Comparison between Landfill Gas and Waste Incineration for Power Generation in Astana, Kazakhstan

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ABSTRACT

The city of Astana, capital of Kazakhstan with population of 804,474 people and a rapid growth in the last 15 years, generates approximately 1.39 kg $capita^{-1}$ day^{-1} of municipal solid waste (MSW). Nearly 600-800 tons of MSW are collected daily and 97% of the collected waste in Astana is disposed on landfills. The operation of the oldest landfill started in 1972, whilst the newest landfill (first cell) started in 2006. The newest landfill was built using modern technologies, including a biogas collection system.

Astana as most urban areas in developing nations faces great challenges in the management of its MSW, whereas at the same time its rapid growth demands more and more energy in its path to development. Thus, the practical possibility to use MSW to generate electricity should be evaluated. This paper presents a prefeasibility study aiming to identify the better waste-to-energy technology to be implemented in Astana. The performance of landfill gas (LFG) and waste incineration (WI) technologies were compared, via technical-economic simulation of the corresponding Net GHG Reduction (tCO_2 yr^{-1}), Electricity Exported rate (MWh yr^{-1}), Net Present Value (NPV) in USD and Internal Rate of Return (IRR) in %.

Keywords: *Landfill, Waste Incineration, Electricity Production, Municipal Waste, Astana*

INTRODUCTION

Municipal Solid Waste (MSW) disposal in most developing countries around the world poses major environmental problems. Several problems arise from insufficient collection and bad disposal systems resulting in environmental and public health problems. To face the future problems in waste management, and to meet the demands of renewable energy resources, it is important that the waste is converted into energy. There are several technologies that can be used to produce energy from waste, such as landfill gas utilization and incineration.

Astana is the capital city of the Republic of Kazakhstan with a population of approximately 804,474 (Inquiry Office Info-Tses, 2013). Waste management problems in Astana can be well understood in the light of rapid urbanization in many cities along Kazakhstan. As the economic situation improves, with Astana constituting approximately 8.5% of the total GDP of US$ 151.67 billion in 2011 (Mudrichenko, 2012; Predictor, 2013) the concerns for waste management rise since a stronger economy often leads to an increased waste production due to a higher purchasing capacity.

About 1,118 t of MSW are generated per day in the metropolis, and the collection capacity is only approximately 600-700 t (54-63%). The waste that is collected undergoes engineered landfilling. The solid waste that is not collected is indiscriminately dumped or burned. The composition of domestic waste in Astana is presented in Table 1.

Current policies that guide the management of solid waste include:

- Environmental Code of the Republic of Kazakhstan (with alterations and amendments as of 17.07.2009).
- Order of the Ministry of Health of the Republic of Kazakhstan № 555 dated 28.07.2010 on the approval of sanitary rules "Sanitary facilities requirements for domestic purposes".
- Resolution of the Government of the Republic of Kazakhstan dated March 6, 2012 № 291. On approval of the Sanitary Rules "Sanitary requirements for the collection, use, application, processing, transportation, storage and disposal of production and consumption waste".

- Sanitary rules of solid waste landfills organization and maintenance N 3.01.016.97 * 9 (Logged Sanitary requirements for the content of sites for solid waste approved by Order of the Acting Minister of Health of the Republic of Kazakhstan dated March 24, 2005 № 137).
- SN RK 1.04-15-2002. "Landfills for municipal solid waste".
- Program of Modernization of municipal solid waste management for the years 2013-2050.

The basis for the “Program of Modernization of municipal solid waste management for the years 2013-2050” is:

- Concept of transition of Kazakhstan to a green economy, approved by the President of the Republic of Kazakhstan, dated May 30, 2013 № 577.
- P. 72 of Action Plan of the Government of Republic of Kazakhstan to implement the “Concept of transition of Kazakhstan to a green economy, approved by the President of the Republic of Kazakhstan”, dated August 6, 2013 № 750.

This program aims to increase efficiency, reliability, environmental and social acceptability of MSW collection, transportation, processing and disposal services. The targets of the program include:

- Achievement of maximum degree of extraction of secondary raw materials from MSW and its subsequent use.
- Achievement of maximum degree of processing organic fraction of MSW and minimization of disposal of biodegradable fraction to landfills.
- Increase of use of waste potential for the development of green energy.
- Ensuring effective and efficient operation of systems for the collection, removal, treatment and disposal of solid waste in settlements.

