An Economic Analysis of Feedstock Costs on Small- and Large-scale Biomass Gasification Systems

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With dwindling fossil fuel reserves and the rapid industrialization of third-world countries, alternative sources of electricity are needed now more than ever. One proposed method is to generate electricity from biomass (simply put- any organic based compound). For the most part, biomass is confined to agricultural products, agricultural/forest residues, woody biomass (wood chips), and municipal solid waste (MSW). These feedstocks can be gasified in a system that produces electrical and thermal energy.

This study examined the economic feasibility of a small-scale gasification generator (72kWe) and a large-scale gasification plant (50MWe). The research varied the feedstock cost to account for MSW, corn stover, a cheap hardwood estimate, and an expensive hardwood estimate. After inputting these numbers into a financial model, the study compared the calculated cost of producing one kWh of electricity to the state averages in the Mid-Atlantic and New England states. In these areas, the price of electricity produced was significantly lower than the average price in each state. The research was able to determine that the payback period for investors would be less than 5 years in the small-scale scenario and less than 10 years in the large-scale scenario. While these are both attractive investments, the small-scale payback period is short enough to attract investors despite the economic climate. It was determined that secluded towns and facilities that produce a large volume of waste would gain the maximum economic benefit from a small-scale generator.

Future studies should focus on confirming these results and examining the impact of different regions and feedstocks on the overall economic performance of the systems. It seems, however, that biomass-to-electricity generation is a promising and economically viable source of renewable energy.

Introduction

There is, perhaps, no other industry more important to human survival than the energy industry. With the ever increasing oil prices and the point of peak oil – the point at which oil production is highest from fossil fuels – behind us, it is more crucial now than ever to develop alternative sources of energy [4]. To exacerbate the problem, population growth in third-world countries continues at an incredible pace. As these countries industrialize and grow, energy demand will grow as well. To sustain this growth and supplant the dwindling supply of fossil fuels, new sources of power are needed [1].However, in an industry as large as energy, it is crucial that energy prices remain low to attract consumers. Numerous start-ups, from biofuel producers to wind farms, have failed to attract investors or gain economic traction because their product is not cost-effective and cannot compete with the current methods.

The most common scale of electricity production is that of a large power plant. Today, the United States relies on large nuclear, hydroelectric, and coal plants for electrical energy. While most large plants in the U.S. are not renewable, a number of plants using biomass as an energy source have been built and have successfully produced energy for the last few decades. The term biomass can be expanded to include any material that is organically-based; however, it is more commonly used to refer to material that is plant based (such as wood, agricultural products, or agricultural residues) or non-hazardous wastes (mainly municipal solid waste).Most biomass plants in service today simply combust the biomass in the presence of oxygen to evaporate water to turn a steam turbine. The turbine can then be connected to the grid so that the utility companies can sell the electricity produced. While this method is easily maintained and operated, the logistics and economics of building a large scale (>1 MW) are extremely difficult and have limited the building of such plants [11, 12].

Fortunately, distributed generation – the concept in which a specific locale produces its own energy either for its own purposes or sells the energy back to the grid – may be able to provide renewable power at cost competitive rates readily in a variety of scenarios. Under the general definition, distributed generation (DG) can include everything from photovoltaic cells to micro-turbine generators. However, most decentralized power generation is performed through individual turbine generators [3]. The idea of distributed generation is not new; as new generator technologies have been unveiled this idea has been applied to them. An emerging technology on the threshold of breaking into the industry is that of small-scale, combined-heat-and-power (CHP) biomass gasification. Gasification is a well-proven process used to turn a carbonaceous feedstock (like coal or biomass) into synthesis gas (syngas), an approximately 2.5 to 1 ratio of hydrogen (H_2) to carbon monoxide (CO). Furthermore, small-scale, CHP systems are able to handle a variety of feedstocks, are cheap to maintain and purchase, and can produce electricity that is cost-competitive with current prices from utility companies. All of these factors make these gasifier/generator systems a potentially viable source of renewable energy that may prove to be economically efficient [2].

