Feasibility of waste gasification technologies in the USA

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Abstract: Governments across the globe have adopted different programs to deal with increasing amounts of municipal solid waste (MSW) including recycling, waste prevention programs, and waste-to-energy (WTE) technologies, such as gasification. Deciding on a specific WTE technology involves an understanding of a complex blend of factors including location, haul distance, regulations, capital costs, feedstock availability, tipping fees, taxes, electricity price, and incentives which do not necessarily denote a linear behaviour. Therefore, the business feasibility of gasification technologies is still unclear. This paper includes the development of a model that combines the aforementioned factors in the context of a potential gasification plant in the USA. The model successfully concluded that location is the most sensitive factor for most of the cases. Authors include a geographical analysis which may be used, in combination with the model, to decide on regional energy options and new business opportunities.

Keywords: gasification; municipal solid waste; MSW; electricity production; economic analysis; USA.

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1 Introduction

In recent years, the generation of municipal solid waste (MSW) has grown steadily due to factors including rapid population growth and urbanisation. In 2010, approximately 250 million tons of MSW was generated in the USA compared to 208 million tons generated in 1990 (EPA, 2013). Despite various waste management programs focused on recycling and waste prevention, small states are facing difficulties in processing the increased volumes of waste (*Waste Business Journal*, 2015). Many states, primarily in the East Coast, are choosing to pay tipping fees to export their waste to states located in the midland, which have larger landfill capacities.

An alternative to exporting waste is to adopt waste conversion technologies. Through waste-to-energy (WTE) technologies, waste is converted into various fuels used to generate an energy supply. Incineration is a common form of WTE technology that effectively reduces large volumes of waste. However, WTE technologies like incineration raise environmental and ethical concerns including debates around not-in-my-backyarders, visual aesthetics, and emissions.

Gasification is a new emerging WTE technology that uses waste to produce renewable energy more efficiently while offering a less controversial environmental alternative. Countries including Japan, Denmark, and the Netherlands have embraced WTE opportunities through waste management policies. Despite technological advances, WTE technologies are affected by a number of complex factors including location, haul distance, regulations, capital costs, feedstock availability, tipping fees, taxes, electricity price, and incentives. These factors do not appear to have been studied within a single model. Understanding the blend of technical, economic and geographic conditions that favour the adoption of more energy-efficient technologies is still a gap in the research literature.

1.1 Gasification

Gasification is the partial combustion of organic matter at an oxygen concentration below stoichiometric proportions. The process results in a gas product known as synthesis gas (syngas), which is a mixture of hydrogen, carbon monoxide, carbon dioxide, methane, small quantities of hydrocarbon oils and ash, as shown in Table 1.

Table 1 Typical ranges for syngas composition

Gasifier gas (syngas) composition	
Component	*(Vol. %)*
H_2	25–30
CO	30–60
CO_2	5–15
H_2O	2–30
CH_4	0–5
H_2S	0.2–1
COS	0–0.1
N_2	0.5–4
Ar	0.2–1
NH_3 + HCN	0–0.3

Source: Ciferno and Marano (2002)

Coal gasification technologies were developed in the 18th century to produce fuel to light towns. Throughout WWII, coal gasification was used in the Fischer-Tropsch process to produce liquid fuel and other commodity chemicals such as fertilisers. Gasification was also used to produce fuels for electricity generation and for the production of fine chemicals like ethanol. Interest in coal gasification dropped in the 1950s due to discoveries of large reservoirs of natural gas, but the need for syngas only intensified. The oil crisis in the 1970s renewed interest in coal gasification, however interest reduced again due to the oil glut in the 1980s. Today, the rise of energy costs, along with the increasingly accepted notion that human development needs to reduce its dependence on fossil fuels to be sustainable, supports the idea that gasification will play an important part in the transition towards a world with sustainable energy sources (Maurstad, 2005; Higman and van der Burgt, 2008; Younas and Asif, 2016).

1.2 Previous work

Research performed on the feasibility of biomass and MSW gasification before and during the 1990s focused primarily on the technical description and optimisation of the biomass gasification process (de Souza-Santos, 1999). Still, valuable work was produced regarding the economic potential of the process (Bellarmine and Turner, 1994; Bridgwater, 1995; Faaij et al., 1997; Tellini et al., 2007). The development and operation of commercial-scale waste and biomass gasification plants have shed light on the technical uncertainties of the processes. This has led to the opportunity of carrying out multiple economic analyses of currently operating plants.

Penniall and Williamson (2009) investigated wood refuse gasification, which provided heat and on-site electricity to sawmills in New Zealand. A key finding in their study highlighted the need to secure a reliable and sufficient source of feedstock that would allow the plant to operate at optimum capacity at all times and be financially feasible. A conclusion from this observation, which is explored in this paper, is that the proximity of the feedstock source to the plant location plays an important role in securing the vitality of waste gasification projects.

