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Waste-to-Energy Technology

Contents

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What Is Waste-to-Energy Technology?

Waste-to-Energy (WTE) technology utilizes Municipal Solid Waste (MSW) to create electric and heat energy through various complex conversion methods

- WTE technology provides an alternative source of renewable energy in a world with limited or challenged fossil reserves
- MSW is considered a source of renewable energy because it contains a large amount of biological and renewable materials
  - There is a significant excess supply of MSW (primarily in landfills) around the globe
  - The demand for MSW as a fuel source has increased
- The most common conversion method of MSW to energy is combustion, and although it is currently entrenched in the market, there are two emerging technologies moving toward the forefront
  - Biological treatment method via anaerobic digestion
    - Anaerobic digestion is a waste-to-fuel application; waste can be converted into purified biogas which can then be used to power gas engines or turbines to create heat or electricity. The biogas can also be purified and compressed to be used as vehicle fuel
    - Thermal treatment methods that yield energy in the form of heat and electricity include combustion, gasification, and pyrolysis
- Columbia University researchers assert that technology breakthroughs in recent years now make sending trash to landfills a waste of energy
  - The study, co-authored by researchers at the university's Earth Engineering Center, determined that if the United States took all the non-recycled plastic currently sent to U.S. landfills each year and instead sent that trash to a WTE power plant, it would produce enough electricity for 5.2 million U.S. homes annually
  - Some states are taking advantage of the latest waste management technology. Connecticut, for example, has the best record for this, achieving a recovery of 65% on plastic waste when including both recycling and WTE conversion
  - Other states with the best record for capitalizing on the energy of waste include (in order) Massachusetts, Hawaii, Maine, Virginia, Minnesota, New Jersey, New York, Maryland, and Pennsylvania

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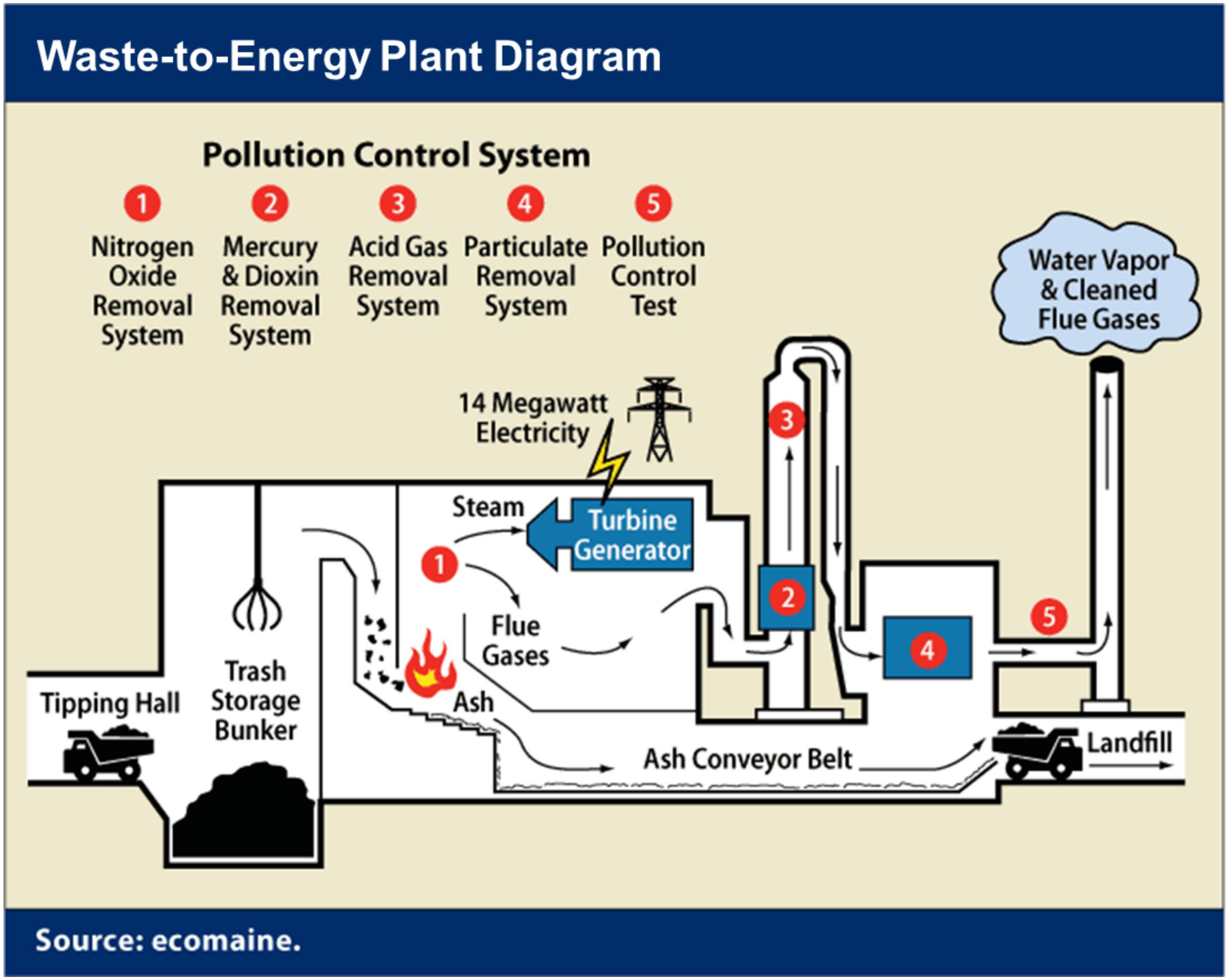
Source: Pike Research. “Waste-to-Energy Technology Markets,” Columbia University report, April 2011

WTE Plant Diagram

Combustion is currently the primary method of converting waste to energy.



