Association for Lansing Power and Heat Alternatives (ALPHA)

Environmentally Friendly Energy Alternatives for Milliken Station Lansing, NY

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OVERVIEW

Executive Summary

Lansing, NY has found itself in a difficult predicament. With the rise of unconventional fuel sources through the exploration of shale gas, energy fuel source prices have dropped. Coal, traditionally one of the cheapest sources of fuel, is being supplanted by natural gas. This has led to a significant decrease in energy production at Milliken Coal Station, which in turn has caused a drop in tax revenue for the town of Lansing. When the facility was fully operational, Lansing was receiving tax revenue from the electricity sales. However, the introduction of natural gas has reduced the operations of the facility, as coal is a less cost competitive solution for the electricity grid.

The town of Lansing is suffering the repercussions of a significant source of revenue. Most specifically, the Lansing School District, being public, must face budget restrictions due to the loss of revenue for the town. The heating and cooling costs are a substantial part of the operational costs of the facility. Therefore, the problem of lost revenue has the opportunity to be addressed in one of two ways: increase revenue by bringing Milliken Station back on line (this project specifically suggests using a green source) or decrease the heating and cooling costs at the school.

Team ALPHA (Association for Lansing Power and Heat Alternatives) has been tasked with exploring various possible solutions to this problem. We represent twelve students in the Master of Engineering program in Engineering Management at Cornell University. Three technological solutions were considered for phase I of the project: Combined Heat and Power with District Energy (CHP/DE), Biomass, and Waste-to-Energy (WTE). They were evaluated at a high level on three criteria: economic feasibility, environmental merit, and logistic feasibility.

After a short evaluation of all three technologies, the team made a thorough evaluation of the technology found to be optimal in the situation, WTE. We chose this technology after ruling out the other two, largely due to economical infeasibility for biomass, and logistical concerns regarding combined heat and power. WTE was chosen, as it appeared to potentially be cost competitive, could use existing infrastructure with minor capital investments for facility changes at Milliken Station, and has the additional environmental benefit of reducing landfilling of municipal garbage.

Excluded from this project was in-depth technical work around the facility itself, such as operating conditions like temperatures and pressures. Our mission was to use publicly available information as well as some primary interviews, in order to develop a cost model and economic evaluation, a logistical plan that covered fuel sourcing, transport, and disposal, and an environmental analysis that showed garbage to be ultimately competitive with coal in energy production.

In our following detailed analysis, we proposed a $68M repurposing of Milliken station for Waste to Energy Conversion at 140MW capacity, which leads to approximately 1.3 billion kilowatt hours of electricity produced per year. Over a twenty year period, the net present value of such a facility was estimated at just over $200M, breaking even in about ten years, with an internal rate of return at around 11.5%. This station will utilize the existing railway infrastructure, reducing the impact of garbage trucks on roads, as well as reducing carbon footprint due to reduction in usage of coal and the prevention of methane which would otherwise be produced by municipal waste at landfill sites.

Background and Motivation

The U.S. economy keeps growing moderately, but rising prices for energy products are worrying producers and consumers across the country. The total size of the energy market has been relatively stable; however, slight changes in the energy consumption structure, including an increasing supply of natural gas and decreasing demand in coal, has led to several economic opportunities related to alternative energy development in Lansing. From an energy sustainability point of view, we developed innovative technologies to decrease the impact energy production has on the environmental and to maximize the use of natural renewable resources. Our team analyzed the feasibility of implementing three alternative energy facilities: combined heat & power (CHP), waste to energy conversion (WTE), and biomass, to provide the best combination of an economical and ecological solution to the city of Lansing, NY.

Project Goals

The objective of this project assessed the technical and economic feasibility of alternative energy opportunities in Lansing, NY. Based on this main purpose, three possible approaches were used to achieve our goal of changing the source of energy production in Lansing.

Specifically, we aimed at repurposing the Milliken Station Plant and lowering the cost of energy for some major customers in Lansing. We conducted comprehensive feasibility analysis for three potential feasible technologies: Combined heat and Power and District Energy (CHP&DE), Waste to Energy Conversion System, and Biomass-fired Electricity Generation. We provided a recommendation and implementation plan specific to Waste to Energy. This suggestion may result in the reactivation of this facility, providing a valuable commodity to the local population and generating critical tax revenue to benefit the local government.

Gaps & Limitations

Given the expansive scope of this project, it is important to realize particular limitations in our analysis. Technical and economic evaluations were done rigorously, although assumptions based on future predictions are inherently uncertain. For example, crucial approximations for discount rates, technology efficiencies, and capital expenses are bound to change based on the implementation time frame of the project. In this regard, the team did its best to ensure that evaluations are representative of the technological and economic climate in which they ought to be carried out. The approach to replacing the AES coal plant ultimately laid on a subjective evaluation based on a prioritization of economic, environmental, and political factors. That is, our project is limited to highlighting the cost-benefit analysis within each realm of implementation, rather than positing one factor over the other to make an unequivocal decision. The main objective of this project was to consider alternative energy technologies currently in the market. This means that many relevant and effective systems such as natural gas have not been considered, although those systems may have benefits. Such a limitation was of course necessary to carry out the project—however, it is important to keep this in mind when significant conclusions are reached from the analyses.

Project Milestones, Deliverables, Time Table

As discussed above, there is clear motivation behind the repurposing of Milliken Station. Without a feasible alternative, the town will continue to suffer from the significant loss of tax revenue generated by electricity production. It is therefore paramount that a viable alternative be assessed and selected from the options of biomass, CHP/DE, and waste to energy.

Major milestones can be summarized in the following:

- **Assessed and gained understanding of three main technologies <u>9/20/12</u>**
    - Biomass

    - Combined Heat and Power with District Energy
    - Waste to Energy
- **Assessed infrastructure and needs of Lansing and nearby geography <u>10/5/12</u>**
    - Perform any economic and feasibility studies of technologies that appear promising
    - Determine population and demand growth potential
- **Defined most likely technology and perform advanced feasibility study <u>10/12/12</u>**
    - Determined economics and NPV of the repurposing project **<u>10/26/12</u>**
        - Capital investments
        - Construction costs
        - Energy price
            - Tax credits
        - Tax revenue generated by newly functioning facility
    - Determined logistical concerns of energy supply **<u>10/26/12</u>**
        - Materials sourcing distribution
            - Biomass source and transportation
            - Landfill waste resources
        - Energy and Heat (if applicable) distribution to local facilities
            - Local facilities that would primarily benefit (e.g. Cargill Salt Mine)
            - Current infrastructure and required improvements
        - Energy demand and fluctuations
    - Determined environmental impact of repurposing project **<u>10/26/12</u>**
        - Recycling or disposal of old equipment
        - Carbon and other emissions of new project over time compared to Milliken previously
- **Weighted costs and benefits <u>11/2/12</u>**
    - Check priorities of localities to properly weigh each criterion to see if this tech will meet town's interests
- **Made recommendation for implementation or pull out <u>11/9/12</u>**
- **Final Presentation <u>11/15/12</u>**

Team Composition

Members

Michelle Chau is a Master of Engineering candidate in Engineering Management at Cornell University graduating in December 2012. She completed her BS degree in biological engineering with a minor in biomedical engineering. Her research experience consists of studying cancer cell migration in microfluidic devices. In her research group she conducts literature reviews and data analysis for publications and presentations. Her other work experience includes managing the supply chain for a retail business. She has had some knowledge with bioenergy but has not studied renewable energy extensively.

Hwan Choi studied Operations Research as an undergraduate student in Cornell University and he is now a candidate for master of engineering, concentrating on engineering management. The highly technical program required Hwan to obtain both quantitative analytical skills and qualitative thinking skills. He is familiar with manipulating and working with datasets from coursework and projects that requires simulation modeling and analysis. As an intern analyst in the infrastructure team of Macquarie Capital, Hwan participated in acquisition and divesture transaction of a company that owns combined heat and power plants. Throughout the project, he was able to pick up basic knowledge about CHPs and power market trends. With two years of experience in ROK-US Combined Forces Command and internship experiences, Hwan knows what is required as a part of a team. Due to the interest in the resource and energy industry, Hwan is looking forward to the technical and economic analysis to optimize the performance of CHP in Lansing.

Benting Hu is a Masters of Engineering candidate in Engineering Management winter at Cornell University graduating this winter. She acquired her BS degree in material science and engineering. Her undergraduate research was focused on developing new environmental friendly composite material and bio-medical material. She also has working experience in finance institution, marketing and retailing. She joined the waste energy team and will bring her knowledge to both economical and technical field of this project.

Joshua Lazoff, 22, is getting a Masters of Engineering degree in Engineering Management and will be graduating May 2012. His undergraduate studies are in Information Science, Systems and Technology from Cornell University.

Molly McDonough completed her Bachelor of Science in Mechanical Engineering at Cornell University in May 2012. She is currently working towards a Master of Engineering in Engineering Management at Cornell, and will graduate in May 2013. She is looking forward to this opportunity to apply past experiences and gain new ones related to sustainable energy.

Sandra Quah has a bachelor’s degree in Materials Science & Engineering from Cornell University, and is pursuing a master’s in Engineering Management at Cornell University to be completed in winter of 2012. Her undergraduate focus was mainly in the semiconductor industry, and she has done research in the field of thin films and rapid thermal processing equipment. In addition to these, Sandra is interested in the merging of business and technology, particularly in how technology can be used to increase efficiency in business operations, and the impact that new technologies can have in our day-to-day lives. Beyond work, Sandra is involved in a Christian fellowship at Cornell, and enjoys singing, playing guitar, reading tech blogs, and eating good food.

Kartik Shastri is a Master of Engineering Management Student concentrating in Energy Systems. As an undergraduate student at Cornell University, Kartik graduated with a B.A. in Economics and Asian Studies and a B.S. in Materials Science & Engineering. Kartik has a passion for energy technologies, working specifically with renewables in both lab and industry settings. Based on his academic and industrial experiences, Kartik runs a blog on our energy future at theenergetic.wordpress.com.

Justin Steimle has a bachelor's degree in Materials Science and Engineering with a minor in business that he earned at Cornell in May, 2012. He will be graduating in December with a Master of Engineering degree in Engineering Management. Justin has worked in operations as an intern for L'Oreal and as a business development analyst for Novomer Inc, and hopes to one day start his own tech based company.

Wan Hua Xie is currently pursuing her Masters degree in Engineering Management with an anticipated graduation date of December 2012. She is doing her functional specialization in Energy Systems Management. This past May, Wan received a B.S. degree in Chemical Engineering with a minor in Biomedical Engineering. In her free time, she enjoys playing volleyball, traveling, and reading a good book.

Marrisa Yang received her Bachelor of Science in Operations Research and Information Engineering at Cornell University in May 2012. She is continuing her education at Cornell, and is expected to graduate with her Master of Engineering degree in Engineering Management in 2013.

Martin Yu graduated as an Environmental Engineer in May 2012 from Cornell University, and is now pursuing a Master's degree in Engineering Management at Cornell University. He is interested in the business area as well and obtained a minor in business when he was an undergraduate student. He took the solid waste engineering course and has knowledge on waste-to-energy systems. He is very excited to be part of this project team, and he hopes to learn more about alternate energy systems through participating in this research project.

Jordan (Dan) Zhao completed her bachelor's degrees in Biotechnology and Economics in Jinan University, China. Jordan is currently working towards her Master degree of Engineering Management at Cornell and is expected to graduate in December of 2012. She interned at Pfizer China this past summer and developed data collection and analysis for sale and distribution activities by using spreadsheet modeling. She will apply her technical and economic knowledge to this project.

Skills Matrix

Table 1: Skills Matrix of Team Members

Skills and Knowledge	Engineering-related	Business-related	Energy Technology- related	Computer-related
Martin Long	B.S. in Environmental Engineering	Minor in Business	Waste-to-Energy	General: Word, Excel, Powerpoint; Coding: MATLAB,
Justin Steimle	B.S. in Materials Science Engineering	Minor in Business, Business Development Internship	n/a	Office Suite, MATLAB, Mathematica, basic
Molly McDonough	BS in Mechanical Engineering	Entrepreneurship class, and other current management courses	Sustainable design intro to engineering, survey of green	Office Suite, MATLAB, ANSYS, SolidWorks, ProE, Labview
Josh Lazoff	B.S. in Information Science, Systems and Technology	n/a	n/a	5 years of coding experience
Benting Hu	B.S. in Materials Science Engineering	Minor in Business, Intenship in Bank-risk management, marketing	Waste-to-Energy	Word, Excel, Powerpoint, Access
Hwan Choi	B.S. in Operations	n/a	Combined Heat and Power Plant	Word, Excel,
Jordan Zhou	B.S in Bioengineering	Dual Degree of Economics	Biomass	Word, Excel, Powerpoint, Project
Kartik Shastri	B.S. in Materials Science & Engineering	B.A. in Economics, Consulting experience	Energy Systems coursework, internships in alternative energy	Office, MATLAB, VBA, Mathematica
Michelle Chau	B.S. in Bioengineering	Courses in finance and supply chain	Bioenergy	Word, Excel, Powerpoint, MATLAB
Marrisa Yang	B.S. in Operations Research	Courses in finance and accounting	n/a	Word, Excel, Powerpoint, Java, Matlab, SQL
Wan Xie	B.S. in Chemical Engineering	Program Management internships	Waste-to-Energy	MS Project, Word, Excel, Powerpoint; MATLAB; Java;
Sandra Quah	B.S. in Materials Science & Engineering	Courses in accounting, electronic commerce	n/a	Word, Excel, Powerpoint, Matlab, Mathematica, JAVA