Yagi and Nakata (2011) performed an economic analysis of forest biomass gasification in Japan. The study focused on using gasification as a way to manage forest residue. An important result analyses how geographical resources allow a plant to work at a profitable capacity. This can be translated to the biomass gasification process, independently of the type of feedstock used, as it confirms the importance of continuous operation at optimum capacity. Another interesting result is the trade-off between plant size and transportation costs. The study shows that while economies of scale tend to benefit larger plants, cost pressure associated with the transport of a higher quantity of feedstock from more distant locations may also set an important limitation.

Choy et al. (2004) studied the impact of process design on the feasibility of small scale MSW gasification for a university campus heat and electricity generation. The study investigated the financial viability of a 10 ton per day facility. Their work concluded that a plant of such a small scale is not an attractive investment; however, doubling the capacity to 20 tons per day, even at these small scales, already shows benefits from economies of scale.

Upadhyay et al. (2012) completed an economic feasibility study on the potential of biomass gasification for power generation in northwestern Ontario. Their work analysed the cost structure and estimated per unit electricity production cost and the effect of increasing scales.

While research has successfully addressed many of the technical uncertainties and economic variables related to biomass gasification, there is less information on the business potential for MSW gasification (in the USA). Regional and local effects such as tipping fees, regulation of electricity prices, incentives and taxes have not received full attention. Under certain circumstances, these factors become tipping points when evaluating the potential of new investments.

2 Objective

The objective of this study is to provide a high-level model for determining the financial feasibility of waste gasification projects in the USA. The model evaluates the relative impact of process and economic variables by providing an analysis of the business potential of a given project. It also serves as a tool to assess the business potential through the estimation of profit structures, net present value, electrical power generation, and other technical and financial factors.

The customisation of almost all variables is desirable for a high-level model of this type for two main reasons:

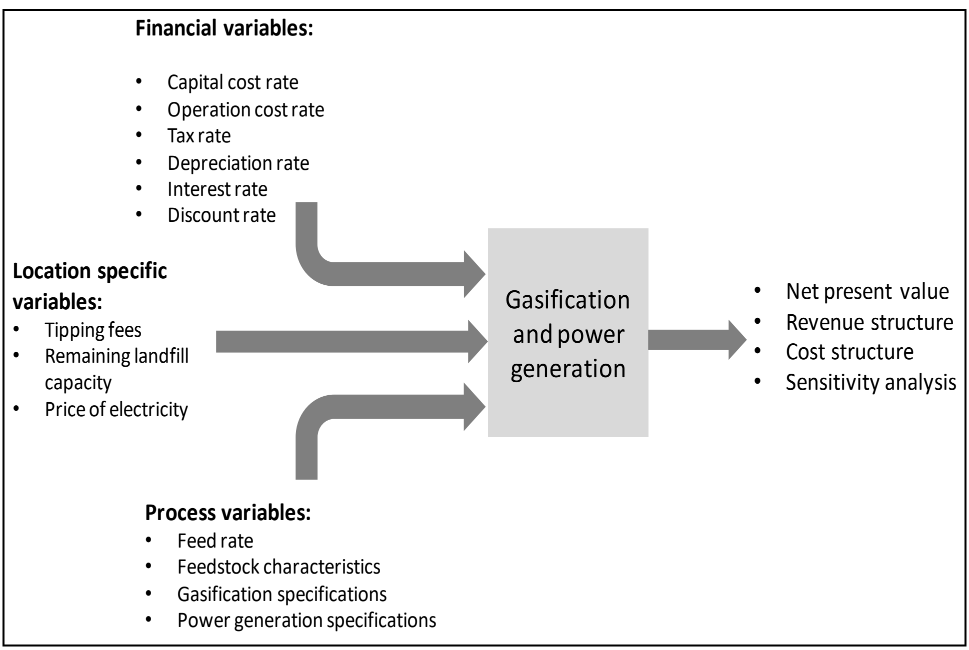
1 Waste gasification plants are commonly built using technologies originally designed for coal or coal-waste mixtures. This means that plants are usually retrofitted to accommodate the specific conditions of each project. This implies a lack of standardisation that can be factored in using a high-level model.

2 A ‘user-defined’ option allows customised analysis of a specific project.

3 Method

The model is designed to use information available in literature and compilations from the *Waste Business Journal* (2015) for data specific to each state on waste generation, tipping fees, and electricity prices. Figure 1 illustrates the model developed to analyse the gasification technology. The structure of the model allows for the customisation of variables in the most common ranges described in literature on operating waste gasification plants. The three main categories used are financial variables, location-specific variables, and process variables. Together, these are applied to calculate the indicators of financial feasibility: net present value, revenue structure, and cost structure.