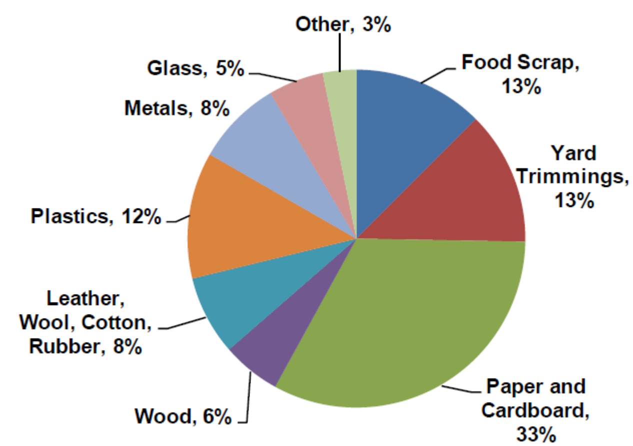
Source: Ecomaine

Supply of MSW for WTE

The feedstock for WTE is predominantly MSW, which at the present time is widely available around the world

- More than a billion tons of MSW is processed in landfills each year
  - Growth rates of waste in most industrialized countries is comparable to GDP growth and energy consumption
  - Despite plans of increased investment in WTE technology, 20-year projections indicate that MSW is a sustainable feedstock supply
- Unlike most other biofuel inputs, using MSW feedstock for WTE is a low-cost supply and can actually create a revenue stream via tipping fees from landfill operators
  - Landfill owners have a significant incentive to divert MSW to alternative sites due to the high costs and time involved in permitting additional landfill capacity
  - In some cases, it is not possible to permit new landfills or expand existing landfill capacity
- MSW can be defined in different ways depending on the nation or international organization involved; the definition has significant effects on the WTE markets
  - The quality and contents of MSW are dependent upon the definition and the characteristics of the landfill
  - The International Energy Agency (IEA) defines MSW with regard to waste in WTE as household waste and commercial and industrial waste that has a composition similar to that of household waste

MSW Composition, Segmentation by Item, United States: 2007



(Source: U.S. EPA, 2008)

Source: Pike Research. "Waste-to-Energy Technology Markets," Columbia University report, April 2011

MSW: The WTE Process

Waste is collected within a municipality, delivered to WTE facilities, and converted into a form of usable energy

- In most developed countries, almost all waste that is generated is collected by municipal or private services
  - The IEA maintains that "MSW is waste typically collected and managed by local municipalities, i.e., it is predominantly the waste generated by households and collected from households or from areas to which households have access to deposit their waste. It also includes wastes of a similar nature derived from the commercial and industrial waste sector"
- MSW is transported by trucks with a capacity of multiple tons of MSW per trip. Rather than being delivered to traditional landfills, a percentage of landfill waste is diverted to WTE facilities
  - The number of trucks visiting a plant each day and the distance the trucks must travel are dependent upon the size and location of the plant
  - Each WTE plant may have contracts with one or more waste collection companies to guarantee a set amount of daily waste delivered
    - Depending on the contract, waste haulers may pay a tipping fee to the WTE plant rather than paying a gate rate to a landfill. Usually, the plant will have to pay for the transportation costs of delivering to the plant instead of a closer landfill. Other contracts may provide that the haulers pay for transportation themselves but not pay the tipping fee
    - These contracts may have provisions that WTE plants either earn revenues on hauling feedstock or receive feedstock at no cost
- Depending on the conversion method, the waste may be pretreated for conversion through a process of inspecting and sorting, which is an added cost to the facility

Source: ScottMadden research

Sustainability of MSW as a WTE Feedstock

Feedstock supply for MSW must be analyzed to ensure a sustainable, long-term supply, but feedstock supply risks can be mitigated through multiple long-term contracts between the suppliers and the WTE facility

- MSW availability is driven by three variables: population, diversion, and the economy
  - Projected MSW availability is calculated as the population multiplied by the MSW per capita
  - Recycling is currently the only diversion to pose a potential threat to MSW availability, but even in states with aggressive recycling programs, MSW landfill capacity is only modestly lowered
- Future population and MSW diversion numbers are used to calculate long-term availability of MSW as a feedstock
- Ranges of feedstock availability and cost are developed through scenario analysis population, the economy, landfill capacity projections, and by determining if there are other users of MSW for landfills targeted as feedstock sources for a particular project

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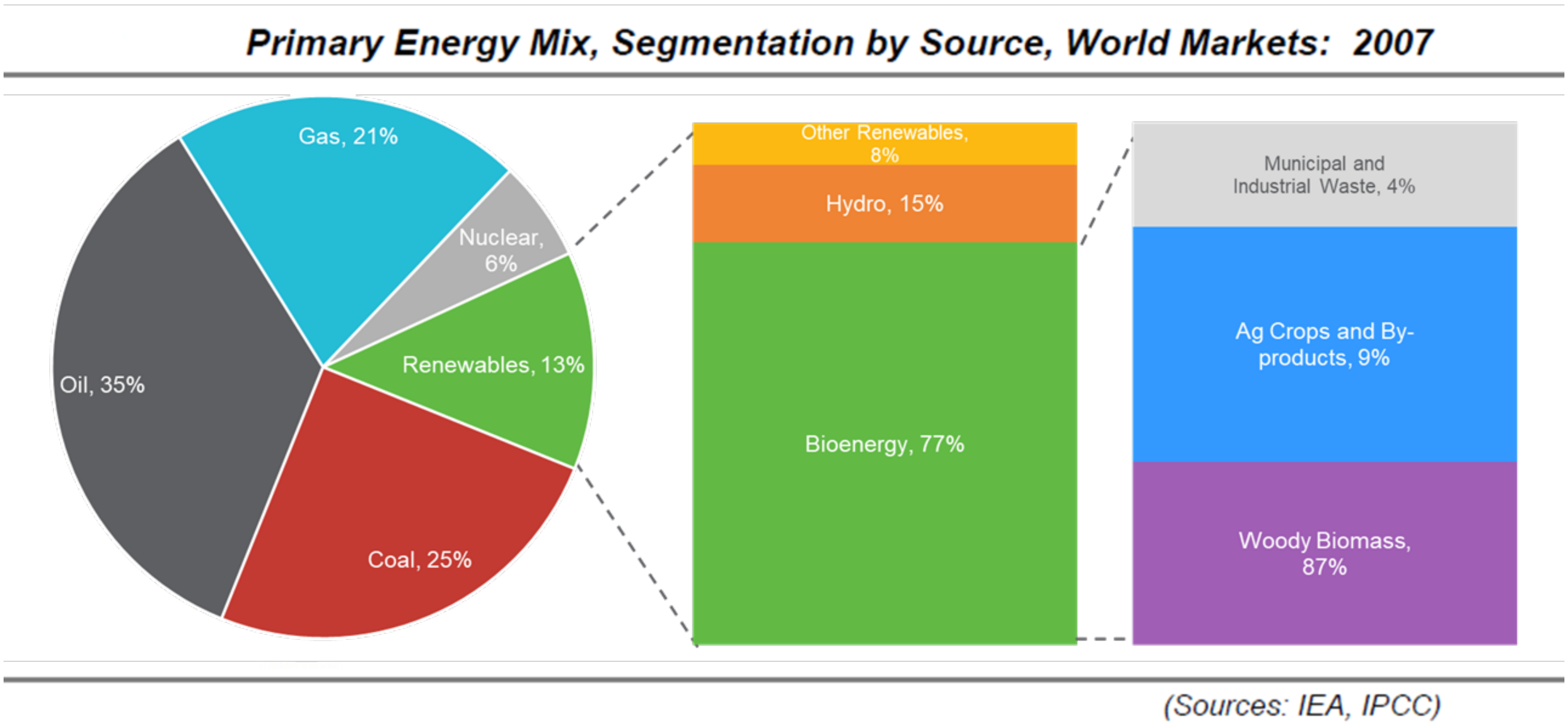
Source: ScottMadden market advisory report for Fulcrum Sierra Biofuels

