Technical Applicability of Small-Scale Incineration with Energy Recovery Scheme as An Effective Thermal Treatment for Infectious Healthcare Waste in San Lazaro Hospital, Manila

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Abstract — Incineration is a method of treating and reducing waste widely used in developed countries. Since the implementation of the ban on incineration, the Philippines is the only one with a nationwide ban on incineration. Furthermore, it did not allow the idea of technological advancement, which left the country far from the technologies used by other countries in treating and reducing waste. This study evaluates the technical applicability of the small-scale waste-to-energy incinerator as a means of waste reduction and treatment of infectious healthcare waste in San Lazaro Hospital, Manila. The evaluation was conducted using several tools such as the Health Risk Assessment, Cost-Benefit Analysis, and the Cost-Effectiveness Analysis and compared it with the expert's opinion gathered through the several surveys from Delphi Technique. From the study, researchers have concluded that through the proposed design flow which includes APCDs – Air Pollution Control Devices with gas emission calculation, results from little to zero toxic substances which makes the technology internationally and locally compliant with the air quality standards. Through the cost-benefit analysis and cost-effective analysis, it was found that the WtE incineration technology is economically feasible and cost-efficient. According to the opinions of the experts conducted through the Delphi Technique, pyrolysis is the best available technology available. Incineration with energy recovery scheme fails in the criteria of environmental and health safety, however, the study shows that with the application of engineering controls and techniques the incineration technology passes all criteria of technical applicability for selecting the best technology available.

Keywords: *Incineration, infectious healthcare waste, Waste Treatment, Waste Generation Rate, Waste-to-Energy*

I. INTRODUCTION

According to S. Cutler (2020), due to the COVID-19 pandemic, the world will be overwhelmed with healthcare waste and one of the repercussions of the excessive supply of healthcare waste will be based on the healthcare waste management system. Based on the reports on Wuhan, the volume of healthcare waste from 40 tons per day became 240 tons per day, a 600-percent increase in volume.

Based on the Asian Development Bank survey, Manila is expected to generate the most Covid-19 related healthcare waste, succeeded by Jakarta, and other major cities. Manila, Capital of the Philippines, is projected to generate 280 tons of healthcare waste per day from a volume of 47 tons produced daily pre-pandemic. In two months, an excess of 16,800 tons of healthcare waste is expected in the nation's capital. S. Peters (2020) quoted, "If you do not dispose of medical waste urgently, this is the worst-case scenario that can happen, based on what happened in Wuhan. You will get overwhelmed, and the most vulnerable people in your community are going to suffer the most, Treatment of healthcare waste is typically by autoclaving, irradiation before disposing in a landfill or incinerated. One of the disputed waste treatments in the Philippines is incineration. Incineration is said to be banned in the RA 8749, which is the Clean Air Act (ADB, 2020).

However, according to Geri Sañez of EMB-DENR, the interpretation of the law on the ban of incineration is flawed, and incineration is not totally banned in the Philippines. The Department of Environment and Natural Resources can allow incineration as long as it complies with the standards. In the Philippines, environmentalists decry incineration as an option to resolve problems in excess waste as there are some issues of the violation of the method in the Philippine Clean Air Act of 1999. Based on RA 8749 – Clean Air Act, SECTION 20. Ban on Incineration. — Incineration, hereby defined as the burning of municipal, bio-chemical and hazardous wastes, which process emits poisonous and toxic fumes, is hereby prohibited" however, according to the DENR Memorandum Circular No. 2002-05, "Section 20 does not absolutely prohibit incineration as a mode of waste disposal; rather only those burning process which emits poisonous and toxic fumes are banned." which is based on the Supreme Court Decision

II. METHODOLOGY

The structure of the paper will focus on five main points about the Waste Generation Rate, the Technical Applicability Criteria of the project, the Assessment of the Applicability using HRA, CBA, and CEA, and the Evaluation of the Technical Applicability Criteria

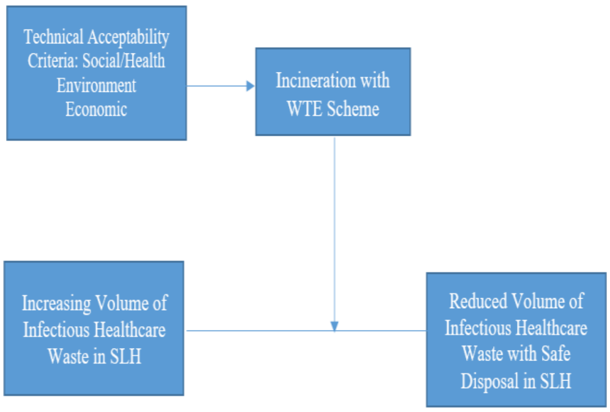

Figure 1. Conceptual Framework

The steps to be taken in determining the Infectious Waste Generation Rate are to review the literature and studies of countries applying the technology and project the amount of the possible volume as time increases by researching the current waste rate and adding the infectious waste increase using the expected number of patients.

The second phase of the project is done by defining the technical definition of incineration, designing the process of flow of the Thermal WtE scheme including the determination of gas emissions, and developing the technical applicability criteria which will be used as a basis of the evaluation of sustainable development.

The third phase is about assessing the social, health, environmental, economic consideration of the technical applicability of the technology using Health Risk Assessment, Cost-Benefit Analysis, Cost-Effective Analysis. The analysis is determined through evaluating the public health impacts, environmental issues caused, and the economic impact of the WtE incineration method. Moreover, the benefits are evaluated in their volume, pollution, and cost efficiency and effectivity.

The fourth phase is about evaluating the developed technical applicability criteria using the Delphi technique where a set of experts will evaluate the technical applicability criteria to verify if the study is useful and accurate

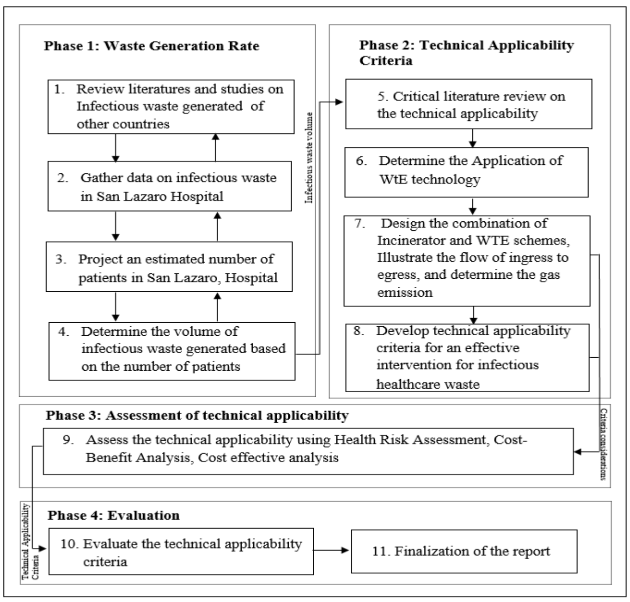

Figure 2. Methodological Framework

Treatment

Cost-Benefit Analysis

Cost-Benefit analysis can be used for decision making, analyzing systems or projects, or determine the intangibles' value. It is built by identifying the benefits and associated costs of technology, system, and project. The output of a cost and benefit analysis will be a concrete finding that can be used as a decision-making tool that will yield a reasonable conclusion and its feasibility.

