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A RISK ASSESSMENT FRAMEWORK FOR EVALUATING HEALTH RISKS FROM NEW AND EMERGING WASTE MANAGEMENT TECHNOLOGIES

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ABSTRACT

Until recently, landfills and waste-to-energy (WTE) facilities were the two basic technologies available to process residual (post-recycled) municipal solid waste. These technologies have both advantages and drawbacks, and their relative merits have been debated many different ways. Risk assessments of both technologies have been used to examine their potential threats to human health and the environment, and have found both landfills and WTE facilities can be operated in an environmentally acceptable manner. Neither alternative, however, has gained general public acceptance, and planned projects are often controversial. There remains considerable skepticism, for example, that landfill liners will be effective over long periods of time, and a general uneasiness over the safety of waste combustion. The interest in emerging conversion technologies, such as gasification and anaerobic digestion, as an alternative to conventional landfills and WTE facilities is thus understandable. However, there is some concern that the environmental impacts of conversion technologies are not well understood, as no commercial facilities exist in the United States. Development of a risk assessment framework for evaluating conversion technologies will serve two purposes. First, it will ultimately facilitate objective evaluation of potential risks to health and the environment as well as comparative evaluation with respect to traditional landfill and WTE technologies. Second, it will initiate a conceptual model of environmental impacts that will be useful in identifying key emissions and data gaps. Our presentation will set forth an initial risk assessment framework, focusing on the emissions and residuals of conversion technologies, and using available data to characterize and project health risk impacts.

NOMENCLATURE

EC – European Commission
HAP – Hazardous Air Pollutant
MPRA – Multi-pathway risk assessment
MSW – Municipal solid waste
NAAQS – National Ambient Air Quality Standard
PCDD/PCDFs – Polychlorinated dibenzo(*p*)dioxins and furans
Syngas – Synthesis (combustible) gas
WTE – Waste-to-energy

INTRODUCTION

New waste conversion technologies are being proposed with growing frequency as an alternative means of disposing of residual (post recycling) municipal solid waste. In part, the emergence of novel waste conversion technologies has resulted from a desire to move away from the conventional landfill and waste-to-energy approaches, which are perceived to have negative environmental consequences. One area of concern and means of comparison among solid waste management technologies centers on the release of air pollutants. So-called “criteria” pollutants, which include particulate matter, sulfur dioxide, nitrogen oxides, and carbon monoxide, are typically emitted in the largest quantities and are subject to well-defined regulations designed to meet and maintain National Ambient Air Quality Standards (NAAQSs). Greenhouse gas emissions, often based on life cycle analyses, are another relevant concern. However, it is the so called “air toxics,” a category of pollutants emitted at smaller levels, that often command public concern and attention, and are the focus of this paper. Air toxics comprise a host of metals and organic compounds that are capable (at sufficient levels of exposure) of causing cancer and other adverse health effects. Many “air toxics” are designated as Hazardous Air Pollutants (HAPs) under the auspices of the U.S. Clean Air Act, and the field of risk assessment has evolved to assess their potential dangers.

Landfills produce a variety of gases due to the anaerobic decay of organic components of municipal solid waste. Typically odorous, landfill gas is composed mostly of methane and carbon dioxide (in roughly equal volumes), but also contains traces of a host of other volatile chemicals [1]. Analyses of landfill gas also identified the presence of a variety of HAPs [1] that led in part to the development of standards for landfill gas capture and treatment (treatment usually being through combustion, both with and without energy recovery) [2]. Waste-to-energy facilities emit a different set of compounds and in the late 1980s were identified as significant emitters of mercury and polychlorinated dibenzo(*p*)dioxins and furans (PCDD/PCDFs). Even though control technologies and measures have greatly reduced emissions of these pollutants, their association with the waste-to-energy industry remains.

Human health risk assessment has been applied to both landfills and waste-to-energy facilities, and risk assessment methods have evolved and matured into objective, consensus-based approaches that have been codified in detailed regulatory guidance [3–5]. Feedback from risk assessment predictions has been used by the solid waste industry to identify risk reduction opportunities. Thanks in part to targeted controls and emission reductions, recent risk assessments of both landfills and waste-to-energy facilities demonstrate that emissions from modern, properly controlled and operated facilities do not present significant risks to public health [6–8].

