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Clean Incineration of Solid Waste: A Cost-Benefit Analysis for Manila

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This report provides information on the potential health impacts of two methods of waste incineration in Manila, the Philippines. To do this, it models the performance of a hypothetical incineration facility, using two different technologies. Using a combination of pollution dispersion and health impact modelling, the study investigates how dioxin pollution from the incinerator would increase the occurrence of cancer in the surrounding population. This health impact is economically valued and added to the direct costs of running the incinerator. The report finds that incineration technology is available that meets the Philippines's national pollution guidelines on dioxin emissions – namely modular starved-air incineration should therefore be re-examined.

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CAA	Clean Air Act
CDD/CDF	Total tetra-through octa-chlorinated dibenzo-p-dioxin/ chlorinated dibenzofurans, 2,3,7,8-tetrachlorodibenzo-p-dioxin, and dibenzofurans
DENR	Department of Environment and Natural Resources
DRE	Destruction and removal rate efficiency
DSI	dry sorbent injection
EMB	Environmental Management Bureau
EMS-HAPS	Emissions Modeling System for Hazardous Air Pollutants
EPA	Environmental Protection Agency
ERM	Environmental Resources Management
ESWMA	Ecological Solid Waste Management Act
ISCLT	Industrial Source Complex Long Term Dispersion Model
ISCST	Industrial Source Complex Short Term Dispersion Model
I-TEQ	International Toxicity Equivalence
kg-bw	kilogram bodyweight
MB	Marginal Benefit
MB/RC	Mass Burn/Rotary Kiln
MC	Marginal Cost
mg	milligram
MMDA	Metro Manila Development Authority
MOD/SA	modular starved-air
MSW	Municipal Solid Waste
MWIs	Municipal Waste Incinerators
NCEA	National Center for Environmental Assessment
NCR	National Capital Region
Nm^3	Normal cubic meter
OWS	Occupational Wage Survey
PCBs	polychlorinated biphenyls
PCDDs	polychlorinated dibenzo-para dioxins
PCDFs	polychlorinated dibenzofurans
pg	picogram
PM	particulate matter
PPP	purchasing power parity
psig	pounds per square inch gauge
SCRAM	Support Center for Regulatory Air Modeling
TCDD	tetrachlorodibenzo-para-dioxin
TEF	toxic equivalence factor
tpd	tons per day
TSCREEN	toxic screening model
UNEP	United Nations Environment Programme
USEPA	United States Environmental Protection Agency
VSI	Value of Statistical Injury
VSL	Value of Statistical Life
WTP	Willingness to pay

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EXECUTIVE SUMMARY

The Philippine's ban on municipal waste incinerators imposed through the Clean Air Act (CAA) of 1999 is aimed at protecting its citizens from the harmful effects of dioxins. However, with the growing problem of solid waste management in Metro Manila due to the lack of landfill sites and the limited ability to recycle, the ban has created animosity between Metro Manila local government officials who view incineration as the most cost-effective and rapid solution to the Municipal's solid waste problem, and environmentalist groups who cite cost and health impacts of dioxin emissions from municipal waste incineration and claim that it diverts efforts away from the correct strategy of recycling, reuse, and recovery.

The ban on incineration limits the options available to local government units on the disposal of solid wastes. Although a section of the Philippine society would argue that recycling, reusing, and composting is the correct solution to the solid waste crisis of Metro Manila, most local government units opt to develop landfills. Even the Philippine Ecological Solid Waste Management Act of 2000 supports this option and requires that all open dump sites be converted into sanitary landfills by 2005. The principal reason for not being able to resolve the issue by amending the CAA is the lack of metrics (measurement/quantification) that will allow the objective evaluation of the incineration ban. This study attempts to address this issue as well.

This study looked into two incineration technologies: mass burn rotary kilns and the modular starved-air incinerators, both equipped with dry sorbent injection and fabric filters to control emissions. The mass burn rotary kiln which is claimed to meet the Philippine dioxin standard is being contemplated by the Philippine Government to be installed in Metro Manila. However, emission tests conducted by the US Environmental Protection Agency - National Center for Environmental Assessment (USEPA-NCEA) refutes this claim. In contrast, modular starved-air incinerators have been proven to meet dioxin standards based on actual emission monitoring conducted by the USEPA-NCEA. The proven ability to meet the Philippine dioxin standard is the only basis used in this study to label an incineration technology as clean.

The difference in the engineering installation and running costs of these technologies were compared with the avoided health damages (from shifting to a cleaner incineration technology). Air dispersion modeling was used to determine the number of people at risk from dioxin exposure through the air. The amount of dioxin inhaled was extrapolated to determine total exposure and using the USEPA cancer slope factor, the number of people at risk of developing cancer was estimated and valued using the value of statistical life approach.

It was concluded that, should the ban on incineration be lifted, modular starved-air incinerators are clearly the favoured choice over mass burn rotary kilns – the kind currently contemplated by the government. Modular starved-air incinerators would not only create much less pollution and fewer health damages, they would also be less expensive.

1.0 INTRODUCTION

The Republic Act 8749, also known as The Philippine Clean Air Act (CAA) of 1999, ushered in a new era in air quality management in the country by introducing innovative approaches such as providing authority to mix different policy tools. The CAA of 1999 strengthened environmental regulatory powers, introduced market-based instruments, and encouraged cooperation, self-regulation and citizen participation in all aspects of air quality management programs. The CAA 1999 also shifted the strategy for pollution abatement from control to prevention, and provides financial systems for implementing funding programs. Also, for the first time, it attempted to link ambient air management to emission standards through emission quotas and charge systems for both stationary and mobile sources.

The ban on incineration is controversial in two respects. First, it severely affects hospitals[1] that treat hazardous medical waste solely through incineration, and local government units considering incineration to manage municipal waste, without providing commercially viable alternatives. Second is the ambiguity in the wording of the Act. For example, Section 20 of the Act provides as follows:

> Sec. 20. Ban on Incineration – Incineration, hereby defined as the burning of municipal, biomedical and hazardous waste**, which process emits poisonous and toxic fumes,** is hereby prohibited. *(emphasis supplied)*

This is open to at least two interpretations, the easier of which is a total ban on incineration that sits well with many environmental groups. The other interpretation, which was the real intent of the writers[2] of the Act, is to ban incineration that emits

[1] The CAA called for a phase-out of existing incinerators dealing with bio-medical waste no later than May 2002.
[2] Personal communication with engineer, Roselita Paloma, Secretary to the House Committee on Ecology, March, 2002.

poisonous and toxic fumes – dioxins[3] not exceeding 0.1 nanogram/m^3 over a 5-8 hour sampling time. The Department of Environment and Natural Resources (DENR), based on the Implementing Rules and Regulations, interpreted Section 20 as a total ban on incineration technology and hence began promoting non-burn technologies[4]. What is ironic is that the DENR banned incineration despite its ability to meet dioxin standards, but promotes non-burn technologies that also emit these pollutants (within the same standards).

The ban has created animosity between Metro Manila local government officials[5] who view incineration as the most cost-effective and rapid solution to municipal solid waste disposal, and environmentalist groups who cite the cost and health impacts of incineration and claim that it diverts efforts away from the correct strategy of recycling, reuse, and recovery[6]. Two Congressmen; Caloocan City Representative, Edgar Erice, and Ilocos Representative, Eric D. Singson[7], and two Senators; John Osmena and Aquilino Pimentel, support the amendment of the CAA to remove the ban on incineration. Environmentalist groups headed by Green Peace and Mother Earth Unlimited are prepared to block moves to lift the ban. Meanwhile, in the midst of these debates, the municipal solid waste problem continues to grow.

The principal reason for the non-resolution of the CAA's amendment is the lack of metrics that allows the objective evaluation of the incineration ban. The technical and financial feasibility of operating incinerators that meet (and even exceed) dioxin standards and an enumeration of a long list of health and environmental impacts has dominated the arguments supporting or blocking moves to amend the CAA and allow incineration. The installation and running costs of incineration technology are well-defined but the monetary value of its health impacts in the country remains to be estimated. This policy study addresses the metrics gap by estimating the health damage attributable to a hypothetical municipal solid waste incineration plant emitting dioxins,

[3] 'Dioxin' is a catch-all term referring to a category of chemicals and compounds that share similar chemical structures and biological characteristics. Under this category are chlorinated dibenzo-para dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs), and certain polychlorinated biphenyls (PCBs). There are more than 200 types of dioxins based on the possible combinations of chlorine atoms linkages. Of the 75 possible PCDDs and 135 possible PCDFs, 17 have significance to health. The most toxic and most studied is 2,3,7,8-tetrachlorodibenzo-para-dioxin (TCDD) which is the subject of this study. Dioxins are produced inadvertently by a number of human activities and the main source in developed countries is the incineration of municipal wastes in old plants. Dioxins are emitted to the air environment mainly as particulate matter, settling on crops and soil, eventually getting into the food chain, and accumulating in fatty tissue. Humans are most exposed to dioxins in food (98%), and only 2% through direct inhalation. The 2,3,7,8-TCDD is considered by the US National Cancer Institute as the most potent carcinogen tested on laboratory animals. The non-cancer effects of 2,3,7,8-TCDD includes the disruption of the endocrine glands and immune system and impairment of fetal growth.

[4] The incinerator destruction chamber is free of oxygen and heat-conducting materials are used. Fire is not used as source of heat.

[5] Namely Metro Manila Mayors headed by Mayor Lito Atienza.

[6] See *Philippine Daily Inquirer* issues dated July 24, November 10-13, November 23, and December 17, 2001.

[7] Respectively filed House Bills No. 3828 and 3886 seeking to amend the CAA and lift the incineration ban.

and comparing the incremental cost of controlling these emissions with the corresponding benefits from reduced health damages.

The Philippine Ecological Solid Waste Management Act (ESWMA) of 2000 addresses the solid waste management problem of the country by emphasizing the need to recycle, reuse, and recover valuable resources. The ESWMA reinforces the ban on incineration and excludes this from best practices in the management of wastes[8]. In fact, the Act promotes the disposal of waste through landfills by requiring the upgrade of open dump sites to controlled dump sites[9] by the year 2003, and the replacement of the latter with sanitary landfills by the year 2005. The study by Bennagen et al (2002) estimated that the private cost of waste disposal to landfill sites in Metro Manila amounted to USD40 per ton in 1999 prices. The social cost was estimated by doubling the private cost because of the poor waste disposal practices in the country. (Private cost is the cost borne by private individuals in disposing their waste without accounting for the costs to society i.e. environmental cost, opportunity cost, etc.) Two studies in the United States computed that the social cost of sanitary landfill disposals ranged from USD 67 to USD 75 per ton which is roughly equal to the private cost of disposal (Repetto et al 1992 as cited in Bennagen et al 2002).

