

Waste to Energy



Methane captured from agricultural waste could be a valuable source of energy



A biogas digester separates animal waste into manure and valuable methane



Biogas derived from waste products can be employed for automotive applications

Summary

The term “waste to energy” has traditionally referred to the practice of incineration of garbage. Today, a new generation of waste-to-energy technologies is emerging which hold the potential to create renewable energy from waste matter, including municipal solid waste, industrial waste, agricultural waste, and waste byproducts. The main categories of waste-to-energy technologies are physical technologies, which process waste to make it more useful as fuel; thermal technologies, which can yield heat, fuel oil, or syngas from both organic and inorganic wastes; and biological technologies, in which bacterial fermentation is used to digest organic wastes to yield fuel.

The Payoff

Waste-to-energy technologies can address two sets of environmental issues at one stroke – land use and pollution from landfills, and the well-know environmental perils of fossil fuels. However, waste-to-energy systems can be expensive and often limited in the types of waste they can use efficiently; only some can be applied economically today.



Waste

2006 Market Size
\$50.0 million

Cumulative Venture Capital (1995 to 2006)
\$126.8 million

Cumulative IPO Value (1995 to 2006)
\$0 million

The Basics

Waste-to-energy technologies convert waste matter into various forms of fuel that can be used to supply energy. Waste feedstocks can include municipal solid waste (MSW); construction and demolition (C&D) debris; agricultural waste, such as crop silage and livestock manure; industrial waste from coal mining, lumber mills, or other facilities; and even the gases that are naturally produced within landfills. Energy can be derived from waste that has been treated and pressed into solid fuel, waste that has been converted into biogas or syngas, or heat and steam from waste that has been incinerated. Waste-to-energy technologies that produce fuels are referred to as waste-to-fuel technologies. Advanced waste-to-energy technologies can be used to produce biogas (methane and carbon dioxide), syngas (hydrogen and carbon monoxide), liquid biofuels (ethanol and biodiesel), or pure hydrogen; these fuels can then be converted into electricity. (For further information on the conversion of waste biomass into biofuels like ethanol and biodiesel, please see Technology Profile 3.1.2, “Biofuels.”) The primary categories of technology used for waste-to-energy conversion are physical methods, thermal methods, and biological methods.

Technology Alternatives

Physical

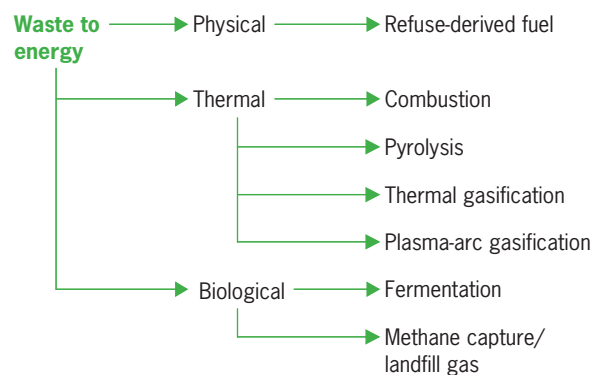
Physical waste-to-energy technologies mechanically process waste to produce forms more suitable for use as fuel, producing refuse-derived fuel (RDF) or solid recovered fuel (SRF). RDF is a fuel produced by either shredding solid waste (such as MSW, C&D debris, or sludge) or treating it with steam pressure in an autoclave. RDF consists largely of organic materials taken from solid waste streams, such as plastics and biodegradable waste. The municipal waste is first processed to remove glass, metals, and other materials that are not combustible (many of which can then be recycled). Autoclaving (treating with high-pressure steam) kills viruses and other potential pathogens, and it also causes plastics to soften and flatten, paper and other fibrous material to disintegrate, and bottles and metal objects to be cleaned of labels. This process reduces the volume of the waste by up to 60%, and the residual material can then be compressed into pellets or bricks and sold as solid fuel. Burning RDF is more clean and efficient than incinerating MSW or other solid waste directly, but the processing adds to costs.