MSW as a Source of Energy

In 2007, MSW made up about 0.4% of the world's energy mix. As investment in renewable sources of energy increases, investment in WTE and the percentage of MSW as a global provider of energy will increase as well.



- As of 2010, 86 plants operate in 24 U.S. states and have capacity to process more than 97,000 tons of municipal solid waste per day
- Although the 2010 WTE electric generating capacity is only around 250 MW, there is also the production of process steam in cogeneration plants

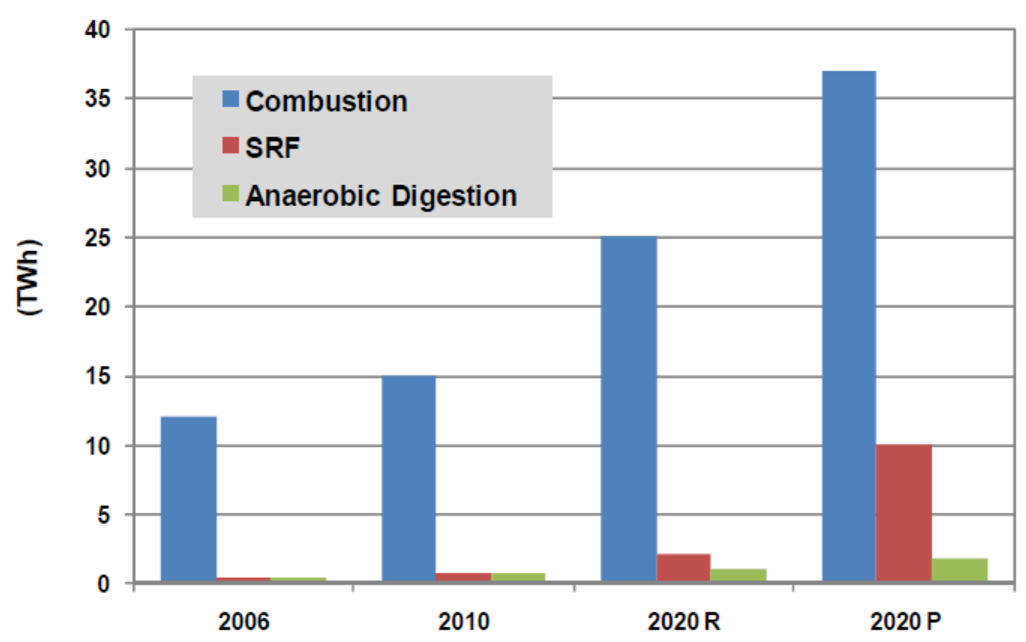
Source: Pike Research

MSW: Conversion Technologies

There are multiple technologies for converting MSW to energy, but these technologies are not in competition with each other

- Incineration of waste is the most prevalent form of converting MSW to energy. The waste is combusted, and the heat or biogas created is harnessed and either distributed as heat or converted into another form of useful energy—steam or electricity
- Combustion processes are classified as mass burn combustion, where waste is not pre-sorted, or RDF combustion, a more costly process where recyclable materials are sorted from the rest of the waste. This process is also known as the Solid Recovered Fuel (SRF) combustion process
- Another thermal treatment process is gasification, which is effective in minimizing air pollutants. Gasification occurs in the presence of limited oxygen and generates a synthetic gas to be used in a heat and electricity-producing gas turbine
- A third process, pyrolysis, is now reaching market maturity. It is a thermochemical process that produces synthetic gas (syngas) and most recently cellulosic ethanol
- Anaerobic digestion is a form of biological treatment where organic material is treated and the output biogas is rich in methane. The biogas can be cleaned and used, turned into heat and electricity, or used for methane

Renewable Electricity Output by WTE MSW Treatment Method, EU-27: 2006-2020



(Source: CEWEP)

Source: Pike Research. "Waste-to-Energy Technology Markets," Columbia University report, April 2011