Organizational Structure

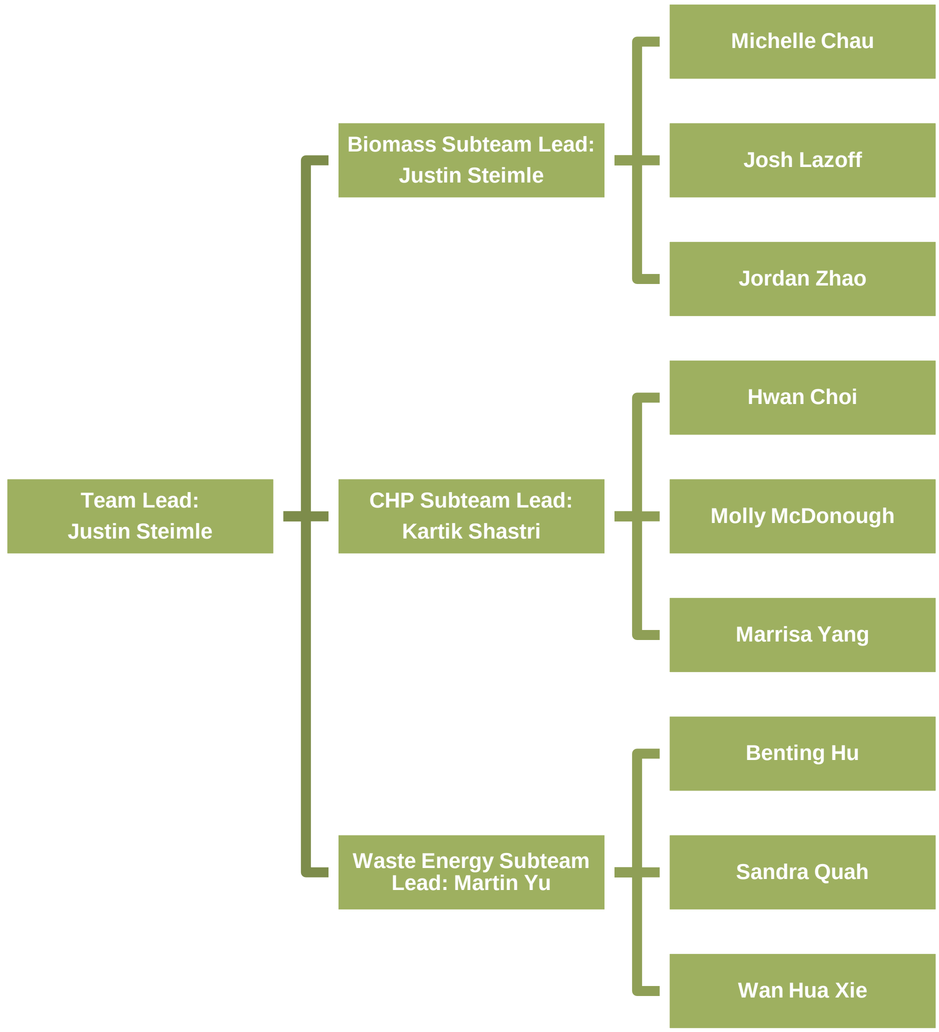


Figure 1. Phase 1 of Team Structure

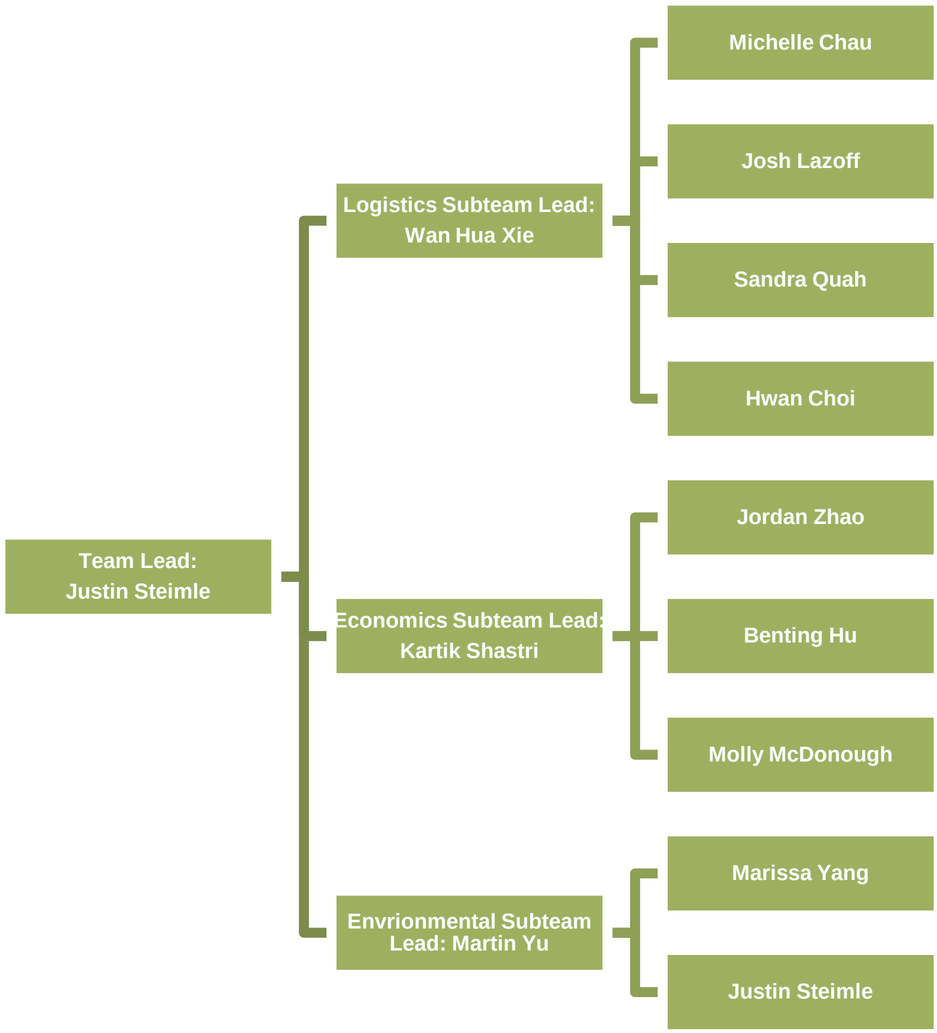


Figure 2. Phase 2 of Team Structure

Literature Review

Introduction

Milliken Station, a coal plant located in Lansing, New York, has ceased operation as of 2012, with the possibility of being permanently decommissioned. Our team has investigated three possibilities to repurpose the facility in order to continue to supply the local town with electricity, potentially with a partnership with the local school district and nearby Cargill Salt Mine. Repurposing this plant into a working facility will fill the gap in income tax revenue left after the coal plant shut down, supporting the needs of the town.

Below are our preliminary findings, discussing three potentially feasible technologies: Biomass, Combined Heat and Power with District Energy, and Waste to Energy Conversion. We discuss the technologies involved for each, as well as the scoping and logistical and distribution requirements for the operations of these types of facilities.

Biomass

Introduction

Biomass is a carbon-based organic material composed of molecules; primarily containing hydrogen, oxygen, and nitrogen. Biomass can be categorized as ‘old’ or ‘new’, the former being the fossil fuel more typically known as crude oil, and the latter being made of renewable sources such as wood, crops, animal waste, landfill gas, alcohol fuels, hemp, poplar, willow, sorghum, switchgrass, and sugarcane, with wood being the most popular. Even industrial waste can sometimes be used.

Emissions produced by biomass are negligible if harvested appropriately, done by retaining the CO_2 produced by combustion in new plants. This is accomplished by rerouting the CO_2 towards growing crops, which absorb the gas and are subsequently used in the facility as biomass as well, yielding no net CO_2 footprint. This use of CO_2 uptake by growing plants throughout their lifecycle creates a closed loop system [8]. Producing renewable energy through biomass has been a studied alternative energy system in the United Kingdom for some time [21], and has been steadily growth in Korea [12].

Methods of Conversion

Direct combustion is the simplest way of obtaining energy by releasing it in a form of heat also known as CHP. A variety of thermodynamic processes can be used to convert part of this heat into electric power. In contrast to its ease of use, due to that fact that the fuel is not pre-processed, it contributes greatly to pollution, proving its inefficiency and placing direct combustion as a poor alternative for the environment.

An alternative to direct combustion is known as co-firing, which is seen as the most cost-effective approach. Co-firing was first introduced as a way to support wood products and agricultural industries, reduce fossil fuel CO_2 emissions, and reduce nitrogen airborne emissions. This method has several technological options. In one, small amounts of biomass, which is only just a bit cleaner than using exclusively coal, can be mixed with coal before being input into the coal boilers. However, this approach may cause problems if the type of biomass and its particle size interferes with the coal burning.

A second approach with co-firing is separately preparing the biomass and subsequently firing it in the boiler. This is known as co-firing with separate injection. This method also requires special attention to the size of the biomass and fuel preparation. The last approach for co-firing is gasification based. This method is the most flexible in terms of the base fuel it accepts, overcoming the challenges mentioned above in the other two co-firing methods [20].

Re-powering is when a previous coal plant is converted into a full biomass firing facility. Biomass gasification involves heating biomass under pressure with a small amount of oxygen and converting it into a mix of hydrogen and carbon monoxide called syngas. This gas can then be run through a gas turbine or burned and run through a steam turbine to create electricity [60].

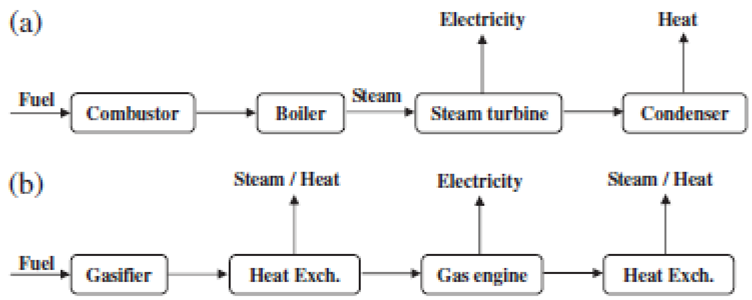


Figure 3: Direct combustion vs. co-firing of biomass [12].

Anaerobic digestion utilizes microorganisms to break down biomass in a controlled environment to produce the greenhouse gases methane and carbon dioxide. Used to process sewage, animal manure and landfill waste, this biomass production method uses the resulting methane for heat and power and this prevents the methane from leak into the environment [60]. An alternative model would allow for the co-firing of waste materials with biomass, a practice that exists already with coal.

Existing Infrastructure

Biomass sources are both numerous and plentiful. Existing industries like forestry already have the capability of producing the necessary fuel, and would clearly benefit from an increased demand for their product. Additionally, products and waste could be harvested from local agricultural sources. Given the surplus of food in the United States, especially corn and soy, biomass conversion may serve as a viable use for this product [8]. Finally, the primary landfill gas, methane could be harvested from nearby landfills, taking a otherwise wasted greenhouse gas created by microorganisms and turning it into usable fuel. This would directly compete with the simple Waste-to-Energy Plant described above which would negate the production of methane by pulling its fuel sources from the landfill.

Current Biomass Operating Plants

The Arabale Biomass Renewable Energy Power Plant (ARBRE) is located in Selby, Yorkshire. It was the United Kingdom's first wood fuelled gasification electricity plant. It was supposed to produce 10 MW of electricity and export 8 MW of it to the local grid. The plant required 40,000 dry tons, which was collected within a 400 mile radius. However, the plant did not survive due to technical and financial reasons [21].

On the other hand, a successful plant in the United Kingdom was the Elean Power Station (EPS), located in Ely, Cambridgeshire. It is currently the world's largest straw-fuelled power station in operation. It has a capacity of 38 MW and an annual requirement of 200,000 tons of straw that is collected from farmers in a 50 mile radius. It currently generates 270 GWh per year [56]. Its development was first rejected due to concerns with pollution, visual impact, traffic pressure, and noise, environmental, and landscape impacts. The developers addressed this issue by revising their proposal to target the public's concerns. It is now up and running without any conflicts and has a good relation with the local people [21].

Currently in the United States, the New Hope Power Partnership has a biomass power plant located in Florida. This plant has a capacity of 140 MW and uses sugar cane fibers and urban wood as fuel. It can supply electricity for nearly 60,000 homes [57].

Gaps & Limitations

As with every new technology, there are gaps and limitations with it. Biomass co-combustion is the most effective way of supplying energy. Biomass is burned in combination with fossil fuels. Therefore, existing fossil fuel systems have to be modified. To be efficient, biomass must be dried and pelletized, which leads to additional costs. If the pellets are not small or fine enough, the combustion will be ineffective. In addition, energy companies have to be convinced biomass value chain are profitable and sustainability can be managed. Thus, public awareness of biomass as a renewable energy source must be raised. Also, we need to know how the future demand for biomass for energy conversion will change, its future role, and its availability and cost. The cost of burning biomass is usually greater than for fossil fuels. At a larger scale, the use of biomass could threaten food security and induce climate change. There is a limit to the extent that biomass can contribute to energy needs. The efficiency of biomass currently can only satisfy about 5% of the global energy consumption. However, only a certain amount of energy crops grown at a time and they have a long mobilization lead-time. Therefore, if additional energy is needed, it will most likely come from crops for food. This would threaten food security if too much is taken for energy production, limiting the crops for the food market.

Combined Heat and Power/ District Energy

Introduction

Combined Heat and Power (CHP) plants are more efficient than traditional electricity and heat generation methods because they generate both heat and electricity simultaneously. In traditional power generation, nothing useful is done with the heat produced as a byproduct of electricity production. CHP uses this heat in two ways: through distribution as another useful energy, and to produce more electricity and heat. Due to these built in efficiencies, this system lowers emissions and saves resources because less fuel is needed to meet the same population’s energy needs.

District Energy (DE) is a term that refers to any energy system that produces thermal energy at a central plant and is then distributed as steam, hot water, or chilled water to customers. This is desirable over the current separated heating or cooling systems because of improved efficiency, reliability, and convenience. The heat generated by the power production is preserved, and there is no need for each person to have his own boiler and furnace, which can malfunction and need replacement. Questions may remain, however, regarding reliability and cost competitiveness with more conventional systems.

Technology

CHP

There are different types of power generation technologies that can be used for CHP. The two most common types are gas turbines and steam turbines. With gas turbines, the plant uses fuel such as natural gas to generate electricity and produce heat as byproduct of power generation. After producing electricity using a gas turbine, steam generated in the heat recovery steam generator of the gas turbine drives a steam turbine to further produce more electricity and heat. With steam turbines, electricity is produced as a byproduct of heat, rather than heat being the byproduct. Steam turbines do not directly convert fuel to power. The heat energy is produced in the boiler and transferred to the turbine as a form of steam to generate electricity. Steam turbines can be operated with various types of fuels including all types of coal, wood, and others.

This initial review focuses on these two common types (steam and gas turbines) because they are the only types that can produce a similar output capacity to what is needed at Milliken Station [18]. Steam turbines are also the only type of production method in widespread use that can operate on coal, so this method may require the least change to the existing Milliken coal-fired plant. However, we are not considering coal as a feasible option due to the current economic climate. In addition, the cost of a CHP system is relatively high on a per kW of capacity basis, an important factor to consider [42]. Another important point to consider is that the heat produced by CHP systems is not only useful in the winter for heating, but can also be utilized in the summer by absorption chillers to power the cooling systems.