Health risk assessment is potentially a valuable tool for helping to demonstrate that waste conversion technologies can operate in an environmentally acceptable manner. Risk assessment methods developed for traditional solid waste facilities are in large part applicable and transferable. To date, such assessments for conversion technologies have not been completed for facilities proposed in the United States as such assessments were not required for permitting, or because the proposed facilities have not yet begun the permitting process. Information on contaminant emissions is available, but limited to either data from commercial facilities overseas or to pilot or demonstration facilities in North America. As such, conceptual risk assessments have been developed for this paper that illustrate the types of data required to conduct comprehensive evaluations, using information gained from traditional waste management facilities to infer the types of contaminants and releases that may be relevant to waste conversion facilities. As some conjecture is involved, it must be emphasized that the risk assessment framework is of greater relevance than the specific pathways discussed.

The general methods of risk assessment are first presented, followed by a description of waste conversion processes. These steps are melded to develop conceptual risk assessment frameworks for evaluating waste conversion technologies.

HEALTH RISK ASSESSMENT

The National Research Council [9] set forth a formal and generic structure for quantitative risk assessment as a series of four interrelated elements, as illustrated in Figure 1.

Hazard Identification seeks to recognize contaminants that might be generated and released to the environment. Both qualitative and quantitative elements are involved, as initially a process is viewed in an open-ended manner to identify potential environmental threats, and is followed by modeling and measurement to derive numerical estimates of releases. Applied to new conversion technologies, hazard identification entails some degree of conjecture that can build upon knowledge of similar waste management and industrial processes. Consideration of likely control technologies is also relevant, as some potential contaminant releases will be mitigated through use of pollution control technologies and operation design.

Exposure Assessment is the process of estimating how and to what degree humans and other environmental receptors will encounter emitted pollutants. Contaminant exposure can occur through inhalation, ingestion, and dermal contact. The inhalation pathway is of potential relevance as most waste conversion technologies will likely release contaminants to air. Ingestion could be relevant under at least two circumstances. Persistent, bioaccumulative pollutants released to air could deposit and enter foodwebs (rendering multi-pathway risk assessment appropriate, as described below), or contaminants might be introduced directly to terrestrial and aquatic environments either as products designed for beneficial use (such as compost) or inadvertently due to inadequate controls or management (*e.g.*, leaching from a faulty landfill). Contaminant exposure through dermal contact is possible through a number of environmental media but is usually of a smaller magnitude of importance compared with inhalation and ingestion pathways. Exposure assessment necessarily depends on many process and site specific factors. For example, application or absence of control technologies affects the level of a potential release. The degree of dispersion and dilution of a contaminant released to air depends on its height of release, thermal buoyancy, and aerodynamic effects, all of which affect ground-level concentrations. Further, the specific locations of people working and living in the vicinity of a facility influence the significance of potential releases, as well as their habits and resources. Exposure assessment of chemicals such as mercury and PCDD/PCDFs must account for environmental bioaccumulation, as exposure to these HAPs occurs mostly through dietary means. Multi-pathway risk assessment (MPRA) is a tool designed to evaluate the various ways that human and ecological receptors can be exposed to pollutants initially emitted to air. In the case of human health MPRAs, potential exposure to pollutants starts with the direct inhalation of the compounds while they are present in air, followed by modeling of indirect pathways whereby compounds deposit to the ground, become incorporated within soils and foodstuffs, and then are consumed either inadvertently (within soil) or purposely (within people's diets). Figure 2 conceptually illustrates the process of tracking and simulating the means by which air pollutants may travel through the environment and enter foodwebs [10]. Ecological MPRAs are similar, though relevant exposure endpoints include flora and fauna present in essentially all environmental compartments. The consideration of both direct and indirect exposure pathways is termed multi-pathway exposure assessment, and represents the attempt to develop estimates of total potential exposures.

Toxicity Assessment involves the estimation of harm potentially caused by exposure to a contaminant, and is typically undertaken through dose-response studies in both laboratory animals and (less commonly, but preferably) humans. Risk assessment of environmental chemicals focuses on two categories of adverse health effects: the risk of initiating or promoting cancer, and the risk of all other adverse systemic, non-cancer effects (broadly and inclusively construed). Chemicals that have received adequate study are typically examined by regulatory authorities such as the U.S. EPA to develop numerical values for dose-response parameters. Typically, toxicity mechanisms for inhalation and ingestion exposures are considered separately. For chemicals that have been found to cause cancer in humans or animals, a zero threshold model, based on experimental data, is typically used to estimate the incremental likelihood of cancer (per given level of exposure). For a non-cancer health effect, a threshold model is typically applied based on the premise that a safe (reference) level of exposure exists, below which exposure to a chemical can be tolerated without risk of irreversible adverse consequences. Estimates of reference concentrations (inhalation) and doses (ingestion) typically include generous safety factors to compensate for various uncertainties.