Figure 1 Model structure



3.1 Feedstock characteristics

MSW is comprised of different ratios of organic and inorganic refuse from residential, commercial, and public sources. Paper and cardboard constitute around 29% of the waste, with yard trimmings and food scraps accounting for approximately 27%. Plastics, rubber, leather, and textiles comprise close to 20% of the mix, along with metals, glass, and other non-gasifiable components constituting the remaining 12%–15% (Table 2, EPA, 2013). Moisture content varies depending on the type of waste, but a reasonable estimate can be set at a range of 21% to 28% at the moment of floor tipping (Choy et al., 2004).

Table 2 MSW generation, recycling, and disposal in the USA: facts and figures for 2010

Average composition of MSW in the US, 2010	
Food scraps	14%
Paper	29%
Yard trimmings	13%
Wood	6%
Rubber, leather and textiles	8%
Plastics	12%
Metals	9%
Glass	5%

Source: EPA (2013)

Heating value and moisture content are directly associated with the composition of MSW and strongly influence the aptness of the waste to be a gasification feedstock.

The heating value of fuel refers to the amount of chemically bound energy available (measured in units of energy per amount of matter). The type of gasification technology and the oxidising agent have a strong influence over the final syngas product (Upadhyay et al., 2012). The quality of the syngas depends on the heating value of the gas where lower heating value feeds result in gas with a lower heating value and higher impurities (Ciferno and Marano, 2002; Fichtner Consulting Engineers Ltd., 2004). Table 3 presents the characteristics of MSW considered in the model.

Table 3 Characteristics of MSW considered in the model

MSW characteristics		
Average heating value (MJ/kg)	*Moisture content (wt)*	*Non-gasifiable components*
9.5	21%	12%

Source: PNNL (2008)

Moisture content is factored as a percentage of the bulk weight of the feedstock (Ciferno and Marano, 2002). The gasification process has productivity limits in respect to water content (Quaak et al., 1999). It is important to consider plant design with respect to the feedstock supply (Eckard, 2011) because for feedstock with high water content, the cost of the drying phase can represent up to 10% of the capital investment costs of the project (Quaak et al., 1999). The typical waste mix of MSW in the USA is used as a model for the moisture content and heating value ranges used in the gasification model (Higman and van der Burgt, 2008; Choy et al., 2004; Fichtner Consulting Engineers Ltd., 2004; Tchobanoglous et al., 1993; Chin and Franconeri, 1980; PNNL, 2008). Table 4 presents several heating values of MSW reported in literature.

Table 4 Heating values of MSW reported in literature.

MSW heating values from literature	
Reported value (MJ/kg)	*Source*
13.6	Choy et al. (2004)
11.1	Tchobanoglous et al. (1993)
10.0	Higman and van der Burgt (2008)
11.9	EIA (2007)
9.50	Chin and Franconeri (1980)

3.1.1 Feedstock rate

The model calculations are based on the estimated characteristics of feedstock entering the gasification process. The model considers feedstock between 25,000 tons and 300,000 tons per year and increases by 25,000 ton per year intervals. The model can, therefore, analyse the economic differences between small and large-scale projects.

3.2 Gasification stages

The gasification operation can be divided in terms of the main transformations, processes, and equipment used. Subdivisions of this segmentation include pre-treatment, gasification, gas clean-up, and power generation (Bridgwater, 1995).

A report produced by Advanced Energy Strategies for the Alameda Public Utilities Board segments the gasification process in terms of the products obtained in each stage (i.e., dry feed, raw gas, clean gas, and power) (Morris and Waldheim, 1998). Pre-treating MSW before the gasification stage ensures that non-gasifiable and recyclable materials are removed (e.g., metals, glass, bulky objects), moisture content is compatible with process specifications, and particle size is optimal for performance.

The equipment associated with waste gasification is highly dependent on the desired product and can lead to variations in the initial capital requirements. The approximate structure for capital costs includes 15% for pre-treatment, 15% for gasification and product conditioning, 30% for energy generation stages, and 40% for general systems such as electricity, controls, and buildings (Faaij et al., 1997).

The stages of MSW gasification used in the model are based on a combination of the segmentation strategies referenced above:

1 *handling and pre-processing:* waste reception, storage, grinding, and drying

2 *conversion and conditioning:* feed system, gasification, gas cooling, and scrubbing

3 *electricity generation:* generation of electricity from syngas.