Health Risk Assessment

Health Risk Assessment is a tool used to estimate the probability and nature of adverse health effects who might be exposed to harmful substances or chemicals in a contaminated environment setting, present, or the future. The steps for a health risk assessment are as follows: (1) Hazard identification, (2) Dose-Response Analysis, (3) Exposure Assessment, (4) Risk Characterization.

Cost-Effectiveness Analysis

Cost-effectiveness analysis is used to examine the intervention's cost and health impacts. It develops a comparative analysis to another intervention through estimating the costs to gain a unit of a health outcome, i.e a like life-year gained or death prevented. It determines the impacts of intervention in health and costs compared to an alternative intervention.

Delphi's Technique

Delphi method is used to predict an event or condition that is based on rounds of questionnaires given to a group of experts and is shared with the group after every round. Changing their answer is allowed after each round sharing the answers of the other groups' answers. The technique is used to reach the most appropriate response through consensus. The consensus can be swayed as they see the opinions of other experts making this method effective.

III. RESULT AND DISCUSION

The researchers used different tools to determine the impact on the different parameters set in conducting the study about the proposed applicability project in San Lazaro Hospital. As discussed in the Methodology in Chapter 3, there are different phases to be conducted using the specific methods indicated in Figure 3, which is the Matrix of the Methodological Framework. For phase 1, the results of the data gathered through the interviews of experts from San Lazaro Hospital indicate that the massive increase in the growth rate of healthcare waste, including the infectious waste correlates to the on-going Novel Corona Virus present in most countries, including the Philippines. The growth in waste is not only prevalent in San Lazaro Hospital, but is also occurring in hospitals and areas in other countries in America, Europe, South-East Asia, Eastern Mediterranean, Africa, and Western Pacific is becoming a global problem which requires immediate engineering solution. The occurrence of the global pandemic emphasized the need for advanced technologies, and preparedness in handling infectious wastes. In South-east

Asian countries, countries such as China, rely on medical waste incinerators to efficiently solve the problem with the massive volume of infectious waste. The interviews with experts in the Department of Environment and Natural Resources, and the experts in San Lazaro Hospital, conducted by the researchers, points out to the acceptance of using the modernized technology if proven to be cost-efficient and environmentally safe according to the standards.

Waste Generation Rate in Other Countries

The occurrence of the Novel Corona Virus has resulted in a remarkable increase in the volume of generated waste globally. In Hubei China, the province alone is said to have experienced a massive increment of 600% increase in the waste generated due to COVID-19 patient cases. In Istanbul, values of the highest rate of generated waste were estimated to be 14,500 tons, from 1.68 kg/bed/day in 2017. In contrast, the scale volume for the generated waste in Jakarta, Indonesia was 12,740 tons after 60 days of the Coronavirus infection.

Waste Generation Rate in San Lazaro Hospital, Manila

According to Tirso Villacarlos – Pollution Control Officer of San Lazaro Hospital, Manila, approximately 7,000 kilograms of infectious wastes per month, and an additional 10,000 kilograms of general healthcare waste is being generated in the year 2019; this brings about 234 kilograms per day of infectious waste and 334 kilograms of general healthcare waste per day.

Table 1: Infectious and Hazardous Waste Generation from 2019 to 2020

Year	January	February	March	April	May	June	July	August	September	October	November	December
2019	6994	8444	7137	7572	3392	5062	4451	6436	7394	5122	5849	4746
2020	4840	4250	5851	6382	9536	7659	16800	18956	-	-	-	-

In the year 2020, from March to September, the average waste generation is approximately 11 tons of infectious waste and 10 tons of general healthcare waste per month. Infectious waste generation from 2019 to 2020 increased by about 58 – percent. The waste generation rate is 0.5 kg/bed.

The projection of beds from March to December of 2020 is currently 30 – percent of the total authorized bed capacity which is 150 beds out of 500 beds. If in cases of an increase in the number of COVID patients, San Lazaro Hospital is authorized to increase the number of beds allocated to COVID patients to up to 50 – percent. The composition of the total infectious coming from COVID and other infectious wards is 60 – percent and 40 – percent respectively (Villacarlos, 2020).

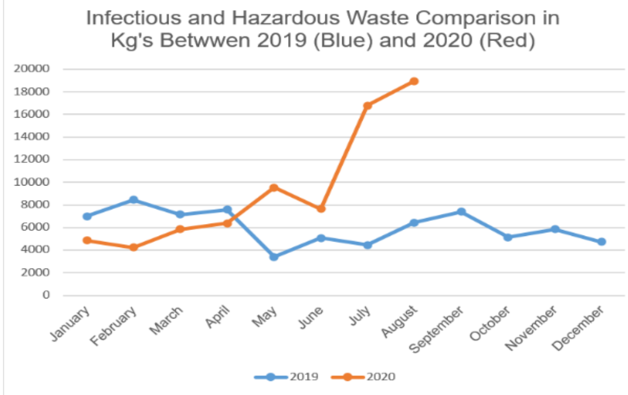

Figure. 3 Infectious and Hazardous Waste Comparison in Kg's Between 2019 and 2020

Note: Average waste generation of General Healthcare waste is approximately 10 tons per month

Projection of Patients in San Lazaro Hospital

The San Lazaro Hospital is a 500-bed capacity tertiary health facility for communicable diseases in Manila, the Philippines as indicated by the Department of Health. Since the occurrence of the Corona Virus, the hospital mandated a bed allocation of 30% from its total capacity, giving a 150 bed for the COVID infected patients. However, the Department of Health has ordered an increased allocation of 50%, or 250 beds to accommodate the surge capacity of patients in the future and to give safety of factor.

Projected Volume of Waste Generated in San Lazaro Hospital, Manila

At maximum, if the hospital will utilize 50% of its bed capacity for COVID patients, the projected volume of infectious healthcare waste will be 7500 kg per month, considering a generation rate of 1kg/bed. This value will be added to the generated infectious waste in other wards which also has infectious waste. The computed volume of infectious waste in other wards is 3750 kg per month. The total projected volume of infectious waste is 11250 kg per month. In contrast, if the hospital will not increase its capacity by 30% for COVID patients, the volume of waste generated will be 9750 kg, with a difference of 1500 kg.

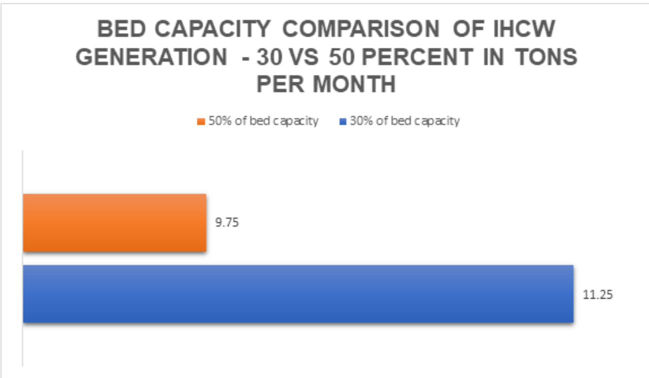

Figure. 4 Bed Capacity Comparison of IHCW Generation – 30 vs 50 Percent in tons

Technical Applicability

According to Loan (2017), knowledge on the situation of baseline data on the current waste management is important. The baseline data comprises the generation of wastes, availability of the technology, financial resources, and involvement of stakeholders, institutional framework, and policies/regulations.