Basic Components: Steam Method

The basic components of a steam turbine-based CHP system are the boiler, steam turbine, and condenser. The boiler is the heat source of the CHP system that converts water to high pressure steam by burning fuel. Water is pumped into the boiler and heated, and energy in the form of heat goes to the steam turbine. Electricity is then generated in the multistage steam turbine. The turbine is composed of stationary sets of blades, which are called nozzles, and moving sets of adjacent blades called rotor blades. Stationary blades accelerate the steam to high velocity by expanding it to lower pressure. Rotor blades change the steam flow, which creates force and generates power as an output. Then, low-pressure steam is condensed back into liquid form. The water is mixed with “feed water” and pumped back to the boiler. Steam turbines are reliable, efficient, have a long working life, and their power to heat ratio can be changed as needed.

Basic Components: Gas Method

The basic components of the gas turbine based CHP system are the gas turbine and the heat recovery exchanger. This gas turbine produces the electricity, and the heat exchanger converts the high temperature exhaust into a usable heat form. There is possibly also an intermediate step in which a steam turbine captures this heat, recovered from the exhaust, to produce more electricity. This adds to the expense, but raises the efficiency of the plant. Gas turbines also have fairly low emissions, do not require cooling, and are very reliable. Both gas turbines and steam turbines have benefits and drawbacks.

District Energy

The district heating network of pipes transports heat produced at the plant directly to the consumer to be used in the building. Insulated pipes are laid as a pair of supply and return lines. Each pipe has a leakage detection sensor arranged in loops which are linked to a geographic information system to allow prompt detection and repair. Unfortunately, due to heat loss when transported over a large distance, this option is not possible for the Milken Energy Plant, placing it out of consideration.

CHP Metrics

From an economic perspective, CHP has the ability to outperform many conventional technologies, due to its systems approach to generating electrical and thermal energy simultaneously. Channeling heat from the combustion step into a district energy setup allows for an increase in both efficiency and cost savings. The economics of CHP generation can be broken down into installed capital & infrastructure, operating & maintenance costs, and resource & fuel costs. Although the exact economic calculations vary, an average of $.06/kWh is a legitimate result [6]. This result is very competitive with electricity prices which hover around $.07/kWh for the industrial sector [19]. Additionally, the installation costs in such an analysis can be greatly reduced if the CHP generation plant is being built in place of an existing facility, as system remodeling can be very cost effective.

The benefits from CHP are not limited to the economic factors. Environmental improvements are a significant reason for much government support of the technology. The fundamental ability of CHP systems to capture otherwise waste heat and remove the boilers for thermal generation results in specific emissions reductions. In evaluating the annual CO_2 emissions of a CHP generation system, the EPA found that an average of 525g CO_2 are generated per kWh produced [27]. Contrasting this with 1020g CO_2/kWh from fossil-fuel plants, the environmental improvement is clear, showing a nearly 50% reduction in CO_2. Moreover, the transition to a CHP-based energy generated economy garners further environmental support, as a large portion of the United States' stock of boilers will be depleted over the next decade [10]. Combining this factor with the economic incentive to remodel an existing facility, CHP becomes a viable option from the standpoint of performance metrics.

Current CHP/DE Operating Plants

Examples of CHP and DE can be traced as far back as 1893, when a German town hall was heated via steam that came from a nearby power plant [71]. CHP/DE expansion continued throughout West Germany, with an increase from 20 plants to 36 during 1933-1938 [43]. However, the next jump in CHP development didn't occur until the late 1950s, which was concurrent with the expansion of new housing developments; the existing CHP/DE networks were used in delivering heat to the new residential areas [7]. The energy crisis of 1973 led to a government investment of $750 million for expansions in CHP/DE four years later in 1977 [13].

Along with Germany, Finland has also been using CHP/DE to generate energy. Termia Oy developed a plant in Lisalmi that sells the electricity it produces to Atro Group (the parent company of Termia Oy) and heat to local customers [68]. After conducting a feasibility study in 1997, Termia Oy decided to start construction in 1999, and the plant began commercial operation in 2002[8], generating 14.7 MW of electrical output and 30 MW of DE.

However, Europe is not the only place where CHP/DE is being utilized. Harbin Power Engineering Ltd. and Uzbekenergo have signed a contract for modernizing the Angren Combined Heat and Power Plant in the Tashkent region of Uzbekistan, which currently provides electricity for both industrial facilities and the residents in the surrounding region [21]. Countries in East Asia have been investigating the potential of building combination heat and power (BCHP), or CHP designed for commercial buildings such as offices and hotels [12]. Although BCHP has only just started to appear in China, with a total of seven buildings using BCHP in Beijing and Shanghai, it has a strong presence in Japan where it has been used in over 1000 cases [20].

Gaps & Limitations

Similar to the biomass technology, there are also gaps and limitations with the CHP technology. Many CHP systems utilize natural gas, which is not a renewable source of energy. In terms of cost, CHP systems may have a longer payback period of 7-15 years, depending on whether or not the system can produce enough electricity to export to a grid. CHP systems are also less responsive to seasonal fluctuations and changes in the amount of energy required. For example, they are likely to produce excess heat during summer months. This heat can be used in an AC or cooling system. An important thing to consider is turbine specific limitations. Gas turbines require highly pressurized gas (or an in-house gas compressor). Microturbines have relatively low mechanical efficiency. Steam turbines can utilize a variety of fuels, but are often slow to start up and have low power to heat ratios. Reciprocating engines can be used in place of turbines; however, they also have high maintenance costs and an increased level of air emissions. Reciprocating engines are also limited to the use of cogeneration applications at lower temperatures.

Waste-to-Energy

Introduction

The global waste-to-energy (WTE) industry has been growing substantially in the past decade. It was shown that the WTE capacity increased by about 4 million metric tons per year from 2001-2007 [18]. However, the WTE industry in the US has not followed this global trend. In 2007, only 13 percent of the 250 million tons of municipal solid waste generated in the country was burned [42]. Up till March 2012, there were only 86 WTE plants operating in 24 states across the US [6]. In order to understand the current situation of the WTE industry in the US and in the world, we researched this energy generation method, focusing on its technological, economical, and environmental aspects. We also decided to closely investigate and study a few currently operating WTE plants.

Technology

WTE generates energy from waste through the use of combustion and biochemical technologies. The main and most dominant WTE technology is mass combustion. This technology is popular because of its simplicity and relatively low capital cost [19].

It involves aerobic combustion of waste, making it more useful as fuel. Thermal and biological technologies are the new technologies made available in recent years. Thermal technologies produce heat, fuel oil or syngas from both organic and inorganic wastes, while biological technologies produce fuel by bacterial fermentation of organic wastes [27].

WTE facilities fall into two general categories: mass-burn and refuse derived fuel (RDF). Mass burn facilities burn waste without significant pre-processing (Figure 1). On the other hand, RDF processes convert MSW into a type of fuel by removing materials with low heat values (glass, metals, and organics) and then shredding the remaining waste [10]. This creates a fuel with uniform characteristics, which can then be burned on site or transported (Figure 2). Currently, the most popular WTE technology is mass burning because of its simplicity and lower capital cost.

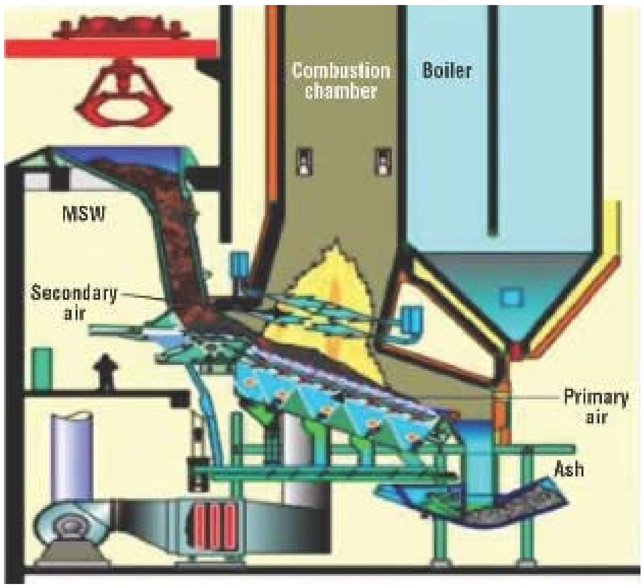


Figure 4: Schematic diagram of mass-burn combustion chamber in Italy [19]

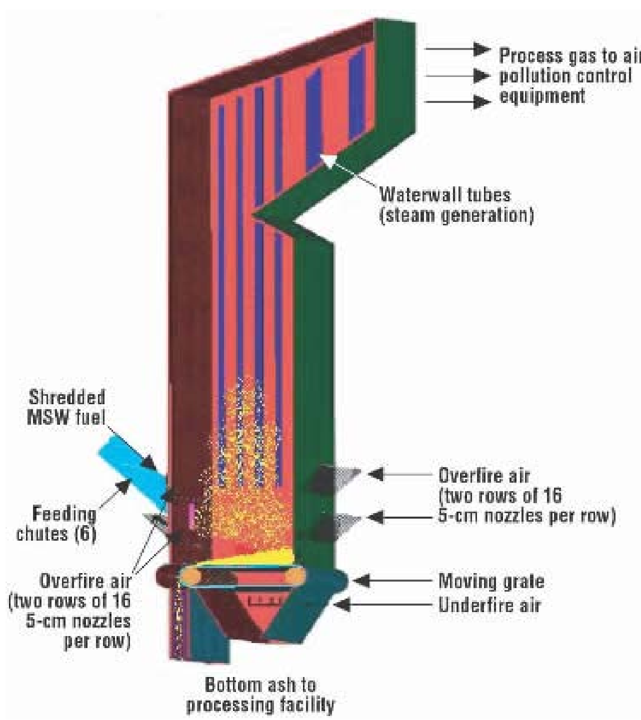


Figure 5: Schematic diagram of RDF-type process [19]

Many different processes are used in the combustion phase of WTE. For instance, in the US, moving grates or rotary kilns are common. The moving grate consists of a grate on an incline where combustion takes place, while the waste in rotary kilns is incinerated in a rotating chamber. In Europe, fluidized bed boilers are more common, which combusts pre-processed waste on a bed of hot sand and ash. There is constant airflow from beneath the bed, which keeps the waste moving and allows for more complete combustion [10]. Heat is recovered by conduction through the walls of the combustion chamber and from the flue gas from combustion. This heat can then be used to produce steam, which drives a turbine and generates electricity.

The removal of emissions from the flue gas is very important. After heat recovery, the flue gas passes through air pollution control methods using electrostatic precipitators and fabric filters to remove particulate matter. The combination of fabric filters and dry scrubbers can remove 99% of the HCl, 95% of the SO2, and 90% of the mercury from the flue gases [10]. Nitrogen oxides are removed by using Selective Catalytic Reduction (SCR), which adds ammonia to the flue gas and can remove 70% of the NOx emissions [10].

Economic Overview

An average WTE plant generates about 550 kWh per ton of waste [71]. The revenue per ton of waste would be about $20 to $30, assuming a price of four cents per kWh [71]. One of the major costs associated with WTE plant is the capital costs required to build the plant. It costs about $110,000 to $140,000 per daily ton of capacity [71]. In addition, employees, materials, supplies and ash disposal would also add to the operating costs of WTE plant.

The economic benefits generated by WTE plant include the energy generated, the tipping fees paid by communities, and recycling of materials such as metals. The rising of energy costs and offering of federal production tax credit recently have further enhanced the incentives of companies to expend the capacity of their currently existing WTE plants and to build new ones [71].

Environmental Impact

Solid waste combustion produces nitrogen oxides, sulfur dioxide, hydrogen chloride, carbon monoxide, particulate matter, ashes, and highly toxic pollutants like mercury compounds and dioxins. Furthermore, since WTE plants use water in boilers and in cooling, discharging this water to surrounding fresh water can harm aquatic habitats [71].

Although WTE plants were listed by the US EPA as major sources of mercury and dioxin/furan emissions in the late 1980s, the US WTE industry has spent over one billion dollars in upgrading its pollution control system since then. In addition, EPA has implemented the federal Maximum Achievable Control Technology (MACT) regulations, and has significantly cut down the emissions of toxic pollutants by the US WTE facilities such as dioxin. In 2002, EPA estimated that the total annual dioxin emission rate from all WTE facilities in the US was less than 12 grams, in comparison to 550 grams emitted by backyard barrel burning [43]. Recently, the EPA has confirmed that WTE plants in the US have less environmental impact than most other sources of electricity [19].

Despite the reductions in emissions achieved by WTE plants, there is still opposition from some environmental groups in the US. They are unaware of the environmental benefits of WTE, and that the disposal of MSW into landfills also creates a potentially large environmental impact. Landfills have a potential to contaminate adjacent waters, and emit biogas produced by anaerobic digestion [19]. Modern landfills do try to collect their gaseous emissions. However, the number of gas wells provided is limited, resulting in only a fraction of the biogas being collected. The biogas contains about 54% methane and 46% CO_2 [19]. This usage results in 1.32 tons of CO_2 per ton of MSW that is not captured (calculated based on the global warming potential of methane) [19]

Though fear of emission is a legitimate concern, transporting trash to landfills in faraway locations is expensive, and results in heavy fuel emissions. A WTE plant could severely reduce these emissions through localized trash collection to the plant. A study from the 2009 E.P.A study found that even landfills which collect methane to produce electricity ("landfill gas to energy" or LFGTE) emit about twice as much climate-warming gas as WTE plants per kWh. In addition, landfills produce methane, which is 21 times more potent as a greenhouse gas than the carbon dioxide released in the WTE process. The EPA also states that "the greenhouse gas emissions for WTE ranges from 0.4 to 1.5 $MTCO_2eq/MWh$, whereas the most aggressive LFGTE scenario results in 2.3 $MTCO_2e/MWh$. WTE also produces lower NOx emissions than LFGTE, whereas SOx emissions depend on the specific configurations of WTE and LFGTE". [7] The comparison of LFGTE, the current direct alternative to WTE, demonstrates that investing in WTE would be beneficial to reducing human impact on the environment.

Currently Operating WTE Plants

The Covanta Onondaga WTE plant is located at Jamesville, New York. This 39 MW plant operates 24 hours per day, 7 days per week [13]. It combusts about 350,000 metric tons of waste and generates about 220,000 to 225,000 MWh per year. It generates 630 kWh per metric ton of waste combusted [13].

The WTE plant had an agreement with National Grid in which the National Grid had to pay a floor price of $0.06 per kWh for the electricity generated by the plant until 2009 [13]. The cost of the WTE facility was approximately $140 million, and the total financing for the project was $178 million [13].

For every ton of nonhazardous solid waste processed at the WTE, a nominal 1 ton of carbon dioxide is prevented from entering the atmosphere, and 1 barrel of oil is saved for each ton of solid waste processed [13]. The facility is a "zero discharge" plant, with no wastewater discharged to the surroundings other than the sanitary discharge from restrooms and showers [13]. The plant injects anhydrous ammonia and activated carbon into the furnace to control NOx and mercury emissions respectively. It also installs acid gas scrubbers with the baghouse to meet federal and state air emission limits [13].