In the last two decades, these generators have been modified so that the excess heat produced from the process can be used for space heating or other thermal applications. The most common and simplest method of gasifying biomass feedstocks is called downdraft gasification. During downdraft gasification, the biomass is moved into a chamber where it is partially combusted, losing its moisture, and then subjected to pyrolysis. The products of this react with oxygen in both oxidation and reduction reactions to produce the syngas [8]. From there, the syngas is used to power a turbine generator which produces electricity (in the same way the large power plant works). There are several types of gasifiers, which mainly affect the way biomass is fed into the system. These include downdraft, updraft, cross-draft, and fluidized bed gasification; out of all of these methods, downdraft gasification produces the least amount of tar and therefore is the easiest to operate and maintain. In CHP mode, the thermal energy can be used to heat air or water for common space heating techniques – such as forced air heating [6].

Combined-heat-and-power substantially increases the overall efficiency of the system. This enables the system be economically viable for a number of locations and feedstocks. When using standard diesel as a fuel for a CHP generator studies have found that the economic benefits are significant enough to provide an incentive for the initial investment. A CHP system allows for energy savings in both electricity and heating costs, which offsets the heavy initial investment within a few years [5, 14]. Small-scale biomass gasifiers are meant to be versatile in that they can handle a variety of feedstocks. Nearly every type of agricultural residue, from corn stover to rice hulls, forest residue (like wood chips), municipal solid waste (MSW) have been successfully tested in a gasifier-generator system [9, 13]. This allows the most readily available, cheapest feedstock to be used so that the best economic return is possible.

In the Northeastern section of the United States, MSW is readily available in and around the metropolitan areas. Also, while there is not the volume of corn stover that there is in the Midwest “corn belt”, several thousand tons of corn stover are currently being produced in western New York and Pennsylvania [7]. The base feedstock for most gasifier systems, hardwood, costs more than the aforementioned “situational” feedstocks, but is readily available and easiest for most downdraft gasifiers to handle. The cost of feedstock (and related costs like feedstock transportation and pretreatment) is paramount to the economic success of a small-scale facility; this cost is the main expenditure of such a facility [10, 15]. In order to attract investors and gain a reasonable return on investment in the Northeast, the feedstock price must be low enough to allow for an electricity price below the current average utility prices.

Methods

Technology

The small-scale gasification unit used was based off of IST Energy Inc.'s GEM ("Green Energy Machine") 3T120. This is a downdraft gasification system with an automatic feeder and biomass conditioner built in. The biomass conditioner dries the feedstock and converts it into pellets so that the gasification process can be run in a more streamlined and efficient manner. The system can handle nearly all types of non-hazardous wastes, crop residues, forest residues, and plastics. The study assumed a throughput of three tons per day, which is the maximum the machine can handle. Maximum electrical, thermal, and ash output were assumed in CHP mode as well. Electrical production was recorded at 72 kW per hour, thermal energy production was recorded at 614,000 Btu per hour (enough heat for a 200,000 square foot building for an entire year), and ash production was recorded at 5% of biomass feedstock input per day. The system was also considered operational for 152 hours per week, which leaves 16 for maintenance and system rest (this is a conservative assumption, only 4 hours per week of maintenance is needed). The maintenance would be carried out by 2 part-time, trained employees [16].

The large-scale, downdraft gasification power plant was based roughly off the McNeil Generating Station in Vermont. This system does not need a pretreatment vessel as biomass does not need to be pelletized; the feedstock must have a low enough moisture content however. This facility would be assumed to process 76 dry tons of feedstock per hour to produce 50 MW per hour of electricity. The facility would produce 5000 tons per year of ash; of this, 10% would be bottom ash, 25% would be fly ash, and 65% would be captured by the facilities cleaning system [17]. Operating time was held consistent with that of the small-scale unit (again this is a conservative assumption). In total 22 people would be employed by such a facility: 18 standard operators, 3 foremen, and 1 supervisor.

Costs and Prices

The retail price of IST's GEM 3T120 is set at $1.1 million; "other project costs" (including wiring, fencing, and pouring a cement base) were set at 40% of the initial capital investment costs and working capital was set at 18% of the initial investment. Maintenance was recorded as $35,000 per year when considering a 156 hour week. Maintenance personnel salaries were calculated using data from previous studies and models created by Nexant Inc. General Plant overhead was assumed to be 60% of the total direct, fixed costs while property and insurance taxes were set at 1% of the initial capital investment. Finally, the return on investment (RoI) calculation used a 20% return as a middle-of-the-road figure to determine whether the payback period would be less than or greater than five years. This calculation is necessary to guarantee investors a return on their investment so that the capital for such a project can be raised.