Thermal

Thermal waste-to-energy technologies use heat or combustion to treat wastes. Methods include the following:

- **Combustion.** Municipal waste can be directly combusted in waste-to-energy incinerators as a fuel with minimal processing, in a process known as “mass burn.” Heat from the combustion process is used to turn water into steam, which is used to

Technology Tree



power a steam-turbine generator to produce electricity. Next-generation waste incinerators also incorporate air-pollution-control systems, though ash or other pollutants captured in this process must still be disposed of.

- **Pyrolysis and thermal gasification.** Pyrolysis uses heat to break down organic materials in the absence of oxygen, producing a mixture of combustible gases (primarily methane, complex hydrocarbons, hydrogen, and carbon monoxide), liquids, and solid residues. Low-temperature pyrolysis can also be used to produce a synthetic diesel fuel from waste-film plastic, for example. A beneficial byproduct of pyrolysis is a kind of charcoal called “biochar,” which can be used as a fertilizer and can also be used to absorb CO₂ and other emissions from coal-fired power plants (see the Technology Profile 3.4.1, “Carbon Sequestration”). Thermal gasification of waste, in contrast to pyrolysis, takes place in the presence of limited amounts of oxygen. The gas generated by either of these processes can be used in boilers to provide heat, or it can be cleaned up and used in combustion turbine generators. Whereas incineration converts the input waste into energy onsite, pyrolysis and thermal gasification allow the production of fuel that can be transported. In addition, the gases, oils, and solid char from pyrolysis and gasification can also be purified and used as a feedstock for chemical production and for other applications.
- **Plasma-arc gasification.** Plasma-arc waste-to-fuel gasification uses a plasma-arc torch to produce temperatures as high as 13,000 °F. This extreme heat breaks down wastes, forming syngas (hydrogen and carbon monoxide) and a rock-like solid byproduct called slag, which can be used in construction or road asphalt. As in coal gasification, the syngas can be converted into a variety of marketable fuels – including ethanol, natural gas (methane), and hydrogen – or it can be used to generate electricity directly (see Technology Profile 3.1.3, “Coal Gasification”). Plasma converters could consume nearly any type of waste, including concrete, steel, and toxic chemicals, but the technology requires large energy inputs and

Competing Technologies		
Technology	Advantages	Disadvantages
Waste reduction	<ul style="list-style-type: none"> • Low-tech, low-cost • Reduces amount of waste that must be dealt with in any fashion 	<ul style="list-style-type: none"> • Requires change in behavior • Doesn't produce energy
Recycling	<ul style="list-style-type: none"> • Reduces waste without need for incineration or other more advanced methods 	<ul style="list-style-type: none"> • Requires change in behavior • Doesn't produce energy • Consumes energy
Composting	<ul style="list-style-type: none"> • Reduces waste without need for incineration • Produces fertilizers 	<ul style="list-style-type: none"> • Requires change in behavior • Doesn't produce energy
Landfill dumping	<ul style="list-style-type: none"> • Quick, easy disposal of waste • Doesn't involve incineration 	<ul style="list-style-type: none"> • Uses potentially valuable land • Doesn't produce energy • Can leach toxins into groundwater • Releases significant greenhouse-gas emissions, especially methane
Solar power	<ul style="list-style-type: none"> • Free beyond initial capital investment and maintenance • More consistent supply of power than some other renewable sources • Available to many regions 	<ul style="list-style-type: none"> • Efficiency of only 6% to 20% • Requires consistent minimum levels of sunlight; not suitable for cloudy climates or useful after sundown
Tidal energy	<ul style="list-style-type: none"> • Zero emissions • Can produce more power per turbine than wind 	<ul style="list-style-type: none"> • High maintenance costs • Requires proximity to coast or river • Somewhat intermittent: power not generated at slack tide • Still in early R&D phase
Hydroelectric power	<ul style="list-style-type: none"> • Low-cost energy generation • Renewable nonpolluting resource • Creates new reservoirs or lakes 	<ul style="list-style-type: none"> • Dam construction can destroy habitats and alter local ecosystems • Must be located on significant waterway; not suitable for drier regions
Wind power	<ul style="list-style-type: none"> • Free beyond initial capital investment and maintenance • Already cost-competitive with fossil fuels • Can supply localized power independent of grid • Relatively small footprint • Zero emissions 	<ul style="list-style-type: none"> • Efficiency of only 20% to 30% for ground-based systems • High initial capital cost Intermittent power production
Nuclear power	<ul style="list-style-type: none"> • Well-established and cost-competitive with the least expensive energy sources used today • Lower emissions – i.e., pollutants and greenhouse gases – than coal and other conventional power 	<ul style="list-style-type: none"> • Radioactive waste from power plants takes hundreds to thousands of years to decay, and therefore must be stored in a safe long-term location • Risk of “meltdown” or Chernobyl-scale disasters • Capital costs to build safe plants are large