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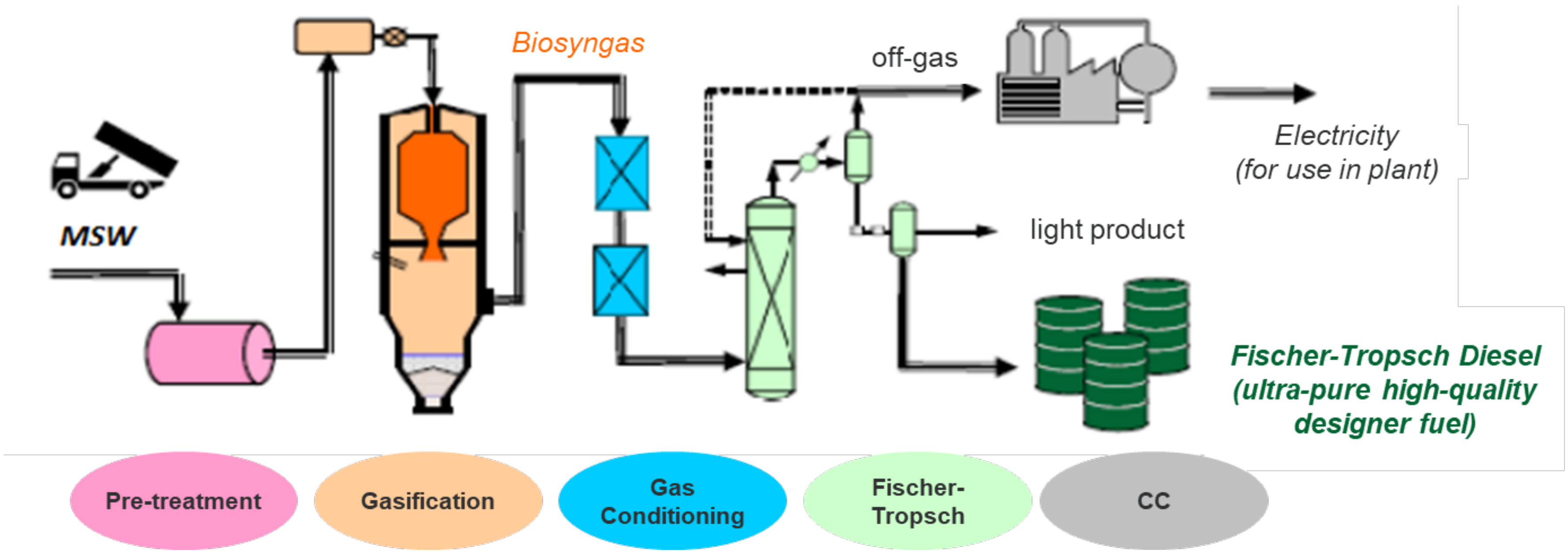
MSW Treatment Through Gasification and Pyrolysis

Gasification and pyrolysis are types of thermal treatments used to convert MSW to energy. Gasification is a process that uses high temperatures (without combustion) to decompose materials to produce syngas

- Syngas is generally used to power gas engines or turbines to generate heat or electricity but can also be used as a fuel itself or as an intermediate in producing other fuels and chemicals
  - Using syngas to generate heat or electricity is more efficient than combusting MSW
  - Syngas can be used to produce synthetic diesel—this liquid form of syngas is cleaner and more efficient than many alternative liquid fuels
- When compared to a WTE combustion process, gasification significantly reduces air emissions and produces a product with a higher thermal efficiency



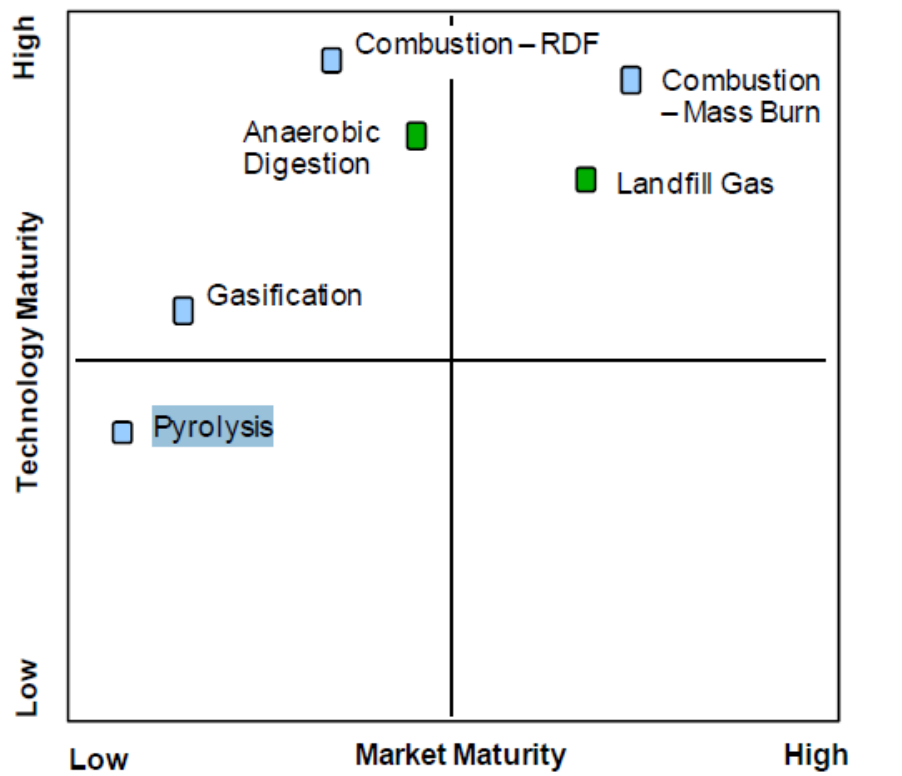
Source: ScottMadden research

MSW Treatment Through Gasification and Pyrolysis (Cont'd)

Pyrolysis has been demonstrated at pilot and small commercial scale—advancement to large scale could be a game changer. Pyrolysis is an advanced form of gasification that chemically decomposes organic materials by heat in the absence of oxygen. The process typically occurs under pressure and at very high operating temperatures—around 500 degrees Celsius