The selling price for ash produced as a by-product was set at $0 per dry ton for IST's system due to insufficient testing. The ash and bio-char produced have not been successfully used for agricultural purposes. In a large scale plant, fly ash price was set at $19 per dry ton while bottom ash was recorded at $2 per dry ton. Natural gas prices were set at mid-August 2011 levels in accordance with EIA records.

The effect of biomass prices on the payback period, price per kWh, and annual cost was examined using 3 different feedstocks and 4 different prices. Municipal solid waste (MSW) was considered to be -$30 per dry ton when assuming a standard tipping fee for the Northeastern United States: $60 per ton. Corn stover was considered essentially “free” because it is normally gathered in 1 centrally located area by farmers in western NY and PA. There is little current use for corn stover apart from forage or recycling nutrients into the soil, hence there is broad interest in raising its value by converting it to energy. This would be an ideal spot for a generator/gasifier system. Biomass hardwood was considered at 2 prices: $60 per dry ton and $70 per dry ton. The MSW price was changed to -$60 for the large-scale plant. Otherwise, the same prices were also used when examining the economic performance of the large-scale biomass power plant [18].

The McNeil Generating Station was completed for $67 million in 1981; this price was subsequently inflated to be $174 million in 2011. “Other project costs” were again assumed to be 40% of the initial capital investment and working capital was 18.75% of the initial capital investment. The selling price for ash was also kept the same as ash produced via this process may be more valuable than that produced by the small-scale system. Worker salaries were based on previously recorded figures by Nexant Inc. Maintenance costs were set at 2% of the initial capital investment and direct overhead costs were set at 45% of the costs of the labor and supervision. General Plant overhead and taxes were set at the same rate as in the small-scale application. The RoI calculation here used a 20% return again.

The Model

The model was organized so that the annual cost, price per MWh, and price per kWh were all summations of the various individual sections. The individual sections were raw materials, by-product credits, utility costs, direct fixed costs, and allocated fixed costs. The costs were then summed up to find the cash cost annually, per MWh, and per kWh. A depreciation value of 10% of the initial capital investment was then assessed and added to the cash cost. Finally, a return on investment calculation was included using 20% (or 5-year payback period) as a basis.

To determine annual throughput in dry tons per year and annual production in kWh or MWh per year consumption factors were analyzed and multiplied by the run time (in hours) per year. As mentioned previously, maximum throughput in the small-scale and large-scale facilities were assumed at 3 tons per day and 1,824 tons per day respectively. When multiplied by the number of hours per year (8112 hours), the annual production and throughput can be calculated. From here the product yield in kWh per dry ton was calculated by dividing the throughput by the annual production yield.