remains early stage, with the first demonstration plants planned to come online in 2007.

Biological

Biological waste-to-energy technologies are those that use microbes or other organisms to produce fuels from waste. Varieties include the following:

- **Methane capture/landfill gas.** Landfilling is still the primary method of disposal of municipal solid waste and C&D debris in the U.S. and many other countries. If left undisturbed, landfill waste produces significant amounts of gaseous byproducts, consisting mainly of carbon dioxide (CO₂) and methane (natural gas, CH₄). This “landfill gas” or “biogas” is produced by the anaerobic (oxygen-free) digestion of organic matter. Carbon dioxide and methane are both greenhouse gases that increase the risk of climate change when they are released unimpeded into the atmosphere, but methane is also a useful source of energy and therefore worth collecting as a biogas. Landfill gas can be captured via a collection system, which usually consists of a series of wells drilled into the landfill and connected by a plastic piping system. The gas can then be burned directly in a boiler as a heat-energy source, or, if the biogas is cleaned by removing water vapor and sulfur dioxide, it can be used directly in internal-combustion engines, or for electricity generation via gas turbines or fuel cells.
- **Biogas plants.** Anaerobic digestion to produce biogas can occur either naturally (as in landfill gas), or in a controlled environment like a biogas plant. Feedstocks in such plants could include food-processing waste or other agricultural waste such as manure. The process begins with the placement of waste and various types of bacteria into an airtight container called a digester. Advanced digester systems can now produce biogas with a pure methane content higher than 95%. The biogas can then either be burned directly in boilers, or cleaned