Table 1 Waste composition in Astana (Ministry of Regional Development 2012)

Waste Type	Major Items	Percentage
Organic waste	Vegetable and fruit parts, left-over foods, yard trimmings, wood	**28%**
Inert waste	Rubble, ashes, yard sand, bones	**12.4%**
Plastic	Bottles, containers, polythene bags, parts of electrical and electronic goods, worn-out tires	**18.5%**
Paper	Cardboard, newspapers, old/torn books, ruffled paper	**13%**
Metal	Cans, household utensils, wires, auto and bike	**0.9%**
Textile and Leather	Clothes, footwear, bags, cuttings from tailoring shops	**9.8%**
Landscaping waste		**1.5%**
Construction waste		**1.4%**
Glass	Bottles, drinking glass, jars, mirrors, louvers, auto windscreens, computer monitor screens	**14.5%**

Presently, Kazakhstan as a subscriber to Kyoto Protocol has proposed its “average yearly emissions to be 90% of 1990 levels during the period of 2013-2020” (Climate Action Tracker, 2013). However, there are no tax reliefs or incentives in the management of waste and procurement of waste treatment equipment and currently implemented policies are expected to increase emissions even further. Additionally, current electricity export rate in the Republic of Kazakhstan is around 70 USD per MWh for cogeneration systems (Astanaenergosbyt, 2014). The policies that give guidelines, examine and approve utility rates, monitor standards of performance for provision of services, and maintain a registry of public utilities are embodied in:

- Law of the Republic of Kazakhstan “On Electricity” N 588, 9 July 2004.
- Resolution of the Government of the Republic of Kazakhstan, dated December 7, 2000 N1822 “On approval of legal acts in the field of electricity”.
- Resolution of the Government of the Republic of Kazakhstan dated April 9, 1999 N 384 “On the power development program up to 2030”.

The objective of this paper is to assess and compare, at pre-feasibility level, the performance of landfill gas and waste incineration to energy projects in Astana (Republic of Kazakhstan), in terms of technical, environmental and economic criteria. The assessment will account for the amount of energy generated, emissions reduction, investment and operation costs, and financial outcome of both options.

MATERIALS AND METHODS

1. LANDFILL GAS FOR POWER GENERATION

1.1 LFG Generation Modeling

Most of the waste generated by human daily activities is sent to landfills. Within 1 year of the initial deposit of waste, the landfill gas (LFG) produced by the decomposition of waste should be exploitable with a composition of approximately 50% methane, 50% carbon dioxide, with roughly 1% of other organic and inorganic compounds (EPA, 2008). The Scholl Canyon model was utilized to estimate the potential for LFG generation of the site. This model considers that the LFG generation follows a first-order kinetics function and ignores the first two stages of bacterial activity (i.e., aerobic decomposition and transition, according to chart by Tchobanoglous et al., 1993). The waste composition and annual precipitation are the starting point for the modeling since they affect the generation rate and potential. The equation of the Scholl Canyon model for a single-fixed portion of mass, m_i, is the following (IPCC, 1996):

$$Q_{LFG,t,i} = k * L_o * m_i * e^{-k(t-i)} \quad (1)$$

Where:

i = the year of waste placement [year]

t = current year [year]

$Q_{LFG,t,i}$ = amount of LFG generated in current year (t) by the waste m_i [m^3 $year^{-1}$]

k = LFG generation rate constant [$year^{-1}$]

L_o = waste potential LFG generation capacity [m^3 t^{-1}]

m_i = amount of waste disposed in year i [t $year^{-1}$]

This equation is generalized to estimate the current emissions from waste placed in all years. Thus, eq. 1 can be added for values of m_i in consecutive years, resulting in:

$$Q_{LFG,t} = \sum_{i=initial\_year}^{t} Q_{LFG,t,i} = \sum_{i=initial\_year}^{t} k * L_o * m_i * e^{-k(t-i-lag)} \quad (2)$$

Note that there is a lag time required to reach the anaerobic stage, which is incorporated into the model replacing ¨t¨ by ¨t - lag¨. The lag time may range from 200 days to several years (IPCC, 1996). In this work the lag time is taken as 1 year.