Results

Small-Scale Economics

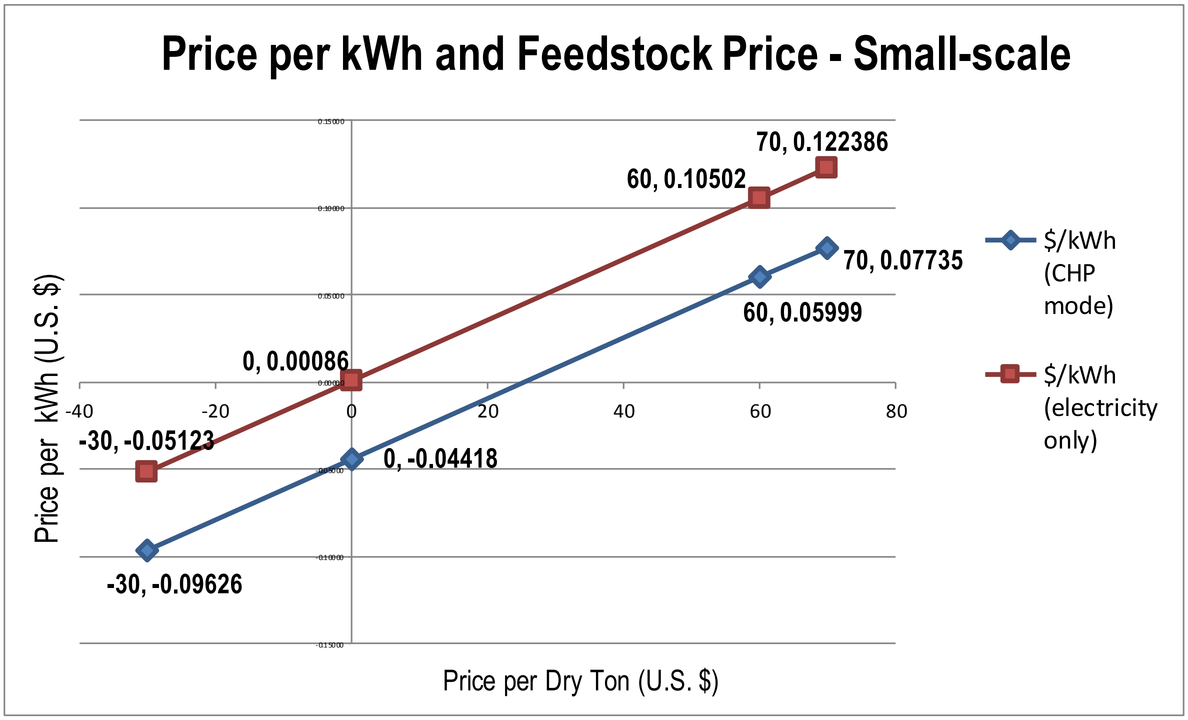
After taking working capital and other project costs into account, the final initial capital investment came out to be $1.817 million. By adding a 20 percent return on investment (RoI) factor into the cost calculation, the relative payback period was easy to determine. If the cost per kWh (in U.S. $) generated by the model is less than the EIA average retail price, the payback period will be less than five years. This comparison was done on a state-by-state basis for the Northeast. After inputting the four price variations (-$30, $0, $60, $70) into the model, the prices per kWh were calculated to be less than the state average in nearly every sector and in nearly every state among those considered when the system is operating in CHP mode. The state electricity prices for the studied geographical area are shown in Table 1 while the electricity prices for the system are shown in Graph 1.

Table 1. Average Retail Price of Electricity to Ultimate Customers by End-Use Sector, by State, Year-to-Date through May 2011 and 2010

Cents per Kilowatt-hour

Census Division and State	Residential		Commercial[1]		Industrial[1]		Transportation[1]	
	2011	2010	2011	2010	2011	2010	2011	2010
New England	**16.01**	**16.62**	**14.34**	**15.03**	**12.52**	**12.49**	**8.02**	**9.13**
Connecticut	18.04	19.42	15.74	16.61	13.46	14.65	10.38	12.96
Maine	15.56	15.62	12.47	12.49	9.2	9.2	--	--
Massachusetts	14.73	15.44	14.1	15.23	13.2	12.83	6.44	6.99
New Hampshire	16.49	15.97	14.23	13.98	12.59	12.62	--	--
Rhode Island	15.69	15.89	12.76	13.29	11.33	12.74	14.03	12.97
Vermont	16.1	15.34	13.93	13.32	9.82	9.39	--	--
Middle Atlantic	**15.41**	**15.24**	**13.18**	**13.33**	**8.56**	**8.49**	**12.79**	**12.75**
New Jersey	16.34	15.93	13.3	13.42	11.55	11.13	10.55	12.39
New York	17.64	18.12	15.09	15.31	9.54	9.88	14.08	14.39
Pennsylvania	13.01	12.45	9.86	10.12	7.82	7.61	9.26	7.77

Graph 1: (A) shows the change in price per kWh as feedstock price is increased. (B) Also shows how CHP mode greatly affects the electricity prices



It was found that, when in CHP mode, the payback period would be less than five years regardless of feedstock price, state, or energy sector. However, when the system's heat output is not being utilized in CHP mode, the system yields a payback period of less than five years in only the residential and commercial energy sectors in most states. The system is far less competitive in Pennsylvania and the Industrial sectors of almost every state in the region when not in CHP mode. When moving from CHP mode to electricity-only, the price per kWh increases by an average of 70%.