Solutions can be identified through the use of these baseline data. It is important to assess the applicability of given criteria as not all technologies are feasible for adoption. Solid waste management criteria are dynamic and versatile under the conditions, situations, and circumstances of solid waste. Twelve criteria are considered which are; technological development, solid waste types, the scale of operation, final products, investment cost, operating expenses, land requirement, adverse impacts, energy recovery, and food security (Loan, 2017).

Design Flow of WTE – Incinerator

Typically, medical waste incinerators are controlled-air incinerators; the proposed flow of the WtE facility is shown in figure 6. Proposed Design Flow of WtE Incinerator. The proposed design flow of the WtE Incinerator was derived from The Database of Waste Management Technologies (2014) where fabric filter and wet scrubber are the air pollution control devices used in the study. According to the study, the emission factor used is based on the EPA (2004) data on existing WtE technologies in the EU. The process of the proposed design flow; combustion happens at the furnace, typically a two-part chamber, a lower and upper combustion chamber. A wet scrubber is a type of air pollution control device (APCD) where it transfers the pollutants from the air to a liquid stream where it can achieve a 70% efficiency removal of HCI and 30% efficiency removal for SO2. A 93-96% removal can be achieved with the addition of an alkaline reagent. A fabric filter is also a widely used APCD and can achieve 99.99% of particulate matter removal. (EPA, 1995)

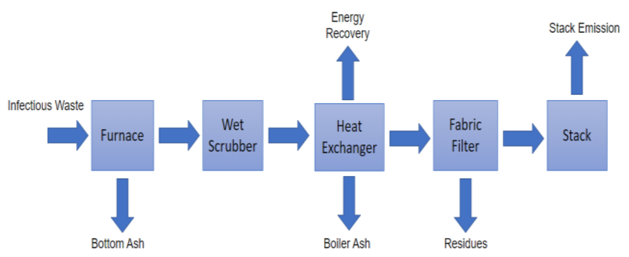

Figure 5: Proposed Design Flow of WtE Incinerator – Ingress to Egress

Gas Emission Calculation

Emission rating values in lbs/ton are taken from the Environmental Protection Agency (EPA); emissions were calculated in tons per year. Values calculated from removal efficiency of APCDs – wet scrubbers and fabric filter has shown almost 99.99% removal efficiency in most aspects of the National Ambient Air Quality Standards in the Philippines. However, calculated values are theoretical and will still be dependent on how San Lazaro Hospital handles operation and maintenance. Theoretically, emission reduction from wet scrubbers and fabric filters are enough to reduce dioxin and furans emissions with almost 0 nanogram per cubic meter. As per RA8749, dioxin and furans should be limited to 0.1 ng/m3, and the proposed APCDs have shown that it can suffice the clean air act standards.

Table 2: Emission Reduction from Wet Scrubber

Pollutants	HCl	SO_2	PM	Hg	PCDDs	PCDFs
Unit	lbs/ton	lbs/ton	lbs/ton	lbs/ton	lbs/ton	lbs/ton
Emission Factor	0.139	0.0257	1.48	0.0173	0.00000184	0.00000492
Unit	tons/yr	tons/yr	tons/yr	tons/yr	tons/yr	tons/yr
Emission Reduction from WS	0.015846	0.00293	0.16872	0.0019722	2.0976E-07	5.6088E-07

Table 2-1: Emission Reduction from Fabric Filter

Pollutants	HCl	SO_2	PM	Hg	PCDDs	PCDFs
Unit	lbs/ton	lbs/ton	lbs/ton	lbs/ton	lbs/ton	lbs/ton
Emission Factor	5.65	894.7	0.175		0.00000268	0.0000085
Unit	tons/yr	tons/yr	tons/yr	tons/yr	tons/yr	tons/yr
Emission Reduction from FF	0.6441	101.996	0.01995	-	3.0552E-07	0.000000969

Table 2-2: Dioxin and Furan Reduction in ng/m3

APCD	PCDDs	PCDFs	Unit
WS	71835.61644	192082.1918	ng/m^3
FF	104630.137	331849.3151	ng/m^3
Residual	0	0	ng/m^3

Table 2-3: Total Emission from proposed WtE – Incinerator

	HCl	SO_2	PM	Hg	PCDDs	PCDFs	Unit
Reduced Emission	0	0	0	0	0	0	Tons/yr

Technical Applicability Criteria

The criteria for the technology's technical applicability are designed to serve as a guide for decision-makers, lawmakers, and other concerned parties in deciding on what is the best technology available. The technical key criteria were taken from the UN Environmental Programme (2019). According to the study, the physical and challenges of the strategic aspects are necessary to evaluate and should be assessed during the planning phase on the selection of the technology carefully. The technology's technical criteria should be assessed by experts and decisions are based on the overall performance of the technology.

The researchers put together a list of key criteria based on the UNEP: Considerations for Informed Decision Making (2019) to help the management of San Lazaro Hospital to be able to guide the management on choosing the best technology to be able to ease the increasing volume of infectious waste and the additional cost of outsourcing the treatment of infectious waste. The technical applicability criteria should just not be without basis but with an assessment. The researchers have assessed this criterion using Health Risk Assessment, Cost-Benefit Analysis, and Cost-Effectiveness Analysis.

Table 3. Technical Key Criteria – Health, Environmental, Economic, Social

Key Criteria
Internationally and locally compliant with the emission standards by the enforcing agencies
Energy produced is locally available to local users and is available for sale
Health risk can be mitigated and regulated
Skilled staff can be recruited and maintained
Treatment of the by-products is locally available

Health Risk Assessment

This phase aims to enumerate the possible effects, impacts of the medical incinerator with a waste-to-energy scheme and indicate the range and levels of toxicity of the emissions in the human body of the project in San Lazaro Hospital.

Hazard Identification

According to the Department of Environment and Natural Resources, the incinerator project's risk is the Dioxin and Furans, the heavy metals emission in the form of the bottom ash and fly ash and the wastewater from the process. The Dioxin and Furan's potential atmospheric transport and capacity for bioaccumulation in the ecosystem in the vicinity of San Lazaro Hospital are some of the significant problems that might be encountered if the technology is implemented. Moreover, another major problem encountered if the incinerators were not regulated is the oxidation of heavy metals. The heavy metals that are oxidized and not destroyed during incineration were partitioned between the more massive particles, which are the bottom-ash, and the lighter particles, which were flue gas, and fly ash. Though several advancements were made internationally for the pollutants, the risk of failure and leak after certain conditions are not met is still not completely gone. Studies from the WHO (World Health Organization) support that the long-term health impacts of uncontrolled incinerators can alter the neurodevelopmental, reproductive, and develop carcinogenic agents that can increase the mortality and morbidity rate in the San Lazaro Hospital vicinity. The potential Ecological effects of the project in San Lazaro's vicinity include deterioration of the air quality and contamination of soil, water, and crops.