Not all the LFG can be captured, but for engineered landfill gas facilities, an efficiency value between 50 and 75% is reasonable and can be achieved in Astana´s landfill gas facility. Table 2 suggests a value of k = 0.03 $year^{-1}$ for the conditions observed in the city of Astana (annual precipitation of 300 mm and moderately decomposable waste, since there is 28% of organic waste) (National Natural Park Burabay, 2014). In the absence of data, the EPA recommends to use, for pre-feasibility approximations L_o=170 m^3 of methane per ton of waste. Therefore, in this study, the typical L_o value will be used.

Table 2: Suggested k values for corresponding annual precipitation (The World Bank, 2004)

Annual Precipitation	**Range of k Values**		
	Relatively Inert*	**Moderately Decomposable**	**Highly Decomposable**
<250 mm	0.01	0.02	0.03
>250 to <500 mm	0.01	0.03	0.05
>500 to <1000 mm	0.02	0.05	0.05
>1000 mm	0.02	0.06	0.09

***** (Energy Information Administration, 2001)

1.2 System Configuration

LFG is collected and treated in order to use the methane for power generation. Methane is 25 times more powerful as a greenhouse gas (GHG) than CO_2 (EPA, 2010), therefore energy will not only be produced, but pollution will also be minimized. The use of LFG for power generation consists of three main stages: collection, pretreatment, and energy production.

- **Collection:** Vertical wells are drilled and connected to pipes for the transportation of collected LFG. In order to achieve the highest possible efficiency, these wells must be located according to the depth, age and geometry of the site. If the site is still in process of filling, then the use of horizontal collection trenches should be considered.

  A blower is needed to create the vacuum that will move the LFG through the piping. The criteria to be taken into account for the blower selection are the capacity of the equipment and the blower must be able to handle the estimated peak production of LFG.

- **Pretreatment:** The pretreatment is highly dependent on the combustion technology to be used for power generation, which in this case is a reciprocating engine. The first stage corresponds to water removal, as water can affect the efficiency of the generation plant by accumulating in the piping and reducing the space available for LFG, contributing to more pressure loss than expected. Another problem with the excess of water is that two-phase flow may turn into an unstable flow pattern and could complicate the operation of the plant. The water removed from the LFG has the characteristics of landfill leachate (slightly acidic) and needs to be disposed of responsibly, either by storing and transporting to a treatment facility or by installing an in-site leachate treatment facility. These costs will need to be taken into account in the financial analysis of this option. The second stage of the pretreatment consists in particle removal; the most frequently used techniques are filter pads and cyclones; the use of this second step of pretreatment should be evaluated as the LFG will be used in a reciprocating engine and this machine requires certain fuel quality conditions to operate properly.
- **Energy Production:** As mentioned before, the selected technology is a reciprocating engine, which as compared to a steam turbine, does not require the extra components, such as, condensers, cooling towers, makeup water treatment, and feed pumps (The World Bank, 2004).

Sometimes, an additional stage is considered. This is related to flue gas treatment for which a cost-benefit analysis should be performed to determine if it is justified (not considered in this pre-feasibility analysis).

2. WASTE INCINERATION FOR POWER GENERATION

2.1 Fuel Potential

The quality of the combustion from waste fuel depends on the energy content of the waste, measured as its Higher Heating Value (HHV) or Lower Heating Value (LHV), two concepts well known for most fossil fuels and related to the amount of heat released by the complete combustion of the fuel, with and without considering the non-condensed steam as part of the combustion products, respectively (Finet, 1987). In this analysis, the LHV is proposed, which is considered to be attractive when it has at least a value of 6 MJ kg^{-1} all year with an average of 7 MJ kg^{-1} throughout the year (Haukohl, 1999). According to the same author, the annual amount of waste for incineration should be no less than 50,000 metric tons, and the weekly variations in the waste supply to the plant should not exceed 20 % as basic conditions for a Municipal Waste Incineration plant. The furnace must be designed for stable and continuous operation and complete burnout of the waste and flue gases (i.e., CO<50 mg N^{-1} m^{-3}, TOC<10 mg N^{-1} m^{-3}).

From the waste composition data and the waste disposal rate (ton $year^{-1}$), the moisture content was calculated using mass fraction of MSW in Table 3. This step is called Proximate Analysis. The next step is the Ultimate Analysis where the dry weight of the feed waste is multiplied with chemical fractions in Table 4. This estimates the waste composition, which includes carbon, hydrogen, oxygen, nitrogen, sulfur, and ash, of the feed municipal waste in dry basis. Using the modified Delong formula for biomass fuel, the LHV can be found from the feed waste chemical composition. The fuel potential of the waste incineration is the total heat produced (GJ/hour) in the furnace as the product of the dry mass of feed waste and LHV.