The plant was awarded Gold for the 2012 Excellence Awards from the Solid Waste Association of North America (SWANA). The award aims to recognize outstanding solid waste facilities that enhance environmentally and economically sound solid waste management with the use of effective technologies and processes [68].

Gaps & Limitations

There are gaps and limitations with the WTE technology as well. WTE emissions are regulated under the federal Clean Air Act and the Resource Conversion and Recovery Act. Therefore, certain permits are required. Federal and state regulations enforce emission limits for sulfur dioxide, hydrogen chloride, nitrogen oxides, carbon monoxide, particulates, cadmium, lead, mercury, and dioxins. Resource Conversion and Recovery Act requires testing of the plants' ash residue to ensure that it is properly disposed of and not hazardous. States often have even stricter environmental limits on the facilities than the federal government (i.e. stricter emission limits and additional regulations for solid waste management, recycling, noise, site selection, transportation, water use, and water management). Although the EPA has confirmed that WTE plants in the U.S. have less environmental impact than most other sources of electricity, there is still opposition from some environmental groups in the US. These sentiments pose a potential problem for the construction of new plants within the US. Support for WTE plants will be low if energy prices and landfill disposal costs are low. Landfilling is cheaper except in cases where the MSW must be transferred long distances, due to the added transportation costs [7]. However, landfilling is not sustainable, and the amount of land lost to landfilling has grown substantially over the past 50 years.

Analysis

Biomass

Economic Analysis

The following assumptions were made in the economic analysis for the renewable energy alternative biomass. The plant would operate at a 50 MW capacity continuously. Thus, it would generate approximately 1.2 million kWh/day. Since biomass has an energy content of 6 kWh/kg [44], the plant would need 220 tons of biomass daily for combustion. This yields 80,335 tons/year and 2.9 tons/hectare of biomass [31]. Therefore, if forest residues were to be used, 107 square miles of forest would have to be cleared each year. In addition, the biomass technology has only 35% efficient electricity conversion and the cost of fuel is $35/ton [41]. In total, there would be a yearly cost of $2.8M/year for feedstock. Other costs include ash disposal, which is 1% of the feedstock cost [41]. The CAPEX of the plant would be approximately: $4264/kW * 50000kW = $213M CAPEX for the stoker boiler. A stoker boiler of 50 MW would match the capacity of the plant [41]. Operations and maintenance costs are 3% of capital expenditure (mid-range) and there is a 10% discount rate for biomass facilities [41]. The electricity can be sold to the grid for $0.041/kWh [32]. Income would be taxed at 2.35% [62].

The analysis does not account for other capital expenditures related to the conversion of Milliken Station. It also does not cover transmission inefficiencies, potential pricing fluctuations, feedstock pricing charges and possible limited capacity usage at the facility.

The following figures summarize the breakeven analysis and economic feasibility of using biomass as the alternative renewable energy source. A 300 MW plant analysis is also shown for comparison.

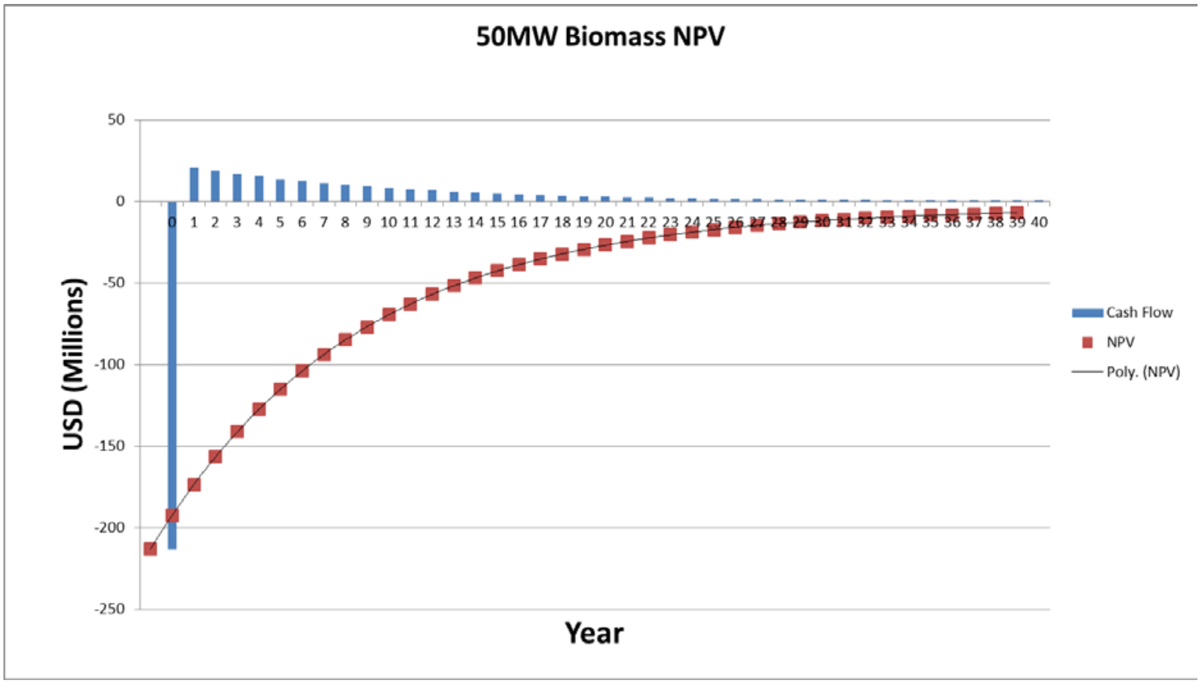


Figure 6. Breakeven Analysis for a 50 MW Biomass Facility

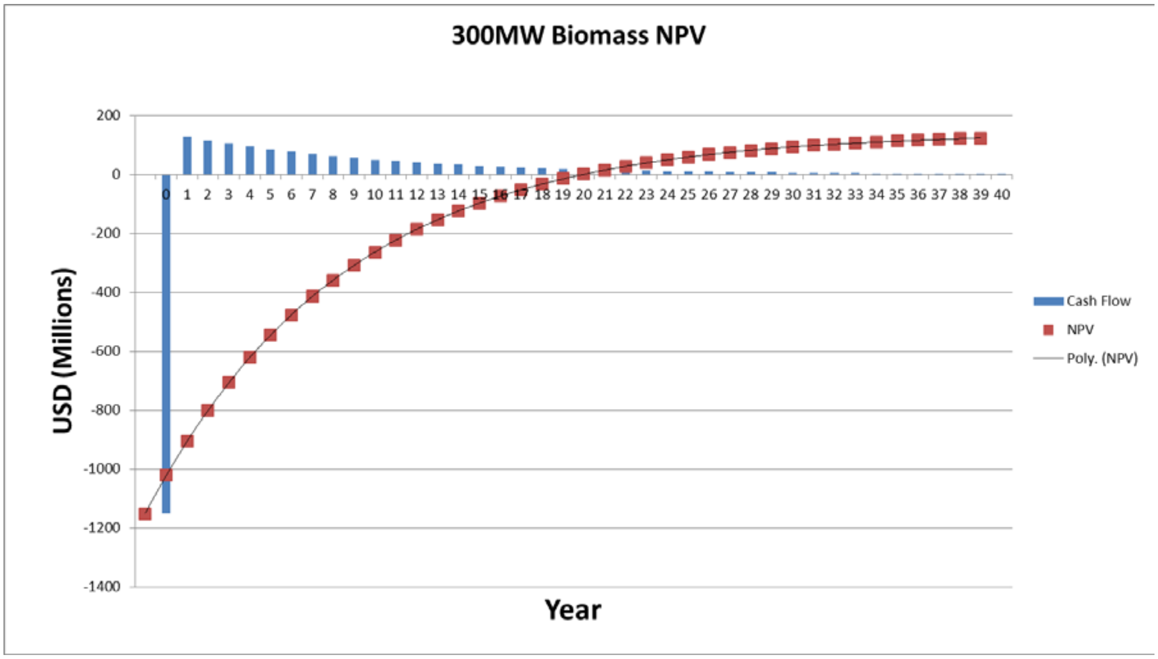


Figure 7. Breakeven Analysis for a 300 MW Biomass Facility

BIOMASS Economic Feasibility

	revenue	fuel and ash	O&M costs	cash flow	NPV
0				-213.2	-213.2
1	30.66	-2.828	-6.396	20.932254	-192.26775
2	30.66	-2.828	-6.396	18.8390286	-173.42872
3	30.66	-2.828	-6.396	16.9551257	-156.47359
4	30.66	-2.828	-6.396	15.2596132	-141.21398
5	30.66	-2.828	-6.396	13.7336518	-127.48033
6	30.66	-2.828	-6.396	12.3602867	-115.12004
7	30.66	-2.828	-6.396	11.124258	-103.99578
8	30.66	-2.828	-6.396	10.0118322	-93.98395
9	30.66	-2.828	-6.396	9.01064898	-84.973301
10	30.66	-2.828	-6.396	8.10958408	-76.863717
11	30.66	-2.828	-6.396	7.29862567	-69.565091
12	30.66	-2.828	-6.396	6.56876311	-62.996328
13	30.66	-2.828	-6.396	5.91188679	-57.084441
14	30.66	-2.828	-6.396	5.32069812	-51.763743
15	30.66	-2.828	-6.396	4.7886283	-46.975115
16	30.66	-2.828	-6.396	4.30976547	-42.665349
17	30.66	-2.828	-6.396	3.87878893	-38.78656
18	30.66	-2.828	-6.396	3.49091003	-35.29565
19	30.66	-2.828	-6.396	3.14181903	-32.153831
20	30.66	-2.828	-6.396	2.82763713	-29.326194
21	30.66	-2.828	-6.396	2.54487341	-26.781321
22	30.66	-2.828	-6.396	2.29038607	-24.490935
23	30.66	-2.828	-6.396	2.06134747	-22.429587
24	30.66	-2.828	-6.396	1.85521272	-20.574374
25	30.66	-2.828	-6.396	1.66969145	-18.904683
26	30.66	-2.828	-6.396	1.5027223	-17.401961
27	30.66	-2.828	-6.396	1.35245007	-16.049511
28	30.66	-2.828	-6.396	1.21720506	-14.832306
29	30.66	-2.828	-6.396	1.09548456	-13.736821
30	30.66	-2.828	-6.396	0.9859361	-12.750885
31	30.66	-2.828	-6.396	0.88734249	-11.863542
32	30.66	-2.828	-6.396	0.79860824	-11.064934
33	30.66	-2.828	-6.396	0.71874742	-10.346187
34	30.66	-2.828	-6.396	0.64687268	-9.6993141
35	30.66	-2.828	-6.396	0.58218541	-9.1171287
36	30.66	-2.828	-6.396	0.52396687	-8.5931618
37	30.66	-2.828	-6.396	0.47157018	-8.1215916
38	30.66	-2.828	-6.396	0.42441316	-7.6971785
39	30.66	-2.828	-6.396	0.38197185	-7.3152066
40	30.66	-2.828	-6.396	0.34377466	-6.971432

Figure 8. Biomass Economic Feasibility for a 50 MW Facility

Conclusion

It is questionable whether a biomass facility of this size using local wood sources as a feedstock could have a positive NPV. Although this analysis contains many assumptions, which makes this alternative appealing, it seems that a biomass facility is not the best option economically. A 50 MW facility will take more than 40 years to break even. A 300MW facility may show slight potential at a long time frame of approximately 20 years, though this is still highly questionable. Initial capital expenditures are estimated at 90% cost/kwh of 50MW facility based on data extrapolation. Changes in our assumptions would drastically change the number of years to breakeven.

CHP/DE

Economic Analysis

The following twenty year economic analysis of combined heat and power with district energy (CHP/DE) evaluated the expenses the system has and the profits it makes, and calculated the NPV and IRR. A NPV of $158,820 was found and an IRR of 14%. The expenses and profits for the system are highly dependent on its production capacity so the necessary capacity was calculated first.

The production capacity was calculated based on how much heat the Lansing schools would need, since the project's primary motivation was to help the school district afford their operating costs. The capacity was determined using data on their heating needs for the past two years, indicating a use of 9700GJ of heat annually. An efficiency of 55% for heat production and 26% efficiency for electricity production were assumed due to typical values of representative CHP systems [22]. These efficiencies with a heating need of 9700GJ necessitate 17,640GJ of gas; which produces approximately 1,274,000kWh of electricity. Using these values along with a gas price of $8 per GJ and electricity cost of $0.08 per kWh; the annual gas expenditure is approximately $141,100, a gas cost savings to the schools is of $77,600, and an electricity income is of $101,900. The gas cost savings to the school does not take into account the extra gas they would need to purchase due to inefficiencies in their boilers. They spend an average of $111,500 on gas; 80% of the amount the schools would save on gas was included in the NPV calculations. Next, the installation and maintenance costs were calculated for a CHP system of this size by using an installation and purchasing cost of $85,000 per turbine. Three turbines would be needed to generate enough heat, so the total installation cost would be $255,000. The maintenance cost of 2% of electricity output was anticipated, equaling $25,500 annually.

The electricity produced would be sold to the Cargill salt mine to meet their ongoing energy needs. To estimate the electricity need two different methods were used. For the first method, the energy used by US salt mines overall was found, and the amount of salt capable of being mined using that energy. Next, how much salt is currently being mined at the Cargill salt mine was found. Their electricity need was calculated by assuming that their ratios of salt mined to overall salt mined would be the same as their ratio of electricity used to overall electricity used. This method estimates their electricity usage to be around 1,060TJ per year; which would mean that only 0.43% of their energy needs can be covered. This indicates that we would not even come close to being able to supply a substantial part of their electricity.

The cash flow from the fuels and the school heating cost savings were calculated next. This was done using an expected increase in energy prices of 3% per year. The cash flow from fuels for the first year was simply the amount made through electricity sales minus the amount spent on gas; for every subsequent year, the previous year's cash flow was multiplied by 1.03. The same process was applied to the school heating cost savings with the first year simply being 80% of their average expenditure: $89,200. Using this data, along with the installation and maintenance costs, the net annual cash flow was calculated for the next twenty years. The net cash flow and a discount rate of 7% yielded the NPV value of $158,800 that was stated previously. The IRR was also calculated from the net cash flow to be 14%.