3.3 Modelling the conversion phase

The model assumes that the feedstock is ready to enter the drying, sorting and gasification stages. Feedstock with high water content has less combustible matter per kilogram of fuel (Ciferno and Marano, 2002). The main variables used in the model are: the mass feed rate of waste that enters the process, the type of waste, and the proportion of non-gasifiable components in the waste mix [equation (1)]. An 80% conversion rate from gasifiable waste feedstock to clean syngas was used throughout the model in accordance to maximum gasification efficiency ranges (Higman and van der Burgt, 2008).

$$P_g \approx \frac{F \times \left(1 - C_{H_2O} - C_{n.g.}\right) \times \eta}{\rho_{Syg}} \tag{1}$$

where

P_g is the volumetric flow of syngas in m^3 per year

F is the mass feed rate in tons per year

C_{H_2O} is the proportion of water in the feed

$C_{n.g.}$ is the proportion of non-gasifiable material in the feed

η is the overall conversion of the gasification process

ρ_{Syg} is the density of product syngas in ton/m^3.

The gas-cleaning phase prepares the product gas for power generation using a furnace or combined cycle system. The cleaning, cooling, and scrubbing removes tars, alkali metals, and dust that would make the gas unsuitable for power generation (Ciferno and Marano, 2002). In the model, we assume that the matter lost during the gas cleaning and scrubbing is not significant, and thus, no impact on the mass balance is considered in the calculations.

In order to simulate the match between feedstock heating value and product quality, the model links feedstock specifications to the resulting quality of the product (i.e., low heating value feedstock yields low heating value syngas).

3.3.1 Power generation

Depending on the technology used in the power generation stage and the quality of the process design, electric efficiency can range from 5% to 40% (Ciferno and Marano, 2002; EIA, 2015). A report by Fichter Consulting Engineers on the feasibility of waste gasification in the UK (Fichtner Consulting Engineers Ltd., 2004), analysed the electrical efficiency of different power generation systems. Their analysis included steam cycle, gas engine, and combined cycle systems. The results indicated a low-end efficiency of 20%, corresponding to the simple steam cycle, and a top efficiency of 34% for the combined cycle system. The model considers discrete values for the overall electrical efficiency of 25%, 30% and 35% in equation (2). The model also assumes that the electricity generated is sold back to the electrical grid at a price range of \$0.09 to \$0.12 per kWh, which coincides with reported ranges of electricity prices (DSIRE, 2015).

$$E = \frac{P_g \times H_{c_{syg}} \times \varepsilon}{3.6} \quad (2)$$

where

E is the electricity generated in kWh per year

$H_{c_{syg}}$ is the heat of combustion of the product syngas in MJ per ton/m^3

ε is the overall electric efficiency of the process 3.6 is the conversion factor from MJ to kWh.

3.3.2 Revenue structure

As previously stated, WTE tipping fees vary across states from close to $30 per ton to over $90 per ton. This disparity is directly related to the remaining landfill capacity available in each region, with those with low remaining capacity having the highest costs to landfill. The value of alternative waste management options becomes more attractive as landfill capacity continues to decrease. Table 5 presents the main sources of revenue for MSW gasification plant.

Table 5 Sources of revenue for MSW gasification plant

Revenue sources	
Waste-to-energy tipping fees	= (waste treated) × (tipping fee)
Electricity generation	= (electricity generated) × (price of electricity sold into the grid)
Incentives	= (electricity generated) × (overprice of electricity through incentives)

The model accounts for the fact that incentives for renewable energy use vary throughout the nation with a customisation option that overestimates the price of electricity fed into the grid per kWh. The model takes into account a $0.01 to $0.03 per kWh increase similar to the models used in states with moderate potential to benefit from gasification technologies because of lower than average remaining landfill capacity, but also lower than average tipping fees for their region. Examples of such states include California, Colorado, and Michigan, which have federal and state incentives in place purchasing electricity derived from technologies such as landfill gas (Granatstein, 2003).