Table 3 Fraction (%) of water, combustibles and ash of MSW (Magrinho & Semiao, 2008)

Waste Part	**Water**	**Combustibles**[*]	**Ash**
Paper	23	72.55	4.45
Plastic	20	74.24	5.76
Textiles	10	87.75	2.25
Wood	20	78.4	1.6
Yard	65	33.43	1.58
Other Fuel Waste	10	78.66	11.34
Glass	2	1.08	96.92
Metals	3	9.22	87.79
Other Waste Materials and fines	20.5	36.58	42.92

* Combustible components are Carbon, Hydrogen, Oxygen, Nitrogen, and Sulfur

Table 4 Dry chemical composition of MSW by mass (Magrinho & Semiao, 2008)

Waste Part	**Chemical Composition (%)**					
	Carbon	**Hydrogen**	**Oxygen**	**Nitrogen**	**Sulfur**	**Ash**
Food	46.7	8	38.88	2.13	0.12	4.17
Paper	43	7	44	0.2	0.02	5.78
Plastic	60	10	22.8	0	0	7.2
Textiles	55	6.6	31.2	4.5	0.2	2.5
Wood	49	6	42.7	0.2	0.1	2
Yard	47.8	6	38	3.4	0.3	4.5
Other Fuel Waste	53.8	8.9	23.3	0.83	0.57	12.6
Glass	0.5	0.1	0.4	0.1	0	98.9
Metals	4.5	0.6	4.3	0.1	0	90.5
Other Waste Materials and fines	26.3	3	16.08	0.5	0.12	54

2.2 Greenhouse Gas Emissions from Waste Incineration

One of the main aspects to be assessed in this project is referred to GHG emissions reduction associated to each of the two technologies of energy production from waste in relation to the conventional electricity production in Astana. The GHG emissions reduction is an important criterion of the pre-feasibility report. The emission per mass of waste burned is converted to emission per energy produced using fuel potential and feed rate value.

For the amount of municipal waste to be incinerated, the estimated emission factor of Nitrogen Oxide in a continuous incinerator is 50 gr N_2O t^{-1} of waste of wet mass and the CO_2 emission is estimated with Eq. 3 (Guendehou, Koch, Hockstad, Pipatti & Yamada, 2006). The value of 44/12 in the equation is the mass conversion factor from C to CO_2. Fossil carbon fraction is assumed as 35% for this calculation and additionally CH_4 emission factor was assumed as zero (Wikner, 2009). This last assumption represents the advantages of Waste incineration in averting methane release to the atmosphere (SEA, 2009).

$$CO_2 Emission = \sum_i (SW_i \times dm_i \times CF_i \times FCF_i) \times (44/12) \quad (3)$$

Where:

SW_i = feed waste type i based on wet mass (t/year)

dm_i = dry mass fraction in the waste of type i

CF_i = carbon mass fraction in the dry matter of waste type i

FCF_i = fraction of fossil carbon in the total carbon

i = type of waste incinerated

2.3 System Configuration

General set-up of the facilities in the power generation system for the waste incinerator considered in this case study consists of five stages, as explained below:

- **Pretreatment stage**: drying process in the receiving pit. This is necessary, so waste composition data can be used directly to estimate the heat generated in the furnace.
- **Incineration stage**: using the moving grate furnace.
- **Heat recovery stage**: utilizing the heat of the flue gas from the incineration to form steam for a low-pressure steam boiler. This alternative is convenient when energy recovery from the process is designed for electricity use only.
- **Energy production stage**: Integrating the system with the incineration sub-system to generate electricity, based on a conventional Rankine cycle with a steam turbine, condenser, boiler, and pump.

- **Emission control stage**: Using a series of selective non-catalytic reduction, semi-dry scrubber, activated carbon, and a bag house filter for an incinerator system with capacity of 600 t day^{-1} - 900 t day^{-1} (Kuo, Lin, Chen, Tseng & Wey, 2011).

3. RETScreen SIMULATION

The first step is to define the objectives and the options to be considered. The next step is to evaluate the costs of each option. After that, the GHG emissions from each option are quantified. Once this is done, the options need to be compared and ranked according to their cost/environmental performance and finally, decide which solution is the most cost-environmental effective (SEPA, 2006).