Key Players

Name	Type	Country	Comment
Agri-Therm	Private/Specialist	Canada	Has developed a mobile pyrolysis plant for the production of bio-oils from agricultural waste biomass. The company is capable of processing 10 tons of dried biomass per day.
Ozmotech	Private/Specialist	Australia	Has developed ThermoFuel Quad Chamber technology that uses pyrolysis and a catalytic converter to convert waste plastic directly into diesel fuel. The process can handle unsorted, unwashed plastic waste.
Plasco Energy	Private/Specialist	Canada	Developing plasma-conversion technology to convert municipal solid waste and other feedstocks into syngas for electricity production. The firm has received \$18 million in private funding and a \$6 million contract from the Canadian government.
Nanologix	Public/Diversified	U.S.	Has developed patent-protected bacteria for anaerobic digestion that can consume organic waste and release hydrogen. Welch's Foods is testing a pilot project on its grape-processing wastewater.
Startech Environmental	Public/Specialist	U.S.	Aiming to commercialize its Plasma Waste Converter, based on plasma-torch technology for transforming solid waste into syngas.
Microgy	Subsidiary/Specialist	U.S.	Commercializing a proprietary anaerobic-digester technology which the company says can generate significantly more biogas than other digestion methods. A subsidiary of Environmental Power, Microgy has annual revenues of \$50 million per year.
Integrated Environmental Technologies	Private/Specialist	U.S.	Developing its Plasma Enhanced Melter waste-conversion technology, based on a carbon-rod plasma-arc system, to convert municipal solid waste and other feedstocks into syngas for electricity production.
Renovar Energy	Private/Specialist	U.S.	Designs and builds projects to capture, clean, and pipe landfill gas to power plants.
Highmark Renewables	Private/Specialist	Canada	Commercializing its Integrated Manure Utilization System (IMUS) process for the anaerobic digestion of livestock manure. A single IMUS plant will consume about 100 tons of wet manure daily, equal to about 20% of the total output from a nearby livestock feedlot.
Sustec Schwarze Pumpe	Private/Specialist	Germany	Operates a gasification plant for fluid and solid waste, which produces highly purified methanol for fuel and other applications.
Covanta Energy	Subsidiary/Specialist	U.S.	One of the largest waste-to-energy businesses in the U.S. Its 25 large-scale plants convert more than 30,000 tons of municipal waste per day. Covanta is a subsidiary of Danielson Holding.
Waste-to-Energy Research and Technology Council (WERT)	Trade organization	International	Technical group that brings together engineers, scientists and officials from industry, academia, and government to increase the recovery of materials and energy from waste and reduce the environmental impact of waste disposal.
Ze-gen	Private/Specialist	U.S.	Developing a gasification process to produce syngas from municipal solid waste, C&D debris, and other sources.
Arkenol	Private/Specialist	U.S.	Has developed and patented several processes for the production of ethanol from agricultural waste. Arkenol is partnering with BlueFire Ethanol, which recently received a \$40 million federal grant for a bioethanol plant in California.
Renewable Environmental Solutions	Subsidiary/Specialist	U.S.	Joint venture of ConAgra Foods and Changing World Technologies; uses a high-pressure reformation process called TCP (Thermal Conversion Process) to convert organic waste into fuel oil. The company has shipped more than 6,000 barrels of fuel so far.

and supplied as natural gas. Biogas plants can transfer electrical energy to the main utility grid, or they can generate power for use on-site in applications like lighting, processing plants, ethanol plants, and greenhouses. Biogas plants have been deployed in India, Israel, Australia, and elsewhere.

- **Fermentation.** Fermentation uses yeast to generate liquid ethanol from biomass waste. (For more information on this process, please see the Technology Profile 3.1.2, "Biofuels.")

Key People

Name	Position	Comment
Garry Baker	CEO, Ozmotech	Ozmotech has developed technology to convert waste plastic into diesel fuel.
Roderick Bryden	President & CEO, Plasco	Plasco is developing plasma-conversion technology to convert waste into syngas.
Rick Honaker	Professor, Department of Engineering, University of Kentucky	Developing methods for extracting premium fuel coal and lumber waste currently dumped into refuse ponds and landfills.
Richard E. Kessel	President & CEO, Microgy	Microgy is commercializing proprietary anaerobic digestion technology for livestock waste.
Xiaomei Li	Research Scientist, Alberta Research Council (Canada)	Developed the Integrated Manure Utilization System (IMUS) anaerobic digester used by Highmark Renewables.
Larry Gilbert	President, Renovar Energy	Renovar builds projects to capture landfill gas for fuel.
Michael Ladisch	Professor, Department of Agricultural and Biological Engineering, Purdue University	Developing portable “tactical biorefinery” for military use, which separates inorganic waste from food waste and then uses yeast in a bioreactor to ferment the waste into ethanol or biogas that can be used to generate electricity on-site.