- Bio-oil, a gas, and char are the products of the pyrolysis process
  - Bio-oil is a purified, liquid renewable energy source which can be used to produce power and heat for industrial boilers
- Pyrolysis as WTE technology has been piloted and is beginning to be tested in the markets
- Pyrolysis is also reaching commercialization in the production of cellulosic ethanol

Positioning of WTE Technologies, Market vs. Technology Maturity



(Sources: Pike Research, NAWTEC)

Source: Pike Research. "Waste-to-Energy Technology Markets," Columbia University report, April 2011

MSW: Anaerobic Digestion

Anaerobic digestion (AD) is the only form of biological treatment of MSW. It creates the least amount of waste and is the most efficient conversion technology yet has the smallest contribution to total energy output of WTE

- AD produces a biogas which can be used to produce electricity, process steam, or in the transportation sector
  - In this biological process, microorganisms are used to break down organic waste in the absence of oxygen in an enclosed vessel. Temperature, moisture, nutrient contents, and pH of the organic matter are key factors in the process
  - The biogas from AD consists of 60%-70% methane, 30%-40% carbon dioxide, and other trace chemicals
    - Biogas can be used to power a gas engine or turbine, or it can be compressed and purified for use as vehicle fuel
    - Methane may also be extracted from the biogas for direct use
- Many forms of AD exist, and some of these are more efficient than others. Efficiency of the AD process depends on the form of waste used as feedstock as well as the vessel used to host the process
  - Until recently, AD adopters have been individual farms looking for ways to reduce their environmental (waste) footprint and thus have been focused less on economics than other non-financial factors
    - In these cases, the main feedstock for AD has been animal waste as opposed to MSW
  - Municipal sewage contains biomass solids, so AD is also used in wastewater treatment plants to reduce volume of those solids. However, AD of sewage produces other harmful chemicals not found in AD of farm animal waste
  - Landfill gas (LFG)-to-energy is a less efficient form of AD that harnesses and uses gas from pre-existing landfills
- Two drawbacks of AD are its by-product and its need to be pre-treated
  - In addition to the methane-rich biogas created in the AD process, a digestate, in either a solid or liquid form (depending on either dry or wet input) is also created as a by-product. The digestate must be disposed of or composted in solid form or purified and treated in its liquid form. This treatment process requires expensive, complex technologies
  - In order for MSW to be used in this process, it must be inspected and sorted to remove plastics and other contaminants. This added cost reduces the efficiency of AD

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Source: Pike Research. “Waste-to-Energy Technology Markets,” Columbia University report, April 2011; ScottMadden’s “Anaerobic Digestion: Farm Waste”

MSW: Anaerobic Digestion (Cont'd)

LFG technology is proven commercially

- LFG-to-energy is a form of AD and is a biological treatment method of WTE. LFG-to-energy has existed and has proven successful for many years. Since the 1970s, U.S. landfills have collected LFG for conversion to useful energy
  - LFG is created during the decomposition of organic substances in MSW when it is dumped, compacted, and covered
    - Gas formation is influenced by a number of factors such as the landfill material, the storage height and density of the landfill material, water content, air temperature, atmospheric pressure, and precipitation levels
  - LFG-to-energy as a method of WTE conversion does not require new technology but instead depends on harnessing the methane, carbon dioxide, and nitrogen that is and always has been created by MSW
    - LFG-to-energy is economically attractive because, unlike other WTE conversion technologies, it does not require a new facility. Gas can be collected from an existing landfill and either used as is, upgraded to a higher-quality gas, or converted to energy through combustion, a gas turbine, or a steam turbine
      - Existing landfills may already have gas collection systems in place, and adding a power plant requires minimal capital investment
  - Direct use of LFG or gas-to-power projects are the most viable for LFG-to-energy; upgrading LFG to a high-BTU pipeline gas is not cost effective for most plants
    - Piping the medium-BTU LFG directly to nearby gas customers for boiler or industrial is the most efficient use of LFG; however, this method requires nearby demand of a lower BTU-value gas
    - Converting gas to electricity with combustion engines or turbines allows the plant to use or sell generated electricity
  - The finite number of existing landfills and their limited capacities are the leading drawbacks for investing in this technology
    - Few landfills are thought to recover more than 60% of available LFG even with well-designed systems
    - The decomposition process in a landfill providing gas with sufficient methane content lasts approximately 15 to 25 years, with the gas volume decreasing continuously over the years, once landfilling concludes
    - EPA has already identified the potential sites for LFG utilization, and market competition is already well established

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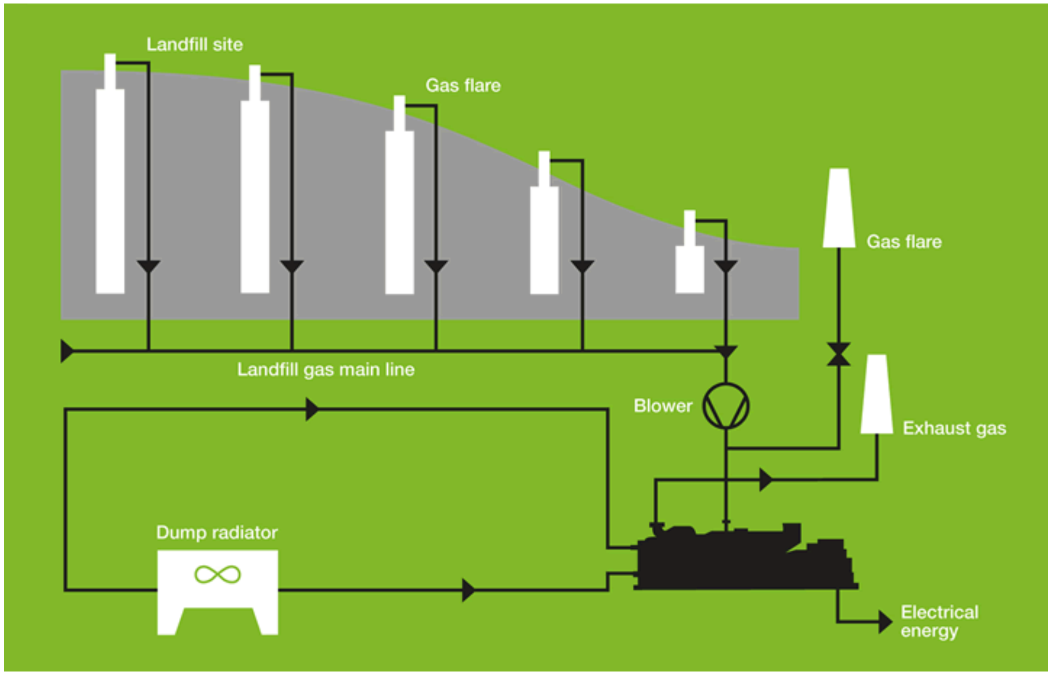
Source: ScottMadden research