Dose-Response Assessment

The Dose-Response Relationships depend on the pollutant. Each pollutant has different levels of acceptability in a body. The table below quantifies the human responses to exposure to each pollutant at a different period. Chronic exposure means that a person has been repetitively exposed to the pollutant for an extended period. The exposed population is the workers, patients, and residents within a 6.43 km radius for the Dioxin and Furans, and a 10 km radius for the Fly Ash. The severity of exposure in Dioxin and Furan is higher at locations near the source. In contrast, the fly ash is much more harmful at locations farther than the source because the particle's radius becomes smaller, and does easily accumulate in the respiratory system. Table 6 contains the health impacts of harmful emissions that could be obtained when using the technology.

Table 4: Health Impacts of Harmful Emissions from Uncontrolled Incineration

Health Impacts	Short-term Exposure	Chronic Exposure	Significant Exposure	Range of emissions
Dioxin and Furans	May cause skin lesions known as chloracne	Exposure causes ranges of toxicity, such as immunotoxicity, developmental and neurodevelopmental effects, and effects on thyroid and steroid hormones and reproductive function.	Ingestion of dioxin and furans through intake of contaminated meat causes development of cancer, damage in the immune system, the endocrine system and reproductive functions.	Tolerable Daily Intake: 1 – 4 pg TEQ/kg-day Tolerable Monthly Intake: 70 pg/kg of body weight
Heavy Metals: Bottom-ash	No effect	Development of cancer and other respiratory diseases	Ingestion of bottom-ash results to nervous system impacts, development delays, problems in behavior, and defects in cognitive systems.	EPA Guideline As: 0.03μg/m3 Cd: 0.01 μg/m3 Pb: 0.15μg/m3
Heavy Metals: Fly Ash	Pulmonary and Systematic Inflammation	Increased mortality rate due to respiratory and cardiovascular dysfunction	Inhalation causes neurodevelopmental, respiratory, and other health problems.	-
Wastewater from wet scrubber	Microbial Risk, and Exposure to Virus	Chemical Risk	Ingestion causes enterococcus, shigella, and salmonella	Dibromochloromethane: 5.2 μg/L Crtotal: 470 μg/L Cr(VI): 10μg/L

Exposure Analysis

The exposure can be through inhalation of substances, direct contact in the body through dermal exposure, and ingestion. The risk of hazardous substances varies on different factors, including how a person is exposed and how much intake was acquired, individual susceptibility, or exposure to other similar substances associated with the component. Since the vicinity of San Lazaro Hospital is highly populated, the risk of exposure is not limited to waste collectors, health workers, patients, and other workers, but also to the residents residing in the area. It is stated that the fly ash is likely to contribute to compartment environmental pollution on a scale of 10km, on-air, and can be distributed over a much greater distance over hundreds of kilometers away. Moreover, a study from the Environmental Protection Agency in 2007 states that the dioxin and furans level are present in a 3.21 km radius. Studies confirm that the effects on children and infants are more harmful than on adults.

Exposure Pathway

The exposure pathway is modeled below, as gathered from the study of the WHO conducted in 2004. The released dioxin and furans, and the flue gas from the incinerator, which is available in the air can be inhaled by the workers, and residents residing near the San Lazaro Area. Moreover, it travels by air, to the atmosphere, and transpose through series of environmental cycles, which in turn drops off as precipitate, which when in direct contact with humans, can affect the person. In addition to that, the water, which is absorbed by soil transports in groundwater, and contaminates the groundwater, and accumulates in crops, which when ingested at high levels, might affect people in San Lazaro Area. Moreover, the bottom-ash, which is a coarse-granules, which will be collected after the treatment can harm the collectors of bottom-ash in San Lazaro when the particles are inhaled or if dermal contact will happen. In addition to that, when disposed of in landfills, it produces heavy metal pollution in soils, and in turn, will percolate in the groundwater. The exposure happens when the animals eat or drink crops such as the grass that grows above the contaminated area. The contaminants stay in the body fat of the animals and are passed on to humans, after consuming the meat. In contrast, the population is exposed to the wastewater from wet scrubber when there is direct dermal contact or ingestion of the pollutants.

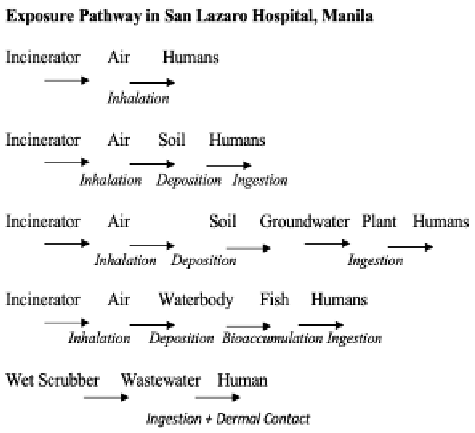

Figure 6: Exposure Pathway in San Lazaro Hospital, Manila

Risk Characterization

Associated with the project are the health hazards from its emissions. The potential issues from the technology are the air emission from the waste to energy plants, which were the discharge of a range of air contaminants, including dioxin and furans, and heavy metals. Polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans (PCDD/Fs) are ubiquitous lipophilic pollutants, with toxicity output, chemical persistence in the environment, the potential for atmospheric transport, and its capacity for bioaccumulation in the ecosystem, and food chain. There are 210 kinds of dioxin and furans with the same chemical skeleton and have chlorine atoms in its components. Furans have similar components but have a different chemical skeleton. The substances' toxicity varies widely. The most toxic type is referred to as 2,3,7,8-tetrachlorodibenzo-p-dioxin, or simply TCDD. Dioxin and furans can be acquired mostly from the burning of municipal and medical waste.

Another major problem in incinerators is the presence of heavy metals. Metals are inorganic substances that were oxidized and are not destroyed during the process of incineration. Therefore, most of the metals submitted to combustion will exit the process as oxides, being partitioned between the heavier particles, which are the bottom-ash, and the lighter particles, which were fly gas.

Table 5: Qualitative Risk Characterization of Risk from Incinerator Emissions

Qualitative Description	Dioxin and Furans	Bottom Ash	Fly Ash	Wastewater from Wet scrubber
Description	These pollutants are often found in the air, water, plants, and soil, as a result of combustion processes.	These are incombustible by-products of incinerators which are considered pollutants, once uncontrollably displaced at environment.	Pollutants containing heavy metals compounds. It is typically ranging between 10 and 100 micron and can damage various systems when exposed.	These are the wastewater residues produced after the wet scrubber remove the harmful gases through scrubbing with water.
Assessment of Exposure	Ingestion of the Dioxin and Furans causes cancer, and damage to reproductive systems. In addition to that, exposure to Dioxin and Furans causes its presence in blood levels.	Significant exposure increases a person's risk of cancer development, lung diseases, kidney disease, and gastrointestinal illnesses.	Inhalation of Fly Ash trigger inflammation and immunological reactions. When inhaled, these particles often stay in lungs which can also cause other respiratory problems, or death.	The produced wastewater causes microbial and chemical hazards upon exposure. Ingestion of wastewater can cause the transmission of viruses and bacteria in it.
Data Used	World Health Organization	Taiwan Environmental Protection Agency	National Research Council, WA, DC	United States Environmental Protection Agency

