MW	80GW	$190-250/MWh	• Proof of concept for most up-and-coming technologies	• Capital, especially for unproven technologies • Links to transmission grid • Permitting	• Incentives, especially for designs not used before e.g. non-parabolic designs or new heat transfer fluids • Clear direction on permitting for large projects which cannot currently get planning permission in the US • Attractive tax treatment of RD&
5. Biomass incinerat-ion/ gasificat-ion/ anaerobic digestion	45GW	150GW	$70-148/MWh $90-170/MWh $80-189/MWh	• Proven technology available (combustion) • Gasification still requires R&D • AD monitoring as efficiency is highly dependent on operation	• Short term: capital availability • Feedstock: supply and prices – lack of transparent market and hedging instruments • Turnkey/equipment provider	• Long-term and stable financial support in form of feed-in tariffs or green certificates • Incentives for farmers to produce energy crops • Incentives for foresters to collect residues
6. Municipal Solid Waste-to-Energy	18GW	50GW	$38-157/MWh	• Proven technology available (combustion) • Gasification still requires development	• Slow permitting process (public opposition) • Turnkey provider • Long lead time for boilers and turbines	• Landfill diversion targets or ban on biodegradable waste landfill • Increasing gate fees/taxes

Energy					• Long lead time for boilers and turbines	
7. Geothermal	10GW	40GW	$55-83/MWh	• Enhanced Geothermal Systems (EGS) using hot dry rocks • Improving resource exploration technology • Smaller plug-and-play modules for low-grade resource power conversion	• Drilling rig availability • Power plant construction delays • Permitting delays	• Rate support in the form of Renewable Portfolio Standard, feed-in tariff or green certificates • Country goals specific for geothermal • Accelerated planning process
8. Small hydro	60GW	190GW	$70-120/MWh	• Mature technology, but variability as a result of rainfall volumes (intermittent) • Improvement of run-of-river turbines and technologies to be more efficient	• Better resources are far away from grid and from consumer centres • Environmental and social issues when project is not well planned and studied • Depends on rainfall volumes • General opinion still doesn't differentiate small from large hydro and their benefits / disadvantages	• Clear and objective environmental legislation • Accelerated / streamlined approval processes (as these projects are small hydro, and not large) • Incentives / regulation to remove grid bottlenecks
9. Sugar-based ethanol	80 billion litres per annum	250+ billion litres per annum	Competitive with oil at around US$45 per barrel	• Mass adoption of efficient cogeneration equipment • Ability to use efficiently all cane residues • Biotechnology for longer term / geographical viability: transgenic cane • Adoption of flexible fuel vehicles in different countries • Transfer of technology to different sugar-producing countries	• Import tariffs/corn ethanol subsidies • Lack of hedging instruments/no liquid futures market or long term contracts • Logistics to keep costs low and increase export capability: transport, storage and port facilities • Price of oil below US$ 50 for external market	• Definition of sustainability criteria and international standards • End of import tariffs in EU, US, Japan • Adoption of blend targets • Brazil: legislation to allow for use of transgenic cane
10. Next Generation biofuels	100 million litres per annum	100+ billion litres per annum	Competitive with oil at around US$ 150 per barrel	• Selection or development of economically optimal feedstocks • Lower biomass conversion costs using enzymes, bacteria, fungi, heat and pressure • Development of algae-based biofuels	• Feedstock production to quantity and quality required • Cost of feedstock collection/delivery to biorefineries • Ability of existing infrastructure to cope with next generation biofuels volume	• Capital support from governments for demonstration-scale projects • Blending subsidies to ensure demand – especially during periods of low oil prices • Incentives for farmers to produce energy crops • Attractive tax treatment of RD&D