LFG Process Flows

Example LFG Extraction Layout with Active Gas Collection

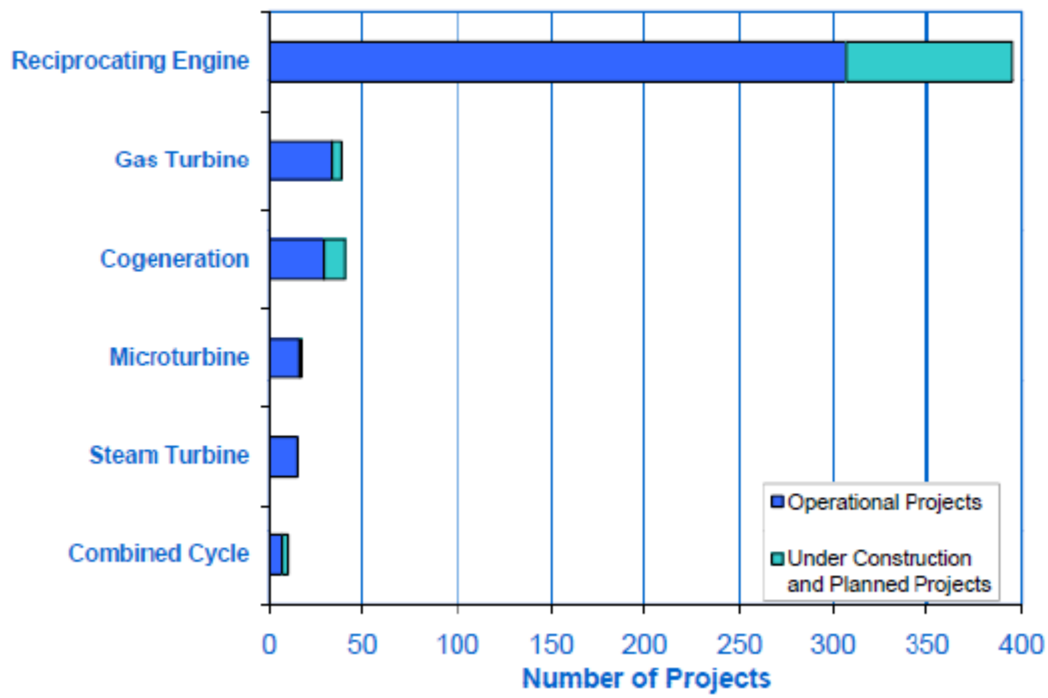


- Perforated tubes are drilled into the landfill body and interconnected by a pipework system. Utilizing a blower, the gas is sucked from the landfill, compressed, dried, and fed into the gas engine
- For safety reasons, the installation of a gas flare is recommended so that excess gas can be burned off in the event of excessive gas production
- In most cases, the electrical power generated is fed into the public grid

Source: Clark Energy

Electric Generation Technology Trends for LFG

The most prevalent technology for electricity production from LFG is the reciprocation engine, although other technologies are utilized, depending on the size of the LFG well.