Table 6: Quantitative Risk Characterization from Incinerator Emission

Quantitative Description	Dioxin and Furans	Bottom Ash	Fly Ash	Wastewater from Wet Scrubbers
Magnitude of Environmental Risk	Harmful emission at level greater than 0.01 nanogram	Toxic at chronic exposures	Toxic even at small levels	Exposure causes risk of virus body accumulation

Uncertainties of data

Risk assessment studies involve considerable uncertainty. Despite considerable effort and progress in evaluating incineration's health risks in developing countries, there are several critical data limitations and inadequacies, specifically on small-scale incinerators' health impacts. The Risk Characterization of the World Health Organization in 2004 states that there are not many studies available involving the environmental and health impacts of the small-scale waste incinerator; with the knowledge of this, it's hard to associate and correlate the health and environmental impact of the large-scale incinerator, with the impact of the small-scale incinerator with the waste-to-energy scheme project in San Lazaro Hospital. However, UNDP Class 2, for medical waste, indicates that there are 3.00 mg/Mg emissions relevant to small-scale medical waste incinerators. Another uncertainties and limitations are the poor quality of the emission data, as the results vary from a wide variety of environmental settings.

Cost-Benefit Analysis

Status Quo

The existing treatment and disposal method used in San Lazaro Hospital was sufficient, given the expected conditions when the hospital produced 7 tons of infectious healthcare waste per month. However, the pandemic's occurrence, which has resulted in a sudden increase in the waste produced, has revealed the need to use other techniques that are more efficient and sustainable. The existing method has a long-term loss and adverse effects. The impacts of no active link to long-term environmental, health, and economic impact. According to the information gathered during the interview, the hospital currently utilizes its budget for the treatment using a third-party service provider and then dispose of the residual waste in the landfill. The existing treatment method using an autoclave is effective in sterilizing and removing any bacteria and viruses. The method has been effective in dealing with a certain volume of waste; however, it will be less efficient at large masses considering the capacity of the service providers to treat waste. The table below contains the list of possible impacts in Health, and in the Environment of not changing the existing method of treatment of infectious waste.

The large amount of treated waste dumped at landfills will create a nuisance in the area and consume considerable space. If the use of a landfill in the disposal of medical waste, there will be a higher demand for space, and several factors will be compromised, including the vicinity area that will be affected.

In addition to that, several studies have proven that landfills have a remarkable impact on air, nature, land, humans, and biodiversity. If the existing methods will be continued, and no action will be made, the soil fertility might be affected as the mixture of the toxic substances can impact the quality of the areas surrounding the site. In addition to that, the effects can compound on biodiversity, as the soil's capability to produce local vegetation may be permanently altered.

Furthermore, if the constructed landfills are not properly designed and constructed, the treated infectious waste can contaminate drinking-water sources as the leak can be transported through cycles. Its other possible damage and effect are on the damage to the air quality. Studies from the Environmental Hazard of Medical states that, as materials from the landfill decompose, a certain level of methane gas is released, which can trap a 20 level higher heat in the atmosphere, higher than that of carbon dioxide. It is essential to emphasize the possible remediation costs if the system continues.

The health impacts of not changing the method of treatment include the increased number of patients. It is essential to consider the risk of exposure to the infectious diseases obtained during the transportation of the wastes to the facility since it will pass through a series of pathways that could have been infected. The table below contains a summary of the estimate of the cost of treatment for the impacts of retaining the autoclaving method.

Table 7. Status Quo – Without Incineration

	Status Quo	
Environmental Impacts	**Intervention**	**Cost**
Soil Contamination	In-situ Soil Remediation	$30-$750 per cubic yard of treated Air
Pollution	Air Quality Monitoring	PhP 38,000,000
Ground Water Pollution	Groundwater Contamination	
Biodiversity Impacts		Unquantifiable
Additional Landfill	Construction and Design Cost	Php 37,000,000
Health Impacts		
Increased COVID Patients	Hospitalization Treatment or Death Cost	Average Cost around Php 800,000,000 – 1,500,000
Transmission of other Infectious Diseases	Hospital Treatment or Death Cost	Average around Php 200,000

As stated in the manual, the cost of soil remediation is $30-$750 per cubic yard of treated Soil, and the budget for the air quality monitoring as per the MMDA's report is PHP 38,000,000. Moreover, according to studies, the cost of groundwater remediation is $1,700,000/ 1000 gal/yr. Another possible loss is the cost of Biodiversity impacts. According to the Romanian Ministry of Environment and Forest, the loss of species is approximately 20 to 300 species per hectare. Moreover, the natural species in the area are being replaced by species such as rats, and crows, which feeds on refuse. The availability of landfills creates visual and health impacts, which increases the exposure to harmful bacteria, which can lead to disease development. The average cost for hospitalization of COVID patients, according to Rappler's Interviews and studies, is around Php 800,000- Php 1,500,000.

Cost of Intervention

According to Waste to Energy International (2015), based on their experience in construction and different contacts from producers worldwide, the cost of an incineration plant can be estimated through the empiric formula below.

$$I = 2.3507 \times C^{0.7753}$$

Equation 1: Investment Cost of WtE Incineration Based on Capacity.

Where I is the investment cost in a million dollars and C is the plant capacity (1000 metric tons of waste/year). The cost may vary depending on the technology implemented, it could be burning on the fluidized bed, or the grate, hazardous and infectious wastes costs significantly more as it sometimes requires rotary kiln for significant volumes and advanced flue gas cleaning systems.

Investment Cost Estimation

The table below presents a summary of the cost of investment based on different plant capacities. Based on our waste generation data, the rate of infectious and general HCW in 2019 is approximately 80 and 192 tonnes per year, respectively. While in 2020, the average IHCW and General Healthcare Waste are estimated to be about 132 tonnes and 251 tonnes per year.

Different options of plant capacity are calculated based on different types, scenarios, and rates. For the year 2019, all infectious and general healthcare waste is considered at an average rate. From March to September of 2020, the calculated total waste generated annually (TWGA) is also average. In August 2020, the maximum rate of IHCW and Total HCW is considered 19 tonnes and 29 tonnes per month, respectively. The computed cost for different options is still free from interest if paid for a certain period of years.

Table 8. Investment Cost Estimations Based on Plant Capacity

Option	TYPE	TWGA (Tons/yr)	Date	Rate	Scenario	Investment Cost
Option 1	Total HCW	348	Aug-20	Maximum	Pandemic	₱52,887,589.25
Option 2	Total HCW	192	2019	Average	Pre-Pandemic	₱33,351,150.95
Option 3	Total HCW	251	March-September 2020	Average	Pandemic	₱41,052,009.40
Option 4	IHCW	228	Aug-20	Maximum	Pandemic	₱38,104,324.79
Option 5	IHCW	80	2019	Average	Pre-Pandemic	₱16,917,377.89
Option 6	IHCW	132	March-September 2020	Average	Pandemic	₱24,942,980.79

Note: *TWGA – Total Waste Generated Annually

Revenue Potential

Feed-in Tariff

This project would be classified as part of the RA513 – Renewable Energy Act and be eligible for Feed-in Tariff. Currently, the feed-in tariff is Php 6.63/kWh in the biomass category. For uncertainties, The financial model in Feed-in Tariff is assumed to be around Php 6/kWh. Annual Revenue computed is assumed to maximize the capacity of the WtE incinerator.