Risk Characterization is the step that combines exposure and toxicity assessment to develop numerical estimates of cancer and non-cancer risk due to chemical exposure. Typically the potential risks due to individual chemicals are added together to derive cumulative estimates. State-of-the-art practice has to a large extent standardized the calculation of risks, which are typically compared to levels of acceptability established by federal and state regulatory authorities (*e.g.*, the acceptable range of incremental cancer risk of 1 to 100 in a million established by the U.S. EPA in its Superfund program). An important but underappreciated element of risk characterization is uncertainty analysis, which is particularly pertinent to comparisons among chemicals that have varying degrees (both in quantity and quality) of toxicological information.

As the toxicity assessment and risk characterization stages of risk assessment rely principally on convention, the art of applying risk assessment to waste conversion facilities rests in the hazard identification and exposure assessment stages. These aspects depend on careful consideration of processes and operations. The basic conversion technology descriptions that follow should thus be viewed from the perspectives of identifying the presence of potentially toxic chemicals in the processes and the means by which they may be introduced to the environment, either as a result of facility design or through inadvertent release.

WASTE CONVERSION TECHNOLOGIES

Application of the hazard identification and exposure assessment steps of risk assessment demands a thorough understanding of the manner in which contaminants could be released to the environment as byproducts of waste conversion processes. There are two general categories of technologies – anaerobic digestion and thermal processing – that have been proposed for commercial operation.

Anaerobic Digestion

Digestion is the reduction of carbon-based organic materials through controlled decomposition by microbes, accompanied by the generation of liquids and gases. The biological process of digestion may be aerobic or anaerobic, depending on whether air (containing oxygen) is introduced into or excluded from the process.

In the anaerobic digestion of municipal solid waste (MSW), the biodegradable, organic components (*e.g.*, food waste, yard trimmings, garden waste, cardboard, paper) are metabolized by microorganisms in the absence of oxygen, producing a biogas (primarily methane and carbon dioxide), a solid byproduct (called "digestate", which is generally considered to be an immature compost), and reclaimed water. In an overview fashion, anaerobic digestion can be described by three primary steps: (1) pre-treatment, or separation/preparation of the MSW received for processing; (2) digestion of the prepared organic feedstock, and (3) post-treatment of the digestate, to produce a mature compost. Pre-treatment and post-treatment requirements are dependent on the particular digestion technology used, the characteristics of the MSW, and the overall objectives of the project (*i.e.*, whether to maximize diversion of MSW from landfilling through recovery of nondegradable materials and recyclables and through beneficial use of resulting compost, or to more generally stabilize the organic fraction of MSW prior to landfilling). An additional and significant process step is the management and use of the biogas generated during the anaerobic digestion process.

For processing mixed MSW, pre-treatment or preparation/separation is necessary for separating biodegradable, organic materials from other waste components as well as for size reduction and preparation of the organic feedstock. Pre-treatment will result in residue requiring disposal, generally consisting of sand, stones, broken glass, and other inert materials present in the waste stream. Pre-treatment can be combined with recovery of traditional recyclables that are not readily biodegradable and not of value in the digestion process. Recovered recyclables may include ferrous metal, aluminum, other non-ferrous metal, plastic, and glass.

In general, maximizing the recovery of recyclables and the removal of non-degradable, inert materials during pre-treatment will result in a higher quality compost at the end of the process. Pre-treatment technologies can include standard material recovery configurations (*e.g.*, magnets, eddy current separators, trommels, screens, and other sorting mechanisms) combined with size-reduction equipment (*e.g.*, shredders, pulpers) and other waste preparation equipment (*e.g.*, mixers). One technology offers a unique, water-based, preparation/separation system that removes recyclables and inert materials and prepares the organic feedstock in an integrated manner with a wet digestion system.

The separation and preparation of biodegradable, organic material from the MSW results in an organic feedstock for the digestion process. The fundamental objective of anaerobic digestion is to produce a large quantity of methane-rich biogas and a small quantity of well-stabilized digestate from the organic feedstock. In all anaerobic digestion technologies, the process occurs in an enclosed, controlled environment (i.e., within the "digester", or "bioreactor"). However, different digestion technologies are available, which produce different results regarding biogas and compost quantity and characteristics. The process may be "wet" or "dry", depending on the percent solids of the organic feedstock in the digester. The process temperature may also be controlled in order to promote the growth of a specific population of microorganisms, with process temperatures ranging from approximately 35-55°C (95-131°F). The process may be conducted in a single-stage or two-stage reactor vessel, and on a continuous or batch basis. Retention times of material in the digester can also vary. Average retention time of solids in the digester range from 21 days for the "dry" digestion process to approximately 80 days for the "wet" digestion process. For the wet process, while the solids retention time is high (80 days), the hydraulic retention time, or the time for the liquid to pass through the digester, is low (*i.e.*, 1 day).