The assessment was performed using RETScreen simulation software. The general simulation mode was defined as power project, central grid type, method-2 analysis, and LHV reference. The electricity generation was simulated using reciprocating engine for LFG and steam turbine for waste incineration. Both technologies were designed to receive 270,000 ton year^{-1} of waste disposal.

3.1. Energy Model for LFG

The assumption used to generate energy model for LFG is that the project life of the proposed technologies is 25 years, which is a typical life span of these technologies. The main output of this model is the Power Capacity (kW) and amount of Electricity Exported to the Grid (MWh) per year. Based on existing and projected engineered landfills in Astana the input data for the analysis was collected and summarized in Table 5. From these fixed parameters, the LFG generation curve is plotted and subsequently used to select the capacity of the reciprocating engine.

Table 5 Landfill conditions

Parameter	
Year landfill opened	2015

Year landfill closed	2040
Size (acres)*	124
Waste disposal rate (t/yr)	270,000
Methane generation constant k (yr^{-1})	0.03
Methane by volume of LFG (%)	50
Methane generation Potential L_o (m^3/t)	170
LFG collection efficiency (%)	75

* The area of the new landfill is 124 acres (Irgibayev, 2010).

3.2. Energy Model for Waste Incineration

Several steam turbine cycle operating parameters, as seen in Table 6, were predefined. Availability of the system was chosen from the maximum value of new power system, and seasonal efficiency was chosen as an average value taken from literature. Power system capacity (steam flow, operating pressure, and turbine efficiency) were calculated by matching with the waste fuel potential.

Table 6: Operating parameters for steam turbine-power cycle

Parameters	**Values**
Back Pressure (kPa)*	50
Superheated Temperature (°C)*	550
Return Temperature (°C) **	90
Availability of system in a year (hours)	8,401
Turbine Seasonal Efficiency	75%

* (Udomsri, Petrov, Martin & Fransson, 2011)

** Suggested value from RETScreen

3.3. Emission Analysis Model

In Astana, 100% of electricity is generated by coal in thermal power plants (Astanaenergosbyt, 2013). Significance of Methane (CH_4) was accounted for as 25 times more powerful as a GHG than Carbon Dioxide (CO_2), and for Nitrogen Oxide (N_2O) a factor of 298 was used (IPCC, 2007). Emission factors in kg GJ^{-1} of CO_2, CH_4, and N_2O for landfill gas burning and waste incineration were the input values.

3.4. Cost Analysis Model

In this model, all costs related to the project are summed into two main groups of expenses which are initial cost, and annual cost. Initial costs can be found in Tables 7 and 8, and annual costs can be found in Tables 9 and 10, where values correspond to year 2014 by considering inflation rate over time. Table 7 Indexed to year 2014, initial cost database for Waste Incineration (Udomsri et al., 2010)

Table 7 Indexed to year 2014, initial cost database for LFG (EPA 2008)

Type	**Unit Cost**	**Unit**
Power System		
Steam Turbine Equipment	238.4	\$ kW^{-1}
Substation	279,889	\$
Waste Incineration System		
Ash and material hauling	10.8	\$ ton^{-1}

Furnace	119.2	\$ kW^{-1}
Boiler and flue gas duct	140.9	\$ kW^{-1}
Flue gas treatment	22	% of construction of boiler and furnace

Table 8 Indexed to year 2014, initial cost database for LFG (EPA 2008)

Initial costs for LFG were adjusted to 2014 by using CPI inflation indices (United States Department of Labor n.d.).

Type	**Unit Cost**	
Power System		
Reciprocating Engine & Pretreatment Equipment	1,866	\$ kW^{-1}
Substation	279,889	\$
LFG Collection System		
Collection and Flaring System	26,340	\$ acre^{-1}

The power capacity from the energy model determined the size of the steam turbine system and reciprocating engine system; the model can then calculate the total cost for each power system. The waste disposal rate was important to estimate the size and also the total cost of the waste incineration system and the LFG capturing system.