2.0 BACKGROUND

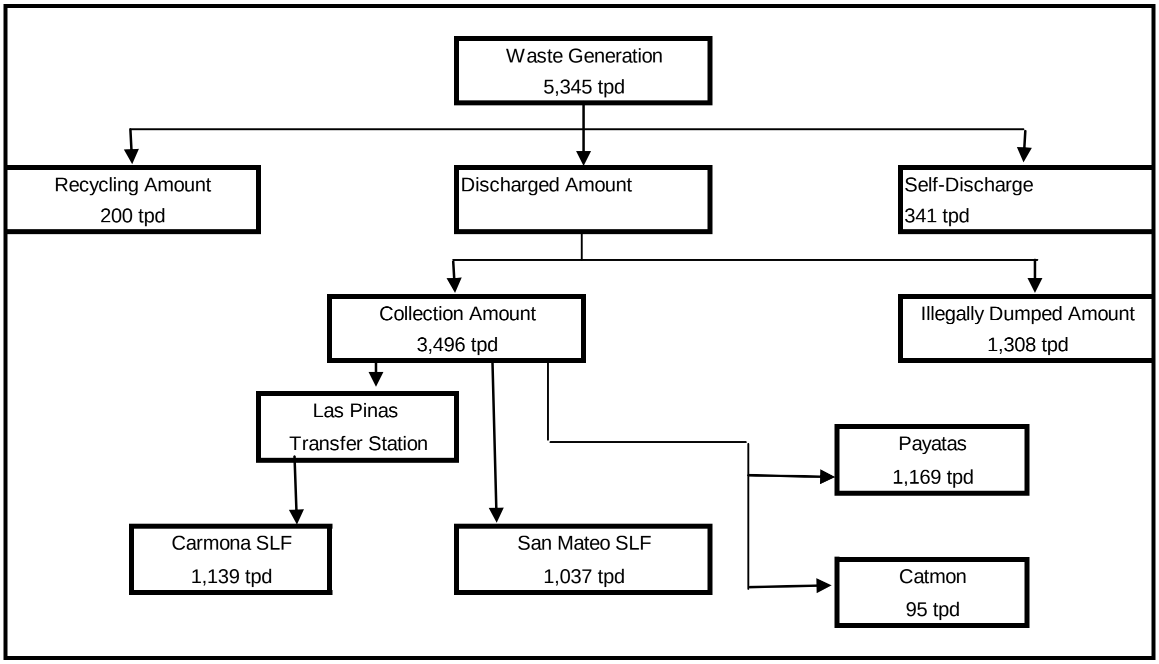
2.1 Existing Municipal Solid Waste Management Problem in the National Capital Region (NCR)

In 1997, the Metro Manila Development Authority estimated that Metro Manila generated 5,345 tons per day (tpd) of solid waste of which 3.7% is recycled, 65.4% is collected and disposed of in sanitary landfills and open dump sites, and the remainder is self-discharged (6.4%) and illegally dumped (24.5%)[10]. In 1997, the Carmona and San Mateo sanitary landfills handled 2,176 tpd while the Payatas and Catmon open dump sites handled 1,264 tpd (see Figure 1).

[8] Sec.2 (D) Ecological Solid Waste Management Act 2000.

[9] The law requires controlled dump sites to provide soil cover, runoff control, perimeter fencing, and recordkeeping – this does not apply to open dump sites.

[10] Pacific Consultants International Kokusai Kogyo Co., Ltd. (1999) "The Study on Solid Waste Management for Metro Manila in the Republic of the Philippines". Japan International Cooperation Agency and Metropolitan Manila Development Authority, Republic of the Philippines.



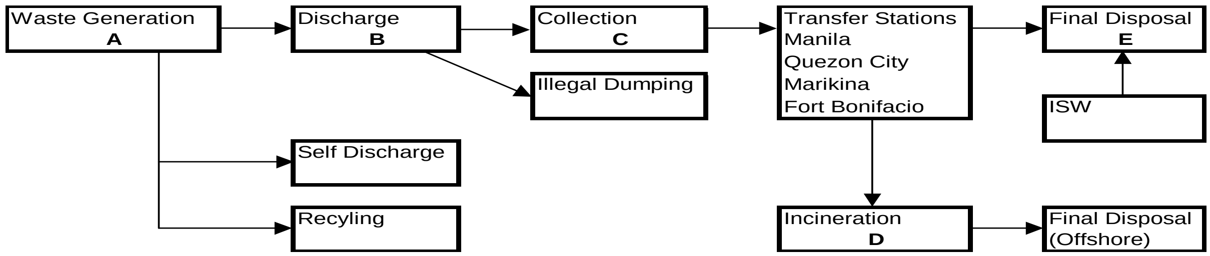
Source: Pacific Consultants International (1999)
Note: SLF – sanitary landfills

Figure 1. Waste Flow in Metro Manila (1997)

The Carmona and San Mateo landfills reached their limit and ceased accepting waste in 1998 and 2000, respectively. The Payatas open dump temporarily stopped accepting solid waste due to a freak "waste slide" accident that buried and killed several scavengers living in the dump. The resulting lack of disposal sites has led to the piling up of uncollected municipal solid waste, culminating in a garbage crisis in the Metro. The government's immediate administrative and policy reactions were to create the Commission of Solid Waste Management and pass the Solid Waste Management Act 2000. Alternative disposal sites were needed and this resulted in a plan to revive two sanitary landfill sites; the Montalban (in Rizal) and the Navotas (in Manila) landfills which respectively handled 600 tpd and 200 tpd. With the re-opening of the Payatas dump site in 2000 and these two landfill sites, the disposal problem has been somewhat alleviated but still, more than half of the Metro's solid waste remained uncollected.

Before the enactment of the Clean Air Act 1999, the Metro Manila Development Authority (MMDA) identified incineration as an integral part of its waste management plan. Incineration addressed an estimated 493 tpd in 1998 and was estimated to almost double its capacity by 2010 at 864 tpd [11]. Figure 2 presents the Metro's solid waste stream for the said period.

[11] There are conflicting figures on how much municipal solid waste will be incinerated. The same Pacific Consultants International Study quoted a higher figure, with the intention of a phased-approach to incineration to start at 500 tpd in the year 2005, increasing to 3,000 tpd by the year 2010.



Year	A	B	C	D	E
1998	5745	5169	3760	493	4191
1999	6145	5534	4024	525	4482
2000	6545	5898	4288	558	4774
2001	6894	6178	4600	586	4944
2002	7242	6459	4911	615	5114
2003	7590	6739	5222	643	5285
2004	7938	7019	5533	671	5455
2005	8286	7299	5844	699	6029
2006	8692	7695	6342	733	6466
2007	9097	8091	6839	765	6903
2008	9502	8487	7337	798	7340
2009	9907	8882	7834	831	7778
2010	10312	9278	8332	864	5718

Source: Pacific Consultants International (1999)
Note: Figures are in tons per day.

Figure 2. Estimated Waste Streams for Metro Manila 1998-2010

The Philippines had early but very limited experience in municipal solid waste incineration. The MMDA[12] revealed that research and development on municipal waste incinerators started as early as 1969 by the Quezon City government. A 2 x 150 tpd municipal waste incinerator was installed in 1971 and operated until 1978. The incinerator had the dual role of treating municipal waste and generating electricity. The incinerator was a mass burn refractory wall type with reciprocating grates. The boilers, one for each incinerator, were of natural circulation type and able to generate 19,850 pounds of steam per hour at 400 psig (pounds per square inch gauge) and 626 ^{o}F. A 2.5 megawatt (MW) turbine generator converted steam into 3,300 volts of electric power. A mechanical cyclone separator provided dust control.

Operational problems attributable to design and poor maintenance hounded this particular municipal incinerator – these included low solid waste tonnage resulting in under-ultilization, unsorted waste causing clogging of hopper and reciprocating grates, furnace corrosion, slagging in the combustion chamber, and corrosion of economizers. In

[12] Personal communication with engineer, Silverio B. Carullo Jr., Officer-in-Charge, Environmental Sanitation Center, North Sector, MMDA, November 2002.

1992, a technical assessment was undertaken to determine the viability of retrofitting and re-operating the incinerator. It concluded that the incinerator had reached obsolescence and due to problems of smoke and odor[13], was no longer suitable for the site, which had grown densely populated over the years. The re-operation plan of the Quezon City Waste Incinerator was scrapped.

2.2 Current Initiatives in Municipal Solid Waste Management

The MMDA and the National Solid Waste Management Commission have prioritized the development of new sanitary landfills for reason of their being immediate, large-scale solutions to the solid waste management problem. However, owing to the difficulty in complying with regulations, and the costs involved, this particular strategy takes time to be implemented. As a stopgap measure, several waste diversion projects are being implemented to ease the problem, and subsequently prolong the life of present landfills. These projects have included:

- Construction and operation of two recycling and composting plants with a capacity of 200 tpd (e.g., LCV processing center in Pier 18, and the Kalookan City's Rapid Composting Technology).

- Pilot projects on the conversion of processed residual wastes into fabricated construction materials.

- Local-based composting projects (e.g. Paranaque 100 tpd composting projects that use 40-foot container vans).

- Intensification of recycling – from 6% in 1997 to 13% in 2000.

- MMDA Ordinance 99-004 requiring waste segregation at the household level.

- Intensification of waste trading – 39% increase in volume from 1998 to 2000.

2.3 The Uncertain Future of Waste Incinerators in Metro Manila

In 1994, the Ramos Administration attempted to solve the solid waste problem in the Metro by issuing Memorandum Order No. 2020, Series 1994 on "Creating an Executive Committee to Oversee the Build-Operate-Transfer Implementation of Solid Waste Management Projects for Waste Disposal Sites in Carmona, Cavite and San Mateo, Rizal." The Committee invited private companies to bid for these projects and in 1997, the Jancom Environmental Corporation won the project to build and operate a solid waste incinerator in San Mateo. Although the project bidding and awarding was marred with controversy causing delays in the implementation, perhaps the more substantive issue was the CAA enactment and its ban on incineration. The MMDA interpreted the provision as a technology ban making the Jancom project illegal. The DENR-

[13] Abis, L. and F.A. Uriarte, Jr. (undated). "Metro Manila Solid Waste Master Plan – Quezon City Incinerator."

Environmental Management Bureau (EMB) supported the MMDA's interpretation[14]. Jancom, acting on the belief that the ban on incinerators applied only to technologies that were not able to meet the standard, appealed to the Supreme Court to contest the MMDA's interpretation. On April 10, 2002, the Supreme Court ruled in favor of Jancom[15]. The principal authors of the CAA, House Representative Nereus Acosta and Senator Gregorio Honasan, denounced the Court's interpretation.

On July 12, 2002, the DENR issued Memorandum Circular No. 5 clarifying the incineration ban in relation to the Supreme Court's ruling and "allowed incineration of toxic and hazardous waste as well as bio-medical wastes"[16]. This invalidated the CAA's mandated phase-out of bio-medical waste incinerators which was due to be completed by May 2002. In contrast, the Environmental Management Bureau (EMB) upheld the ban on municipal waste incinerators based on the reason that the bureau lacked the capability to monitor emissions.

In August 2001, the Philippine Congress passed the Republic Act 9003 (otherwise called the Ecological Solid Waste Management Act 2001) that required the practice of ecological waste management. Incineration was excluded as part of ecological waste management.

2.4 Other Emissions from Municipal Waste Incinerators (MWIs)

A wide array of air pollutants are emitted by municipal waste incinerators. Although this study focuses on dioxin emissions, it is recognized that other pollutants have the potential to cause harm to health. These pollutants from MWIs, as identified by the United States Environmental Protection Agency (USEPA), include nitrogen oxide (NO_x), carbon monoxide (CO), acid gases (HCl: hydrochloric acid, SO_2: sulfur dioxide), particulate matter (PM), metals (cadmium [Cd], lead [Pb], mercury [Hg], arsenic [As], nickel [Ni], chromium [Cr]), and toxic organics (air pollutants PCDDs/PCDFs: polychlorinated dibenzo-para dioxins/ polychlorinated dibenzofurans, polycyclic aromatic hydrocarbons [PAHs], polychlorinated biphenyls [PCBs]).

[14] March 16, 2001, document as quoted by the MMDA "EMB ... upon review and evaluation of the (Jancom) document, … found your proposal a burn technology similar to incineration and not in accordance with the laws and regulations, ... it falls squarely within the prohibition."

[15] A Built-Operate-Transfer (BOT) waste-to-energy project proposal was submitted by Jancom Environmental Corporation – it won the tender in 1997. There were delays in the signing of the BOT contract and unfortunately for Jancom, the Clean Air Act banning incineration was passed during this time. The Presidential Committee on Flagship Programs and Projects subsequently informed Jancom that it could no longer pursue the project for various reasons including the CAA. However, the MMDA continued with another bidding and prequalification for the solid waste management for Metro Manila. Jancom filed a case against the MMDA with the Pasig Trial Court and won. The MMDA filed an application for a temporary restraining order with the Court of Appeal which was dismissed. The MMDA then appealed to the Supreme Court; the appeal was also dismissed. The Supreme Court interpreted that the ban "… does not absolutely prohibit incineration as a mode of waste disposal; rather only those burning processes which emit poisonous and toxic fumes are banned." The Supreme Court agreed with the Court of Appeal and stated "It may not, thus, be argued that the Clean Air Act prohibits all forms of incineration as to make the contract in question violative of the Clean Air Act."

