Considerations for waste gasification as an alternative to landfilling in Washington state using decision analysis and optimization

Philip Behrend a, Bala Krishnamoorthy b, *

a Washington State University, 31 Aspen Ridge Lane, Newport WA 99156, United States
b Washington State University Department of Mathematics, 14204 NE Salmon Creek Ave, Vancouver, WA, 98686, United States

Abstract

The United States is among the highest waste-producing nations in the world, but unlike many other developed nations, it processes only a fraction of its waste for recycling or energy production. The feasibility of alternatives to landfilling was explored using a multi-criteria decision-making model and a linear optimization model. Specifically, further development of waste gasification in Washington State was considered. In Washington, landfilling is still the primary form of waste management, resulting in significant environmental and social costs. The first stage of the analysis entailed the identification of the most effective gasification method for a plant located in Seattle with the objective of significant waste diversion from the largest waste processing site in Washington, the Roosevelt Regional Landfill. The Analytic Hierarchy Process (AHP) was employed to perform an objective comparison. This process ranked the gasification alternatives using various criteria and determined that steam gasification was superior to the other options, due to capacity and clean byproduct gases. Subsequently, a network optimization model was constructed to compare the cost of steam gasification and landfilling over a ten-year period, determining whether gasification plants would be viable in Seattle and Alaska. Results indicate that the Seattle gasification plant would be a superior option to current landfilling practices while an Alaska plant would be infeasible, in part due to the limited quantity of waste transported from Alaska to Roosevelt. Gasification methods will become more cost-effective as technology evolves, suggesting that currently infeasible methods have future potential.

Keywords: Waste gasification; Landfilling; Analytic hierarchy process (AHP); Linear optimization

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1. Introduction

Methods for effective disposal of waste have been a dilemma since the beginning of urbanization. Until the 20th century, citizens primarily disposed of waste in the streets, destabilizing the surface and creating an environment conducive to the spread of disease. As a result of the Industrial Revolution in the late 19th century, populations in cities increased rapidly and greater quantities of municipal solid waste (MSW) were produced. During this period, some manufacturers recognized the value of industrially repurposing waste to meet production demands. For example, bones from slaughterhouses were processed to extract phosphorus, which was then used to make matches (Barles, 2002).

As MSW became a greater public health concern at the beginning of the 20th century, rudimentary waste
management techniques were created. Initial waste management consisted of collecting urban waste and dumping it away from the city. In conjunction with landfilling, scrap metal recycling gained popularity during World War II due to the scarcity of resources. After the war, recycling declined until legislation in the 1970s renewed the incentive to recover used materials (Kollikkathara et al., 2009).

Waste incineration gained popularity until the 1960s because it was cheap and rapidly reduced the mass of waste. However, public outcry against the toxic gases emitted by incineration plants prompted the Clean Air Act, which terminated unregulated incineration (Louis, 2004). This legislation, along with the discovery that garbage incineration produces cancer-causing dioxins, diverted investment away from combustion of refuse.

In contrast to the United States, many European countries invested in cleaner incineration technology rather than abandoning it. Due to investment in clean waste-to-energy technology, many European countries landfill a minimal proportion of their waste. Germany, an international leader in waste management, recycles 70%, incinerates close to 30%, and landfills less than 1% of its refuse. In Denmark, waste-to-energy plants provide 18% of the country’s district heating production while reducing the volume of combusted MSW by over 80% (Shibamoto et al., 2007; Christensen et al., 2013). Much of Europe has recognized MSW as a resource, and they are reaping the economic benefits.

In addition to sustainable waste management, much of Europe has reduced consumption of non-renewable energy sources. For example, Spain generated nearly half of its electricity from zero-emission technologies such as wind and nuclear power in 2014. In fact, Spain is the first country to generate the majority of its energy from wind power. A review of recent literature, however, presented unfortunate results regarding the true cost of wind energy. Wind energy has the potential to destabilize the power grid due to its unpredictability (Simmons et al., 2015). Many wind farms also have transmission problems, as was observed at a promising wind farm in McCamey, Texas. The study concluded that, without heavy government subsidies, wind power is not a viable energy source and that government funds should be more productively allocated.

Photovoltaic solar energy (PV) is another technology that has received significant investment in recent years. Multiple initiatives in the European Union have incentivized the use of PV, and in 2010, Germany installed more PV than the entire rest of the world during the previous year (Timilisina and Kerdgelashvili, 2017). In spite of the investment, PV only accounts for about 7% of Germany’s electrical power generation, in part due to the inefficiency of PV solar cells. At peak performance, thin-film silicon solar cells reach 12%–13% efficiency (Wirth, 2017). By comparison, gas turbines routinely operate at over 50% efficiency (Noroozian and Biki, 2016). Wind and solar energy are two popular alternative energy options, but the disadvantages are clearly documented. Consequently, analysis of other energy generation methods is valuable.

As the United States slowly makes the transition to more effective energy generation and waste management, evolving technology presents multiple possibilities. Although Europe has had success with incineration, more efficient processes are being developed, including steam gasification. The gasification process reforms MSW into primarily elemental constituents and syngas. Syngas, comprising of CO and H2, is used to produce clean biofuels. Gasification is more environmentally friendly than incineration but it is a costly technology that requires an organized waste management infrastructure (EPA, 2005). Therefore, a careful analysis is needed to compare the advantages of gasification as the United States advances beyond inefficient landfills. The main scope of our work is to use decision analysis and optimization techniques to identify the best mode of gasification based on various aspects including efficiency, economics, and environment concerns, and further identify the best location(s) for such gasification plant(s) in the state of Washington, such that these plants offer both environmental and economic advantages in the long run.

An examination of existing research on optimization models for waste management was conducted, which refined the scope of the research question. A recent literature review studied the use of multi-criteria decision-making methods for waste management and found that many researchers prefer to use the Analytic Hierarchy Process due to its simplicity and structured approach (Achillas et al., 2013).

The Analytic Hierarchy Process (AHP) is a systematic optimization technique that was developed in the 1960’s to satisfy the need for quantitative decision-making (Forman and Gass, 1996). The model allows for a synthesis of many complex variables in real-world situations and is applicable in a variety of contexts, including business, industry, healthcare, government, etc. Using the AHP, criteria and sub-criteria are given weights by the user (typically on a scale of 1–9) to reflect their importance. Matrices of the weights are created, and the eigenvector corresponding to the dominant eigenvalue of the matrices represents the relative importance of each criteria (at each level). The model may be used to select a single best option from many alternatives.

Review of the literature also found that optimization models for waste management could be categorized based on two topics: optimal strategy and optimal location. The objective of optimal location is to minimize transportation costs among feasible potential locations for a facility. Optimal strategy is concerned with comparing technologies to determine the most effective option based on a variety of criteria, such as environmental impact, cost, or societal perception (Achillas et al., 2013).

Several techniques from operations research are commonly used to model various waste management tasks. Since waste originates from many different areas and must be transported for processing, a network optimization model is a natural modeling choice. Network optimization models are a class of optimization models which define a network of nodes and arcs that may simulate waste generation, transportation and processing (Ahuja et al., 1993). A majority of the studies considered by the literature review employed integer programming in conjunction with network models. Most of the integer programming models use binary decision variables to decide whether or not to construct a waste processing facility. The major optimization objectives included minimization of transportation cost, processing cost, or fixed costs associated with facility construction and operations. Most studies evaluated the potential effect of landfills and recycling facilities, but did not consider waste gasification, presenting an opportunity to extend existing research (Ghiani et al., 2014).
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