Conclusion

These values do not take into account the added installation costs of the DE piping network to the schools or the amount of heat that would be lost in transport from the power plant to the schools. There are extremely good piping technologies now that can transport DE up to 26 miles; so the heat lost may not be substantial. Unfortunately, the better the piping purchased, the higher the initial startup costs. Figuring out what piping would be best for this project, what path we would put it in, and what heat would be lost over this distance on average would be a significant undertaking. However, because CHP/DE is not the best option without these added expenses, further analysis was unnecessary. Waste to energy was found to be a better option from both economic and environmental perspectives.

WTE

Scenarios

We investigated two different scenarios, one in which we convert and refit Milliken Station and the second in which we build a completely new plant. Scenario 1 results in a lower capital investment by keeping existing equipment that can be used, such as boilers, turbines, generators, condensers, and all appropriate filtration systems for air pollutants. Only new equipment needed to handle the extra demands of a WTE facility such as a waste dumping floor, additional filters for pollutants, and extra ash collectors need to be purchased. Essentially, we will convert the 300MW coal power plant to a 140MW WTE plant. The plant will process on average 3500 tons of waste per day, transported using the existing Norfolk Southern rail lines that previously transported coal to the facility. For Scenario 2, we assumed that all equipment will be replaced and took a conservative estimate for NPV calculations. We also looked into different location choices for this scenario.

WTE Logistics

Energy Content

New York State Department of Environmental Conservation estimates 33 percent of solid waste generated in the NYS are paper, which takes the largest portion. Organic wastes such as food scraps and yard trimmings take 23 percent, and plastics, including plastic bottles and film plastics, make up 13 percent of waste generated. Wood, glass, metals and textiles each takes about 5 percent of the solid waste. Durables that are composed with dissimilar materials in a single product such as electronics and diapers take 13 percent of waste produced in the New York State.

U.S. Energy Information Administration categorizes municipal solid wastes into two large sections: biogenic and non-biogenic components. Biogenic wastes indicate paper, textiles or wood, and non-biogenic ones are plastics or rubber. Non-biogenic components of the waste contain 23MMBtu of heat in a ton, which is about twice more energy than the biogenic components that contains 11.1MMBtu of heat per ton (EC Table 1) [45].

One ton of solid waste contains about 12MMBtu of heat. Due to the large portion of paper in solid waste, 34 percent of heat comes from paper. Plastics and durables each produce 20 percent of the heat, and organic wastes make up 10 percent. Metals and glass contribute very small portion of the heat generated. Textiles and wood produce 10% of the heat (EC Table 2) [38].

Table 2: Heat Content of Biogenic and Non-biogenic Materials

Biogenic	Heat content (MMBtu/ton)	Non-biogenic	Heat content (MMBtu/ton)
Newsprint	16	Rubber	26.9
Paper	6.7	PET	20.5
Containers	16.5	HDPE	19.5
Textiles	13.8	PVC	16.5
Wood	10	LDPE	24.1
Food Waste	5.2	PP	38
Yard trimmings	6	PS	20.5
Leather	14.4	Other (plastic)	18.1
Average	11.075	Average	23.0125

Table 3: Percentage of Heat and Waste

	Waste %	Heat (MMBtu)	Heat %
Paper	33%	4.3	34%
Glass	4%	0.0	0%
Plastics	13%	3.0	24%
Metals	5%	0.0	0%
Organics	23%	1.3	10%
Textiles	6%	0.8	7%
Wood	4%	0.4	3%
Durables	12%	2.8	22%
Total	100%	12.6	100%

Transportation

Delivery to Site

Waste transportation will be done by railway to the waste-to-energy facility. The sources of waste will largely be from New York City and Binghamton, as both produce large amounts of waste (an average of about 11,000 tons/day) and are conveniently located along the Norfolk Southern freight train lines. Images of the Norfolk Southern lines reaching New York City and Binghamton are below in Figure T1 and 2.

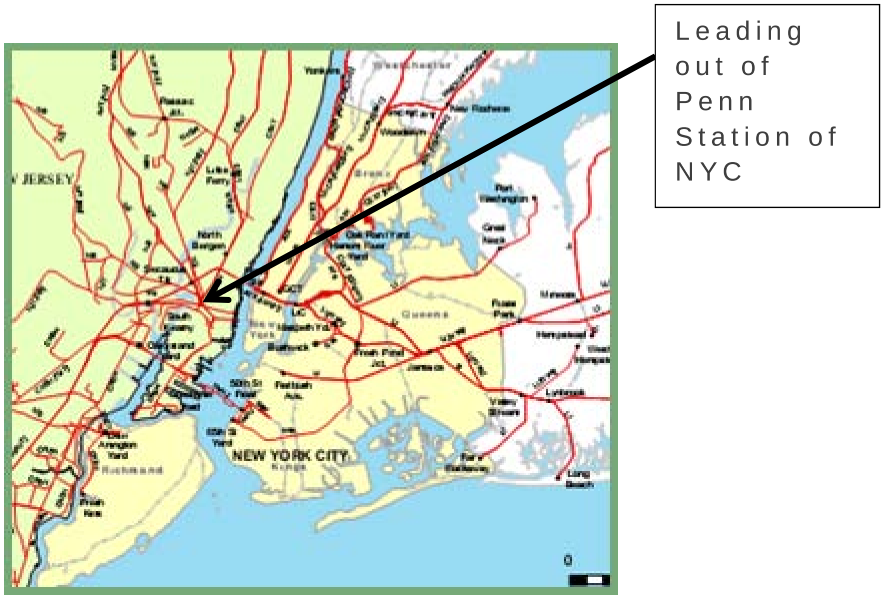


Figure 9. Norfolk Southern lines run from New York City north to upstate New York.

Figure 10. Norfolk Southern freight train lines also run directly from Binghamton to the Milliken Station.

Ash Disposal

As a byproduct of the WTE process, ash, which is about 25% of the original waste by weight, must be disposed of. There are two types of ash: non-hazardous ash, and hazardous ash. Non-hazardous ash is bottom ash, which can be sent to the Seneca Meadows Landfill as normal waste at a disposal cost of $100/ton. This type of ash is not harmful to the environment, and is used typically in construction and as a landfill covers [33]. Bottom ash usually composes 75 to 90% of total ash produced by WTE [58]. Hazardous ash tends to have higher concentrations of metals and organic materials, and as a result requires special disposal [58]. In order to address this requirement, the WTE fly ash will be deposited at a special monofill at Seneca Meadows Landfill at the same disposal cost as bottom ash. These two types of ash are sometimes combined to create a more stable and safe ash to deposit and their mixture is also sometimes used as a daily cover in landfills instead of soil. Only 10% of bottom ash is being reused in the United States, but as the public becomes more accepting to the idea of WTE, this number will grow, decreasing the cost of ash disposal [33].

WTE Economic Analysis

Cost Analysis

The cost analysis includes two scenarios; one to convert the Milliken plant to WTE and another to construct brand-new WTE without affiliation to original Milliken except the location. The total cost is made up by initial investment of WTE and ongoing operating and maintenance cost. Based on the cost analysis of comparable WTE facilities in other countries, we scale the cost in terms of difference between the capacity of WTE in our case with the recently established WTE plant in the Republic of Croatia (Zagreb).

As we discussed in the part of logistics analysis, the capacity of WTE plant is to process 3500 tons of waste per day. The capacity of electricity generation is 140MW. WTE capacity in terms of TPD of waste processes is around 12 times than the one in the reference of WTE in Republic of Croatia.

Initial Cost

Investment costs could vary with respect to several factors: design of the WTE plant based on its capacity, existence of the local infrastructure, and the possibility for selling of energy.

It is necessary to construct road infrastructure, weighing area, and waste reception storage. Estimated cost of $68,184,408 includes costs of construction of the access roads and the foundations for waste storage. The combustion system with steam generator is estimated to be $173,425,560 million for the scenario 1 because the existing equipment such as generators, boilers, and condensers could be leveraged into new system. For scenario 2, all the equipment would be replaced. The cost of scenario 2 is estimated to be $289,042,601.

The water and steam system consists of a water treatment facility, air cooled condensers, and turbines. For scenario 1, we assume no costs associated to this system because all the components in water and steam system presently exist. Also, no expense on the construction under the scenario 2 is considered.

The total cost of components of the WTE plant without the cost of gas cleaning system are analyzed including costs of design, construction, electro-mechanical installations and other investment cost is given in the Appendix 1.

The investment costs of gas cleaning system

Cleaning of gases plays an important part of the overall waste combustion process. The selection of the technology for gas treatment depends on gas composition, emission limit value, local conditions (water supply, waste water treatment, etc), and estimation of operating and investment costs. In our case, the wet treatment of gas is taken into consideration. The wet system consists of a wet flue gas treatment system, electrostatic precipitator, and selective catalytic reduction system. The detailed breakdown of the costs is shown in the Appendix 1.

Operating and Maintenance Costs

The maintenance costs of the combustion system and the steam generator are proportional to the waste flow. The annual maintenance cost is estimated at 4% of total investment cost for scenario 1, because the maintenance frequency and fee for existing equipment is higher than that of scenario 2, which is 3% of the total investment. The cost of emission fee for CO_2 is determined by annual quantity of CO_2 per ton of waste, which is discussed further in Environmental Analysis. The choice of wet treatment allows a relatively lower cost of emission fee to that of bag filter system. The cost of reagents to filter other waste gases is listed and calculated in the Appendix 2. Labor cost assumes that the WTE plant will work 24 hours a day in three shifts, seven days a week. The personnel of WTE plant include workers, engineers, maintenance, and managers. The payment for the personnel in US is twice that of the payment in the Republic of Croatia; this is relevant as we used the Croatian estimates as a base and thus require a scaling factor to make particular values relevant. That is, in our case, the annual cost of labor is estimated to be $32,870,814.

To sum up, the total costs of operating and maintenance under the two scenarios are $67,956,080 and $74,211,258 respectively. From another perspective, the O&M of scenario 1 is 69 USD/ton, whereas it is 75 USD/ton in the case of scenario 2. The decomposition of the O&M expense is displayed in the Appendix 2.

Revenue

The revenue generated by a WTE plant can be mainly categorized to three groups: electricity, tipping fee, and metal recovery. The calculation is based on the assumption that the prices for goods sold are constant without inflation. The biggest portion comes from the tipping fee which constitutes $69.5 million of the total income. Electricity is another main source of revenue; $54.8 million is gained given constant unit electricity price. Lastly, metal recovery brings $8.3 million benefit to the total income.

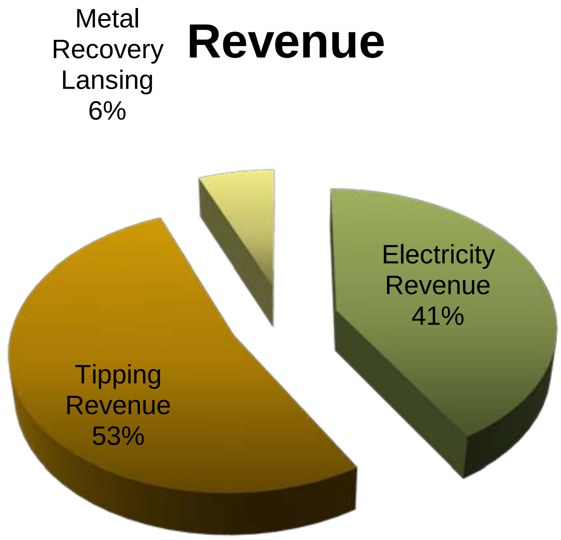


Figure11. Revenue breakdown

Electricity Revenue

Based on the capacity of WTE plant, around $1 billion kWh of electricity will be generated each year. We assume the unit price to be $0.052/kWh based on the average price of the electricity sold to grid around the Lansing area; thus $54,754,424 revenue will be generated by plant each year.

Tipping Fee

According to the assumption, about 1 million tons of waste will be processed through the WTE plant. The average tipping for waste to energy is much higher than landfill, but differs greatly from region to region. We assume $55/ton to be competitive with $60/ton provided by SMI. The total revenue from the tipping fee is $69,535,719.

Metal Recovery

The metals come from 5% of the total waste by weight. About 52,568 tons of metal are sorted each year. The metal recycling profit is $7.2/ton, yielding $8,352,411 total income profit.

Uncertainty

In our economic model, there are multiple parameters for which assumptions and approximations have been made to reach a conclusive result. However, due to the uncertain behavior of these parameters, it is important to reflect our results as a range based on such variation. For the purpose of our analysis, the goal is to highlight key factors within the project that contribute to the success of the project, or lack thereof. Thus, we do not explore uncertainty in discount rate, inflation, and other financial terms, although these exist and can influence our model to a great extent.

Instead, we look to the three differentiated revenue streams and the associated uncertainty in each to properly model total revenue. In each input stream (electricity revenue, tipping revenue, and metal recycling/recovery revenue) we identify the source of uncertainty and model the parameter as a random variable using a probabilistic analysis package called Risk Solver Platform for Excel. In electricity revenue, the price of electricity is the term most subject to fluctuation with regional prices varying up to $0.07 USD/kWh in some cases. As outlined in the revenue section above, the mean electricity price we assume is $0.041 USD/kWh and model the random variable as a normal distribution with standard deviation $0.005 USD/kWh. In the case of electricity revenue, there is the additional component of tax credits from the Production Tax Credit (PTC), which is included in our model.

Revenue collected from accepting waste is the largest component of total revenue, and the uncertainty in this input arises from the tipping fee parameter. Again, we use a normal distribution to create a random variable for such a price; the variable has a mean of $55 and standard deviation of $3. The final revenue stream created from recycling metal waste contains a degree of uncertainty based on the variation in the percent of total waste that is available for recycling. The mean value of 5% for this parameter is normally distributed with standard deviation 1%. The table below summarizes each random variable in our model.