As stated earlier, anaerobic digestion results in a solid byproduct, called "digestate". Digestate is generally immature compost. It consists of organic material that is not readily digestible, along with inorganic material that escaped preprocessing. Digestate is usually in the form of a slurry of varying consistency. Wet digestion technologies produce a digestate with a thinner, or wetter, consistency than dry digestion technologies. The digestate is commonly dewatered, with the liquid returned to the process or managed as a wastewater. The dewatered solids may be screened to remove inorganic materials, and are then aerobically finished to produce stable, mature compost, for sale as a product. Large-scale, long-term markets are not yet established in the United States for use of compost generated from mixed MSW. However, aerobic MSW compost has existed for more than 20 years and has found beneficial, low-grade use in the United States [11].

The extent of post-treatment required to achieve a stable, mature compost, as well as the quantity of compost produced, varies based on the digestion technology used. Typically, the quantity of compost ranges from approximately 15% to 25% by weight of the MSW received. Also, depending on the extent of separation and preparation conducted prior to the digestion process, some technologies require more post-processing than others (*e.g.*, some technologies require screening of digestate prior to aerobic finishing, and/or screening of mature compost, in order to improve the quality of the resulting compost for purposes of beneficial use).

Anaerobic digestion produces a biogas, composed primarily of methane and carbon dioxide. Higher-quality biogas has a higher percentage of methane, with individual digestion technologies producing biogas with methane concentrations ranging from approximately 55% to 80%. Biogas may also include small amounts of contaminants, such as hydrogen sulfide (H_2S). The concentration of H_2S and other contaminants in the biogas generally depends on the characteristics of the MSW. Technologies are available to remove contaminants and otherwise improve the quality of the biogas (*i.e.*, achieve a higher percentage of methane), if such a step is necessary for a particular project. Often without any cleanup steps, the biogas can be beneficially used to generate electricity. Combustion of the biogas in a reciprocating engine is most common. The electricity is used to first meet process needs, with the remaining electricity sold to the grid. The net electricity generated for sale can range between 125-250 kilowatt hours per ton of MSW processed (kWh/ton).

Thermal Processing

Thermal technologies encompass a variety of processes that use or produce heat, under controlled conditions, to convert MSW to usable products. The organic fraction of MSW is converted to energy, and the inorganic fraction is recovered as products (*e.g.*, metal). Thermal technologies can potentially convert all organic components of MSW into energy (*i.e.*, all carbon and hydrogen-based materials, including plastic, rubber, textiles, and other organic materials that are not converted in biological processes). Thermal processing includes such technologies described as gasification, plasma gasification, pyrolysis, cracking, and depolymerization. Distinctions between the different thermal technologies center around the processing temperature, the means of maintaining the elevated temperatures, and the degree of decomposition of the organic fraction of the MSW. Some of these distinctions are noted below.

Thermal processing occurs in a high-temperature reaction vessel. Reactor temperatures range from approximately 800°F for a cracking technology to as high as 8,000°F for a plasma gasification technology. Within the reaction vessel, the organic fraction of the MSW is converted to a gas typically composed of hydrogen, carbon monoxide and carbon dioxide gases. This gas is commonly called synthesis gas or “syngas”. Some thermal technologies, such as pyrolysis, cracking and depolymerization, produce a gas that also consists of various low molecular weight organic compounds. For these technologies, the gas is sometimes called a fuel gas rather than a synthesis gas. Thermal technologies sometimes introduce a supplemental fuel (*e.g.*, natural gas, coke, etc.) to improve the quality and consistency of the synthesis gas. Plasma gasification technologies commonly use electricity to produce an electric arc to elevate the temperature and enhance dissociation of the molecules in the MSW. The syngas (or fuel gas) and other products of the thermal technologies represent unoxidized or incompletely oxidized compounds, which is the intent, and which differentiates these technologies from the more complete combustion attained in traditional waste-to-energy (WTE) projects. The gases can be pre-cleaned to remove contaminants such as sulfur, chlorine and mercury prior to being used to make fuels or combusted to produce electricity. Advantages of thermal conversion technologies compared to WTE technology include the potential for using the gas to make fuels, reduced air pollutant emissions, and increased beneficial use of MSW via materials recovery, reuse and power generation.