The annual costs are $86,594, $117,014, $177,854, and $187,994 (listed in order of increasing feedstock price: -$30 to $70). These represent the cash cost prices and does not include the depreciation or return on investment calculations.

With regards to the consumption factors, it was calculated that 584,064 kWh of electricity would be produced over the span of 1 year. The system would use 1,014 dry tons of biomass per year and would yield 576 kWh for every ton of biomass.

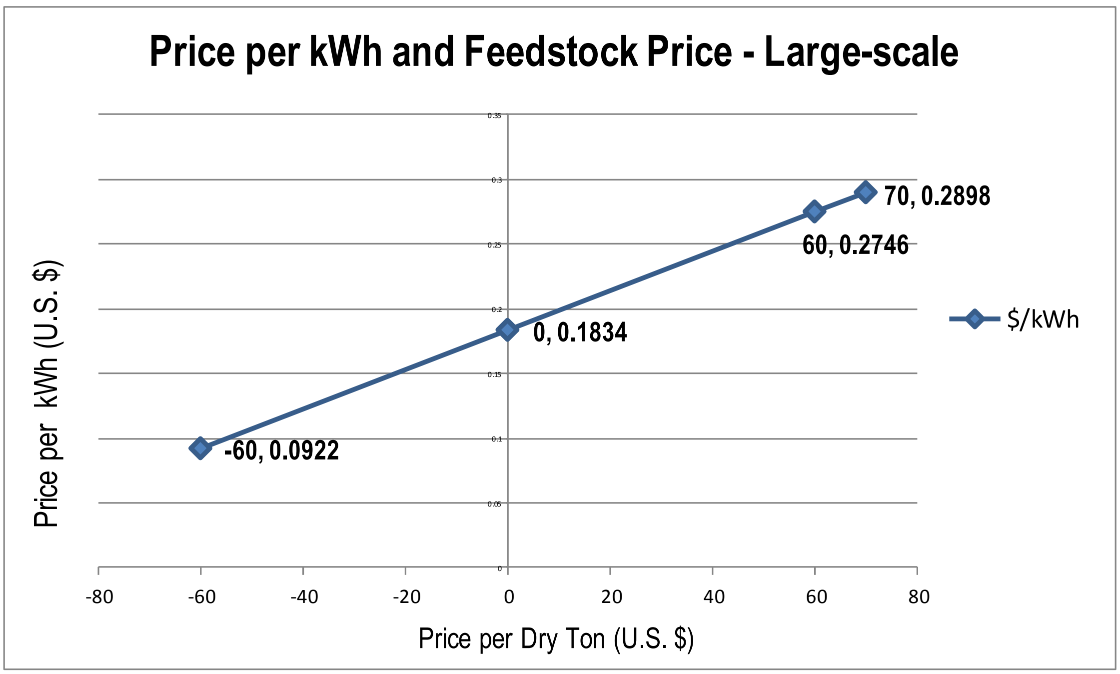
Large-scale Economics

For the biomass gasification power-plant the final initial capital investment cost was calculated to be $289.3 million. Using the same method we used to determine the payback period in the small-scale scenario, we were able to determine if the payback period would be greater or less than five years. In this scenario, the two biomass hardwood feedstocks ($60 and $70) would make the plant not profitable as the electricity prices would be a full $.10 to $.15 greater than the state and sector averages. When corn stover and other “free” feedstocks were considered, the power plant would have borderline success. In some states and sectors this plant would yield a payback period of less than five years while in some states it would not. However, this plant would produce a short payback period in nearly every state when it assesses a tipping fee of $60 for accepting MSW. Graph 2 shows exactly how the electricity prices would vary with feedstock prices in the large-scale scenario.

The annual cash costs here were calculated at -$26,000,000, $10,000,000, $46,000,000, and $52,000,000 (listed in order of increasing feedstock price: -$60 to $70). Again, this does not include the RoI or depreciation calculations. The biomass power plant would produce 416,000

MWh per year while using 600,560 dry tons of biomass. The product yield was calculated at 657.89 kWh per dry ton of biomass.