IP Outlook

Many waste-to-fuel specialists are pursuing aggressive patent-coverage strategies. Ozmotech owns the IP on its pyrolysis technology for the conversion of waste plastic directly into diesel fuel, with patents around the world. However, other companies, mindful of threats from patent infringers, pursue a different tack. One developer of plasma-arc waste-conversion technology, Startech, has limited its patents to a specific torch-positioning apparatus for its waste-conversion system and for a ceramic membrane component of its attached hydrogen-generation system. The company has declined to seek patents on any other intellectual property it has developed, choosing instead to “protect them as trade secrets,” relying on nondisclosure and noncompete agreements with collaborators.

Drivers

Technology drivers

- Improved pollution and emissions controls for combustion.** One of the primary objections against waste incineration, even when used to generate energy, has been that burning releases particulate matter and pollutants like nitrogen oxides (NO_x) into the atmosphere. However, improved technologies for treating gas waste streams are mitigating these concerns (see Technology Profile 3.2.1, “Air Pollution Control Technologies”).
- Advanced non-incineration conversion methods.** New technologies like pyrolysis, thermal gasification, and plasma-arc gasification are providing ways of generating energy from waste that avoid many of the pollution concerns around incineration, and may provide better economics for waste-to-energy as well.

- Hydrogen production enabling other clean technologies like fuel cells.** Waste-to-energy systems like thermal gasification-based waste conversion plants can be fitted with direct hydrogen generation. While many countries are interested in developing a hydrogen infrastructure for fuel-cell-powered vehicles, in most cases, including the U.S. and Canada, current plans include only hydrogen generation from coal plants. Waste-to-energy systems could provide a more sustainable solution.

Strategic drivers

- Reduction in landfill dumping.** Landfills require large amounts of land that could be used for other purposes. Municipalities that run out of space for landfills must pay to have their garbage and construction debris shipped somewhere else. For example, Toronto pays to have almost 800,000 tons per year of its excess garbage shipped to Michigan, at \$22 per ton. New York City pays up to \$120 per ton to ship its solid waste to landfills. Converting municipal waste to energy reduces the volume of ordinary solid waste bound for landfills by up to 90%, and by producing useful products can help cut costs further.
- Reduced dependence on fossil fuels.** With advanced technologies, waste can be used to generate fuel that does not require mining or drilling for increasingly scarce and expensive non-renewable fossil-fuel resources.
- Reduced greenhouse-gas emissions and pollution.** Using waste as a feedstock for energy production reduces the pollution caused by burning coal or other fossil fuels. While traditional incineration still produces CO₂ and pollutants, advanced methods such as gasification have the potential to provide a double benefit: reduced CO₂ emissions compared with incineration or coal plants, and reduced methane emissions from landfills.

Milestones

Date	Milestone	Impact
2009	U.S. government passes legislation mandating that all large cattle farms and feedlots must install anaerobic digesters to convert manure into biogas.	According to the EPA, this mandate could result in greenhouse-gas reductions equivalent to more than 100 million tons of CO ₂ per year.
2011	California buys thermal gasification waste-to-energy systems for its largest landfills.	This adoption could provide a large-scale proving ground for this technology, potentially bringing it into widespread use.
2015	Conversion of plastic waste into diesel fuel becomes standard practice for municipal waste management.	This step could not only reduce landfill waste, but would also help enable the bioplastics market, as these plastics cannot be recycled with standard plastics.

- **Eligibility for carbon credits and tax incentives.** Because they replace fossil-fuel use, most advanced waste-to-energy technologies are eligible for greenhouse-gas emission credits. These credits can be used by corporations to offset greenhouse-gas emissions, or sold as a commodity via carbon cap-and-trade programs like the Chicago Climate Exchange. In addition, government programs in several EU countries are promoting the use of biogas from waste and offering tax incentives for producers.