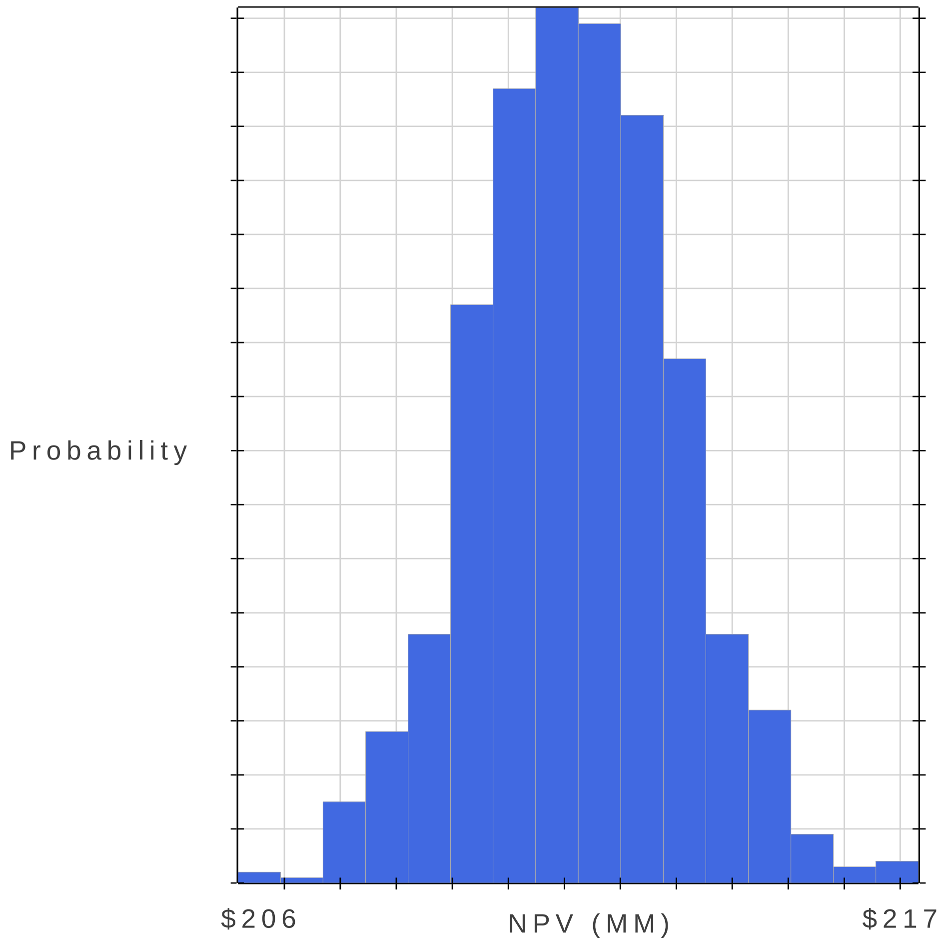
Table 4: Random Variables in Economic Model

Variable	Type	Mean	Standard Deviation	Coefficient of Variation
Electricity Price	Normal	$0.041	$0.005	12.2%
Tipping Fee	Normal	$55.00	$3.00	5.5%
% Recovered Metal	Normal	5%	1%	20.0%

Results Analysis

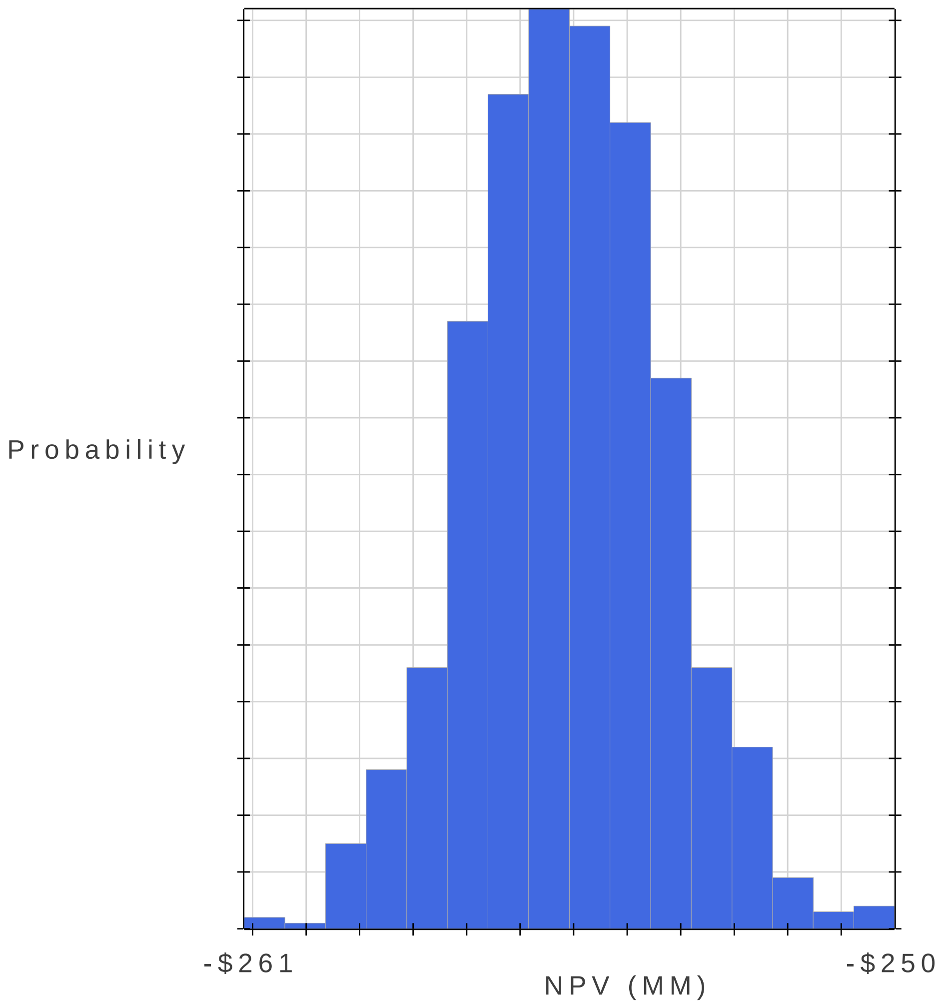
Our economic feasibility analysis was performed using the Risk Solver Platform Simulation Tool. The model was simulated 1000 times to reflect the varying parameters discussed above. The result indicating variables that we model are net present value (NPV), internal rate of return (IRR), and breakeven years. These results are simulated for both the repurposing project as well as the new plant project; we first display the repurpose situation. Figure 14 below is the resulting probability density function (PDF) of the repurposing project's NPV over 1000 trials, with the frequency of each range is indicated as well:

Figure 12: Repurpose Simulated NPV PDF



We can contrast this result with that of the new plant situation. The viability of this project seems to be threatened by a much lower mean NPV and a distribution in which positive value is rare. Figure 13 shows the PDF of the NPV for constructing a new WTE plant.

Figure 13: New Plant Simulated NPV PDF



A separate approach to understand the viability of these projects was to conduct a breakeven analysis using a simply payback model. This allows a direct comparison of the capital costs and annual profit under each situation to tabulate a time period in which the project is expected to recover the capital costs. The results for the breakeven analysis for each scenario are also simulated and are tabulated along with the NPV and IRR results in the table below. As these are based on repeated trials, the given values are a 95% confidence interval for each result. Though there is a high standard deviation for all of the results, the confidence interval is narrowed due to the large number of simulated trials.

Table 5: Results Indicating Economic Feasibility

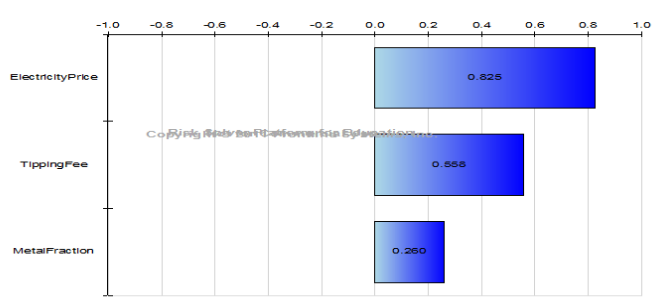
Scenario	NPV (Discount Rate = 7%)	IRR	Break even Years (Simple Payback)
Repurpose	$(206 MM, 217 MM)	(11.27, 11.47)%	(9.48, 9.64)
New Plant	$(-261 MM, -250 MM)	(3.21, 3.39) %	(18.93, 19.29)

Sensitivity Analysis

To best understand the variation in these results, we conduct a sensitivity analysis based on the three random variables, which is shown in the figure below:

Figure 14: Repurpose Sensitivity Analysis

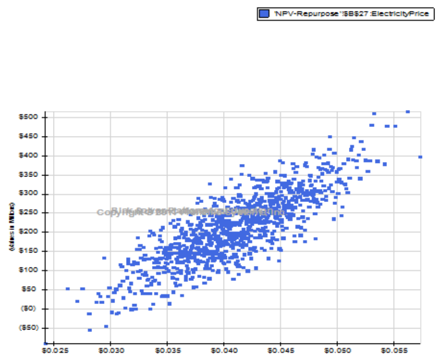
Sensitivity of outcome

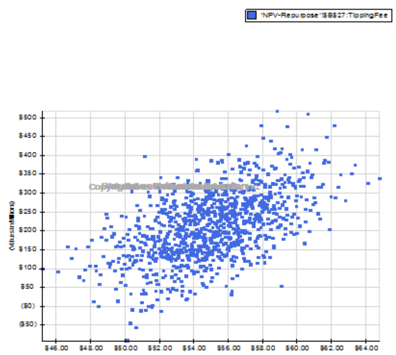


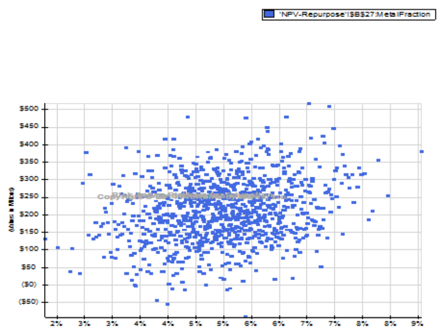
From the above displayed graph, the value of 0.825 for sensitivity of outcome in relation to the random variable clarifies that the uncertainty in electricity place is the factor that contributes the most to variance in NPV results. This defined value represents the variance in the expected value for NPV due to the input variable. The requisite conclusions can be drawn by comparing the magnitudes of the graphed values. The importance of electricity price is primarily because of the high coefficient of variation in the electricity price in comparison to that of tipping fees. Though the fraction of metal recycled for revenue also contains a great deal of uncertainty in relation to the precise percentage, the overall revenue generated from this stream is much less than the others. The uncertainty from electricity plays the most important role in defining the range of NPV, followed by uncertainty in tipping fees and the fraction of metal recovered.

A useful way to represent the cause for the results from this sensitivity is to graphically isolate the variation in NPV due to variation in each parameter. Figure 15 displays scatter plots of NPV for the repurposing situation versus each of the three revenue parameters discussed above.

Figure 15: Scatter Plots of NPV versus (a) Electricity Price, (b) Tipping Fees, and (c) Fraction of Metal Recovered







These scatter plots show the impact of variance across each factor, with the scatter plot for electricity showing the most direct linear trend. A positive trend is expected for all of the variables as increasing any of the parameters will directly lead to an increase in NPV. That being said, these plots display the results of all 1000 simulation in which all three parameters were being changed. Thus, the ability for electricity price to show a clear trend despite variation in the other two variables is an indication of its importance.

Though these results are of the sensitivity analysis conducted for the NPV in the repurpose scenario, they directly reflect the sensitivity of our other calculated results as well. This is because the NPV in the new plant scenario and breakeven years for both scenarios, are all similarly based on the total revenue. These three parameters are ultimately important since they sum to total revenue. A sensitivity analysis was conducted on the other three results and functions in the same manner. The only exception to this is that the impact of variance of the parameters functions in the opposite direction on breakeven years than NPV. This is of course due to the fact that an increase in revenue decreases the time period required to recover capital costs for the project. Put differently, the values for variance in outcome due to the three input variables are identical for NPV and IRR in both scenarios. On the other hand, the magnitude of variance in breakeven years due to the three variables is the same as that of NPV and IRR, though these values are negative; NPV and IRR increase with revenue, whereas breakeven years decrease with revenue.

Appendices 3 and 4 contain full details regarding the results from the economic analyses for the repurpose and new plant scenarios respectively.

WTE Environmental Impact

In this section of the report, we will discuss several topics: the types and impact of pollutants generated by WTE to our surrounding environment, the technologies used by to control pollution, the estimated net carbon footprint of the WTE facility compared to that of the Milliken coal-fired plant, and the potential environmental benefits and recycling opportunities that WTE can bring.

Pollutants

The technology for WTE has significantly improved in recent decades with the implementation of the Clean Air Act [70] and the federal Maximum Achievable Control Technology (MACT) regulation [46], leading to dramatic reduction of all emissions. In 2003, the EPA stated that WTE now produces electricity with less environmental impact than almost any other source [70]. However, it is still essential to know about the type and impact of pollutants generated by the WTE to our surrounding environment.

Air Pollutants

Waste combustion produces acid gases such as sulfur dioxide, hydrogen chloride and hydrogen fluoride. These gases are produced by burning sulfur, chloride, and fluoride-containing wastes. It is estimated that the average air emission rate of sulfur dioxide in the US from municipal solid waste-fired generation is about 1.2 lbs/MWh [52]. All these gases, especially sulfur dioxide, can cause respiratory problems to humans if they are inhaled [35][29][30]. In addition, they cause acid rain, which will damage metal and limestone structures as well as harm aquatic organisms in open waters [35][29][30].

Waste combustion also produces nitrogen oxides when nitrogen-containing wastes are burned. It is estimated that the average air emission rate of nitrogen dioxide in the US from municipal solid waste-fired generation is about 6.7 lbs/MWh [52]. Nitrogen oxides, similar to the acid gases listed above, can cause respiratory problems to humans and form acid rain when dissolved in atmospheric moisture [25]. In addition, they can react with volatile organic compounds (VOC) under sunlight to form smog, which damages human lungs as well [34]. Furthermore, they react readily with common organic chemicals to form toxic products such as nitroarenes and nitrosamines [16].

Heavy metals, including cadmium, chromium, mercury, and lead, may be present in the exhausted gas from the WTE facility. The presence of these heavy metals in the exhausted gas may be due to combustion of waste containing electronics, batteries, and ceramics. Health risks associated with cadmium include kidney damage and increased possibility of bone defects and fractures [5]. Exposure to mercury can cause neurological damage and death [5]. Consumption of high levels of lead can lead to serious toxic effects on the gastrointestinal tract, joints, kidneys and reproductive systems [5].

Dioxin and furans may be formed by attachments of chloride to benzene rings during waste combustion [40]. Excessive exposure to them may damage the heart, immune system, liver, skin, and thyroid gland, and may cause cancer as well [64]. In addition, they are dispersed through air and deposited onto soil and vegetation. Because they degrade very slowly, they may be consumed by animals and become further concentrated up the food chain, causing further problems [64].

Total Suspended Particulates are emitted from WTE facility as well. They include dust, tiny objects of liquid, soot, and other materials [69]. Smaller particulates can cause respiratory diseases, while larger particulates can cause stomach cancer [69].

Solid Wastes

Waste combustion produces bottom ash and fly ash, which are the non-combustible residues of combustion in the incinerator. Fly ash contains fine particles that rise with flue gases, while bottom ash contains particles that don't rise with flue gases [61]. Fly ash usually contains more toxic substances than bottom ash, such as include trace levels of arsenic, barium, beryllium, boron, cadmium, chromium, thallium, selenium, molybdenum, and mercury [61]. Understandably, people are concerned with the presence of these substances. As such, they have to be disposed in special landfill such as an ash monofill and cannot be disposed in places where metals can leach into the water supply through rainwater, causing groundwater contamination [59]. A monofill is a land fill specializing in collection of bottom, fly, or combined ash from municipal waste. The minimum liner required for an ash monofill is a single composite liner with a leachate collection and removal system [39].