Graph 2: Shows how increasing the cost of biomass feedstock influences the cost of electricity produced

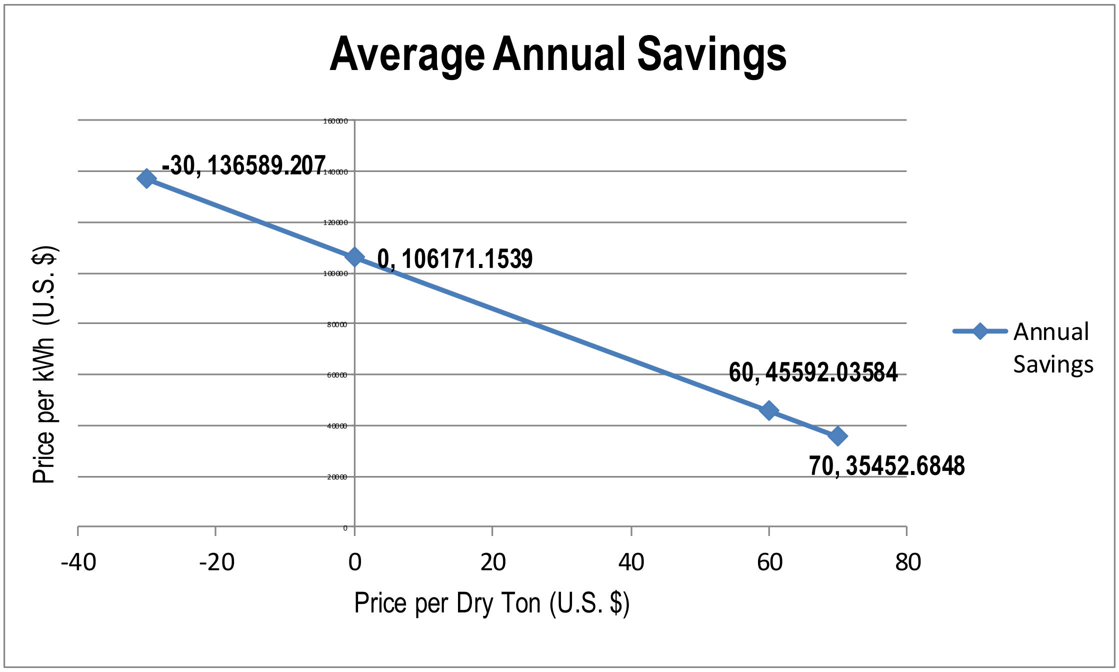


Discussion

The small-scale facility examined in the study (based on IST Energy's 3T120) proves to be an excellent investment as per the model results. While in CHP mode (in which the system is both electrically and thermally efficient), the small-scale generator will yield a payback period of less than five years when a 20% rate of return is assumed. The return on investment can therefore be increased above 20%; this would likely attract many investors and lead to a very successful project. When the system is being used to generate electrical energy alone, it may not be an attractive investment in the industrial sector but can still have moderate success in the commercial and residential sectors – when consuming cheap feedstocks.

A more straightforward comparison was done comparing the annual savings when the electricity produced from the generator was cheaper than the state averages. The commercial electricity price average was used as a middle-of-the-road measurement when subtracting the difference in prices. The average savings for the New England states was then averaged together with that of the Mid-Atlantic States to form Graph 3. This graph only takes into account the price per kWh when the system is in CHP mode. As shown before, the heat aspect of the system plays a large role in determining the effective cost per kWh of the electricity produced. Graph 3 shows that when using a "free" feedstock ($0 of additional costs), the owner will save a little over $106,000 a year. This would allow the system to pay for its self in a little over ten years when no outside influences are assumed. However, state loan and grant programs are present in every state examined and would aid investors in paying for the unit, thus shortening the amount of time needed for the system to pay for itself.

Graph 3: Shows the average annual savings in U.S. $ per year for the entire geographical area studied (New England and Mid-Atlantic states) when the small-scale unit is operating in CHP mode.