[16] The Secretary to the House Committee on Ecology, Roselita Paloma, opined that this Memorandum Circular is illegal.

2.5 Dioxin Description, Health Impacts, and Chemistry of Formation

Dioxins, furans, and polychlorinated biphenyls (PCBs) are a family of chemicals with similar properties and toxicity which share a common carbon-oxygen framework. Dioxins are composed of two benzene[17] rings that can be linked in three different ways. If the benzene rings are joined by a six-member ring with two oxygen atoms, it belongs to the family of dibenzo-p-dioxins. Dibenzo is a short form for the two benzene rings where a carbon atom is located at the vertex of each hexagon. The '-p-' stands for para which denotes the opposite locations of the oxygen atoms[18].

The location of the chlorine atoms, instead of the normal hydrogen atoms, joining the carbon atoms defines the dioxin cogener. If the benzene rings are joined by a five-member ring with a single oxygen atom, the resulting isomer belongs to the furans family. If the benzenes are connected directly, they belong to the biphenyl family.

There are 75 dioxins, 135 furans, and 209 PCB cogeners but only 7, 10, and 12, respectively, are toxic[19]. Cogeners that have three or fewer chlorine atoms lack the dioxin-like toxicity or its ability to bind to the cell soluble protein, aryl hydrocarbon or Ah receptor found in the cells of all vertebrates, which controls the turning on or off of genes in the production of specific proteins. One of the genes affected when the dioxin binds to the Ah receptor is the CYP1A1 gene which is responsible for the immune system. Another gene influences hormone metabolism and growth factors which can cause genetic changes that lead to cell proliferation, increased risk of mutations, or cancer[20].

Not all dioxins are toxic, and those that are have different levels of toxicity. The environmental risk assessment of samples containing many different cogeners of dioxin is difficult. Initially, the risk assessment approach was limited to the concentration of 2,3,7,8 in full tetrachlorodibenzo-para-dioxin (TCDD) – the most toxic of the dioxin family members. The Toxic Equivalency Factors (TEF), a widely accepted approach in assessing risks associated with dioxins, allows the assessment of a complex mixture of all dioxins and furans into a single Toxic Equivalent Quotient or TEQ[21]. This is achieved by

[17] Benzene (CAS# 71-43-2) is a colorless liquid with a sweet odor and is a very commonly used chemical in the manufacture of plastics, resins, nylon, synthetic fibres, rubbers, lubricants, dyes, detergents, drugs, and pesticides. It is a natural part of oil and gasoline. Benzene evaporates quickly into the air, dissolves slightly in water, and is highly flammable. Benzene is a known carcinogen and long-term exposure to it causes leukaemia, and cancer of blood-forming organs.

[18] L.A. Shadoff (1994)

[19] CHEJ (1999)

[20] CHEJ (1999)

[21] The TEF/TEQ approach was crafted through a consensus meeting of World Health Organization members to conveniently estimate the toxicity of a mixture of dioxins. The approach has several limitations. First is the assumption that all dioxins have the same toxicity mechanism of binding with Ah receptors. Second is the addition of toxicity (the toxicity of each cogener is added to determine the toxicity of polluted air, e.g. if the polluted air has (2,3,7,8-Cl_4DD) and (1,2,3,7,8-Cl_5DD) then these components were multiplied to the I-TEF to get the total toxicity. However, it is possible that these components may have synergistic or antagonistic relations that could amplify or reduce the total toxicity, which discounts the synergistic and antagonistic relationship that could exist among these cogeners. Third, again for convenience to harmonize studies, is the order of magnitude of 1, 0.1, 0.001, and so on.

multiplying the concentration of each of the 17 cogeners with the corresponding TEF (International and World Health Organization) as provided in the Table 1.

This approach in estimating dioxin toxicity is also applied to emission standards – expressed in nanograms[22], TEQ/Nm^3 or the minimum risk level of exposure – in picogram/kg-body weight-day (weight or amount of dioxin for each kilogram of human body weight for each day – the exposure is a function of the body weight and the duration of exposure).

Table 1. Toxic Equivalent Factors for Dioxins and Furans

Cogener		I-TEFs	WHO-TEFs
2,3,7,8-tetrachlorodipenzo dioxin	(2,3,7,8-Cl_4DD)	1	1
1,2,3,7,8-pentachlorodibenzo dioxin	(1,2,3,7,8-Cl_5DD)	0.5	1
1,2,3,4,7,8-hexachlorodibenzo dioxin	(1,2,3,4,7,8-Cl_6DD)	0.1	0.1
1,2,3,6,7,8-hexachlorodibenzo dioxin	(1,2,3,6,7,8-Cl_6DD)	0.1	0.1
1,2,3,7,8,9-hexachlorodibenzo dioxin	(1,2,3,7,8,9-Cl_6DD)	0.1	0.1
1,2,3,4,6,7,8-heptachlorodibenzo dioxin	(1,2,3,4,6,7,8-Cl_7DD)	0.01	0.01
octachlorodibenzo dioxin	(Cl_8DD)	0.001	0.0001
2,3,7,8-tetrachlorodipenzo furan	(2,3,7,8-Cl_4DF)	0.1	0.1
1,2,3,7,8-pentachlorodibenzo furan	(1,2,3,7,8-Cl_5DF)	0.05	0.05
2,3,4,7,8-pentachlorodibenzo furan	(2,3,4,7,8-CL_5DF)	0.5	0.5
1,2,3,4,7,8-hexachlorodibenzo furan	(1,2,3,4,7,8-Cl_6DF)	0.1	0.1
1,2,3,6,7,8-hexachlorodibenzo furan	(1,2,3,6,7,8-Cl_6DF)	0.1	0.1
1,2,3,7,8,9-hexachlorodibenzo furan	(1,2,3,7,8,9-Cl_6DF)	0.1	0.1
2,3,4,6,7,8-hexachlorodibenzo furan	(2,3,4,6,7,8-CL_6DF)	0.1	0.1
1,2,3,4,6,7,8-heptachlorodibenzo furan	(1,2,3,4,6,7,8-CL_7DF)	0.01	0.01
1,2,3,4,7,8,9-heptachlorodibenzo furan	(1,2,3,4,7,8,9-CL_7DF)	0.01	0.01
Octachlorodibenzo furan	(CL_8DF)	0.001	0.0001

Source: UNEP (2001). Standardized Toolkit for Identification and Quantification of Dioxin and Furan Releases.

Notes: I-TEF: International-Toxic Equivalent Factors;
WHO-TEF: World Health Organization-Toxic Equivalent Factors

2.6 Chemistry of Dioxin Formation

Dioxins (PCDDs/PCDFs) can result from a combination of formation mechanisms, depending on design, combustion conditions, solid waste feed characteristics (the way the solid waste is introduced to the burning chamber – by gravity or ram), and type and operation of air pollution control device (APCD) equipment. Dioxin and furan formation mechanisms have been studied since the late 1970s when dioxins were found in municipal waste combustor emissions. Lustenhouwer et al (1980) originally advanced three theories to explain the presence of dioxins: (1) dioxin emissions from trace dioxins in the fuel; (2) dioxin emissions from gas-phase precursors similar to

[22] One billionth of a gram.

dioxins such as chloro-aromatics via homogeneous (gas-gas phase) reactions or heterogeneous (gas-solid phase) condensation reactions between gas-phase precursors and catalytic particle surface; (3) *de novo* synthesis of dioxins from carbon sources that are chemically quite different from the dioxin and furan ring structures. *De novo* synthesis involves heterogeneous, surface-catalyzed reactions between carbonaceous particulates and an organic or inorganic chlorine donor.

It is now generally accepted that Theory 1 cannot fully explain the levels of dioxin emissions measured in the incinerator, considering that the dioxins decompose rapidly at temperatures above 1,700^{o}F. Theory 2's homogeneous reactions are also believed to play a relatively minor role, and kinetic modeling by Shaub and Tsang (1983) suggested that the homogeneous gas-phase rate formation could not account for observed yields of dioxins, and at high temperatures present in the combustion zone, the multi-step process necessary for the dioxin formation cannot compete with its destruction. Theory 2's heterogeneous reactions where the chloro-aromatic precursors which might already be present in the fuel, and Theory 3, which does not require that chloro-aromatic precursors be present on fly ash or in the gas stream, are now believed to explain the presence of dioxin emissions from incinerators.

Theory 3 does not require the chloro-aromatic precursors and dioxins may be synthesized *de novo* from gas-solid and solid-solid reactions between carbon particulates, air, moisture and inorganic chlorides in the presence of a metal catalyst, primarily divalent copper (Stieglitz et al 1989a and 1989b). Activated carbon has also been implicated as a catalyst (Dickson et al 1992).

The most important findings in the formation of dioxins inside the incinerator are:

- Dioxin emissions from combustion devices are a result primarily of heterogeneous, surface-catalyzed reactions in the combustion area outside the furnace.

- Experimental evidence suggests that these reactions occur within a temperature range of approximately 390^{o}F to 750^{o}F (200^{o}C to 400^{o}C) or wider, with maximum formation occurring near 570^{o}F (300^{o}C).

- Conditions conducive to downstream formation include (1) the presence of particulates, which allow for solid-catalyzed reactions; (2) post-furnace particulate residence time in the critical temperature window (approximately 400^{o}F to 750^{o}F); (3) the presence of chlorine and organic precursors, including chloro-aromatics; and (4) a shortage of formation inhibitors, such as sulfur.

- Poor combustion can substantially increase dioxin formation, possibly through increased soot formation (providing more catalytic reaction sites for dioxin formation), increased formation of dioxin precursors, and increased gas-phase formation of dioxins, although sufficient oxygen also appears to be necessary (Gullett et al 1992).

Approaches that have been successfully demonstrated in full scale systems for controlling dioxin emissions include:

- The maintenance of good combustion conditions to limit organic precursors and soot;
- Rapid flue gas quenching or other measures to minimize post-furnace particulate residence;
- Adjusting the time in the critical temperature zone (post-combustion chamber and heat exchanger);
- The use of formation inhibitors; and
- End-of-pipe flue gas cleaning techniques for PCDDs/PCDFs removal or catalytic decomposition.

2.7 Defining the "With" and "Without" Costs-Benefit Analysis Scenarios Using Dioxin Emission Factors

The "With Project" scenario is defined as the incineration technology and post-combustion controls that will meet the Philippine dioxin emission standard of 0.1 nanogram (10^{-9}g)/m^3. Conversely, the "Without Project" scenario is the incineration technology and post-combustion control that will not meet the standard.

To identify which combination of incineration technology and post-combustion control can meet the 0.1 nanogram I-TEQ/m^3 emission standard, three sets of emission factors were evaluated. These emission factors are:

- USEPA-AP42 "Compilation of Air Pollutant Emission Factors. Volume 1: Stationary Point and Area Sources";
- the United Nations Environment Programme (UNEP) "Standardized Toolkit for Identification and Quantification of Dioxin and Furan Releases"; and
- USEPA-National Center for Environmental Assessment (USEPA-NCEA) Database of Sources of Environmental Releases in the United States (Version 3.0).

Only the USEPA-NCEA provided actual dioxin source strength terms that included actual dioxin emission measurements, and stack parameters needed in the dispersion modeling. Although the USEPA-AP42 provided a much wider range of incineration technology and combinations of post-combustion controls, these emission factors were expressed in actual mass emission rates (kilograms of dioxin / Mg of refuse processed) and not the toxic equivalent (I-TEQ). While the UNEP emission factors are expressed in terms of toxic equivalents, the categories of incineration technology and post-combustion controls are defined so broadly (e.g., low technology versus high technology incineration, and minimal versus good air pollution control) that they cannot accurately capture the incineration technologies being evaluated.