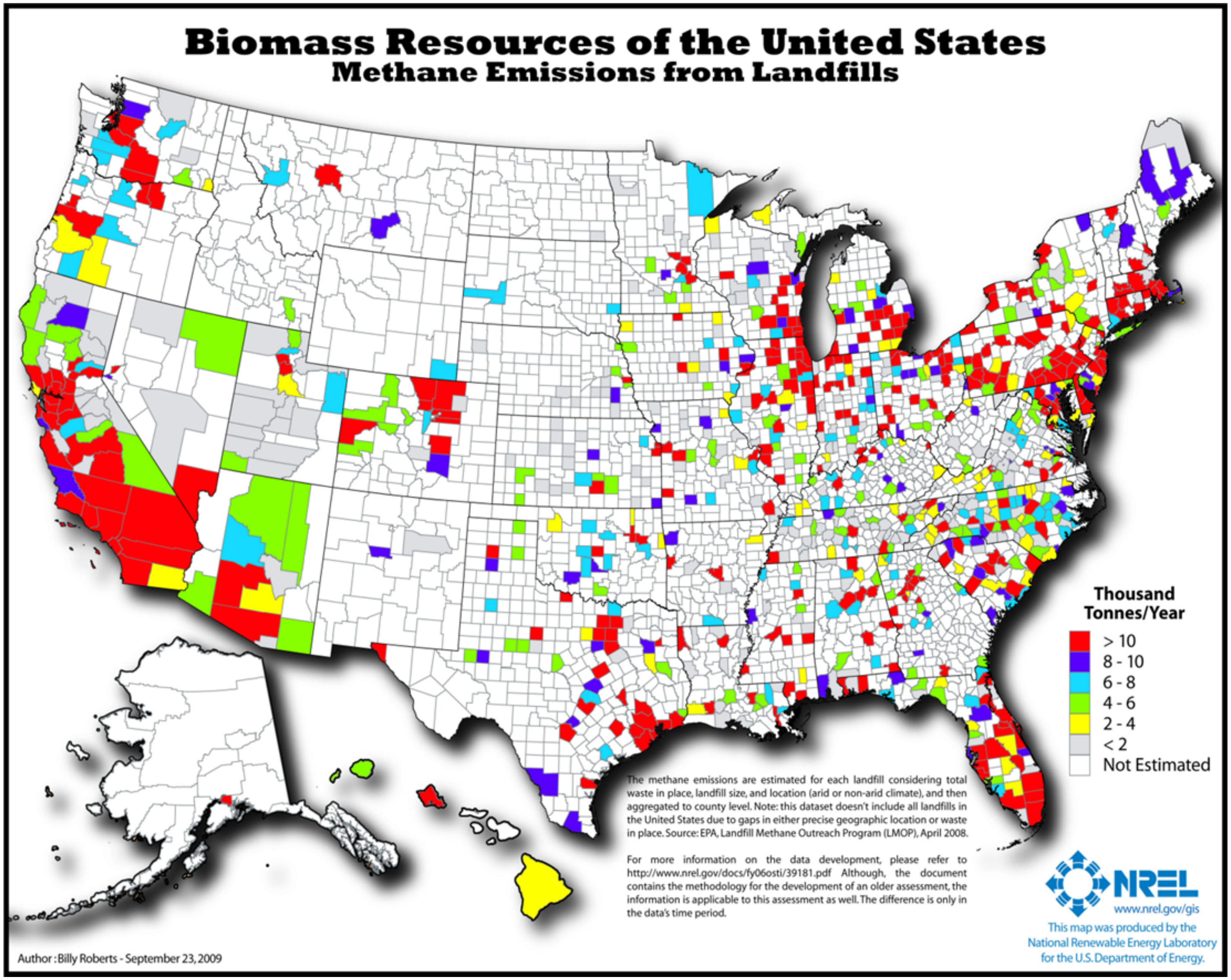


- As of July 2011, there are 558 operational LFG energy projects in the United States and approximately 510 landfills that are good candidates for projects

Source: EPA

Methane Emissions from Landfills

LFG methane exists in significant concentrations throughout the United States.



Source: GE Energy

Source: NREL

Current State of WTE

Over the last 15 years, the United States has been lagging in the WTE market. Western Europe and Asia Pacific have had the most exposure to the market

- There are currently more than 900 WTE plants in operation around the globe, producing more than 130 TWh of electricity from an estimated 0.2 billion tons of MSW
- There are several factors that could drive WTE technology to grow in the United States
  - Demand for energy-from-waste will depend on conversion efficiencies and also on the inability for new landfills to be expanded or new landfills to be constructed
  - Several government initiatives encourage domestic growth of WTE technology as a source of renewable energy
    - Tax credits, subsidies, GHG emissions restrictions, and renewable energy legislation are a few of those initiatives
- The market for WTE technology in the European Union (EU) varies significantly by country
  - In 2009, nearly 400 plants produced more than 30 TWh of electricity and 55 TWh of heat, enough to power eight million households
  - The Scandinavian countries and Germany have invested significant resources to WTE technology and are leading the EU
- WTE in the Asia-Pacific region is made up mostly of China and Japan. Combined, those nations generate nearly half of all WTE revenue in the world. It is expected that the Asia-Pacific region will continue to lead in WTE development through the decade
- The use of WTE technology for island nations is perhaps even more significant. The combinations of an abundance of seawater and a lack of fresh water and landfill space provides a perfect implementation scenario for a WTE plant
  - By using MSW to generate electricity, island nations can prevent the need for future landfilling and also provide cheap energy to power desalination plants. Desalination can be accomplished through reverse osmosis, powered by electricity, or through a thermal desalination process powered by heat energy

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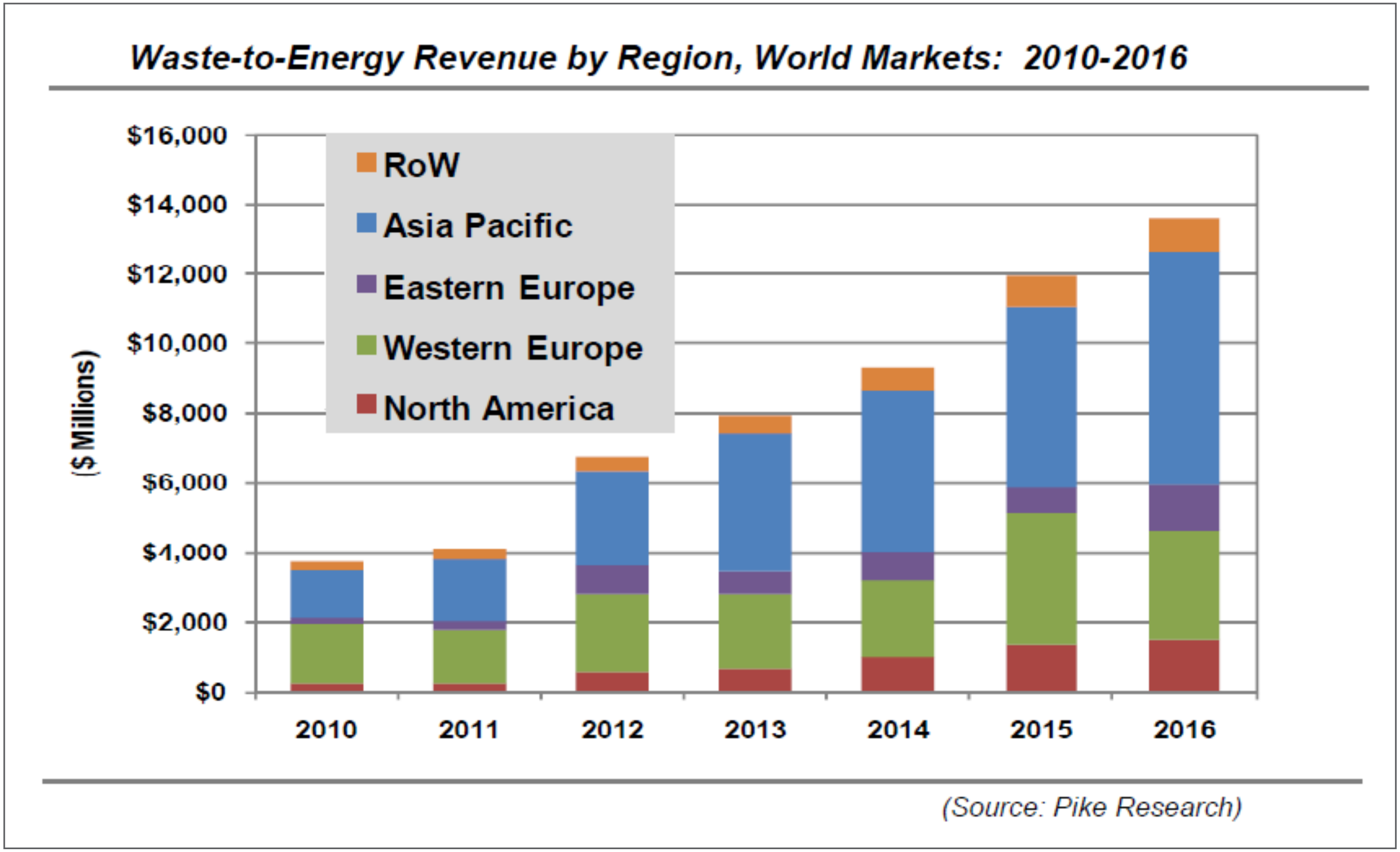
WTE Projected Revenue in the World Markets