With some thermal technologies, such as gasification, the inorganic fraction of MSW is commonly recovered in the form of a vitrified material (*i.e.*, a solid, glassy substance often called "aggregate" or "slag"), mixed metals, industrial salts, chemicals, and other byproducts. Some thermal technologies, such as pyrolysis and cracking, generate a char (*i.e.*, a carbon-based solid) rather than a vitrified product. Depending upon market conditions and environmental requirements, these byproducts of thermal processes may have beneficial uses or may require landfill disposal. The amount of byproducts considered to be a residue requiring disposal, rather than a marketable product, ranges from 0% to approximately 10% by weight of the MSW received for processing.

In an overview fashion, thermal processing of MSW can be described in two primary steps: (1) pre-processing, if required, and (2) thermal conversion, including combustion of the gas to generate electricity. Pre-processing requirements can often be minimal for thermal processing technologies. Except for the common requirement to remove or size-reduce very large, over-sized materials such as furniture and large appliances, many thermal processing technologies do not require size reduction or separation of MSW by component. This is not always the case, as some of the thermal technologies shred the waste prior to processing. While recyclables such as metals can be recovered in a pre-processing step, and such metals are recovered as recyclables, many of the thermal technologies recover the metal after the thermal conversion process. Although not required in many thermal processes, pre-processing to recover recyclables can be provided.

The thermal conversion process results in a syngas (or fuel gas) and other products, as described above. The gas may be converted to energy by using it as a fuel in traditional boilers, reciprocating engines and combustion turbines. While a large amount of electricity can be generated, a sizable amount of electricity is also needed to support process operations. Net electricity production can range between 500-700 kWh/ton. As an alternative to energy generation, the syngas may be processed into fuels, such as ethanol.

Some of the thermal technologies pre-clean the syngas prior to combustion using standard, commercially available technology to remove sulfur compounds, chlorides, heavy metals and other impurities. Pre-cleaning the syngas prior to combustion can be more cost-effective than post-combustion controls. Even with pre-cleaning, most technologies apply some post-combustion air pollution control technology. The extent of syngas cleaning and the type of post-combustion air pollution control varies by technology.

HAZARD IDENTIFICATION OF MSW CONVERSION

For purposes of this paper, sufficient information exists from both direct and related sources to identify likely types of releases and to develop preliminary generic risk models. In many cases, available information, along with reasonable assumptions about facility performance and design standards, suggests that MSW conversion technologies can operate without engendering significant risk to public health. What has not been done for this paper is a specific application, which will depend on a multitude of process and site specific factors. The goal at present is to identify potential releases and use existing data to anticipate and characterize (to the extent possible) their nature. The discussion starts with identification of possible releases, and culminates in a preliminary, integrated risk assessment matrix.

Anaerobic Digestion Facilities

The primary source of air emissions from anaerobic digestion is from the combustion of the biogas to produce electricity. Combustion is typically done in an engine or turbine, and emissions are expected to be similar to those from combusting landfill gas. If the biogas is used to manufacture a fuel, such as compressed natural gas, there would not be combustion of the biogas. Although design and operational practices make the potential for fugitive releases of biogas small, there could be an inadvertent leak or other fugitive source. Further production of fuel (if undertaken) could also result in fugitive emissions of volatile compounds as the complexity of chemical processing increases. Such releases may well be at insignificant levels, as the likely operational goal of odor control. Since the biogas is produced from the breakdown and decay of MSW, there may be similarities between the biogas and the landfill gas produced in municipal solid waste landfills. If so, the detailed chemical composition data available for landfill gas may be relevant to anticipating trace level constituents of biogas. The U.S. EPA [1] has identified roughly 170 volatile chemicals in landfill gas in addition to methane and carbon dioxide (its main components, similar to biogas). Hydrogen sulfide (H_2S) is likely to be the most important air toxic in biogas, in which it has been identified at levels up to 1% [12]. Similar to landfills, an inadvertent release of biogas from, for example, a break in a pipe, could be of concern due to the acute toxicity of H_2S. Sufficient levels of fugitive emissions might also be of concern for risk assessment, as the U.S. EPA has derived a reference concentration (toxicity guideline) of 1.4 parts per billion (ppb) that is lower than many published odor thresholds [13]. H_2S has been found to be the most important chemical in landfill gas risk assessments [6], although the large safety factor imbedded in EPA's reference concentration may overemphasize potential risks to human health [14].