Depending on the type of scrubber used in removing acid gases, scrubber solids may be produced and need to be disposed. Scrubber solids will be produced if a dry scrubber is used [26].

Wastewater

The sources of wastewater associated with WTE facility are cooling tower blowdown, ash quench water, boiler wastewater, and scrubber effluent. The cooling water is usually warmer than the water in the surrounding environmental, and may reduce the water quality and harm the aquatic life when it is discharged to surrounding water sources [52]. In addition, wastewater will be produced if wet scrubber is used [26].

Pollution Control Technologies

Flue Injection

Injection of ammonia into the furnace helps control the amount of nitrogen oxides in the exhausted gas through the reaction below:

$2NO + 2NH_3 + O_2 + H_2O + H_2 \rightarrow\rightarrow 2N_2 + 5H_2O$ (Temperature < 1200°C) [4]

In addition, activated carbon adsorbs mercury, other metals, dioxins, and furans [4]. Injection of activated carbon in the furnace can therefore help get rid of these compounds from the exhausted gas. Subsequent removal of the combined substances is needed by scrubbing or filtering.

Scrubber Systems

Scrubbers can be used to neutralize acid gases. There are two types of scrubbers: wet scrubber and dry scrubber [4].

Wet scrubbers neutralize acid gases using neutralizing agents such as lime and sodium carbonates. Precipitates are then produced and removed by scrubbing liquid. Wastewater is produced from the use of wet scrubber [4].

Dry scrubber neutralizes acid gases using very fine water spray with lime. Precipitates are then produced and removed as solids or remain in suspension with water droplets [4].

Fabric Filter

Fabric filter can be used to remove particulates and suspended liquids. Gases enter the bag fabric filters through the dirty-air inlet. The particulates in the gases are then filtered out by the fabric filters and form filter cakes. These filter cakes are transported out to dust disposal, while the filtered air then passes out through the clean-air outlet into an induced-draft fan [4]. It is worth noticing that Baghouse has an impressive removal efficiency of 99% [1].

Carbon Footprint

Operation

WTE Plant

In order to calculate the carbon footprint of the WTE plant, we first need to estimate the ratio of the average amount of fossil fuel-derived CO_2 to the total amount of CO_2 emitted during operations.

The ratio can be estimated using the average amount of fossil fuel-derived CO_2 (996 lbs/MWh or 0.50 tons/MWh) and the average CO_2 emissions for WTE facilities in the US (2,988 lbs/MWh or 1.49 tons/MWh), to find that 33.3% of all CO_2 emissions are derived from fossil fuels [53].

If we assume that the annual power output of the plant is 1,051,200 MWh and that the plant emits 1,566,288 (or roughly 1,570,000) tons of CO_2 per year, then one third of those emissions will be derived from fossil fuels. Therefore, approximately 526,000 tons of fossil fuel-derived CO_2 will be emitted per year.

The fossil fuel derived CO_2 emissions for WTE facilities is our main concern, as those emissions are increasing the levels of CO_2 in the atmosphere and environment. On the other hand, the biomass-derived portion of the CO_2 emissions for WTE facilities is considered to be part of the Earth's natural carbon cycle. The plants and trees that make up the paper, food, and other biogenic waste remove CO_2 from the air while they are growing. This CO_2 is the returned to the air when the biomass-derived portion is burned, and therefore is not considered additional CO_2 in the environment.

Milliken Coal-fired Plant

To calculate the carbon footprint for operating Milliken as a coal-fired plant, we will need to multiply the average CO_2 emissions per MWh of electricity generated, which is 2249 lbs per MWh, or 1.12 tons/MWh, by Milliken's annual power output.

The annual power output can be calculated as 300 MW per hour multiplied by 24 hours per day multiplied by 365 days in a year; 2,628,000 MWh are produced annually at Milliken. Therefore, the average annual CO_2 emission for the Milliken coal-fired plant is 2,943,360 tons (or approximately 2,940,000 tons).

Transportation

Wastes for WTE

To estimate the carbon footprint caused by the waste transportation needed for WTE, we have made two assumptions:

1) The facility will need 3,500 tons of waste per day, half of which will come from NYC and the other half from Binghamton (This is just a general assumption. In reality, it is likely that most of the waste will come from NYC, since NYC is a much larger city and generates much more waste than Binghamton does per day.)
2) The waste will be transported by freight rail.

The amount of CO_2 emitted per 1,000 ton/waste miles is 0.033 tons [36].

Knowing that the distance between the Milliken Station site and NYC is 250 miles, and that the distance between Millikan and Binghamton is 70 miles, we calculated the daily amount of CO_2 emissions.

As there are 0.033 tons of CO_2 emitted per 1,000 ton/waste miles and 1,750 tons of waste are transported 250 miles from NYC, approximately 14.44 tons of CO_2 emissions are derived from the waste from NYC. A similar calculation can be used to show that (0.033/1000)*1,750*70= 4.08 tons of CO_2 emissions are derived from the waste from Binghamton. Therefore, approximately 18 tons of CO_2 are emitted daily.

If approximately 18 tons of CO_2 are produced daily, then 6,700 tons of CO_2 will be produced per year in this situation.

Ashes for WTE

In order to calculate the carbon footprint for the transportation of ashes, we must consider two different cases of ash disposal for the WTE plant at Milliken: Case 1 is that both fly ashes and bottom ashes go to SMI. This is the ideal case for our project; Case 2 is that fly ashes go to Long Island ash monofills, which are the only two ash monofills available in the NY State [39], while bottom ashes go to SMI. This case was considered because SMI might not be available for specialized monofilling of toxic ash.

Case 1: Both fly ashes and bottom ashes go to SMI

Three assumptions are used in this case:

1) Heavy-duty trucks with a capacity of 15 m^3 are used to transport the ashes.

2) The weight of the ash produced is 25% of the amount of waste that is burned. Since a total of 3,500 tons of waste are burned daily, 875 tons of ash will be produced [54].
3) The density of the ashes is 1 ton/m^3 [37].

To calculate the number of trips needed per day, we divide the total amount of ash (875 tons) by the truck capacity (15 tons) and find that we need 59 trips. Since the distance between Milliken station and SMI is 37 miles, the total distance traveled is 2183 miles.

Now that we have the total distance the waste needs to travel, we can calculate the daily CO_2 emissions. The average CO_2 emissions for a heavy-duty truck (per 1000 vehicle miles traveled, or VMT) is 1.444 tons [36].

Therefore, the daily CO_2 emissions are (1.444 tons CO_2/1,000 VMT)*2183 miles, which is 3.15 tons, and the annual amount of CO_2 emitted is 1,150.6 (or roughly 1,200) tons.

Case 2: Fly ashes→ Long Island ash monofills, bottom ashes→ SMI

Four assumptions are used in this case:
1) Heavy-duty trucks with a capacity of 15 m^3 are used to transport the ashes [3].
2) The weight of the ash produced is 25% of the amount of waste that is burned. Since a total of 3500 tons of waste are burned daily, 875 tons of ash will be produced [54].
3) The weight of the fly ash is 20% of the total weight of the ash produced, and the weight of the bottom ash is 80% of the total ash produced. Since 875 tons of ash is produced daily, 175 tons of it will be fly ash and the remaining 700 tons will be bottom ash [54].
4) The density of the ashes is 1 ton/m^3 [37].

Since fly ash and bottom ash must be disposed of at two different sites, we will need to calculate the trips needed per day for each site. As the fly ash will be deposited at Long Island, and the truck capacity is 15 tons, 12 trips will be needed daily to dispose of all 175 tons. The 700 tons of bottom ash, however, will be taken to SMI, and 47 trips will be required in order to transport all of the bottom ash.

As there are 270 miles between Milliken Station and Long Island, and 37 miles between Milliken and SMI, the total distance traveled by the fly ash is 3240 miles (12 trips multiplied by 270 miles per trip), while the bottom ash will travel 1739 miles (47 trips multiplied by 37 miles per trip). Therefore, the total daily distance traveled is 4,979 miles.

As in case 1, the average CO_2 emissions for a heavy-duty truck are 1.444 tons per 1000 VMT. Therefore, 7.19 tons of CO_2 will be emitted daily (1.444 tons*4,979 miles/1,000 VMT), and 2,624.2 (or 2,600) tons emitted annually.

Coal for Milliken Coal-fired Plant

To calculate the carbon footprint that arose from transporting coal to the Milliken coal-fired plant, two assumptions are used:

1) All the coal is sourced from Virginia (This is just a general assumption. In reality, it is also possible to source coal from West Virginia or Kentucky, which are actually bigger coal producers than Virginia.)
2) The Milliken coal plant has an energy efficiency of 40%, therefore 40% of the energy content of the coal is converted into electricity.

Since coal has an energy content of 6,150 kWh/ton [2], the amount of coal needed to generate 300MW per day is 2,900 tons. This can be calculated by finding the total energy needed to generate 300MW (300MW, or 300,000 KW, per hour multiplied by 24 hours divided by 0.4, the energy efficiency) divided by the energy content of coal.

The CO_2 emissions for freight rail per 1000 ton-miles are 0.033 tons [36].

Since the distance between Milliken Station and the coal source in Virginia is 500 miles, 47.85 tons of CO_2 are emitted daily (0.33 tons of CO_2 multiplied by 2,900 tons of coal per day multiplied by 500 miles traveled, divided by 1,000 tons of waste-miles). Therefore, 17,465.25 (or approximately 17,000) tons of CO_2 are emitted annually.

Ashes for Milliken Coal-fired Plant

At Milliken coal-fired plant, the coal ash is landfilled right on site, so ash transportation is not needed. Therefore, the carbon footprint for the transportation of ashes is 0 for Milliken coal-fired plant.

Net Carbon Footprint for the WTE System Relative to the Coal-Fired Plant

The previous sections contain all the estimates necessary to calculate the net carbon footprint for the WTE system. These estimates are summarized in Table 6.

Table 6: Operations and Transportation Emissions

	Annual CO_2 Emissions (tons)			
	Operations	Fuel Transportation	Ash Transportation (Case 1)	Ash Transportation (Case 2)
WTE	560,000	6,700	1,200	2,600
Coal-fired	2,940,000	17,000	0	0

We also normalized the annual CO_2 emissions by the power output of both plants. The estimate CO_2 emissions per MWh by both plants are summarized Table 7.

Table 7: Operations and Transportation Emissions per MWh

	CO_2 Emissions per MWh (tons)			
	Operations	Fuel Transportation	Ash Transportation (Case 1)	Ash Transportation (Case 2)
WTE	0.53	0.0064	0.0011	0.0025
Coal-fired	1.1	0.0065	0	0

The annual net carbon footprint is the sum of the CO_2 emissions from operations, fuel transportation, and ash transportation, with the results summarized in Table 8.

Table 8: Annual CO_2 Emissions (tons)

	Annual CO_2 Emissions (tons)	
	Case 1	Case 2
WTE	567,900	569,300
Coal-fired	2,957,000	2,957,000

Therefore, the differences in CO_2 emissions for the WTE and Coal-fired systems are: -2,389,100 tons for case 1 and -2,387,700 tons for case 2.

The net carbon footprint per MWh is the sum of the CO_2 emissions per MWh from operations, fuel transportation, and ash transportation, with the results summarized in Table 9.

Table 9: CO_2 Emissions per MWh (tons)

	CO_2 Emissions per MWh (tons)	
	Case 1	Case 2
WTE	0.54	0.54
Coal-fired	1.1	1.1

Therefore, the difference in CO_2 emissions per MWh for the WTE and coal-fired systems is 0.56 tons for both cases.

The total CO_2 emissions per MWh for both plants is very close to the CO_2 emissions per MWh from the plant operation, since plant operation generates most of the CO_2 emissions among all the activities.

Avoided Landfill Methane Emissions by WTE

On average, 0.584 tons of methane is avoided per ton of waste; these emissions include methane that arises from the decay of waste in landfills, generation of electricity, and the recycling of ferrous metals [24].

Since 3500 tons of waste are combusted daily, that means 2,040 tons of methane are avoided daily, as 0.584 tons of methane can be avoided per ton of waste. Therefore 746,000 tons of methane are avoided on an annual basis. In comparison, the total amount of methane emissions by landfills in the US for 2009 was about 130 million tons of CO_2 equivalents [51].

Environmental Benefits

Reducing the Dependency on Landfills

The amount of landfill space available in the New York State is limited. Currently, the largest active landfill in the New York State is the Seneca Meadows Landfill, and it was estimated that the landfill may be exhausted by as early as 2023 [67]. Disregarding this fact, the continuous use of greenlands for landfilling is not a sustainable solution for waste management. The building of a WTE plant at the Milliken Station site can offer a sustainable solution for waste management, reducing the dependency on landfills while providing a steady supply of green electricity.

Reducing the amount of Pollutant Emissions

As mentioned above, the technology for WTE has significantly improved in recent decades with the implementation of the Clean Air Act [70] and the federal Maximum Achievable Control Technology (MACT) regulation [46], leading to dramatic reduction of all emissions. In 2003, the EPA stated that WTE now produces electricity with less environmental impact than almost any other source [70].

Reducing the amount of Greenhouse Gas Emissions

It was estimated that the average carbon dioxide emissions rate in the US from WTE is 2988 lbs (about 1.36 metric tons) of carbon dioxide per megawatt-hour, one-third of which is derived from fossil fuel [53]. It was also found that nearly 1 ton of CO_2 equivalent is avoided for every ton of waste combusted by a WTE plant [47]. A

WTE plant provides for the avoidance of greenhouse gases in three ways. Firstly, a megawatt of electricity generated by WTE plant prevents a megawatt of electricity from being generated by a conventional power plant, such as coal-fired power plant, and thus, creates a net saving of emissions of greenhouse gases [47]. Secondly, WTE plant helps recycle ferrous and/or non-ferrous metals, which is more energy efficient than mining raw materials for the production of new metals such as steel. As a result, a significant amount of energy is saved and a large amount of greenhouse gas emissions are avoided [47]. Last but not least, when a ton of solid waste is combusted in a WTE plant, the methane that would have been generated if the waste was sent to a landfill instead is avoided [47]. It is worth noticing that methane is a strong greenhouse gas, one which is 21 times stronger than CO_2 [47].