Table 9 Indexed to year 2014 annual cost database for Waste Incineration (Udomsri et al., 2010)

Type	**Unit Cost**	
Workforce	2.15	\$ ton^{-1} yr^{-1}
Operation and Maintenance	7.49	\$ ton^{-1} yr^{-1}
Chemical Reagents for Flue Gas Control	1.33	\$ ton^{-1} yr^{-1}
General and Administrative	1.01	% of workforce, O&M & flue gas control
MSW, ash, material hauling and others	10.84	\$ ton^{-1} yr^{-1}

Table 10 Indexed to year 2014 annual cost database for LFG (EPA, 2008)

Type	**Unit Cost**	
Engine O&M	198	\$ kW^{-1}
LFG Collection System O&M	4500	\$ $acre^{-1}$

3.5. Financial Summary Model

Financial indicators are calculated in this model based on macroeconomic variables suitable for the study, as in Table 11. The main source of project income is the sale of electricity exported by the system.

Table 11 Financial evaluation parameters

General Financial Parameters	
Electricity Escalation Rate	8%
Inflation rate	5.4%

Discount Rate	9%
Project Life	25 years
Debt Ratio	50%
Debt Interest Rate	4.5%
Debt Term	10 years

Inflation rate in Kazakhstan was taken as 5.4 % per annum based on data of September, 2013 (National Bank of Kazakhstan 2013). The Central Bank discount rate was 5.5% per annum based on data on 31 December 2012 (Trading Economics, 2013). However, accounting for extra uncertainties associated to the prefeasibility analysis, the discount rate was taken as 9% which is much more conservative. The annual nominal interest rate in foreign currency (USD $) was taken as 4.5 % (Kazakhstan Deposit Insurance Fund, 2013). Debt ratio was assumed as 50% and debt term of 10 years.

3.6. Climate Considerations

Atmospheric conditions of the location are a determining factor of the project performance. Astana's climate conditions were already available in the database of RETScreen. The database already covers monthly and annual average condition of: air temperature, humidity, atmospheric pressure and earth surface temperature.

4. RESULTS AND DISCUSSION

4.1. Power Generation Comparison

From the Proximate Analysis, the feed waste in Astana contained 32% of moisture (Ministry of Regional Development, 2012), and chemical composition on the dry basis of the feed waste can be found in Table 12. Both helped to determine the LHV during the incineration.

Table 12: Ultimate analysis of feed waste for waste incineration

C	H	O	N	S	Ash
31.7%	6.9%	36.7%	1.0%	0.1%	23.7%

The waste incineration power system capacity was adjusted, as presented in Table 13. This capacity determined the steam turbine size.

Table 13 Waste Incineration power system capacity

Parameters	Values	Units	Remarks
Waste Feed Rate	270,000	t yr^{-1}	
Dry Weight of Feed Waste	183,600	t yr^{-1}	Based on dry content fraction
Feeding Rate to the Incineration	20.96	t h^{-1}	
Lower Heating Value	14.25	GJ t^{-1}	
Fuel Potential	**298.6**	**GJ h^{-1}**	Based on Feeding Rate and LHV

Steam Flow	68,600	kg h^{-1}
Operating Pressure	80	bar
Turbine Efficiency	75	%
Fuel Required*	**291.4**	**GJ h^{-1}**

* A design criteria, fuel required should not exceed fuel potential

The sizing of the reciprocating engine is taken from the amount of LFG to be produced during the life of the landfill as plotted in Figure 1. RETScreen also generated the amount of electricity exported as seen in Table 14.

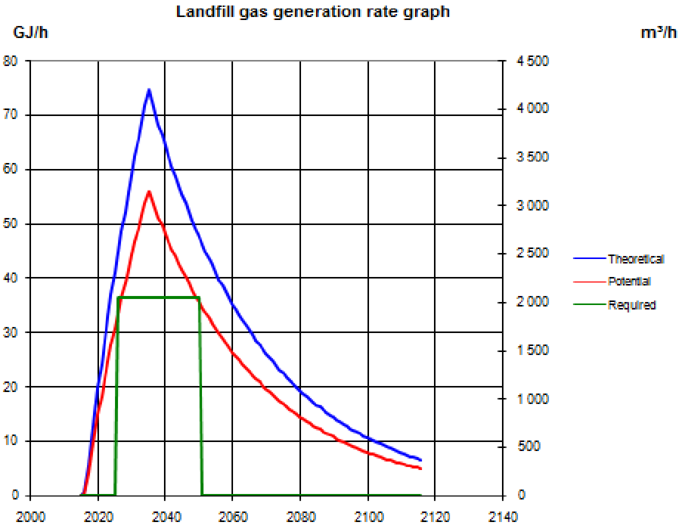

Figure 1: Landfill Gas generation graph

*y-axis is the energy amount (GJ h^{-1}) produced by the gas, and x-axis is the year.