The USEPA-NCEA emission factors, like the USEPA-AP42 were generated from individual facility test data conducted by US State agencies, trade associations, Environmental Protection Agency (EPA) program offices, and EPA regulatory dockets. These factors measured and tracked all toxic dioxin cogeners and reported each concentration, provided total mass emissions, and computed toxic equivalents. All NCEA emission factors, being derived from existing incinerator facilities, cover a wide range and combination of post-combustion control technologies.

Table 2. NCEA Municipal Solid Waste Incinerator Emission Factors

Emission Factors from USEPA-National Center for Environmental Assessment (USEPA-NCEA)

Incinerator Type	Control Equipment	No. of Facility	Total PCDDs/PCDFs/kg Waste Processed	
			ng/kg	ng-TEQ/kg
Mass Burn - Rotary Kiln	Dry Sorbent Injection and Fabric Filter	1	131.21777	46.98478
Mass Burn - Rotary Kiln	Dry Sorbent Injection and Hot-Side Electrostatic Precipitator	1	13472.40844	284.98974
Mass Burn - Rotary Kiln	Dry Scrubber and Fabric Filter	1	33.61506	0.62181
Mass Burn - Refractory Wall	Dry Scrubber and Cold-Side Electrostatic Precipitator	1	2195.79484	51.13374
Mass Burn - Refractory Wall	Cold-Side Electrostatic Precipitator	1	13449.68859	235.5029
Mass Burn - Refractory Wall	Hot-Side Electrostatic Precipitator	1	4323.06426	472.91439
Modular Excess-Air	Cold-Side Electrostatic Precipitator	2	946.795	16.23850
Modular Excess-Air	Hot-Side Electrostatic Precipitator	1	795.5287	117.88520
Modular Starved-Air	Hot-Side Electrostatic Precipitator	1	2906.201	79.00200
Modular Starved-Air	Dry Sorbent Injection and Fabric Filter	1	2.04039	0.02472
Mass Burn Water-walled	Dry Scrubber and Cold Side Electrostatic Precipitator	2	354.56464	6.09559
Mass Burn Water-walled	Dry Sorbent, Carbon Injection, and Fabric Filter	1	62.3875	1.50224
Mass Burn Water-walled	Dry Scrubber and Fabric Filter	6	34.87281	0.66981
Mass Burn Water-walled	Dry Sorbent Injection, Carbon Injection, and Hot-Side Electrostatic Precipitator	1	404.64167	7.73773
Mass Burn Water-walled	Hot-Side Electrostatic Precipitator	7	15380.14211	478.35254
Mass Burn Water-walled	Dry Sorbent and Fabric Filter	2	67.55722	1.91443
RDF	Cold-Side Electrostatic Precipitator	1	15471.13246	231.09751
RDF	Hot-Side Electrostatic Precipitator	1	75537.30809	1491.75091
RDF	Dry Scrubber and Cold Side Electrostatic Precipitator	1	29.07249	0.52747
RDF	Dry Scrubber and Fabric Filter	2	11.91536	0.23956

Note: RDF = Refuse Derived Fuel

Source: NCEA Database of Sources of Environmental Releases of Dioxin Like Compounds in the United States (Version 3.0) March, 2001.

Note that the dioxin standard is expressed in terms of concentration or nanogram I-TEQ/m^3 and cannot be readily compared with the USEPA-NCEA emission factors which is expressed in terms of activity rate or nanogram I-TEQ/ton of refuse burned. To allow comparison, the municipal waste incinerator F-factor, defined as the ratio of the gas volume of the products of combustion to the heating value of the waste, equivalent to 9,570 dscf/10^^{6} Btu[23], was used. Applying the typical heating value of solid waste in Metro Manila of 3,100 Btu, only an incineration technology and post-combustion control that has an emission factor of equal to or less than 0.1852 ng I-TEQ/kg[24] will be able to meet the Philippine emission standard. Based on the USEPA-NCEA database, only the modular starved-air incinerator with dry-sorbent injection and fabric filter (MOD/SA), will be able to meet the dioxin standard. This is considered as the clean incineration of solid waste applicable to the "With Project" scenario.

Modular MWIs are shop-fabricated with a capacity ranging from 5 to 10 tpd and are designed to handle unprocessed wastes. The modular incinerator's typical design has two combustion chambers – a primary chamber where waste is fed, and burned for up to 12 hours, and a secondary chamber into which excess air is injected to complete the burning process – temperatures of up to 1,200^{o}C are maintained here. The most common type of modular incinerator is the starved-air design (MOD/SA), where combustion air is injected at the sub-stoichiometric level and results in flue gas rich in unburned hydrocarbons. These unburned hydrocarbons are completely burned in the secondary chamber. Older designs of MOD/SA do not include heat recovery but more recent designs include waste heat boilers. MOD/SA incinerators are equipped with auxiliary fuel burners used for start-ups. High temperatures and sufficient mixing of flue gas in the secondary chamber result in low CO, PM, and trace organic emissions.

Since only one incineration technology was able to meet the Philippine dioxins dioxin standard, any remaining incineration technology mentioned in the USEPA-NCEA database[25] can be used in the "Without Project" scenario. Choosing a technology that emits the highest level of dioxins (uncontrolled dioxin emissions), and comparing this with the MOD/SA model, will generate large marginal benefits. The incineration technology being contemplated by the Philippine Environmental Management Bureau (EMB), a mass burn rotary kiln type incinerator equipped with dry scrubber and fabric filter, was used to define the "Without Project" scenario. This type of incinerator, based on the USEPA-NCEA dioxin emission factor database, will not meet the Philippine

[23] Developed by USEPA using USEPA Method 19, dscf = dry standard cubic feet, Btu = British thermal unit

[24] 9,570 ft3/10^6 x 3,100 Btu/lb x 0.0624= 1.852 m^3/kg
1.852 m^3/kg x 0.1 ng I-TEQ/m^3 = 0.182 ng I-TEQ/kg

[25] The USEPA-NCEA covered six different types of incineration technologies, and 21 different combinations of incineration technology and post combustion controls.

emission standard[26]. Sumitomo Heavy Industries Ltd. proposed to the EMB a mass burn rotary kiln incinerator type with a secondary combustion chamber to destroy dioxins, equipped with fabric filter to remove particulates, and dry sorbent (lime and activated carbon) injections to remove HCl, SO_x, and dioxins. Excess heat can be utilized to generate steam for possible power generation, preheat the combustion air to reduce fuel cost, and supply hot water to nearby communities.

Mass burn MWIs use gravity or mechanical ram systems to feed municipal solid waste (MSW) to a moving grate. Mass burn MWIs are further classified into mass burn/water-walled (MB/WW), mass burn/rotary water-walled (MB/RC), and mass burn/refractory-wall (MB/RW) designs.

In earlier designs of the MB/RW (Mass Burn - Refractory Wall) incinerator, an overhead crane fed the waste into the combustion chamber. Now, hydraulic rams are predominantly used. Watertubes are used in the construction of the combustion chamber wall. A rotary combustion chamber that sits at an angle and rotates at about 10 revolutions per hour causes the waste to advance and tumble down as it burns. Also, the MB/RW operates at about 50 percent excess air.

It is interesting to note that both incineration technologies employ similar post-combustion controls to reduce dioxin emissions. Fabric filters, also known as baghouses, are principally used to control particulate matter (PM) and metals emissions from incinerators. Removal is accomplished by passing flue gas through a multiple cylindrical shaped fabric. Fabric filters have PM removal efficiencies of greater than 99 percent. Decreasing the fabric filter inlet temperatures decreases the formation of dioxins, and in combination with acid gas control devices like spray drying and dry sorbent injection, and wet scrubbing, lower dioxin emissions are achieved.

Dry sorbent injection (DSI) is used in incinerators primarily to reduce acid gas emissions (SO_2 and HCl). There are two different types of DSIs depending on the location where the dry alkali sorbents are injected. If the sorbent is injected downstream of the combustor and upstream of the PM control, then it is called a duct sorbent injection. In furnace sorbent injection, the sorbent is directly injected into the combustion chamber. Alkali sorbents, usually hydrated lime or sodium bicarbonate, react with HCl and SO_2 to form calcium chloride and calcium sulfite. These reaction products are collected through the PM collectors.

[26] Sumitomo Heavy Industries Ltd., the Engineering and Environment Group, Environment and Energy Center, and the Municipal and Industrial Waste Engineering Division submitted a technical proposal to the Environment Management Bureau to construct an industrial waste treatment and disposal facility using a rotary kiln water-walled type of incinerator equipped with fabric filter and dry scrubber to control emissions. A wet scrubber and a catalytic denitrification (removal of nitrogen from the emissions to further control emissions are offered as optional equipment. A measured trial burn in Malaysia without the denitrification equipment reported dioxin emissions of 0.002 ng I-TEQ/Nm^3 or a destruction and removal rate efficiency (DRE) of 99.9999%. It is emphasized that the results from a trial burn and actual emissions using mixed municipal wastes may result in different emissions. A similar incinerator, also equipped with a dry scrubber and fabric filter, was listed in the USEPA-NCEA database, the Duchess County Resource Recovery Facility, Poughkeepsie, New York and was found to have an emission factor of 1.33 ng I-TEQ/kg of waste which is higher than the 0.1852 ng I-TEQ/m^3 emission factor needed to meet the Philippine dioxin emission standards.

2.8 Describing the Hypothetical Incineration Plants and Defining Their Location for Dispersion Modeling

Since there are no existing MWIs in the Philippines, this study resorts to the use of hypothetical plants to define stack parameters needed in the dispersion modeling, using the "With Project" and "Without Project" definitions. "Hypothetical" here would refer to the existing rotary kiln water-walled incinerator equipped with dry sorbent injection and fabric filter, and the modular starved-air incinerator, both of which have the same post-combustion control, using near-actual stack monitoring data (plant-specific dioxin emission factor, actual stack exit temperature, actual stack exist velocity, actual stack height, and actual stack diameter of an incineration plant operating in the US – information needed for modeling), burning Metro Manila waste[27], being 'placed' in a location deemed suitable for incinerators by the Environmental Management Bureau.

These incinerators have the following features:

Table 3. Description of Incinerators

Features	Incinerator Type	
	Mass Burn, Rotary Kiln Water-walled	**Modular Starved-Air**
Parameters	Dry Sorbent Injection, Fabric Filter	Modular Starved-Air, Dry Sorbent Injection, Fabric Filter
Activity Rate	200 tons per day	100 tons per day
Dioxin Emission Factor	1.33 ng I-TEQ/kg of waste[28]	0.02 ng I-TEQ/kg
Number of Combustors	2	3
Number of Stacks	1	1
Stack Height	61 meters	42.7 meters
Stack Exit Velocity	16.35 m/s	0.438 m/s
Stack Exit Temperature	183.1 ^oC	213.9 ^oC
Name of Existing Incinerator	Dutches County Resource Recovery Facility, Poughkeepsie, NY	St. Croix Waste to Energy Facility, New Richmond, Wisconsin

[27] Heating value of Metro Manila waste.
[28] The difference between Tables 2 and 3 emission factors is that Table 2 is an average for 6 incinerator plants having the same combustion technology and post-combustion control while Table 3 is the actual emission factor generated for Dutches County Resource Recovery Facility, Poughkeepsie, NY. This is the only plant in this sub-category that has the stack parameters needed to run the ISCST390 model.

Discussions with the Environmental Management Bureau revealed that 19 sites were initially identified in at least two studies[29] as potential locations of MWIs. However, the most suitable sites are in the vicinity of the LIMA Technology Center, an industrial estate located 65 kilometers south of Manila. This site was used in the dispersion modeling.

3.0 THEORETICAL AND ANALYTICAL FRAMEWORK

3.1 Marginal Benefits and Residual Damages

The main reason for the ban on incineration is the negative impact of its emissions, particularly dioxins, on human health. This technology ban, as discussed earlier, has compounded the solid waste management problem in Metro Manila. It has also stifled future innovation both in the development of incineration methods and control technologies.