Residual digestate produced by anaerobic digestion of municipal solid waste could potentially contain chemical residues. Since the digestate is likely to be considered for beneficial use as compost, potential risks from exposure to chemicals could be relevant. Recent data from demonstration facilities were not identified, but a study of the chemical composition of compost derived from a facility in Massachusetts that processes municipal solid waste and biosolids indicates the presence of various metals and semi-volatile organic compounds. A risk assessment based on assumed use of the compost as a soil amendment indicated no significant concerns to human health due to residual chemicals in the compost with the exception of phthalates (a derivative of plastics) and pesticides that were identified in some samples at levels above screening-level risk-based concentrations for soil [15]. Pathways included in the risk assessment included incidental ingestion of soil, dermal contact with soil, and consumption of vegetables grown in the soil. Risk calculations were also based on residential (unrestricted) use of the compost. The relevance of these chemicals to compost produced in anaerobic digestors is unknown, but does suggest prudence in characterizing the composition of residual materials to be used as compost, and consideration of permissible uses for compost material may also be relevant.

Thermal Processing Facilities

Point source emissions (*i.e.* stack emissions) from thermal treatment facilities will result from combustion of the synthesis gas to generate electricity. If the synthesis gas from a thermal treatment facility is being used to manufacture a fuel, then such stack emissions would not exist. Similar to anaerobic digestion, thermal processing facilities have the potential to emit syngas and VOCs through leaks or fugitive sources, although this is not likely due to design and operating practices at these facilities.

Thermal treatment facilities are net producers of energy, but use energy internally for the process. Energy for internal use can be provided through heat recovery, the combustion of fossil fuel such as natural gas, and/or electricity generated on site or purchased. Syngas may or may not be used as a source of energy for facility use. Aside from the traditional criteria pollutants (which will need to be considered to demonstrate compliance with risk-based NAAQSs), MSW combustion byproducts often include a number of air toxics (as demonstrated through testing of waste-to-energy and landfill gas treatment systems). Risk assessments of traditional MSW management facilities have typically identified two contaminants to be of greatest potential importance: mercury and PCDD/PCDFs. There has been some testing of emissions of these compounds from thermal treatment facilities. A summary of available test results [16] is provided in Table 1 along with similar test results from a recently constructed WTE facility and commonly quoted regulatory guidelines [17,18]. First, it should be noted that all measured values are lower than the EC and U.S. EPA regulatory limits, but that these limits are based on control technology considerations, and not necessarily health risk criteria. With this caveat, it is interesting that measured values of mercury and PCDD/PCDFs at the thermal conversion facilities are generally lower or comparable to the modern (well controlled) waste-to-energy facility, though the degree of variability is substantial among facilities. The statistics for mercury are influenced by analytical limits of detection (six of eleven values are reported at <7 µg/dscm; the median value therefore reflects this detection limit). The limited data for plasma arc facilities and high temperature gasification facilities show lower emissions of both mercury and PCDD/PCDF compared with the WTE measurements.

A detailed site-specific multi-pathway risk assessment for the WTE facility [8] found very low levels of risk (well below regulatory limits). Based on simple extrapolation, the comparability of effluent concentrations of the key pollutants mercury and PCDD/PCDFs suggests that potential health risks from thermal treatment facilities should be similarly small (or even lower). However, many other factors must be considered. First and foremost, effluent concentrations do not necessarily translate to proportional emission rates, which also depend on the volumetric rate at which stack-gas effluent is released. Intuitively, since less of the net combustible waste is consumed by a thermal treatment process than by a waste-to-energy process, less stack effluent should be produced, and hence overall contaminant emission from a thermal treatment plant should be lower than a waste-to-energy plant with equivalent stack-gas (effluent) levels. But dispersion characteristics must also be considered. If, for example, a hypothetical thermal treatment facility is built with a shorter smokestack, ground-level concentrations of contaminants may be higher per the same level of emission, and potential exposure to contaminants may be similar to a facility with a taller stack despite lower emission rates. Facility-specific risk assessments also depend on site-specific factors such as terrain, demographics, and characteristics of the local population (such as the propensity to consume locally-grown or caught food).

Thermal processing residuals are likely to be more chemically stable and much lower in organic content than those produced by anaerobic digestion processes. For example, plasma arc processes produce a vitrified, inert residual byproduct resistive to leaching. Due to their anticipated stability, thermal processing residuals will likely be targeted as a commercial product for beneficial reuse. It is conceivable that metals might leach from residuals, and if so, the specifics of application might require evaluation to determine whether there are potential avenues for exposure to contaminants. However, indications are that thermal processing residuals are largely inert, and hence significant risks from their reuse in the environment are not likely.