Note: RPS = Renewable Portfolio Standard; PTC = Production Tax Credit

Source: New Energy Finance

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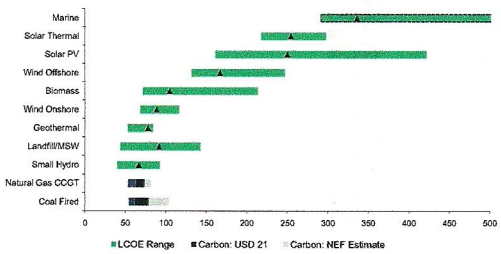
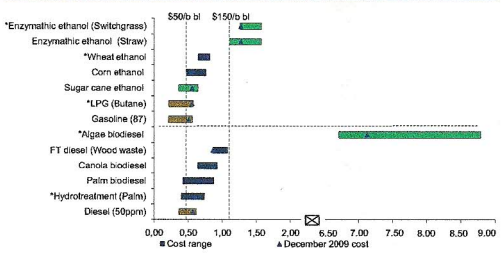
Figure 19: Levelized Costs of Energy Q3 2009, US$ per MWh



Note: Levelized cost of energy (LCOE) is the US$/MWh price for an inflation-adjusted fixed-price off-take agreement that offers the project developer the minimum equity return necessary to undertake the project. For example, an LCOE of US$100/MWh for a wind farm indicates that after factoring in cost of development time and cost, construction, turbine costs, balance of plant, short and long-term financing and operating costs, signing a power purchase agreement at US$100/MWh would return the owner of the project exactly their 'hurdle rate'. The central scenario is based on a 10% equity IRR as a hurdle rate for all technologies, to represent the perspective of a "technology agnostic" developer. Central scenario assumes cost of back-up capacity is not borne at the project level. Eight leading power generation technologies included, plus marine for comparison purposes.

Source: New Energy Finance

Figure 20: Levelized Costs of Liquid fuels Q3 2009, US$ per barrel



Note: The cost range for each technology is based on minimum and maximum feedstock cost in the analyzed period and the minimum and maximum conversion cost for each technology. Central scenario is based on a 10% equity IRR as a hurdle rate for all technologies, to represent the perspective of a "technology agnostic" developer.

* Palm-based biofuels have not been chosen here as "key" technologies due to persistent concerns about their role in deforestation. Canola, wheat, corn and other feedstocks have been excluded due to their competition with food agriculture.

Source: New Energy Finance

These technologies may be the frontrunners but they are by no means the only possible contributors to a cleaner energy future. Many other emerging technologies have potential in the longer term.

Nuclear power will play a growing role in the future energy mix, subject to the successful resolution of concerns over costs, safety concerns, waste disposal and proliferation. It has accounted for around 16% of total electricity production worldwide since the 1980s, and is poised for a renaissance in many countries around the world. However, a full discussion of the merits, problems and possible role of nuclear power is beyond the scope of this report.

One of the most striking developments of the past 18 months has been the precipitous drop in the price of clean energy (see Figure 19 and Figure 20). Over the four previous years, the best manufacturers and technology providers had been working behind the scenes to drive down their costs. However, the soaring demand for equipment from project developers meant that these cost reductions were not passed on to clients. Turbine prices were on an upward trend, and solar module costs did not drop between 2005 and 2008, despite the steep experience curve along the sector's whole value chain.

All of that changed in 2009. In most sectors, the levelized cost of renewable energy – i.e. the cost per unit before taking into account any subsidies or support mechanisms – fell by an average of 10%. In onshore wind, turbine prices fell to their lowest levels for many years, finishing 2009 up to 20% below early 2008 levels. This was, however, somewhat offset by higher financing costs, leaving the levelized cost some 10% down for the year. In the solar sector, the fall was far more dramatic, with the price of solar photovoltaic modules coming down by 50% in the course of the year.

Offshore wind alone bucked the trend: costs continued to rise as projects moved into deeper waters, facing increasingly complex construction and capital costs, and as the rush in project financings – particularly in the United Kingdom – has brought into sharp focus the predicted bottlenecks in installation ships and high-voltage cables.

As the capital markets recover, the net cost of financing for renewable energy will drop sharply. Although bank rates are expected to rise from their historic lows as the global economy slowly emerges from recession, this will be more than offset by the reduction in risk premiums, which remain at unprecedented levels. For almost all clean energy technologies – wind, solar, geothermal, marine, hydro and energy efficiency – the bulk of costs are borne up-front, with no fuel costs during the life of a project, making them more sensitive to higher net interest rates than fossil fuels. An improvement in the capital markets can therefore be expected to have a significant impact on the competitiveness of renewable energy sources.