Pollution control technologies for incinerators may be installed to significantly reduce emissions. Discussions in an earlier section (Section 2.7) show that these technologies can control and meet the current emission standard of 0.1 nanogram/m^3. However, remaining uncontrolled emissions may still result in considerable health damage. The ban may not be lifted if such health damage is substantial.

The acceptability of the residual health damage to the affected community becomes relevant at this juncture. This situation is depicted in Figure 3. From an economic standpoint, the optimal level of emissions is where the difference between the total benefit and cost from the installation of pollution control is the greatest (e*). This is also the point where the marginal benefit of pollution control equates with the marginal cost. However, the decision to continue to ban or lift the ban on incineration does not only depend on the avoided damages due to pollution control but also on the residual damage cost even with pollution control technology. Lifting the ban may not be acceptable if the residual damage is still significant.

[29] These studies are “The Study on Hazardous Waste Management in the Republic of the Philippines”, EX Corporation Kokusai Kogyo Co. Ltd (June 2001) and “The Study on Solid Waste Management for Metro Manila in the Republic of the Philippines”, Pacific Consultants International (1999).

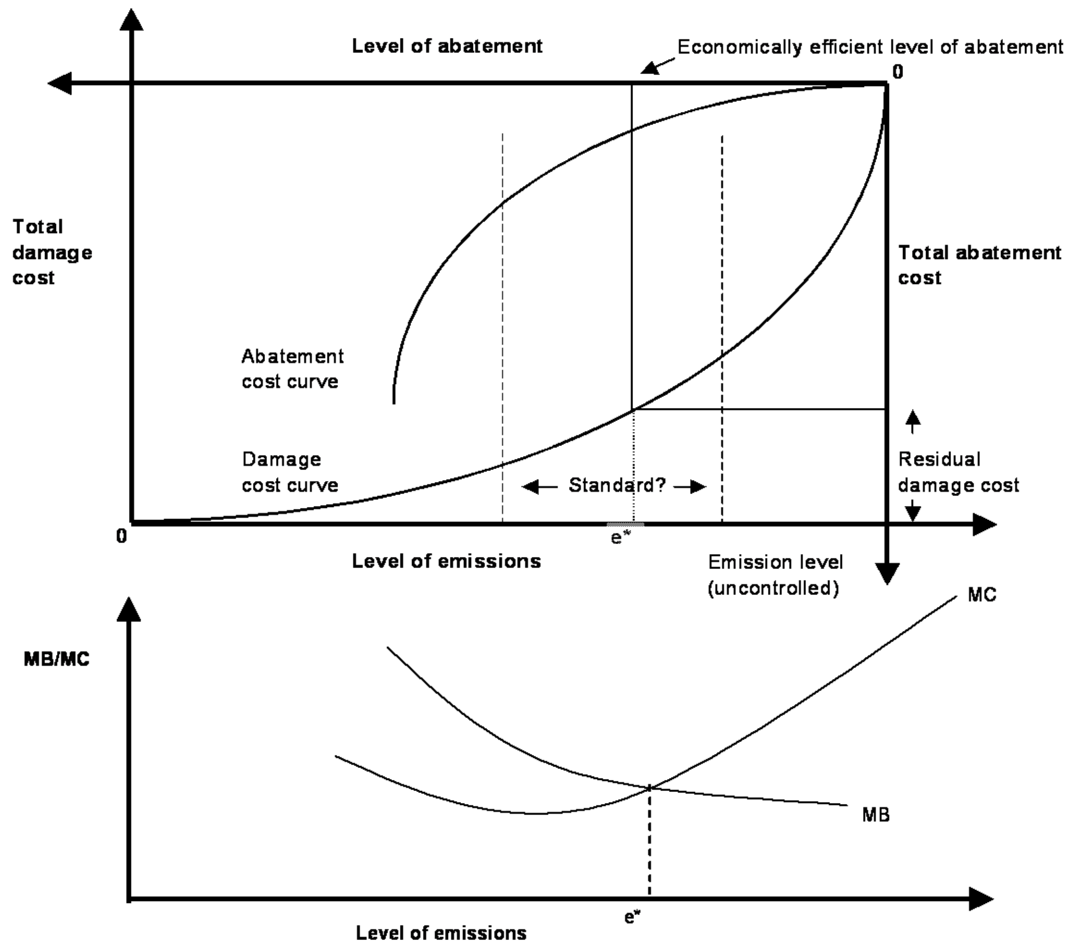


Figure 3. Optimal Level of Emission

Figure 3 also depicts how the efficient level of emissions with pollution control relates with the standard. Ideally, a balance in both the pollution abatement cost and damage cost should be made in setting the standard to optimise costs. This would also mean setting the standard at the intersection of marginal abatement cost (MC) and marginal damage cost (MB) or where the distance between the abatement cost curve and the damage cost curve is largest (e*).

For this study, 0.1 nanogram/m^3 of dioxin was established as the standard using the Philippine Clean Air Act. This would mean, on one hand, that the standard is too stringent if it is below the emission level where MB=MC and it is worth lowering the standard. On the other hand, it is worth imposing stricter standards if it falls beyond the emission level where MB=MC.

Table 4. Comparison of "Without" and "With" Project Scenarios of the Proposed Costs and Benefits Analysis of the Municipal Solid Waste Incineration in Metro Manila

"Without" Scenario (Base Case)	**"With" Scenario**
Sumitomo Heavy Industries Ltd. Proposal (rotary kiln, dry sorbent injection-lime, carbon injection, fabric filter) with CDD/CDF emission factor of 1.33 ng I-TEQ/kg of waste. For dispersion modeling, the stack parameters of a similar existing incinerator in the US, the Dutchess County Resource Recovery Facility, Poughkeepsie, New York were used.	Modular-Starved Air, dry sorbent injection, and fabric filter from the USEPA-NCEA Database with a CDD/CDF emission factor of 0.02 I-TEQ/kg of waste. For dispersion modeling purposes, the stack parameters of a similar existing incinerator in the US, the St. Croix Waste to Energy Facility, New Richmond, Wisconsin were used.

Notes:
(1) CDD/CDF = total tetra-through octa-chlorinated dibenzo-p-dioxin/ chlorinated dibenzofurans, 2,3,7,8-tetrachlorodibenzo-p-dioxin, and dibenzofurans
(2) Related literature review that majority of the combustors in the US are water-walled to allow heat recovery and reuse. The selection of what combustor to use in the base case will be revealed after discussions with government regulators, local and foreign manufacturers/vendors of combustors.
(3) Other emission factors will be subject to characterization and evaluation of applicability.

3.2 Valuation of Health Damage

Health damage attributable to MSW incinerators is computed using a risk-based approach and dose-response function. Because of the absence of information regarding ingestion exposure to dioxin, the information regarding inhalation exposure is used to extrapolate total exposure to dioxin. The computation of inhalation exposure is taken from Environmental Resources Management (ERM) in Hong Kong (2000) which prepared a note on the "Assessment of the Risks Associated with Exposure to PCDD/Fs" as a supplement to the main report entitled "An Assessment of Dioxins Emissions in Hong Kong". The equation used in the note is as follows:

$$INH\ (mg/kg/day) = \frac{(Ca \times IR \times ET \times EF \times ED \times ABS)}{(BW \times AT)}$$

Where:

INH = inhalation exposure (mg/kg/day)
Ca = concentration of dioxin in ambient air (mg I-TEQ/m^3)
IR = inhalation rate (m^3/hr), assumed to be 0.83 m^3/hr
ET = exposure time (hr/day), assumed to be 24 hrs/day
EF = exposure frequency (days/year), assumed to be 330 days/year
ED = exposure duration (year), assumed to be 70 years, Filipinos' average life expectancy
ABS = absorption fraction (unitless), assumed to be 1
* (Unitless means having no dimension in terms of time, mass & length)
BW = body weight (kg) of Filipinos, assumed to be 50 kg
AT = averaging time of dioxins (days), assumed to be 23,100 days (70 years *330 days)

Since the ISCST390 model's predicted ambient concentration is in picogram I-TEQ/m^3 (1x10-12 g/m^3), this was converted to mg I-TEQ/m^3 as required in the computation.

To compute the total exposure, specific assumptions had to be made regarding the ratio of inhalation exposure and ingestion exposure. In this study, it was assumed that 10% of total exposure can be attributed to inhalation exposure. This means that the inhalation rate has to be multiplied by 10 to derive total dioxin exposure from all pathways. Based on the USEPA Dioxin Reassessment in 1997, more than 90% of exposure to dioxin is through ingestion. A sensitivity analysis was also conducted decreasing the percentage of inhalation exposure to 2% based on the ERM in the Hong Kong (2000) study.

Although a multitude of adverse health effects results from dioxin exposure, only the risk of acquiring cancer due to dioxin exposure is estimated. Lifetime cancer risk is calculated by multiplying exposure (ingestion and inhalation) with the slope factor.

Cancer risk = exposure x slope factor

The slope factor provides a conservative approach in establishing a relationship between exposure and risk since it assumes that any degree of exposure to dioxin has a certain amount of risk. The USEPA cancer slope factor of $1 \text{ X } 10^{-4}$ pg/kg-bw/day[30] is used.

The lifetime cancer risk calculated above is divided by 70, the average human life expectancy in the Philippines, to determine the annual individual risk coefficient. The population at risk is multiplied by the risk coefficient to determine the number of cancer cases for a particular year.

No. of cancer cases = individual risk coefficient x population at risk

A study by Oka et al (1997), as cited in Kishimoto et al (2000), concludes that the average loss of life expectancy due to one year's exposure to the level that will cause one cancer death is 0.16. This means that every year, 16% of those who have cancer, die.

3.3 Morbidity and Mortality

Theoretically, the "willingness to pay (WTP)" approach is the best measure of the change in an individual's welfare (Freeman 1993). This is based on the premise that the affected individual can provide the best judgment regarding the effect of a pollutant to his well-being. The limit of WTP is the amount of income that a particular person can earn. For this study, determining an individual's WTP to avoid mortality (incidence of death) and morbidity (incidence of illness) provides the most accurate estimate of computing the cost of health damage due to dioxin exposure.

[30] Based on USEPA Health Assessment Document for 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) and Related Compounds. External Review Draft, 2000.

The WTP approach, however, is expensive and time-consuming. Other techniques can be used to evaluate the costs of health damage from exposure to a particular pollutant, such as the benefits transfer approach using the Value of Statistical Life (VSL) estimated in similar studies. VSL is a measure of the aggregate WTP of people at risk from pollution exposure. While the benefits transfer approach using VSL adopts VSL estimates from previous studies ("study sites"), these estimates are adjusted to the existing site ("policy site") to reflect differences in income, preferences and other characteristics.

Several studies have estimated VSL using the wage differential approach. This is based on the idea that workers are faced with different risks on the job, and the wage they earn reflects the degree of risk they face. VSL estimates indicate the workers' willingness to accept riskier jobs. The VSL estimated in these studies can be used as an estimate of health benefits from a particular environmental policy.

A study by Simon et al (1999) valued the mortality risks of workers in the manufacturing sector in India using compensating wage differentials, and converted these estimates to Value of Statistical Life (VSL) and Value of Statistical Injury (VSI). Wages and other relevant information were taken from the Occupational Wage Survey (OWS) conducted by the Indian Labor Bureau. The computed VSL and VSI ranged from USD 153,000 to USD 358,000 and from USD 477 to USD 2,870 in 1990 dollars, respectively. The VSL was also compared with the value of foregone earnings of the sample Indian workers. A ratio of VSL to foregone earnings of 20:48 was computed.

Liu et al (1997) also conducted a compensating wage study in Taiwan using labor market data from 1982 to 1986. The risk coefficients were found to be positive and statistically significant which means that wage differentials are present in jobs with mortality risks. The computed VSL amounted to USD 413,000 in 1990 dollars which was lower than those estimated for developed countries. The study concluded that the simple adoption of a benefits transfer function from developed countries is deficient in measuring the VSL in developing countries.