MSW Handling

As with current MSW management facilities, most waste conversion facilities will include the collection and processing of MSW (or residuals derived from MSW). Waste processing at present transfer stations and waste-to-energy plants typically occurs in an enclosed space at a “tipping” floor. Even in its early aerobic phase, MSW undergoes decay that can produce considerable odors, and practices have been developed in the waste management industry to contain odors (and hence reduce or eliminate the release of associated chemicals to ambient air). Use of negative pressurization, whereby active ventilation is used to draw air into the waste processing area, is common practice. In waste-to-energy facilities, the induced ventilation can be used as a source of combustion air. MSW conversion facilities can also be designed in a manner to prevent fugitive emissions of volatile chemicals from waste handling. However, it may not be possible to prevent all releases if operating practices to prevent such releases are not followed. Odors associated with waste processing indicate the presence of volatile organic chemicals. Some data are available to characterize potential MSW processing emissions. A waste-to-energy facility burning refuse-derived fuel undertook a comprehensive study of the chemical composition of air vented from its odor handling system to the outdoors and found a variety of different chemicals (Cambridge Environmental, 2005). Ethanol was consistently detected at the highest concentrations. Also detected (at lower concentrations, and in some cases sporadically) were acetone, benzene, bromomethane, carbon disulfide, chloromethane, chloroform, cyclohexane, 1,4-dichlorobenzene, ethylbenzene, freons 11 and 12, heptane, hexane, methylene chloride, methyl ethyl ketone, 2-propanol, styrene, tetrachloroethylene, toluene, 1,1,1-trichloroethane, 1,2,4-trimethylbenzene, vinyl chloride, and xylenes. Overall release rates of these chemicals were small. A case-specific evaluation of these chemicals found no significant risks to human health given the level of dilution received by emissions prior to reaching local residents at ground-level. By analogy and extrapolation, it is likely that waste conversion facilities will build in mechanisms to limit odor migration from MSW processing areas, and will not release significant quantities of chemicals to the environment. To the extent it might be necessary to evaluate such releases, the aforementioned data may be useful.

SUMMARY AND CONCLUSIONS

In addition to the pilot and demonstration facilities operating in North America, several commercial conversion technology facilities are currently being planned, procured, permitted and designed in the United States. Additional data will emerge in coming years as will the preparation of site specific health risk assessments Conceptually, knowledge gained from traditional waste management facilities provides a sense of potential contaminants and emission sources. Moreover, health risk assessments of landfills and waste-to-energy facilities provide both a framework for evaluating MSW conversion technologies and the expectation that the facilities can be operated in an environmentally acceptable manner. It is possible that MSW conversion processes might result in unanticipated contaminants and releases, but even if this happens, the environmental diligence that has developed in the waste management industry makes it more likely that such releases will be identified and (if necessary) mitigated.

Finally, note that there may be additional considerations relevant to health risk assessment. For example, consideration of potential wastewater streams has not been included under the premise that facilities can and will be designed with no net discharge of process wastewater. As such, design plans for specific facilities should be considered to identify potential sources of environmental contaminants.

Table 2 is a qualitative summary of possible contaminant releases from MSW conversion facilities based largely on extrapolation of knowledge of traditional MSW management facilities. Many of the Table 2 scenarios are hypothetical and expected to be mitigated through process design and controls, and hence should be viewed as prudent reminders of issues that could arise if neglected. Notes indicate the types of potential risks and their likelihood in view of current environmental practices. Based on this qualitative analysis, it is likely that project-specific risk assessment applications will find insignificant risks to human health, and will help to demonstrate that MSW conversion processes will operate in an environmentally acceptable manner.

There are many factors that determine whether MSW management facilities are viewed as safe and acceptable. Risk assessment is an objective means of evaluating potential health hazards, but the acceptability of facilities often hinge on their performance and perception. MSW conversion facilities will be substantial industrial installations, combining the characteristics of facilities that handle and process MSW with those of chemical manufacturing (in the production of syngas). Thus, the ability of MSW conversion technologies to maintain an acceptable public image depends not only on achieving low emissions and environmental impacts, but also on practical diligence and implementation.

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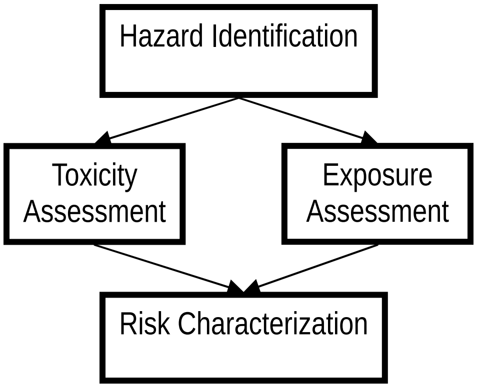