Table 9: Potential Revenue from Energy Recovery via Feed-in Tariff

Option	Type	Capacity (Tons/yr)	Date	Rate	Scenario	Energy Recovery (kWh/ton)	Feed-in Tariff (Php/kWh)	Annual Revenue
Option 1	Total HCW	348	Aug-20	Maximum	Pandemic	550	6	₱1,148,400
Option 2	Total HCW	192	2019	Average	Pre-Pandemic	550	6	₱633,600
Option 3	Total HCW	251	March-September 2020	Average	Pandemic	550	6	₱828,300
Option 4	IHCW	228	Aug-20	Maximum	Pandemic	550	6	₱752,400
Option 5	IHCW	80	2019	Average	Pre-Pandemic	550	6	₱237,600
Option 6	IHCW	132	March-September 2020	Average	Pandemic	550	6	₱435,600

Note: *Energy Recovery Value Taken From U.S. EPA where Average Energy Recovery From WtE Incinerators is Around 550-650kWh

Revenue from Treatment Charge from Waste of Other Facilities

Average Waste Generated (AWG) per year is assumed from the waste generation rates of 2019. This study assumes the average waste generation of San Lazaro Hospital to determine the available capacity per year based on the different options' capacity for the computation of annual revenue from treatment charges from the waste of other facilities. According to San Lazaro Hospital, their service provider's current charge for their treatment – Autoclaving of infectious Waste is Php 15 per kg and Php 30-35 per kg for pyrolysis treatment. Conservatively, we estimated the treatment charge to be around Php 25 per kg. The potential total annual revenue is calculated to be the annual revenue from electricity sales and treatment charges from the waste of other facilities.

Table 10. Potential Revenue from Treatment Charge from Waste of Other Facilities

Option	Type	Capacity (Tons/yr)	AWG per year	Available	Php per kg	Annual Revenue
Option 1	Total HCW	348	192	156	25	₱3,900,000
Option 2	Total HCW	192	192	0	25	₱-
Option 3	Total HCW	251	192	59	25	₱1,475,000
Option 4	IHCW	228	72	156	25	₱3,900,000
Option 5	IHCW	80	72	0	25	₱-
Option 6	IHCW	132	72	60	25	₱1,500,000

Table 11. Total Annual Revenue

Option	Type	Total Annual Revenue
Option 1	Total HCW	₱5,048,400
Option 2	Total HCW	₱633,600
Option 3	Total HCW	₱2,303,300
Option 4	IHCW	₱4,652,400
Option 5	IHCW	₱237,600
Option 6	IHCW	₱1,935,600

Sensitivity Analysis

Sensitivity analysis' purpose is to understand how realistically and impregnable the financial model will be. We assessed the sensitivities of key variables – CAPEX, OPEX as this will determine the income-loss statement of the financial model. The best-case scenario of the sensitivity analysis is at a 12% return on investment where the operating expenditures are either plus (+) or minus (-) 20%. The applied sensitivity is at (+) or (-) 20% of capital expenditures and operating expenditures to determine the maximum and minimum return of investment. The results are shown below.

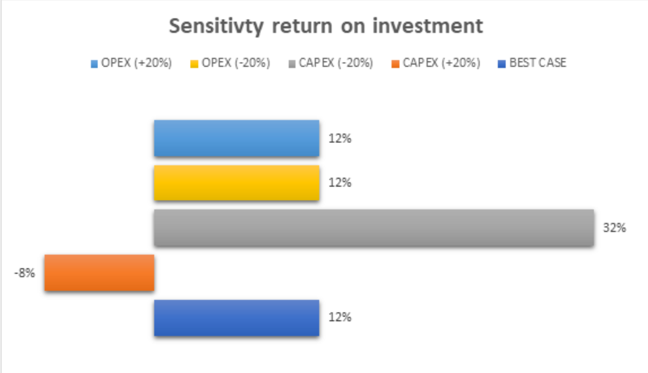

Figure 8. Sensitivity Analysis on Return of Investment

Operating Expenditures

OPEX data is taken from a pre-feasibility study in Quezon City's WtE Plant in 2016; sensitivity analysis of OPEX (+20%) is also considered as the variability of operation and maintenance cost is most likely. To support this data from QC's data of Operating Expenditures, according to Ricardo Energy and Environment (2016), operating expenses from a WtE plant costs around 50-70 USD. Php to the USD exchange rate is estimated to be around Php 48-50 per USD; however, the variability of Php to USD relies on the country's economic performance. Conservatively, a much higher peso to dollar exchange rate was considered in the study, which is Php 51/ USD.

Table 12: Estimated Operating Expenditures

Operating Expenses

	USD/Ton	Php/USD
Chemicals and consumables	4.1	51
Operational staff	6.1	51
Maintenance and overhauls	14.2	51
Treatment of leachate and ashes	8.1	51
Utilities	4.1	51
Others	4.1	51
Total	48.84	51
Sensitivity Analysis	1.2	

Return of Investment

According to UNEP's Waste to Energy: Informed Decision Making, WtE plants have a maximum life of 40 years. The study assumes only a 20-year life span for the incinerator as technology grows fast; the technology might be outdated in the coming years. Investment is calculated with a compound interest of 5% assuming it is payable for 10 years. The operating expenditures are expected to have a 1% increase each year, whilst the revenue is also taken conservatively, as the revenue from the first year of its operation will still stay as it is until the end of the WtE Incinerator's life span.

Based on the financial model, WtE Incinerator – Option 4 with a capacity of 228 tonnes per year is the only option with a positive profit amounting to Php 17,548,620.94 over the course of its 20 years operating. The annual revenue from treatment can increase depending on the SLH's management; however, for the conservation of this study increase in revenue will not be on account.

Table 13: Cumulative total of Revenue, Investment, OPEX – Option 4

Option 4

	Cumulative Total
Revenue	₱93,048,000
Investment	₱62,758,184.83
Operating Expenditures	₱12,741,194.23

Note: Assuming WtE Incinerator is payable for 10 years with a compound interest of 5%

Cost-Benefit Ratio

In conclusion, the estimated cumulative total benefits of the WtE Incinerator in 20 years is around Php 93,048,000 while the total cost of intervention in which in this study is calculated as the total investment with 5 % interest and is payable for 10 years plus operating expenditures with an annual price increase of 1% has amounted to Php 75,499,379.06, the cost-benefit ratio is 1.23 and concludes that the WtE – Incinerator Option 4 is Feasible.

Cost-Effective Analysis

According to San Lazaro Hospital, their service provider's annual cost in their treatment of infectious waste is around Php 1.2 million, with only 80 tons of infectious waste being collected. With the massive increase in the volume of infectious waste, San Lazaro Hospital's current service provider is subjecting the hospital to a different treatment – pyrolysis of infectious waste, which cost significantly doubles the current cost (30 to 35 pesos per kg of waste) of San Lazaro Hospital in outsourcing the treatment of infectious waste. For 80 tons of waste, the cost of pyrolysis treatment per year is around Php 2.8 million. Yearly, the cost of the WtE Incinerator, excluding revenue, is Php 6.9 million that can accommodate 228 tons per year of waste.