Notice that recovered LFG by the engineered system is not completely used since the installed engine has a fixed full capacity operation under the peak generation of the LFG facility. The unused LFG is accounted as the area between the "potential" and the "required" curves, in Fig. 1.This unused collected LFG will be flared and therefore, not utilized for power production. Notice also, that LFG collection represents approximately a 50% of methane collection given the expected composition of the collected gas.

Table 14 Power generation comparison

		Landfill Gas	**Waste Incineration**
Power Capacity	kW	4,000	16,447
Electricity Exported	MWh yr^{-1}	32,000	138,170

4.2. Environmental Impact Comparison

Table 15 shows that GHG emission reduction from the waste incineration was 201,263 tCO_2, while for landfill gas system the reduction was 197,005 tCO_2, showing a insignificant difference in favor of Waste Incineration system in this aspect.

Table 15 GHG Emissions comparison

Technology	**Emission Factor (kg GJ^{-1})**			**Year Net Annual GHG Emission Reduction* (tCO_2)**
	CO_2	**CH_4**	**N_2O**	
Landfill Gas	0	0.0040	0.00010	197,005
Waste Incineration	0	0	0.	201,263

(*) As compared to Coal Power Plant producing same amount of yearly electricity

4.3. Financial comparison

As a consequence of having a larger power system, the waste incineration system presents higher initial costs, as indicated on Table 16. On the other side, the reciprocating engine is more expensive compared to the steam turbine cycle for waste incineration, since it is a more complex machine. The initial cost also determined the amount of debt to be paid annually. This debt payment increased the total annual cost of each project during the loan term. Waste incineration rendered an Energy Production Cost of 54.90 USD/MWh, whereas LFG rendered 46.57 USD/MWh, an almost 10% less expensive solution.

In the next table, initial costs and annual savings and costs are depicted at year ¨0¨values.

Table 16: Project cost and income comparison (at year ¨0¨ values)

Cost Breakdown	**Landfill Gas**	**Waste Incineration**
Initial Cost		

Power System	$	7,743,889	6,232,118
Balance of System & misc.	$	4,036,863	21,126,495
Total Initial Cost	**$**	**11,780,752**	**27,358,613**
Annual Cost and Debt Payments			
Operation and Maintenance	$	1,350,000	8,645,633
Debt Payment - 10 years	$	744,419	1,728,775
Total Annual Cost	**$**	**2,094,419**	**10,374,408**
Annual Income	**$**	**2,240,000**	**9,671,900**

It is important to recall that Table 16 presents costs at year ¨0¨ values, which are indexed at the Inflation Rate of 5.4% annually, while the annual income has its origin on the electricity savings which are indexed with the energy escalation rate of 8%. In addition, the annual cost reflects the presence of debt payment, which will keep a constant value throughout the years and will end in year 10. Hence, for the Waste Incineration solution, despite at year ¨0¨ the annual cost is higher than the annual income, this difference reverses quickly as the years advance, and become exponential closer to year 10. The cumulative cashflow for this case, in Fig. 2, shows this phenomenon.

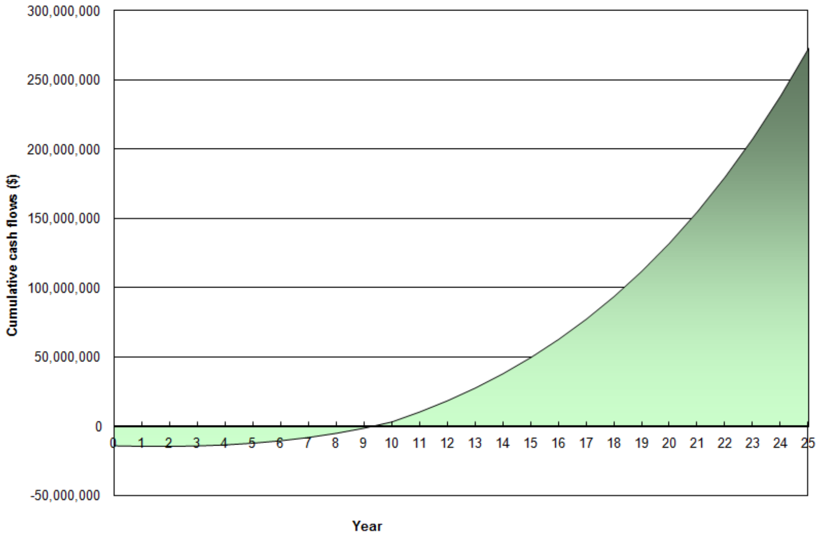

Figure 2: Cumulative Cashflow for Waste Incineration project, as provided by RETScreen.