3.4 Location

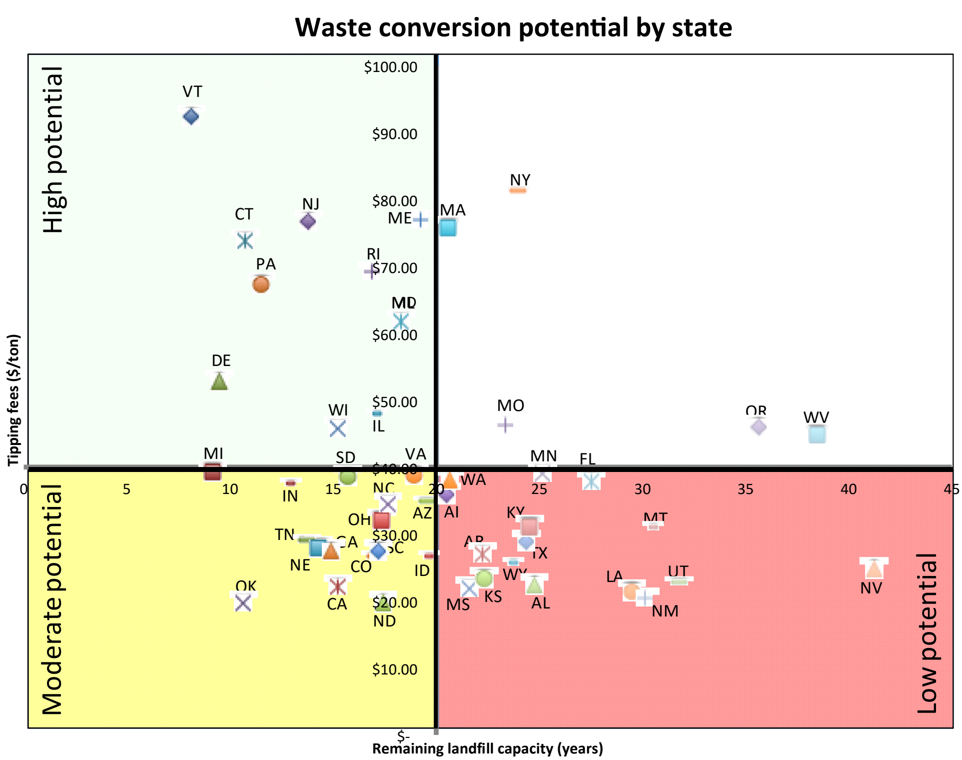
Regional WTE tipping fee values are used to evaluate the relative impact on the financial feasibility. According to our results, WTE tipping fees represent a primary revenue source, accounting for over 60% of the total revenue. Depending on the buy-back price of electricity in the given state or region, along with the incentives set in place, the financial feasibility of a plant can improve if the electricity generated is used to power the facility instead of being sold directly to the grid.

The price at which utility providers buy electricity from third parties is not standardised across all states and is subject to highly complex regulations. To avoid including varieties of electricity rates in the model, we used discrete values for the direct sale of electricity from \$0.07 to \$0.12 per kWh, to capture a range of the average price of electricity in the commercial sector for many states (DSIRE, 2015; Granatstein, 2003).

Fiscal incentives exist in different forms in every state; however, some of the common structures for incentives are an over-price for the buy-back electricity rate and fiscal deductions impacting the taxable profit (Granatstein, 2003). We included a range of over-price of \$0.01 to \$0.02 cents per kilowatt-hour to account for the over price of the buyback electricity rate. To simulate the fiscal deductions, we applied discounts of 5%, 10% and 15% over operation costs.

For gasification to become an attractive alternative to landfills, significant stress needs to exist over the region's remaining landfill capacity. The gasification potential analysis represented in Figure 2, shows that several north eastern states present the above mentioned characteristic. A common factor for these states is that they all have high urban populations and little to no-land to use as landfills. In regions that form low landfill capacity clusters, there is a trade-off between savings from exporting the waste to high landfill capacity regions, and the hauling costs incurred on transportation of waste over long distances. Thus, gasification opens the possibility of treating waste within the generator state and reducing the amount of waste that needs to be landfilled by up to 95%, as only non-gasifiable waste and gasification sub-products would ultimately reach the landfills.

Figure 2 Distribution of gasification potential for US states matrix (see online version for colours)



Source: *Waste Business Journal* (2015)

We have classified the potential for gasification in four quadrants:

1 *high potential:* states that have tipping fees above the national average and remaining landfill capacity below the national average

2 *moderate potential:* states that have tipping fees and remaining landfill capacity below the national average

3 *low potential:* states that have tipping fees below the national average and remaining landfill capacity above the national average

4 *unclear potential:* states that have tipping fees and remaining landfill capacity above the national average.

North eastern states tend to show the greatest potential for alternative waste management options from increased pressures due to decreasing landfill capacities and rising landfill tipping fees. This opens the possibility of waste conversion technologies such as gasification to become more competitive in the renewable energy sector.

3.5 Cost structure

3.5.1 Capital cost, initial investment

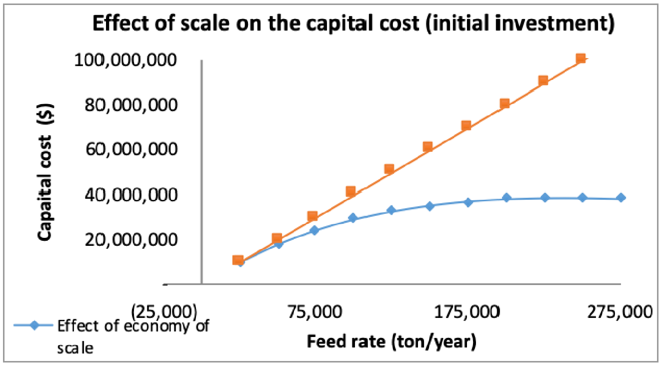
Specifications for waste gasification plants strongly depend on the type of feedstock, gasification technology, and desired products. A lack of standardisation causes many plants to be very particular in design and explains the scarcity of commercial scale plants that are currently operational.