Bowland and Beghin (1998) adopted a meta-analysis approach to analyze wage-differential studies in developed countries and estimated a VSL function that can be useful for developing countries accounting for differences in income, risk and other relevant variables. The VSL function derived was used to estimate the WTP of individuals to reduced risk of death from air pollution in Santiago, Chile, for the year 1992. Estimates of VSL ranged from USD 519,000 to USD 675,000 in purchasing power parity (PPP). This estimate was further compared with a World Bank estimate using the human capital approach and VSL estimates by Desvouges et al (1995). The World Bank estimate was USD 36,172 in 1992 dollars while the Desvouges estimate was USD 1,616,807 in 1992 PPPUSD.

The VSL estimated from the benefits transfer method is used in this study to value health damage, particularly the upper bound estimate (USD 358,000) from Simon et al (1999) to account for differences in incomes and prices between India and the Philippines. The VSL was adjusted to 2000 prices and converted to Philippine pesos at an exchange rate of 1.42, then multiplied by the number of mortality cases to derive the estimate of total health damage. In doing the benefits transfer, it was assumed that the elasticity of the VSL with respect to income was equal to 1.0[31]. A sensitivity analysis was conducted using the central estimate of 0.40 income elasticity as calculated in the Benefits and Costs Analysis of the Clean Air Act in the US (1999). This study derived three estimates of elasticity of income, namely: 0.08, 0.4, and 1.0. These elasticity estimates were also reported in the white paper entitled "Valuing Fatal Cancer Risk Reductions" prepared by USEPA in 2000.

4.0 DIOXIN DISPERSION MODELING

The Industrial Source Complex Short Term (ISCST)[32] dispersion model was used to model dioxin emissions from a hypothetical municipal solid waste incinerator based on the following factors:

- chlorinated dibenzo-para dioxins/chlorinated dibenzo furans (CDD/CDF) is "non-reactive with oxygen or water…and they persist in the environment for long periods of time"[33] . ISC, being a steady state model requires that pollutants to be modeled are non-reactive.

- CDD/CDF is usually bound to particles and eventually settles in the soil and plants and enters the food chain. ISCST can handle particulates dispersion and deposition[34].

The assessment of other United States Environmental Protection Agency (USEPA) programs that are designed to handle air toxic emissions include toxic screening model (TSREEN) and Emissions Modeling System for Hazardous Air Pollutants (EMS-HAPS). TSCREEN, like other screening models of USEPA, is a worst-case scenario simplified calculation intended to determine air quality threats and the need for further more complex modeling. It searches through all meteorological conditions and reports highest concentrations, which may or may not occur in the study area. The EMS-HAPS is an extremely complicated model and requires a tremendous amount of information currently unavailable in the country.

Potential health effects from combustors are known to be localized. Gaussian- based dispersion models are frequently used to predict pollutant concentrations in ambient air.

[31] This means that VSL increases in perfect proportion with income, assuming individual preferences in the Philippines and in India are identical.

[32] Although the Long Term (ISCLT) model is also applicable to CDD/CDF emissions it has, for a long period, not received updates from the Support Center for Regulatory Air Modeling. ISCLT is also less flexible. It has a limited default receptor capacity of 2,500 points and changing this would require revisions in the FORTRAN source code and re-compilation which, as experience has shown, is quite problematic.

[33] Zook, 1994; IARC, 1997; and ATSDR, 1998 as quoted by the Center for Health, Environment, and Justice (1999).

[34] However, the authors could not conduct wet deposition (to ascertain the amount of pollutants attached to raindrops that fall to the ground due to gravity) due to lack of hourly rainfall records in the Synoptic Stations in the Philippines.

The ISCST model is a straight-line, steady-state Gaussian plume equation, and with some modifications[35], is applicable for the prediction of plumes from point source emissions. ISCST accepts hourly meteorological data (surface and upper air) records to determine the conditions for plume rise, transport, and diffusion needed to estimate the concentration for each source and receptor.

For a steady-state Gaussian plume, the hourly concentration at downwind distance x (meters) and crosswind distance y (meters) is given by the equation:

$$\chi = \frac{QKVD}{2\pi \, u_s \sigma_y \sigma_z} \exp\left[-0.5\left(\frac{y}{\sigma_y}\right)^2\right]$$

where:

Q = pollutant emission rate (mass per unit time)

K = a scaling coefficient to convert calculated concentrations to desired units (default value of 1×10^6 for Q in g/s and concentration in g/m^3)

V = vertical term

D = decay term

σ_y, σ_z = standard deviation of lateral and vertical concentration distributions (m)

exp = exponent

The Vertical Term includes the effects of source elevation, receptor elevation, plume rise, limited mixing in the vertical term and the gravitational settling and dry deposition of particulates (with diameters greater than about 0.1 microns).

Detailed algorithm descriptions of the downwind and crosswind distances, Wind Speed Profile and default values for each stability category, Huber-Snyder and Shulman-Scire Plume rise methods, and Pasquill-Gillford dispersion parameters can be found in the ISC Model Documentation available on the USEPA Support Center for Regulatory Air Modeling (SCRAM) homepage[36].

[35] These modifications to the basic Gaussian plume equation include ground reflection, and mixing height limits to terminate vertical spreading between the ground surface and the mixing height.
[36] http://www.epa.gov/scram001/

The ISCST dispersion model has been successfully used in several studies[37] to predict dioxin ground-level concentrations from different sources. Municipal waste incinerators are considered as continuous and constant sources of dioxin emissions, given their waste combustion rates and emission factors corresponding to the incineration technology and post-combution controls used. The effects of post-combustion control failures, cold starts, and other operational upsets resulting in elevated uncontrolled emissions were discounted in the modeling since such spikes (as would be seen in a graph) are expected to be short-term compared to the 15-year horizon in computing health damages. In modeling the increase in the number of incineration plants to meet the projected MMDA demand, a 50m stack centerline interval between each stack was assumed. Plume dispersion was modeled within a 50-kilometer radius from the site.

5.0 RISK MAPPING

Risk mapping is the process of determining the number and location of people at risk to dioxin ambient concentrations (Figure 4). The process involves the overlay of two thematic maps – predicted annual average dioxin concentration from the dispersion modeling and year 2000 population distribution taken from the National Statistics Office.

[37] Examples of these applications are Tran K.T. (2001) "A Comprehensive Risk Assessment Model for Hazardous Waste Combustion Facilities", USEPA Region 6 (2000) and "Combustion Human Health Risk Assessment for Angus Chemical Company, Sterlington, Louisiana" as cited in Tran K.T. (2001).

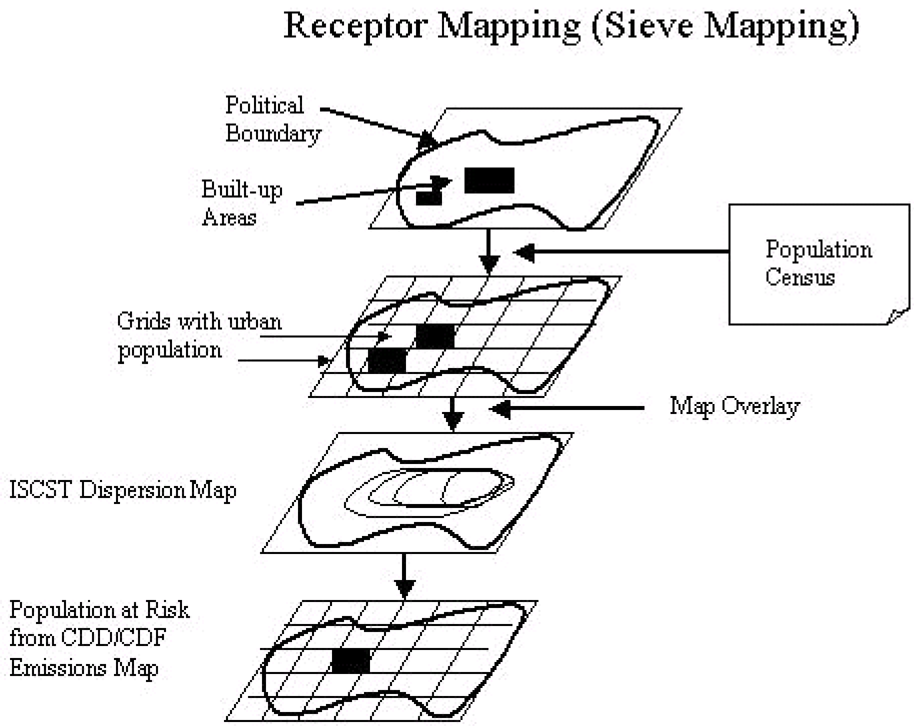


Figure 4. Procedure for Risk Mapping

Figure 5 illustrates the location of the hypothetical incineration plant (the square in the middle of the map) and circumscribed are the municipalities within a 50-kilometer radius. The site has an elevation of 330 meters above mean sea level and has two types of wind systems: the north-east monsoon which starts in October, peaks in January and starts to wane in the later part of April; and the south-east monsoon which starts in May, peaks in August and recedes in the later part of September.

The total number of individuals at risk from dioxin emissions is provided in Table 5, while Figures 5 and 6 are dispersion plumes for both scenarios.

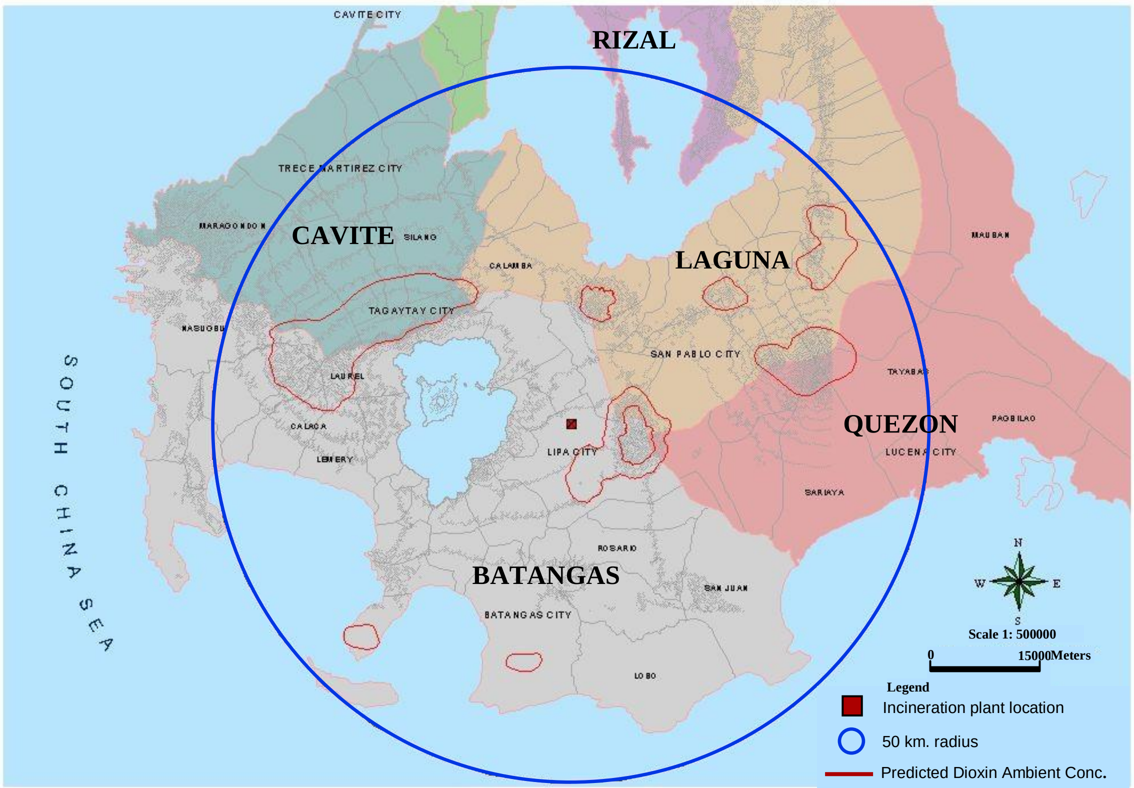


Figure 5. Predicted Annual Average Dioxin Dispersion in the "Without Project" Scenario 2000