Table 14: Cost-Effectiveness Analysis – WtE Incineration

Scheme	Cost per Year	E (Volume Reduction)	C / E
Waste-to-Energy Incinerator	₱6,843,730.00	228	₱30,016.36

Based on the analysis, a ton of waste costs around 30,000 pesos or 30 pesos per kilogram for treating infectious waste. This is still a cheaper option than outsourcing the treatment of waste with no return on investment.

Delphi Technique

The researchers relied on the Delphi technique to collectively gather an independent group of experts to state their opinion about the project's feasibility that could be used in San Lazaro Hospital, Manila. This consensus technique was accomplished after the three rounds of surveys. The results of the survey were then used to compare with the researchers' results.

Sample Size

The criteria chosen by the researchers in selecting the number of participants from the target population of Experienced Sanitary Engineers were based on the minimum requirements of the Delphi Technique, which needed 15 experts. These experts are from different fields but have sufficient knowledge of the topic, which significantly impacts the study results.

Selection of Experts

Experts selection is the most important key part of the technique as the quality of the study is dependent on the knowledge of the experts on the subject. The criteria of experts' selection are:

(1) Licensed Civil or Sanitary Engineer

(2) Related work experience in the field

(3) Knowledgeable in public health

(4) Highly trained and experienced in the field of environmental and sanitary engineering

Experts should have at least background and experience in environmental and sanitary engineering. They should also be capable of contributing inputs and are capable of learning from other experts' opinions.

Round 1 of Experts' Opinion

Experts who agreed to participate were asked to answer based on their personal and expert opinion with not being limited to their length and style of their answers. 15 experts confirmed to participate and returned the questionnaire filled with answers. The experts are civil and sanitary engineers and are subdivided from water and sanitation, wastewater, waste management, construction and management, plumbing, and fire protection, all with sufficient knowledge of the topic through their years of practice. For the first question, (7) of the participants answered pyrolysis, (6) participants answered incineration, and (2) participants answered autoclave as the best technology available in treating infectious waste. The second question was to determine which technology will contribute the most pollutants, (12) of the participants thinks that incineration technology will contribute the most pollution in the air, water, and soil, (2) of the experts replied that all treatment method will contribute to pollution, whilst (2) of the experts' responded with chemical disinfection and pyrolysis. In terms of cost-efficiency, (7) of the experts agreed that incineration is the most cost-efficient technology, (5) of the experts responded autoclave is the most cost-efficient technology, while (2) experts answered pyrolysis. With social acceptability, (9) of the survey questionnaires came back with autoclave, (5) are pyrolysis and, the rest (2) is incineration. The content of the answered questionnaires is summarized with significant items of round one in the Delphi survey.

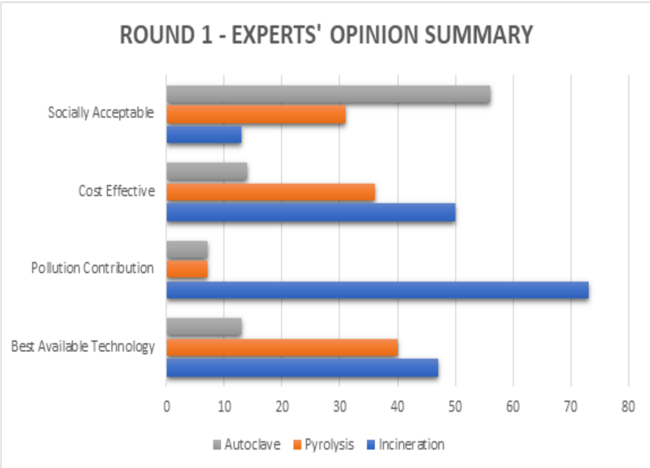

Figure 9. Round 1 of Experts' Opinion – Summary

Round 2 of Experts' Opinion

Round 2 of the survey was answered by the same group of experts based on their personal and expert opinion. The group was asked to rate each technology from the Round accordingly, from 1 to 5, with 5, as the highest. Fifteen experts confirmed to participate and returned the questionnaire filled with answers.

For the first question, (2) participants gave the incineration technology a mark of 2, while (6) participants gave a mark of 3, (2) participants gave a mark of 4, and (5) participants gave a mark of 5. The mean score for the incineration technology for the first question is 3.66, while the mean score for Pyrolysis and Autoclave is 3.93, and 3.8, respectively.

When asked to rate the incineration technology according to its capability of reducing the volume of waste, (4) participants gave a mark of 3, while (3) participants gave a mark of 4, and (8) participants gave a mark of 5. These values gave a mean score of 4.26 for incineration technology, while the mean score for Pyrolysis and Autoclave for this section is 4, and 2.93 respectively.

When the experts were asked to rate according to long-term economic feasibility, the incineration technology was given a mark of 3 by (5) participants, a mark of 4 by (4) participants, and a mark of 5 by (6) participants. These values gave a mean score of 4.06 for incineration technology, while the mean score for Pyrolysis and Autoclave for this section is 3.53, and 3.33 respectively.

When asked to rate according to its Applicability and Effectivity of Treating and Reducing Infectious Healthcare waste in San Lazaro Hospital, Manila, of the 15 experts, (3) participants gave a mark of 3 for incineration technology, (4) participants gave a mark of 4, and (8) gave a mark of 5. Giving a mean score of 4.33 for incineration, while the mean score for Pyrolysis is 4.26, and 3.53 for the Autoclave.

The content of the answered questionnaires is summarized with significant items of round two in the Delphi survey. The results show that the experts think they prefer Pyrolysis compared to Autoclave and Incineration in terms of Environmental and Health Safety. However, considering the capability to reduce waste volume, economic feasibility, and technology effectiveness, the experts favor incineration over the Pyrolysis and the Autoclave.

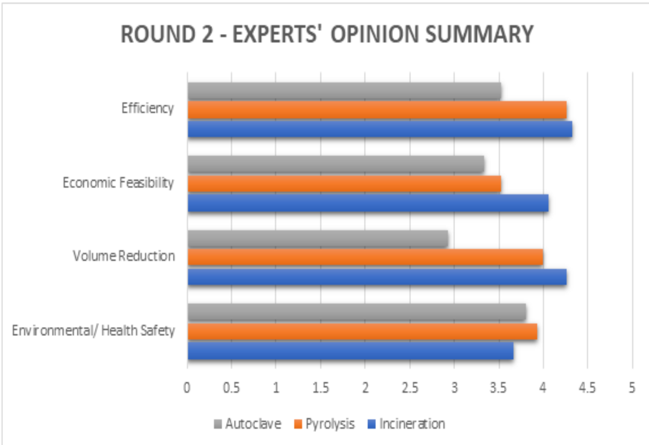

Figure 10. Round 2 of Experts' Opinion – Summary

Round 3 of Experts' Opinion

The final round of the survey is all about ranking the criteria for selecting the best technology available. The question for round 3 of the survey is "In terms of the importance of selecting the best technology, which criterion should be the first, second, third, and fourth?" and the criteria given are (1) Environmental and Health Safety, (2) Volume Reduction, (3) Economic/Financial Aspect, (4) Efficiency in Treatment of Infectious Healthcare Waste.