The report, 'Thermal and digestion WTE technologies worldwide' published by SBI Energy in 2011, found that the capital cost for waste gasification plants ranges from $1,300 to $2,000 per kW. However, due to ancillary systems, the cost for an entire project is estimated at $4,979 per kW or $399 per ton per year, with a peak cost of $524 per ton per year. The estimated capital cost for biomass gasification in Ontario ranges from $2,500 to $5,500 per kW with a power generating capacity ranging from 10 to 50 kW (Upadhyay et al., 2012). Values of $2,750 per kW power production were also reported for a combined cycle system (Eckard, 2011).

The model considers a capital cost including pre-treatment, gasification, and electricity generation stages estimated at a range of $350 to $550 per ton treated. Using these specifications, the range for the annual mass of feed is 25,000 to 300,000 tons and a range of $2,296 to $5,300 for the capital cost per kWh of power installed.

Capital costs per ton decrease as plant capacity increases due to the economic scale of the production system (Upadhyay et al., 2012). The cost of ancillary and logistic services grows at a lower rate than the cost associated directly to the level of production, which means that economies of scale favour plants with larger capacities. In order to include this effect of scale in the model, a capital cost scale factor was used in the calculations Figure 3.

Figure 3 Effects of compound capital cost scale factor of 0.9 on the capital cost as scale increases using baseline specifications (see online version for colours)



3.5.2 Operation costs

Operation costs for a gasification plant can be divided into fixed operating costs and variable operating costs (Choy et al., 2004). Fixed costs such as labour, maintenance, and insurance do not vary widely with a change in the production rate. Therefore, variable operating costs depend on the amount of product produced including the variable costs of raw materials, utilities, and ancillary systems such as the gasification agent. A study by Fichtner Consulting Engineers Ltd. (2004) estimated $30 per metric ton of waste and the model considers a $25 to $40 per metric ton of waste treated in the operating cost.

Table 6 Description of variables considered in the net present value calculation

Waste treated (ton/year)
× Tipping fees ($/ton)
= Revenue from tipping fees
= Revenue from energy generation
= Incentives revenues
= Total revenues
– Operation costs
– Depreciation
EBIT
– Taxes
– Interest expense
= Net income
+ Depreciation
– CAPEX
= Free cash flow
Discounted cash flow
NPV

3.6 Net present value calculation

Net present value is one of the main indicators of financial viability of a plant (Table 6). The calculation follows the revenue and cost models as well as standard financial variables including cash flow in a ten-year period. To better represent the increase of waste generation over time, the model factors an annual increase of waste treated and WTE tipping fees.

$$NPV = \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} - C_0$$

Net present value is a major indicator for financial feasibility because it is sensitive to process and financial variables that can provide a discrete measure of business opportunity. A sensitivity study of these factors was performed to determine the regions that show the best financially viability for plant location.

4 Results and discussion

Different parameters associated with the process and the location of a project were evaluated. To isolate the effects resulting from a particular variable, all other variables were maintained at the baseline model. The parameters studied included feed rate, tipping fees, and buyback price of electricity. Additionally, a sensitivity analysis was performed to identify the relative impacts of the above variables, as well as the capital and operation costs.

4.1 Baseline scenario

A baseline scenario was defined in order to evaluate the financial impact of changes in key process and financial variables. The baseline conditions were selected based on the operating ranges described in the previous sections (Tables 7 and 8).

No incentives were considered in the baseline model since they are specific to the regulation of the particular regions where projects are being developed. Instead, the impact of possible incentives regarding electricity price, was reflected by a reduction of the buy-back price per kWh of electricity. California was selected as the state for the baseline scenario because it’s reported region-specific variables lie close to the average values for the USA, thus, simplifying the sensitivity analysis.

4.2 Effect of scale

Net present value was calculated at increasing feed rates of MSW (25,000 to 300,000 ton per year). Figure 4 show that higher feed rates have the expected positive effect over the value of the project. At baseline conditions, the net present value becomes positive at approximately 100,000 tons per year. By considering average per capita waste generation in the USA at 4.38 pounds per person per day (EPA, 2013), we can estimate the required population to supply this amount of waste, and consequently, the regions that could potentially achieve profitability for a gasification plant.