Other Environmental Benefits

The building of a WTE plant at the Milliken Station site can potentially reduce the transport of waste to distant landfills as well as interstate truck traffic, and thus reduce overall energy consumption and diesel exhaust [70].

Recycling Opportunities

WTE technology is not incompatible with recycling—in fact, communities with WTE facilities may have a higher rate of recycling compared to that of the national average [48]. Since many of these facilities also have locations where members of the community can drop off their unwanted items, these members may be more likely to bring their unwanted recyclables to these drop-off centers instead of throwing them away [48]. Since materials such as glass and aluminum can be recovered and traded in the global market, WTE facilities would therefore have an economic incentive to implementing an integrated WTE/recycling program [9].

However, there is also potential in recycling plastic products, which range from the common, such as disposable water bottles, to the unconventional, including products generated from the electronics industry [14]. For example, an energy company called Agilyx claims that it can produce crude oil with a process-to-energy ratio of more than 6 to 1, and do so with minimal emissions [28].

Metal Recovery

Each year, 49% of the total amount of ferrous metal that passes through WTE facilities in the US is recovered, leading to 700,000 tons of recovered metal on an annual basis [17]. However, only 8% of all non-ferrous metal (comprised mostly of alumina and excluding copper) in WTE facilities is recovered annually—the other 92% (180,000 tons) ends up in a landfill [17]. At $100 per ton for iron and $800 per ton for non-ferrous metals, WTE facilities could recover $70 million from ferrous metals and $12.8 million from non-ferrous metals, for a total of $82.8 million annually [17].

There are many possible ways to recover metals in the WTE facility. They range from manual separation of large pieces at the tipping floor to metal separation from the ash at the back-end of the WTE process or alternatively at regional metal recovery facilities. The largest factor in mass burn plants is if they have the recovery equipment needed in the first place.

If the plant does not have the recovery equipment, metals are not separated systematically. Large objects are removed to avoid damage to the plant's equipment. On the other hand, plants that have metal recovery first separate the large pieces as well. They further have back-end metal recovery where they salvage ferrous metals from the bottom ash. The “Grizzly feeder” and magnetic separation do this. The main disadvantages of this are that the metals are oxidized and not recoverable if the combustion temperature is too high. Ash also adheres to the metals and all these factors lower the market value [66].

A good alternative is to have a regional metal recovery facility to partner with. Here the metal recovery system uses many techniques to get as much out of the waste as possible. This includes shredding and screening, magnetic separation, eddy current separation, and manual separation. The main metals that are taken out through this process are ferrous metals, non-ferrous metals, copper, and stainless steel [66]. The disadvantage is the shipping cost. The advantages are less ash adhesion and additional revenue of selling the metals recovered on top of the fact that the facility is more efficient due to the waste burning better and equipment being damaged less. There is also the added benefit of not having to pay unnecessary tipping fees for landfilling metals. The savings in tipping fees as well as the revenue from selling the metals make a clear case for metal recovery.

In conclusion, mass burn facilities at the very least should have grizzly feeders and magnetic separation. The next level of metal recovery would be to install eddy current separators or better yet partner with a regional metal recovery facility, which would help reduce costs due to economies of scale. The benefits are an additional revenue stream from selling metals as well as saving money by paying less tipping fees and doing your part in protecting the environment.

Plastic Recycling

Plastic waste can be used for a variety of purposes—an obvious option is to reprocess used plastics into pellets that can be used in new products [47], such as reusable grocery bags. It can be used in petrochemical processing and may even be converted into a fuel alternative to oil [63] [15]. For example, Envion (an energy company located in Washington, D.C.) claims that it can convert plastic into oil using a process that involves thermal cracking, therefore extracting hydrocarbons without the use of a catalyst [50]. Although the product may need to be blended with other chemicals, it may be sold as gasoline or diesel afterwards, and the conversion process only costs about $10 a barrel [23]. Other energy companies such as RES Polyflow and the Dow Chemical Corporate are also investigating the potential of converting plastic into fuel[65][11]. In comparison to metal recovery, plastic waste recycling is a relatively newer process, but one that may be worth investigating further in the future.

Conclusions

Our technical and economical analysis of all three renewable energy technologies, CHP/DE, biomass, and WTE, led to our choice of technology, WTE. We chose this technology after ruling out the other two, largely due to economical infeasibility for biomass, and logistical concerns regarding combined heat and power. To save costs, Milliken Station, which used to be a coal-fired plant, can be repurposed to become a WTE facility. The advantages of WTE include a sustainable solution for waste management and providing a reliable supply of green electricity. In addition, using waste as a fuel will reduce the dependency on landfills. The technology WTE can reduce the amount of greenhouse gas emissions. Lastly, a WTE plant can benefit the local economy of Lansing by retaining cost within the community with taxes. However, with every new technology, there are also disadvantages. The top three problems are low efficiency, high capacity cost, and public resistance. But there has been a gradual acceptance for WTE plants in the past couple of years due to the success of such plants in European countries. If these problems can be overcome, a WTE plant should be feasible and profitable.

Future Opportunities

An obvious future opportunity for this project is to compare the technical and economical feasibility of WTE plant to repurposing Milliken Station to become a natural gas facility. The station was shut down to begin with because coal prices were increasing while natural gas prices remained affordable and cheap.

To help change the public's view on using waste as a fuel for energy, a greenhouse demonstration can be conducted to show the residents of Lansing what energy from waste can do. For example, providing the greenhouse energy with waste can show that everyday produce and nature can be grown easily. In addition, expansion can be expanded to the Lansing schools to gain more support.

We may also be interested in studying the possibility of using tertiary sewage plant product as a fuel source. But like waste, using sewage as a fuel is met by public resistance. However, again like waste, the abundance of sewage guarantees that energy can always be made and the sewage is being used up instead of stored away in a landfill.

Lastly, district energy can be explored. A WTE plant can provide excess heat, which can be sold to the grid, hospitals, schools, or homes in the surrounding area.

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Appendix

Appendix 1: Initial Cost of WTE

The structure of initial cost of WTE plant				
Type of cost			Repurpose	New Plant
	Cost/EUR	Cost/ USD	Lansing Case Estimation	Lansing Case Estimation
Infrastructure and waste storage	4,600,000	5,883,400	68,184,408	68,184,408
Combustion system and steam generator	19,500,000	24,940,500	173,425,561	289,042,601
water and steam system	8,000,000	10,232,000	-	118,581,580
(including water treatment facility, air cooled condenser, condensation turbine)				
Design	2,000,000	2,558,000	29,645,395	29,645,395
Construction	7,000,000	8,953,000	51,879,441	103,758,882
Electro-mechanical installation	5,000,000	6,395,000	-	74,113,487
Other investment cost	6,000,000	7,674,000	71,148,948	88,936,185
Gas cleaning system				
SCR process (selective catalytic reduction system)	1,500,000	1,918,500	22,234,046	22,234,046
Electrostatic precipitator	1,200,000	1,534,800	17,787,237	17,787,237

Wet Scrubbing treatment	5,000,000	6,395,000	74,113,487	74,113,487
Total	59,800,000	76,484,200	**508,418,524**	**886,397,310**
Annual Initial Cost breakdown (20)			**25,420,926**	**44,319,866**

Appendix 2: Operating and Maintenance Cost

Operating and Maintenance cost				
Type of cost	**EUR/YR**	**USD/YR**	**USD/YR(REPUROSE)**	**USD/YR (NEW PLANT)**
System maintenance(4% of investment costs)	2,392,000	3,059,368	20,336,741	26,591,919
Natural gas	85,000	108,715	157,491	157,491
Process Water	12,000	15,348	177,872	177,872
Reagent for (SCR) (NH3)	40,000	51,160	592,908	592,908
Reagent for Wet treatment(NaOH)	35,000	44,765	518,794	518,794
Bottom Ash Disposal	138,000	176,502	2,045,532	2,045,532
Flying ash from the electrostatic precipitator	193,000	246,847	2,860,781	2,860,781
Solidified flying ash	253,000	323,587	3,750,142	3,750,142
Wet treatment residues	56,000	71,624	830,071	830,071
Emission fee	11,371	14,544	168,549	168,549
Compensation fee	246,000	314,634	3,646,384	3,646,384
Labor	1,108,800	1,418,155	32,870,814	32,870,814
Total O&M cost	4,570,171	5,845,249	67,956,080	74,211,258
		including inflation	**72,094,605**	**78,730,724**
		USD/TONNE	**62**	**68**
		USD/TON	**69**	**75**

Appendix 3 –Repurpose Scenario Results

Figure 16: Repurpose Simulated IRR PDF

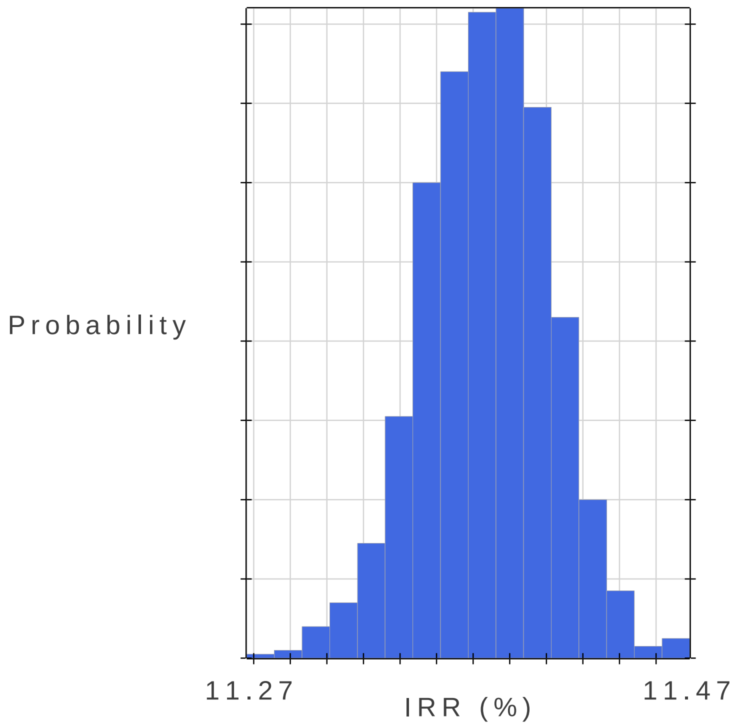


Figure 17: Repurpose Simulated Breakeven PDF

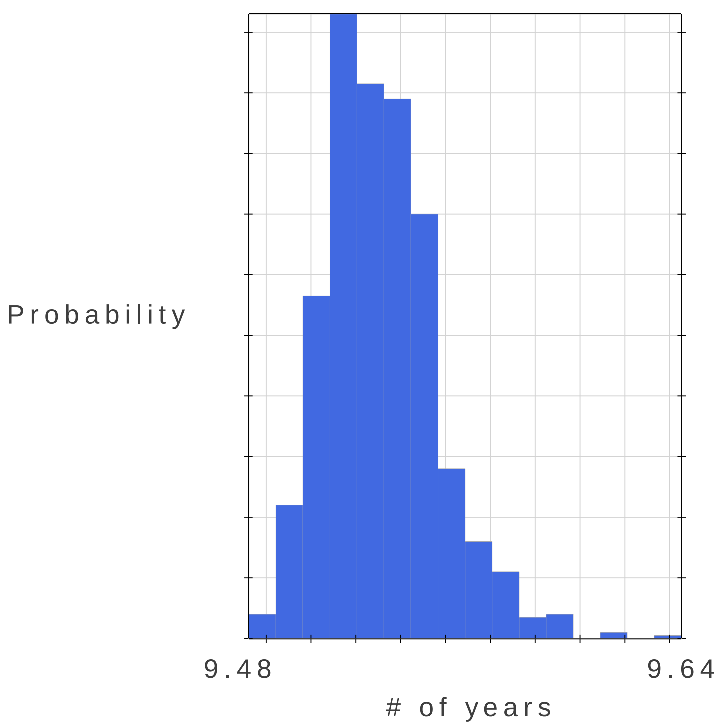
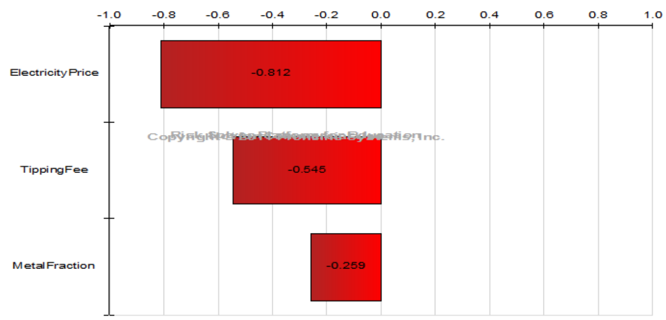


Figure 18: Repurpose Breakeven Sensitivity Analysis



Appendix 4: New Plant Scenario Results

Figure 19: New Plant Simulated IRR PDF

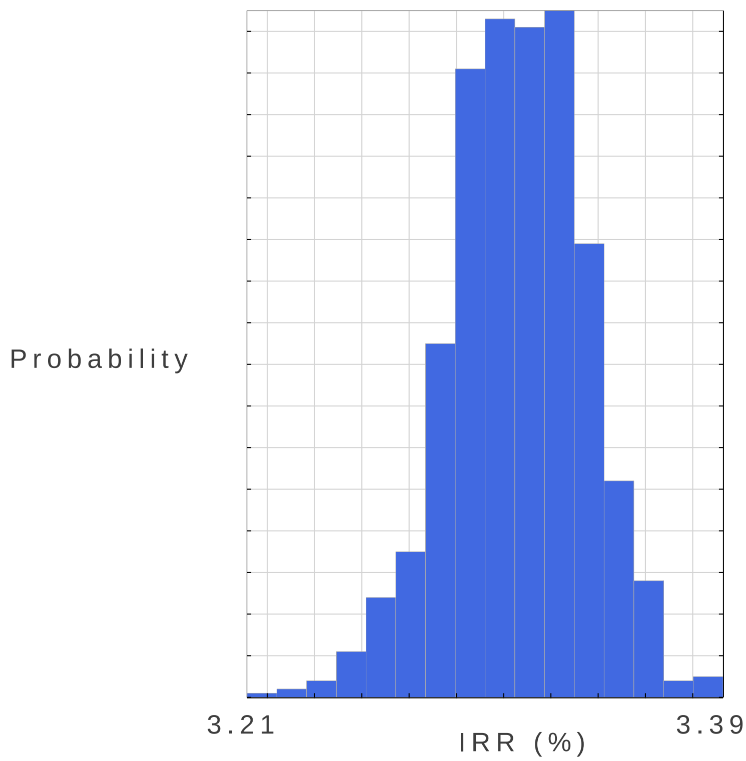


Figure 20: New Plant Simulated Breakeven PDF