For suburban and urban applications, biomass hardwood may be the most viable feedstock. Even though there is a large quantity of MSW in these areas, most municipalities have existing contracts with landfills and waste-to-energy plants. Due to this, it is not reasonable to assume that a small-scale generator would be able to use MSW as a feedstock (unless the owner of the unit produced large quantities of MSW). MSW must also undergo a separation process before it can be gasified to remove plastics, metals and pressure treated wood since these compounds can become dangerous chemicals under gasification conditions. Corn stover (the $0 feedstock), is also not applicable in more developed areas, as it would not be readily available and would be expensive due to transportation costs. Fortunately, the unit is still economical when biomass hardwood is used as a feedstock and the unit is operating in CHP mode.

In rural areas, where the unit may be used only for electrical purposes due to the nature of local structures, corn stover is the ideal feedstock. Corn stover is already stored at a central location in western New York and Pennsylvania so there are no additional costs associated with the feedstock (this is why it essentially costs $0). Whether the system operates in CHP mode or not, the price of the electricity produced would be much less than the average selling price in both NY and PA. A "free" feedstock for urban and suburban areas would consist of MSW that is produced on-site by the owner of the generator. Examples of this include hospitals, industrial-parks, and universities. This application of the system would produce a very quick return on investment and would be a very attractive investment.

The large-scale biomass power plant is much more costly than the small-scale model in terms of both the annual costs and the price per kWh. In a theoretical scenario in which corn stover was used as a feedstock, the cost plus return per kWh would be $0.1834 compared to nearly $0 for the small-scale unit (not in CHP mode). Also, hardwood is not a feasible feedstock as the electricity asking price is a great deal above the state averages. This would mean that the payback period would need to be longer than five years, and/or customers would need to be willing to pay a premium price for renewable electricity. However, MSW (at a price of -$60 due to a standard tipping fee) yields a price per kWh of about $.09 which is well under the average electricity price for the region examined. This would make investing in such a plant an attractive investment as it would have a high rate of return (over 20%).

Feedstock price is the major variable when considering the large-scale plant. The major costs, besides feedstock cost, are the maintenance, general plant overhead, and labor costs. The depreciation and return on investment calculations contributed the greatest portion to the final price per kWh. These two factors also contribute more than $60 million in to the annual costs.

Once the investors are paid back in full, potentially with interest, the money designated for return on investment will greatly decrease as money will only be needed to run the plant (as opposed to the capital costs).

For both small and large-scale facilities, government subsidies would cover a large portion of the initial capital costs. Depending on the state, up to 50% of the capital costs can be covered by state-sponsored long-term loan or grant programs. All of the states in the studied region also have programs in place that award money for every kWh of electricity produced. These programs are intended to allow alternative energy producers to produce cost-competitive electricity. This would further increase the annual savings for both scales and enable a wider range of feedstocks (based on price) to be utilized effectively.

This study did not have the luxury of studying a working small-scale unit already in place in the economy. All of the system specifications are based on recently demonstrated and prototype systems and information provided by IST Energy. The exact product yield was calculated in this study and not by IST themselves. This is true for thermal energy as well; IST has provided the study with a rounded estimate on the amount of heat the system produces at full capacity. The large-scale model is based off a plant that combusts the biomass and does not gasify the biomass. However, any additional costs involved in gasification would most likely be offset by the increased efficiency that gasification technologies have over combustion technologies. Finally, the throughput and by-product data are based on the combustion plant and not a gasification plant.

This study did find that both small-scale and large-scale gasification systems are economically viable. These units could supplant a large portion of nonrenewable energy sources with a viable alternative. Feedstock prices have a great impact on the final price per kWh produced and therefore the feedstock must be picked accordingly for each system and location. Hardwood biomass and corn stover are the best options for the small-scale unit while MSW is impractical unless the owner of the system produces a large quantity of MSW. It was also found that CHP mode has a big effect on electricity prices and should be utilized whenever possible. For the large-scale power plant, MSW (at -$60) is the only feedstock that allows for a high return rate. Many plants of similar size do use MSW to generate electricity already so this is a practical solution.

Future research in this area would implement the empirical results from working prototypes to verify that the assumptions and results of this study are accurate. Similar studies can also be conducted for other regions in the United States and for other specific systems. When a case study can be conducted, the government incentives and subsidies should be recorded to calculate their impact on the system's economic performance. The feasibility of introducing different feedstocks into the studied systems should also be examined in order to find new, economically viable feedstocks.

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