Table 5. Number and Distribution of Persons at Risk from Dioxin Emissions in the "With" and "Without" Project Scenarios

Year	Population At Risk	
	"Without Project"	"With Project"
2000	7,042,595	4,052,233
2001	7,289,086	4,199,562
2005	8,364,394	4,696,211
2010	9,934,276	5,789,238

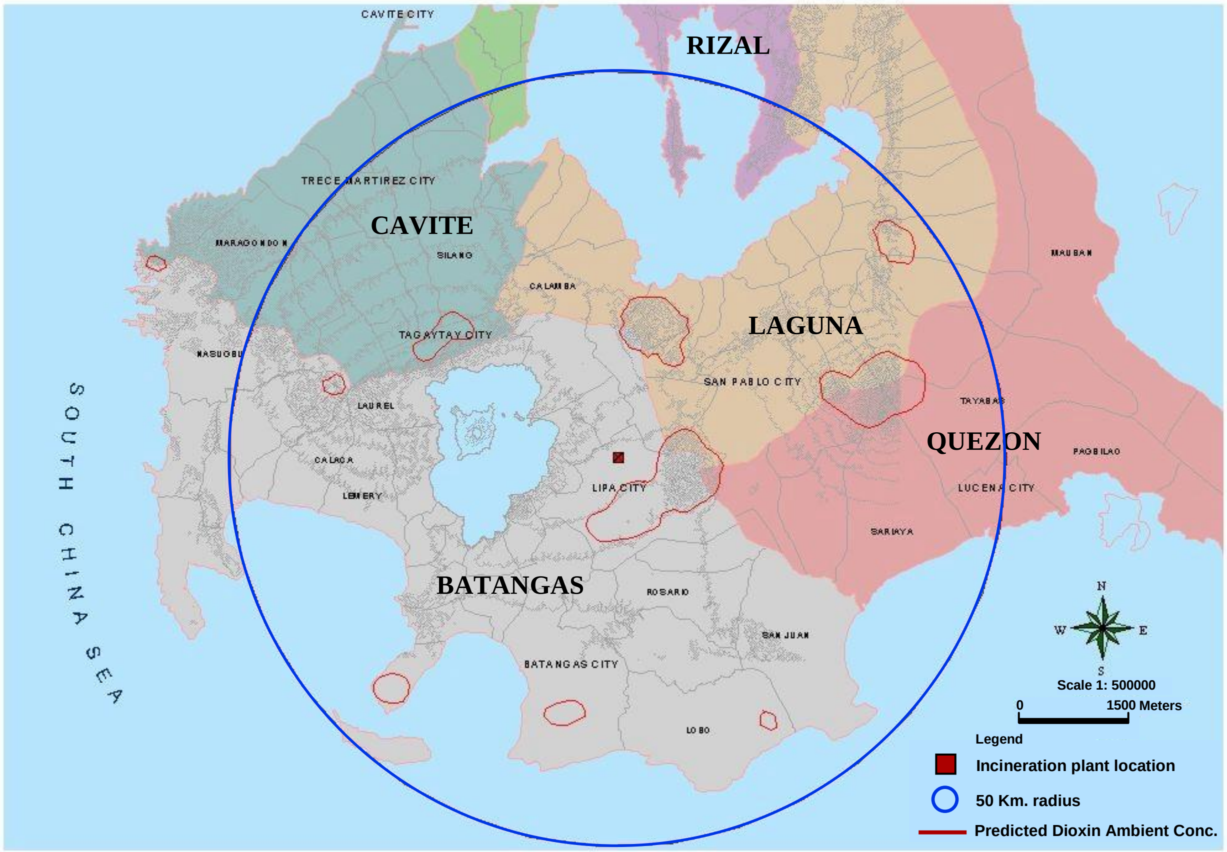


Figure 6. Predicted Annual Average Dioxin Dispersion in the “With Project” Scenario 2000

6.0 ASSESSMENT OF IMPACTS

6.1 Quantification of Health Damage from Dioxin Exposure

The extent of health damage was measured by accounting for possible incidences of cancer in the “With Project” and “Without Project” scenarios. The health damage computation for this study offers a lower bound estimate of the real damage from exposure to dioxin since it measures only the probability of mortality from acquiring cancer. As mentioned earlier, incineration plants emit pollutants other than dioxins that can cause other illnesses and death with extreme or prolonged exposure. Table 6 shows the incidence of cancer and mortality cases for the “With” and “Without Project” scenarios over a 15-year period from 2000 with the assumption that inhalation exposure is 10% of the total exposure based on the USEPA Dioxin Reassessment in 1997.

Table 6. Number of Cancer Cases and Mortality, 2000-2014, at 10% Inhalation Exposure

Damage	Without Project	With Project	Avoided Mortality
Cancer Cases	5,974	2,347	
Mortality	955	376	579

Population was projected to increase by 3.5% annually. Appendix A shows the number of cancer and mortality cases from 2000-2014. The shift to a cleaner incineration technology translates to an avoided mortality of 579 persons from 2000-2014. In a simulation lowering the percentage of inhalation exposure while increasing cancer and mortality cases, the number of lives saved because of the technology shift also increases (Appendix B). Assuming a 2% inhalation exposure rate, the "Without Project" scenario resulted in 29,870 and 4,775 cancer and mortality cases, respectively as compared with 11,735 and 1,880 in the "With Project" scenario, yielding 2,895 cases of avoided mortality by using cleaner technology over 15 years.

6.2 Valuation of Benefits and Costs

The risk of mortality due to cancer from dioxin exposure was measured through the benefits transfer approach using the VSL estimate in the study by Simon et al (1999) for India. The VSL estimate was adjusted based on differences in prices and incomes between Philippines and India. In 2000, per capita GNP-purchasing power parity (PPP) of the Philippines was 80% greater than that of India. Applying the USD 358,000 VSL estimate by Simon et al (1999), a factor of 1.8 for differences in income, income elasticity of 1.0, and an inflation rate of 4% in 2000, gives a VSL estimate of USD 670,176 or P 28,150,000 for the Philippines at an exchange rate of 1.42, the average exchange rate in 2000.

The present value of adverse health effects attributable to incineration technology, at a 15%[38] discount rate and 2000 prices, in the "Without Project" scenario amounted to P 12.8 billion as compared with P 4.9 billion for the "With Project" scenario. This translates to avoided health damage of P 7.8 billion in terms of avoided mortality because of the technology shift (Appendix A). Furthermore, savings in capital and operating cost amounting to P 2.9 billion, valued in 2000, were realized due to technology shift. Total benefits amounted to P 10.7 billion with a residual health damage of P 4.9 billion. Appendix A provides the details of the computation of benefits and costs of the two incineration technologies. Mortality cases are assumed to be a factor of 0.16 of total cancer cases (as cited in Kishimoto et al 2000). Mortality cases multiplied by the unit value of a statistical life provide the total value of health damages. The VSL is assumed to increase by 6% annually given an average increase in prices of 6% in the Philippines.

[38] 15% is the discount rate applied by the Philippine National Economic and Development Authority in conducting benefits and costs analyses.

Sensitivity Analyses

Sensitivity analysis, assuming 2% inhalation exposure, resulted in a mortality value amounting to P 63.8 billion in the "Without Project" scenario and P 24.6 billion in the "With Project" scenario. Given this, avoided health damage amounted to P 39.2 billion (Appendix B). Total incremental benefits including savings from capital costs amounted to P 42.1 billion.

Another sensitivity analysis lowering the income elasticity to 0.4, but assuming an inhalation exposure of 10%, resulted in value of mortality cases equal to P 9.0 billion in the "Without Project" scenario and P 3.5 billion in the "With Project" scenario (Appendix C). The value of total avoided health damage registered at P 5.5 billion. Total benefits including savings in capital costs amounted to P 8.4 billion.

Table 7 summarizes the total net benefits and residual health damages in different simulation scenarios.

Table 7. Summary of Net Benefits and Residual Damages in Different Simulation Scenarios (Billion Pesos)

Benefits/Damage	**at 10% inhalation exposure, 1.0 income elasticity**	**at 2% inhalation exposure, 1.0 income elasticity**	**at 10% inhalation exposure, 0.4 income elasticity**
Net Benefits	10.7	42.1	8.4
Residual Health Damage	4.9	24.6	3.5

Capital and Operating Costs of Selected Technologies

In the valuation of MWIs and post-combustion control capital and annual costs, the formulae given in Table 8 were used. The unit costs are provided in Table 9.

It may appear ironic that the "With Project" scenario, with higher efficiencies in dioxin removal, will actually cost less that the "Without Project" scenario. Costs of MWIs increase by capacity – these may be measured in terms of the volume of flue gas emitted i.e the more air required to burn waste, the bigger will be the burning equipment and pollution control. Since modular starved-air model operates at sub-stoichiometric levels where the amount of combustion air injected is less than ideal, it generates less flue gases. In contrast, the mass burn-rotary kiln operates at 50% excess air. Therefore, to burn the same amount of solid waste, the modular starved-air incinerator will be smaller and less costly than a rotary kiln incinerator.

Table 8. Bases for MWIs and Post-Combustion Control Capital and Operating Costs

Items	Modular Starved-Air	Mass Burn-Rotary Kiln	Sources
Flue Gas Rate (a)	2,005.3 scfm/100 tpd	25,095 scfm/200 tpd	USEPA-NCEA Database
Activity Rate	Year 2000 2001-2004 2005-2009 2010-2015	Waste to be Incinerated 600 tpd 800 tpd 900 tpd 1,200 tpd	Study of Solid Waste Management for Metro Manila
Capital Cost			
Combustor	a x USD 100/scfm	a x USD 60/scfm (1995 prices)	EPA-CICA Fact Sheet Thermal and Regenerative Incinerator http://www.epa.gov/ttn/ catc/dir1/fthermal.pdf and http://www.epa.gov/ttn/ catc/dir1/fthermal.pdf
Fabric Filter	a x USD 16/scfm (1988 prices)	a x USD 16/cfpm (1988 prices)	EPA-CICA Fact Sheet, Fabric Filter, http://www.epa.gov/ttn/ catc/dir1/ff-pulse.pdf
Dry Sorbent Injection	USD 311,520 (1991 prices for small incinerators with 100 ft^2)	USD 311,520 (1991 prices for small incinerators)	EPA Air Pollution Control Cost Manual. http://www.epa.gov/ttn/ catc/dir1/cost_toc.pdf
Annual Operating Cost			
Combustor	a x USD 6/scfm	a x USD 50/scfm (1995 prices)	EPA-CICA Fact Sheet Thermal and Regenerative Incinerator http://www.epa.gov/ttn/ catc/dir1/fthermal.pdf
Fabric Filter	a x USD 14.5/scfm (1988 prices)	a x USD 14.5/scfm x (1988 prices)	EPA-CICA Fact Sheet, Fabric Filter. http://www.epa.gov/ttn /catc/dir1/ff-pulse.pdf
Dry Sorbent Injection	Assumed at 70% of capital cost	Assumed at 70% of capital cost	EPA Air Pollution Cost Control Manual. 6th Ed. www.epa.gov/ttn/catc/dir1/c s3-2cha2.pdf

Notes: scfm = standard cubic feet per minute
CICA = US-Mexico Border Information Center on Air Pollution

Table 9. Unit Cost of Incineration Plant (Million Pesos, 2000 prices)

Item	Cost	Modular Starved-Air	Rotary Kiln
Combustors			
	Capital Cost	11.88	89.17
	O & M Cost	0.83	89.17
Fabric Filter			
	Capital Cost	1.50	18.72
	O & M Cost	1.36	16.96
Dry Sorbent Injection			
	Capital Cost	25.12	25.12
	O & M Cost	17.58	17.58

Source: USEPA Air Pollution Technology Fact Sheets
Notes: These unit costs were used to compute capital and annual O & M costs, assuming an annual inflation rate of 1.06.
Exchange rate USD1:42 P

7.0 CONCLUSIONS AND RECOMMENDATIONS

The study concludes that an incineration technology that operates within accepted pollution standards is not only available but would actually be less costly than other incineration methods that produce more pollution. If the current ban on incineration in the Philippines is motivated by the perception that all incineration technologies are equally harmful - or that cleaner technologies are unaffordable - then that perception has been shown here to be false.