Table 7 Process variables adopted for the baseline model

Baseline scenario: process variables	
Feedstock	
Type	MSW
Moisture content (%wt)	21%
Heating value (MJ/ton)	9,500
Non-gasifiable components (%wt)	12%
Gratifier specifications	
Conversion	0.8
Capital cost ($/ton)	400
Operation costs ($/ton/y)	30
Days per year	350
Location	
Region	Pacific
Landfill tipping fees ($/ton)	22
Waste-to-energy tipping fees ($/ton)	68
Remaining landfill capacity (ton)	611,596,632
Remaining landfill capacity (years)	15.23
Energy generation process	
Heating value of syngas (MJ/ton/m^3)	8
Electricity buyback price ($/kWh)	0.09
Electricity generation efficiency	30%

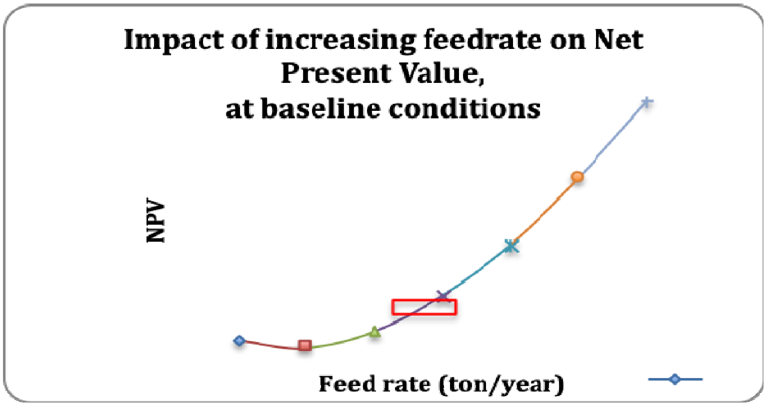
Table 8 Financial variables adopted for the baseline model

Baseline scenario: financial variables	
Incentives as an overprice of electricity ($/kWh)	None
Capital cost scale factor	0.9
Growth rate of MSW tons processed	1%
Growth rate of tipping fees	2%
Interest rate	6%[a]
Depreciation rate	10%
Tax rate	30%
Discount rate	10%[b]

Source: [a]Faaij et al. (1997) and [b]Penniall and Williamson (2009)

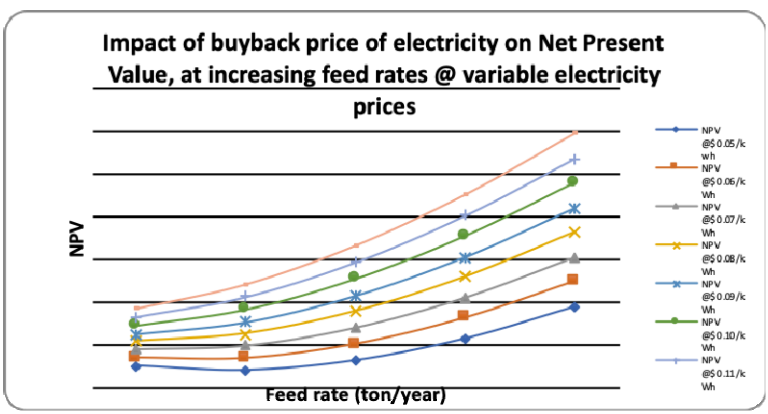
In the particular case of the baseline scenario, the 100,000 ton per year feed rate corresponds to a minimum population of approximately 135,000. Evidently, the same gasification plant would not treat all the waste generated by a population of this size, nor would it all be gasifiable material. Thus, a more conservative figure would indicate a minimum population of approximately 200,000 people to supply a 100,000 ton per year plant.

Figure 4 Net present value as a function of feed rate at baseline conditions (see online version for colours)



Buyback prices for electricity were incorporated into net present value calculation, at a range of \$0.07 to \$0.12 per kWh (Figure 5). At higher prices, the positive impacts can allow smaller scale designs with a feed rate of fewer than 60,000 tons per year to still be profitable.

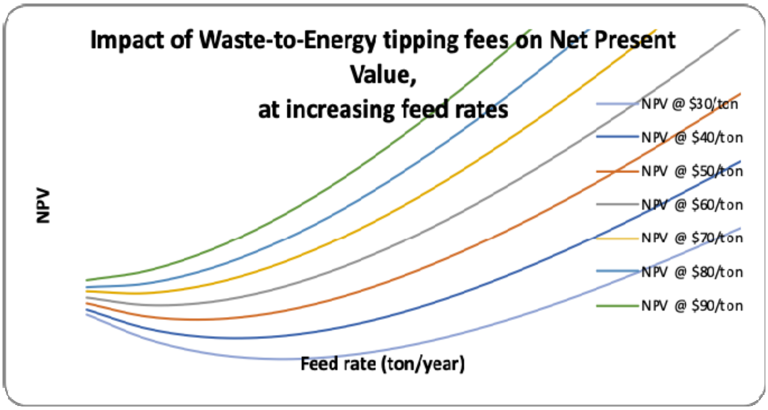
Figure 5 Net present value as a function of feed rate at varying electricity prices (see online version for colours)