Similarly, despite there is a very small positive difference between the annual savings and the annual costs for the Landfill Gas project, at year ¨0¨ value, the trend is again potentially increased as the years advance, based again on the energy escalation rate that is larger than the inflation and the limited debt term (see Fig. 3).

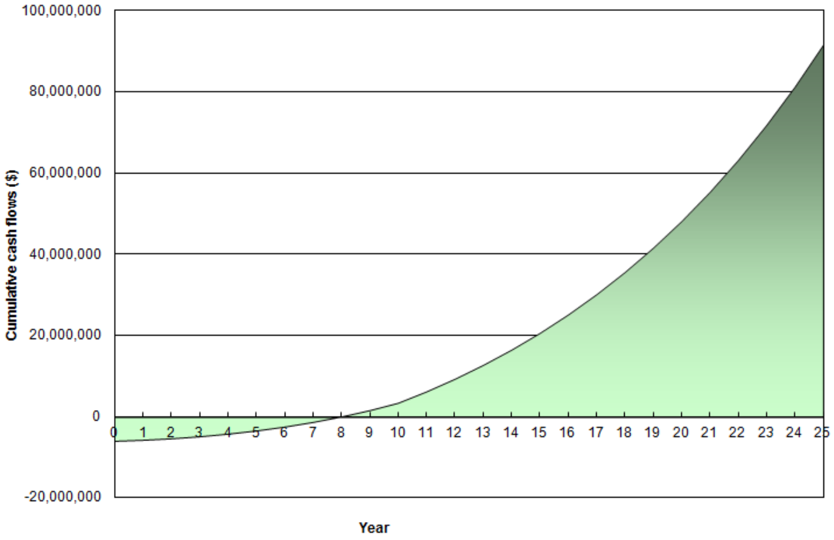

Figure 3: Cumulative Cashflow for Landfill Gas project, as provided by RETScreen.

As appreciated on Table 17, both projects depict a high level of profitability, with differences basically on favor of Waste Incineration regarding NPV and Benefit-Cost ratio, and an almost insignificant difference in IRR on equity.

Table 17 Financial results comparison

Financial Results	Landfill Gas	Waste Incineration
IRR on Equity	20.6%	19.9%
Net Present Value (NPV)	$16,663,300	$46,386,636
Benefit-Cost Ratio	3.83	4.39

4.4. Choosing between LFG and WI

It can be observed that a large quantity of GHG can be reduced with both technologies; being Waste Incineration slightly more environmentally friendly. Both technologies will generate profit, but LFG leads to a cost of energy production that is 15% lower than the cost obtained for Waste Incineration. However, in term of IRR on equity both technologies render an approximately similar value, while Waste Incineration gives around 1.15 times the Benefit-Cost ration obtained by LFG, which was in fact very reasonable as well. Despite the energy production via LFG proves to be the less expensive solution, it has weakness related to the need of more space for its implementation. Approximately, LFG requires 124 acres of land compared to the 35 acres required by waste incineration.

CONCLUSIONS

LFG and waste incineration are potentially excellent waste-to-energy solutions in Astana. Both technologies offer a promising outstanding financial performance and significant reduction of GHG emissions. The application of these technologies in the context of waste management in Astana could be a turning point towards sustainable development. Based on the simulations results, LFG is the better option regarding the cost of production of energy, but Waste Incineration is much better in terms of NPV and Benefit-Cost ratio. Additionally, it has to be accounted the fact that LFG requires much larger land space, but current engineered landfill facilities could be used for that effect. If the extension of the project to other cities in Kazakhstan without landfills is considered in the future, the space availability and the cost of the land must be accounted in the analysis, as well as the engineering of the site; in such cases, waste incineration could turn to be a very strong and viable comparative option. Nevertheless, a feasibility analysis is now required to obtain a determinant answer to the feasibility of any of these two technologies.

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