The incremental incineration technology cost of complying with the 0.1ng I-TEQ/m^3 Philippine dioxin standards is less than the avoided health damage from dioxin emissions. This study has revealed that substantial incremental health benefits can be derived from shifting to a cleaner incineration technology with concomitant savings in the costs of technology. The costs, both capital and operation and maintenance, of the modular starved-air is far below the cost of the rotary kiln. This indicates that a cleaner technology, in terms of dioxin removal efficiency, is not necessarily more expensive.

We have assumed that ten percent of people's exposure to dioxin comes from inhalation. In other words, we estimated inhalation exposure and multiplied by ten to arrive at total exposure. From these estimates of total exposure, we then estimated health damages and their monetary value. However, we do not have conclusive evidence about the precise percentage of exposure that comes from inhalation. If that percentage is less than ten percent, then total exposure would be correspondingly higher. (For example, if inhalation exposure is actually two percent of total exposure, then our estimates for the value of health damage would need to be multiplied by five.)

A comparison of the economic and environmental costs of incineration versus those of other waste disposal options, such as landfill, was beyond the scope of the study. But preliminary estimates of landfill costs from other studies (e.g Bennagen 2002) suggest that they can be quite high. More extensive research on the costs and environmental impacts of landfill would be invaluable for purposes of comparison. Given the difficulties the country faces in achieving its targets with current methods, careful consideration of all the options - based on evidence rather than perception - is badly needed.

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APPENDIX A

Benefits and Cost Analysis of Incineration Technology (at 10% Inhalation Exposure, 1.0 Income Elasticity)

	2000	***2001***	***2002***	***2003***	***2004***	***2005***	***2006***	***2007***	***2008***	***2009***	***2010***	***2011***	***2012***	***2013***	***2014***	***Total Cases***
"With Project"																
Health Damage																
Cancer Cases	78	96	100	103	107	145	150	155	161	166	202	210	217	225	232	2,347
Mortality Cases	12	15	16	17	17	23	24	25	26	27	32	34	35	36	37	376
VSL/unit (million P)	28	30	32	34	36	38	40	42	45	48	50	53	57	60	64	
Total Health Damage (million P)	338	448	506	570	604	866	958	1,058	1,166	1,284	1,613	1,817	1,982	2,161	2,355	
Present Value (million P)	**4,924**															
Direct Cost (million P)																
Capital	231	41				103					138					
O and M	119	147	156	165	175	238	253	268	284	301	389	413	437	464	491	
Total Direct Cost	350	188	156	165	175	342	253	268	284	301	527	413	437	464	491	
Present Value (million P)	**1,602**															
Total Cost, Present Value (million P)	**6,526**															
"Without Project"																
Health Damage																
Cancer Cases	214	295	301	307	313	338	350	362	375	388	509	527	546	565	584	5,974
Mortality Cases	34	47	48	49	50	54	56	58	60	62	82	84	87	90	94	955
VSL/unit (million P)	28	30	32	34	36	38	40	42	45	48	50	53	57	60	64	
Total Health Damage (million P)	957	1,402	1,518	1,643	1,777	2,034	2,236	2,455	2,692	2,948	4,133	4,488	4,928	5,403	5,982	
Present Value (million P)	**12,757**	7,833														
Direct Cost (million P)																
Capital	399	141									238					
O and M	371	525	556	589	625	662	702	744	789	836	1,107	1,174	1,244	1,319	1,398	
Total Direct Cost	770	666	556	589	625	662	702	744	789	836	1,345	1,174	1,244	1,319	1,398	
Present Value (million P)	**4,479**	**2,877**														
Total Cost, Present Value (million P)	**17,236**															

Appendix A cont.

Marginal Health Benefit (in million P)	619	955	1,012	1,073	1,173	1,168	1,278	1,397	1,525	1,664	2,520	2,672	2,945	3,242	3,627
Marginal Cost (in million P)	(421)	(478)	(401)	(425)	(450)	(321)	(449)	(476)	(505)	(535)	(818)	(761)	(807)	(855)	(906)
Net Benefit (in million P)	1,040	1,433	1,413	1,497	1,623	1,488	1,727	1,873	2,030	2,199	3,339	3,433	3,752	4,097	4,534
Incremental Health Benefits (present value, million P)	**7,833**														
Benefits from Technology Shift (present value, million P)	**2,877**														
Total Benefits (Present Value, million P)	**10,710**														

Notes:

The VSL was valued using the estimates in the study by Simon et al (1999), adjusting for differences in incomes.

Estimate resulted to a unit VSL equal to USD 670,176 or P 28,150,000 in 2000 prices

Prices are expected to increase 6% every year

Exchange rate is USD1:42 P

Inhalation exposure to dioxin assumed to be 10% of total exposure

APPENDIX B

Benefits and Cost Analysis of Incineration Technology (at 2% Inhalation Exposure, 1.0 Income Elasticity)

"With Project"	***2000***	***2001***	***2002***	***2003***	***2004***	***2005***	***2006***	***2007***	***2008***	***2009***	***2010***	***2011***	***2012***	***2013***	***2014***	***Total Cases***
Health Damage																
Cancer Cases	390	480	500	515	535	725	750	775	805	830	1,010	1,050	1,085	1,125	1,160	11,735
Mortality Cases	60	75	80	85	85	115	120	125	130	135	160	170	175	180	185	1,880
VSL/unit (million P)	28	30	32	34	36	38	40	42	45	48	50	53	57	60	64	
Total Health Damage (million P)	1,689	2,238	2,530	2,850	3,021	4,332	4,791	5,290	5,832	6,420	8,065	9,083	9,912	10,807	11,773	
Present Value (million P)	**24,620**															
Direct Cost (million P)																
Capital	231	41				103					138					
O and M	119	147	156	165	175	238	253	268	284	301	389	413	437	464	491	
Total Direct Cost	350	188	156	165	175	342	253	268	284	301	527	413	437	464	491	
Present Value (million P)	**1,602**															
Total Cost, Present Value (million P)	**26,222**															
"Without Project"																
Health Damage																
Cancer Cases	1,070	1,475	1,505	1,535	1,565	1,690	1,750	1,810	1,875	1,940	2,545	2,635	2,730	2,825	2,920	29,870
Mortality Cases	170	235	240	245	250	270	280	290	300	310	410	420	435	450	470	4,775
VSL/unit (million P)	28	30	32	34	36	38	40	42	45	48	50	53	57	60	64	
Total Health Damage (million P)	4,785	7,012	7,590	8,213	8,884	10,170	11,180	12,274	13,459	14,742	20,667	22,442	24,638	27,016	29,910	
Present Value (million P)	**63,783**	39,163														
Direct Cost (million P)																
Capital	399	141									238					
O and M	371	525	556	589	625	662	702	744	789	836	1,107	1,174	1,244	1,319	1,398	
Total Direct Cost	770	666	556	589	625	662	702	744	789	836	1,345	1,174	1,244	1,319	1,398	
Present Value (million P)	**4,479**	**2,877**														
Total Cost, Present Value (million P)	**68,263**															

Appendix B cont.

Marginal Health Benefit (in million P)	3,096	4,774	5,060	5,364	5,863	5,838	6,388	6,983	7,627	8,322	12,602	13,358	14,726	16,210	18,137
Marginal Cost (in million P)	(421)	(478)	(401)	(425)	(450)	(321)	(449)	(476)	(505)	(535)	(818)	(761)	(807)	(855)	(906)
Net Benefit (in million P)	3,517	5,252	5,461	5,788	6,313	6,159	6,838	7,460	8,131	8,857	13,420	14,119	15,533	17,065	19,043
Incremental Health Benefits (present value, million P)	**39,163**														
Benefits from Technology Shift (present value, million P)	**2,877**														
Total Benefits (Present Value, million P)	**42,041**														

Notes:

The VSL was valued using the estimates in the study by Simon et al (1999), adjusting for differences in incomes.

Estimate resulted to a unit VSL equal to USD 670,176 or P 28,150,000 in 2000 prices

Prices are expected to increase 6% every year

Exchange rate is USD1:42 P

Inhalation exposure to dioxin assumed to be 2% of total exposure

APPENDIX C

Benefits and Cost Analysis of Incineration Technology (at 10% Inhalation Exposure, 0.4 Income Elasticity)

"With Project"

	2000	***2001***	***2002***	***2003***	***2004***	***2005***	***2006***	***2007***	***2008***	***2009***	***2010***	***2011***	***2012***	***2013***	***2014***	***Total Cases***
Health Damage																
Cancer Cases	78	96	99	103	107	145	150	155	161	166	202	210	217	224	232	2,345
Mortality Cases	12	15	16	16	17	23	24	25	26	27	32	34	35	36	37	375
VSL/unit (million P)	20	21	22	24	25	26	28	30	32	33	35	38	40	42	45	
Total Health Damage (million P)	245	322	354	388	426	613	673	738	810	889	1,148	1,259	1,381	1,515	1,662	
Present Value (million P)	**3,458**															
Direct Cost (million P)																
Capital	231	41				103					138					
O and M	119	147	156	165	175	238	253	268	284	301	389	413	437	464	491	
Total Direct Cost	350	188	156	165	175	342	253	268	284	301	527	413	437	464	491	
Present Value (million P)	**1,602**															
Total Cost, Present Value (million P)	**5,060**															

"Without Project"

	2000	***2001***	***2002***	***2003***	***2004***	***2005***	***2006***	***2007***	***2008***	***2009***	***2010***	***2011***	***2012***	***2013***	***2014***	***Total Cases***
Health Damage																
Cancer Cases	214	295	300	306	313	338	350	362	375	388	509	527	546	565	584	5,972
Mortality Cases	34	47	48	49	50	54	56	58	60	62	81	84	87	90	94	956
VSL/unit (million P)	20	21	22	24	25	26	28	30	32	33	35	38	40	42	45	
Total Health Damage (million P)	678	988	1,069	1,155	1,249	1,432	1,571	1,723	1,891	2,074	2,887	3,167	3,475	3,812	4,182	
Present Value (million P)	**8,974**	5,516														
Direct Cost (million P)																
Capital	399	141									238					
O and M	371	525	556	589	625	662	702	744	789	836	1,107	1,174	1,244	1,319	1,398	
Total Direct Cost	770	666	556	589	625	662	702	744	789	836	1,345	1,174	1,244	1,319	1,398	
Present Value (million P)	**4,479**	**2,877**														
Total Cost, Present Value (million P)	**13,453**															

Appendix C cont.

Marginal Health Benefit (in million P)	432	666	715	767	823	818	898	985	1,081	1,186	1,739	1,908	2,094	2,297	2,520
Marginal Cost (in million P)	(421)	(478)	(401)	(425)	(450)	(321)	(449)	(476)	(505)	(535)	(818)	(761)	(807)	(855)	(906)
Net Benefit (in million P)	853	1,144	1,115	1,192	1,273	1,139	1,347	1,461	1,585	1,721	2,558	2,669	2,900	3,152	3,426
Incremental Health Benefits (Present Value, million P)	**5,516**														
Benefits from Technology Shift (Present Value, million P)	**2,877**														
Total Benefits (Present Value, million P)	**8,393**														

Notes:

The VSL was valued using the estimates in the study by Simon et al (1999), adjusting for differences in incomes.

Estimate resulted to a unit VSL equal to USD 471,005 or P 19,780,000 in 2000 prices

Prices are expected to increase 6% every year

Exchange rate is USD1:42P

Inhalation exposure to dioxin assumed to be 10% of total exposure