Challenges

Technology challenges

- **Lack of versatility.** Many waste-to-energy technologies are designed to handle only one or a few types of waste (whether plastic, biomass, or others). However, it is often impossible to fully separate different types of waste or to determine the exact composition of a waste source. For many waste-to-energy technologies to be successful, they will also have to become more versatile or be supplemented by material handling and sorting systems.
- **Waste-gas cleanup.** The gas generated by processes like pyrolysis and thermal gasification must be cleaned of tars and particulates in order to produce clean, efficient fuel gas.
- **Conversion efficiency.** Some waste-to-energy pilot plants, particularly those using energy-intensive techniques like plasma, have functioned with low efficiency or actually consumed more energy than they were able to produce. For example, many sites in India have been forced to shut down because they were not financially sustainable once government subsidies ran out.

Strategic challenges

- **Regulatory hurdles.** The regulatory climate for waste-to-energy technologies can be extremely complex. At one end are regulations that may prohibit a particular method, typically incineration, due to air-quality concerns, or classify ash byproducts of waste-to-energy technologies as hazardous materials. At the other end, while changes in the power industry have allowed small producers to compete with

established power utilities in many areas, the electrical grid is still protected by yet more regulations, presenting obstacles to would-be waste-energy producers.

- **High capital costs.** Waste-to-energy systems are often quite expensive to install. Despite the financial benefits they promise due to reductions in waste and production of energy, assembling the financing packages for installations is a major hurdle, particularly for new technologies that aren't widely established in the market.
- **Opposition from environmental and citizen groups.** Because traditional incineration-based waste-to-energy technologies can produce significant pollution from the burning of waste, environmental and citizen groups have often opposed such systems. Developers argue that advanced technologies like pyrolysis release few emissions, and that any pollution that is released is captured with emissions-control systems. However, many activists remain unconvinced, and some express concern that using waste as a feedstock for energy generation will cause municipalities to abandon their efforts in waste reduction, recycling, and composting.

Momentum: High

As energy prices, population growth, and concerns regarding greenhouse-gas emissions continue to rise, so will the need for alternative energy – and alternatives to landfills and livestock-waste lagoons. The U.S. ranks as the world's largest producer of solid waste, currently generating more than 230 million tons of municipal solid waste per year. Traditional incineration facilities currently process about 14% of this waste, producing enough electricity for 2.8 million homes. In Europe more than 400 incineration plants process more than 50 million tons of municipal solid waste per year, and in China's Shandong Province, construction has begun on a large incineration plant capable of generating 200 million kWh of electricity per year. The eager adoption of these incumbent waste-to-energy methods provides a strong base for emerging technologies to build on. On the biofuels front, many producers of ethanol biofuels have begun to respond to criticisms that their "environmentally friendly" products rely too heavily on fossil fuels for their production, and

Key Venture Capital Transactions

Company	Amount invested (US\$ millions)	Date	Country	Round	Total VC funding through 1995-2006 (US\$ millions)
GreenFuel Technologies	\$17.8	4/11/2006	U.S.	B	\$19.8
Plasco Energy Group	\$16.0	9/19/2006	Canada	B	\$22.9
Sterecycle	\$15.0	10/16/2006	U.K.	B	\$16.9
Bedminster International	\$10.0	5/12/2006	Ireland	Other	\$10.0
Solena Group	\$10.0	11/19/2002	U.S.	Other	\$10.0

Key M&A/IPO Events

Company	Amount (US\$ millions)	Date	Country	Type	Acquiring company/ticker
Waste Management	\$583	3/27/2006	New Zealand	M&A	Transpacific Industries Group
TAD Energia Ambiente	\$192	5/15/2006	Italy	M&A	Acea
Sterile Technologies Group	\$131	2/27/2006	Ireland	M&A	Sterecycle
Batneec Dumfries	\$1.46	5/17/2006	U.K.	M&A	Scotgen
AddPower	\$1.0 (est.)	10/5/2006	Sweden	M&A	International Power Group

they are now using biogas from landfills or feedlots to power their refineries – biogas power for biofuels. Before they can see broader adoption, new waste-to-fuel technologies need to overcome high

costs and become more flexible in processing heterogeneous waste streams, but the demand for these technologies will remain strong.