WTE revenue is projected to grow over the next five years in the Asia-Pacific region.



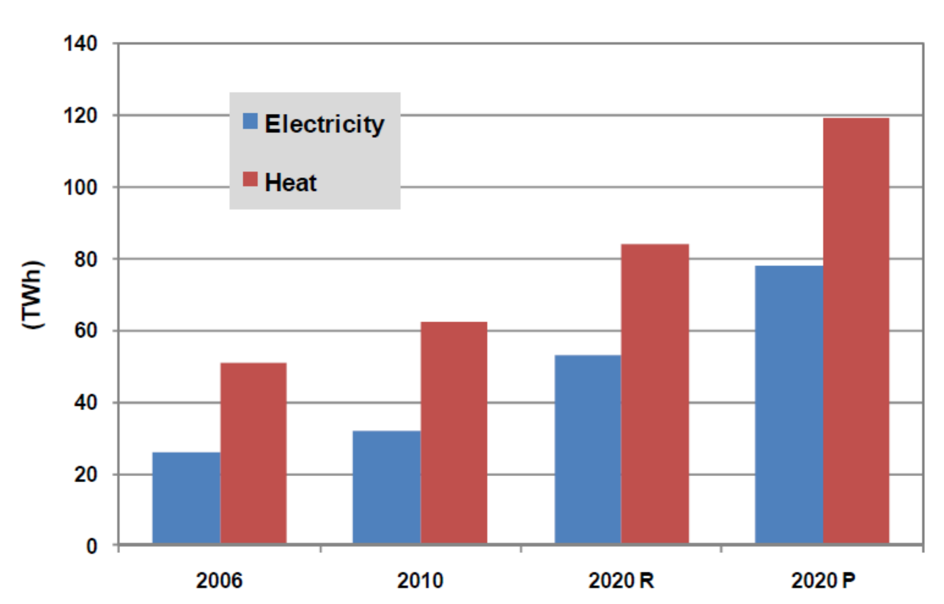
Source: Pike Research. "Waste-to-Energy Technology Markets," Columbia University report, April 2011

Increased Capacity and Future Growth of WTE

A range of factors will drive the demand for WTE technology through the next decade and beyond. The graph shows the realistic (R) and potential (P) output from thermal treatment of MSW through 2020

- Global demand for energy will continue to rise, especially in developing nations
- Global supply of MSW will continue to grow in line with GDP. Only a few countries around the world have been able to reduce MSW compared to GDP
- The world's non-renewable fuel sources are being depleted
  - Uncertainty of future availability of energy will lead to investment in alternative energy sources
- Governments are imposing policies and regulations to promote development of renewable energy technology and to reduce GHG emissions
- Proper investment in WTE technology has the potential to generate significant revenues in many parts of the world

Thermal Treatment MSW, Total Energy Output, EU-27:[2] 2006-2020



(Source: CEWEP)

Source: Pike Research. "Waste-to-Energy Technology Markets," Columbia University report, April 2011; ScottMadden research

Government Policies and Regulations on WTE Market

As with most renewables, incentives and governmental intervention are key growth drivers

- Due to the many negative effects of landfills, some governments are implementing landfill taxes, while others are banning landfills altogether
  - In the 1990s, the U.S. EPA enacted stricter air emissions standards on incinerators. This not only required WTE plants to reduce air pollution but also reduced non-WTE incineration
    - New incineration regulations also led to higher standards of disposal of ash and residue from WTE plants
  - The EU landfill directive limits the disposal of biodegradable waste in landfills
  - Landfill taxes encourage the use of WTE by increasing the cost of simply dumping waste
- Due to recent awareness of global climate change, many governments have enacted policies regarding the release of GHG emissions into the environment
  - With regard to waste management, the Intergovernmental Panel on Climate Change (IPCC) recognizes WTE as a GHG emissions-reduction process
  - According to IPCC projections, increased capacity of WTE plants could reduce emissions by 90 million tons CO_2 equivalent by 2020
- Many policies that promote investment in renewable energy technologies, including WTE technology, have been put into place
  - Federal government tax credits, stimulation packages, subsidies, etc. are awarded to both the private and public sectors for WTE investment
- Policies and taxes have been enacted in order to decrease our dependence on fossil fuels for energy

Source: ScottMadden research; IPCC reports

How ScottMadden Can Help

- ScottMadden has experience in the WTE area
  - We have evaluated Department of Energy projects for MSW feedstocks
  - We have performed detailed MSW feedstock (landfill) sustainability assessments
  - We understand the WTE value chain, including the markets and technologies within the value chain
- ScottMadden can provide assistance in the following areas:
  - Performing project due diligence
  - Assisting in development of a WTE strategy
  - Performing a feedstock analysis (feedstock sustainability and costs)

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