4.2.1 Effect of tipping fees

Much like in the analysis of electricity prices (Figure 6), higher tipping fees support the financial viability of gasification plants at lower scales. An additional benefit of gasification plants is the reduction of close to 90% of the waste that reaches landfills (Bellarmine and Turner, 1994; Fichtner Consulting Engineers Ltd., 2004; EIA, 2015). This may have a positive impact on the social perception of WTE technologies that have not been successfully adopted in the past due to 'not in my backyard' policies.

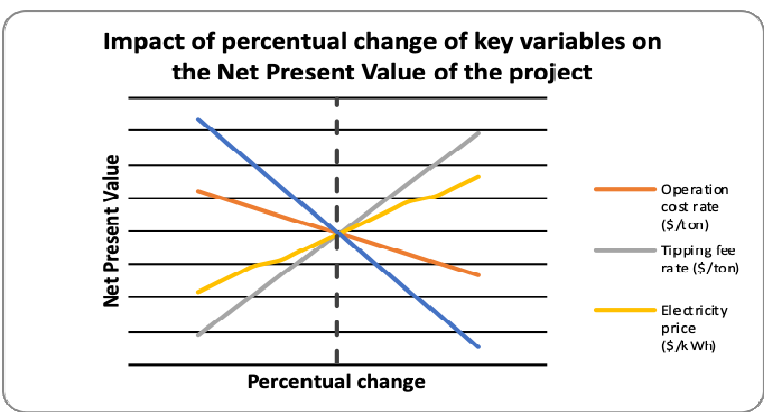
Figure 6 Net present value as a function of feed rate at varying WTE tipping fees (see online version for colours)



4.3 Sensitivity analysis

The sensitivity analysis (Figure 7), assessed the impact on the net present value caused by changes in the operating cost and capital cost rates, price of electricity, and landfill tipping fees, relative to the baseline. Throughout this exercise, the feed rate was kept constant at 100,000 tons per year while the other variables were independently analysed through individual percentile variations.

Figure 7 Sensitivity analysis for process variables (see online version for colours)



The relative impact of the variables over the net present value of the project is in direct relation to the steepness of the line resulting from calculating the NPV in terms of a percentage deviation from the baseline. Table 9 shows the change in NPV for a percentile change.

Table 9 Net present value changes due to a 1% deviation for selected variables

	Change resulting from a 1% increase
Concept	*NPV ($)*
Capital costs	–341,980
Operating costs	–125,107
Electricity price	191,512
Tipping fees	303,931

From Table 9, we see that the capital cost rate significantly affects the profitability of the project. An increase in 1% to the capital cost rate, results in a negative impact of almost $350,000 on the profitability of the project. In contrast, the operation cost rate has a lower negative impact of $125,000 per percentual increase. Tipping fees have a positive impact on profitability where each percent increase accounts for a positive impact of $300,000. The price of electricity also has a slightly more moderate impact on $200,000 increase in profitability per percent increase.

The results imply that revenues and costs can be segmented into high impact and moderate impact categories depending on their effect on NPV. Capital costs and tipping fees are of special interest, since optimising the NPV should focus on minimising the former and maximising the later.

5 Conclusions

Waste conversion technologies have developed in direct response to the increasing generation of MSW, paired with the constantly decreasing landfill space. Among these technologies, gasification has been adopted by countries like Japan and areas of the European Union. In the USA, financial and regulatory factors have made determining the profitability of a gasification plant highly dependent on location and waste feed rate. Research by equipment and plant manufacturers has focused on technological designs and process specifications in an attempt to characterise the process for optimum efficiency. Location plays a significant role because tipping fees are determined on a state-by-state basis and can account for a large profit. Furthermore, a local population must provide the minimum 100,000 tons of waste per year in order to return a profit.

Our research focused on a model that could determine the effects of key variables associated with revenue and cost structures. The model's sensitivity analysis identified that location (tipping fees) and capital costs play the largest impact on the net present value of a gasification project. While other key variables such as operating costs and the price of electricity play important roles, these variables play more of a secondary role.

The model developed and presented in this paper is flexible and can accommodate inputs from various regions, including feedstock composition, federate, and tax incentives, which vary among states and countries. Technology adoption is a multi-criteria management decision. The work presented in this paper can serve as a tool and a source of knowledge to support better decisions.

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