Figure 1 Conceptual Risk Assessment Framework

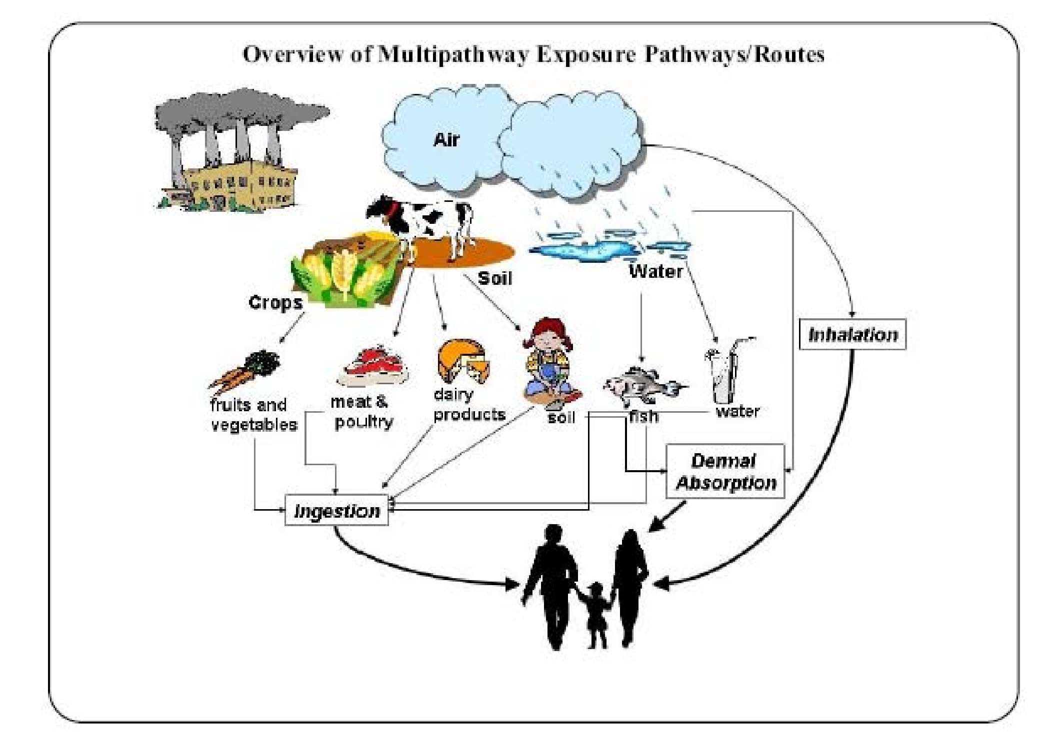

Figure 2 Conceptual multi-pathway risk assessment diagram, from the U.S. EPA OAQPS’s Air Toxics Risk Assessment Reference Library [10].

Table 1 Reported Stack-gas Concentrations of Mercury and PCDD/PCDF for Thermal Processing Facilities

Category	Median measured Stack-Gas Concentrations (Range and number of facility tests in parentheses)	
	Mercury in µg/dscm	PCDD/PCDF in ng/dscm TEQ
Gasification – all categories[a]	7 (0.1 – 8 , 11 tests)	0.021 (0.000013 – 0.056, 16 tests)
Plasma Arc	0.2 (0.2 – 0.67, 3 tests)	0.0058 (0.000013 – 0.0092 , 3 tests)
Pyrolysis	–	0.0067 (0.00058 – 0.025, 3 tests)
High Temperature	–	0.031 (0.016 – 0.045, 2 tests)
Recent Waste-to-Energy Facility[b]	1.4	0.012
Benchmark Standard	50[c,d]	0.1[c]

Notes
a Gasification data compiled by CE-CERT [16]
b Cambridge Environmental [8]
c EC [17]
d U.S. EPA [18]

Table 2 Qualititave Risk Assessment of MSW Conversion Facilities

Release Type	Potential Contaminants of Concern	Potential exposure pathways	Applicable Technology (A = anaerobic digestion, T = Thermal Processing)	Likely Design Mitigation	Likely Significance of Potential Health Risk
Fugitive emissions of waste handling & processing odors	VOCs	Inhalation	A & T	Use of negative pressure in waste handling building	Very low if odor control is effective
Fugitive emissions of syngas and VOCs (if produced)	Hydrogen sulfide, and various VOCs	Inhalation	A & T	Syngas cleaning to remove sulfur; Odor and leak monitoring	Low unless leaks are significant
Stack emissions of combustion byproducts, if syngas is combusted and fuel is not manufactured	Mercury and PCDD/PCDF	Inhalation and ingestion (foodweb)	A & T	Combustion practices (if necessary) and air pollution controls	Low – preliminary data are comparable or lower than a modern WTE facility; facility-specific data are important
Use of residual compost	Phthalates and pesticides	Compost-amended soil (incidental ingestion; dermal contact; vegetable ingestion)	A	Compost testing and screening	Low