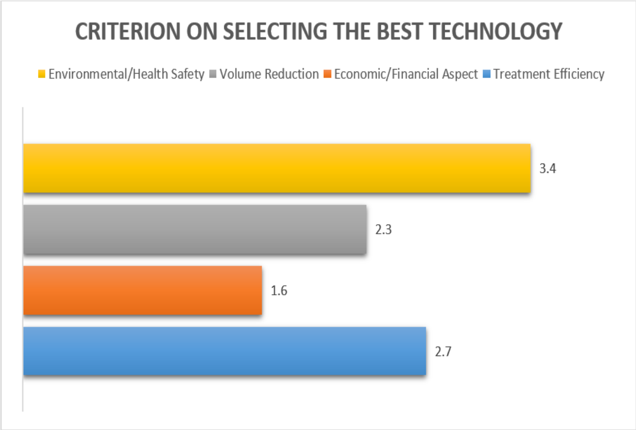

Figure 11. Summary for the Ranking of the Criterion in Choosing the Best Technology

According to experts, environmental / health safety is their most important criteria when selecting the best technology available. 60 – percent of the participants acknowledged that environmental / health safety is their priority criteria. The second priority is treatment efficiency, with a score of 2.7 out of 4. The third in ranking would be volume reduction, with a score of 2.3 out of 4, participants agree that volume reduction would be their third priority out of the four criteria. The least priority is the economic/financial aspect. 60 – percent of the participants decided that when it comes to selecting the best technology, economic and financial aspects would be the least of their concern.

Best Available Technology

The results gathered from round 1, 2 show that incineration with an energy recovery scheme ranks as the best technology due to its waste volume reduction capability, energy recovery, and treatment efficiency. See Figure. The results of the third round of the survey indicate that 40 – percent of the criteria should be in consideration of environmental/health safety, 30 – percent rating should be treatment efficiency, 20 – percent on volume reduction, and 10 – percent of the criterion should be allotted for the economic and financial aspect of the technology.

Table 15: Criterion Equivalent Weight According to Experts

Criteria	Rank	Percentage
Environmental/Health Safety	1	40%
Treatment Efficiency	2	30%
Volume Reduction	3	20%
Economic/Financial Aspect	4	10%

Table 20. Best Available Technology According to Experts

Technology	Rank	Score
Pyrolysis	1	3.65 / 4
Incineration w/ Energy Recovery Scheme	2	3.62 / 4
Autoclave	3	3.17 / 4

The result of round 3 indicates that if these criterion with equivalent weight were to be considered in the selection of the best available technology, pyrolysis would be considered the best available technology with a slim advantage of 3.65 than incineration with an energy recovery scheme's score of 3.62 and autoclave with 3.17.

Technical Applicability vs Experts' Opinion

The evaluation of the findings between the technical applicability and the experts' opinion is similar in the results of round 1 and 2. The experts' have expressed their opinions that incineration might be economically efficient, high treatment capability, and high-volume reduction, but it's not environmentally safe and is a health hazard. These opinions of the experts matched the researchers' health risk assessment, however, due to the consideration of the high risk of incineration, the researchers suggested a series of engineering controls and techniques which shows the ingress and egress of the design flow of the proposed incineration with energy recovery scheme technology. The proposed design flow includes APCDs – Air Pollution Control Devices with gas emission calculation with results of little to zero toxic substances which makes the technology internationally and locally compliant with the air quality standards. In terms of economic efficiency and volume reduction, cost-benefit analysis and cost-efficiency analysis were applied. The researchers set the parameters of volume reduction of incineration and pyrolysis with 228 and 80 tons, respectively. The cost per ton of waste in pyrolysis is Php 35,000.00 whilst Incineration cost only around Php 30,000.00 per ton of waste. Also, according to the cost-benefit analysis which comes with a financial model, the benefits outweigh the cost with a score of 1.23 which is a feasible technology and is capable of having a return of Php 17,548,620.00. If the environmental/health safety, treatment efficiency, and volume reduction capability were all present in both technologies – pyrolysis and incineration then it all goes down to economic/financial efficiency.

IV. CONCLUSION AND RECOMMENDATION

Conclusion

This paper was conducted to determine the potential and effectiveness of the Small-scale waste incinerator with the Waste-to-Energy scheme in San Lazaro Hospital. The applicability test results confirm that the project is economically profitable compared to the current system. Since there is no accurate way to compute the value of the infectious healthcare waste produced per year during the pre-pandemic era, as the generated waste varies each month, depending on several conditions such as the occurrence of seasonal diseases, but it is known that the range of the waste generated is within the expected range for their budget of 1.2 M, yearly. However, the researchers predicted that the increase in the growth rate of infectious healthcare waste in San Lazaro for the first quarter of the year 2020, due to the Novel Corona Virus's occurrence, will be sustained for the next few years due to its permanent impacts. With the uptrend of waste generated, the current system will not be as efficient in the treatment and volume reduction of waste, which will affect other resources in the long run. Therefore, it is necessary to invest in an efficient technology that will help the institution in the long run by providing a profit gain.

From the results of the several surveys conducted using the Delphi technique, incineration appealed to experts' groups and was deemed the best available treatment technology for handling infectious healthcare waste due to its effectiveness in treating infectious waste and its capacity to reduce the volume of waste, and the profit. However, since there are not enough studies conducted in the Philippines to support technology safety and applicability in the country, most experts still deem the project as unsafe; thus, it is also not socially acceptable.

The researchers have found out that the project is Economically feasible and cost-effective because the Energy contained in the Infectious Healthcare Waste will be converted to electricity and that there will be a return of investment in its 11th year, compared to other technologies with no return. Moreover, the technology will be sustainable, as there will be up to 90% on-site waste reduction, which will reduce the waste emitted in landfills, which will provide less environmental pollution. In addition to that, under controlled conditions and good design, emissions will not be harmful to the environment and humans. In conclusion, the researchers have found out that there will be more benefits in doing the project than rejecting the project and not taking action.

Recommendation

The researchers recommend San Lazaro Hospital implement the project due to the stable waste generation potential, electricity generation potential, sustainability and profit potential, and the project's lesser environmental impacts if implemented under controlled conditions, compared to not taking practical actions.

Future researchers may also consider focusing more on the security of environmental and health safety, which is one of the significant concerns that hinder investment. The discovery of the WtE project's potential may lead to a permanent solution to the existing and probable problems inclined with infectious healthcare wastes. In terms of risk management, future researchers may consider the associated risks in the study and come up with a risk management model to further address the risks of incineration technology.

Moreover, in conducting surveys, it would be best to consult a group of individuals who have excellent knowledge of Modern Waste treatment technologies and is in the practice of Public Health Engineering or Solid Waste Management.

Given these findings, the researchers recommend that government agencies be open to adaptation and support the WtE projects, as it will effectively address the problems in infectious healthcare waste, particularly in considering the generation of large volume and air quality control and sustainability. The initiative, and the government's support, will pave the way to transitioning a sustainable approach that will benefit the country. The project's future success will propagate to another; hence, it will encourage investors and create a good WtE market and advance the technology through innovations that will level to the global market.

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